DRAFT

NIST CYBERSECURITY PRACTICE GUIDE

DOMAIN NAME SYSTEMS-BASED ELECTRONIC MAIL SECURITY

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(INCLUDING PARTS A, B, C)

ADDITIONAL CONTENT:
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NATIONAL CYBERSECURITY CENTER OF EXCELLENCE

NIST Special Publication 1800-6 **NIST Cybersecurity Practice Guide**

DOMAIN NAME SYSTEMS-BASED ELECTRONIC MAIL SECURITY

1800-6A
Executive Summary

1800-6B
Approach, Architecture, and Security Characteristics
For CIOs, CSOs, and Security Managers

1800-6C
How-To Guides
For Security Engineers

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For additional information and supplemental materials relating to this document and project, please see https://nccoe.nist.gov/projects/building_blocks/secured_email.

Comments on this publication may be submitted to: dns-email-nccoe@nist.gov

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NATIONAL CYBERSECURITY CENTER OF EXCELLENCE

The National Cybersecurity Center of Excellence (NCCoE) at the National Institute of Standards and Technology (NIST) addresses businesses' most pressing cybersecurity problems with practical, standards-based solutions using commercially available technologies. The NCCoE collaborates with industry, academic, and government experts to build modular, open, end-to-end reference designs that are broadly applicable and repeatable. The center's work results in publicly available NIST Cybersecurity Practice Guides, Special Publication Series 1800, that provide users with the materials lists, configuration files, and other information they need to adopt a similar approach.

To learn more about the NCCoE, visit http://nccoe.nist.gov. To learn more about NIST, visit http://www.nist.gov.

NIST CYBERSECURITY PRACTICE GUIDES

NIST Cybersecurity Practice Guides (Special Publication Series 1800) target specific cybersecurity challenges in the public and private sectors. They are practical, user-friendly guides that facilitate the adoption of standards-based approaches to cybersecurity. They show members of the information security community how to implement example solutions that help them align more easily with relevant standards and best practices.

The documents in this series describe example implementations of cybersecurity practices that businesses and other organizations may voluntarily adopt. The documents in this series do not describe regulations or mandatory practices, nor do they carry statutory authority.

PRACTICE GUIDE
NIST SP 1800-6A

Domain Name Systems-Based Electronic Mail Security

Executive Summary

- Both public and private sector business operations are heavily reliant on electronic mail (email) exchanges but the integrity of these transactions is often at risk, including financial and other proprietary information as well as the privacy of employees and clients.
- Protocols such as Transport Layer Security (TLS), Secure/Multipurpose Internet Mail Extensions (S/MIME), Domain Name System Security Extensions (DNSSEC), and Domain Name System (DNS) Authentication of Named Entities (DANE) exist and are capable of providing needed email security and privacy protection.
- Impediments such as the absence of comprehensive configuration instructions for a composed set of mail client, mail transfer agents, and DNS security components, absence of resource guides to easily implemented software libraries and software applications for system administrators, and functional characteristics of security applications that negatively impact the performance of email systems have limited adoption of these existing security and privacy protocols.
- Operating email systems without employing available security and privacy protocols increases the opportunities for attackers to breach sensitive enterprise information by introducing false addresses into mail messages, disrupting secure communication signaling, and improving the probability of successfully inducing enterprise users to open malicious attachments - still the most common method for introducing malware and breaching enterprise systems.
- The National Cybersecurity Center of Excellence (NCCoE) developed a set of example DNS-based email security solutions that organizations can use to facilitate implementation of security and privacy protocols, thus reducing the likelihood of a data breach. The solution sets include tools that support installation and set-up of trustworthy email systems.
- The security characteristics in this guide are informed by guidance and best practices from standards organizations. How the solution set addresses security requirements and best practices is addressed in a volume that includes the security approach, architecture, and security characteristics.
- The NCCoE's approach uses both open source and commercially available products that can be included alongside current mail products in existing infrastructure.
- The example solution is described in a “How To” guide that shows how to implement a set of standards-based, commercially available cybersecurity technologies in the real world. The guide will help organizations utilize technologies to reduce the risk of untrustworthy email, while saving them research and proof of concept costs.

THE CHALLENGE

Whether the security service desired is authentication of the source of an email message or assurance that the message has not been altered by or disclosed to an unauthorized party, organizations must employ some cryptographic protection mechanism. Economies of scale and a need for uniform security implementation drive most enterprises to rely on mail servers and/or Internet service providers (ISPs) to provide security to all members of an enterprise. Many current server-based email security mechanisms are vulnerable to, and have been defeated by, attacks on the integrity of the cryptographic implementations on which they depend. The consequences of these vulnerabilities frequently involve unauthorized parties being able to read or modify supposedly secure information, or to use email as a vector for inserting malware into the system in order to gain access to enterprise systems or information. Protocols exist that are capable of providing needed email security and privacy, but impediments such as unavailability of easily implemented software libraries and software applications characteristics that complicate operation of email systems have limited adoption of existing security and privacy protocols.

THE SOLUTION

The Domain Name System-Based Security for Electronic Mail (Email) project has produced a proof of concept security platform that demonstrates trustworthy email exchanges across organizational boundaries. The goals of the project include authentication of mail servers, signing and encryption of email, and binding cryptographic key certificates to the servers. The Domain Name System Security Extension (DNSSEC) protocol is used to authenticate server addresses and certificates used for Transport Layer Security (TLS) to DNS names. The business value of the security platform demonstrated by this project includes improved privacy and security protection for users' operations and improved support for implementation and use of the protection technologies. The platform also expands the set of available DNS security applications and encourages wider implementation of DNSSEC, TLS and S/MIME to protect internet communications.

Project deliverables include:

- demonstration prototypes of DNS-based secure email platforms
- this publicly available NIST Cybersecurity Practice Guide that explains how to employ the platform(s) to meet industry security and privacy best practices as well as requirements for federal government agencies
- platform documentation necessary to efficiently compose a DNS-based email security platform from off-the-shelf components
- recommendations for effective implementation in a manner that is consistent with applicable standards documentation

Approach

The secure email project involves composition of a variety of components that have been provided by a number of different technology providers, including Microsoft Corporation, the Internet Systems Consortium, Secure64, Fraunhofer IAO, and Stichting NLnet Laboratories. Each of these collaborators has entered into a Cooperative Research and Development Agreement (CRADA) with NIST to participate in this consortium effort. These components include client systems, DNS/DNSSEC services, mail transfer agents (MTA), and certificate sources.

We demonstrate how security can be supported through standards-based configuration and operation DNS servers, electronic mail applications and MTAs in a manner that supports trustworthy email by the organization.

The guide:

- identifies the security characteristics needed to sufficiently reduce the risks to information exchanged by email
- maps security characteristics to standards and best practices from NIST and other organizations
- describes a detailed example solution, along with instructions for implementers and security engineers on efficiently installing, configuring, and integrating the solution into existing IT infrastructures
- provides an example solution that is operationally practical and evaluates the performance of the solution in real-world scenarios

BENEFITS

Our example solution has several benefits, including the following:

- reduces risk so that employees are able to exchange personal and enterprise information via email with significantly reduced risk of disclosure or compromise
- enables the use of existing security protocols more efficiently and with minimal impact to email service performance
- integrates capabilities into various server and client IT infrastructure environments
- enhances visibility for system administrators into email security events, providing for recognition of authentication failures that could result in device and data compromises
- implements both commercial and open source industry standard network and email security controls reducing long term costs and decreasing the risk of vendor lock-in
- can be extended to other enterprise information exchange technologies that are growing in use (e.g., text messages, chat)

TECHNOLOGY PARTNERS AND COLLABORATORS

The technology vendors who participated in this project submitted their capabilities in response to a call in the Federal Register. Companies with relevant products were invited to sign a Cooperative Research and Development Agreement with NIST, allowing them to participate in a consortium to build this example solution. We worked with:

- Microsoft Corporation
- NLnet Laboratories
- Secure64
- Internet Systems Consortium
- Fraunhofer IAO

SHARE YOUR FEEDBACK

You can get the guide through the NCCoE web site, http://nccoe.nist.gov. Help us make it better by sharing your thoughts with us as you review the guide. If you adopt this solution for your own organization, share your experience and advice with us. We recognize that technical solutions alone will not fully enable the benefits of our solution, so we encourage organizations to share lessons learned and best practices for transforming the business processes associated with implementing it.

- email dns-email-nccoe@nist.gov
- join our Community of Interest to offer your insights and expertise; email us at dns-email-nccoe@nist.gov

To learn more by arranging a demonstration of this reference solution, contacting us at dns-email-nccoe@nist.gov.

The National Cybersecurity Center of Excellence at the National Institute of Standards and Technology addresses businesses' most pressing cybersecurity problems with practical, standards-based example solutions using commercially available technologies. As the U.S. national lab for cybersecurity, the NCCoE seeks problems that are applicable to whole sectors, or across sectors. The center's work results in publicly available NIST Cybersecurity Practice Guides that provide modular, open, end-to-end reference designs.

LEARN MORE

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NIST SPECIAL PUBLICATION 1800-6B

NIST Special Publication 1800-6B **NIST Cybersecurity Practice Guide**

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1800-6B
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The documents in this series describe example implementations of cybersecurity practices that businesses and other organizations may voluntarily adopt. The documents in this series do not describe regulations or mandatory practices, nor do they carry statutory authority.

ABSTRACT

This document describes a security platform for trustworthy email exchanges across organizational boundaries. The project includes reliable authentication of mail servers, digital signature and encryption of email, and binding cryptographic key certificates to sources and servers. The example solutions and architectures presented here are based upon standards-based open-source and commercially available products.

KEYWORDS

authentication; data integrity; domain name system; digital signature; electronic mail; encryption; internet addresses; internet protocols; named entities; privacy

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1 Summary

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This National Institute of Standards and Technology (NIST) Cybersecurity Practice Guide addresses the challenge of providing digital signature technologies to provide authentication and integrity protection for electronic mail (email) on an end-to-end basis, and confidentiality protection for email in transit between organizations. It implements and follows recommendations of NIST Special Publication 800-177 (SP 800-177), *Trustworthy Email*. Detailed protocol information and implementation details are provided in SP 800-177. Domain Name System[1] protection features are consistent with SP 800-81-2, *Secure Domain Name System (DNS) Deployment Guide*.

The NIST Special Publication 1800-6 series of documents contain:

- rationale for and descriptions of a Domain Name System-Based (DNS-Based) Electronic Mail (Email) Security platform that permits trustworthy email exchanges across organizational boundaries and
- a series of How-To Guides, including instructions for installation and configuration of the necessary services, that show system administrators and security engineers how to achieve similar outcomes

The solutions and architectures presented are built upon standards-based, commercially available products. These solutions can be used by any organization deploying email services that is willing to implement certificate-based cryptographic key management and DNS Security Extensions (DNSSEC)[2]. Interoperable solutions are provided that are available from different types of sources (e.g., both commercial and open source products) and function in different operating systems environments.

This summary section describes the challenge addressed by this Volume B (*Approach, Architecture, and Security Characteristics*); describes the solution demonstrated to address the challenge; benefits of the demonstrated solution; lists the technology partners that participated in building, demonstrating, and documenting the solution; and explains how to provide feedback on this guide. Section 2, How to Use This Guide explains how each volume of the guide may be used by business decision makers, program managers, and Information Technology (IT) professionals such as systems administrators; and Section 3, Introduction provides a high-level project overview. Section 4, Approach provides a more detailed treatment of the scope of the project, describes the assumptions on which security platform development was based, describes the risk assessment that informed platform development, and describes the technologies and components that were provided by industry collaborators to enable platform development. Section 5, Architecture describes the usage scenarios supported by project security platforms, including Cybersecurity Framework[3] functions supported by each collaborator-contributed component. Section 6, Outcome describes any changes in users' mail processing experience imposed by the additional security functionality, and summarizes changes to systems administrators' experiences with respect to integrating the new capabilities into their systems and in systems operations and maintenance. Section 7, Evaluation summarizes the test sequences that were employed to demonstrate security platform services, the Cybersecurity Framework functions to which each test sequence is relevant, the NIST SP 800-53-4 controls that applied to the functions being demonstrated, and an overview of

1. RFC 1591, *Domain Name System Structure and Delegation*
2. RFC 4033, *DNS Security Introduction and Requirements*
3. *Framework for Improving Critical Infrastructure Cybersecurity*, Version 1.0, National Institute of Standards and Technology February 12, 2014 http://www.nist.gov/cyberframework/upload/cybersecurity-framework-021214.pdf

platform performance in each of the two applications scenarios demonstrated. Section 8, Future Build Considerations is a brief treatment of other applications that might be explored in the future in demonstrating the advantages of broader DNS security adoption. Appendices are provided for acronyms, references, and a mapping of the DNS-Based Email Security project to the Cybersecurity Framework Core[4] and informative security references cited in the Cybersecurity Framework Core.

1.1 The Challenge

Both private industry and the government are concerned about email security and the use of email as an attack vector for cybercrime. Business operations are heavily reliant on email exchanges and need to protect the confidentiality of business information, the integrity of transactions, and privacy of individuals. Cryptographic services are used to authenticate the source of email messages, protect against undetected unauthorized alteration of messages in transit, and maintain message confidentiality. Efficiency and policies support reliance on mail servers to provide cryptographic protection for email rather than on end-to-end security operated by individual users. However, organizations need to protect their server-based email security mechanisms against intrusion and man-in-the-middle attacks during automated cryptographic service negotiation. In the absence of an appropriate combination of DNSSEC and certificate-based protections, any of these attacks can result in disclosure or modification of information by unauthorized third parties. The attacks can also enable an attacker to pose as one of the parties to an email exchange and send email that contains links to malware-ridden websites. If other content in a fraudulent message successfully motivates the user to click on the link or the user's system is configured to automatically follow some links or download content other than text, the malware will infect the user's system. Inclusion of links to malware is a major factor in most confirmed data breaches. Consequences of such breaches can range from exposure of sensitive or private information, to enabling fraudulent activity by the attacker posing as the victimized user, to disabling or destroying the user's system-or that of the user's parent organization. Beyond avoidance of negative consequences to users, improved email security can also serve as a marketing discriminator for email service providers.

Implementation of DNSSEC and DNS-Based Authentication Of Named Entities (DANE)[5] have been impeded in the past by a shortage of easily used software libraries and by the fact that most available email applications of the protocols respond to absent or incorrect digital signatures by neither permitting delivery of the message nor alerting the mail server that failure to deliver is based on a DNSSEC issue. The consequence of the first impediment is that, unless forced by policy to do so, IT organizations defer DNSSEC/DANE implementation pending availability of more mature software libraries. The consequence if the second is that, when DNSSEC and DANE are turned on, mail servers experience severe service degradation or crashes due to large numbers of retransmission attempts.

4. http://www.nist.gov/cyberframework/
5. RFC 6698, *The DNS-Based Authentication of Named Entities (DANE) Transport Layer Security Protocol*: TLSA

1.2 The Solution

DNSSEC protects against unauthorized modifications to domain name information to prevent connection to spoofed or malicious hosts. The NCCoE initiated a collaborative project with industry partners to develop a proof-of-concept security platform that provides trustworthy mail server-to-mail server email exchanges across organizational boundaries. Products comprising the security platform include client mail user agents (MUAs)[6], DNS servers (authoritative and caching/recursive)[7], mail transfer agents, (MTAs)[8], and X.509 cryptographic key certificate sources (components and services). The network infrastructure products are similar to those found in every enterprise and used to perform basic IT functions and handle email. The certificate utilities are needed to produce X.509 certificates[9] for mail servers and end users to support Transport Layer Security (TLS)[10] and Secure/Multipurpose Internet Mail Extensions (S/MIME)[11]. This initial project focuses on Simple Mail Transfer Protocol (SMTP)[12] over TLS and S/MIME.

The DNS-based secure email building block project has demonstrated a security platform, consistent with SP 800-177, that provides trustworthy email exchanges across organizational boundaries. The project includes authentication of mail servers, digitally signing and encrypting email[13], and binding cryptographic key certificates to the servers. The software library issue was addressed in SP 1800-6c by providing installation and configuration instructions for using and maintaining existing software libraries (including installation support applications). At the same time, inclusion of software developers and vendors in the development and demonstration process revealed software and implementation guidance shortcomings that have been corrected.

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6. According to NIST Special Publication (SP) 800-177, an MUA is a software component (or web interface) that allows an end user to compose and send messages and to one or more recipients. An MUA transmits new messages to a server for further processing (either final delivery or transfer to another server).

7. According to Section 3.2 of SP 800-177, there are two main types of name servers: authoritative name servers and caching name servers. The term **authoritative** is with respect to a zone. If a name server is an authoritative source for DNS resource records for a particular zone (or zones) of DNS addresses, it is called an **authoritative name server** for that zone (or zones). An authoritative name server for a zone provides responses to name resolution queries for resources for that zone, using the records in its own zone file. A **caching name server** (also called a resolving/recursive name server), by contrast, provides responses either through a series of queries to authoritative name servers in the hierarchy of domains found in the name resolution query or from a cache of responses built by using previous queries.

8. Also according to SP 800-177, mail is transmitted, in a "store and forward" fashion, across networks via Mail Transfer Agents (MTAs). MTAs communicate using the Simple Mail Transfer Protocol (SMTP) described below and act as both client and server, depending on the situation.

9. RFC 5280, *Internet X.509 Public Key Infrastructure Certificate and Certificate Revocation List (CRL) Profile*

10. RFC 5246, *The Transport Layer Security (TLS) Protocol Version 1.2*

11. RFC 5751, *Secure/Multipurpose Internet Mail Extensions (S/MIME) Version 3.2 Message Specification*

12. RFC 5321, *Simple Mail Transfer Protocol*

13. Cryptographic protection, while voluntary for the private sector has, for a number of applications been made mandatory for federal government agencies (see Managing Information as a Strategic Resource, OMB Circular A-130)

1.3 Benefits

Sectors across industries, as well as the federal government, are concerned about email security and the use of email as an attack vector.[14] Both public and private sector business operations are heavily reliant on email exchanges. The need to protect the integrity of transactions containing financial and other proprietary information and to protect the privacy of employees and clients are among the factors that motivate organizations to secure their email. Whether the service desired is authentication of the source of an email message, assurance that the message has not been altered by an unauthorized party, or message confidentiality, cryptographic functions are usually employed. Economies of scale and a need for uniform implementation drive most enterprises to rely on mail servers to provide security to the members of an enterprise rather than security implemented and operated by individual users. Many server-based email security mechanisms are vulnerable to attacks involving:

- faked or fraudulent digital certificates
- otherwise invalid certificates
- failure to actually invoke a security process as a result of connection to or through a fraudulent server

Even if there are protections in place, some attacks have been able to subvert email communication by attacking the underlying support protocols such as DNS. Attackers can spoof DNS responses to redirect email servers and alter email delivery. DNSSEC was developed to prevent this. DNSSEC protects against unauthorized modifications to network management information and host IP addresses. DNSSEC can also be used to provide an alternative publication and trust infrastructure for service certificates using the DNS-based Authentication of Named Entities (DANE) resource records.

The business value of the security platform that results from this project includes improved privacy and security protections for users' communication, as well as improved management of DNS and email security operations. Addressing the software library and message retransmission issues, respectively, reduces the difficulty and cost of installing and maintaining DNSSEC and DANE. Mitigating the major cause of system errors resulting from faulty deployment of DNSSEC and DANE will encourage use of capabilities already present in many email systems. Demonstration and publication of these improvements encourages wider implementation of the protocols that provide Internet users with confidence that email has been protected and reaches the intended receiver in a secure manner. The demonstrated platform addresses three of the five core Functional Categories in the Framework for Improving Critical Infrastructure Cybersecurity and many requirements of relevant security standards and guidelines. Implementation of the platform will be increasingly important as a market discriminator as public awareness of email security and privacy issues grows.

14. "How Cybercrime Exploits Digital Certificates," Infosec Institute, *General Security*, July 28, 2014, http://resources.infosecinstitute.com/cybercrime-exploits-digital-certificates

1.4 Technology Partners and Collaborators

The technology vendors who participated in this build submitted their capabilities in response to a notice in the Federal Register. Companies with relevant products were invited to sign a Cooperative Research and Development Agreement (CRADA) with NIST, allowing them to participate in a consortium to build this example solution. We worked with:

- Microsoft Corporation
- NLnet Laboratories
- Secure64
- Internet Systems Consortium
- Fraunhofer IAO

1.5 Feedback

You can improve this guide by contributing feedback. As you review and adopt this solution for your own organization, we ask you and your colleagues to share your experience and advice with us.

- email dns-email-nccoe@nist.gov
- join our Community of Interest to offer your insights and expertise; email us at dns-email-nccoe@nist.gov

Or learn more by arranging a demonstration of this example solution by contacting us at dns-email-nccoe@nist.gov

2 How to Use This Guide

This NIST Cybersecurity Practice Guide demonstrates a standards-based reference design and provides users with the information they need to replicate this approach to email security. The reference design is modular and can be deployed in whole or in parts.

This guide contains three volumes:

- NIST SP 1800-6a: Executive Summary
- **NIST SP 1800-6b: Approach, Architecture, and Security Characteristics - what we built and why (you are here)**
- NIST SP 1800-6c: How-To Guides - instructions for building the example solution

Depending on your role in your organization, you might use this guide in different ways:

Business decision makers, including chief security and technology officers will be interested in the Executive Summary (NIST SP 1800-6a), which describes the:

- challenges enterprises face in implementing and operating a trustworthy email service
- example solution built at the NCCoE
- benefits of adopting the example solution

Technology or security program managers who are concerned with how to identify, understand, assess, and mitigate risk will be interested in this part of the guide. NIST SP 1800-6b describes what we did and why. Section 4.4, Risk Assessment will be of particular interest. This section provides a description of the risk analysis we performed and maps the security services provided by this example solution to the *Framework for Improving Critical Infrastructure Cybersecurity* and relevant security standards and guidelines.

You might share the Executive Summary, NIST SP 1800-6a, with your leadership team members to help them understand the importance of adopting standards-based access management approaches to protect your organization's digital assets.

IT professionals who want to implement an approach like this will find the whole practice guide useful. You can use the How-To Guides, NIST SP 1800-6c, to replicate all or parts of the build created in our lab. The How-To guide provides specific product installation, configuration, and integration instructions for implementing the example solution. We do not re-create the product manufacturers' documentation, which is generally widely available. Rather, we show how we incorporated the products together in our environment to create an example solution.

This guide assumes that IT professionals have experience implementing security products within enterprises. While we have used a suite of commercial and open source software products to address this challenge, this guide does not endorse these particular products. Your organization can adopt this solution or one that adheres to these guidelines in whole, or you can use this guide as a starting point for tailoring and implementing parts of a solution that would support the deployment of an trustworthy email system and the corresponding business processes. Your organization's security experts should identify the products that will best integrate with your existing tools and IT system infrastructure. We hope you will seek products that are congruent with applicable standards and best practices. Section 4.5, Technologies, lists the products we used and maps them to the cybersecurity controls provided by this reference solution.

A NIST Cybersecurity Practice Guide does not describe “the” solution, but a possible solution. This is a draft guide. We seek feedback on its contents and welcome your input. Comments, suggestions, and success stories will improve subsequent versions of this guide. Please contribute your thoughts to dns-email-nccoe@nist.gov.

3 Introduction

As stated in section 1.1, both public and private sector business operations are heavily reliant on electronic mail (email) exchanges. They need to protect the integrity of transactions that may include financial and other proprietary information. The privacy of employees and clients is also a factor that motivates organizations to secure their email systems. Security services such as the authentication of the source of an email message, assurance that the message has not been altered by an unauthorized party, and confidentiality of message contents require the use of cryptographic functions. A need for uniform security implementation drives most enterprises to rely on mail servers to provide security to the members of an enterprise rather than rely on end users to implement a security policy on their own. However, most current server-based email security mechanisms are vulnerable to, and have been defeated by, attacks on the integrity of the cryptographic implementations on which they depend. The consequences frequently involve unauthorized parties being able to read or modify supposedly secure information, or to use email as a vector for inserting malware into the enterprise. Improved email security can help protect organizations and individuals against these consequences and also serve as a marketing discriminator for email service providers as well as improve the trustworthiness of enterprise email exchanges.

Domain Name System Security Extensions for the Domain Name System are technical mechanisms employed by domain owners to protect against unauthorized modification to network management information. DANE is a protocol that securely associates domain names with cryptographic certificates and related security information so that clients can better authenticate network services. In spite of the dangers of failure to authenticate the identities of network devices, adoption of DNSSEC has been slow. Demonstration of DANE-supported applications such as reliably secure email may support increased user demand for domain name system security. Follow-on projects might include HTTPS, IOT, IPSEC keys in DNS, and DNS service discovery.

The DNS-Based Email Security project demonstrated proof of concept security platforms composed of off the shelf components that provides trustworthy mail server-to-mail server email exchanges across organizational boundaries. The DANE protocol is used to authenticate servers and certificates in two roles in the DNS-Based Security for Email Project: (1) By binding the X.509 certificates used for Transport Layer Security (TLS) to DNSSEC signed names for mail server-to-mail server communication; and (2) by binding the X.509 certificates used for Secure/Multipurpose Internet Mail Extensions (S/MIME) to email addresses encoded as DNS names. These bindings support trust in the use of S/MIME certificates in the end-to-end email communication. The resulting platforms encrypt email traffic between servers and allow individual email users to obtain other users' certificates in order to validate signed email or send encrypted email.[1] The project will include an email sending policy consistent with a stated privacy policy that can be parsed by receiving servers so that receiving servers can apply the correct security checks.

1. S/MIME can do this now, but DANE makes it easier to actually use.

Documentation of the resulting platform includes statements of the security and privacy policies and standards (e.g., Executive Orders, NIST standards and guidelines, IETF RFCs). This also includes technical specifications for hardware and software, implementation requirements, and a mapping of implementation requirements to the applicable policies, standards, and best practices.

The secure email project has involved composition of a variety of components that were provided by several different technology providers. Components include MUAs, DNSSEC capable DNS servers, MTAs, and cryptographic certificate sources. These components are used to generate and host DNSSEC signed zones and TLS enabled mail services.

This project resulted in demonstration of support to MUAs and MTAs by four DNS-based secure email platforms and this publicly available NIST Cybersecurity Practice Guide that explains how to employ the suite(s) to meet security and privacy requirements. This guide also provides platform documentation necessary to compose a DNS-based email security platform from off the shelf components that composed the prototype platforms.

4 Approach

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4.1 Audience

This guide is intended for individuals responsible for implementing security solutions in organizations' IT support activities. Current IT systems, particularly in the private sector often lack integrity protection for domain name services and electronic mail. The platforms demonstrated by the DNS-Based Email Security project, and the implementation information provided in these Practice Guides permit integration of DNS and email integrity services and email confidentiality services with minimum changes to existing infrastructure or impact to service operations. The technical components will appeal to system administrators, IT managers, IT security managers, and others directly involved in the secure and safe operation of the business IT networks.

4.2 DNS-Based Electronic Mail Security Project Scope

The DNS-Based Electronic Mail Security project is consistent with NIST SP 800-177 and demonstrates the use of off-the-shelf Transport Layer Security (TLS), Domain Name System (DNS) Security Extensions (DNSSEC), and DNS-based Authentication of Named Entities (DANE) components to achieve trustworthy electronic mail (email) objectives in a manner that is consistent with NIST SP 800-81-2.

4.2.1 Transport Layer Security (TLS)

The project uses TLS to protect confidentiality of email messages exchanged between mail servers. TLS relies on keys stored as X.509 digital certificates. These certificates can be used to authenticate the identity (server, domain or organization) of the certificate owner.

4.2.2 Domain Name System (DNS) Security Extensions (DNSSEC)

The project uses DNSSEC to authenticate and protect the integrity of DNS data. DNSSEC uses digital signatures over DNS data to prevent an attacker from tampering with or spoofing DNS responses. Mail servers use the DNS to find the destination of email as well as storing other artifacts necessary for email security (see below).

4.2.3 DNS-based Authentication of Named Entities (DANE)

The project uses DANE, a protocol that securely associates domain names with cryptographic certificates and related security information so that they can't be fraudulently modified or replaced to breach security. DNSSEC binds the X.509 certificates used for TLS to DNS.

4.2.4 Binding X.509 Certificates with DANE

The project also uses DANE to bind the X.509 certificates used for S/MIME to email addresses encoded as DNS names verified by DNSSEC.

4.2.5 Demonstration of Digital Signature and Encryption of Email

The project demonstrates sending encrypted messages between email systems resident in different DNS domains, where the email exchanges between two organizations' email servers are carried over TLS, and the TLS key management is protected by DANE and DNSSEC. Signed email was sent between a message originator and a receiving party using end user applications (end-to-end) in different DNS domains, where the email exchanges between organizations were carried over TLS, the email messages were signed and verified with S/MIME on the end-users' client devices, and the S/MIME key management was protected by DANE and DNSSEC. In addition, the project demonstrated that the use of DNSSEC and DANE blocks an attempt by a fraudulent mail server to pose as the legitimate mail server for the receiver of the email.

4.2.6 Demonstration of End-to-end Digital Signature of Mail

The project's digital signature demonstration included sending S/MIME signed email between a message originator and a receiving party using end user applications in different DNS domains. The email exchanges between organizations are carried over TLS, the email messages are signed and verified with S/MIME on the end-users' client devices, and the S/MIME certificates are stored in the DNS and protected by DNSSEC. This aspect of the project also demonstrated that use of DANE blocks an attempt by a fraudulent actor to pose as the email originators.

4.3 Assumptions

4.3.1 Security and Performance

The email platforms and DNS services demonstrated provide email integrity and confidentiality protection. An underlying assumption is that the benefits of using the demonstrated platforms outweigh any additional performance risks that may be introduced. The security of existing systems and networks is out of scope for this project. A key assumption is that all potential adopters of one of the demonstrated builds, or any of their components, already have in place some degree of network security. Therefore, we focused on what potential new system vulnerabilities were being introduced to end users if they implement this solution. The goal of this solution is to not introduce additional vulnerabilities into existing systems, but there is always inherent risk when adding systems and adding new features into an existing system.

4.3.2 Modularity

This assumption is based on one of the NCCoE core operating tenets. It is reasonably assumed that organizations already have mail client and server systems in place. Our philosophy is that a combination of certain components or a single component can improve email security for an organization; they may not need to remove or replace most existing infrastructure. This guide provides a complete top-to-bottom solution and is also intended to provide various options based on need.

4.3.3 Technical Implementation

This practice guide is written from a "how-to" perspective, and its foremost purpose is to provide details on how to install, configure, and integrate the components. The NCCoE assumes that an organization has the technical resources to implement all or parts of the build, or has access to companies that can perform the implementation on its behalf.

4.3.4 Operating System and Virtual Machine Environments

This project was conducted primarily in a Vmware vcenter server version 6.0.0 Build 3018523 virtual machine environment. It is assumed that user organizations will be able to install the demonstrated applications in cloud-hosted VMs, local virtual machine or local native server client environments. This project uses Centos 7, Windows Server 2012R2, and Windows 10 operating systems. Operating systems were chosen based on the requirements of the software.

The DNS-based secure email building block project assumes, and is dependent upon, the availability of off-the shelf information security technology. Particular products and expertise on which the project is dependent include those for MUAs, MTAs, DNS servers (authoritative and recursive) and X.509 certificate utilities.

4.4 Risk Assessment

According to NIST SP 800-30, *Risk Management Guide for Information Technology Systems*, "Risk is the net negative impact of the exercise of a vulnerability, considering both the probability and the impact of occurrence. Risk management is the process of identifying risk, assessing risk, and taking steps to reduce risk to an acceptable level." The NCCoE recommends that any discussion of risk management, particularly at the enterprise level, begin with a comprehensive review of NIST 800-37, *Guide for Applying the Risk Management Framework to Federal Information Systems*. The risk management framework (RMF) and its associated references for identified security functions provides a baseline for organizing and relating to organizational objectives of:

1. the risks to electronic mail and the networks it transits
2. the security requirements to be met in order for the security platform to reduce these risks

While this guide does not present a full risk assessment, it does highlight the broad categories of threats and vulnerabilities associated with electronic mail.

4.4.1 Threats

Below are common threats associated with electronic mail:

- use of email as a vehicle for introducing malware
- use of email as a delivery mechanism for social engineering attacks
- theft or destruction of data communicated by email and/or its attachments due to loss or unauthorized/unintentional disposal of messages
- loss of privacy resulting from unauthorized access to email

- unauthorized modification of information communicated by email
- malicious fraudulent creation of messages or attachments attributed to third parties

4.4.2 Vulnerabilities

Vulnerabilities are commonly associated with mail client applications, mail transfer applications, and network applications that are employed in creation, delivery, and reading of email. However, vulnerabilities can be exploited at all levels in the information stack. For up-to-date information regarding vulnerabilities, this guide recommends that security professionals leverage the National Vulnerability Database (NVD). The NVD is the U.S. government repository of standards-based vulnerability management data [https://nvd.nist.gov].

4.4.2.1 Client System Vulnerabilities

Organizations are getting better at protecting network perimeters, and companies with mature security programs usually allow only certain ports through the firewall and harden Internet-accessible servers to minimize the attack surface. As a result, attackers are paying closer attention to client-side vulnerabilities on internal workstations. These client-side vulnerabilities often are as simple as unpatched software on a desktop or laptop. Most client systems run at least one operating system and quite a few applications. Listing specific vulnerabilities for each is beyond the scope of this guide, but a current list of vulnerabilities and information regarding patches are available from NIST's National Vulnerability Database referenced above. Depending on the nature of a vulnerable application, an attacker may exploit it using a specially crafted email attachment or by convincing the user to visit a malicious Web site. Web browsers are common targets. Other attractive targets include Adobe Acrobat[1], Macromedia Flash[2], QuickTime[3] and Java Runtime Environment[4].

4.4.2.2 Mail Server Vulnerabilities

Mail servers have many of the same vulnerabilities as client systems, but we also need to be aware of protocol-based vulnerabilities involving access to valid lists of email addresses, vulnerabilities to relay exploits for malware insertion, vulnerabilities to email header disclosures, and vulnerabilities to viruses and worms. In the case of SMTP, one way that attackers can verify whether e-mail accounts exist on a server is simply to telnet to the server on port 25 and run the VRFY command.[5] The VRFY command makes a server check whether a specific user ID exists. Spammers often automate this method to perform a **directory harvest attack**, which is a way of gleaning valid e-mail addresses from a server or domain for hackers to

1. See https://www.cvedetails.com/vulnerability-list/vendor_id-53/product_id-497/Adobe-Acrobat-Reader.html.
2. See https://www.cvedetails.com/vulnerability-list/vendor_id-73/product_id-1950/version_id-8545/Macromedia-Flash-Player-6.0.29.0.html.
3. See https://web.nvd.nist.gov/view/vuln/detail?vulnId=CVE-2015-7117.
4. See https://web.nvd.nist.gov/view/vuln/detail?vulnId=CVE-2015-4903.
5. A number of ISPs now block port 25.

use. Scripting this attack can test thousands of e-mail address combinations. The SMTP command EXPN may allow attackers to verify what mailing lists exist on a server. Yet another way to capture valid e-mail addresses is to use applications such as *theHarvester* to glean addresses via Google and other search engines. In Microsoft Exchange, account enumeration is not generally an issue.

In environments other than Microsoft Exchange, account enumeration is not generally an issue. In such environments, the best solution for preventing this type of e-mail account enumeration depends on whether you need to enable commands like SMTP's VRFY and EXPN commands. In general, it is important to ensure that company e-mail addresses are not posted on the web.

Protocols like SMTP relay let users send e-mails through external servers. Open e-mail relays aren't the problem they used to be, but they can still be sources of vulnerabilities. Spammers and hackers can use an e-mail server to send spam or malware through e-mail under the guise of the unsuspecting open-relay owner.

In the case of email header disclosures, e-mail servers configured with typical defaults, may be vulnerable to divulging information such as internal IP addresses of e-mail clients, software versions of client and e-mail servers along with their vulnerabilities, or host names that can divulge network naming conventions

Email systems are regularly targeted by malware such as viruses and worms. It is necessary to verify that mail servers' antivirus software is actually working. As in the case of client systems vulnerabilities, NIST's National Vulnerability Database (https://nvd.nist.gov) is a frequently updated source of vulnerabilities that affect mail servers.

4.4.2.3 Network Vulnerabilities

The MITRE Corporation's Common Vulnerability Enumeration (CVE) lists more than 85,000 vulnerabilities that can affect web servers, System Query Language (SQL) servers, DNS servers, firewalls, routers, and other network components (see https://cve.mitre.org). These include vulnerabilities to denial of service, code execution, overflow, cross-site scripting, directory traversal, process bypass, unauthorized gaining of information, SQL injection, file inclusion, memory corruption, cross-site request forgery, and http response splitting. Many of the vulnerabilities are operating system or applications-based. Others are protocol based (e.g. vulnerabilities inherent in IP[6], TLS, DNS[7], BGP[8], SMTP and other network protocols). As in the case of client systems vulnerabilities, NIST's National Vulnerability Database (https://nvd.nist.gov) is a frequently updated source of vulnerabilities that affect network servers.

4.4.3 Risk

Risks are examined from the point of view of consequences of vulnerabilities being exploited. Some examples of these consequences include legal liability, consequences of failure to comply with regulations, confidentiality breaches, loss of productivity, and damage to organizational reputation.

6. RFC 791, *Internet Protocol*
7. RFC 1034, *Domain Names - Concepts And Facilities*
8. RFC 4271, *A Border Gateway Protocol 4 (BGP-4)*

- New and existing regulations are force organizations to keep a record of their emails and to protect their employee and customer privacy. For example, the Health Insurance Portability and Accountability Act (HIPAA) requires health care institutions to keep a record of their email communications and secure confidentiality of information. In the new IRS regulation Circular 230, the IRS requires tax advisors to add an email disclaimer to any emails including tax advice, expressly stating that the opinion cannot be relied upon for penalty purposes. The U.S. Securities and Exchange Commission and Gramm-Leach-Bliley Act impose similar duties on financial institutions. Steep penalties can apply to those organizations that do not comply with their industry's regulations. In a case lasting from 2000 until 2005, a well-known financial institution was recently forced to pay 20 million dollars in penalties by the Securities and Exchange Commission for not diligently searching for email back-up tapes and over-writing multiple back-up tapes.
- Most confidentiality breaches occur from within the company. These breaches can be accidental, but they can also be intentional.
- With respect to legal liability, organizations are generally held responsible for all the information transmitted on or from their system, so inappropriate emails sent on the company network can result in multi-million dollar penalties.
- Employees sending personal emails and sifting through spam mail can cause major loss of productivity.[9]
- Even just a badly written email, or an email containing unprofessional remarks will cause the recipient to gain a bad impression of the company that the sender is representing. Fraudulent email attributable to an organization can do far more damage to an organization's reputation, both in terms of the response elicited and in terms of loss of confidence in the cybersecurity reliability of the organization

A number of cybersecurity actions are recommended to reduce these risks. The Framework Core identified in NIST's *Framework for Improving Critical Infrastructure Cybersecurity* is a set of cybersecurity activities, desired outcomes, and applicable references that are common across critical infrastructure sectors. The Core presents industry standards, guidelines, and practices in a manner that allows for communication of cybersecurity activities and outcomes across the organization from the executive level to the implementation/operations level. The Framework Core consists of five concurrent and continuous Functions: Identify, Protect, Detect, Respond, and Recover. When considered together, these functions provide a high-level, strategic view of the lifecycle of an organization's management of cybersecurity risk.

9. Current SPAM filtering solutions consist of some sort of filtering at the network or the PC level, and they don't reveal the details of the sender without looking up the source. It takes some work for the recipient. This will always put us one step behind the bad guys. DNS provides the necessary Internet-wide scaling and DNSSEC achieves this authentication.

4.4.4 Cybersecurity Framework Functions, Categories, and Subcategories Addressed by the DNS-Based Email Security Project

The *Framework for Improving Critical Infrastructure Cybersecurity*[10] (Cybersecurity Framework) provides a common language for understanding, managing, and expressing cybersecurity risk both internally and externally. It can be used to help identify and prioritize actions for reducing cybersecurity risk, and it is a tool for aligning policy, business, and technological approaches to managing that risk. It can be used to manage cybersecurity risk across entire organizations or it can be focused on the delivery of critical services within an organization. Different types of entities - including sector coordinating structures, associations, and organizations - can use the Cybersecurity Framework for different purposes, including the creation of common Profiles. As stated above, the Framework Core provides a set of activities to achieve specific cybersecurity outcomes, and references examples of guidance to achieve those outcomes. The Core is not a checklist of actions to perform. It presents key cybersecurity outcomes identified by industry as helpful in managing cybersecurity risk. The Core comprises four elements: Functions, Categories, Subcategories, and Informative References.

- **Functions** organize basic cybersecurity activities at their highest level. These Functions are Identify, Protect, Detect, Respond, and Recover. They aid an organization in expressing its management of cybersecurity risk by organizing information, enabling risk management decisions, addressing threats, and improving by learning from previous activities. The Functions also align with existing methodologies for incident management and help show the impact of investments in cybersecurity. For example, investments in planning and exercises support timely response and recovery actions, resulting in reduced impact to the delivery of services.
- **Categories** are the subdivisions of a Function into groups of cybersecurity outcomes closely tied to programmatic needs and particular activities. Examples of Categories include “Asset Management,” “Access Control,” and “Detection Processes.”
- **Subcategories** further divide a Category into specific outcomes of technical and/or management activities. They provide a set of results that, while not exhaustive, help support achievement of the outcomes in each Category. Examples of Subcategories include “External information systems are cataloged,” “Data-at-rest is protected,” and “Notifications from detection systems are investigated.”
- **Informative References** are specific sections of standards, guidelines, and practices common among critical infrastructure sectors that illustrate a method to achieve the outcomes associated with each Subcategory. The Informative References presented in the Framework Core are illustrative and not exhaustive. They are based upon cross-sector guidance most frequently referenced during the Framework development process.

The DNS-Based E-Mail Security Building Block project supports the Cybersecurity Framework's Protect, Detect, and Respond Functions. Applicability to specific categories, subcategories, and functions is described in the following paragraphs.

10. *Framework for Improving Critical Infrastructure Cybersecurity*, Version 1.0, National Institute of Standards and Technology February 12, 2014. http://www.nist.gov/cyberframework/upload/cybersecurity-framework-021214.pdf

4.4.4.1 Protect

The Protect function develops and implements the appropriate safeguards needed to ensure delivery of critical infrastructure services. This function supports the ability to limit or contain the impact of a potential cybersecurity event. Examples of outcome Categories within this Function that are addressed by the DNS-Based E-Mail Security project include: Access Control and Protective Technology.

1. **Access Control (PR.AC)**

   The Protect Function's Access Control Category supports an outcome in which access to assets and associated facilities is limited to authorized users, processes, or devices, and to authorized activities and transactions.

   a. **PR.AC-1**

      The **PR.AC-1** subcategory under Access Control supports identities and credentials being managed for authorized devices and users. The security platform resulting from the DNS-Based E-Mail Security project supports effective management of the credentials associated with the addresses from which electronic mail purportedly originates and the integrity of the user identities associated with the electronic mail.

      The original design of the Domain Name System (DNS) did not include security; instead, it was designed to be a scalable distributed system. DNSSEC and DANE attempt to add security, while maintaining backward compatibility with the existing DNS. DNSSEC was designed to protect applications (and caching resolvers serving those applications) from using forged or manipulated DNS data. All answers from DNSSEC protected zones are cryptographically signed (i.e., digital signature over DNS data). By checking the digital signature, a DNS resolver is able to determine whether the information is authentic (i.e. unmodified and complete) and is served on an authoritative DNS server. While protecting IP addresses is the immediate concern for many users, DNSSEC can protect any data published in the DNS, including text records or mail exchange (MX) records, and can be used to bootstrap other security systems that publish references to cryptographic certificates stored in the DNS.

      All DNSSEC responses contain signed DNS data. DNSSEC signature validation allows the use of potentially untrustworthy parties if (for example) the mail server is using a self-signed certificate. The protocol permit configuration of systems to accept messages whether or not they are digitally signed. The security platform developed under the DNS-Based E-Mail Security project permits electronic mail clients and transfer agents to be configured systems to send email messages to only server whose DNS entries are digitally signed. At the client systems level (e.g., Outlook, Postfix, Thunderbird), digital signature of the mail messages themselves can also be applied on user-to-user basis. In the user-to-user case, the signature provides assurance of the integrity of the identity of the sender rather than just the identity of the DNS zone(s) associated with the sender.

   b. **PR.AC-3**

      The **PR.AC-3** subcategory under Access Control supports management of remote access. One of the most common vectors for malware infection is a user clicking on a link that is included in an e-mail message from a spoofed source. Clicking on the link enables remote access to the user's system, and preventing delivery of e-mail from bogus sources represents a management control protecting against remote access by malicious entities. The DNS-Based E-Mail Security project's demonstrated security platform can be used as a basis for accepting or refusing electronic mail based on authenticated data stored in the DNS. This has an added benefit of supporting protection against remote access based on other than e-mail functions.

c. **PR.AC-5**

The **PR.AC-5** subcategory under Access Control supports protection of network integrity by incorporating network segregation where appropriate. The DNS-Based E-Mail Security project does not employ specifically network segregation principles. However, it does support network integrity by providing operationally feasible mechanisms for preventing connections or message delivery to sources that do not implement a specified set of DNS security extensions. Rigorous adherence to a minimum security configuration can enforce effective isolation of a network from entities that do not conform to the network's security requirements.

2. **Data Security (PR.DS)**

The Protect Function's Data Security Category supports an outcome in which information and records (data) are managed consistent with the organization's risk strategy to protect the confidentiality, integrity, and availability of information. The DNS-Based E-Mail Security project demonstrates a capability to provide source and content integrity protection by employing digital signature of messages and confidentiality protection by encrypting messages.

a. **PR.DS-1**

The **PR.DS-1** subcategory under Data Security supports protection of data at rest. The user-to-user digital signature capability demonstrated by the DNS-Based E-Mail Security project can provide an ability to verify the source and content integrity of stored e-mail messages where the digital signature is stored with the rest of the message. This supports integrity protection for data-at-rest.

b. **PR.DS-2**

The **PR.DS-2** subcategory under Data Security supports protection of data in transit. In addition to user-to-user digital signature of e-mail, the DNS-Based E-Mail Security project demonstrates a capability to provide source and content integrity protection to data-in-transit by employing server-to-server confidentiality protection to data-in-transit by employing server-to-server encryption.

c. **PR.DS-6**

The **PR.DS-6** subcategory under Data Security supports use of integrity checking mechanisms to verify software, firmware, and information integrity. The digital signature of e-mail demonstrated by the DNS-Based E-Mail Security project's security platform supports automatic integrity checking of information communicated in e-mail messages. DNSSEC and DANE protect the integrity of address information.

3. **Protective Technology (PR.PT)**

The Protect Function's Protective Technology Category's goal is to ensure the security and resilience of systems and assets by managing a technical security solution consistent with related policies, procedures, and agreements.

a. **PR-PT-4**

The **PR.PT-4** subcategory under Protective Technology supports protection of communications and control networks. The DNS-Based E-Mail Security project demonstrates a capability to provide source and content integrity protection by employing digital signature of communications and confidentiality protection by encrypting communications. The support demonstrated for use of DNSSEC and DANE protocols also support communications and control network integrity by demonstrating operationally feasible mechanisms for refusing connections to or message delivery from sources that do not implement a specified set of DNS security extensions. Rigorous adherence to a minimum security configuration can be use to enforce isolation networks from entities that do not conform to the network's security requirements.

4.4.4.2 Detect

The Detect Function develops and implements the appropriate activities needed to identify in a timely manner the occurrence of a cybersecurity event. Examples of outcome categories within this function that are addressed by the DNS-Based E-Mail Security project include Security Continuous Monitoring and Detection Processes.

1. **Security Continuous Monitoring (DE.CM)**

   The Security Continuous Monitoring Category supports an outcome in which information system and assets are monitored at discrete intervals to identify cybersecurity events and to verify the effectiveness of protective measures. While not a classic example of continuous monitoring, the DNS-Based E-Mail Security platform has the ability to automatically check all DNS responses for correct digital signatures.

   a. **DE.CM-1**

   The **DE.CM-1** subcategory under Security Continuous Monitoring supports monitoring of networks to detect potential cybersecurity events. While not a classic example of continuous monitoring, the demonstrated capability of the DNS-Based E-Mail Security platform to automatically check all inbound DNS responses for valid digital signatures permits identification of attempts to spoof systems using bogus DNS data. Automatic signing and signature validation for e-mail permits continuous checking for false sender identities and modification of message content.

   b. **DE.CM-6**

   The **DE.CM-6** subcategory under Security Continuous Monitoring supports monitoring of external service provider activity to detect potential cybersecurity events. While not a classic example of continuous monitoring, the demonstrated capability of the DNS-Based E-Mail Security platform to automatically check all inbound DNS responses for valid digital permits detection and prevention of attempts by invalid service providers (e.g., bogus Certificate Authorities or Mail Transfer Agents) to spoof users' systems (including man-in-the-middle attacks).

2. **Detection Processes (DE.DP)**

   The Detection Processes Category supports an outcome in which detection processes and procedures are maintained and tested to ensure timely and adequate awareness of anomalous events.

a. **DE.DP-4**

The **DE.DP-4** subcategory under Detection Processes supports event communication of detection information to appropriate parties. One of the shortcomings of most DNSSEC and DANE mechanisms is that they abort delivery of messages from sources whose DNSSEC signature checks fails to validate and do not provide any indication that failure is due to an invalid signature. This usually results in numerous retransmissions and consequent performance degradation or possible crashes. The DNS-Based E-Mail Security platform includes in its DNS resolvers notifications of DNS signature failures to mail agents in order to prevent consequent performance degradation. This communication of detection information has the potential to mitigate one of the primary impediments to private sector adoption of DNSSEC.

4.4.4.3 Respond

The Respond Function develops and implements the appropriate activities to take action regarding a detected cybersecurity event. This Function supports the ability to contain the impact of a potential cybersecurity event. Examples of outcome categories within this function that are addressed by the DNS-Based E-Mail Security project include: Response Planning, Communications, and Mitigation.

1. **Response Planning (RS.RP)**

The Response Planning Category supports an outcome in which response processes and procedures are executed and maintained, to ensure timely response to detected cybersecurity events.

a. **RS.RP-1**

The **RS.RP-1** subcategory under Response Planning supports execution of a response plan during or after an event. Inclusion of DNS and email security in security planning for systems connected to the Internet will necessarily include responses to detection of invalid digital signatures that include security flagging of connections and messages, and/or refusing connections and delivery of messages. Concurrent with detection of validation failure detection, these responses are demonstrated by the DNS-Based E-Mail Security platform.

2. **Communications (RS.CO)**

The RS.CO-2 subcategory under Communications supports reporting of events consistent with established criteria. As stated under DE.DP-4, one of the shortcomings of most DNSSEC and DANE mechanisms is that they abort delivery of messages to destinations whose DNSSEC signature checks fail but do not provide any indication that the failure is due to an invalid signature. In order to prevent consequent performance degradation, the DNS-Based E-Mail Security platform includes in its DNS resolver configuration notifications of DNSSEC signature failures to mail agents (i.e. configuration to log relevant DNSSEC issues). This communication of detection information has the potential to mitigate one of the primary impediments to private sector adoption of DNSSEC. It also provides a mechanism that can be exploited to provide to external stakeholders information involving failures of DNSSEC signature checks.

a. **RS.CO-2**

The **RS.CO-2** subcategory under Communications supports reporting of events consistent with established criteria. As stated under DE.DP-4, one of the shortcomings of most DNSSEC and DANE mechanisms is that they abort delivery of messages to destinations whose DNSSEC signature checks fail but do not provide any indication that the failure is due to an invalid signature. In order to prevent consequent performance degradation, the DNS-Based E-Mail Security platform includes in its DNS resolvers notifications of DNSSEC signature failures to mail agents. This communication of detection information has the potential to mitigate one of the primary impediments to private sector adoption of DNSSEC. It also provides a mechanism that can be exploited to provide to external stakeholders information involving failures of DNSSEC signature checks.

3. **Mitigation (RS.MI)**

   a. **RS.MI-1**

      The **RS.MI-1** subcategory under Mitigation supports containment of incidents. In the case of incidents that compromise the integrity of network systems through which electronic mail is routed, the effects of the compromise can be limited to those local systems and devices that have not implemented the integrity and confidentiality mechanisms demonstrated by the DNS-Based E-Mail Security platform.[11]

   b. **RS.MI-2**

      The **RS.MI-2** subcategory under Mitigation supports mitigation of incidents. The DNS-Based E-Mail Security project demonstrates user-to-user digital signature of messages. Retention of their digital signatures with stored messages permits later determination of whether the messages have been modified in storage. This can be a mitigating factor in the case of incidents that involve introduction of fraudulent information into electronic mail records. The project's demonstration of server-to-server encryption provides confidentiality protection for data-in-transit. This confidentiality protection can serve as a mitigating factor in the case of incidents involving unauthorized access to messages captured by network devices that sit between the sender's and recipient's mail servers.

4.4.5 Cybersecurity References Directly Tied to those Cybersecurity Framework Categories and Subcategories Addressed by the DNS-Based Email Security Project

The following security references were followed in accepting components for the DNS-Based Email Security platform, designing the platform, conducting demonstrations of the platform, and documenting the platform. The Framework functions, categories, and subcategories addressed by these references are listed for each reference. While many of the references were written as standards and guidelines to be applied to federal government agencies, their recommendations may also be applied in the private sector as best practices that support Cybersecurity Framework functional categories and subcategories. Those subcategories addressed by the DNS-Based Email Security platform are in **boldface**.

11. Note that, if a system is subverted, a lot of assumed security goes out the window. A subverted sending MTA could still be seen as valid by receivers for example.

1. *Security Requirements for Cryptographic Modules*, Federal Information Processing Standard (FIPS), FIPS 140-2, May 2001. http://csrc.nist.gov/publications/fips/fips140-2/fips1402.pdf

   FIPS 140-2 provides a standard that is required to be used by Federal organizations when these organizations specify that cryptographic-based security systems be used to provide protection for sensitive or valuable data. Protection of a cryptographic module within a security system is necessary to maintain the confidentiality and integrity of the information protected by the module. All cryptographic components employed by the Federal government outside the national security community, including NCCoE security platforms that employ cryptography, must conform to FIPS 140-2. This standard specifies the security requirements that will be satisfied by a cryptographic module. The standard provides four increasing qualitative levels of security intended to cover a wide range of potential applications and environments. The security requirements cover areas related to the secure design and implementation of a cryptographic module. These areas include cryptographic module specification; cryptographic module ports and interfaces; roles, services, and authentication; finite state model; physical security; operational environment; cryptographic key management; electromagnetic interference/electromagnetic compatibility (EMI/EMC); self-tests; design assurance; and mitigation of other attacks.

   Within the context of the Cybersecurity Framework, FIPS 140-2 provides standards for “Protection” to be provided by cryptographic modules (PR.AC-2, **PR.AC-3**, PR.AC-4, **PR.DS-1**, **PR.DS-2**, PR.DS-5, **PR.DS-6**, PR.IP-3, and **PR.PT-4**) and “Detection” of failures or other exception conditions that might affect the protection afforded to systems by cryptographic modules (**DE.CM-1**, DE.CM-2, and DM.DP-3).

2. *Guide for Applying the Risk Management Framework to Federal Information Systems: A security Lifecycle Approach*, NIST Special Publication, SP 800-37 Rev. 1, Joint Task Force Transformation Initiative; February 2010 with updates as of June 5, 2014. http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-37r1.pdf

   SP 800-37 Rev. 1 provides guidelines for applying the Risk Management Framework (RMF) to federal information systems. Systems to which the RMF is to be applied include NCCoE use case and block activities. The RMF promotes the concept of near real-time risk management and ongoing information system authorization through the implementation of robust continuous monitoring processes; provides senior leaders with the necessary information to make cost-effective, risk-based decisions with regard to the organizational information systems supporting their core missions and business functions; and integrates information security into the enterprise architecture and development life cycle. Applying the RMF within enterprises links management processes at the information system level to management processes at the organization level through a risk executive (function) and establishes lines of responsibility and accountability for security controls deployed within organizational information systems and inherited by those systems (i.e., common controls).

   The six-step RMF includes security categorization, security control selection, security control implementation, security control assessment, information system authorization, and security control monitoring. With respect to the Cybersecurity Framework, SP 800-37 assumes that system components, business environment and governance structure have been identified. The risk assessment that underlies categorization is based on the assumed understanding of these factors. SP 800-37 also focuses on impacts of security incidents rather than on threats that take advantage of system vulnerabilities to create those impacts. The control selection, control implementation, and system authorization recommendations of SP 800-37 do not map directly to the Cybersecurity Framework.

However, SP 800-37 does provide recommendations relevant to **Identify** (ID.RA-5, ID.RA-6, ID.RM 1, and ID.RM-2 in Section 3.1), **Protect** (PR.IP-3, and PR.IP-7 in Sections 3.4 and 3.6), and **Detect**, (DE.AE-5 and **DE.CM-1** in Section 3.6) elements of the Cybersecurity Framework.

3. *Guidelines on Electronic Mail Security*; NIST Special Publication; SP 800-45 Ver. 2; Tracy, Jansen, Scarfone, Butterfield; February 2007.
   http://csrc.nist.gov/publications/nistpubs/800-45-version2/SP800-45v2.pdf

   SP 800-45 provides guidelines intended to assist organizations in installing, configuring, and maintaining secure mail servers and mail clients. Specifically, the publication discusses in detail:

   a. email standards and their security implications
   b. email message signing and encryption standards
   c. the planning and management of mail servers
   d. securing the operating system underlying a mail server
   e. mail-server application security
   f. email-content filtering
   g. email-specific considerations in the deployment and configuration of network protection mechanisms, such as firewalls, routers, switches, and intrusion detection and intrusion prevention systems
   h. securing mail clients
   i. administering the mail server in a secure manner, including backups, security

   As suggested by its 2007 publication date, SP 800-45 doesn't reflect the most recent developments in electronic mail security, especially the more recent IETF RFCs (e.g., SMIMEA[12] and TLSA[13]), but the recommendations it makes are still germane.

   With respect to the Cybersecurity Framework's **Identify** category and its subcategories, SP 800-45 recommends risk management activities, but does not go into detail that maps to subcategory references. In the Protect category, subcategory references **PR.AC-1**, **PR.AC-3**, PR.AC-4, **PR.AC-5**, PR.AT-1, PR.AT-2, PR.AT-5, **PR.DS-2**, **PR.DS-6**, PR.IP-2, PR.IP-4, and PR.PT-1 are addressed by the guideline. In the **Detect** category, subcategory references DP-1 and **DE.DP-4** are addressed by the guideline. In the **Respond** category, subcategory references DE.AE-2, DE.CM-1, DE.CM-4, DE.CM-5, DE.CM-8, DE.DP-1, and DE.DP-4 are addressed. In the **Respond** category, subcategory references RS.RP-1, **RS.CO-1**, RS.CO-2, RS.AN-1, and RS.IM-1 are addressed by the guideline. In the **Recover** category, subcategory reference RC.RP-1 is addressed by the guideline.

4. *Federal S/MIME V3 Client Profile*, NIST Special Publication, SP 800-49, Chernick, November 2002. http://csrc.nist.gov/publications/nistpubs/800-49/sp800-49.pdf

12. See *Using Secure DNS to Associate Certificates with Domain Names For S/MIME* (draft-ietf-dane-smime-02) and *Using Secure DNS to Associate Certificates with Domain Names For S/MIME* (draft-ietf-dane-smime-12)
13. RFC 6698, The DNS-Based Authentication of Named Entities (DANE) Transport Layer Security (TLS) Protocol: TLSA

SP 800-49 was developed to provide organizations with approaches to assure that Secure/Multipurpose Internet Mail Extensions (S/MIME) products can interoperate and meet the e-mail security needs of federal agencies both with respect to security features and adequate cryptographic algorithms. This profile states requirements for

implementing sets of cryptographic algorithm suites specified elsewhere by the standards development organizations. The profile specifies a set of e-mail security features (e.g., encrypted e-mail and signed receipts) that are mandatory for federal agencies. SP 800-49 adds specificity to the S/MIME standards, while attempting to avoid violating those standards. As its 2002 publication date suggests, SP 800-49 is even more dated with respect to protocols than SP 800-45 (e.g., recommending the now deprecated SHA-1 instead of SHA-2 for hashing, and the deprecated Triple DES rather than AES for encryption). However, it too, makes security recommendations that are still germane. The SP 800-49 requirements and recommendations fall into the Cybersecurity Framework **Protect** category. It provides guidelines that address the subcategory references **PR.DS-2**, **PR.DS-6**, and (less precisely) **PR.PT-4**.

5. *Guidelines for the Selection, Configuration, and Use of Transport Layer Security (TLS) Implementations*; NIST Special Publication; SP 800-52 Rev. 1; Polk, McKay, Chokhani; April 2014. http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-52r1.pdf

   Transport Layer Security (TLS) provides mechanisms to protect sensitive data during electronic dissemination across the Internet. SP 800-52 provides guidance in the selection and configuration of TLS protocol implementations, while making effective use of Federal Information Processing Standards (FIPS) and NIST- recommended cryptographic algorithms. SP 800-52 requires that TLS 1.1 be configured with FIPS-based cipher suites as the minimum appropriate secure transport protocol and recommended that agencies develop migration plans to TLS 1.2 by January 1, 2015. This Special Publication also identifies TLS extensions for which mandatory support must be provided and some other recommended extensions. Like SP 800-49, the SP 800-52 requirements and recommendations fall into the Cybersecurity Framework **Protect** category. The guideline addresses the subcategory references **PR.DS-2**, **PR.DS-6**, and (less precisely) **PR.PT-4**.

6. *Security and Privacy Controls For Federal Information Systems And Organizations*, NIST Special Publication, SP 800-53 Rev. 4, Joint Task Force Transformation Initiative, April 2013. http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-53r4.pdf

   SP 800-53 provides a catalog of security and privacy controls for federal information systems and organizations and a process for selecting controls to protect organizational operations (including mission, functions, image, and reputation), organizational assets, individuals, other organizations, and the nation from a diverse set of threats, including hostile cyberattacks, natural disasters, structural failures, and human errors. The controls are customizable and implemented as part of an organization-wide process that manages information security and privacy risk. The controls address a diverse set of security and privacy requirements across the federal government and critical infrastructure that are derived from legislation, Executive Orders, policies, directives, regulations, standards, and/or mission/business needs. The publication also describes how to develop specialized sets of controls, or overlays, that are tailored for specific types of missions/business functions, technologies, or environments of operation. Finally, the catalog of security controls addresses security from both a functionality perspective (the strength of security functions and mechanisms provided) and an assurance perspective (the measures of confidence in the implemented security capability). Addressing both security functionality and security assurance ensures that information technology products and the information systems built from those products using sound systems and security engineering principles are sufficiently trustworthy.

SP 800-53 Rev. 4 addresses all Cybersecurity Framework categories and subcategories. Only the RC.CO-1 (Reputation after an event is repaired) and **RC.CO-2** (Recovery activities are communicated to internal stakeholders and executive and management teams) references under the **Recover**: Communications subcategory are not addressed by SP 800-53.

7. *Recommendation for Key Management: Part 1 - General*, NIST Special Publication 800-57 Part Rev.4, Barker, January 2016; *Part 2 - Best Practices for Key Management Organization*, NIST Special Publication 800-57 Part 2, Barker, Barker, Burr, Polk, and Smid, August 2005; and *Part 3 - Application-Specific Key Management Guidance*, NIST Special Publication, SP 800-57 Part 3 Rev. 1, Barker and Dang, January 2015. http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-57pt1r4.pdf, http://csrc.nist.gov/publications/nistpubs/800-57/SP800-57-Part2.pdf, http://nvlpubs.nist.gov/nistpubs/SpecialPublications/ NIST.SP.800-57Pt3r1.pdf

   NIST Special Publication 800-57 provides cryptographic key management guidance. Part 1 provides general guidance and best practices for the management of cryptographic keying material. Part 2 provides guidance on policy and security planning requirements for U.S. government agencies. Part 3 of this Special Publication provides guidance when using the cryptographic features of current systems that may not exhibit all of the properties recommended by Part 1 of the guideline. Part 3 includes applications-specific recommendations for, among other applications, the Public Key Infrastructure (PKI), Internet Protocol Security (IPsec), Transport Layer Security (TLS) Secure/Multipart Internet Mail Extensions (S/MIME), and Domain Name System Security Extensions (DNSSEC). All of these recommendations apply directly to the DNS-Based E-Mail Security Building Block.

   SP 800-57 addresses all of the Cybersecurity Framework categories except **Detect**. Audit is the primary mechanism relied on in SP 800-53 for detection purposes. The categories and subcategory references that are addressed by the guideline include Identify (ID.AM-2, ID.BE-3, ID.BE-4, ID.BE-5, ID.GV-1, ID.GV-4, ID.RA-4, and ID.RA-5), **Protect** (**PR.AC-1**, PR.AC-2, **PR.AC-3**, PR.AC-4, PR.AT-2, PR.AT-3, PR.AT-4, **PR.DS-1**, **PR.DS-2**, PR.DS-3, PR.DS-4, **PR.DS-6**, PR.IP-2, PR.IP-3, PR.IP-4, PR.IP-5, PR.IP-6, PR.IP-9, PR.PT-1, PR.PT-2, PR.PT-3, and **PR.PT-4**); **Respond** (**RS.RP-1**, RS.CO-1, **RS.CO-2**, RS.CO-3, RS.AN-2, and **RS.MI-2**); and **Recover** (RC.RP-1).

8. *Secure Domain Name System (DNS) Deployment Guide*, NIST Special Publication, SP 800-81-2, Chandramouli and Rose, September 2013. http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-81-2.pdf

   The DNS is a distributed database that enables access to Internet resources via user-friendly domain names, rather than IP addresses, by translating domain names to IP addresses and back. The DNS infrastructure is made up of computing and communication entities called name servers, each of which contains information about a small portion of the domain name space. The name data provided by DNS is intended to be available to any computer located anywhere in the Internet. SP 800-81-2 provides deployment guidelines for securing DNS within an enterprise. The primary security goals for DNS are data integrity and source authentication, which are needed to ensure the authenticity of name information and maintain the integrity of name information in transit. This document provides extensive guidance on maintaining data integrity and performing source authentication. This document presents guidelines for configuring DNS deployments to prevent many redirection attacks that exploit vulnerabilities in various DNS components.

The categories and subcategory references that are addressed are limited to **Identify** (ID.AM-2 and ID.RA-6), **Protect** (**PR.AC-1**, **PR.AC-3**, **PR.AC-5**, PR.AT-2, **PR.DS-2**, PR.DS-5, **PR.DS-6**, PR.IP-3, PR.IP-4, PR.IP-6, and PR.IP-9), and **Detect** (**DE.CM-1** and DE.CM-7).

9. *A Framework for Designing Cryptographic Key Management Systems*; NIST Special Publication; SP 800-130; Barker, Branstad, Smid, Chokhani; August 2013. http://nvlpubs.nist.gov/nistpubs/SpecialPublications/ NIST.SP.800-130.pdf

   SP 800-130's framework for Designing Cryptographic Key Management Systems (CKMS) contains topics that should be considered by a CKMS designer when developing a CKMS design specification. For each topic, there are one or more documentation requirements that need to be addressed by the design specification. Thus, any CKMS that addresses each of these requirements would have a design specification that is compliant with this framework. A CKMS will be a part of a larger information system that executes processing applications. While the CKMS supports these applications by providing cryptographic key management services, the particular applications or particular classes of applications are beyond the scope of this framework.

   SP 800-130 addresses all of the Cybersecurity Framework categories The categories and subcategory references that are addressed include **Identify** (ID.BE-4, ID.GV-1, ID.GV-2, ID.GV-3, ID.GV-4, ID.RA-1, ID.RA-2, ID.RA-3, ID.RA-5, and RM-1); **Protect** (**PR.AC-1**, PR.AC-2, PR.AC-4, **PR.AC-5**, PR.AT-1, PR.AT-2, PR.AT-4, PR.AT-5, PR.DS-1, PR.DS-2, PR.DS-3, **PR.DS-6**, PR.DS-7, PR.IP-1, PR.IP-3, PR.IP-4, PR.IP-5, PR.IP-6, PR.IP-9, PR.MA-1, PR.PT-1, PR.PT-2, PR.PT-3, and **PR.PT-4**); **Detect** (DE.AE-4, **DE.CM-1**, DE.CM-4, **DE.CM-7**, DE.CM-8,DE.DP-1, DE.DP-2, DE.DP-3, and DE.DP-5); **Respond** (**RS.RP-1**, RS.CO-1, **RS.CO-2**, RS.AN-2, **RS.MI-1**, and RS.MI-2); and **Recover** (RC.RP-1).

10. *A Profile for U.S. Federal Cryptographic Key Management Systems (CKMS)*; Third Draft; NIST Special Publication; SP 800-152; Barker, Smid, Branstad; December 18, 2014. http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-152.pdf

    Draft SP 800-152 covers major aspects of managing the cryptographic keys that protect federal information. Associated with each key is specific information (e.g., the owner identifier, its length, and acceptable uses) called metadata. The computers, software, modules, communications, and roles assumed by one or more authorized individuals when managing and using cryptographic key management services are collectively called a Cryptographic Key Management System (CKMS). The Profile for U. S. Federal Cryptographic Key Management Systems (FCKMSs) has been prepared to assist CKMS designers and implementers in selecting the features to be provided in their "products," and to assist federal organizations and their contractors when procuring, installing, configuring, operating, and using FCKMSs.

    SP 800-130 addresses all of the Cybersecurity Framework categories. The categories and subcategory references that are addressed include **Identify** (ID.AM-3, ID.AM-5, ID.BE-4, ID.BE-5, ID.GV-1, ID.GV-2, ID.GV-3, ID.GV-4, ID.RA-1, ID.RA-3, ID.RA-5, ID.RA-6, RM-1, and RM-2); **Protect** (**PR.AC-1**, PR.AC-2, **PR.AC-3**, PR.AC-4, **PR.AC-5**, PR.AT-1, PR.AT-2, PR.AT-4, PR.AT-5, **PR.DS-1**, **PR.DS-2**, PR.DS-3, PR.DS-4, **PR.DS-6**, PR.DS-7, PR.IP-1, PR.IP-3, PR.IP-4, PR.IP-5, PR.IP-6, PR.IP-7, PR.IP-8, PR.IP-9, PR.IP-12, PR.MA-1, PR.PT-1, PR.PT-2, PR.PT-3, and **PR.PT-4**); **Detect** (DE.AE-4, **DE.CM-1**, DE.CM-4, **DE.CM-7**, DE.CM-8, DE.DP-1, DE.DP-2, DE.DP-3, and DE.DP-5); **Respond** (**RS.RP-1**, RS.CO-1, **RS.CO-2**, RS.AN-2, **RS.MI-1**, **RS.MI-2**, RS.MI-3, and RS.IM-2); and **Recover** (RC.RP-1 and RC.IM-2).

11. *Trustworthy Email*; NIST Special Publication 800-177; Chandramouli, Garfinkle, Nightingale and Rose; Draft Publication; September 2016.
    http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-177.pdf

    NIST Special Publication 800-177 serves as a complimentary document to SP 800-45. SP 800-177 addresses email protocol security and provides descriptions, guidelines and recommendations for deploying new email security protocols such as SMTP over TLS, email supported by DANE, and other non-cryptographic authentication (e.g. Sender Policy Framework, etc.). Discussions of SMTP over TLS and S/MIME relate directly to the work on the DNS-Based Email Security Project builds.

    With respect to the Cybersecurity Framework's Identify category and its subcategories, SP 800-177 recommends risk management activities, but does not go into detail that maps to subcategory references. In the **Protect** category, subcategory references **PR.AC-1**, **PR.AC-3**, PR.AC-4, **PR.AC-5**, PR.AT-1, PR.AT-2, PR.AT-5, **PR.DS-2**, **PR.DS-6**, PR.IP-2, PR.IP-4, and PR.PT-1 are addressed by the guideline. In the **Detect** category, subcategory references DP-1 and **DE.DP-4** are addressed by the guideline. In the **Respond** category, subcategory references DE.AE-2, DE.CM-1, DE.CM-4, DE.CM-5, DE.CM-8, DE.DP-1, and DE.DP-4 are addressed. In the Respond category, subcategory references RS.RP-1, RS.CO-1, **RS.CO-2**, RS.AN-1, and RS.IM-1 are addressed by the guideline. In the **Recover** category, subcategory reference RC.RP-1 is addressed by the guideline.

4.4.6 Other Security References Applied in the Design and Development of the DNS-Based Email Security Project

The following references provided additional security and protocol standards and guidelines that were applied during design and development of the DNS-Based Email Security Project.

1. *Systems Security Engineering: An Integrated Approach to Building Trustworthy Resilient Systems*, Draft, NIST Special Publication, SP 800-160, May 2014.
   http://csrc.nist.gov/publications/drafts/800-160/sp800_160_second-draft.pdf

   NIST Special Publication 160 defines system security engineering processes that are tightly coupled to and fully integrated into well-established, international standards-based systems and software engineering processes. The project supports the federal cybersecurity strategy of “Build It Right, Continuously Monitor” and consists of a four-phase development approach that will culminate in the publication of the final systems security engineering guideline at the end of 2014. The four phases include:

   a. **Phase 1**: Development of the system security engineering technical processes based on the technical systems and software engineering processes defined in ISO/IEC/IEEE 15288:2008

   b. **Phase 2**: Development of the remaining supporting appendices (i.e., Information Security Risk Management (including the integration of the Risk Management Framework [RMF], security controls, and other security- and risk-related concepts into the systems security engineering processes), Use Case Scenarios, Roles and Responsibilities, System Resiliency, Security and Trustworthiness, Acquisition

Considerations, and the Department of Defense Systems Engineering Process (Summer 2014)

c. **Phase 3**: Development of the systems security engineering nontechnical processes based on the nontechnical systems and software engineering processes (i.e., Agreement, Organizational Project-Enabling, and Project) defined in ISO/IEC/IEEE 15288: 2008 (Fall 2014)

d. **Phase 4**: Alignment of the technical and nontechnical processes based on the updated systems and software engineering processes defined in ISO/IEC/IEEE DIS 15288:201x(E) (Fall or Winter 2014, subject to the final publication schedule of the international standards bodies)

The full integration of security engineering discipline into the systems and software engineering discipline involves fundamental changes in the traditional ways of doing business within organizations. This may involve breaking down institutional barriers that, over time, have isolated security activities from the mainstream organizational management and technical processes, including, for example, the system development life cycle, acquisition/procurement, and enterprise architecture. The integration of these interdisciplinary activities requires the strong support of senior leaders and executives, and increased levels of communication among all stakeholders who have an interest in, or are affected by, the systems being developed or enhanced.

2. *Internet X.509 Public Key Infrastructure Certificate and CRL Profile*; IETF RFC 2459; Housley, Ford, Polk, Solo; January 1999. https://www.rfc-editor.org/rfc/rfc2459.txt

   RFC 2459 is one part of a family of standards for the X.509 Public Key Infrastructure (PKI) for the Internet, but the RFC is a standalone document; implementations of this standard proceed independent from the other parts. The RFC profiles the format and semantics of public key certificates and certificate revocation lists for the Internet. Procedures are described for the processing of certification paths in the Internet environment. Encoding rules are provided for popular cryptographic algorithms. Finally, ASN.1 modules are provided in the appendices for all data structures defined or referenced.

3. *Threat Analysis of the Domain Name System (DNS)*, IETF RFC 3833, Atkins and Austein, August 2004. https://tools.ietf.org/html/rfc3833

   RFC 3833 attempts to document some of the known threats to the DNS, and, in doing so, measure the extent to which DNSSEC is a useful tool in defending against these threats.

4. *Internet X.509 Public Key Infrastructure Certificate and Certificate Revocation List (CRL) Profile*; Proposed Standard; IETF RFC 5280; Cooper, Santesson, Farrell, Boeyen, Housley, Polk; May 2008. https://datatracker.ietf.org/doc/rfc5280/

   RFC 5280 profiles the X.509 v3 certificate and X.509 v2 certificate revocation list (CRL) for use in the Internet. The RFC provides an overview and model of the specified approach, describes the X.509 v3 certificate format in detail, with additional information regarding the format and semantics of Internet name forms. Standard certificate extensions are described and two Internet-specific extensions are defined. A set of required certificate extensions is also specified, the X.509 v2 CRL format is described along with standard and Internet-specific extensions, an algorithm for X.509 certification path validation is described, and an ASN.1 module and examples are provided.

5. *Simple Mail Transfer Protocol*, IETF RFC 5321, Draft Standard, Kleinstein, October 2008. https://tools.ietf.org/html/rfc5321

RFC 5321 is a specification of the basic protocol for Internet electronic mail transport. It covers the SMTP extension mechanisms and best practices for the contemporary Internet, but does not provide details about particular extensions. Although SMTP was designed as a mail transport and delivery protocol, this specification also contains information that is important to its use as a "mail submission" protocol for "split-UA" (User Agent) mail reading systems and mobile environments.

6. *Secure/Multipurpose Internet Mail Extensions (S/MIME)*, Version 3.2, Message Specification, Proposed Standard, IETF RFC 5751, ISSN: 2070-1721, Ramsdell and Turner, January 2010. https://tools.ietf.org/html/rfc5751

   RFC 5751 defines Secure/Multipurpose Internet Mail Extensions (S/MIME) version 3.2. S/MIME provides a consistent way to send and receive secure MIME data. The RFC describes methods for digital signatures to provide authentication, message integrity, and non-repudiation with proof of origin; encryption to provide data confidentiality; and to reduce data size.

7. *Use Cases and Requirements for DNS-Based Authentication of Named Entities (DANE)*, IETF RFC 6394, ISSN: 2070-1721, Barnes, October 2011. https://tools.ietf.org/html/rfc6394

   Many current applications use the certificate-based authentication features in Transport Layer Security (TLS) to allow clients to verify that a connected server properly represents a desired domain name. Typically, this authentication has been based on PKI certificate chains rooted in well-known certificate authorities (CAs), but additional information can be provided via the DNS itself. This document describes a set of use cases in which the DNS and DNS Security Extensions (DNSSEC) could be used to make assertions that support the TLS authentication process. The main focus of this document is TLS server authentication, but it also covers TLS client authentication for applications where TLS clients are identified by domain names.

8. *The DNS-Based Authentication of Named Entities (DANE) Transport Layer Security Protocol: TLSA*, Proposed Standard, IETF RFC 6698, ISSN: 2070-1721, Hoffman and Schlyter, August 2012. https://tools.ietf.org/html/rfc6698

   Encrypted communication on the Internet often uses Transport Layer Security (TLS), which depends on third parties to certify the keys used. RFC 6698 provides means to improve on that situation by standardizing on methods to enable the administrators of domain names to specify the keys used in that domain's TLS servers. This requires matching improvements in TLS client software, but no change in TLS server software.

9. *Updates to the Internet X.509 Public Key Infrastructure Certificate and Certificate Revocation List (CRL) Profile, Proposed Standard*, IETF RFC 6818, ISSN: 2070- 1721, Yee, January 2013. https://tools.ietf.org/html/rfc6818

   RFC 6818 updates RFC 5280, the *Internet X.509 Public Key Infrastructure Certificate and Certificate Revocation List (CRL) Profile*. It changes the set of acceptable encoding methods for the explicit Text field of the user notice policy qualifier and clarifies the rules for converting internationalized name labels to ASCII. The RFC also provides some clarifications on the use of self-signed certificates, trust anchors, and some updated security considerations.

10. *SMTP security via opportunistic DANE TLS*, RFC 7672, Dukhovni and Hardaker, May 26, 2015. https://tools.ietf.org/html/rfc7672

The RFC describes a downgrade-resistant protocol for SMTP transport security between Message Transfer Agents (MTAs), based on the DNS-Based Authentication of Named Entities (DANE) TLSA DNS record. Adoption of this protocol will enable an incremental transition of the Internet email backbone to one using encrypted and authenticated Transport Layer Security (TLS).

11. *Using Secure DNS to Associate Certificates with Domain Names For S/MIME*, IETF Internet Draft Work in Progress, draft-ietf-dane-smime-12, Hoffman and Schlyter, July 31, 2016. https://datatracker.ietf.org/doc/draft-ietf-dane-smime/

    The draft RFC for using secure DNS to associate certificates with domain names for S/MIME describes how to use secure DNS to associate an S/MIME user's certificate with the intended domain name; similar to the way that DANE (RFC 6698) does for TLS.

4.5 Technologies

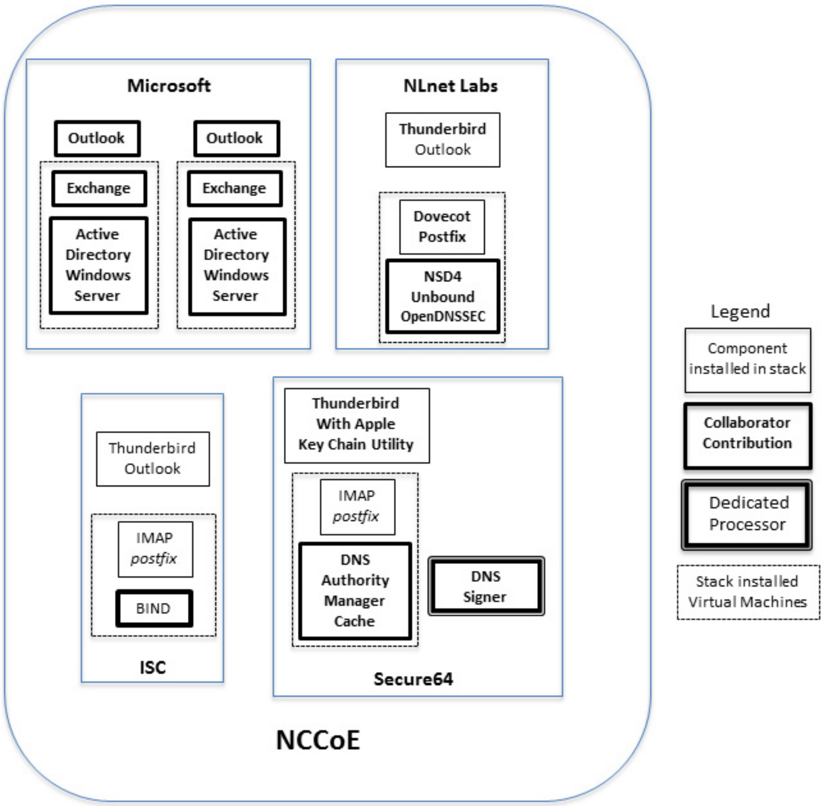
The laboratory configuration employed for the DNS-Based Email Security project included components contributed by several sets of collaborating organizations. One of the component sets is Windows-based. The others are Linux-based. There were also three Mail User Agents (MUAs): Microsoft Outlook, Mozilla Thunderbird (on Linux), and a Thunderbird MUA equipped with a DANE-aware Apple Key Chain utility[14] that were able to interact to all the mail servers via IMAP. While the Windows-based contribution used Server 2016 DNS services, the Linux-based contributions included three different implementations for DNS. One was based on NSD4 and Unbound authoritative and recursive servers, one was based on the Berkeley Internet Name Domain (BIND) DNS server, and one was based on the Secure64 DNS services. Secure 64 also contributed DNS services hosted on dedicated processors using SecureT micro O/S technology. Collaborators assisted in installation and initial configuration of products and, as necessary, in composition of components for different test cases.

Figure 4.1 below depicts, at a high-level, collaborator contributions used to support the demonstration project. Elements identified in boldface are components provided or adapted by the collaborator. Other elements were incorporated into the stack to permit checking out the installed component's functionality.

Collaborator contributions identified below are organized with respect to the contributor as initially installed and checked out at the NCCoE. The architecture described in Section 5 below permits demonstration of the interconnection of components provided by different collaborators and initially checked out independently.

14. A utility for Public Key Retrieval into the Apple Key Chain. This utility is delivered on a MacBook loaded with Apple Mail and is a program for the MacBook that will fetch SMIMEA records and put them in the keystore so that we can demonstrate end-to-end security.

Figure 4.1 DNS-Based Email Security Collaborator Contributions



4.5.1 Microsoft

The Microsoft environments were contributed to support demonstration Scenario 1. Two environments were configured on the laboratory's VMware virtual machines (See figure 4.1 above). Each stack included the ability to demonstrate Office Outlook[15] as an MUA, included Exchange Server 2016[16] as MTAs, and used Active Directory running on Microsoft Windows Server 2016[17] for DNS services. The Microsoft contribution included DNSSEC aware DNS recursive server, DNSSEC aware DNS authoritative server (IETF RFC 4033, 4034, and 4035), an MTA that can do SMTP over TLS (RFC 3207), management tools to configure servers and for debugging purposes, X.509 certificate sources, FIPS 140-2 validated cryptographic software, and support for multifactor authentication. The stacks were also able to be configured to demonstrate that Exchange could be used with either an Outlook or a Thunderbird MUA. Other test cases demonstrated using Exchange with a combination of other providers' DNS implementations.

15. https://en.wikipedia.org/wiki/Microsoft_Outlook
16. https://products.office.com/en/exchange/microsoft-exchange-server-2016
17. https://www.microsoft.com/en-us/server-cloud/products/windows-server-2016/

4.5.2 NLnet

The NLnet contribution focused on DNS services to support both demonstration scenarios. NLnet software was initially configured on the laboratory's VMware virtual machines. The components included NSD4 4.1.9[18], Unbound[19], and OpenDNSSEC[20] software for DNS services and Postfix and Dovecot for mail services. NSD4 is an authoritative only, high performance, open source name server. Unbound is a validating, recursive, caching DNS resolver. OpenDNSSEC is a set of software for signing DNS zones that are then served using NSD. While OpenDNSSEC can be configured to sign zone files or to sign zones transferred in via DNS zone transfer (AXFR), in these scenarios, it is used to sign local zone files in these scenarios. Like with the Microsoft stack above, multiple MUAs were configured to send and receive mail with the NLnet components via SMTP and IMAP.

4.5.3 ISC

The ISC contribution was focused on the BIND DNS server and supported both demonstration scenarios. BIND was initially configured on the laboratory's VMware virtual machines and included configuration for Postfix and Dovecot for email. BIND[21] is open source software that is considered the reference implementation of DNS, but it is also production-grade software, suitable for use in high-volume and high-reliability applications. BIND features response rate limiting (RRL), support for FIPS 140-2 validated hardware cryptographic modules, the optional ability to retrieve zone data directly from an external database, the ability to use in-line signing to automatically re-sign records as they are updated, and a scalable master/slave hierarchy. Like the other stacks, all three MUAs were able to connect and use the stack for DNS and email.

4.5.4 Secure64

The Secure64 contributions were focused on DNS services to support both demonstration scenarios. The Secure64 environment included an automated online Secure64 DNS Signer as well as DNSSEC-capable VM images of DNS Cache, DNS Authority, and DNS Manager. DNS Manager provided centralized management of Secure64 DNS Cache software and configurations and provided network-wide monitoring of key performance indicators. DNS Manager allowed creation of groups of servers and assignment of configurations to a group, a single server, or all servers. DNS Authority is an authoritative signer and server as a single platform. DNS Cache, DNS Authority, and DNS Manager were configured on the laboratory's VMware virtual machine; and the DNS Signer was provided as a high-assurance implementation delivered on a Secure64 dedicated appliance. Secure64 contributions were able to demonstrate Outlook, Thunderbird, or Thunderbird equipped with an Apple Key Chain utility as MUAs and use Postfix as an MTA and Dovecot to provide IMAP for clients.

18. http://www.nlnetlabs.nl/projects/nsd/
19. http://unbound.net
20. https://www.opendnssec.org
21. https://www.isc.org/downloads/bind/

5 Architecture

5.1 Usage Scenarios Supported 36
5.2 Architectural Overview 38

The Security platform architecture used for the DNS-Based Email Security project included combinations of components from different sources that supported two usage scenarios for DANE-enabled secure email in four different systems environments.

5.1 Usage Scenarios Supported

The scenarios supported include:

- “ordinary” email where the email exchanges between two organizations' email servers communicate over TLS with a STARTTLS extension, and relevant TLSA records are published in the receiver's DNS zone protected by DNSSEC; and
- end-to-end signed email, where the email exchanges between users in different organizations are carried over a channel protected by TLS (using the STARTTLS extension), and relevant artifacts used for signing and channel protection are published in a DNS zone protected by DNSSEC. Subsequently, these artifacts are used for S/MIME and TLS validation.

In both scenarios, end-entity and personal certificates were generated from Certificate Authorities (CAs). Use of “well known” (i.e. installed as trust anchors in hosts), local enterprise CAs, and self-signed certificates were demonstrated.

While the second scenario demonstrated signing of emails, it does not include an end-to-end encrypted email scenario. Signing addresses the main security concerns in enterprise environments, which are the target of the project, but may neglect concerns of individual users who may also want to reduce information disclosure to their email providers. The two scenarios that are included may, however, serve as enablers for end-to-end encryption. Participation by parties having a primarily end-to-end encryption focus may succeed in generating industry support for the building blocks needed to support end-to-end encryption.

In more detail, the project's security platforms use the STARTTLS extension to include encryption of communications between two MTAs, as well as the signature of individual messages using S/MIME. The encryption and decryption with S/MIME on the end user's client was excluded from the current platform demonstration.

5.1.1 Usage Scenario 1

An individual needs to enter into an email exchange with an individual in another organization Each individual exchanges email via the respective parent organizations' mail servers. Users connect to their organizations' respective mail servers within a physically protected zone of control.

In this scenario, the privacy policy of the parent organizations requires encryption of the information being exchanged. The security afforded by the cryptographic process is dependent on the confidentiality of encryption keys from unauthorized parties. The mail servers are configured to use X.509 certificates to authenticate themselves during an encryption key establishment process.

DNSSEC is employed to ensure that each sending mail server connects to the legitimate and authorized receiving mail server from which its X.509 certificate is obtained. DANE resource records are employed to bind the cryptographic keying material to the appropriate server name. STARTTLS is employed to negotiate the cryptographic algorithm to be employed with TLS in the email exchange in which the PII is transferred. Encryption of the email message is accomplished by the originator's email server, and decryption of the email message is accomplished by the recipient's email server.

Demonstrations of the security platform in this scenario include an attempt by a fraudulent mail server to pose as the legitimate receiver of the email and a man-in-the-middle attacker to attempt to disrupt the signal that TLS is available for the desired destination. In the latter attack, the goal is to force unencrypted transmission of the email. Both attempts should fail due to use of DNSSEC and DANE.

5.1.2 Usage Scenario 2

An individual needs to enter into an email exchange with an individual in another organization. Each individual exchanges email via the respective parent organizations' mail servers. Users connect to their organizations' respective mail servers within a physically protected zone of control.

The policy of the parent organizations requires cryptographic digital signature of the message to provide integrity protection source authentication of the email message. S/MIME is a widely available and used protocol for digitally signing electronic mail. Each organization has therefore generated X.509 certificates for their users that include the public portion of their signature keys. These certificates are then published in the DNS using the appropriate DANE DNS Resource Record (RR) type.

DNSSEC is used to provide assurance that the originating user's mail server connects to the intended recipient's mail server. DANE records are employed to bind the cryptographic certificates to the appropriate server (for TLS) and individual user (for S/MIME), respectively. TLS is employed to provide confidentiality. Digital signature of the email message is accomplished by the originator's email client. Validating the signature (hence the integrity of the authorization provided in the email message) is accomplished by the recipient's email client.

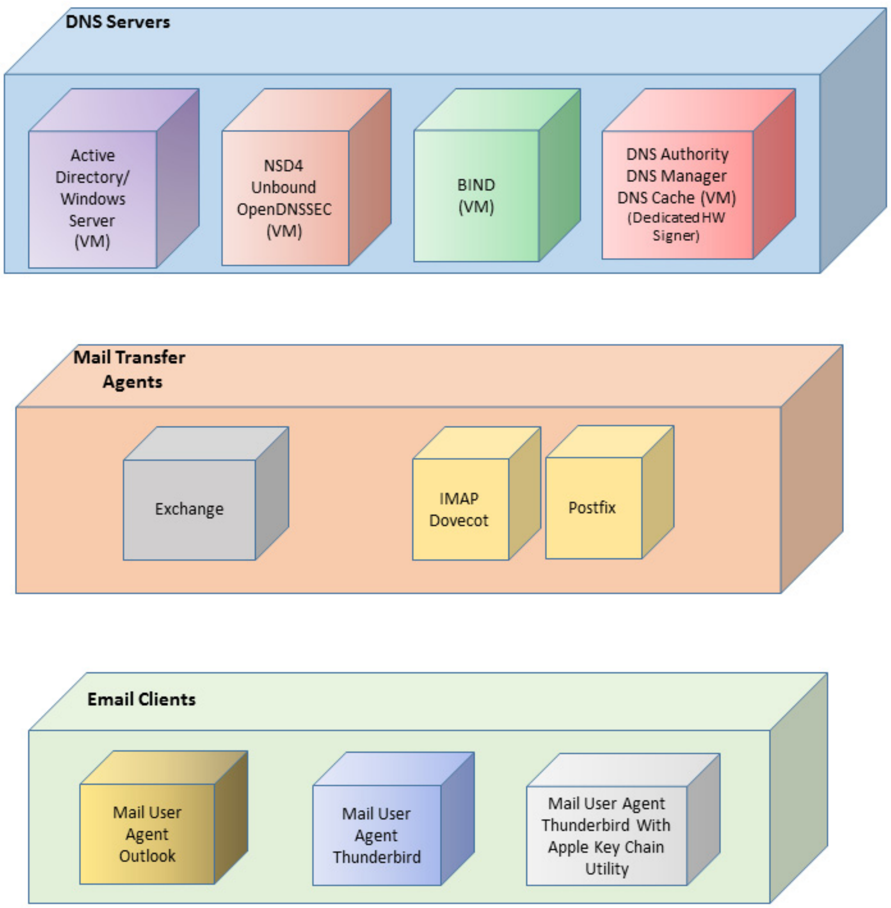
Demonstrations of the security platform in this scenario include an attempt by a fraudulent actor to pose as the originator of the email and a man-in-the-middle attacker attempting to disrupt the validation the S/MIME signature. Both attempts fail due to use of DNSSEC and DANE records.

5.2 Architectural Overview

The laboratory architecture for the DNSSEC-Based Email Security project was designed to permit interconnection of Microsoft Outlook and Thunderbird MUAs with Microsoft Exchange and Postfix/Dovecot MTAs. It demonstrates the interconnection of either MTA with any of the DNS services contributed by collaborators. Two instantiations of each MTA type were established to demonstrate email exchanges between MTAs of the same type or different types. The various component combinations are then demonstrated with three different TLSA RR parameters: a self-signed certificate, use of local certificate authorities, and use of well-known certificate authorities.

Figure 5.1 is a deployment diagram of the architecture used for demonstrating DNS-Based Email Security.

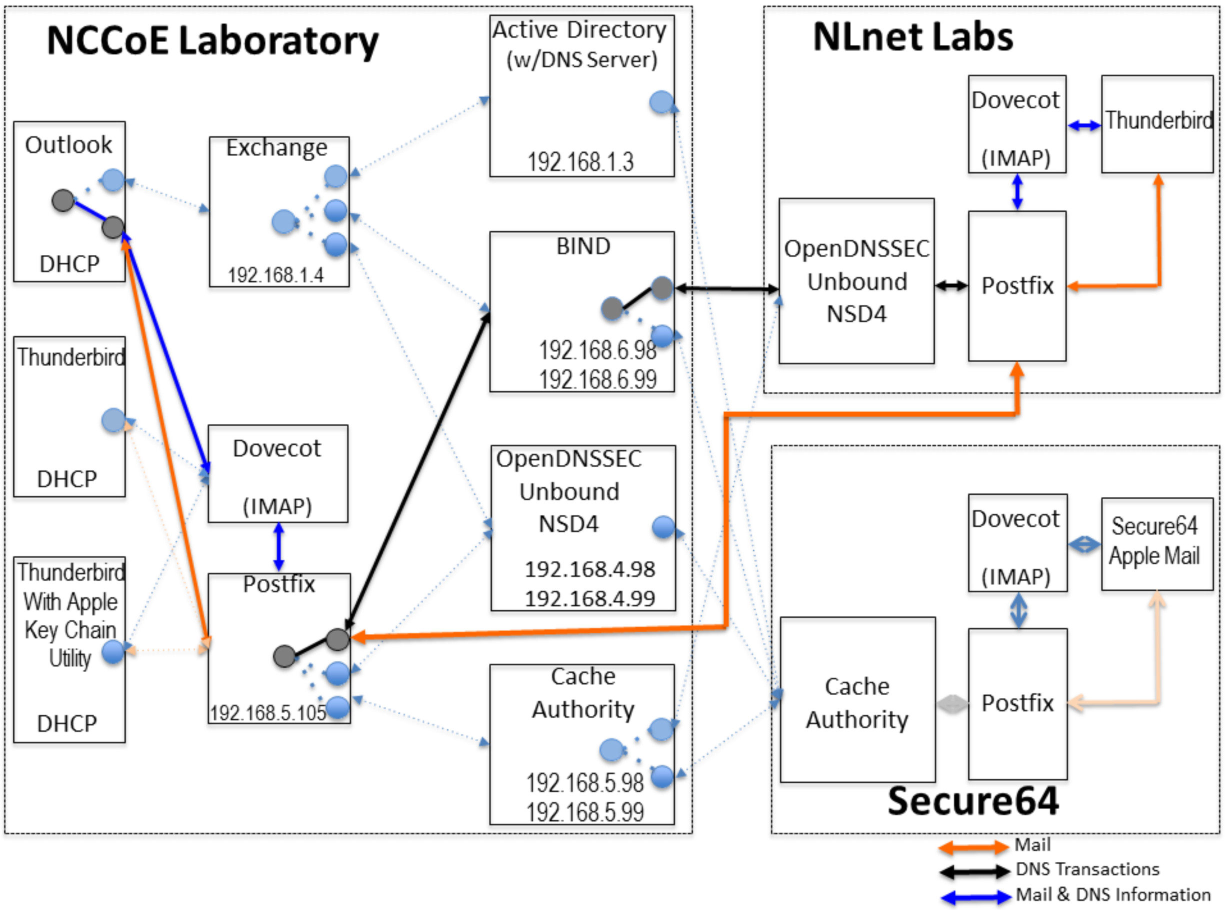
Figure 5.1 DNS-Based Email Security Deployment Diagram



For test documentation purposes, the receiving MTA is named differently depending on the receiver's DNS service zone and the TLSA option being demonstrated. The sending MTA's implementation and DNS infrastructure can also vary for each test, but share the same basic processes.

The design of the environment permits interconnection of components provided by different collaborators (see figure 5.2).

Figure 5.2 DNS-Based Email Security Test Set-up



The depiction shows that the project security platform test/demonstration activity was based on three different clients, two MTAs, and four DNS service configurations in the lab at the NCCoE exchanging messages with NLnet Labs and Secure64. All messages were signed (a mail client function) and encrypted (server to server). We worked with one remote location at a time, driven by whichever is ready first. The message exchanges, including DNS activity will be logged at each end (lab and remote correspondent).

The solid connectors in the depiction illustrate one case. The dotted lines depict the other cases we'll want to demonstrate. A switch convention is used to reflect configuration options, but the project team actually configures each component for each option.

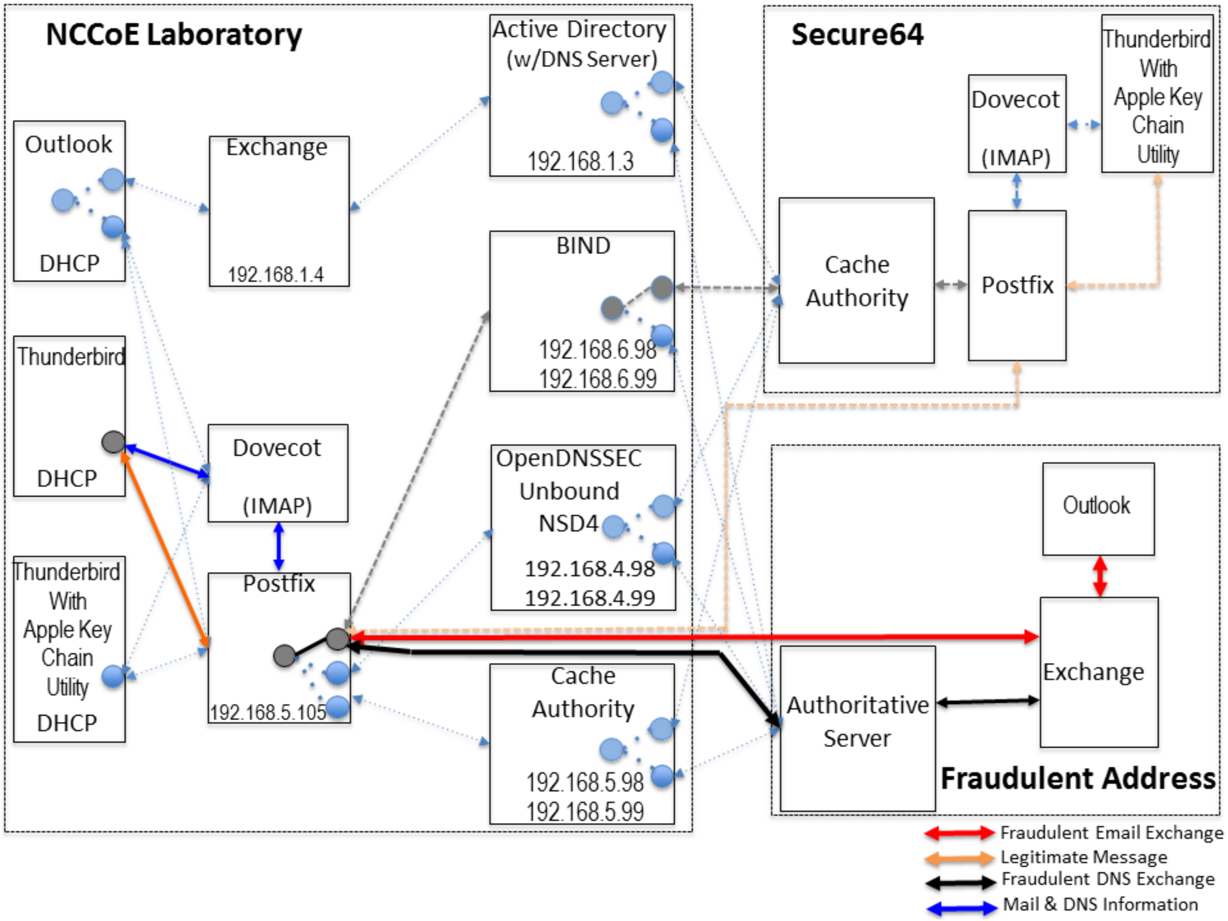
The orange arrows between the mail clients and the Postfix MTA reflect the fact that clients submitted email directly to the SMTP server for relay, while using Dovecot only to get mail. (The depiction in figure 5.2 reflects that IMAP isn't used to submit mail, only retrieve it, so the MUA sent mail directly to the Postfix server, but received the reply through the Dovecot server.)

The project team demonstrated 30 different events using various combinations of MUA, MTA, and DNS Server components divided among five test sequences. In each sequence, signed and encrypted messages were sent from a sender to a recipient. Both Exchange and Postfix encrypted mail by default. Most of the exchanges employed either self-signed certificates or local CAs (see Appendix C). The BIND configuration was set up to obtain and validate certificates from the NIST Advanced Networks Technology Division's (ANTD's) DNS source (acting as a root CA). (See section 7 below for test sequence sets.) Both Exchange and Postfix encrypted mail by default. Most of the exchanges employed either self-signed certificates or local CAs.

In one test sequence, fraudulently S/MIME signed email was sent from a malicious sender to recipients using Outlook and Thunderbird MUAs configured to use Exchange and Postfix as MTAs. The Outlook/Exchange configuration used Active Directory as its DNS server. The configurations employing Postfix/Dovecot MTAs were demonstrated with each of the other three contributed DNS Services. In one event, the Thunderbird MUA employed an Apple Key Chain Utility tool that allows a host to obtain X.509 certificates via of DANE RRs. All events were conducted using well-known CA and Enterprise CA-issued certificates for the impersonated sender. The fraudulent site attempted to spoof a valid sending domain belonging to a Secure64 site that was configured with DNS Authority/Cache/Signer DNS services, a Postfix/Dovecot MTA, and Thunderbird equipped with the Apple Key Chain utility. An Outlook/Exchange/ Active Directory set-up acted as the fraudulent site. The email exchange between organizations was carried over TLS, and the email message was S/MIME signed on the fraudulent users' client device. The set-up for this sequence is depicted in figure 5.3 below.

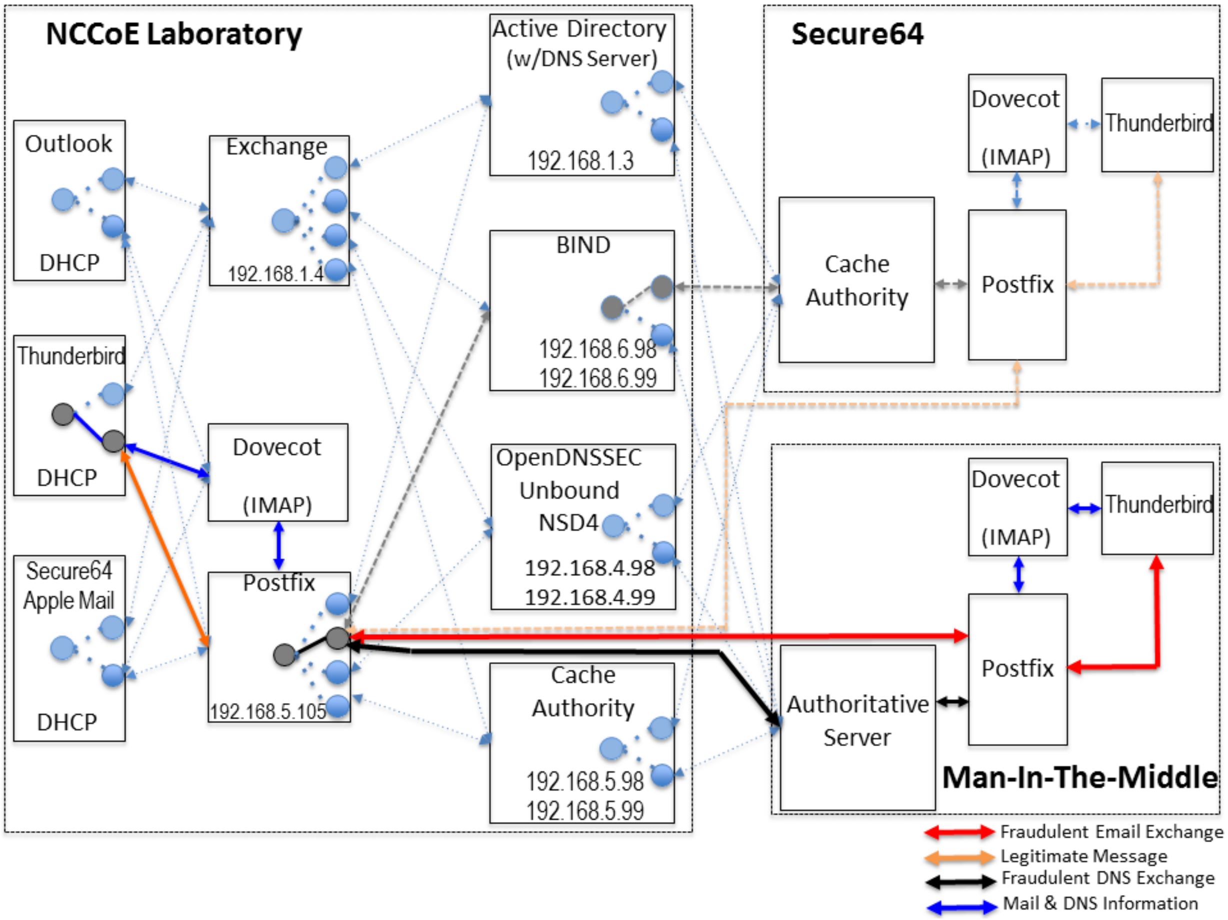
In another sequence, an NCCoE system attempted to send a TLS protected email from Exchange and Postfix MTAs (in turn) to an external Postfix MTA using DNS Authority/Cache/Signer for DNS services. The NCCoE Exchange MTA used Active Directory DNS Services, and the Postfix/Dovecot MTA used BIND and NSD4/Unbound/OpenDNSSEC DNS services. A S/MIME signed email was sent to an external Postfix MTA. Four events were conducted using Well-Known CA issued certificates, four events were conducted using Enterprise CA issued certificates (TLSA/SMIMEA RR parameter of CU=2) for TLS and S/MIME on the receiver side, and three events were conducted using self-signed certificates (TLSA/SMIMEA RR parameter of CU=3) for TLS and S/MIME on the receiver side. An Outlook/Exchange/Active Directory stack acted as a man-in-the-middle and attempted to intercept the message. Figure 5.4 depicts the configuration for a man-in-the-middle demonstration. Note that the sender is being misdirected to a malicious email server only. This is to simulate a lower level attack where email is sent (via route hijacking or similar low level attack) to a Man-in-the-Middle. Figure 5.4 depicts the configurations used with the Thunderbird/Postfix/ Dovecot/Bind option selected.

142 **Figure 5.3 Fraudulent DNS Address Spoofing Configurations**



143

144 **Figure 5.4 Man-In-The-Middle Event Configurations**



145

146 The following subsections describe the architecture's MUA, MTA, and DNS service components and Cybersecurity Framework Core
147 categories supported by those components.

5.2.1 Client Systems and Mail User Agents (MUAs)

Client systems environments are Microsoft Office, Apple Mail, and open-source Linux-based Thunderbird applications. These include both commercial products and open-source software. MUA capabilities associated with the client systems are used to invoke S/MIME digital signature and signature verification for email, but user-to-user encryption is not demonstrated. Collaborators assisted in installation, integration tailoring as necessary, and testing of laboratory configurations.

Table 5.1 Client Systems

Application	Source	Collaborator Configuration Support	Cybersecurity Framework Category
Office Outlook Mail User Agent	Microsoft	Microsoft	PR.AC-1, PR.AC-2, PR.DS-1, PR.DS-2, PR.DS-6, PR.PT-4, RS.MI-2
Thunderbird Mail User Agent	Open (Mozilla)	NLnet Labs	PR.AC-1, PR.AC-2, PR.DS-1, PR.DS-2, PR.DS-6, PR.PT-4, RS.MI-2
Thunderbird with Apple Key Chain	Secure64	Secure64	PR.AC-1, PR.AC-2, PR.DS-1, PR.DS-2, PR.DS-6, PR.PT-4, RS.MI-2

5.2.2 Email Servers

Email servers include both Windows and Linux-based (Dovecot/Postfix) Mail Transfer Agents. Server-to-server encryption was demonstrated in the Postfix environments. Authentication of domain and server identity was based on DNSSEC-signed DANE records. Use of these DANE records is only supported by Postfix at the time of this project. The MTAs support each of the Cybersecurity Framework Functions, Categories, and Subcategories identified in section 4.4.4 above. The servers were demonstrated in different DNS environments and different TLSA RR usage scenarios. In order to demonstrate representative TLSA parameters, the demonstrations used self-signed certificates, end-entity certificates generated by well-known CAs and end-entities generated by enterprise local CAs.

Table 5.2 Mail Transfer Agents

Application	Source	Collaborator Configuration Support	Cybersecurity Framework Category
Exchange 2016[a] Mail Transfer Agent TLS capable	Microsoft	Microsoft	PR.AC-1, PR.AC-2, PR.AC-3, PR.AC-5, PR.DS-1, PR.DS-239, PR.DS-6, PR.PT-439, DE.CM-1, DE.CM-2, DE.DP-4, RS.RP-1, RS.CO-2, RS.MI-2
Postfix Mail Transfer Agent TLS capable DANE capable	Open (postfix.com)	NLnet Labs Fraunhofer Secure64	PR.AC-1, PR.AC-2, PR.AC-3, PR.AC-5, PR.DS-1, PR.DS-2, PR.DS-6, PR.PT-4, DE.CM-1, DE.CM-2, DE.DP-4, RS.RP-1, RS.CO-2, RS.MI-2

a. Exchange provided integrity protection only for PR.DS-1, PR.DS-2, and PR.PT-4 (Scenario 2).

5.2.3 DNS Servers

Both Windows and Linux-based DNS server and support components were contributed. DNS services provided include DNSSEC validating DNS resolvers (stub and recursive) and authoritative DNS servers for DNSSEC signed zones. Support for SMIMEA and TLSA records was demonstrated. The DNS server components support each of the Cybersecurity Framework Functions, Categories, and Subcategories identified in section 4.4.4 above with the exception of PR.DS-1 (protection of data-at-rest).

Table 5.3 DNS Servers

Application	Source	Collaborator Configuration Support	Cybersecurity Framework Category
Active Directory and Windows Server 2016 ▪ Supports DNSSEC	Microsoft	Microsoft	PR.AC-1, PR.AC-2, PR.AC-3, PR.AC-5, PR.DS-2, PR.DS-6, PR.PT-4, DE.CM-1, DE.CM-2, DE.DP-4, RS.RP-1, RS.CO-2, RS.MI-2
BIND[a] ▪ Supports DNSSEC ▪ Supports DANE	Open (ISC)	Internet Systems Consortium (ISC)	PR.AC-1, PR.AC-2, PR.AC-3, PR.AC-5, PR.DS-2, PR.DS-6, PR.PT-4, DE.CM-1, DE.CM-2, DE.DP-4, RS.RP-1, RS.CO-2, RS.MI-2

Table 5.3 DNS Servers

Application	Source	Collaborator Configuration Support	Cybersecurity Framework Category
NSD4 ■ Supports DNSSEC ■ Supports DANE Unbound ■ Supports DNSSEC OpenDNSSEC	Open (NLnet Labs)	Open (NLnet Labs)	PR.AC-1, PR.AC-2, PR.AC-3, PR.AC-5, PR.DS-2, PR.DS-6, PR.PT-4, DE.CM-1, DE.CM-2, DE.DP-4, RS.RP-1, RS.CO-2, RS.MI-2
DNS AUTHORITY DNS MANAGER ■ Supports DNSSEC ■ Supports DANE (Caching authority is labeled DNS CACHE, and signer runs on a dedicated processor)	Secure64	Secure64	PR.AC-1, PR.AC-2, PR.AC-3, PR.AC-5, PR.DS-1, PR.DS-6, PR.PT-4, DE.CM-1, DE.CM-2, DE.DP-4, RS.RP-1, RS.CO-2, RS.MI-2

a. The name BIND stands for "Berkeley Internet Name Domain."

6 Outcome

This section discusses the security platform from the perspective of the user and the system administrator. We define system administrator as a person within the organization who has elevated privileges on the management systems in the build. System administration functions include identification of system components, system installation, system integration, system configuration, configuration monitoring, identification of exception conditions, system maintenance, and status reporting to management.

6.1 The User's Experience

The user's experience varies from relatively minimal additional impact in enterprise environments with established system administration and support to a significant impact in the case of individual self-supported users. Where the enterprise offers systems administration and support services, the user's experience with respect to DNS services is essentially unchanged. One exception is that, where DNSSEC authentication fails, email messages sent to or by a user will not be delivered. This should be an uncommon experience for correspondents but it is up to the enterprise DNS administrator to prevent this happening.

Similarly, for server-to-server encryption, the security protection features should be essentially transparent to the user.

For user-to-user digital signature, the user must first have a certificate installed in their MUA. This may be included in digital identity credentials, or it may be provided by the system administrator in the process of provisioning the user's computer. Otherwise, the procedure required would be similar to that followed in section 3.2 of SP 1800-6C. The steps required vary from platform to platform (e.g., Windows, Linux, Mac), user agent to user agent (e.g., Outlook vs Thunderbird) and how the private key is stored (on the system, smart cards, etc.). Representative user requirements are described below (in this case for Outlook running on MacBook and Thunderbird running on Linux.

6.1.1 User's Digital Signature Experience with Outlook on MacBook

To use digital signatures and encryption, both the sender and recipient must have a mail application that supports the S/MIME standard (e.g., Outlook).

Note: *Before this procedure is started, a certificate must be added to the keychain on the computer. For information about how to request a digital certificate from a certification authority, see MacOS Help or click on "Help" on the Outlook tool bar.*

1. On the **Tools** menu, click **Accounts**.
2. Click the account that is to be used to send a digitally signed message, click **Advanced**, and then click the **Security** tab.

3. Under **Digital signing**, on the **Certificate** pop-up menu, click the certificate that is to be used.

Note: *The **Certificate** pop-up menu only displays certificates that are valid for digital signing or encryption that have already been added to the keychain for the Mac OS X user account. To learn more about how to add certificates to a keychain, see Mac OS Help.*

4. Do any of the following:

To	Do this
Make sure that the digitally signed messages can be opened by all recipients, even if they do not have an S/MIME mail application and can't verify the certificate	Select the **Send digitally signed messages as clear text** check box.
Allow the recipients to send encrypted messages to you	Make sure that signing and encryption certificates have been selected on this screen, and then select the **Include my certificates in signed messages** check box.

5. Click **OK**, and then close the **Accounts** dialog box.
6. In an e-mail message, on the **Options** tab, click **Security**, and then click **Digitally Sign Message**.
7. Finish composing the message, and then click **Send**.

6.1.2 User's Digital Signature Experience with Thunderbird

For purposes of illustration, the description of the user experience with Thunderbird also included certificate management requirements. The example here shows both S/MIME and PGP examples of certificate management. The S/MIME approach is recommended. Note that when using OpenPGP, a FIPS 140-conformant version should always be used.

6.1.2.1 S/MIME Certificate Management

S/MIME certificates are used for digitally signed and encrypted e-mail messages. For information about getting or creating S/MIME certificates, see: http://kb.mozillazine.org/Getting_an_SMIME_certificate.

Installing an S/MIME certificate

Note: *Before a user can create or import his or her own certificate and private key, he or she must first set a master password if this has not already been done. The master password is needed so that imported certificates are stored securely. See* http://kb.mozillazine.org/Master_password *for instructions for setting a master password.The user may have his or her own personal certificate and private key in a .p12 or .pfx file, and may wish to import it into Thunderbird. Once a Master Password has been set, the user can import/install a personal S/MIME certificate from a .p12 or .pfx file by doing the following steps.*

1. Open the Certificate Manager by going to **Tools -> Options... -> Advanced -> Certificates -> Manage Certificates...**.
2. Go to the tab named **Your Certificates**.
3. Click on **Import**.
4. Select the **PCKS12** certificate file (.pfx or .p12).
5. It will ask the user for the master password for the software security device. The user enters his or her master password and clicks **OK**.
6. Next, it will ask the user for the password protecting his or her personal certificate. If the user's .p12 or .pfx file has a password, he or she enters it here, otherwise leave this field empty. Then click **OK**.

The S/MIME certificate should now have been imported. If the certificate was not trusted, consult the instructions at http://kb.mozillazine.org/Thunderbird_:_FAQs_:_Import_CA_Certificate.

Configuring Thunderbird for using the certificate to sign email

Go to **Tools -> Account Settings...** in Thunderbird. Then find the account with the email address that matches the email address in the certificate that has just been installed. Choose **Security** under that account and select the certificate that has just been installed. The rest of the options should be self explanatory. When the user selects a certificate in Account Settings, that selection only applies to the account's default identity or identities. There is no user interface for specifying certificates for an account's other identities. If desired, this can be worked around by editing the settings manually, copying the settings from an account's default identity to some other identity. The settings have names ending in: signing_cert_name, sign_mail, encryption_cert_name and encryptionpolicy.

User Installation of a Self-Signed S/MIME Certificate

If the SMIME certificate in a user's .p12 or .pfx file is a self-signed certificate for the user's own identity, then before that file can be installed into the tab named **Your Certificates**, the user must first install that certificate as a certificate authority in the **Authorities** tab. The PKCS12 certificate file will not install into the **Authorities** tab. The user will need a copy of a self-signed certificate that does not contain the user's private key. This is usually in the form of a .cer file. One way to obtain the .cer form of a certificate from the .p12 file is to use the Firefox Add-on Key Manager to extract the .cer certificate from the .p12 file. With that Add-on installed in Thunderbird, the user goes to **Tools -> Key Manager Toolbox -> Key Manager -> Your Keys**, select his or her key, selects **Export** and chooses **X.509** as file format.

1. Go to **Tools -> Options... -> Advanced -> Certificates -> Manage Certificates...**.
2. Go to the **Authorities** tab.
3. Click on **Import**.
4. Select the **.cer** file.
5. It will ask the user for what purposes he or she wants to trust the certificate. Select **Trust this CA to identify email users.**

6. Click **OK** to complete the import.

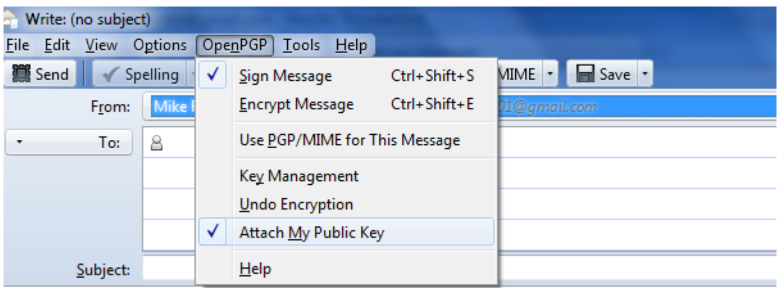
Note: *Thunderbird automatically adds other people's S/MIME certificates to the **Other People's** tab of a user's Certificate Manager when he or she receives from them a digitally signed message with a valid signature and with an S/MIME certificate issued by a recognized and trusted Certificate Authority (CA). CA certificates that appear in Thunderbird's "Authorities tab are recognized, and may also be trusted. CA certificates that do not appear in that tab are considered **unrecognized**. An S/MIME certificate that was issued by an unrecognized CA will not be automatically added to the **Other People's** tab of the user's Certificate Manager. If the user attempts to manually import an S/MIME certificate that was issued by an unrecognized CA, nothing will happen--literally. Thunderbird will not even display an error dialog. It will just not import the S/MIME certificate. This is generally not a problem when receiving an S/MIME certificate that was issued by a trusted Certificate Authority (CA), but could be a problem for a certificate that was issued by an unrecognized or untrusted CA, or for a certificate that is self-signed (i.e. it has no CA other than itself). So, before a user can import an S/MIME certificate that is issued by an unrecognized CA or is self-signed, he or she must first acquire and import the certificate for the issuing CA. In the case of a self-signed certificate, a .cer file needs to be acquired from the individual whose certificate the user wishes to add.*

6.1.2.2 PGP Example of Sending and Receiving Public Keys

Sending a public key via email

To send signed messages to other people, the user must first send them the public key:

1. Compose the message.
2. Select **OpenPGP** from the Thunderbird menu bar and select **Attach My Public Key**.



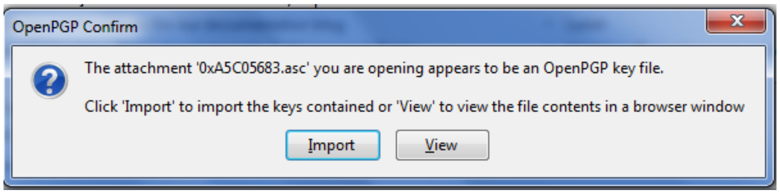
3. Send the email as usual.

Receiving a public key via email

To verify signed messages from other people, the public key must be received and stored:

1. Open the message that contains the public key.
2. At the bottom of the window, double click on the attachment that ends in .asc. (This file contains the public key.)

3. Thunderbird automatically recognizes that this is a PGP key. A dialog box appears, prompting the **Import** or **View** of the key. Click **Import** to import the key.

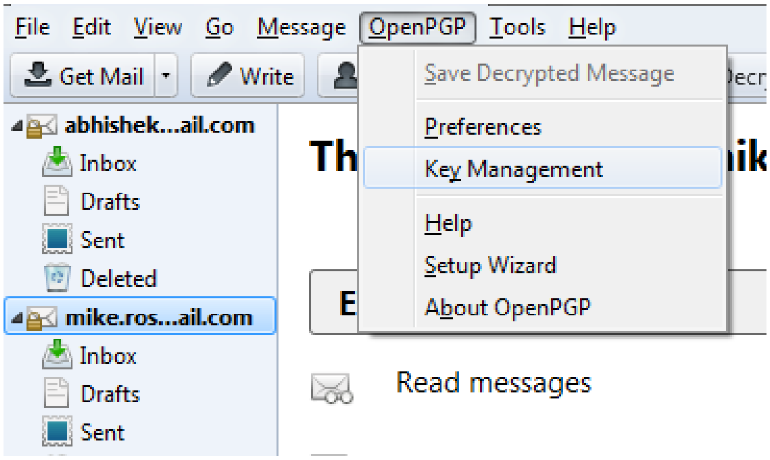


4. A confirmation that the key has been successfully imported will be shown. Click **OK** to complete the process.

Revoking a key

If the private key may have been compromised (that is, someone else has had access to the file that contains the private key), revoke the current set of keys as soon as possible and create a new pair. To revoke the current set of keys:

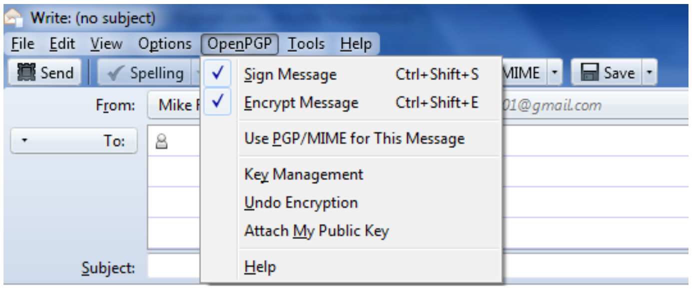
1. On the Thunderbird menu, click **OpenPGP** and select **Key Management**.



2. A dialog box appears as shown below. Check **Display All Keys by Default** to show all the keys.
3. Right-click on the key to be revoked and select **Revoke Key**.
4. A dialog box appears asking the user if he or she really wants to revoke the key. The user clicks **Revoke Key** to proceed.
5. Another dialog box appears asking for the entry of a secret passphrase. The user enters the passphrase and clicks **OK** to revoke the key.
6. The user sends the revocation certificate to the people with whom he or she corresponds so that they know that the current key is no longer valid. This ensures that if someone tries to use the current key to impersonate the user, the recipients will know that the key pair is not valid.

6.1.2.3 Sending a Digitally Signed Email

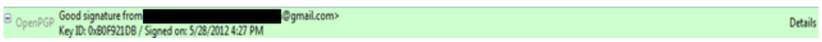
1. Compose the message as usual.
2. To digitally sign a message, select **OpenPGP** from the Thunderbird menu and enable the **Sign Message** option.



3. If the email address is associated with a cryptographic certificate, the message will be signed with the key contained in that certificate. If the email address is not associated with a cryptographic certificate, a certificate must be selected from a list.
4. Send the message as usual.

6.1.2.4 Reading a Digitally Signed Email

When a signed message is received, and If Thunderbird recognizes the signature, a green bar (as shown below) appears above the message. To determine whether or not the incoming message has been signed, look at the information bar above the message body.[1]



If the message has been signed, the green bar also displays the text, “Signed message”. A message that has not been signed could be from someone trying to impersonate someone else.

6.2 The System Administrator’s Experience

The system administrator(s) will generally be responsible for configuring the MUAs, MTA, and DNS servers. Specific installation and configuration instructions and examples are provided in Sections 2, Section 3, Appendix F, Appendix G, and Appendix H of the How-To Guides, SP 1800-6C. Configuration includes setting up and publishing certificates in the DNS as TLSA and SMIMEA RRs. Certificate management using Well-Known CA-issued certificates or Enterprise CA-issued certificates is required for federal government applications and is strongly recommended in other applications. While instructions for configuration for DNSSEC are provided for environments described in SP 1800-6C, this more secure set of configuration options are not generally invoked by default. Therefore, more effort and expertise are needed on the part of the DNS administrator.

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1. If the message is also encrypted on a user-to-user basis, Thunderbird will also ask for the entry of a secret passphrase to decrypt the message.

Configuring and activation of mail servers (MTAs) for channel encryption by default is described in section 3.3 of SP 1800-6C. Summary information is provided here and in links for illustration purposes for Microsoft Office 365 Exchange and Postfix.

In general, the bulk of the system administrator's effort is in acquiring and publishing the necessary certificates. Maintenance of the security functions, once they've been set up, is a relatively routine system administration activity.

6.2.1 Microsoft Exchange

Only Microsoft Exchange for Office 365 encrypts users' data while it's on Microsoft servers and while it's being transmitted between the MTSs. Exchange for Office 365 does provide controls for end users and administrators to fine tune what kind of encryption is desired to protect files and email communications.

6.2.2 Postfix

Postfix TLS support is described at http://www.postfix.org/TLS_README.html. Postfix can be configured to always use TLS when offered by receivers.[2]

2. "Setting Postfix to encrypt all traffic when talking to other mail servers," *Snapdragon Tech Blog*, August 9, 2013. http://blog.snapdragon.cc/2013/07/07/setting-postfix-to-encrypt-all-traffic-when-talking-to-other-mailservers/

7 Evaluation

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7.1 Assumptions and Limitations

This security characteristic evaluation has the following limitations:

- It is not a comprehensive test of all security components, nor is it a red team exercise.
- It cannot identify all weaknesses.
- It does not include the lab infrastructure. It is assumed that its devices are hardened. Testing these devices would reveal only weaknesses in implementation that would not be relevant to those adopting this reference architecture.

7.2 Testing

The evaluation included analysis of the security platforms to identify weaknesses and to discuss mitigations. The focus of this portion of the evaluation was hands-on testing of the laboratory build and examination of product manuals and documentation. Our objective was to evaluate the building block and not specific products. The presence of four primary OSs for domains tested (Linux, MacOS, SourceT Micro OS, and Windows) made complete product-independent hands-on testing unrealistic.

Table 7.1 describes the goals of each sequence of test cases. For each sequence, the Cybersecurity Framework (CSF) Subcategories and associated SP 800-53 control(s), the test environment(s) involved, and evaluation objective of the test are identified. The results of the tests are provided NIST SP 1800-6c.

In all test sequences the sending MTA attempted to establish a TLS protected channel to deliver the email message to the receiver. In the attack scenarios, a malicious actor attempts to disrupt this transfer. In all test sequences, the sending MUA signed the message, and the receiving MUA, checked the signature. Exchange was used only for Scenario 2.[1] In all test sequences, the sending MTA attempted to verify the correctness of all DNS responses via DNSSEC validation. In most scenarios, alice@<somedomain> sent an email to bob@<receivername>. Both senders and receivers had their own (separate) DNS infrastructures consisting of both authoritative and recursive servers. The Exchange as Sender tests were conducted for completeness and for examples of SMTP over TLS w/o DANE support - what it looked like and how well it worked.

1. Exchange MTAs did not attempt to encrypt or decrypt MTA-to-MTA message exchanges.

Table 7.1 Tests Performed

Test Sequence	CSF Subcategories	SP 800-53 Controls	Configuration	Evaluation Objective
Sequence 1	PR.AC-1 PR.AC-2 PR.DS-1 PR.DS-2 PR.DS-6 RS.MI-2	AC-2, AC-17, AC-19, AC-20, IA Family, IR-4, SC-8, SC-28, SI-7	An Outlook MUA, interfacing with an Exchange MTA, was configured to use Active Directory and BIND DNS services in turn. Each of the six configurations exchanged email with ▪ a Secure64 MUA/MTA/DNS service stack that included a Postfix MTA and a Thunderbird MUA running on a Mac OS system ▪ an NLnet Labs MUA/MTA/ DNS service stack that included a Postfix MTA and a Thunderbird MUA running on Linux The events include events showing use of Well-Known CAs (CU-1), Enterprise CAs (CU=2), and Self-Signed Certificates (CU=3) for TLS and S/MIME-enabled mail receivers and S/MIME. Figure 5.2 above depicts the set-up for laboratory support for the Secure64 destination variant of this test sequence.[a]	Email messages between Postfix MTAs were encrypted and successfully decrypted via TLS. (Scenario 1). Signature was logged. All messages were S/MIME signed. Outlook attempted to verify received messages (Scenario 2). Signature verification results were noted. DNS name verification results were noted.
Sequence 2	PR.AC-1 PR.AC-2 PR.DS-1 PR.DS-2 PR.DS-6 RS.MI-2	AC-2, AC-17, AC-19, AC-20, IA Family, IR-4, SC-8, SC-28, SI-7	Outlook and Thunderbird MUAs, configured to use a Postfix MTA with Dovecot IMAP support, were configured in turn to use BIND and Secure64's DNS Authority, DNS Cache, and DNS Signer implementations. Each of the six configurations exchanged email with a Secure64 MUA/MTA/ DNS service stack that included a Thundebird MUA, Postfix/Dovecot MTA, and DNS Signer/DNS Cache/DNS Authority services for processing received messages; and an NLnet Labs MUA/MTA/ DNS service stack that included a Thundebird MUA, Postfix/Dovecot MTA, and NSD4, Unbound, and OpenDNSSEC DNS services. The test events include using Well-Known CA issued (TLSA/SMIMEA CU=1), Enterprise CA issued (CU=2), and Self-Signed Certificates (CU=3). Figure 5.2 above depicts the set-up for laboratory support for this test sequence.	Email messages between MTAs were encrypted and successfully decrypted. (Scenario 1). Signature and encryption were logged. All messages were S/MIME signed. Outlook attempted to verify received messages (Scenario 2). Signature verification results were noted. DNS name verification results were noted.

Table 7.1 Tests Performed

Test Sequence	CSF Subcategories	SP 800-53 Controls	Configuration	Evaluation Objective
Sequence 3	PR.AC-1 PR.AC-2 PR.AC-3 PR.AC-5 PR.DS-2 RS.MI-1	AC-2, AC-4, AC-17, AC-19, AC-20, IA Family, IR-4, SC-7, SC-8	Fraudulently S/MIME-signed email was sent from a malicious sender to recipients using Outlook and Thunderbird MUAs configured to use Exchange and Postfix as MTAs. The Outlook/Exchange configuration used Active Directory as its DNS server. The configurations employing Postfix/Dovecot MTAs were demonstrated with each of the other three contributed DNS Services. In one event, the Thunderbird MUA employed an Apple Key Chain Utility tool that allows a host to obtain X.509 certificates via of DANE RRs. All events were conducted using well-known CA and Enterprise CA-issued certificates for the impersonated sender. The set-up for this sequence is depicted in Figure 5.3 above.	The fraudulent site attempted to spoof a valid sending domain belonging to a Secure64 site. An Outlook/Exchange/ Active Directory set-up acted as the fraudulent site. The email exchange between organizations was carried over TLS, and the email message was S/MIME signed on the fraudulent users' client device. Where Well-Known CA-issued certificates or Enterprise CA-issued certificates were used, and the MTA was DANE aware. The MUA using a SMIMEA utility was able to detect the fraudulent email and mark the email as not validated.
Sequence 4	PR.AC-1 PR.AC-2 PR.AC-3 PR.AC-5 PR.DS-2 PR.DS-6 RS.MI-1 RS.MI-2	AC-2, AC-4, AC-17, AC-19, AC-20, IA Family, IR-4, SC-7, SC-8, SI-7	The sender used an Outlook MUA sending mail through a Postfix/Dovecot MTA and using (in turn): Active Directory and DNS Server, BIND DNS Server, and NLnet Labs DNS Services. Self-signed certificates were used on the legitimate receiver side (TLSA RR parameter CU=3) for TLS. Each of the three configurations attempted to initiate an email exchange with an external Secure64 site. The set-up for this sequence is depicted in Figure 5.4 above.	The man-in-the-middle, an Outlook/Exchange/Active Directory stack, attempted to intercept the email from the NCCoE Laboratory Configuration by acting as a Man-in-the-Middle. The email and DNS transactions were logged in each case, and the results are provided in Volume C Appendix C. Where the MTA was DANE-aware, A detected spoofing. The mail connection to the MTA was established but closed the connection before the mail was transferred. Otherwise, the MTA failed to detect the man-in-the-middle and sent the email.

Table 7.1 Tests Performed

Test Sequence	CSF Subcategories	SP 800-53 Controls	Configuration	Evaluation Objective
Sequence 5	PR.AC-1 PR.DS-6 PR.CM-1 PR.DP-4 PR.CO-2	AC-4, IR-5, SC-5, SC-20, SC-21, SC-23, SI-4, SI-13	A DANE-enabled Postfix MTA sent message traffic to four MTAs with one Authoritative Server serving all four zones. An NSD4 Authoritative DNS server and Unbound recursive server were provided for the Postfix sending MTA, and a Secure64 DNS Authority and Signer provided the DNS services for the recipient zones. We reviewed the log files. One of the recipient MTAs did not employ TLSA, one employed a valid TLSA with the CU set to 3, one employed a TLSA with a certificate usage field of 1, but with an incomplete (i.e. bad) PKI certification path (PKIX failure), and one employed mismatched server cert/TLSA with the certificate usage field set to 3 (DANE validation failure).	A large number of email messages are generated in the Postfix server device using a Python script, and the Postfix MTA sends the messages to each of four recipient MTAs in different zones. In the recipient MTA running without TLSA and that running with a valid matching TLSA and certificate usage field set to 3, all messages should be accepted. In the recipient MTA with a TLSA RR using certificate usage of 1, but with an incomplete PKIX validation path, and the recipient MTA with a mismatched certificate/TLSA (cert usage 3), the sender should close the connection without sending the message. Logwatch running on the sending Postfix server device logged the instances of failure to deliver due to certificate expiration or bad certificate path.

a. The connections depicted in the Figure are actually for the Secure64 variant of the first Sequence 2 configuration. Capabilities for Sequence 1 support are shown as dotted lines.

7.3 Scenarios and Findings

One aspect of our security evaluation involved assessing how well the reference design addresses the objectives of the scenario it was intended to support.

7.3.1 Scenario 1

Scenario 1 involved the ordinary exchange of email between two organizations' email servers carried over TLS, where the TLS key management was protected by DANE and DNSSEC. Private certificates were generated by either well-known CAs, enterprise local CAs or self-signed. User connections to their organizations' respective mail servers were established and maintained within a physically protected zone, and email was encrypted between mail servers using TLS. The confidentiality of encryption keys was maintained such that no unauthorized third party had access to the keys. The mail servers used X.509 certificates to store and transport public keys to establish the TLS channel. DNSSEC ensured that each sending mail server receives the IP address to the legitimate and authorized receiving mail server and (if applicable) validate its X.509 certificate. DANE bound the cryptographic keying material to the appropriate server. TLS was used to protect the confidentiality of the email exchange. Encryption of the email message was accomplished by the originator's email server, and decryption of the email message was accomplished by the recipient's email server using standard server libraries.

The tests included an attempt by a fraudulent mail server to pose as the legitimate mail receiver for a domain. The tests also include a man-in-the-middle attack to attempt to disrupt the TLS connection with the objective of achieving an unencrypted transmission of the email. Both attempts failed due to use of DNSSEC and DANE. In both cases, an indication was made available to the sending email server when the DNSSEC signature associated with the domain data is determined to be invalid.

7.3.2 Scenario 2

Scenario 2 involved end-to-end signed email, where the email exchanges between organizations were carried over TLS as in (1), the email messages were signed and verified with S/MIME on the end-users' client devices, and the S/MIME key management was protected by DANE and DNSSEC. Private certificates were generated by well-known and enterprise local CAs. Self-signed certificates were not used. Individuals established connections to their domains' respective mail servers within a physically protected zone of control. Cryptographic digital signatures were applied to messages to provide authentication and integrity protection for the email. S/MIME was the protocol used for the digital signing. These certificates were then encoded in the DNS using the appropriate DANE DNS record type. DNSSEC ensured that each originating user's mail server connects to the intended recipient's mail server. DANE bound the cryptographic keying material to the appropriate server and individual user digital signature certificates. TLS was employed to protect the confidentiality of the email. Digital signing of email messages was accomplished by originator's MUA, and checking the validity of the signature (hence the integrity of the authorization provided in the email message) was accomplished by recipient's MUA.

The tests in this scenario included an attempt by a fraudulent actor to pose as an originator of the email. This attempt failed due to use of DNSSEC and DANE. The receiving MUA, using a third party SMIMEA tool, was able to fetch the senders real S/MIME certificate from the DNS and confirm that the fraudulent email was signed using a different certificate.

7.3.3 Effects of DANE Errors

In addition to the scenarios described above, a DANE-enabled Postfix MTA sent message traffic to four other postfix MTAs. A single BIND instance was set up to serve the TLSA and A RRs for the four receivers. One of the receiving MTAs did not employ DANE. The second employed DANE with a valid TLSA with the certificate usage field[2] set to 3. The third employed a TLSA with a certificate usage field of 2, but with an incomplete (i.e. bad) PKI certification path (generating a PKIX validation failure). The TLSA contained a local enterprise trust anchor, but the server did not have the full certificate chain (missing intermediate certificate). The final one employed DANE with a TLSA RR using Certificate Usage of 3, but there was a mismatch between the server cert and TLSA RR (generating a DANE validation failure).

Little or nothing appeared in the sender's logs for messages sent to either the MTA not employing TLS or the employing a valid TLSA. The growth rates for logs for the MTA that employed a TLSA with a certificate usage field of 1, but with a PKIX failure and the one that employed mismatched server cert/TLSA (i.e. DANE validation failure) were measured.

When the sender was configured to never use TLS, the mail was sent in plaintext regardless of the TLS/DANE configuration of the receiver. When the sender was configured to use TLS opportunistically, it used TLS regardless of the status of the certificate, or TLSA. In fact, the sender did not issue a query to find TLSA RRs even if published. When the sender used opportunistic DANE, it used TLS when available regardless of the DANE validations results. If validation failed, the mail was still sent and the result was logged as an “Untrusted” or “Anonymous” TLS connection, depending on the presence of a TLSA RR.

Of the four options used in the lab, *dane-only* is the most rigorous in what a sender would accept before sending mail. When the receiver did not offer the STARTTLS option, or lacked a TLSA RR, mail was not sent. Likewise, if a TLSA RR was present, but there was an error in validation (either the TLSA RR itself had an error, or PKIX failed), the mail was not sent. Therefore, use of this option is not recommended for general use as this will result in the majority of email being deferred. It should only be used in scenarios where senders and receivers are coordinated and maintain a stable DANE deployment.

2. RFC 6698, *The DNS-Based Authentication of Named Entities (DANE) Transport Layer Security (TLS) Protocol: TLSA*, Section 2.1.1. https://tools.ietf.org/html/rfc6698#section-2.1.1

8 Future Build Considerations

Both public sector and private sector enterprises are heavily dependent on web-based technology other than email for e-commerce and other public-facing applications. Fraudulent web sites pose at least as great a security and privacy problem as fraudulent email. Further, as email becomes a more difficult medium for malicious entities to use as a penetration vector, other web-based media will be more intensively exploited. Already, emerging communications trends appear to be replacing email exchanges among individuals with other social media (e.g., Baidu, Facebook, Facebook Messenger, Google+, Instagram, Linkedin, Pinterest, Snapchat, Tieba, Tumblr, Twitter, Viber, WhatsApp, and YouTube). Therefore, an extension of the current project that focuses on use of improved DNSSEC applications such as DANE for web applications other than mail may be justified.

Additionally, the test scenarios did not include the Exchange for Office 365 MTA to demonstrate Scenario 1. Future builds might be considered to demonstrate this capability.

Finally, utilities are currently under development that would provide improved support for SMIMEA and improved system notification of failed DNSSEC signature validation events. Future builds might be considered to demonstrate these capabilities as well.

Appendix A Acronyms

ASN	Abstract Syntax Notation
AXFR	DNS Full Zone Transfer Query Type
BIND	Berkeley Internet Name Daemon
BSD	Berkeley Software Distribution
CA	Certificate Authority
CKMS	Cryptographic Key Management System
CRL	Certificate Revocation List
CU	Certificate Usage Type
DANE	DNS-based Authentication of Named Entities
DNS	Domain Name System
DNSSEC	DNS Security Extensions
Email	Electronic Mail
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
FCKMS	Federal Cryptographic Key Management System
FIPS	Federal Information Processing Standard
HIPAA	Health Insurance Portability and Accountability Act
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IP	Internet Protocol
IRS	Internal Revenue Service
ISO	Internet Organization for Standardization
ITL	Information Technology Laboratory
MIME	Multipurpose Internet Mail Extension
MTA	Mail Transfer Agent
MUA	Mail User Agent
MX	Mail Exchange (Resource Record)
NCCoE	National Cybersecurity Center of Excellence
NIST	National Institute of Standards and Technology
OS	Operating System
PKI	Public Key Infrastructure

PKIX	Public Key Infrastructure X.509
RFC	Request for Comments
RMF	Risk Management Framework
RR	Resource Record
S/MIME	Secure/Multipurpose Internet Mail Extensions
SMIMEA	S/MIME Certificate Association (Resource Record)
SMTP	Simple Mail Transfer Protocol
SP	Special Publication
SQL	Structured Query Language
TLS	Transport Layer Security
TLSA	TLS Certificate Association (Resource Record)
UA	User Agent
VLAN	Virtual Local Area Network
VM	Virtual Machine

Appendix B References

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Appendix C DNS-Based Email Security Project Mapping to the Framework Core and Informative References

The following tables map informative NIST and consensus security references to Framework Core subcategories that are addressed by the DNS-Based Email Security platform set. The references do not include protocol specifications that are implemented by the individual products that comprise the demonstrated security platforms. While some of the references provide general guidance that informs implementation of referenced Framework Core functions, the NIST Special Publication references provide specific recommendations that should be considered when composing and configuring security platforms from DNS and email components, implement DNSSEC and mail security platforms, and operating email systems securely.

Table C.1 PROTECT (PR)

Category	Subcategory	Informative References
Access Control (PR.AC): Access to assets and associated facilities is limited to authorized users, processes, or devices, and to authorized activities and transactions.	**PR.AC-1**: Identities and credentials are managed for authorized devices and users	**NIST SP 800-45 Ver. 2** 3, 6 **NIST SP 800-53 Rev. 4** AC-2, IA Family **NIST SP 800-57 Part 2** 3.1.2.1.3, A.3.2, B.5 **NIST SP 800-81-2** 11.7.2 **NIST SP 800-130** 2.1, 5, 6.4.2, 6.4.23, 6.5, 6.6.1, 6.6.2, 6.7.1, 8.2.4 **NIST SP 800-152** 2.10, 4.8, 4.9.1, 5, 6.4, 6.5, 6.6.1, 6.6.2, 6.7.1, 8.2.3, 10.1 **NIST SP 800-177** 4.5, 4.6.5, 4.7, 5.1 **CCS CSC** 16 **COBIT 5** DSS05.04, DSS06.03 **ISA 62443-2-1:2009** 4.3.3.5.1 **ISA 62443-3-3:2013** SR 1.1, SR 1.2, SR 1.3, SR 1.4, SR 1.5, SR 1.7, SR 1.8, SR 1.9 **ISO/IEC 27001:2013** A.9.2.1, A.9.2.2, A.9.2.4, A.9.3.1, A.9.4.2, A.9.4.3

Table C.1 PROTECT (PR)

Category	Subcategory	Informative References
	PR.AC-3: Remote access is managed	**FIPS 140-2** Sec. 4 **NIST SP 800-45 Ver. 2** 9.5 **NIST SP 800-53 Rev. 4** AC 17, AC-19, AC-20 **NIST SP 800-57 Part 1 Rev. 4** 5.3.1, 6.2.2 **NIST SP 800-81-2** 7.2, 9.8, 11.7.5 **NIST SP 800-152** 6.7.1, 8.2, 8.3 **NIST SP 800-177** 4.4.2.1 **COBIT 5** APO13.01, DSS01.04, DSS05.03 **ISA 62443-2-1:2009** 4.3.3.6.6 **ISA 62443-3-3:2013** SR 1.13, SR 2.6 **ISO/IEC 27001:2013** A.6.2.2, A.13.1.1, A.13.2.1
	PR.AC-5: Network integrity is protected, incorporating network segregation where appropriate	**OMB M-08-23** **NIST SP 800-45 Ver. 2 Rev. 4** 8.1.4, 9.5 **NIST SP 800-53 Rev. 4** AC-4, SC-7 **NIST SP 800-81-2** 7.2.8, 7.9, 10.4 **NIST SP 800-130** 6.8.6 **NIST SP 800-152** 6.8.6, 8.3 **NIST SP 800-177** 3, 7 **ISA 62443-2-1:2009** 4.3.3.4 **ISA 62443-3-3:2013** SR 3.1, SR 3.8 **ISO/IEC 27001:2013** A.13.1.1, A.13.1.3, A.13.2.1

Table C.1 PROTECT (PR)

Category	Subcategory	Informative References
Data Security (PR.DS): Information and records (data) are managed consistent with the organization's risk strategy to protect the confidentiality, integrity, and availability of information.	**PR.DS-1**: Data-at-rest is protected	**FIPS 140-2** Sec. 4 **NIST SP 800-53 Rev. 4** SC-28 **NIST SP 800-57 Part 1 Rev. 4** 4.2.5, 5.1.1, 5.2.1, 5.3.4, 5.3.5, 5.3.6, 6.2.2.3 **NIST SP 800-57 Part 2** 2.2, 2.4, 3.2, 4.3, 5.3.3, 5.3.4, A.1.2, A.2.1, A.3.2 **NIST SP 800-130** 1, 2.1, 2.2, 2.9, 6.1, 6.2, 6.5 **NIST SP 800-152** 2.2, 4.3, 4.6, 4.7, 6.1.3, 6.4.14, 6.4.29 **CCS CSC** 17 **COBIT 5** APO01.06, BAI02.01, BAI06.01, DSS06.06 **ISA 62443-3-3:2013** SR 3.4, SR 4.1 **ISO/IEC 27001:2013** A.8.2.3
	PR.DS-2: Data-in-transit is protected	**FIPS 140-2** Sec. 4 **NIST SP 800-45 Ver. 2** All **NIST SP 800-49** 2 **NIST SP 800-52 Rev. 1** 3, 4, D1.4 **NIST SP 800-53 Rev. 4** SC-8 **NIST SP 800-57 Part 1 Rev. 4** 4.2.5, 5.1.1, 5.2.1, 5.3.4, 5.3.5, 5.3.6, 6.2.1.3 **NIST SP 800-57 Part 2** 2.2, 5.3.3, A.2, A.3.1, A.3.2 **NIST SP 800-81-2** All **NIST SP 800-130** 1, 2.1, 2.2, 2.9, 6.1, 6.2, 6.4, 6.7.2 **NIST SP 800-152** 6.1.2, 6.2.1 **NIST SP 800-177** All **CCS CSC** 17 **COBIT 5** APO01.06, DSS06.06 **ISA 62443-3-3:2013** SR 3.1, SR 3.8, SR 4.1, SR 4.2 **ISO/IEC 27001:2013** A.8.2.3, A.13.1.1, A.13.2.1, A.13.2.3, A.14.1.2, A.14.1.3

Table C.1 PROTECT (PR)

Category	Subcategory	Informative References
	PR.DS-6: Integrity checking mechanisms are used to verify software, firmware, and information integrity	**FIPS 140-2** Sec. 4 **NIST SP 800-45 Ver. 2** 2.4.2, 3, 4.2.3, 4.3, 5.1, 6.1, 7.2.2, 8.2, 9.2 **NIST SP 800-49** 2.2.1, 2.3.2, 3.4 **NIST SP 800-52 Rev. 1** 3, 4, D1.4 **NIST SP 800-53 Rev. 4** SI-7 **NIST SP 800-57 Part 1 Rev. 4** 5.5, 6.1, 8.1.5.1, B.3.2, B.5 **NIST SP 800-57 Part 2** 1, 3.1.2.1.2, 4.1, 4.2, 4.3, A.2.2, A.3.2, C.2.2 **NIST SP 800-81-2** All **NIST SP 800-130** 2.2, 4.3, 6.2.1, 63, 6.4, 6.5, 6.6.1 **NIST SP 800-152** 6.1.3, 6.2.1, 8.2.1, 8.2.4, 9.4 **NIST SP 800-177** 2.2, 4.1, 4.4, 4,5, 4,7, 5.2, 5.3 **ISA 62443-3-3:2013** SR 3.1, SR 3.3, SR 3.4, SR 3.8 **ISO/IEC 27001:2013** A.12.2.1, A.12.5.1, A.14.1.2, A.14.1.3
Protective Technology (PR.PT): Technical security solutions are managed to ensure the security and resilience of systems and assets, consistent with related policies, procedures, and agreements.	**PR.PT-4**: Communications and control networks are protected	OMB M-08-23 FIPS 140-2 Sec. 4 NIST SP 800-49 2.4.3, 2.4.4 NIST SP 800-52 Rev. 1 3, 4 NIST SP 800-53 Rev. 4 AC-4, AC-17, AC-18, CP-8, SC-7 NIST SP 800-57 Part 1 Rev. 4 5.3.1, 6.2.2 NIST SP 800-130 8.3 NIST SP 800-152 4.7, 4.11.1, 6.8.6, 8.3 CCS CSC 7 COBIT 5 DSS05.02, APO13.01 ISA 62443-3-3:2013 SR 3.1, SR 3.5, SR 3.8, SR 4.1, SR 4.3, SR 5.1, SR 5.2, SR 5.3, SR 7.1, SR 7.6 ISO/IEC 27001:2013 A.13.1.1, A.13.2.1

Table C.2 DETECT (DE)

Category	Subcategory	Informative References
Security Continuous Monitoring (DE.CM): The information system and assets are monitored at discrete intervals to identify cybersecurity events and verify the effectiveness of protective measures.	**DE.CM-1**: The network is monitored to detect potential cybersecurity events	**FIPS 140-2** Sec. 4 **SP 800-37 Rev. 1** 3.6 **NIST SP 800-45 Ver. 2** 4.1, 5.1.1, 5.1.5, 6.2.1, 6.2.2, 7.2.2 **NIST SP 800-53 Rev. 4** AC-2, AU-12, CA-7, CM-3, SC-5, SC-7, SI-4 **NIST SP 800-81-2** 2, 9, 12, 13 **NIST SP 800-130** 5, 6.8.5, 8.2.4, 9.8.4 **NIST SP 800-152** 6.8.5, 8.2.3, 8.2.4, 8.3, 8.5 **NIST SP 800-177** 3.1.1 **CCS CSC** 14, 16 **COBIT 5** DSS05.07 **ISA 62443-3-3:2013** SR 6.2
	DE.CM-6: External service provider activity is monitored to detect potential cybersecurity events	**NIST SP 800-53 Rev. 4** CA-7, PS-7, SA-4, SA-9, SI-4 **NIST SP 800-81-2** 2, 9, 12, 13 **NIST SP 800-130** 6.8.5, 8.2.4, 9.8.4, 12 **NIST SP 800-152** 6.8.5, 8.2.3, 8.2.4, 8.3, 8.5 **ISO/IEC 27001:2013** A.14.2.7, A.15.2.1
Detection Process (DE.DP): Detection processes and procedures are maintained and tested to ensure timely and adequate awareness of anomalous events.	**DE.DP-4**: Event detection information is communicated to appropriate parties	**NIST SP 800-45 Ver. 2** 9.3 **NIST SP 800-53 Rev. 4** AU-6, CA-2, CA-7, RA-5, SI-4 **NIST SP 800-177** 4.6 **COBIT 5** APO12.06 **ISA 62443-2-1:2009** 4.3.4.5.9 **ISA 62443-3-3:2013** SR 6.1 **ISO/IEC 27001:2013** A.16.1.2

Table C.3 RESPOND (RS)

Category	Subcategory	Informative References
Response Planning (RS.RP): Response processes and procedures are executed and maintained, to ensure timely response to detected cybersecurity events.	**RS.RP-1**: Response plan is executed during or after an event	**NIST SP 800-45 Ver. 2** 9.3 **NIST SP 800-53 Rev. 4** CP-2, CP-10, IR-4, IR-8 **NIST SP 800-57 Part 1 Rev. 4** **NIST SP 800-57 Part 2** 3.1.2.1.3, 3.2.2.6 **NIST SP 800-130** 6.2.1, 6.4.5, 6.4.6, 6.8, 10.1 **NIST SP 800-152** 6.8, 10 **NIST SP 800-177** 4.6 **COBIT 5** BAI01.10 **CCS CSC** 18 **ISA 62443-2-1:2009** 4.3.4.5.1 **ISO/IEC 27001:2013** A.16.1.5
Communications (RS.CO): Response activities are coordinated with internal and external stakeholders, as appropriate, to include external support from law enforcement agencies.	**RS.CO-2**: Events are reported consistent with established criteria	**NIST SP 800-45 Ver. 2** 9.3 **NIST SP 800-53 Rev. 4** AU-6, IR-6, IR-8 **NIST SP 800-57 Part 1 Rev. 4** 8.3.5, 9.3.4, 10.2.9 **NIST SP 800-57 Part 2** 3.1.2.1.2, 3.2.2.10, 3.2.2.14, 3.2.2.15, A.1.1, A.1.4, C.2.2.12 **NIST SP 800-130** 6.8 **NIST SP 800-152** 6.8 **NIST SP 800-177** 4.6 **ISA 62443-2-1:2009** 4.3.4.5.5 **ISO/IEC 27001:2013** A.6.1.3, A.16.1.2

Table C.3 RESPOND (RS)

Category	Subcategory	Informative References
Mitigation (RS.MI): Activities are performed to prevent expansion of an event, mitigate its effects, and eradicate the incident.	**RS.MI-1**: Incidents are contained	**NIST SP 800-53 Rev. 4** IR-4 **NIST SP 800-130** 6.8.1 **NIST SP 800-152** 6.8 **ISA 62443-2-1:2009** 4.3.4.5.6 **ISA 62443-3-3:2013** SR 5.1, SR 5.2, SR 5.4 **ISO/IEC 27001:2013** A.16.1.5
	RS.MI-2: Incidents are mitigated	**NIST SP 800-53 Rev. 4** IR-4 **NIST SP 800-57 Part 1 Rev. 4** 5.3, 5.4, 5.5, 8.3.4, 8.3.5 **NIST SP 800-57 Part 2** 5.3.7, 5.3.8 **NIST SP 800-130** 4.9.3, 6.8, 9.5, 12 **NIST SP 800-152** 3.4.2, 4.5, 6.8, 9.5, 9.8, 12 **ISA 62443-2-1:2009** 4.3.4.5.6, 4.3.4.5.10 **ISO/IEC 27001:2013** A.12.2.1, A.16.1.5

NIST CYBERSECURITY PRACTICE GUIDE

DOMAIN NAME SYSTEMS-BASED ELECTRONIC MAIL SECURITY

How-To Guides

For Security Engineers

Scott Rose
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Chinedum Irrechukwu
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NATIONAL CYBERSECURITY CENTER OF EXCELLENCE

NIST Special Publication 1800-6C **NIST Cybersecurity Practice Guide**

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NIST Cybersecurity Practice Guides (Special Publication Series 1800) target specific cybersecurity challenges in the public and private sectors. They are practical, user-friendly guides that facilitate the adoption of standards-based approaches to cybersecurity. They show members of the information security community how to implement example solutions that help them align more easily with relevant standards and best practices.

The documents in this series describe example implementations of cybersecurity practices that businesses and other organizations may voluntarily adopt. The documents in this series do not describe regulations or mandatory practices, nor do they carry statutory authority.

ABSTRACT

This document proposes a reference guide on how to architect, install, and configure a security platform for trustworthy email exchanges across organizational boundaries. The project includes reliable authentication of mail servers, digitally signing and encrypting email, and binding cryptographic key certificates to sources and servers. The example solutions and architectures presented here are based upon standards-based and commercially available products. The example solutions presented here can be used by any organization implementing Domain Name System-based electronic mail security.

KEYWORDS

electronic mail, digital signature; encryption; domain name system; data integrity; authentication, named entities, internet addresses, internet protocols, privacy

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1 Introduction

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The following guide shows IT professionals and security engineers how we implemented example solutions to the challenge of employing Domain Name System Security Extensions (DNSSEC)[1], and protocol-based digital signature and encryption technologies to protect electronic mail (email). We cover all the products that we employed in our solution set. We do not recreate the product manufacturer's documentation, which is presumed to be widely available. Rather, this guide shows how we incorporated the products together in our environment to provide composed security platforms.

Note: *This is not a comprehensive tutorial. There are many possible service and security configurations for these products that are out of scope for this reference solution set.*

1.1 Practice Guide Structure

This National Institute of Standards and Technology (NIST) Cybersecurity Practice Guide addresses the challenge of providing digital signature technologies to provide authentication and integrity protection for electronic mail (email) on an end-to-end basis, and confidentiality protection for email in transit between organizations.

The NIST Special Publication 1800-6 series of documents contain:

- rationale for and descriptions of a Domain Name System-Based (DNS-Based) Electronic Mail (Email) Security platform that permits trustworthy email exchanges across organizational boundaries
- a series of How-To Guides, including instructions for installation and configuration of the necessary services, that show system administrators and security engineers how to achieve similar outcomes

The solutions and architectures presented are built upon standards-based, commercially available products. These solutions can be used by any organization deploying email services that is willing to implement certificate-based cryptographic key management and DNS Security Extensions (DNSSEC). Interoperable solutions are provided that are available from different types of sources (e.g., both commercial and open source products) and function in different operating systems environments.

This summary section describes the challenge addressed by this Volume C (How-To Guide) the solution demonstrated to address the challenge, the components provided by project collaborators that have been used to compose the security platforms, an overview of how the components are configured to permit construction of platforms that cross product lines, and typographical conventions used in the Practice Guide. Section 2, How to Install and Configure DNS-Protected Email Security Components, provides mail and transport layer security composition and component-centric requirements and recommendations intended to permit using Mail User Agent (MUA)[2], Mail Transfer Agent (MTA)[3], and DNS Services components with MUAs, MTAs, and DNS Services from different vendors and open sources. It includes system requirements, installation instructions and advice and special settings requirements associated

1. RFC 4033, *DNS Security Introduction and Requirements*
2.According to NIST Special Publication (SP) 800-177, a MUA is a software component (or web interface) that allows an end user to compose and send messages and to one or more recipients. A MUA transmits new messages to a server for further processing (either final delivery or transfer to another server). See Section 2, Definitions, at https://tools.ietf.org/html/rfc3888.

with each of the MUA, MTA, and DNS Services components. In most cases where the components are commercial products, links are simply provided to vendor sites. More detailed instructions are provided for downloading, installing, and configuring open-source products. Section 3, Device Configuration and Operating Recommendations, provides some specific advice and tools to support secure ands reliable integration and operation of the security platforms. Topics include certificate acquisition and management options, managing mail transfer agent operation where there are significant numbers of cases of non-delivery of messages due to invalid digital signatures, device setup recommendations, email setup recommendations, and management of exception conditions. Appendix A is a list of Acronyms. Appendix B provides references. Appendix C describes test events and results from exercising different combinations of components into composed security platforms, including system responses to attempts to subvert DNSSEC protection mechanisms. Appendix D is a checklist for recommended secure domain name system deployment practices. Finally, for readers unfamiliar with any of the specific components employed by this project, Appendix E provides a set of high-level collaborator product descriptions for contributed components. Appendix F describes an example NCCoE installation and configuration of components provided by our NLnet Labs collaborator. Appendix G describes an example NCCoE installation and configuration of components provided by our Microsoft collaborator. Appendix H describes NCCoE installation and configuration of components provided by our Secure64 collaborator.

1.2 Build Overview

1.2.1 Usage Scenarios Supported

The scenarios supported include:

- “ordinary” email where the email exchanges between two organizations' email servers communicate over Transport Layer Security (TLS)[1] with a STARTTLS[2] extension, and relevant TLSA[3] records are published in the receiver's DNS zone protected by DNSSEC (Scenario 1 in this document)
- end-to-end signed email, where the email exchanges between users in different organizations are carried over a channel protected by TLS (using the STARTTLS extension), and relevant artifacts used for signing and channel protection are published in a DNS zone protected by DNSSEC (Scenario 2). Subsequently, these artifacts are used for Secure/Multipurpose Internet Mail Extensions (S/MIME)[4] and TLS validation.

3. Also according to SP 800-177, mail is transmitted, in a “store and forward” fashion, across networks via Mail Transfer Agents (MTAs). MTAs communicate using the Simple Mail Transfer Protocol (SMTP) described below and act as both client and server, depending on the situation. See Section 2, Definitions, at https://tools.ietf.org/html/rfc3888.

1. RFC 5246, *The Transport Layer Security (TLS) Protocol Version 1.2*

2. See RFC 3207, *SMTP Service Extension for Secure SMTP over Transport Layer Security*.

3. RFC 6698, *The DNS-Based Authentication of Named Entities (DANE) Transport Layer Security (TLS) Protocol: TLSA*, Proposed Standard (August 2012; Errata) Updated by RFC 7671, RFC 7218

4. RFC 2633, *S/MIME Version 3 Message Specification*

In both scenarios, end-entity and personal certificates were generated from Certificate Authorities (CAs)[1]. Use of “well known” (i.e. installed as trust anchors in hosts), local enterprise CAs and self-signed certificates were demonstrated.

While the second scenario demonstrated signing of emails, it does not include an end-to-end encrypted email scenario. Signing addresses the main security concerns in enterprise environments, which are the target of the project, but may neglect concerns of individual users who may also want to reduce information disclosure to their email providers. The two scenarios that are included may, however, serve as enablers for end-to-end encryption. Participation by parties having a primarily end-to-end encryption focus may succeed in generating industry support for the building blocks needed to support end-to-end encryption.

In more detail, the project's security platforms use the STARTTLS extension to include encryption of communications between two MTAs, as well as the signature of individual messages using S/MIME. The encryption and decryption with S/MIME on the end user's client was excluded from the current platform demonstration.

1.2.2 Architectural Overview

The laboratory architecture for the DNSSEC-Based Email Security project was designed to permit interconnection of Microsoft Outlook, Apple Mail, and Thunderbird MUAs with Microsoft Exchange and Postfix/Dovecot MTAs. It demonstrates the interconnection of either MTA with various DNS services contributed by collaborators. Two instantiations of each MTA type were established to demonstrate email exchanges between MTAs of the same type or different types. The various component combinations were demonstrated with three different TLSA RR[2] parameters: a self-signed certificate, use of local certificate authorities, and use of well-known certificate authorities.

Figure 1.1 is a deployment diagram of the architecture used for demonstrating DNS-Based Email Security.

The following subsections describe the architecture's MUA, MTA, and DNS service components and Cybersecurity Framework Core categories supported by those components. Component descriptions are provided in Appendix E for those not familiar with some of the individual components.

---

1. According to NIST SP 800-177, a trusted Certificate Authority (CA) is licensed to validate applicants' credentials, store their public key in a X.509 [RFC5280] structure, and digitally sign it with the CA's private key. TLS relies on public key cryptography and uses X.509 certificates [RFC5280] to encapsulate the public key, and the CA system to issue certificates and authenticate the origin of the key. An organization can generate its own root certificate and give its members a certificate generated from that root, or purchase certificates for each member from a well-known CA.
2. According to RFC 6698, The TLSA DNS resource record (RR) is used to associate a TLS server certificate or public key with the domain name where the record is found, thus forming a “TLSA certificate association”.

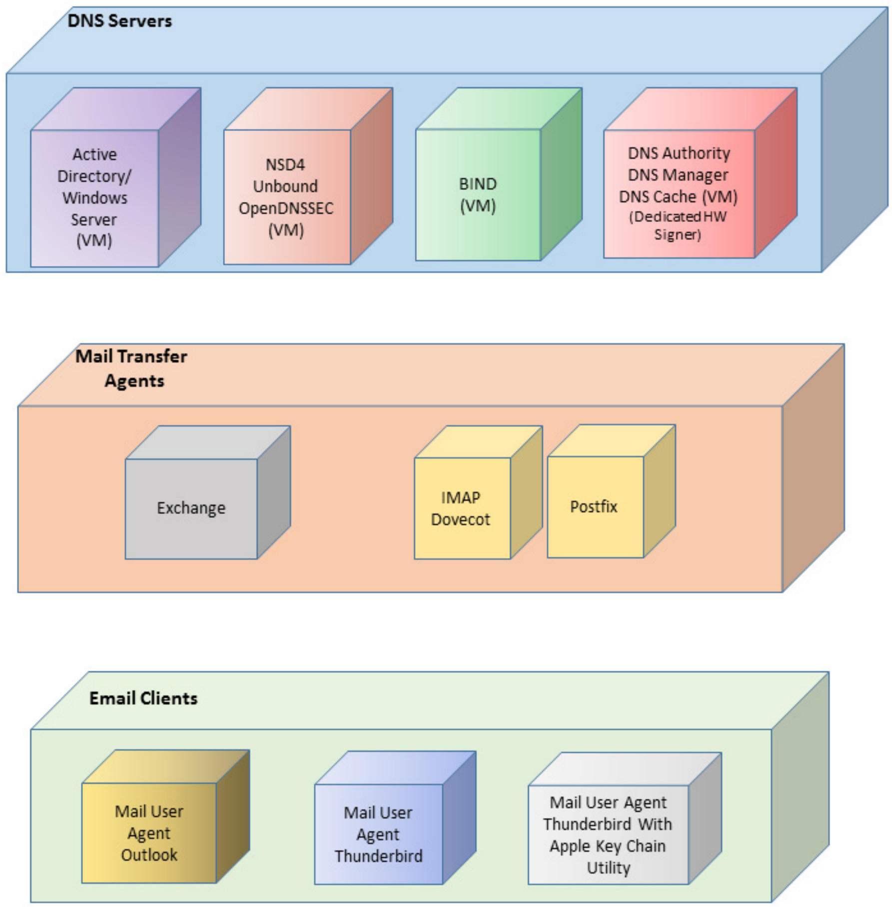
1.2.2.1 Client Systems and Mail User Agents (MUAs)

Client systems environments demonstrated were Microsoft Office, an open-source Linux-based Thunderbird application, and Thunderbird with a Secure64-provided Apple Key Chain utility. This set includes both commercial products and open-source software. MUA capabilities associated with the client systems are used to invoke S/MIME digital signature and signature verification for email, but user-to-user encryption is not demonstrated. Collaborators assisted in installation, integration tailoring as necessary, and testing of laboratory configurations.

1.2.2.2 Email Servers

Email servers include both Windows and Linux-based (Postfix/Dovecot) Mail Transfer Agents. Server-to-server encryption was demonstrated in Postfix environments. Authentication of domain and server identity was based on DNSSEC-signed DANE records. Use of these DANE records is only supported by Postfix at the time of this project. The servers were demonstrated in different DNS environments and different TLSA RR usage scenarios. In order to demonstrate representative TLSA parameters, the demonstrations used self-signed certificates, end-entity certificates generated by well-known CAs and end-entities generated by enterprise local CAs.

Figure 1.1 DNS-Based Email Security Deployment Diagram



1.2.2.3 DNS Servers

Both Windows and Linux-based DNS server and support components were contributed. DNS services provided include DNSSEC validating DNS resolvers (stub and recursive) and authoritative DNS servers for DNSSEC signed zones.[1] Support for SMIMEA and TLSA records was demonstrated. DNS components included Microsoft's Active Directory and DNS Server; Internet Systems Consortium's (ISC's) Berkeley Internet Name Domain (BIND); NLnet Labs' NSD4, Unbound, and OpenDNSSEC; and Secure64's DNS Signer, DNS Authority, DNS Cache, DNS Manager, and Apple Key Chain Utility.

1.3 Typographical Conventions

The following table presents typographic conventions used in this volume.

Typeface/ Symbol	Meaning	Example
Italics	filenames and pathnames references to documents that are not hyperlinks, new terms, and placeholders	For detailed definitions of terms, see the *NCCoE Glossary.*
Bold	names of menus, options, command buttons and fields	Choose **File > Edit**.
Monospace	command-line input, on-screen computer output, sample code examples, status codes	`mkdir`
`Monospace Bold`	command-line user input contrasted with computer output	**`service sshd start`**
blue text	link to other parts of the document, a web URL, or an email address	All publications from NIST's National Cybersecurity Center of Excellence are available at http://nccoe.nist.gov

1. https://www.ietf.org/rfc/rfc1034.txt

2 How to Install and Configure DNS-Protected Email Security Components

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This section explains set up for the component sets provided by project collaborators. Set-up is described for a virtual machine environment. The environment used for this project was the Centos 7 Linux distribution running on VMware. This section includes a description of the laboratory set-up for the capability demonstrations and flow charts for installation and configuration of mail security and DNS security components in an enterprise. This configuration overview is followed by some general instructions for installation and configuration of open source components are provided, with links to source sites for more detailed instructions. Less general installation is provided for commercial components, but links are provided to the vendor sites. Specific installation and configuration instructions for the NCCoE environment are provided as appendices (Appendix F, Appendix G, and Appendix H).

2.1 Laboratory Set-up

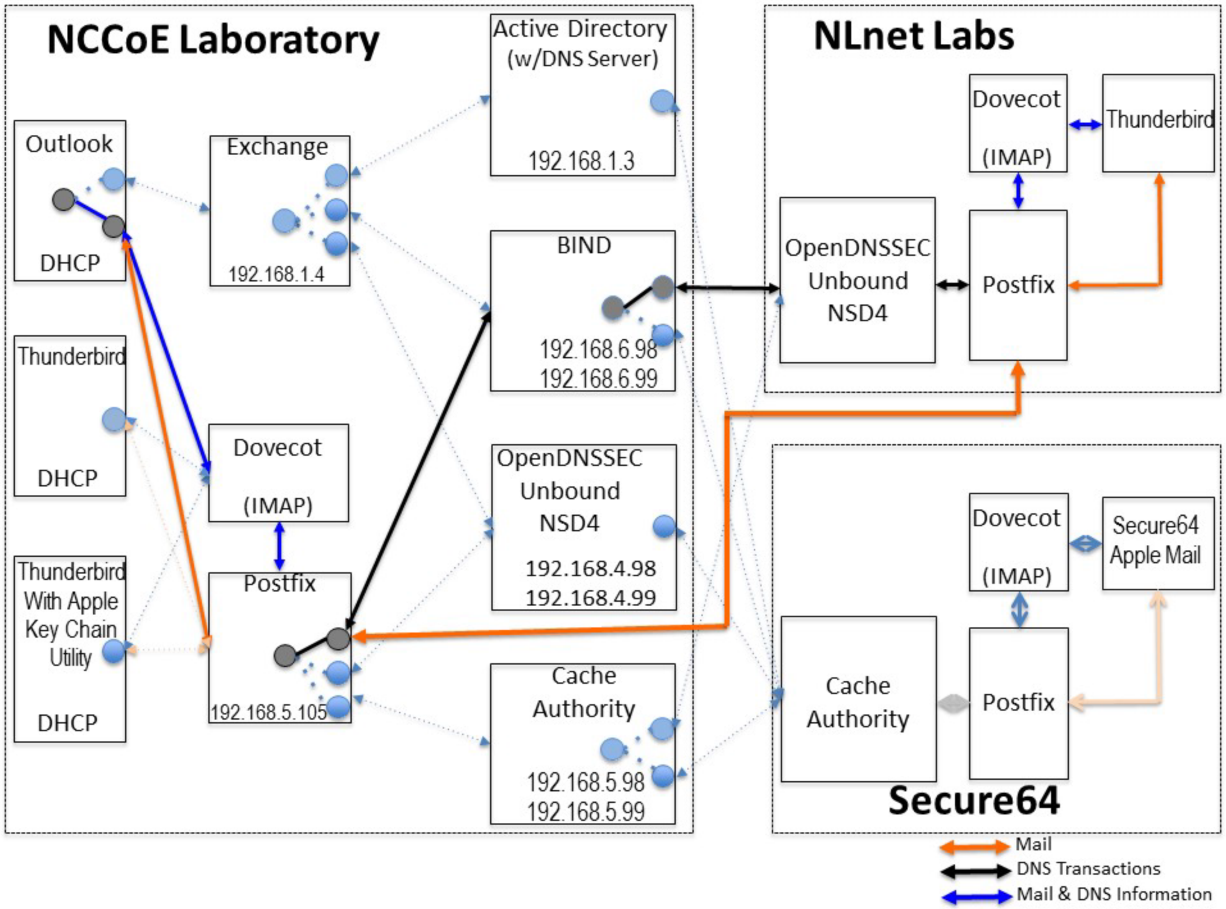
The design of the environment permits interconnection of components provided by different collaborators (see figure 2.1).

The depiction shows that the project security platform test/demonstration activity was based on three different clients, two MTAs, and four DNS service configurations in the lab at the NCCoE exchanging messages with NLnet Labs and Secure64. All messages were signed (a mail client function). Messages sent via a Postfix MTA were encrypted (server to server). The message exchanges, including DNS activity will be logged at each end (lab and remote correspondent).

The solid connectors in the depiction illustrate one case. The dotted lines depict the other cases we'll want to demonstrate. A switch convention is used to reflect configuration options, but the project team actually configures each component for each option.

The orange arrows between the mail clients and the Postfix MTA reflect the fact that clients submitted email directly to the SMTP server for relay, while using Dovecot only to get mail. (The depiction in figure 2.1 reflects that IMAP isn't used to submit mail, only retrieve it, so the MUA sent mail directly to the Postfix server, but received the reply through the Dovecot server.)

Figure 2.1 DNS-Based Email Security Test Set-up



The project team demonstrated 30 different events using various combinations of MUA, MTA, and DNS Server components divided among five test sequences. In each sequence, signed and encrypted messages were sent from a sender to a recipient. Postfix encrypted mail by default. Most of the exchanges employed either self-signed certificates or local CAs (see Appendix C). The BIND configuration was set up to obtain and validate certificates from the NIST Advanced Networks Technology Division's (ANTD's) DNS source (acting as a root CA).

2.1.1 Sequence 1 Set-up

Sequence 1 demonstrated use of well-known CA issued cryptographic certificates (CU=1), enterprise CA issued certificates (CU=2), and self-signed certificates (CU=3) with an Outlook/Exchange/Active Directory and Outlook/Exchange/BIND MUA/MTA/DNS Server stack.[1] Mail was exchanged between the NCCoE and two remote sites. The first site, Secure64 in Ft Collins, Colorado, used a Thunderbird MUA with a utility for MacBook that can fetch SMIMEA records and put them into a key store, a Postfix MTA, and Signer/Authority/Cache DNS servers. The NLnet site used an Intel-hosted Thunderbird MUA, a Postfix/Dovecot MTA, NSD4 and Unbound for processing received messages, and OpenDNSSEC for outbound messages. All messages were S/MIME signed (Scenario 2 only).

Table 2.1 Test Sequence 1

Sequence 1	NCCoE Lab			Remote Sites	Certificate on Receiver Side
Event	MUA	MTA	DNS Service	Secure64 and NLnet Labs	
1	Outlook	Exchange	Active Directory /DNS Server	Enterprise CA issued (CU=2)	Well-known CA issued (CU=1)
2	Outlook	Exchange	Active Directory /DNS Server	Same as 1	Local CA issued (CU=2)
3	Outlook	Exchange	Active Directory /DNS Server	Same as 1	Self-Signed Cert (CU=3)
4	Outlook	Exchange	BIND	Same as 1	Well-known CA issued (CU=1)
5	Outlook	Exchange	BIND	Same as 1	Local CA issued (CU=2)
6	Outlook	Exchange	BIND	Same as 1	Self-Cert (CU=3)

2.1.2 Sequence 2 Set-up

Sequence 2 demonstrated use of an Outlook/Postfix MUA/MTA configuration with a BIND DNS Server, and a Thunderbird/Postfix MUA/MTA configuration with both BIND and DNS Signer/Authority/Cache set-ups. All three certificate usage approaches were demonstrated. Mail was exchanged between the NCCoE and both Secure64 and NLnet Labs sites. As in Sequence 1, the secure64 site used a Thunderbird MUA, a Postfix MTA, and OpenDNSSEC/Unbound/NSD4 DNS servers; and the NLnet Labs site used a Thunderbird MUA, a

1. The integrity of cryptographic certificates is generally checked by verifying a digital signature generated for the certificate by its source. Certificates may be self-signed by an entity that both generates and uses it, signed by the parent enterprise that is responsible for generating and using the certificate, or be signed by some “well-known” third party certificate source that is trusted by organizations using the certificates for cryptographic protection processes. Certificate usage is designated “CU=1” for certificates issued by well-known CAs, “CU=2” for certificates issued by enterprise CAs (also known as Local CAs), and “CU=3” for certificates that are self-signed. CU=1 is generally considered most trustworthy, and CU=3 is considered least trustworthy.

Postfix/Dovecot MTA, NSD4 and Unbound for DNS processing received messages, and OpenDNSSEC for outbound messages. Email messages between MTAs were encrypted and successfully decrypted via TLS; an intermediate processor verified that encryption occurred; inspection of the received message verified that decryption was successful; encryption/decryption results were noted; and all messages were S/MIME signed (Scenarios 1 and 2).

Table 2.2 Test Sequence 2

Sequence 2	NCCoE Lab			Remote Sites	Certificate on Receiver Side
Event	MUA	MTA	DNS Service	Secure64 and NLnet Labs	
7	Outlook	Postfix/ Dovecot	BIND	Thunderbird, Postfix/ Dovecot, NSD4/Unbound/ Open DNSSEC Self-Signed Cert (CU=3)	Well-known CA issued (CU=1)
8	Thunderbird	Postfix/ Dovecot	BIND	Same as 7	Local CA issued (CU=2)
9	Thunderbird	Postfix/ Dovecot	BIND	Same as 7	Self-Signed Cert (CU=3)
10	Thunderbird	Postfix/ Dovecot	DNS Authority/ Cache/ Signer	Same as 7	Well-known CA issued (CU=1)
11	Thunderbird	Postfix/ Dovecot	DNS Authority/ Cache/ Signer	Same as 7	Local CA issued (CU=2)
12	Thunderbird	Postfix/ Dovecot	DNS Authority/ Cache/ Signer	Same as 7	Self-Cert (CU=3)

2.1.3 Sequence 3 Set-up

Sequence 3 used an Outlook/Exchange/Active Directory stack to pose as the remote suite used in Sequence 1 and attempt to spoof an Outlook/Exchange Active Directory stack and a Thunderbird/Postfix configuration served by each of three DNS server types (OpenDNSSEC/NSD4/Unbound, DNS Signer/Authority/Cache, and BIND). All events were conducted using well-known CA and Enterprise CA-issued certificates for the impersonated sender. The email exchange between organizations was carried over TLS, and the email message was S/MIME signed on the fraudulent users' client device.

Table 2.3 Test Sequence 3

Sequence 3	NCCoE Lab			Remote Sites	Certificate on Receiver Side
Event	MUA	MTA	DNS Service	Secure64 and NLnet Labs	
13	Outlook	Exchange	Active Directory	Thunderbird on MacBook, Postfix/Dovecot, DNS Authority/ Cache/Signer Local CA issued (CU=2)	Local CA (CU=1)
14	Thunderbird	Postfix/ Dovecot	NSD4/ Unbound/ OpenDNSSEC	Same as 13	Local CA issued (CU=1)
15	Thunderbird on MacBook	Postfix/ Dovecot	DNS Authority/ Cache/Signer	Same as 13	Local CA issued (CU=1)
16	Outlook	Exchange	Active Directory	Same as 13	Self-Signed Cert (CU=3)
17	Thunderbird	Postfix/ Dovecot	NSD4/Unbound/ Open DNSSEC	Same as 13	Self-Signed Cert (CU=3)
18	Thunderbird	Postfix/ Dovecot	BIND	Same as 13	Self-Cert (CU=3)

2.1.4 Sequence 4 Set-up

Attempts were made to send a TLS protected email from Exchange and Postfix MTAs (in turn) to an external Postfix MTA using DNS Authority/Cache/Signer for DNS services. The NCCoE Exchange MTA used Active Directory DNS Services, and the Postfix/Dovecot MTA uses BIND, NSD4/Unbound/OpenDNSSEC, and DNS Signer/Authority/Cache DNS services. An S/MIME signed email was sent to an external Postfix MTA. Events were conducted using Well-Known CA issued certificates, events using Enterprise CA issued certificates (TLSA/SMIMEA RR parameter of CU=2) for TLS and S/MIME on the receiver side, and three using self-signed certificates (TLSA/SMIMEA RR parameter of CU=3) for TLS and S/MIME on the receiver side. An Outlook/Exchange/Active Directory stack acted as a man-in-the-middle and attempted to impersonate the legitimate receiver.

Table 2.4 Test Sequence 4

Sequence 3	NCCoE Lab			Legitimate Remote Site	Certificate on Receiver Side
Event	MUA	MTA	DNS Service		
19	Outlook	Exchange	Active Directory	Secure64	Well-Known CA (CU=1)
20	Thunderbird	Exchange	BIND	Secure64	Well-Known CA (CU=1)
21	Thunderbird	Postfix	NSD4/Unbound/ Open DNSSEC	Secure64	Well-Known CA (CU=1)

Table 2.4 Test Sequence 4

Sequence 3	NCCoE Lab			Legitimate Remote Site	Certificate on Receiver Side
Event	MUA	MTA	DNS Service		
22	Thunderbird on MacBook	Postfix/ Dovecot	DNS Authority/ Cache/Signer	Secure64	Well-Known CA (CU=1)
23	Outlook	Exchange	Active Directory	Secure64	Local CA (CU=2)
24	Thunderbird	Postfix/ Dovecot	BIND	Secure64	Local CA (CU=2)
25	Thunderbird on MacBook	Postfix/ Dovecot	NSD4/Unbound/ Open DNSSEC	Secure64	Local CA (CU=2)
26	Thunderbird on MacBook	Postfix/ Dovecot	DNS Authority/ Cache/Signer	Secure64	Local CA (CU=2)
27	Thunderbird	Postfix/ Dovecot	Active Directory	Secure64	Self-Cert (CU=3)
28	Thunderbird	Exchange	BIND	Secure64	Self-Cert (CU=3)
29	Thunderbird on MacBook	Postfix/ Dovecot	NSD4/Unbound/ Open DNSSEC	Secure64	Self-Cert (CU=3)

2.1.5 Sequence 5 Set-up

This sequence used an Authoritative DNS Server, a DANE-aware Postfix server, and four Exchange MTAs (each set up differently). One ran without TLSA, one had good TLSA and a self-signed certificate (CU=3), one had bad PKIX and a certificate from a well-known CA (CU=1), and one had a bad TLSA with a self-signed certificate (CU=3). A script running on the Postfix server generates a message stream. Logs of failed DNS events were examined.

2.1.6 How to Deploy SMIMEA and TLSA Software for Trustworthy Email

Set-up for the test sequences required deploying SMIMEA and TLSA, and adding certificates and records for users. Figures 3 and 4 are flowcharts depicting the steps required for installation and configuration of MUAs, MTAs, and DNS servers necessary to trustworthy email. Figure 2.2 depicts the process for setting up secure/multipurpose Internet mail extensions (S/MIME and SMIMEA). Figure 2.3 depicts the process for setting up transport layer security (i.e., TLS and TLSA). The figures assume that the enterprise has deployed DNSSEC, including DANE-aware components. The figures include questions regarding the installation and configuration status of components, and provides recommendations based on the answers to those questions. Together with the Secure Name System (DNS) Deployment Checklist provided as Appendix D, these flowcharts are intended to facilitate establishment of a trustworthy email capability in a wide range of environments.

Figure 2.2 S/MIME and SMIMEA Deployment Flowchart

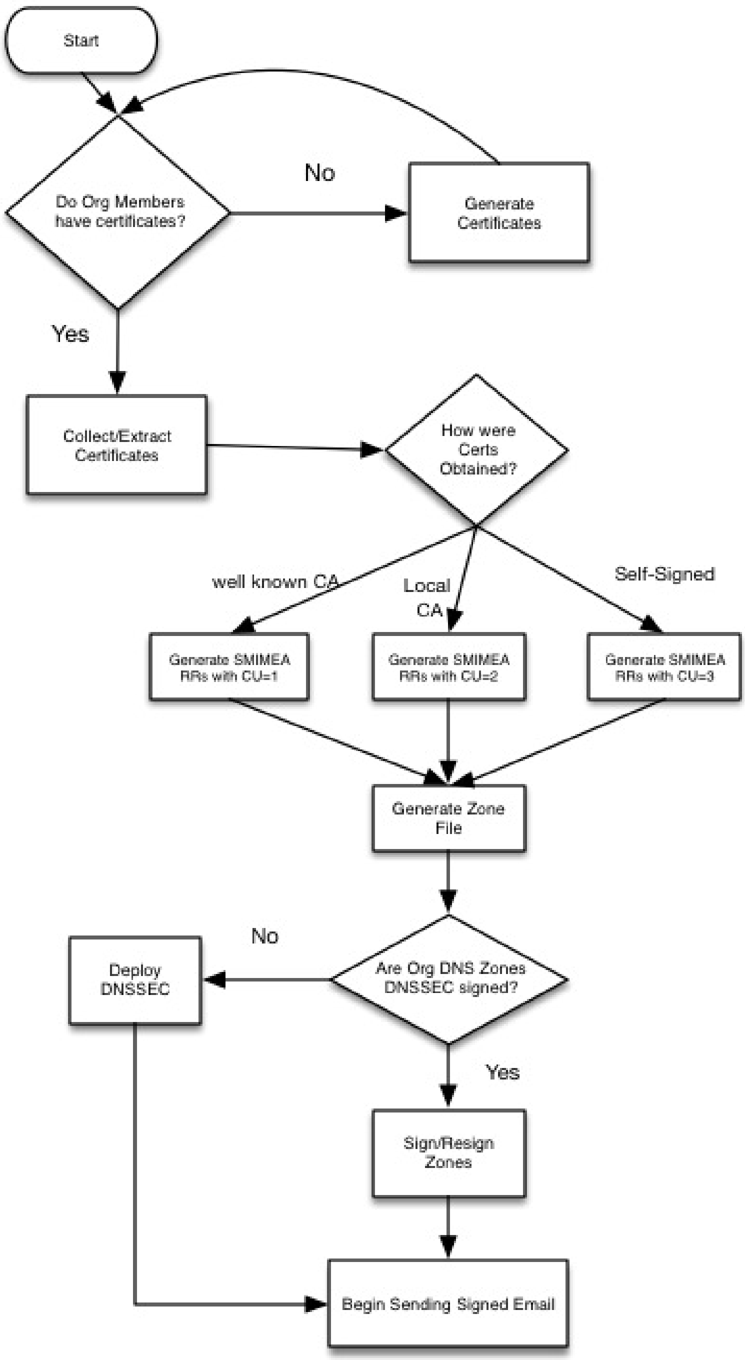
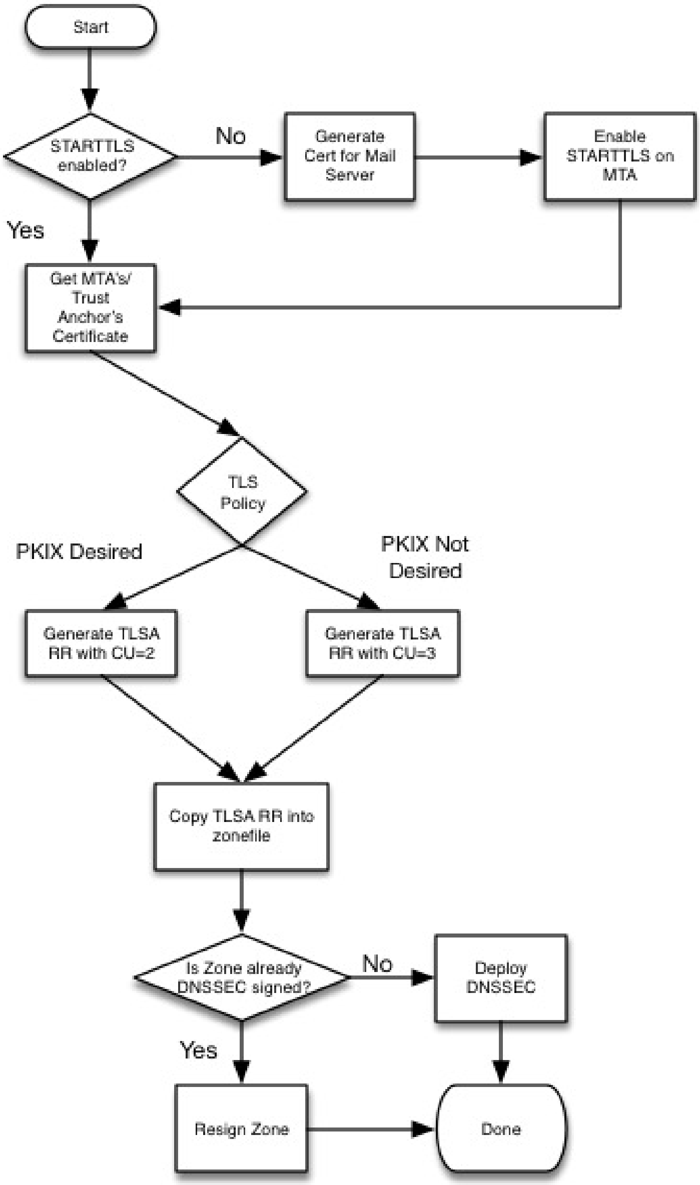


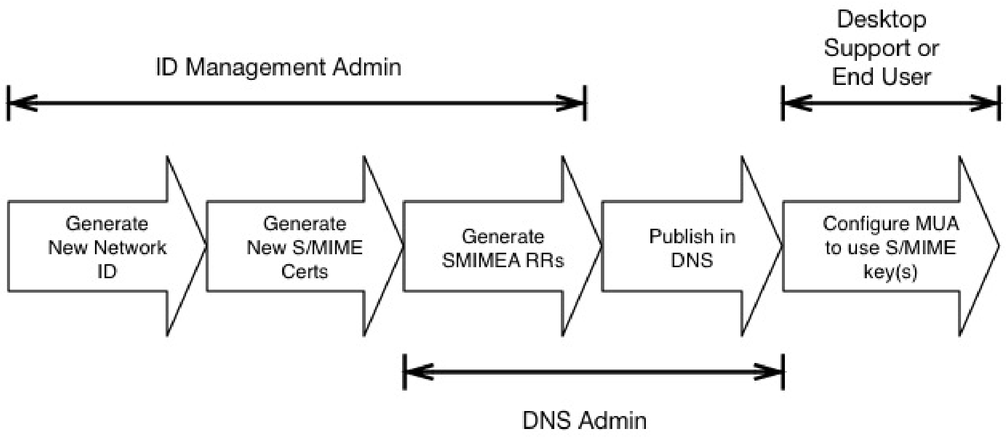
Figure 2.3 TLS/TLSA Deployment Flowchart



2.1.7 Adding and Removing Network Users

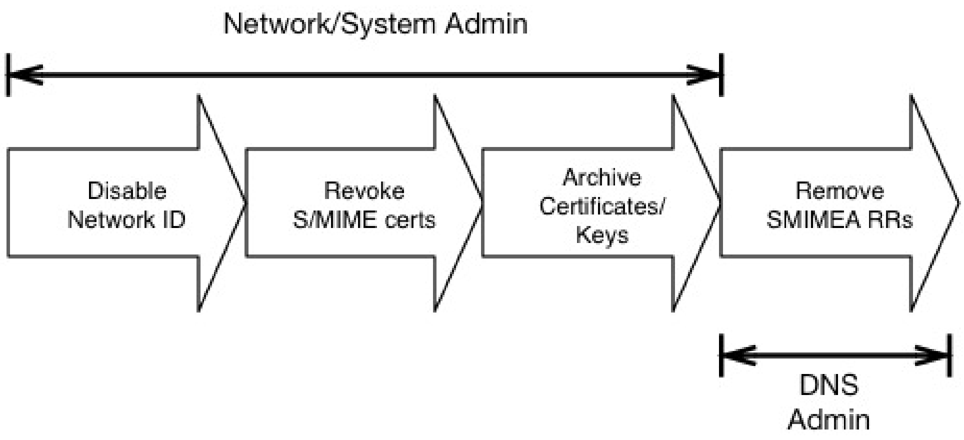
Adding users to networks with trustworthy email enabled involves identity management administrative, DNS administrative, and end user support activities. Figure 2.4 depicts the process for generating user network identities, new S/MIME Certificates for users, and SMIMEA resource records; publishing the records in the DNS, and configuring users' MUAs to use S/MIME keys.

Figure 2.4 Adding Network Users for Trustworthy Email



When a user leaves an organization or access to network resources is revoked for other reasons, it is necessary to revoke the credentials that associate the user with the organization. This action requires the network or system administrator to disable the user's network ID, revoke the user's S/MIME certificates, and archive the certificates and associated keys; and requires the DNS administrator to remove the user's SMIMEA resource records (RRs). Figure 2.5 depicts the flow for this process.

Figure 2.5 Removing Network Users for Trustworthy Email



2.2 How to Install and Configure Microsoft Server-Based DNS-Protected Email Security Components

Outlook, Exchange, Active Directory, and DNS Server are commercial products that can be accessed from Microsoft's web (e.g., https://www.microsoft.com/en-us/). Outlook is generally bundled in Microsoft Office (e.g., Office365 for Windows 10), and DNS Server is bundled in Microsoft Server systems (e.g., Server 2016). Active Directory tools and applications are not installed in Windows 10 by default, but instructions regarding how to get them can be found at http://www.technipages.com/windows-install-active-directory-users-and-computers. DNS Server is bundled with Server 2016. Please note that IP addresses, domain names, and mail addresses are, in many cases, specific to the NCCoE laboratory configuration and must not be used in actual implementations.

2.2.1 Installation Basics and System Requirements

System requirements are product-specific, and installation instructions are highly dependent of version, intended configuration, and tools set employed. The installation process, tools employed, and configuration process followed in setting up the NCCoE Microsoft components are provided as Appendix G to this Practice Guide. Manual pages are provided for individual applications of products and tools (e.g., https://technet.microsoft.com/en-us/library/bb245702(v=exchg.80).aspx and https://technet.microsoft.com/en-us/library/bb123543(v=exchg.141).aspx for Exchange, https://technet.microsoft.com/en-us/library/dn626158(v=exchg.150).aspx for Outlook), and https://technet.microsoft.com/en-us/library/cc732284(v=ws.11).aspx for configuring a DNS server for use with Active Directory domain services; and from a wide variety of third party sources.

2.2.2 Installation of Active Directory, Server, and Exchange in the NCCoE Configuration

Appendix G describes installation and configuration of Active Directory, Server, and Exchange at the NCCoE.

2.3 How to Install and Configure BIND[1]

The current guide for getting started with BIND and instruction on how to build and run named with a basic recursive configuration can be found at https://kb.isc.org/article/AA-00768/46/Getting-started-with-BIND-how-to-build-and-run-named-with-a-basic-recursive-configuration.html. The current BIND 9 Reference Manual can be found at https://www.isc.org/wp-content/uploads/2014/01/Bv910ARM.pdf&hl=en_US. An overview of installation and configuration basics follow. Please note that IP addresses, domain names, and mail addresses are, in many cases, specific to the NCCoE laboratory configuration and must not be used in actual implementations.

2.3.1 Installation Basics and System Requirements

The NCCoE BIND installation was based on Centos 7. ISC specifies that BIND 9 currently requires a UNIX system with an ANSI C compiler, basic POSIX support, and a 64 bit integer type.

ISC has also had success in building and testing on the following systems:

- COMPAQ Tru64 UNIX 5.1B
- Fedora Core 6
- FreeBSD 4.10, 5.2.1, 6.2
- HP-UX 11.11
- Mac OS X 10.5
- NetBSD 3.x, 4.0-beta, 5.0-beta
- OpenBSD 3.3 and up
- Solaris 8, 9, 9 (x86), 10
- Ubuntu 7.04, 7.10
- Windows XP/2003/2008

ISC also has recent reports from the user community that a supported version of BIND will build and run on the following systems:

- AIX 4.3, 5L
- CentOS 4, 4.5, 5
- Darwin 9.0.0d1/ARM
- Debian 4, 5, 6
- Fedora Core 5, 7, 8
- FreeBSD 6, 7, 8
- HP-UX 11.23 PA
- MacOS X 10.5, 10.6, 10.7
- Red Hat Enterprise Linux 4, 5, 6
- SCO OpenServer 5.0.6
- Slackware 9, 10
- SuSE 9, 10

Note: *As of BIND 9.5.1, 9.4.3, and 9.3.6, older versions of Windows, including Windows NT and Windows 2000, are no longer supported.*

1. This product includes software developed by the OpenSSL Project for use in the OpenSSL Toolkit (http://www.openssl.org/), cryptographic software written by Eric Young (eay@cryptsoft.com), and software written by Tim Hudson (tjh@cryptsoft.com).

Information regarding downloading BIND can be found at https://www.isc.org/downloads/bind/

2.3.2 BIND Installation and Configuration

ISC's recommended link for BIND starter information is: https://kb.isc.org/article/AA-00768/46/Getting-started-with-BIND-how-to-build-and-run-named-with-a-basic-recursive-configuration.html. For authoritative configuration, refer to the BIND9 ARM (https://www.isc.org/downloads/bind/doc/bind-9-10/).

To build, just enter:

```
./configure
make
```

Do not use a parallel "make".

2.3.2.1 Environmental Variables

Several BIND environment variables that can be set before running configure will affect compilation:

- **CC**

  The C compiler to use. configure tries to figure out the right one for supported systems.

- **CFLAGS**

  C compiler flags. Defaults to include -g and/or -O2 as supported by the compiler. Please include '-g' if you need to set **CFLAGS**.

- **STD_CINCLUDES**

  System header file directories. Can be used to specify where add-on thread or IPv6 support is, for example. **STD_CINCLUDES** defaults to empty string.

- **STD_CDEFINES**

  Any additional preprocessor symbols you want defined. **STD_CDEFINES** defaults to empty string.

  Possible settings:

  - Change the default syslog facility of **named/lwresd**.

    `-DISC_FACILITY=LOG_LOCAL0`

  - Enable DNSSEC signature chasing support in **dig**.

    `-DDIG_SIGCHASE=1 (sets -DDIG_SIGCHASE_TD=1 and`

    `-DDIG_SIGCHASE_BU=1)`

  - Disable dropping queries from particular well known ports.

    `-DNS_CLIENT_DROPPORT=0`

  - Sibling glue checking in named-checkzone is enabled by default.

To disable the default check set. `-DCHECK_SIBLING=0`.

- named-checkzone checks out-of-zone addresses by default.

  To disable this default set `-DCHECK_LOCAL=0`.
- To create the default pid files in `${localstatedir}/run` rather than `${localstatedir}/run/{named,lwresd}/` set `-DNS_RUN_PID_DIR=0`
- Enable workaround for Solaris kernel bug about /dev/poll

  `-DISC_SOCKET_USE_POLLWATCH=1`
- The watch timeout is also configurable, e.g.,

  `-DISC_SOCKET_POLLWATCH_TIMEOUT=20`

- **LDFLAGS**

  Linker flags. Defaults to empty string.

2.3.2.2 Cross Compiling

The following need to be set when cross compiling:

- **BUILD_CC**

  The native C compiler.
- **BUILD_CFLAGS** (optional)
- **BUILD_CPPFLAGS** (optional)

  Possible Settings:

  `-DNEED_OPTARG=1` (optarg is not declared in <unistd.h>).
- **BUILD_LDFLAGS** (optional)
- **BUILD_LIBS** (optional)

2.3.2.3 Multithreading Support

On most platforms, BIND 9 is built with multithreading support, allowing it to take advantage of multiple CPUs. You can configure this by specifying **`--enable-threads`** or **`--disable-threads`** on the configure command line. The default is to enable threads, except on some older operating systems on which threads are known to have had problems in the past.

Note: *Prior to BIND 9.10, the default was to disable threads on Linux systems; this has been reversed. On Linux systems, the threaded build is known to change BIND's behavior with respect to file permissions; it may be necessary to specify a user with the -u option when running named.*

2.3.2.4 Shared Libraries

To build shared libraries, specify **`--with-libtool`** on the configure command line.

2.3.2.5 Large Servers

Certain BIND compiled-in constants and default settings can be increased to values better suited to large servers with abundant memory resources (e.g, 64-bit servers with 12G or more of memory) by specifying `--with-tuning=large` on the configure command line. This can improve performance on big servers, but will consume more memory and may degrade performance on smaller systems.

2.3.2.6 DNSSEC Support

For the BIND server to support DNSSEC, you need to build it with crypto support. You must have OpenSSL 0.9.5a or newer installed and specify `--with-openssl` on the configure command line. If OpenSSL is installed under a nonstandard prefix, you can tell configure where to look for it using `--with-openssl=/prefix`.

2.3.2.7 HTTP Statistics Channel Support

To support the HTTP statistics channel, the BIND server must be linked with at least one of the following: libxml2 (http://xmlsoft.org) or json-c (https://github.com/json-c). If these are installed at a nonstandard prefix, use `--with-libxml2=/prefix` or `--with-libjson=/prefix`.

To support compression on the HTTP statistics channel, the server must be linked against libzlib (`--with-zlib=/prefix`).

2.3.2.8 Python Support

Python requires '**argparse**' and '**ply**' to be available. '**argparse**' is a standard module as of Python 2.7 and Python 3.2.

2.3.2.9 Files Larger than 2GB

On some platforms it is necessary to explicitly request large file support to handle files bigger than 2GB. This can be done by `--enable-largefile` on the BIND configure command line.

2.3.2.10 Fixed rrset-order Option

Support for the **fixed** rrset-order option can be enabled or disabled by specifying `--enable-fixed-rrset` or `--disable-fixed-rrset` on the BIND configure command line. The default is **disabled**, to reduce memory footprint.

2.3.2.11 IPv6 Support

If your operating system has integrated support for IPv6, it will be used automatically. If you have installed KAME IPv6 separately, use `--with-kame[=PATH]` to specify its location.

2.3.2.12 Installing named and BIND 9 Libraries

The **make install** tool will install **named** and the various BIND 9 libraries. By default, installation is into /usr/local, but this can be changed with the --**prefix** option when running **configure**.

2.3.2.13 Directory Setting Options

You may specify the option `--sysconfdir` to set the directory where configuration files like `named.conf` go by default, and `--localstatedir` to set the default parent directory of `run/named.pid`. For backwards compatibility with BIND 8, `--sysconfdir` defaults to `/etc` and `--localstatedir` defaults to `/var` if no --prefix option is given. If there is a `-prefix` option, `sysconfdir` defaults to $prefix/etc and `localstatedir` defaults to `$prefix/var`.

2.3.2.14 Other Configure Options

To see additional configure options, run `configure --help`. Note that the help message does not reflect the BIND 8 compatibility defaults for `sysconfdir` and `localstatedir`. If you're planning on making changes to the BIND 9 source, you should also `make depend`. If you're using Emacs, you might find `make tags` helpful.

2.3.2.15 Re-running Configure

If you need to re-run configure please run `make distclean` first. This will ensure that all the option changes take.

2.3.2.16 Building with gcc

Building with gcc is not supported, unless gcc is the vendor's usual compiler (e.g. the various BSD systems, Linux).

2.3.2.17 Known Compiler and OS Issues

Known compiler issues include the following:

- gcc-3.2.1 and gcc-3.1.1 is known to cause problems with solaris-x86.
- gcc prior to gcc-3.2.3 ultrasparc generates incorrect code at -02.
- gcc-3.3.5 powerpc generates incorrect code at -02.
- Irix, MipsPRO 7.4.1m is known to cause problems.
- SunOS 4 requires **printf** to be installed to make the shared libraries.
- sh-utils-1.16 provides a **printf** which compiles on SunOS 4.
- Linux requires kernel

2.3.3 Testing

A limited BIND test suite can be run with `make test`. Many of the tests require you to configure a set of virtual IP addresses on your system, and some require Perl. (See bin/tests/system/README for details).

2.3.4 BIND Documentation

The BIND 9 Administrator Reference Manual is included with the source distribution in DocBook XML and HTML format, in the doc/arm directory.

Some of the programs in the BIND 9 distribution have man pages in their directories. In particular, the command line options of **named** are documented in **/bin/named/named.8**.

There is now also a set of man pages for the **lwres** library.

For upgrading from BIND 8, please read the migration notes in **doc/misc/migration**. If you are upgrading from BIND 4, read **doc/misc/migration-4to9**.

Frequently asked questions and their answers can be found in **FAQ**.

Additional information on various subjects can be found in the other **README** files.

2.3.5 BIND Support

Although BIND is open source software, support is available from ISC.

2.4 NSD 4 Requirements, Installation, Setup, and Configuration Components

The links for NSD 4.1.13 tar files, manual pages, and SVN repository can be found at https://www.nlnetlabs.nl/projects/nsd/. This repository provides for downloading of the latest NSD 4 version. NSD 4 can be installed on Unix-based systems (e.g., FreeBSD, OpenBSD, NetBSD, Mac OS X, and Solaris), including Linux systems such as Red Hat Enterprise, Centos, Debian, Ubuntu, and Gentoo. Please note that IP addresses, domain names, and mail addresses are, in many cases, specific to the NCCoE laboratory configuration and must not be used in actual implementations.

2.4.1 NSD 4 Installation Basics

NSD4 is available in distribution repositories such that a package manager can install it with a single command:

For Red Hat Enterprise and Centos (Centos 7 was used in the NCCoE example):

```
yum install nsd
```

For Debian and Ubuntu:

```
sudo apt-get install nsd
```

For Gentoo:

```
emerge nsd
```

2.4.2 NSD 4 Configuration (nsd.conf)

Different paths exist for NSD4 (nsd.conf). Their paths depend on your distribution:

Centos - Red Hat Enterprise: `/etc/nsd/nsd.conf`

Debian - Ubuntu: `/etc/nsd/nsd.conf`

2.4.2.1 Master Configuration

The following is a master configuration for NSD4 for a Centos system. This example shows nsd4 serving the domain dnslabs.dnsops.gov on the IP address 129.6.45.38. The log file for the actual NCCoE installation and configuration of NSD4 with Unbound and OpenDNSSEC for the DNS-Based Email Security project is provided as Appendix F.

```
#
# nsd.conf -- the NSD(8) configuration file, nsd.conf(5).
#
# Copyright (c) 2001-2011, NLnet Labs. All rights reserved.
#
# See LICENSE for the license.
#

# This is a configuration file commented out, you just need to change
the IP and the zone file to customize it.

# options for the nsd server
server:
# uncomment to specify specific interfaces to
bind (default wildcard interface).
# ip-address: localhost
ip-address: 129.6.45.38

# don't answer VERSION.BIND and VERSION.SERVER
CHAOS class queries
# Keep yes for security reasons.
hide-version: yes

# enable debug mode, does not fork daemon process into the background.
# debug-mode: no

# do-ip4
default: yes

# do-ip6
default: yes

# Enable IPv6 as advice.

# the database to use, this is the standard path.
# disable database mode. Explicitly set database: ""
# database: ""
```

```
        # identify the server (CH TXT ID.SERVER entry).
        identity: ""

        # NSID identity (hex string). default disabled.
        # nsid: "aabbccdd"

        # log messages to file. Default to stderr and
         syslog (with facility LOG_DAEMON).
        # logfile: "/var/log/nsd.log"

        # Number of NSD servers to fork, keep 1 for low
        memory VPS
        server-count: 1

        # Maximum number of concurrent TCP connections
         per server.
        # This option should have a value below 1000, 10
         is good for a low memory VPS
        tcp-count: 10

        # Maximum number of queries served on a single
         TCP connection.
        # By default 0, which means no maximum.
        # tcp-query-count: 0

        # Override the default (120 seconds) TCP timeout.
        # tcp-timeout: 120

        # Preferred EDNS buffer size for IPv4.
        # ipv4-edns-size: 4096

        # Preferred EDNS buffer size for IPv6.
        # ipv6-edns-size: 4096

        # File to store pid for nsd in.
        # pidfile: "/var/run/nsd/nsd.pid"

        # port to answer queries on. default is 53.
        # port: 53

        # statistics are produced every number of
         seconds.
        # statistics: 3600
```

```
# if per zone statistics is enabled, file to
 store statistics.
# zone-stats-file: "/var/log/nsd.stats"

# The directory for zonefile: files.
zonesdir: "/etc/nsd/zones"

 #This is the definition of the first zone, you
 must have 1 for every domain.
zone:
 name: dnslabs.dnsops.gov
 #file in the zonesdir that contains the domain
 information.
 zonefile: dnslabs.dnsops.gov.conf

# See https://www.nlnetlabs.nl/projects/nsd/nsd-control.8.html for
nsd-control config
```

2.4.2.2 NSD Zone File

The next step is setting up zone files. The following instructions set up a simple zone file that just defines the SOA, the NS, MX and some address for the domain:

```
;## NSD authoritative only DNS

$ORIGIN dnslabs.dnsops.gov. ; default zone domain
$TTL 86400 ; default time to live

@ IN SOA nev1 admin@dnslabs.dnsops.gov (
2012082703 ; serial number
28800 ; Refresh
14400 ; Retry
864000 ; Expire
86400 ; Min TTL
)

NS nev1.dnslabs.dnsops.gov .
NS nev2.dnslabs.dnsops.gov .
MX 10 mail.dnslabs.dnsops.gov .

mail  IN A 129.6.45.38
www  IN A 129.6.45.38
nev1 IN A 129.6.45.38
nev2 IN A 129.6.45.38
```

```
* IN A 129.6.45.38
@ IN A 129.6.45.38

;## NSD authoritative only DNS
```

For NSD it is a requisite to set your NS name server hostname (nev1.dnslabs.dnsops.gov to 129.6.45.38 in this example) to the same IP address NSD is listening on, the one we have set in the nsd.conf file. This is so important because a resolving DNS server, like BIND, will ask NSD what the current authoritative name server IP address is. NSD will say the name server for `dnslabs.dnsops.gov` is `nev1.dnslabs.dnsops.gov` and its IP is 129.6.45.38. And so 129.6.45.38 is the address that another service like BIND will use to connect.

```
* IN A 129.6.45.38
```

includes the names in the domain `.dnslabs.dnsops.gov`.

2.4.2.3 Compile the NSD Database and Start Daemon

Note: *NLnet Labs advises against running NSD4 in the database mode unless there is a compelling local reason.*

1. General

   `Nsd-control stop/start`

2. Restart Command: If a message is received that there are errors in the zone file, correct them; otherwise restart as follows:

   a. For Red Hat or Centos Server:

      `/etc/init.d/nsd restart`

   b. For Debian or Ubuntu server:

      `/etc/init.d/nsd4 restart`

Note: *A restart is not needed to reload zonefile. Use reload or reconfig.*

2.4.2.4 Testing NSD4

The easiest way to test the NSD4 configuration is to run a **dig** from the resolver querying the NSD server for the domain you just defined, such as:

```
dig @129.6.45.38 dnslabs.dnsops.gov
```

The output should look something like the following:

```
; &lt;&lt;&gt;&gt ; DIG 9.3.6-20.P1.e15_8.2 ;
 &lt;&lt;&gt;&gt; @129.6.45.38 dnslabs.dnsops.gov
; 1(1 server found)
;; global options: printcmd
;; Got answer:
;; -&gt;&gt;HEADER&lt;
```

In this output you should see in the **answer** section the correct association between your DNS name and IP, and in the **AUTHORITY** section the correct association between your NS and the configured IP.

2.4.2.5 NSD4 Support

Although NSD4 is open source software, support is available from NLnet Labs via its subsidiary Open Netlabs (http://www.opennetlabs.com).

2.5 How to Install and Configure OpenDNSSEC

The log file for an actual NCCoE installation and configuration of OpenDNSSEC with Unbound and NSD4 for the DNS-Based Email Security project is provided as Appendix F. For cryptographic operations, OpenDNSSEC uses the PKCS#11 interface supported by hardware security modules (HSMs). As an alternative to real HSMs, the OpenDNSSEC project developed SoftHSM, a drop-in replacement that uses the Botan or OpenSSL cryptographic library. SQLite or MySQL can be used as database back-ends. It is used on the .se, .dk, .nl, .ca, and .uk top-level domains and more. OpenDNSSEC can be downloaded from:

- https://dist.opendnssec.org/source/opendnssec-2.0.1.tar.gz
- https://dist.opendnssec.org/source/opendnssec-2.0.1.tar.gz.sig
- Checksum SHA256: bf874bbb346699a5b539699f90a54e0c15fff0574df7a3c118abb30938b7b346

Please note that IP addresses, domain names, and mail addresses are, in many cases, specific to the NCCoE laboratory configuration and must not be used in actual implementations.

2.5.1 OpenDNSSEC Installation Basics and System Requirements

OpenDNSSEC[1] will run on most Linux, BSD and Solaris operating systems. The community provides binary packages for several platforms to assist installation. This Practice Guide, however, assumes those packages are not available. If you have found an appropriate system to run OpenDNSSEC on, it is time to install its dependencies. OpenDNSSEC relies on a database backend and currently supports MySQL and SQLite. MySQL is recommended because SQLite doesn't scale well and has some known locking issues. Furthermore, OpenDNSSEC depends on:

- ldns, version 1.6.12 and up with the exceptions of 1.6.14 and 1.6.15
- libxml2, libxml2-dev, libxml2

As indicated above, OpenDNSSEC generally assumes use of a cryptographic Hardware Security Module (HSM) via the PKCS#11 interface. An alternative is use of SoftHSM, a software-only implementation of an HSM. SoftHSM depends on Botan (a cryptographic library) version 1.8.5 or greater, or OpenSSL (for SoftHSM 2.0 and higher), and SQLite version 3.3.9 or greater. Install SoftHSM (https://www.opendnssec.org/2016/03/softhsm-2-1-0/) with:

```
$ tar -xzf softhsm-X.Y.Z.tar.gz
```

1. https://www.opendnssec.org/.

```
$ cd softhsm-X.Y.Z $ ./configure
$ make
$ sudo make install
```

By default, the binary will be installed in `/usr/local/bin/` and the configuration is expected to be at `/etc/softhsm.conf`. Open the file and specify a slot for OpenDNSSEC. For example:

```
# SoftHSM slots 0:/var/lib/softhsm/slot0.db
```

The token database does not exist at this stage. It is necessary to initialize it with:

```
$ softhsm --init-token --slot 0 --label "OpenDNSSEC"
```

When prompted, fill in a SO (Security Officer) PIN and user PIN. Remember it, you will need to configure it for OpenDNSSEC. The SO PIN can be used to reinitialize the token. The user PIN is handed out to OpenDNSSEC. If your company does not have a SO, just pick the same PIN for both roles.

Make sure OpenDNSSEC has permission to access the token database.

```
$ chown opendnssec /var/lib/softhsm/slot0.db
$ chgrp opendnssec /var/lib/softhsm/slot0.db
```

2.5.2 OpenDNSSEC Installation

While the log file for an actual installation and configuration of OpenDNSSEC with Unbound and NSD4 for the DNS-Based Email Security project is provided as Appendix F, some more general information regarding OpenDNSSEC installation[1] follows:

Run these commands to install OpenDNSSEC:

```
$ tar -xzf opendnssec-X.Y.Z.tar.gz
$ cd OpenDNSSEC-X.Y.Z $ ./configure
$ make
$ make install
```

By default, the binaries will be installed in /usr/local/bin/ and /usr/local/sbin/. The configuration files are located in the /etc/opendnssec/ directory. The working directories are under /var/opendnssec/.

2.5.3 OpenDNSSEC Configuration Requirements

The default configuration installs default values for entities that just wants to sign their domains with DNSSEC. There are four configuration files for the basic OpenDNSSEC installation:

- **conf.xml** which is the overall configuration of the system
- **kasp.xml** which contains the policy of signing
- **zonelist.xml** where you list all the zones that you are going to sign

---

1. The NLnet Labs OpenDNSSEC team provided most of the text in this section. This text is also available in an expanded form on OpenDNSSEC Wiki https://wiki.opendnssec.org/display/DOCS20/OpenDNSSEC.

- **addns.xml** (per zone, optional) for zone transfers

For now, it is necessary to edit **conf.xml** only because we need to configure the cryptographic security module must be configured (e.g., an HSM or software module such as SoftHSM or SoftHSM 2.x). Make the **Repository** part look like:

```
<Repository name="SoftHSM">
  <Module>/usr/local/lib/libsofthsm.so</Module>
    <TokenLabel>OpenDNSSEC</TokenLabel>
    <PIN>XXXX</PIN>
<SkipPublicKey/>
  </Repository>
```

Here, **XXXX** is the user PIN entered in section 2.4.1 above.

OpenDNSSECs Key and Signing Policy (KASP) provides standard values for signing any zone. However, if an organization chooses to change any value, it is possible to add a new policy, or change values in an existing policy. For example, if a zone uses the **YYYYMMDDXX** format for **SOA SERIAL** values, change the **Serial** parameter in **kasp.xml** from **unixtime** to **datecounter**:

```
<Zone>
    <PropagationDelay>PT9999S</PropagationDelay>
    <SOA>
<TTL>PT3600S</TTL>
    <Minimum>PT3600S</Minimum>
    <Serial>datecounter</Serial>
  </SOA>
</Zone>
```

For full descriptions about all the KASP parameters, see the OpenDNSSEC Wiki[1].

2.5.4 Running OpenDNSSEC

When starting OpenDNSSEC for the first time, it is first necessary to setup the database. There is a control script that starts up two daemons: **ods-enforcerd** that takes care of the key management, and **ods-signerd** that is the actual signer.

Run:

```
$ ods-enforcer-db-setup
*WARNING* This will erase all data in the database; are you sure? [y/n]
y
$ ods-control start
```

At this point, OpenDNSSEC is running. Logs are going to syslog. The setup has imported the two default Key And Signing Policies (KASP), **default** and **lab**. However, no zones are imported yet.

1. OpenDNSSEC Documentation: https://wiki.opendnssec.org/display/DOCS20/kasp.xml.

2.5.5 Adding Zones

Until the zone list **zonelist.xml** is edited, OpenDNSSEC starts with no zones to sign. It is necessary to add zones (and remove zones as necessary). One way to add a zone is to enter the following command:

```
$ ods-enforcer zone add -z example.com
```

This adds the zone **example.com** to OpenDNSSEC with the default KASP. Also by default, the signing is file based. Note that the enforcer doesn't read this file without being told explicitly to do so. Also, the file will not be written when adding new zones via **commandline**.

The signer expects the unsigned file to be at `/var/opendnssec/unsigned/example.com` and puts the signed file at `/var/opendnssec/signed/example.com`. Different paths can be used with **-i** (input) and **-o** (output). You can use a different policy with **-p** (policy).

If a user or administrator wants to use DNS zone transfers for input and output, the type of adapter can be set to DNS, **-j** for input and **-q** for output. It is necessary to set the input and output files to the zone transfer configuration file addns.xml, like this:

```
$ ods-ksmutil zone add -z example.com -j DNS -q DNS \
    -i /etc/opendnssec/addns.xml -o /etc/opendnssec/addns.xml
```

Instructions on how to edit **addns.xml** for zone transfers is described in section 2.5.5.1 below.

The signed zone is then written in the `/var/opendnssec/signed/` directory. It is necessary to notify your name server of the new **zonefile** in order for the zone to also become visible in the DNS. It is possible to configure a **notify** command in **conf.xml** to automatically notify the name server of new zones. For example:

```
<Configuration>
    ...
    <Signer>
    ...
<NotifyCommand>nameserver_control_program reload
      %zone</NotifyCommand>
    </Signer>
</Configuration>
```

Here, **%zone** will be replaced with the name of the zone that has been updated, and **%zonefile** (not used in example) will be replaced with the name of the signed zonefile.

2.5.5.1 OpenDNSSEC as a Bump-in-the-Wire

If a zone has been added with DNS adapters rather than working on files, instead of pointing the input and output to the filenames of the unsigned and signed zones, it is necessary to put in the zone transfer configuration file **addns.xml**. Here, primary name server addresses, ports and TSIG keys (Inbound), and ports and TSIG keys for the secondary name servers (Outbound) are set up. Replace the example values in **addns.xml.sample** installed in `/etc/opendnssec/` with the desired servers and keys and rename it to addns.xml. Also conf.xml needs a socket that listens to DNS traffic:

```
<Configuration>
    ...
```

```
        <Signer>
        ...
    <Listener>
        <Interface><Address>127.0.0.1</Address><Port>53</Port></Interface>
        <Interface><Address>::1</Address><Port>53</Port></Interface>
    <Listener>
        </Signer>
    </Configuration>
```

The above values are also the defaults. OpenDNSSEC can now sign incoming zone transfers (full and incremental) and also reply to SOA, AXFR and IXFR requests.

2.5.5.2 Activating Key Signing Keys (KSK)

At this stage, an attempt to list OpenDNSSEC keys will reveal that the key signing key (KSK) is not yet active:

```
$ ods-enforcer key list -a
Zone: Keytype: State: Date of next transition:
example.com. KSK publish 2016-09-01 00:00:01 example.com. ZSK active
2016-08-31 10:00:01
```

This is because the DS must still be submitted to the parent. The DS is a record that is derived from the KSK and is published in the parent zone. This is used to build a secure chain of trust from the root zone to the users zone. In the example above, OpenDNSSEC expects this to happen at one second past midnight on the first of September 2016. This is 14 hours after initial signing. This is because the default policy has a very conservative propagation delay for the name servers: 12 hours. In this example, it takes an additional hour for the **TTL** and one more for the publish safety parameter - totaling 14 hours Enduring the long propagation delay is necessary because, in order to make sure a zone remains valid, it is necessary to respect a publish safety duration and the **TTL** (in this case derived from the **SOA MINIMUM**). If OpenDNSSEC is ready, the date of next transition be displayed as **waiting for ds-seen**. The DS can then be submitted to the parent. How that is accomplished depends on your organization's registrar. Usually this can be done via e-mail or through a web interface. Retrieve the DNSKEY or DS with:

```
$ ods-enforcer key export
;ready KSK DNSKEY record: example.com. 3600 IN DNSKEY 257 3 8 Aw...
$ ods-enforcer key export -d
;ready KSK DS record (SHA1): example.com.. 3600 IN DS 42112 8 1 8aea...
;ready KSK DS record (SHA256): example.com. 3600 IN DS 42112 8 2
a674...
```

If the DS shows up in the parent zone at all parent name servers, it is safe to run the **`key ds-seen`** command. This command requires the keytag of the key in question. You can see from the DNSKEY and DS records this is 42112 in this example:

```
$ ods-enforcer key ds-seen -z example.com -x 42112
```

The KSK is now also active, and the chain-of-trust is set up.

2.6 Unbound

The log file for an actual NCCoE installation and configuration of Unbound with NSD4 and OpenDNSSEC for the DNS-Based Email Security project is provided as Appendix F. The latest version of unbound (currently 1.5.10) can always be downloaded from http://www.unbound.net/downloads/unbound-latest.tar.gz.[1] Unbound documentation can be found at https://unbound.net/documentation/index.html. Some general installation and configuration information for Unbound is provided in the following subsections. Please note that IP addresses, domain names, and mail addresses are, in many cases, specific to the NCCoE laboratory configuration and must not be used in actual implementations.

2.6.1 Unbound Installation Basics and System Requirements

If your distribution package manager includes a package for Unbound install the package with the package manager. If not, in order to compile the software it is necessary to have **openssl**, and its include files (from a package often called **openssl-devel**). In openssl, run `./configure [options]; make;` and `make install`. For cases in which the **libldns** library is not installed, a version is included with the Unbound source **tarball** and is automatically used. Unbound always uses **sldns** (the included **ldns**). With respect to options for **configure**, the default **config** locations for various files and directories can be customized, as well as the install location for the program with **--prefix=/usr/local**. You can specify `--with-libevent=dir` or `--with-ssl=dir` to link with the library at that location. In general, no options are needed for `./configure`.

On some BSD systems it is necessary to use `gmake` instead of `make`.

It is possible to install with `make install` and to uninstall with `make uninstall`. The uninstall does not remove the **config** file. In the **contrib directory** in the unbound source are sample **rc.d** scripts for unbound (for BSD and Linux type systems).

2.6.2 Unbound Setup and Installation

The **config** file is copied into `/usr/local/etc/unbound/unbound.conf` but some distributions may put it in `/etc/unbound/unbound.conf` or `/etc/unbound.conf`. The **config** file is fully annotated, you can go through it and select the options you like. Or you can use the below, a quick set of common options to serve the local subnet. A common setup for DNS service for an IPv4 subnet and IPv6 *localhost* is below. You can change the IPv4 subnet to match the subnet that you use, and add your IPv6 subnet if you have one.

```
# unbound.conf for a local subnet.
server:
interface: 0.0.0.0
interface: ::0
```

1.Source: unbound-1.5.9.tar.gz; SHA1 checksum: 4882c52aac0ab-cd72a86ac5d06e9cd39576620ce; SHA256 checksum: 01328cfac99ab5b8c47115151896a244979e442e284eb962c0ea84b7782b6990; PGP signature: unbound-1.5.9.tar.gz.asc; License: BSD; Doc: man-page.

```
access-control: 192.168.0.0/16 allow
access-control: ::1 allow
verbosity: 1
```

By default the software comes with **chroot** enabled. This provides an extra layer of defense against remote exploits. Enter file paths as full pathnames starting at the root of the filesystem ('/'). If **chroot** gives you trouble, you can disable it with **chroot: ""** in the **config**. Also the server assumes the username **unbound** to drop privileges. You can add this user with your favorite account management tool (*useradd(8)*), or disable the feature[1] with **username: ""** in the **config**.

Start the server using the script (if you or the package manager installed one) as **/etc/rc.d/init.d/unbound start.** or **unbound -c <config>** as root.

It is possible to setup remote control using **unbound-control**. First run **unbound-control-setup** to generate the necessary TLS key files (they are put in the default install directory). If you use a username of **unbound** to run the daemon from **use sudo -u unbound unbound-control-setup** to generate the keys, so that the server is allowed to read the keys. Then add the following at the end of the config file:

```
# enable remote-control
remote-control:
control-enable: yes
```

You can now use **unbound-control** to send commands to the daemon. It needs to read the key files, so you may need to **sudo unbound-control**. Only connections from *localhost* are allowed by default

2.6.3 Unbound Configuration for DNSSEC

DNSSEC is a mechanism to protect DNS data. It uses digital signatures. To use DNSSEC with Unbound, the public keys for digital signature must be configured. Note that specific distributions, operating systems, or device vendors may have already provided the anchor, securing it with its own vendor-specific update mechanism. In that case, the mechanisms provided from those sources should be used.

2.6.3.1 Trust Anchor

The first step in configuring Unbound for DNSSEC is to obtain an initial trust anchor.[2] The **unbound-anchor** tool provides an initial anchor from built-in values, but for real trust this should be checked thoroughly. The root key is stored in a file, /usr/local/etc/unbound/root.key. Unbound must be able to read and write it, to keep it up to date with the latest key(s). It must therefore reside within the **chroot** of Unbound (if that is used). Access rights are world-readable, user Unbound write only. Use **sudo -u unbound** to start **unbound-anchor** so that the file owner is set to the unbound user (same username as daemon uses). It can optionally be put somewhere else, accessible to the unbound daemon, such as /var/unbound or /etc. You need to pass this value to unbound-anchor (option -a

1. Do not run as **root**.
2. Unbound: How to enable DNSSEC, W.C.A. Wijngaards, NLnet Labs, April 2011.

`file`) and to unbound (**auto-trust-anchor-file**: “file” in **unbound.conf**). The **unbound-anchor** tool creates this file for the administrator if it does not exist. But the administrator must check this file so that it can be trusted. The **unbound-anchor** tool also has a built-in certificate (from the ICANN Certificate Authority) that it will use to update the root key if it becomes out of date, this should be checked too (`–l` option to show it), or provide some other certificate that **unbound-anchor** is to use.

There are trusted community representatives that have sworn and signed attestations, and there may be publications (i.e. in printed form). Please notice that NLnet Labs' **unbound-anchor** tool provides an initial value for convenience, systems administrators must perform the specified checks to obtain trust. The trust anchor can be downloaded via https from IANA: root-anchors.xml (click link and then check the lock icon and the *urlbar* and the hash displayed against the hash you can put as initial value into the **root.key** file, see below for an example of the syntax of how to input the initial value).

Here is the 2010-2011 trust anchor for the root zone. This is the syntax that you can use to provide an initial value for the **root.key** file:

```
. IN DS 19036 8 2
49AAC11D7B6F6446702E54A1607371607A1A41855200FD2CE1CDDE32F24E8FB5
```

2.6.3.2 Update Mechanism Setup

Set the **unbound-anchor** tool to run at system startup, it is part of the Unbound package. A good way is to run it from the **init** scripts, with **`sudo -u unbound`** so that the file permissions work out.

Before **unbound-anchor** is run inside the **init** scripts, you must run **NTP** (in secure mode), so that the time and date have been set properly. Unbound uses RFC5011 updates to keep the anchor updated if it is changed while the computer is in operation, but the unbound-anchor tool is used if it is changed while the computer is not in operation.

In the **unbound.conf** config file, include the root anchor file with the automatic updated anchor statement, like this:

```
server:
    # ... other stuff
    # root key file, automatically updated
        auto-trust-anchor-file: "/usr/local/etc/unbound/root.key"
```

After you change the config, restart unbound. Unbound will then overwrite the key file with status information (such as the last time the key was seen).

2.6.3.3 Testing Unbound Configurations for DNSSEC

Entering **`dig com. SOA +dnssec`** should result in display of the AD flag there. If this is unsuccessful, the Unbound **`option val-log-level: 2`** should log explanations regarding why the DNSSEC validation fails (one line per failed query). Also, http://test.dnssec-or-not.org/ (fun test) or https://internet.nl/ (sober test) and http://www.kaminskybug.se/ (look for a happy bug icon) are useful test tools.

2.6.4 Unbound Support

Although it is open source software, support for Unbound is available from a number of sources, including NLnet Labs.

2.7 How to Install and Configure a DNS Signer Platform

DNS Signer is a commercial product, the installation and configuration instructions can be obtained from the company website, http://www.secure64.com/.

2.7.1 DNS Signer Installation Basics and System Requirements

Secure64 DNS Signer runs on HP Integrity servers with the following minimum configuration:

- 1 dual core Itanium microprocessor
- 4 GB RAM
- 36 GB disk drive
- DVD ROM drive

DNS Signer is a commercial product. Information regarding obtaining the product can be found at http://www.secure64.com/contact.

2.7.2 DNS Signer Installation and Configuration

DNS Signer can be configured to work with an authoritative DNS resolver, (e.g., DNS Authority) or a caching/recursive resolver (e.g., DNS Cache). The process followed for installation of DNS Signer at the NCCoE is included in Appendix H.

2.8 How to Install and Configure a DNS Authority Platform

DNS Authority is a commercial product, the installation and configuration instructions can be obtained from the company website, http://www.secure64.com/. Information regarding obtaining the product can be found at http://www.secure64.com/contact. DNS Authority can be configured to work with a caching/recursive resolver (e.g., DNS Cache) and a DNS Signer. The process followed for installation of DNS Authority at the NCCoE is included in Appendix H.

2.9 How to Install and Configure DNS Cache

DNS Cache is a commercial product, installation and configuration instructions can be obtained from the company website, http://www.secure64.com/. Information regarding obtaining the product can be found at http://www.secure64.com/contact.

2.10 How to Install and Configure a Dovecot/Postfix Mail Transfer Agent

2.10.1 Dovecot Installation Basics and System Requirements

Dovecot can be downloaded from sources identified at the Dovecot Secure IMAP Server site (http://www.dovecot.org/download.html).

2.10.1.1 Compiling Dovecot from Source Code

To compile Dovecot from source code provide the following commands:

```
./configure
make
sudo make install
```

That installs Dovecot under the `/usr/local` directory. The configuration file is in `/usr/local/etc/dovecot.conf`. Logging goes to syslog's mail facility by default, which typically goes to /var/log/mail.log or something similar. If you are in a hurry, you can then jump to QuickConfiguration. If you have installed some libraries into locations which require special include or library paths, you can pass them in the **CPPFLAGS** and **LDFLAGS** environment variables. For example:

```
CPPFLAGS="-I/opt/openssl/include" LDFLAGS="-L/opt/openssl/lib"
./configure
```

It is necessary to create two users for Dovecot's internal use:

- **dovenull**: Used by untrusted imap-login and pop3-login processes (default_login_user setting).
- **dovecot**: Used by slightly more trusted Dovecot processes (default_internal_user setting).

Each of them should also have its own **dovenull** and **dovecot** groups. See http://wiki2.dovecot.org/UserIds for more information.

2.10.1.2 Compiling Dovecot from Git

Dovecot is available from Git, for example with:

```
git clone https://github.com/dovecot/core.git dovecot
```

To compile Dovecot from Git, it is first necessary to run **`./autogen.sh`** to generate the configure script and some other files. This requires that the following software/packages be installed:

- autoconf
- automake
- libtool
- pkg-config
- gettext

- GNU make

It is advisable to add **`--enable-maintainer-mode`** to the configure script:

```
./autogen.sh
./configure --enable-maintainer-mode
make
sudo make install
```

For later updates, the commands are:

```
git pull
make
sudo make install
```

2.10.1.3 Compiling Dovecot with rpmbuild (Mandriva, RedHat, etc.)

Fetch the source rpm from ftp://ftp.surfnet.nl/ or any other mirror. Currently, **dovecot-10.rc26.src.rpm** can be found in the **cooker** subtree. If the current release is newer, unpack the source rpm with **`rpm -ivh dovecot-10.rc26.src.rpm`** to a build environment (`/usr/src/rpm...`) Copy the newer **tarball** from the dovecot site to the **SOURCES** directory of the build environment. Change the **dovecot.spec** file in the **SPECS** directory to reflect the new release and the new name of the **tarball**. The maintainer works with a **bz2 tarball**; a **tar.gz tarball** makes no difference. Issue a **`rpmbuild -ba dovecot.spec`**. The resulting rpm will be placed in `RPMS/i586.` Install with **rpm** or **urpmi**:

```
rpm -ivh dovecot-1.0.rc26.src.rpm
cd /usr/src/rpm
mv ~/downloads/dovecot-1.0.rc28.tar.gz ./SOURCES
cd SPECS
vi dovecot.spec
...edit release and tarball name. Change default options if needed...
rpmbuild -ba dovecot.spec
cd ../RPMS/i586
urpmi ./dovecot-1.0.rc28-1mdv2007.0.i586.rpm
```

During this process missing prerequisites may be detected. Install them and rerun the build process. The spec file also need updating for the new add-ons (**idxview** and **logview**).

2.10.1.4 SSL/TLS Support

Dovecot was initially built to support both OpenSSL and GNUTLS, but OpenSSL is currently used by default, and it should be automatically detected. If it is not, some header files or libraries are missing, or they are in a non-standard path. The **openssl-dev** or a similar package needs to be installed, and if it is not in the standard location, set **CPPFLAGS** and **LDFLAGS** as shown above. By default the SSL certificate is read from `/etc/ssl/certs/dovecot.pem`, and the private key from `/etc/ssl/private/dovecot.pem`. The `/etc/ssl` directory can be changed using the **`--with-ssldir=DIR`** configure option. Both can of course be overridden from the configuration file.

For Linux installations, note that current **inotify** is in the Linux kernel since version 2.6.13 and it is preferred over **dnotify**. If your distribution does not have the required **inotify** header file, it can be obtained from the **inotify maintainer** (the following example requires cURL):

```
mkdir -p /usr/local/include/sys
cd /usr/local/include/sys
curl
ftp://ftp.kernel.org/pub/linux/kernel/people/rml/inotify/headers/inoti
fy.h -O
curl
ftp://ftp.kernel.org/pub/linux/kernel/people/rml/inotify/headers/inoti
fy-syscalls.h >> inotify.h
```

`/usr/local/include` isn't in standard include lookup path, so that needs to be specified to configure:

```
CPPFLAGS=-I/usr/local/include ./configure --with-notify=inotify
```

2.10.1.5 Dovecot Configuration Options

- **`--help`**

  gives a full list of available options

- **`--help=short`**

  just lists the options added by the particular package (= Dovecot)

Options are usually listed as **`--with-something`** or **`--enable-something`**. If you want to disable them, do it as **`--without-something`** or **`--disable-something`**. There are many default options that come from autoconf, automake or libtool. The list of options that Dovecot adds follows:

- **`--enable-devel-checks`**

  Enables some extra sanity checks. This is mainly useful for developers. It does quite a lot of unnecessary work but should catch some programming mistakes more quickly.

- **`--enable-asserts`**

  Enable assertion checks, enabled by default. Disabling them may slightly save some CPU, but if there are bugs they can cause more problems since they are not detected as early.

- **`--without-shared-libs`**

  Link Dovecot binaries with static libraries instead of dynamic libraries.

- **`--disable-largefile`**

  Specifies if we use 32bit or 64bit file offsets in 32bit CPUs. 64bit is the default if the system supports it (Linux and Solaris do). Dropping this to 32bit may save some memory, but it prevents accessing any file larger than 2 GB.

- **`--with-mem-align=BYTES`**

  Specifies memory alignment used for memory allocations. It is needed with many non-x86 systems and it should speed up x86 systems too. Default is 8, to make sure 64bit memory accessing works.

- **`--with-ioloop=IOLOOP`**

Specifies what I/O loop method to use. Possibilities are select, poll, epoll and kqueue. The default is to use the best method available on your system.

- `--with-notify=NOTIFY`

  Specifies what file system notification method to use. Possibilities are dnotify, inotify (both on Linux), kqueue (FreeBSD) and none. The default is to use the best method available on your system. See Notify method above for more information.

- `--with-storages=FORMATS`

  Specifies what mailbox formats to support. Note: Independent of this option, the formats raw and shared will be always built.

- `--with-solr`

  Build with Solr full text search support

- `--with-zlib`

  Build with zlib compression support (default if detected)

- `--with-bzlib`

  Build with bzip2 compression support (default if detected)

SQL Driver Options

SQL drivers are typically used only for authentication, but they may be used as a lib-dict backend too, which can be used by plugins for different purposes.

- `--with-sql-drivers`

  Build with specified SQL drivers. Defaults to all that were found with autodetection.

- `--with-pgsql`

  Build with PostgreSQL support (requires pgsql-devel, libpq-dev or similar package)

- `--with-mysql`

  Build with MySQL support (requires mysql-devel, libmysqlclient15-dev or similar package)

- `--with-sqlite`

  Build with SQLite3 driver support (requires sqlite-devel, libsqlite3-dev or similar package)

Authentication Backend Options

The basic backends are built if the system is detected to support them:

- `--with-shadow`

  Build with shadow password support

- `--with-pam`

  Build with PAM support

- `--with-nss`

  Build with NSS support

- `--with-sia`

  Build with Tru64 SIA support

- `--with-bsdauth`

  Build with BSD authentication support (if supported by your OS)

Some backends require extra libraries and are not necessarily wanted, so they are built only if specifically enabled:

- **`--with-sql`**
  Build with generic SQL support (drivers are enabled separately)
- **`--with-ldap`**
  Build with LDAP support (requires openldap-devel, libldap2-dev or similar package)
- **`--with-gssapi`**
  Build with GSSAPI authentication support (requires krb5-devel, libkrb5-dev or similar package)
- **`--with-vpopmail`**
  Build with vpopmail support (requires vpopmail sources or a development package)

It's also possible to build these as plugins by giving e.g. **`--with-sql=plugin`**.

2.10.1.6 Dovecot Support

Although Dovecot is open source software, support is available from dovecot.org and commercial sources. See http://www.dovecot.org/support.html.

2.10.2 Postfix Installation and Configuration

Postfix was released under the IBM Public License, and source code can be downloaded from http://cdn.postfix.johnriley.me/mirrors/postfix-release/index.html. All Postfix source code is signed with Wietse's PGP key.[1] Instructions for installing Postfix from source code can be found at http://www.postfix.org/INSTALL.html. Postfix manual pages can be found at http://www.postfix.org/postfix-manuals.html.

2.10.2.1 Installation and System Requirements

If you are using a pre-compiled version of Postfix, you should start with BASIC_CONFIGURATION_README and the general documentation referenced by it. INSTALL is only a bootstrap document to get Postfix up and running from scratch with the minimal number of steps; it is not considered part of the general documentation. The INSTALL document describes how to build, install and configure a Postfix system so that it can do one of the following:

- Send mail only, without changing an existing Sendmail installation.
- Send and receive mail via a virtual host interface, still without any change to an existing Sendmail installation.
- Run Postfix instead of Sendmail.

1. See ftp://ftp.porcupine.org/mirrors/project-history/postfix/ for a more extensive archive of tarballs.

According to INSTALL, Postfix development is conducted on FreeBSD and MacOS X, with regular tests on Linux (Fedora, Ubuntu) and Solaris. Support for other systems relies on feedback from their users, and may not always be up-to-date. OpenBSD is partially supported. The libc resolver does not implement the documented "internal resolver options which are [...] set by changing fields in the **_res structure**" (documented in the OpenBSD 5.6 resolver(3) manpage). This results in too many DNS queries, and false positives for queries that should fail.

2.10.2.2 Compiler Specifics

If you need to build Postfix for multiple architectures from a single source-code tree, use the **`lndir`** command to build a shadow tree with symbolic links to the source files. If at any time in the build process you get messages like: `make: don't know how to ...` you should be able to recover by running the following command from the Postfix top-level directory:

```
$ make -f Makefile.init makefiles
```

If you copied the Postfix source code after building it on another machine, it is a good idea to cd into the top-level directory and first do this:

```
$ make tidy
```

This will get rid of any system dependencies left over from compiling the software elsewhere.

To build with GCC, or with the native compiler if people told me that is better for your system, just cd into the top-level Postfix directory of the source tree and type:

```
$ make
```

To build with a non-default compiler, you need to specify the name of the compiler, for example:

```
$ make makefiles CC=/opt/SUNWspro/bin/cc (Solaris)
$ make
$ make makefiles CC="/opt/ansic/bin/cc -Ae (HP-UX)
$ make
$ make makefiles CC="purify cc"
$ make
```

In some cases, optimization will be turned off automatically.

2.10.2.3 Building with Position-Independent Executables

On some systems Postfix can be built with Position-Independent Executables. PIE is used by the ASLR exploit mitigation technique (ASLR = Address-Space Layout Randomization).

```
$ make makefiles pie=yes ...other arguments...
```

(Specify **`make makefiles pie=no`** to explicitly disable Postfix position-independent executable support). Postfix PIE support appears to work on Fedora Core 20, Ubuntu 14.04, FreeBSD 9 and 10, and NetBSD 6 (all with the default system compilers). Whether the `pie=yes` above has any effect depends on the compiler. Some compilers always produce PIE executables, and some may even complain that the Postfix build option is redundant.

2.10.2.4 Dynamically Linked Libraries

Postfix dynamically-linked library and database plugin support exists for recent versions of Linux, FreeBSD and MacOS X. Note that dynamically-linked library builds may become the default at some point in the future.

2.10.2.5 Default Settings and Optional Features

By default, Postfix builds as a mail system with relatively few bells and whistles. Support for third-party databases etc. must be configured when Postfix is compiled. The following documents describe how to build Postfix with support for optional features:

Table 2.5 Postfix Default Settings and Optional Features

Optional Feature	Document	Availability
Berkeley DB database	DB_README	Postfix 1.0
LMDB database	LMDB_README	Postfix 2.11
LDAP database	LDAP_README	Postfix 1.0
MySQL database	MYSQL_README	Postfix 1.0
Perl compatible regular expression	PCRE_README	Postfix 1.0
PostgreSQL database	PGSQL_README	Postfix 2.0
SASL authentication	SASL_README	Postfix 1.0
SQLite database	SQLITE_README	Postfix 2.8
STARTTLS session encryption	TLS_README	Postfix 2.2

Note: *IP version 6 support is compiled into Postfix on operating systems that have IPv6 support. See the* IPV6_README *file for details.*

2.10.2.6 Installing After Compiling

1. Save existing Sendmail binaries

   Some systems implement a mail switch mechanism where different MTAs (Postfix, Sendmail, etc.) can be installed at the same time, while only one of them is actually being used. Examples of such switching mechanisms are the FreeBSD mailwrapper(8) or the Linux mail switch. In this case you should try to “flip” the switch to “Postfix” before installing Postfix. If your system has no mail switch mechanism, execute the following commands (your sendmail, newaliases and mailq programs may be in a different place):

   ```
   ?# mv /usr/sbin/sendmail /usr/sbin/sendmail.OFF
   # mv /usr/bin/newaliases /usr/bin/newaliases.OFF
   # mv /usr/bin/mailq /usr/bin/mailq.OFF
   # chmod 755 /usr/sbin/sendmail.OFF/usr/bin/newaliases.OFF\
   /usr/bin/mailq.OFF
   ```

2. Create account and groups

Before you install Postfix for the first time you need to create an account and a group:

a. Create a user account **postfix** with a user id and group id that are not used by any other user account. Preferably, this is an account that no-one can log into. The account does not need an executable login shell, and needs no existing home directory. Sample password and group file entries follow:

```
/etc/passwd:
postfix:*:12345:12345:postfix:/no/where:/no/shell
/etc/group:
postfix:*:12345:
```

Note: there should be no whitespace before **postfix:**.

b. Create a group **postdrop** with a group id that is not used by any other user account. Not even by the postfix user account. An example of a group file entry follows:

```
/etc/group:
postdrop:*:54321:
```

Note: there should be no whitespace before **postdrop**:.

3. Install Postfix

To install or upgrade Postfix from compiled source code, run one of the following commands as the super-user:

```
# make install (interactive version, first time install)
# make upgrade (non-interactive version, for upgrades)
```

a. The interactive version (**`make install`**) asks for pathnames for Postfix data and program files, and stores your preferences in the main.cf file. If you don't want Postfix to overwrite non-Postfix **sendmail**, **mailq** and **newaliases** files, specify pathnames that end in **.postfix**.

b. The non-interactive version (**`make upgrade`**) needs the `/etc/postfix/main.cf` file from a previous installation. If the file does not exist, use interactive installation (**`make install`**) instead.

If you specify **name=value** arguments on the **`make install`** or **`make upgrade`** command line, then these will take precedence over compiled-in default settings or main.cf settings. The command **`make install/upgrade name=value ...`** will replace the string `MAIL_VERSION` at the end of a configuration parameter value with the Postfix release version. Do not try to specify something like `$mail_version` on this command line. This produces inconsistent results with different versions of the make(1) command.

2.10.2.7 Configure Postfix

See http://www.postfix.org/postconf.5.html for Postfix configuration parameters.

Note: *The material covered in this section from INSTALL Section 10 is covered in more detail in the BASIC_CONFIGURATION_README document. The information presented below is targeted at experienced system administrators.*

1. Postfix configuration files

   By default, Postfix configuration files are in `/etc/postfix`. The two most important files are **main.cf** and **master.cf**; these files must be owned by root. Giving someone else write permission to **main.cf** or **master.cf** (or to their parent directories) means giving root privileges to that person. In `/etc/postfix/main.cf`, you will have to set up a minimal number of configuration parameters. Postfix configuration parameters resemble shell variables, with two important differences: the first one is that Postfix does not know about quotes like the UNIX shell does. You specify a configuration parameter as:

   ```
   /etc/postfix/main.cf:
   parameter = value
   ```

   and you use it by putting a "$" character in front of its name:

   ```
   /etc/postfix/main.cf:
   ```

   other_parameter = $parameter

   You can use **$parameter** before it is given a value (that is the second main difference with UNIX shell variables). The Postfix configuration language uses lazy evaluation, and does not look at a parameter value until it is needed at runtime. Whenever you make a change to the **main.cf** or **master.cf** file, execute the following command in order to refresh a running mail system:

   ```
   # postfix reload
   ```

2. Default domain for unqualified addresses

   First of all, you must specify what domain will be appended to an unqualified address (i.e. an address without **@domain.tld**). The **myorigin** parameter defaults to the local hostname, but that is intended only for very small sites.

   Some examples (use only one):

   `/etc/postfix/main.cf:`

   `myorigin = $myhostname` (send mail as "`user@$myhostname`")

   `myorigin = $mydomain` (send mail as "`user@$mydomain`")

3. Specification of what domains to receive locally

   Next you need to specify what mail addresses Postfix should deliver locally.

   Some examples (use only one):

   ```
   /etc/postfix/main.cf:
   mydestination = $myhostname, localhost.$mydomain, localhost
   mydestination = $myhostname, localhost.$mydomain,
   localhost,$mydomain
   mydestination = $myhostname
   ```

   The first example is appropriate for a workstation, the second is appropriate for the mail server for an entire domain. The third example should be used when running on a virtual host interface.

4. Proxy/NAT interface addresses

The **proxy_interfaces** parameter specifies all network addresses that Postfix receives mail on by way of a proxy or network address translation unit. You may specify symbolic hostnames instead of network addresses.

IMPORTANT: You must specify your proxy/NAT external addresses when your system is a backup MX host for other domains, otherwise mail delivery loops will happen when the primary MX host is down.

Example: host behind NAT box running a backup MX host.

`/etc/postfix/main.cf:`

`proxy_interfaces = 1.2.3.4` (the proxy/NAT external network address)

5. Specification of What local clients to relay mail from

   If your machine is on an open network then you must specify what client IP addresses are authorized to relay their mail through your machine into the Internet. The default setting includes all subnetworks that the machine is attached to. This may give relay permission to too many clients. For example:

   `/etc/postfix/main.cf:`

   `mynetworks = 168.100.189.0/28, 127.0.0.0/8`

6. Specification of what relay destinations to accept from strangers

   If your machine is on an open network then you must also specify whether Postfix will forward mail from strangers. The default setting will forward mail to all domains (and subdomains of) what is listed in **$mydestination**. This may give relay permission for too many destinations. Recommended settings (use only one):

   `/etc/postfix/main.cf:`

   `relay_domains =` (do not forward mail from strangers)

   `relay_domains = $mydomain` (my domain and subdomains)

   `relay_domains = $mydomain, other.domain.tld, ...`

7. Optional: configure a smart host for remote delivery

   If you're behind a firewall, you should set up a **relayhost**. If you can, specify the organizational domain name so that Postfix can use DNS lookups, and so that it can fall back to a secondary MX host when the primary MX host is down. Otherwise just specify a hard-coded hostname. Some examples follow (use only one):

   ```
   /etc/postfix/main.cf:
   relayhost = $mydomain
   relayhost = [mail.$mydomain]
   ```

   The form enclosed with [] eliminates DNS MX lookups. By default, the SMTP client will do DNS lookups even when you specify a relay host. If your machine has no access to a DNS server, turn off SMTP client DNS lookups like this:

   ```
   /etc/postfix/main.cf:
   disable_dns_lookups = yes
   ```

   The STANDARD_CONFIGURATION_README file has more hints and tips for firewalled and/or dial-up networks.

8. Create the aliases database

   Postfix uses a Sendmail-compatible aliases(5) table to redirect mail for local(8) recipients. Typically, this information is kept in two files: in a text file /etc/aliases and in an indexed file `/etc/aliases.db`. The command **`postconf alias_maps`** will tell you the exact location of the text file. First, be sure to update the text file with aliases for root, postmaster and postfix that forward mail to a real person. Postfix has a sample aliases file `/etc/postfix/aliases` that you can adapt to local conditions.

   ```
   /etc/aliases:
   root: you
   postmaster: root
   postfix: root
   bin: root
   etcetera...
   ```

   Note: there should be no whitespace before the ":". Finally, build the indexed aliases file with one of the following commands:

   ```
   # newaliases
   # sendmail -bi
   ```

9. Setting up chroot

   Postfix daemon processes can be configured (via **master.cf**) to run in a chroot jail. The processes run at a fixed low privilege and with access only to the Postfix queue directories (`/var/spool/postfix`). This provides a significant barrier against intrusion. Note that this barrier is not impenetrable, but every little bit helps. With the exception of Postfix daemons that deliver mail locally and/or that execute non-Postfix commands, every Postfix daemon can run chrooted.

   Sites with high security requirements should consider to chroot all daemons that talk to the network: the smtp(8) and smtpd(8) processes, and perhaps also the lmtp(8) client. The default `/etc/postfix/master.cf` file specifies that no Postfix daemon runs chrooted. In order to enable chroot operation, edit the file `/etc/postfix/master.cf`. Instructions are in the file.

   Note also that a chrooted daemon resolves all filenames relative to the Postfix queue directory (`/var/spool/postfix`). For successful use of a chroot jail, most UNIX systems require you to bring in some files or device nodes. The examples/chroot-setup directory in the source code distribution has a collection of scripts that help you set up Postfix chroot environments on different operating systems.

   Additionally, you need to configure syslogd so that it listens on a socket inside the Postfix queue directory. Examples for specific systems:

   FreeBSD:

   ```
   # mkdir -p /var/spool/postfix/var/run
   # syslogd -l /var/spool/postfix/var/run/log
   ```

   Linux, OpenBSD:

```
# mkdir -p /var/spool/postfix/dev
# syslogd -a /var/spool/postfix/dev/log
```

2.10.3 Postfix Installation and Configuration for use with Dovecot

The following elements are necessary for setting up Postfix for Dovecot[1]:

- A domain such as **mydomain.com**
- A hostname for your mail server such as **mail.mydomain.com**
- An SSL certificate that is valid for **mail.mydomain.com**

2.10.3.1 Setting up SSL Certificate

For SSL, you need a certificate and a private key saved in a location such as `/etc/ssl/certs/mailcert.pem` and the key is saved (e.g., in `/etc/ssl/private/mail.key`). Make sure the key is only readable by the root user. How to set up SSL certificates for your website and e-mail depends on your website structure and the CA you use (self-signed, organizational (sub)-ca, or commercial ca for example). Creating a self-signed test certificate is as easy as executing

```
sudo openssl req -x509 -nodes -days 365 -newkey rsa:2048 -keyout
/etc/ssl/private/mail.key -out /etc/ssl/certs/mailcert.pem
```
[2]

and leaving the default values in by just hitting enter on all questions asked.

Most CAs will require you to submit a certificate signing request. (CSR) You can generate one like this:

```
sudo openssl req -nodes -days 365 -newkey rsa:2048 -keyout
/etc/ssl/private/mail.key -out mailcert.csr
```

Fill in the information queried properly, like in this transcript: (Check with the CA you intend to use on what information needs to be in the CSR)

Specific instructions for acquisition of certificates from CAs can be obtained from the CA. An example is provided at: https://www.digitalocean.com/community/tutorials/how-to-set-up-a-postfix-e-mail-server-with-dovecot.

2.10.3.2 Setting up DNS

You still have to set up the DNS with an a record that points to your mail server IP and an MX record that points to the mail servers hostname. Instructions for the standard configuration for Postfix can be found at http://www.postfix.org/STANDARD_CONFIGURATION_README.html.

1. See How To Set Up a Postfix E-Mail Server with Dovecot, DigitalOcean, November 14, 2013. https://www.digitalocean.com/community/tutorials/how-to-set-up-a-postfix-e-mail-server-with-dovecot
2. Don't use this certificate in your system.

2.11 How to Install and Configure a Thunderbird Mail Client

The starting point for installing Thunderbird can be found at https://support.mozilla.org/en-US/kb/installing-thunderbird, and the initial step is to click on the icon designating the operating system on which Thunderbird is being installed (Windows, Mac, or Linux).

2.11.1 Thunderbird Installation Basics and System Requirements

System requirements for installing Thunderbird 45.2.0 on Windows, Mac, and Linux operating systems can be found at https://www.mozilla.org/en-US/thunderbird/45.2.0/system-requirements/.

2.11.2 Thunderbird Installation and Configuration on Windows

Instructions for installing Thunderbird in Windows environments can be found at https://support.mozilla.org/en-US/kb/installing-thunderbird-windows. Selecting **Download** will download Thunderbird on the disk image **Thunderbird 45.2.0.dmg**. After starting the process by clicking **Run**, the Mozilla Thunderbird Setup Wizard will be started. Closing all other applications before starting Setup will make it possible to update relevant system files without having to reboot the computer. After installation, double-clicking on the Thunderbird icon runs the program.

2.11.3 Thunderbird Installation and Configuration on Linux

Instructions for installing Thunderbird on Linux can be found at https://support.mozilla.org/en-US/kb/installing-thunderbird-linux. To install Thunderbird using the package manager, it is necessary to refer to the documentation of the Linux distribution you're using. Complete instructions for installing Thunderbird outside of package management may be available at a distribution support website (e.g., Installing Thunderbird on Ubuntu).

2.11.4 Thunderbird Installation and Configuration on Mac

Instructions for installing Thunderbird on Mac machines can be found at https://support.mozilla.org/en-US/kb/installing-thunderbird-on-mac. The Thunderbird download page automatically detects the platform and language on the computer accessing it. To download Thunderbird in a language other than the one suggested, click on **Other Systems & Languages** for the list of available editions. Click on the OS X installation of your choice to continue. Once the download is completed, the disk image may open by itself and mount a new volume which contains the Thunderbird application. If you do not see the new volume, double-click the Thunderbird **dmg** icon to open it. A Finder window appears, containing the Thunderbird application. Drag the Thunderbird icon to the Applications folder. At this point you can eject the disk image by selecting it in a Finder window and pressing the **command+E** keys or by using the Finder's File menu, and selecting Eject. Open the Applications folder and double-click on the Thunderbird icon to start it. You may get a security warning that

Thunderbird has been downloaded from the Internet. Because you downloaded Thunderbird from the official site, you can click **Open** to continue. The first time you start Thunderbird you will be alerted that it is not your default email application. (The default email application is the program that opens, for example, when you click a link on a web page to an email address.) If you want Thunderbird to be the default email application, click **Yes** to set it as your default mailer. If not (for example if you are just trying out Thunderbird) click **No**.

2.11.5 Thunderbird Configuration for use with Microsoft Exchange

Thunderbird can be used to access Microsoft Exchange servers that support IMAP or POP3. The normal way to use Thunderbird with a Microsoft Exchange Server requires the system administrator to enable the POP/IMAP/SMTP mail servers that are bundled with that server. Otherwise, since Exchange uses a proprietary MAPI protocol, accessing Exchange from Thunderbird can require a plugin or gateway[1] that provides standard, compliant protocols in front of proprietary Exchange (e.g., DavMail, ExQuilla).

In setting up Thunderbird:

1. Open Thunderbird and click the **Tools** menu option. Click **Account Settings**. Click **Account Settings** again to start the process for the Exchange connection.
2. Enter the full name at the first window. This name is what email recipients see in their inbox. In the following text box, enter your email address. Click the **Next** button.
3. Select **IMAP Mail Server** from the drop-down window. Enter the Exchange server name in the **IMAP Server Name** text box. In the **Outgoing Server** text box, enter the Exchange server name again. Click the **Next** button.
4. Check the box labeled **Username** and **password**. Enter your current username used to log into the machine. Remove the check mark in the box labeled Use secure connection. Click **Finish**. The Thunderbird application is ready to send and receive email from the Exchange server.

2.11.6 Thunderbird Configuration for use with Dovecot/Postfix

General step-by-step instructions for setting up Thunderbird can be found at https://products.secureserver.net/email/email_thunderbird.htm (*Setting Up Your POP or IMAP Email Address with Mozilla Thunderbird*).

Instructions for automatic account configuration can be found at https://support.mozilla.org/en-US/kb/automatic-account-configuration. Manual account configuration requires the following information:

- incoming mail server and port (for example, **pop.example.com** and port 110 or **imap.example.com** and port 143)
- outgoing mail server and port (for example, **smtp.example.com** and port 25)

1. Several links to free and commercial gateway and add-on products can be found by using a search engine with the argument "how to configure Microsoft Exchange server in Thunderbird."

- security setting for the connection with the server (for example, **STARTTLS** or **SSL/TLS** and whether or not to use secure authentication)

Instructions can be found at https://support.mozilla.org/en-US/kb/manual-account-configuration.

2.11.7 Thunderbird Support

Although it is open source software, Thunderbird support is available from Mozilla and other sources.

3 Device Configuration and Operating Recommendations

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This section provides additional information regarding for installing, configuring and operating Email and DNS security applications. Section 3.1 provides specific recommendations regarding certificate generation. Section 3.2 describes cryptographic operation and management by users on Outlook and Thunderbird. Section 3.3 describes setting up Exchange and Postfix MTAs to provide server-to-server encryption of email. Section 3.4 provides links to some tools and utilities that are useful in installing, configuring, provisioning, and maintaining DNS-based email security software.

It is recommended that the installation, configuration, and operation of DNS servers be conducted in conformance to NIST SP 800-81-2, the *Secure Domain Name System (DNS) Deployment Guide*. Appendix D provides a checklist for management of secure DNSs. Installation, configuration, and operation of email applications should follow the recommendations of SP 800-177, *Trustworthy Email*.

3.1 Using SSL for Cryptographic Certificate Generation

OpenSSL is a widely used open-source implementation of TLS/SSL and supporting cryptographic libraries for various version of Linux, but can also be used with Mac OS. OpenSSL also contains user utilities for generating cryptographic keys, certificate requests, and X.509 certificates. There is a FIPS-140 approved version of relevant OpenSSL cryptographic modules available for use by federal agencies.

3.1.1 OpenSSL Installation Basics and System Requirements

OpenSSL components and libraries are often standard components in base Linux installs, or can be installed using the built-in repository management system used with the version of Linux in use (e.g. apt-get, yum, rpm, etc.). Administrators may wish to install the developer repositories (*-devel or *-src) to make sure that all necessary header files are installed to support server implementations that rely on OpenSSL for cryptographic support. The latest version of OpenSSL, as well as FIPS approved versions may not be available in repositories and may need to be built from source from the OpensSSL project homepage[1].

In addition to having a base supported operating system, OpenSSL requires Perl 5 and a C compiler and development environment (with tools like **make**) to be successfully compiled and installed.

3.1.1.1 OpenSSL FIPS Approved Installation

Federal agencies or other organizations that are required to use FIPS-140 approved cryptographic modules can use OpenSSL FIPS approved version. These necessary modules are not always available via OS-specific repositories, but must be manually downloaded and compiled. The newly compiled libraries then replace any older, or pre-installed versions[2]. Server daemons (e.g. BIND named, postfix, etc.) that rely on OpenSSL for cryptographic support will then use the FIPS-140 approved version of the libraries.

1. https://openssl.org/
2. https://wiki.openssl.org/index.php/Compilation_and_Installation#FIPS_Capable_Library

3.1.1.2 OpenSSL Installation on Mac OS

Normally, there is no need to install a separate set of cryptographic libraries for Mac OS. OpenSSL is installed in the standard Mac OS distribution provides the same functionality However, if there is a desire to upgrade the standard installation an alternative repository tool (e.g. homebrew[1]) may be necessary or certain files need to be changed[2] in order to build OpenSSL on an Apple system.

3.1.2 OpenSSL Configuration

3.1.2.1 Configuration of OpenSSL to act as a Local Certificate Authority (CA)

OpenSSL can be used to generate certificates and act as a local enterprise Certificate Authority (CA). This is not always advisable as it is very bare-boned set of tools. Enterprises using OpenSSL as their CA must take great care to insure that the root certificate (i.e. the CA certificate that signs all the end-entity certificates) is adequately protected. Compromise of the root certificate private key would allow an attacker to generate arbitrary certificates for spoofed hosts and services. How this root certificate private key is protected is beyond the scope of this document but should include adequate physical, access, and logical controls.

OpenSSL can be used via the openssl command line tool to generate key pairs, and certificates for those key pairs. This certificate generation can be done by adding the certificate data on the command line, or using a configuration file for (organizational) default values. For example, if the organizational policy is for all certificates to have a lifetime of one year (365 days), that value can be set in a configuration file and does not need to be set using command line options unless there is a need to override the default for a specially generated certificate.

The general order in setting up OpenSSL to operate an enterprise local CA (or to generate self-signed certificates) is to: Generate and set up configuration files, generate the root certificate, and finally, generate and sign end entity certificates.

3.1.2.2 The OpenSSL CA Configuration File

Once OpenSSL is installed on the system, the CA admin needs to find and edit the **opnessl.cnf** configuration file. Where this file is located depends on how OpenSSL was installed on the system. Many repository installations will put the file at `/etc/ssl/openssl.cnf` but it may also be found at `/usr/ssl` or `/usr/openssl` or some other directory.

The configuration file is broken down into blocks around openssl commands. Most of these blocks can be left in their default values unless there is a specific policy reason for changing them. The two blocks that enterprise CA admins will likely need to change is [**CA_default**] and [**req**] which contain the default values for cryptographic and hash algorithms, default sizes and lifetimes, and Distinguished Name (country, organizational name, Common Name, etc.) respectively. An example snippet of the configuration file openssl.cnf is given in figure 3.1 below.

1. http://brew.sh/
2. https://wiki.openssl.org/index.php/Compilation_and_Installation#Mac

The values in the [**CA_defaults**] block deal with the components of the CA itself: the directories used, the serial number file, etc. These are used to manage the CA itself, not directly involved with the cryptographic operation of generating key pairs and certificates. CA administrators can set these values to the appropriate directories for their enterprise CA. OpenSSL does not generate some of the necessary directories and files (such as **serial**, which keeps track of the serial numbers of issues certificates). These will need to be created by the admin using a text editor or standard Linux commands.

The values in the [**req**] block deal with the identification data and characteristics of X.509 certificates generated by the CA. These values will most likely need to be edited by enterprise CA administrators. If the enterprise certificate policy dictates that some values must be constant across the organization, it makes sense to make them the default values in the configuration file. For example, the enterprise always wants its HQ location used as the country, state, and locality in every certificate it generates.

Figure 3.1 Example OpenSSL Configuration File

```
[ CA_default ]

dir          = /etc/pki/CA     # Where everything is kept
certs = $dir/certs             # Where the issued certs are kept
crl_dir      = $dir/crl        # Where the issued crl are kept
database     = $dir/index.txt  # database index file.
#unique_subject   = no         # Set to 'no' to allow creation of
                        # several ctificates with same subject.
new_certs_dir     = $dir/newcerts         # default place for new certs.

certificate = $dir/cacert.pem       # The CA certificate
serial       = $dir/serial          # The current serial number
crlnumber    = $dir/crlnumber  # the current crl number
                        # must be commented out to leave a V1 CRL
crl    = $dir/crl.pem          # The current CRL
private_key = $dir/private/cakey.pem# The private key
RANDFILE     = $dir/private/.rand    # private random number file

x509_extensions   = usr_cert        # The extentions to add to the cert

[ req ]
default_bits      = 2048
default_md        = sha256
default_keyfile   = privkey.pem
distinguished_name      = req_distinguished_name
attributes        = req_attributes
x509_extensions   = v3_ca

[ req_distinguished_name ]
countryName             = Country Name (2 letter code)
countryName_default           = XX
countryName_min               = 2
countryName_max               = 2

stateOrProvinceName           = State or Province Name (full name)
#stateOrProvinceName_default  = Default Province

localityName                  = Locality Name (eg, city)
localityName_default          = Default City

0.organizationName            = Organization Name (eg, company)
0.organizationName_default    = Default Company Ltd

organizationalUnitName        = Organizational Unit Name (eg, section)
#organizationalUnitName_default     =

commonName        = Common Name (eg, your name or your server\'s hostname)
commonName_max    = 64

emailAddress            = Email Address
emailAddress_max        = 64
```

The enterprise CA admin can then put these entries in the appropriate line in the configuration file. For example:

```
[ req_distinguished_name ]
countryName                  = Country Name (2 letter code)
countryName_default          = US
countryName_min              = 2
```

```
countryName_max                = 2

stateOrProvinceName            = State or Province Name (full name)
stateOrProvinceName_default    = District of Columbia

localityName                   = Locality Name (eg, city)
localityName_default           = Washington

0.organizationName             = Organization Name (eg, company)
0.organizationName_default     = Department of Examples
```

Once the default values are in place, the configuration file will be used unless overridden in the openssl command line. If the configuration file has been moved to a new directory, the command line option **-config** should be included in the openssl command to point to the location of the new configuration file location.

3.1.2.3 Using Linux Environment Variables to Dynamically Set Common Name and SubjectAltName

Not all of the values can be set via the command line override. The most important value that an enterprise CA admin may want to change is the **subjectAltName** of a certificate. The **subjectAltName** is used to provide alternative hostnames for a server that can be checked during PKIX validation. This allows one server to have multiple names and still use the same key pair for TLS. The **subjectAltName** default can be set in the configuration file, but cannot be set at the command line.

On Linux systems, the following can be used in the configuration file to use environment variables for CommonName (called **COMNAME**) and **SubjectAltName** (called **SAN**). See below:

```
commonName            = Common Name (eg, your name or your
commonName_default    = ${ENV::COMNAME}
commonName_max        = 64

subjectAltName        = ${ENV::SAN}
```

After the changes have been made to the configuration file, the **CommonName** and **SubjAltName** can be set dynamically (either via command line or appropriate system call in scripts, programs, etc.) to set the entries before generating a certificate.

3.1.3 Certificate Generation

3.1.3.1 Generate the Root Certificate

Once the configuration file is edited, the enterprise CA administrator must first generate a root certificate. This can be done using the openssl command line tool, or an included support script CA.pl. The following examples use the command line, as it is flexible and can be used via scripted system calls (that set environment variables, etc.). The basic command to generate a root certificate is:

```
>openssl req -config <config file> \
    -key private/ca.key.pem \
    -new -x509 -days 7300 -sha256 -extensions v3_ca \
    -out certs/ca.cert.pem
```

Here the **-config** option is used to list the location of the configuration file in use. The use of the **-days** option is to increase the lifetime of the root cert over any default value in the configuration file. The root certificate is not like end-entity issued certificates and often requires more configuration possible manual installation in enterprise systems, so should be longer lived for administration purposes (and highly protected). Enterprise CA administrators should consult NIST SP 800-152, *A Profile for U. S. Federal Cryptographic Key Management Systems* for recommendations on how to set up a key management system.

3.1.3.2 Generating Intermediate and End-Entity Certificates

Once the CA infrastructure is set up and the root certificate is generated, the enterprise CA can start generating end-entity and (if desired) intermediate certificates. Intermediate certificates are just that: certificates that are extra "links" in the PKIX validation chain to the root certificate. They are not usually installed as trust anchors, but can be used to sign other (often end-entity) certificates.

The advantage of using intermediate certificates is that they can be used to compartmentalize end-entity certificates, so a compromise of an intermediate cert means that only that certificate (and those it signed) are compromised, and not the entire CA. Intermediate certificates also allow CA administrators to keep the root certificate safely stored offline. Once the root key is used to sign the intermediate certificates, it can be stored offline until new intermediate certificates are needed.

The disadvantages of using intermediate certificates is that they are needed by all clients wishing to do PKIX validation. If a client cannot find (or have stored) all necessary intermediate certificates, it cannot validate all end-entity certificates. Protocols like TLS account for this by having certificate chains available (end-entity and necessary intermediate certificates), but not all protocols do this. DANE is an option for publishing intermediate certificates in the DNS as intermediate certs, or as short-circuited trust anchors, depending on which Certificate Usage (CU) parameter is used [RFC6698].

The general command to generate a new client key pair and certificate is:

```
>openssl req -new -nodes -config <config file> -keyout <key filename>
-out \
    <CSR filename>
```

The above command will generate a key pair and a Certificate Signing Request (CSR) for the new certificate. The **-nodes** option disables the setting of a password for decrypting the private portion of the key pair. This is important to set for server certificates where there is no end user to enter a password (and the private key is needed to set up a TLS connection). For intermediate certificates, this should not be set, as that private key should be protected.

Once the CSR is generated, it is made into a certificate:

```
>openssl ca -config <config file> -out -infiles <CSR filename> -out
<cert name>
```

Then the administrator follows the prompt. Administrators using intermediate keys may also use the **-key <private key>** option to have openssl use the desired intermediate key. Alternatively, the administrator could configure the which signing key to use in the openssl configuration file. Indeed, several separate configuration files could be used if multiple intermediate keys are used for the enterprise CA.

Once the new certificate and key pair have been generated, they must be protected from unauthorized disclosure. They must be security communicated to server administrators so the administrators can configure them for use. Once the key has outlived its lifetime, it must be security retired and removed. These operations should be documented as part of the enterprise key management system.

3.2 Cryptographic Operations (User Actions)

This section provides information regarding user actions necessary for users to invoke digital signature, encryption, and cryptographic certificate management features of Outlook and Thunderbird. The user's experience varies from relatively minimal additional impact in enterprise environments with established system administration and support to a significant impact in the case of individual self-supported users. Where the enterprise offers systems administration and support services, the user's experience with respect to DNS services is essentially unchanged. One exception is that, where DNS authentication fails, email messages sent to or by a user will not be delivered. This should be an uncommon experience for correspondents but it is up to the enterprise DNS administrator to prevent this happening. Similarly, for server-to-server encryption, the security protection features should be essentially transparent to the user.

3.2.1 Outlook

To use digital signatures and encryption, both the sender and recipient must have a mail application that supports the S/MIME standard. Outlook supports the S/MIME standard.

Instructions for user-driven cryptographic functions vary from version to version and platform to platform. Accessing **digital signature** on an Outlook **Help** page usually provides the necessary operator instructions. The example instructions provided here are for Outlook 2016 for Windows 10 and Outlook for Mac 2011.

3.2.1.1 Outlook 2016 for Windows 10

When a user has been issued an S/MIME certificate they can import it into the Outlook 2016's Trust Center to be used for digital signature and encryption based upon the key usages of the certificate. When a smart card containing a secure email digital signature certificate is inserted the Windows operating system, the OS will import the certificate into the user's personal certificate store. This will occur when the user inspects the smart card with the `certutil.exe -scinfo` command or if the following group policy is enabled:

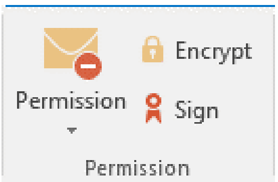
Computer Configuration -> Administrative Templates -> Windows Components -> Smart Card: Turn on certificate propagation from smart card

To view the certificates in the user's certificate store, type `certmgr.msc`.

Configure Outlook 2106 S/MIME Settings:

1. Open Outlook 2016.
2. Click on **File**, and then **Options.**
3. In the left-hand menu click on **Trust Center**.
4. Click on the **Trust Center Settings** box.
5. Click **Email Security** in the left-hand menu.
6. Click the **Settings** button within the Encrypted Email section.
7. Enter a name within the **Security Settings Name** field.
8. Select the Signing Certificate by clicking on the **Choose** button for the signing certificate and select the **Hash Algorithm**.
9. If you have an S/MIME encryption certificate select the **Choose** button for the encryption certificate and select the **Encryption Algorithm**.
10. Select the radio button **Send** to send these certificates with signed messages.

The user can choose to always digitally sign a message by selecting the **Add digital signature to outgoing messages** within the **Trust Center -> Email Security -> Encrypted Email** menu. This will digitally sign every outgoing email. To individually sign an email, within the draft message itself go to **Options** and within the **Permissions** menu select the **Sign** icon.



3.2.1.2 Outlook for Mac 2011 Certificate Management

If the user has a person's certificate in Outlook, he or she can validate a digitally signed message.[1]

1. Importing a Certificate
   a. At the bottom of the navigation pane, click **Contacts** .
   b. Open the desired contact, and then click the **Certificates** tab.
   c. Click , locate the certificate, and then click **Open**.

      Note: To set the default certificate for a contact, select the certificate, click , and then click **Set as Default**.
2. Exporting a Certificate

   Certificates can be exported in three formats: DER encoded X.509, PEM (Base-64 encoded X.509), and PKCS #7. The DER encoded X.509 format is the most common, but the user might want to ask what format his or her recipient requires.

1. This also enables the user to send that person an encrypted message (user to user).

a. At the bottom of the navigation pane, click **Contacts** .

b. Open the desired contact, and then click the **Certificates** tab.

c. Select the certificate, click , and then click **Export**. To set the format of the certificate, make a selection on the **Format** menu.

3. Deleting a Certificate

   a. At the bottom of the navigation pane, click **Contacts** .

   b. Open the desired contact, and then click the **Certificates** tab.

   c. Select the certificate, and then click .

3.2.1.3 Digital Signature

To use digital signatures (or encryption), both the sender and recipient must have a mail application that supports the S/MIME standard. Outlook supports the S/MIME standard.

Note: *Before a user starts this procedure, he or she must first have a certificate added to the keychain on his or her computer. For information about how to request a digital certificate from a certification authority, see Mac Help.*

1. On the **Tools** menu, click **Accounts**.

   The user clicks the account from which he or she wants to send a digitally signed message, clicks **Advanced**, and then clicks the **Security** tab.

2. Under **Digital signing**, on the **Certificate** pop-up menu, the user clicks the certificate that he or she wants to use.

   Note: The **Certificate** pop-up menu only displays certificates that are valid for digital (signing or encryption) that the user has already added to the keychain for his or her Mac OS X user account. To learn more about how to add certificates to a keychain, see Mac OS Help.

3. To make sure that the user's digitally signed messages can be opened by all recipients, even if they do not have an S/MIME mail application and cannot verify the certificate, select the **Send digitally signed messages as clear text** check box.

4. Click **OK**, and then close the **Accounts** dialog box.

5. In an e-mail message, on the **Options** tab, click **Security**, and then click **Digitally Sign Message**.

6. Finish composing the message, and then click **Send**.

3.2.2 Thunderbird[1]

For purposes of illustration, the description of the user experience with Thunderbird also included certificate management requirements. The example here shows both S/MIME and PGP examples of certificate management. The S/MIME approach is recommended. Note that when using OpenPGP, a FIPS 140-conformant version should always be used.

3.2.2.1 S/MIME Certificate Management

S/MIME certificates are used for digitally signed and encrypted e-mail messages. For information about getting or creating S/MIME certificates, see: http://kb.mozillazine.org/Getting_an_SMIME_certificate.

1. Installing an S/MIME certificate

   Important: Before a user can create or import his or her own certificate and private key, he or she must first set a master password if this has not already been done. The master password is needed so that imported certificates are stored securely. See http://kb.mozillazine.org/Master_password for instructions for setting a master password.

   The user may have his or her own personal certificate and private key in a .p12 or .pfx file, and may wish to import it into Thunderbird. Once a Master Password has been set, the user can import/install a personal S/MIME certificate from a .p12 or .pfx file by doing the following steps.

   a. Open the Certificate Manager by going to **Tools -> Options... -> Advanced -> Certificates -> Manage Certificates...**.
   b. Go to the tab named **Your Certificates**.
   c. Click on **Import**.
   d. Select the **PCKS12** certificate file (.pfx or .p12).
   e. It will ask the user for the master password for the software security device. The user enters his or her master password and clicks **OK**.
   f. Next, it will ask the user for the password protecting his or her personal certificate. If the user's .p12 or .pfx file has a password, the user enters it here, otherwise leave this field empty. The user then clicks **OK**.

      The S/MIME certificate should now have been imported. If the certificate was not trusted, consult the instructions at http://kb.mozillazine.org/Thunderbird_:_FAQs_:_Import_CA_Certificate.

2. Configuring Thunderbird for using the certificate to sign email

   Go to **Tools -> Account Settings...** in ThunderBird. Then find the account with the email address that matches the email address in the certificate that has just been installed. The user chooses **Security** under that account and selects the certificate that has just been installed. The rest of the options should be self explanatory. When the user selects a certificate in Account Settings, that selection only applies to the account's default identity or identities. There is no user interface for specifying certificates for an account's other

1. See https://support.mozilla.org/en-US/kb/digitally-signing-and-encrypting-messages

identities. If desired, this can be worked around by editing the settings manually, copying the settings from an account's default identity to some other identity. The settings have names ending in: **signing_cert_name**, **sign_mail, encryption_cert_name**, and **encryptionpolicy**.

3. User Installation of a Self-Signed S/MIME Certificate

   If the SMIME certificate in a user's .p12 or .pfx file is a self-signed certificate for the user's own identity, then before that file can be installed into the tab named **Your Certificates**, the user must first install that certificate as a certificate authority in the **Authorities** tab. The PKCS12 certificate file will not install into the **Authorities** tab. The user will need a copy of a self-signed certificate that does not contain the user's private key. This is usually in the form of a .cer file. One way to obtain the .cer form of a certificate from the .p12 file is to use the Firefox Add-on Key Manager to extract the .cer certificate from the .p12 file. With that Add-on installed in Thunderbird, the user goes to **Tools -> Key Manager Toolbox -> Key Manager -> Your Keys**, selects his or her key, selects **Export** and chooses **X.509** as file format.

   a. Go to **Tools -> Options... -> Advanced -> Certificates -> Manage Certificates...**.
   b. Go to the **Authorities** tab.
   c. Click on **Import**.
   d. Select the **.cer** file.
   e. It will ask the user for what purposes he or she wants to trust the certificate. The user selects **Trust this CA to identify email users**.
   f. Click **OK** to complete the import.

Note: *Thunderbird automatically adds other people's S/MIME certificates to the **Other People's** tab of a user's Certificate Manager when he or she receives from them a digitally signed message with a valid signature and with an S/MIME certificate issued by a recognized and trusted Certificate Authority (CA). CA certificates that appear in ThunderBird's **Authorities** tab are recognized, and may also be trusted. CA certificates that do not appear in that tab are considered **unrecognized**. An S/MIME certificate that was issued by an unrecognized CA will not be automatically added to the **Other People's** tab of the user's Certificate Manager. If the user attempts to manually import an S/MIME certificate that was issued by an unrecognized CA, nothing will happen--literally. Thunderbird will not even display an error dialog. It will just not import the S/MIME certificate. This is generally not a problem when receiving an S/MIME certificate that was issued by a trusted Certificate Authority (CA), but could be a problem for a certificate that was issued by an unrecognized or untrusted CA, or for a certificate that is self-signed (i.e. it has no CA other than itself). So, before a user can import an S/MIME certificate that is issued by an unrecognized CA or is self-signed, he or she must first acquire and import the certificate for the issuing CA. In the case of a self-signed certificate, a **.cer** file needs to be acquired from the individual whose certificate the user wishes to add.*

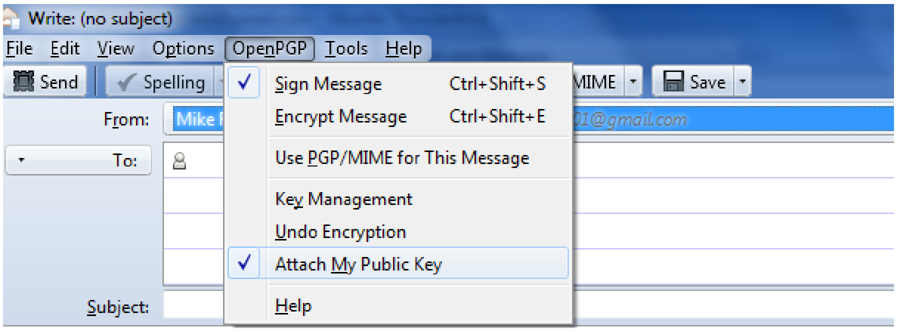
3.2.2.2 PGP Example of Sending and Receiving Public Keys

1. Sending a public key via email

   To send signed messages to other people that the recipients can validate, the user must first send them the public key:

   a. Compose the message.

b. Select **OpenPGP** from the Thunderbird menu bar and select **Attach My Public Key**.



c. Send the email as usual.

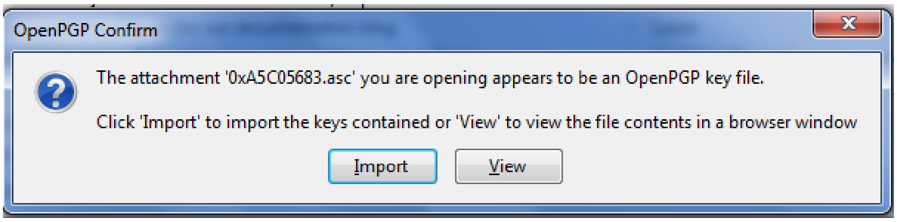
2. Receiving a public key via email

   To verify signed messages from other people, the public key must be received and stored:

   a. Open the message that contains the public key.

   b. At the bottom of the window, double click on the attachment that ends in **.asc**. (This file contains the public key.)

   c. Thunderbird automatically recognizes that this is a PGP key. A dialog box appears, prompting the **Import** or **View** of the key. Click **Import** to import the key.

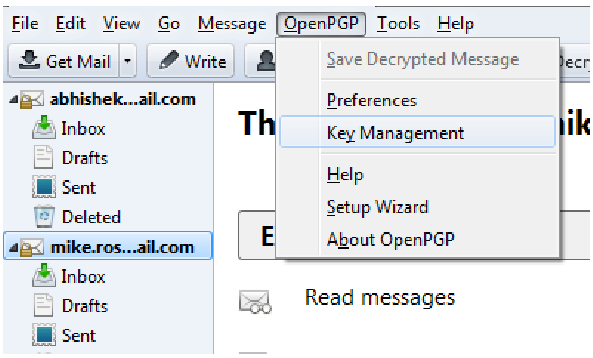


   d. A confirmation that the key has been successfully imported will be shown. Click **OK** to complete the process.

3. Revoking a key

   If the private key may have been "compromised" (that is, someone else has had access to the file that contains the private key), revoke the current set of keys as soon as possible and create a new pair. To revoke the current set of keys:

   a. On the Thunderbird menu, click **OpenPGP** and select **Key Management**.



b. A dialog box appears as shown below. Check **Display All Keys by Default** to show all the keys.

c. Right-click on the key to be revoked and select **Revoke Key**.

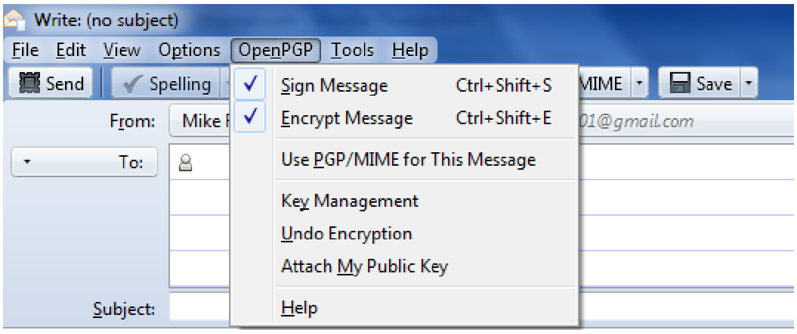
d. A dialog box appears asking the user if he or she really want to revoke the key. Click **Revoke Key** to proceed.

e. Another dialog box appears asking for the entry of a secret passphrase. Enter the passphrase and click **OK** to revoke the key.

The user sends the revocation certificate to the people with whom he or she corresponds so that they know that the user's current key is no longer valid. This ensures that if someone tries to use the current key to impersonate the user, the recipients will know that the key pair is not valid.

3.2.2.3 Sending a Digitally Signed Email

1. Compose the message as usual.
2. To digitally sign a message, select **OpenPGP** from the Thunderbird menu and enable the **Sign Message** option.

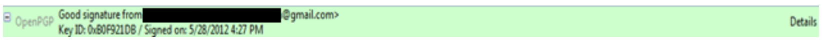


3. If the email address is associated with a cryptographic certificate, the message will be signed with the key contained in that certificate. If the email address is not associated with a cryptographic certificate, a certificate must be selected from a list.
4. Send the message as usual.

3.2.2.4 Reading a Digitally Signed Email

When a signed message is received, and If Thunderbird recognizes the signature, a green bar (as shown below) appears above the message.

To determine whether or not the incoming message has been signed, look at the information bar above the message body.[1]



If the message has been signed, the green bar also displays the text, “Signed message”.

1. If the message is also encrypted on a user to user basis, Thunderbird will also ask for the entry of a secret passphrase to decrypt the message.

A message that has not been signed could be from someone trying to impersonate someone else.

3.3 Server-to-Server Encryption Activation and Use

3.3.1 Office 365 Exchange

Server-to-server encryption (Scenario 1) is available on Exchange for Office 365. Office 365 encrypts users' data while it's on Microsoft servers and while it's being transmitted between the user and Microsoft. Office 365 provides controls for end users and administrators to fine tune what kind of encryption is desired to protect files and email communications. Some technical library links for specific topics are as follows:

- Information on encryption using Office 365 Exchange can be found at https://technet.microsoft.com/en-us/library/dn569286.aspx.
- Information regarding the different types of email encryption options in Office 365 including Office Message Encryption (OME), S/MIME, Information Rights Management (IRM) can be found at https://technet.microsoft.com/en-us/library/dn948533.aspx.
- Information regarding definition of rules regarding email message encryption and decryption can be found at https://technet.microsoft.com/en-us/library/dn569289.aspx.
- Information regarding sending, viewing, and replying to encrypted messages can be found at https://technet.microsoft.com/en-us/library/dn569287.aspx.
- Service information for message encryption can be found at https://technet.microsoft.com/en-us/library/dn569286.aspx.

3.3.2 Postfix

Postfix TLS support is described at http://www.postfix.org/TLS_README.html. Postfix can be set to encrypt all traffic when talking to other mail servers.[1]

3.4 Utilities and Useful Tools

This section provides links to some tools and utilities that are useful in installing, configuring, provisioning, and maintaining DNS-based email security software.

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3.4.1 DANE Tools

3.4.1.1 SMIMEA Retriever Tool

The SMIMEA retriever tool, developed by Santos Jha as part of this project, retrieves SMIMEA records from a DNS for a given email address and stores the certificates in PKCS12 format. This PKCS12 store can subsequently be imported into an MUA such as Thunderbird or Outlook. Since this software is used for offline provisioning of certificates, the developer focused on selector=0 and matching type=0. It is written using Java 8.

3.4.1.2 TLSA Generator

Shumon Huque's online TLSA generator generates TLSA resource records from a certificate and parameters for which prompts are included. The link to the tool is https://www.huque.com/bin/gen_tlsa.

3.4.1.3 High Assurance Domain Toolbox

NIST's High Assurance Domain Toolbox is a collection of perl scripts used to generate and format SMIMEA and TLSA RR's for use with the High Assurance Testbed. Each of these scripts are used independently and not all required to be used if other solutions work better. The tool can be found at https://github.com/scottr-nist/HAD-tlsa-toolbox.

3.4.1.4 Swede

Swede is a tool for use in creating and verifying DANE records. The tool can be found at https://github.com/pieterlexis/swede.

3.4.1.5 Hash-slinger

Hash-slinger is a package of tools created by Paul Wouters of RedHat to make it easy to create records for the DANE protocol that will allow you to secure your SSL/TLS certificates using DNSSEC. The package is available for Linux at: http://people.redhat.com/pwouters/hash-slinger/.

3.4.2 DANE Validation Sites and Testers

3.4.2.1 NIST DANE Testers

NIST's DANE-testers for RFC 6698 conformance can be found at http://dane-test.had.dnsops.gov/.

3.4.2.2 SMIMEA Test Tool

Grier Forensics' SMIMEA Test tool can be found at http://dst.grierforensics.com/#/start.

3.4.2.3 DANE Validator Online Test Tool

The DANE validator online test tool found at https://check.sidnlabs.nl/dane/ attempts to perform validation of a TLSA/PKI pair according to the DANE Internet standard. Note that the tool automatically selects Port 443 and TCP. SNI support is included. The tool set uses the ldns-dane example from LDNS from NLnet Labs.

3.4.2.4 DANE SMTP Validator

The DANE SMTP Validator, an SMTP DANE test tool, can be found at https://dane.sys4.de/.

3.4.3 Other Test Tools

DNSViz is a tool for visualizing the status of a DNS zone. It was designed as a resource for understanding and troubleshooting deployment of the DNS Security Extensions (DNSSEC). It provides a visual analysis of the DNSSEC authentication chain for a domain name and its resolution path in the DNS namespace, and it lists configuration errors detected by the tool. This DNSSEC test tool is not DANE specific, but helpful. It can be found at http://dnsviz.net/.

Appendix A Acronyms

ASN	Abstract Syntax Notation
AXFR	DNS Full Zone Transfer Query Type
BIND	Berkeley Internet Name Daemon
BSD	Berkeley Software Distribution
CA	Certificate Authority
CRL	Certificate Revocation List
CSR	Certificate Signing Request
CU	Certificate Usage Type
DANE	DNS-based Authentication of Named Entities
DNS	Domain Name System
DNSSEC	DNS Security Extensions
Email	Electronic Mail
FIPS	Federal Information Processing Standard
GAL	Global Address List
HTTP	Hypertext Transfer Protocol
IETF	Internet Engineering Task Force
IMAP	Internet Message Access Protocol
IP	Internet Protocol
ITL	Information Technology Laboratory
LDAP	Lightweight Directory Access Protocol
MIME	Multipurpose Internet Mail Extension
MTA	Mail Transfer Agent
MUA	Mail User Agent
MX	Mail Exchange (Resource Record)
NCCoE	National Cybersecurity Center of Excellence
NIST	National Institute of Standards and Technology
NSD	Network Server Daemon
OS	Operating System
PKI	Public Key Infrastructure
PKIX	Public Key Infrastructure X.509
POP	Post Office Protocol
RFC	Request for Comments

RMF	Risk Management Framework
RR	Resource Record
S/MIME	Secure/Multipurpose Internet Mail Extensions
SMIMEA	S/MIME Certificate Association (Resource Record)
SMTP	Simple Mail Transfer Protocol
SP	Special Publication
SQL	Structured Query Language
TLS	Transport Layer Security
TLSA	TLS Certificate Association (Resource Record)
UA	User Agent
VLAN	Virtual Local Area Network
VM	Virtual Machine

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Appendix C Platform Operation and Observations

C.1 Operations Scenarios

Both server-to-server encryption (Scenario 1) and user signature (Scenario 2) of electronic mail are demonstrated. Demonstrations of the security platform include attempts by fraudulent actors to pose as the originator of email and man-in-the-middle attackers attempting to disrupt the validation the S/MIME signature. Events are included that involve all components and demonstrate that each of the MUAs can be used with both MTAs, and both MTAs can run with each of the four DNS stacks. Use of self-signed certificates and of certificates from local and well-known certificate authorities are included. The events do not cover all possible combinations of components for both mail origination and receipt, but they do include demonstration of both Exchange and Postfix as senders, all four DNS services, and both Exchange and Postfix as recipients accessed by both Outlook and Thunderbird MUAs. For each event identified below, we identify the components involved, operator actions required by both the sender and the receiver, and observed results. For purposes of avoiding excessive repetition in test events, each event includes demonstration of both scenarios.

C.1.1 Server-to-Server Encrypted Email in Scenario 1

An individual needed to enter into an email exchange with an individual in another organization that required protected transfer of information. Each individual exchanged email via the respective parent organizations' mail servers. Users connected to their organizations' respective mail servers within a physically protected zone of control.

The policy of the parent organizations required encryption of the information being exchanged. The security afforded by the cryptographic process was dependent on the confidentiality of encryption keys from unauthorized parties. The mail servers were configured to use X.509 certificates to convey keying material during an encryption key establishment process.

DNSSEC was employed to ensure that each sending mail server connected to the legitimate and authorized receiving mail server from which its X.509 certificate was obtained. DANE resource records were employed to bind the cryptographic keying material to the appropriate server name. STARTTLS was employed to negotiate the cryptographic algorithm to be employed with TLS in the email exchange in which the message was transferred. Encryption of the email message was accomplished by the originator's email server, and decryption of the email message was accomplished by the recipient's email server.

C.1.2 Signed Email in Scenario 2

Scenario 2 supports the case of an individual needing to enter into an exchange of email that requires integrity protection with an individual in another organization that. Each individual exchanged email via the respective parent organizations' mail servers. Users connected to their organizations' respective mail servers within a physically protected zone of control.

The policies of the parent organizations required cryptographic digital signature of the message to provide integrity protection and source authentication of the email message. S/MIME is a widely available and used protocol for digitally signing electronic mail. Each organization therefore generated X.509 certificates for their users that included the public portion of their signature keys. These certificates were then published in the DNS using the appropriate DANE DNS Resource Record (RR) type.

DNSSEC was used to provide assurance that the originating user's mail server connected to the intended recipient's mail server. DANE records were employed to bind the cryptographic certificates to the appropriate server (for TLS) and individual user (for S/MIME), respectively. TLS was employed to provide confidentiality. Digital signature of the email message was accomplished by the originator's email client. Validating the signature (hence the integrity of the authorization provided in the email message) was accomplished by the recipient's email client.

C.1.3 Handling of Email from Fraudulent Sender

Demonstrations of the security platform in both scenarios included an attempt by a fraudulent actor to pose as the originator of the email. Where it was implemented, DANE was used to expose the fraudulent originator's attempt.

C.1.4 Handling of Man-in-the-Middle Attack

Demonstration of the security platform in both scenarios also included a man-in-the-middle attacker attempting to disrupt the validation of the S/MIME signature. Where DANE was implemented, the attempts were shown to fail due to use of DNSSEC and DANE records.

C.1.5 Effects of DNS Errors

A DANE-enabled Postfix MTA sent message traffic to four Exchange MTAs with one Authoritative Server serving all four zones. An NSD4 Authoritative DNS server and Unbound recursive server was provided for the Postfix MTA, and a Secure64 DNS Authority and Signer provided the DNS services for the Exchange zones.

C.2 Test Sequences

The test and demonstration events selected were chosen to demonstrate the functionality available in both scenarios, the effectiveness of available DNS services, and the interoperability of components. The event selection objectives also included keeping the events to a manageable number, while capturing significant performance information. As a result, several stacks of contributed MUA, MTA, and DNS service components were demonstrated in the NCCoE laboratory environment, and representative NCCoE laboratory configurations were shown exchanging email with two different external sites using several cryptographic certificate types (certificates from Well-Known CAs (with TLSA RR cert usage (CU) of 1), Enterprise CAs (with TLSA RR cert usage of 2), and Self-Signed CAs (with TLSA RR cert usage of 3). The first external site used Secure64 DNS services, a Postfix MTA, and a Thunderbird MUA with an Apple

Keychain Utility. The second external site used NLnet Labs DNS services, a Postfix MTA, and a Thunderbird MUA.

C.2.1 Test Sequence 1: MUA/MTA/DNS Service Combinations Exchanged Signed and Encrypted Email with a Secure64 Site and an NLnet Labs Site

An Outlook MUA, interfacing with an Exchange MTA, was configured to use Active Directory and BIND DNS services in turn. Each of the six configurations exchanged email with 1) a Secure64 MUA/MTA/DNS service stack that included a Postfix MTA and a Thunderbird MUA running on a Mac OS System, and 2) an NLnet Labs MUA/MTA/ DNS service stack that included a Postfix MTA and a Thunderbird MUA running on Linux. The events include events showing use of Well-Known CAs (CU-1), Enterprise CAs (CU=2), and Self-Signed Certificates (CU=3) for TLS and S/MIME-enabled mail receivers and S/MIME. Digital signature of the messages was logged. All messages were S/MIME signed. Outlook attempted to verify received messages (Scenario 2). Signature verification results were noted. DNS name verification results were noted. Figure 2.1 above depicts the set-up for laboratory support for the Secure64 destination variant of this test sequence.[1]

C.2.1.1 Active Directory and DNS Server in NCCoE Laboratory

The Active Directory, DNS Server, an Exchange MTA, and an Outlook MUA were configured with appropriate certificates for each deployment scenario. These certificate policies include S/ MIME and TLS certificates from a Well-Known CA, certificates from an Enterprise CA, and self-signed certificates (using TLSA and SMIMEA parameters CU=1, CU=2, and CU=3 respectively). Each of these three variations sent S/MIME signed and TLS encrypted email to a Secure64 site and an NLnet Labs site. The Secure64 site was using a MacBook-hosted Thunderbird MUA, a Postfix/Dovecot MTA, DNS Cache/DNS Authority services for processing received messages, and DNS Signer for outbound messages. The NLnet site was using an Intel-hosted Thunderbird MUA, a Postfix/Dovecot MTA, NSD4 and Unbound for processing received messages, and OpenDNSSEC for outbound messages. Each of the events included the NCCoE Laboratory configuration sending a signed and encrypted message to the remote sites, and a signed response being sent from each remote site to the NCCoE configuration.

1. **Event 1:** Outlook MUA Using an Exchange MTA using Well-Known CA issued Certificates for TLS and S/MIME

   Expected Outcome: NCCoE Outlook MUA sent a test message in an S/MIME signed email using Active Directory DNS Services and a Well-Known CA (CU=1) to Secure 64 and NLnet Labs, and both recipients returned responses that were S/MIME signed. The signature for the received messages was verified.

   Observed Outcome: As expected, the messages were authenticated and a log file was saved.

2. **Event 2:** Outlook MUA Using an Exchange MTA using Enterprise CA issued Certificates for TLS and S/MIME

1. The connections depicted in Figure 2.1 are actually for the first Sequence 2 configuration. Capabilities for Sequence 1 support are shown as dotted lines.

Expected Outcome: NCCoE Outlook MUA sent a test message in an S/MIME signed email using Active Directory DNS Services and an Enterprise CA (CU=2) to Secure 64 and NLnet Labs, and both recipients returned responses that were S/MIME signed. The signature for the received messages was verified.

Observed Outcome: As expected, the messages were authenticated and a log file was saved.

3. **Event 3:** Outlook MUA Using an Exchange MTA using Self-Signed Certificate for TLS and S/MIME

   Expected Outcome: NCCoE Outlook MUA sent a test message in an S/MIME signed email using Active Directory DNS Services and a self-signed TLS certificate (CU=3) to Secure 64 and NLnet Labs, and both recipients returned responses that were S/MIME signed. The signature for the received messages was verified.

   Observed Outcome: As expected, the message was authenticated and a log file was saved.

C.2.1.2 BIND in NCCoE Laboratory

The BIND DNS Server, an Exchange MTA, and an Outlook MUA were configured with appropriate certificates for each deployment scenario. These certificate policies include S/MIME and TLS certificates Well-Known CA, certificates from an Enterprise CA, and self-signed certificates (TLSA/SMIMEA parameters CU=1, CU=2, and CU=3 respectively). Each of these three variations sent S/MIME signed and TLS encrypted email to a Secure64 site and an NLnet Labs site. The Secure64 site was using a MacBook-hosted Thunderbird MUA, a Postfix/Dovecot MTA, DNS Cache/DNS Authority services for processing received messages, and DNS Signer for outbound messages. The NLnet site was using an Intel-hosted Thunderbird MUA, a Postfix/Dovecot MTA, NSD4 and Unbound for processing received messages, and OpenDNSSEC for outbound messages. Each of the events included the NCCoE Laboratory configuration sending a signed message to the remote sites, and a signed response being sent from each remote site to the NCCoE configuration.

1. **Event 4:** Outlook MUA Using an Exchange MTA using Well-Known CA issued Certificates for TLS and S/MIME

   Expected Outcome: NCCoE Outlook MUA sent a test message in an S/MIME signed email using a BIND DNS Server and Well-Known CA (CU=1) issued certificates to Secure64 and NLnet Labs, and both Secure64 and NLnet Labs returned a response that was S/MIME signed. The signature for the received messages was verified.

   Observed Outcome: As expected, the message was authenticated and a log file was saved.

2. **Event 5:** Outlook MUA Using an Exchange MTA using an Enterprise CA issued Certificates for TLS and S/MIME

   Expected Outcome: NCCoE Outlook MUA sends a test message in an S/MIME signed email using a BIND DNS Server and an Enterprise CA (CU=2) issued certificates to Secure64 and NLnet Labs, and both Secure64 and NLnet Labs returned a response that was S/MIME signed. The signature for the received messages was verified.

   Observed Outcome: As expected, the message was authenticated and a log file was saved.

3. **Event 6:** Outlook MUA Using an Exchange MTA using Self-Signed Certificates for TLS and S/MIME

Expected Outcome: NCCoE Outlook MUA sent a test message in an S/MIME signed email using a BIND DNS Server and self-signed certificates (CU=3) to Secure64 and NLnet, and both Secure64 and NLnet returned a response that was S/MIME signed. The signature for the received messages was verified.

Observed Outcome: As expected, the message was authenticated and a log file was saved.

C.2.2 Test Sequence 2: MUA/MTA/DNS Service Combinations Exchanged Signed and Encrypted Email with an NLnet Labs Site and a Secure64 Site

Outlook and Thunderbird MUAs, configured to use a Postfix MTA with Dovecot IMAP support, were configured in turn to use BIND and Secure64's DNS Authority, DNS Cache, and DNS Signer implementations. Each of the six configurations exchanged email with a Secure64 site that included a Thundebird MUA, DNS Cache/DNS Signer/DNS Authority DNS services, and Postfix/ Dovecot MTA and an NLnet Labs MUA/MTA/ DNS service stack that included a Thundebird MUA, NSD4, Unbound, and OpenDNSSEC DNS services and a Postfix/Dovecot MTA. The test events include using Well-Known CA issued (TLSA/SMIMEA CU=1), Enterprise CA issued (CU=2), and Self-Signed Certificates (CU=3). Email messages between MTAs were encrypted and successfully decrypted. (Scenario 1). Signature and encryption were logged. All messages were S/MIME signed. Outlook attempted to verify received messages (Scenario 2). Signature verification results were noted. DNS name verification results were noted. Figure 2 above depicts the set-up for laboratory support for this test sequence, with connections selected for Event 7 below.

C.2.2.1 BIND and Postfix/Dovecot in NCCoE Laboratory

Outlook, then Thunderbird mail clients were configured to use Postfix/Dovecot MTAs and BIND DNS servers. Each of these three configurations sent S/MIME signed and TLS encrypted email to a Secure64 site and an NLnet Labs site. The Secure64 site was using a Thunderbird MUA using Secure64's Apple Key Chain Utility tool that allows a host to obtain X.509 certificates via of DANE RRs, DNS Cache/DNS Signer/DNS Authority DNS services, and a Postfix/Dovecot MTA for mail. The NLnet Labs site was using a Thunderbird MUA, a Postfix/Dovecot MTA, and NSD4, Unbound, and OpenDNSSEC DNS Services. Each of the three events included the NCCoE Laboratory configuration sending a S/MIME signed and TLS encrypted message to the Secure64 and NLnet Labs sites, and signed and encrypted responses being sent from the Secure64 and NLnet Labs site to the NCCoE.

1. **Event 7:** Outlook MUA Using a Postfix/Dovecot MTA and Well-Known CA Issued Certificates for TLS and S/MIME

   Expected Outcome: NCCoE Outlook MUA using BIND for DNS sent a test message in an S/ MIME signed email to Secure64 and NLnet Labs. Secure64 and NLnet Labs returned responses that were S/MIME signed and TLS encrypted. The received messages were successfully decrypted, and the signatures were verified. All S/MIME and MTA TLS certificates in this test were issued from a well-known CA and TLSA/SMIMEA RR Certificate Usage parameter set to 1.

   Observed Outcome: As expected, the message was authenticated and decrypted, and a log file was saved.

2. **Event 8:** Thunderbird MUA Using a Postfix/Dovecot MTA and Enterprise CA Issued Certificates for TLS and S/MIME

   Expected Outcome: NCCoE Thunderbird MUA using BIND for DNS sent a test message in an S/MIME signed email to Secure64 and NLnet Labs. Secure64 and NLnet Labs returned responses that were S/MIME signed and TLS encrypted. The received messages were successfully decrypted, and the signatures were verified. All S/MIME and MTA TLS certificates in this test were issued from an enterprise local CA and TLSA/SMIMEA RR Certificate Usage parameter set to 2.

   Observed Outcome: As expected, the message was authenticated and decrypted. and a log file was saved.

3. **Event 9:** Thunderbird MUA Using a Postfix/Dovecot MTA and Self-Signed Certificates

   Expected Outcome: NCCoE Thunderbird MUA using BIND for DNS sent a test message in an S/MIME signed email to Secure64 and NLnet Labs. Secure64 and NLnet Labs returned responses that were S/MIME signed and TLS encrypted. The received messages were successfully decrypted, and the signatures were verified. All S/MIME and MTA TLS certificates in this test were self-signed and TLSA/SMIMEA RR Certificate Usage parameter set to 3.

   Observed Outcome: As expected, the message was authenticated and decrypted, and a log file was saved.

C.2.2.2 Postfix/Dovecot with DNS Authority, DNS Cache, and DNS Signer in NCCoE Laboratory

A Thunderbird client was configured to use DNS Authority, DNS Cache, and DNS Signer Servers and use a Postfix/Dovecot MTA. Each of these three configurations sent S/MIME signed and TLS encrypted email to a Secure64 site and an NLnet Labs site. The Secure64 site was using a Thunderbird MUA that employed Secure64's Apple Key Chain Utility tool that allows a host to obtain X.509 certificates via of DANE RRs, DNS Cache/DNS Signer/DNS Authority DNS services, and a Postfix/ Dovecot MTA for mail. The NLnet Labs site was using a Thunderbird MUA, a Postfix/Dovecot MTA, and NSD4, Unbound, and OpenDNSSEC DNS Services. Each of the three events included the NCCoE Laboratory configuration sending an S/MIME signed and TLS encrypted message to the Secure64 and NLnet Labs sites, and signed and encrypted responses being sent from the Secure64 and NLnet Labs site to the NCCoE.

1. **Event 10:** Thunderbird MUA Using a Postfix/Dovecot MTA and Well-Known CA Issued Certificates for TLS and S/MIME

   Expected Outcome: NCCoE Thunderbird MUA using DNS Authority/Cache/Signer DNS Services and a Postfix MTA sent a test message in an S/MIME signed email to Secure64 and NLnet Labs. Secure64 and NLnet Labs returned that a message that we had S/MIME signed and TLS encrypted. The received messages were successfully decrypted, and the signatures were verified. All certificates in this test were issued from a well-known CA and TLSA/ SMIMEA RR Certificate Usage parameter set to 1.

   Observed Outcome: As expected, the message was authenticated and decrypted, and a log file was saved.

2. **Event 11:** Thunderbird MUA Using a Postfix/Dovecot MTA and Enterprise CA Issued Certificates for TLS and S/MIME

Expected Outcome: NCCoE Thunderbird MUA using DNS Authority/Cache/Signer DNS Services and a Postfix MTA sent a test message in an S/MIME signed email to Secure64 and NLnet Labs. Secure64 and NLnet Labs returned a message that we had S/MIME signed and TLS encrypted. The received messages were successfully decrypted, and the signatures were verified. All certificates in this test were issued from an enterprise CA and TLSA/SMIMEA RR Certificate Usage parameter set to 2.

Observed Outcome: As expected, the message was authenticated and decrypted, and a log file was saved.

3. **Event 12:** Thunderbird MUA Using a Postfix/Dovecot MTA and Self-Signed Certificates for TLS and S/MIME

   Expected Outcome: NCCoE Thunderbird MUA using DNS Authority/Cache/Signer DNS Services and a Postfix MTA sent a test message in an S/MIME signed email to Secure64 and NLnet Labs. Secure64 and NLnet Labs returned a message that we had S/MIME signed and TLS encrypted. The received messages were successfully decrypted, and the signatures were verified. All certificates in this test were self-signed and TLSA/SMIMEA RR Certificate Usage parameter set to 3.

   Observed Outcome: As expected, the message was authenticated and decrypted, and a log file was saved.

C.2.3 Sequence 3: Fraudulent DNS Address Posing as Valid DNS Address Contacting Recipient MTAs

Fraudulently S/MIME signed email was sent from a malicious sender to recipients using Outlook and Thunderbird MUAs configured to use Exchange and Postfix as MTAs. The Outlook/Exchange configuration used Active Directory as its DNS server. The configurations employing Postfix/Dovecot MTAs were demonstrated with each of the other three contributed DNS Services. In one event, the Thunderbird MUA employed an Apple Key Chain Utility tool that allows a host to obtain X.509 certificates via of DANE RRs. All events were conducted using well-known CA and Enterprise CA-issued certificates for the impersonated sender. The fraudulent site attempted to spoof a valid sending domain belonging to a Secure64 site that was configured with DNS Authority/Cache/Signer DNS services, a Postfix/Dovecot MTA, and Thunderbird[1] equipped with the Apple Key Chain utility. An Outlook/Exchange/Active Directory set-up acted as the fraudulent site. The email exchange between organizations was carried over TLS, and the email message was S/MIME signed on the fraudulent users' client device. The set-up for this sequence is depicted in figure C.1 below.

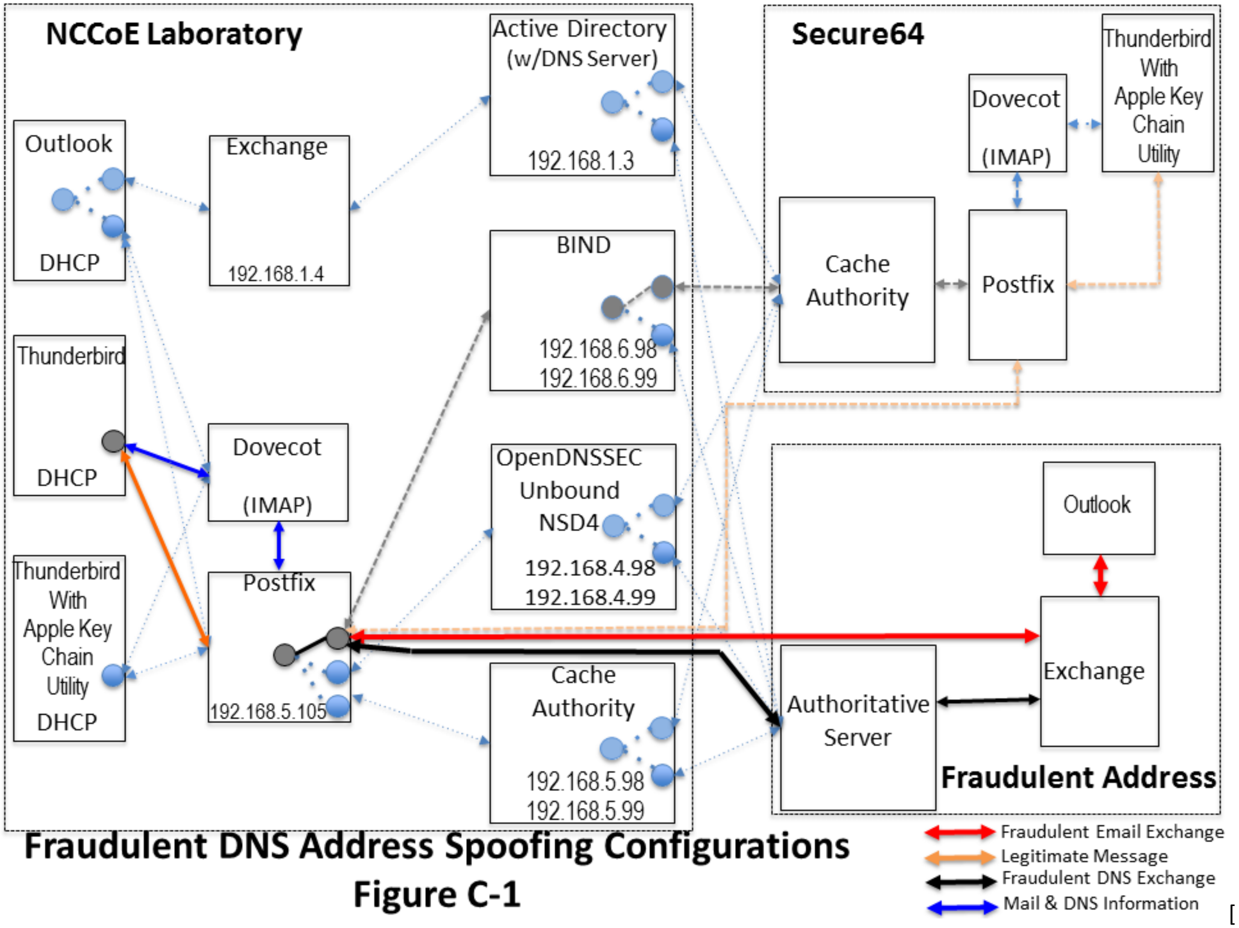
C.2.3.1 Spoofing Attempts Against Exchange and Postfix/Dovecot Configurations Using Enterprise CA Issued Certificates (CU=1)

The target set-up is comprised of (alternatively): Active Directory and DNS Server, BIND DNS Server, NLnet Labs DNS Services, and Secure64 DNS services with Microsoft Outlook/Exchange, Outlook/Postfix/Dovecot, and Thunderbird/Postfix/ Dovecot mail configurations. For purposes of this demonstration, two certificates were issued for each domain. One of these was valid and published as a DNSSEC signed SMIMEA RR in the target's zone. The second (spoofed) certificate

1.Technically, this shouldn't matter. Secure64 isn't sending the mail, so the MUA isn't involved.

is not in the DNS. The fraudulent site possessed the spoofed certificates and, posing as a valid Secure64 site, attempted to send emails to the NCCoE Laboratory target configurations. The email and DNS transactions were logged in each case, and the results are provided below.

Figure C.1 Fraudulent DNS Address Spoofing Configurations



1. **Event 13:** Outlook MUA, Exchange MTA, and Active Directory DNS Services

Expected Outcome: Using S/MIME, Outlook validated the message from the attacker (as DANE is not enabled in Outlook at this time).

Observed Outcome: As expected and a log file was saved.

2. **Event 14:** Thunderbird MUA, Postfix/Dovecot MTA and NLnet Labs DNS Services

   Expected Outcome: Using S/MIME and DANE, Thunderbird recognizes that the certificate has not been validated and does not deliver the message to the user. Thunderbird will flag the signature as invalid.

   Observed Outcome: As expected and a log file was saved.

3. **Event 15:** Thunderbird MUA, Postfix/Dovecot MTA and Secure64 DNS Services

   Expected Outcome: Using S/MIME and DANE, Thunderbird with the Apple Key Chain Utility recognizes that the certificate has not been validated and does not deliver the message to the user.

   Observed Outcome: As expected and a log file was saved.

C.2.3.2 Spoofing Attempts Against Exchange and Postfix/Dovecot Configurations Using Self-Signed Certificates (CU=3)

The target set-up is configured to use Active Directory with Outlook and Exchange; and in a separate set of tests: BIND and NLnet Labs DNS Services (alternatively) were configured with a Thunderbird MUA and a Postfix/Dovecot MTA. The fraudulent site, posing as a valid Secure64 site, attempted to send an email to the NCCoE Laboratory target. The email and DNS transactions were logged in each case, and the results are provided below.

1. **Event 16:** Postfix MTA Using an Active Directory DNS Service

   Expected Outcome: Using only S/MIME, Outlook will fail to validate the message from the attacker as it was signed by an untrusted root, but not marked as a possible attack.

   Observed Outcome: As expected and a log file was saved.

2. **Event 17:** Postfix MTA Using a BIND DNS Service

   Expected Outcome: Using S/MIME and DANE, Thunderbird with the Apple Key Chain Utility recognizes that the certificate has not been validated and does not deliver the message to the user.

   Observed Outcome: As expected and a log file was saved.

3. **Event 18:** Postfix MTA Using an NLnet DNS Service

   Expected Outcome: Using S/MIME and DANE, Thunderbird with the Apple Key Chain Utility recognizes that the certificate has not been validated and does not deliver the message to the user.

   Observed Outcome: As expected and a log file was saved.

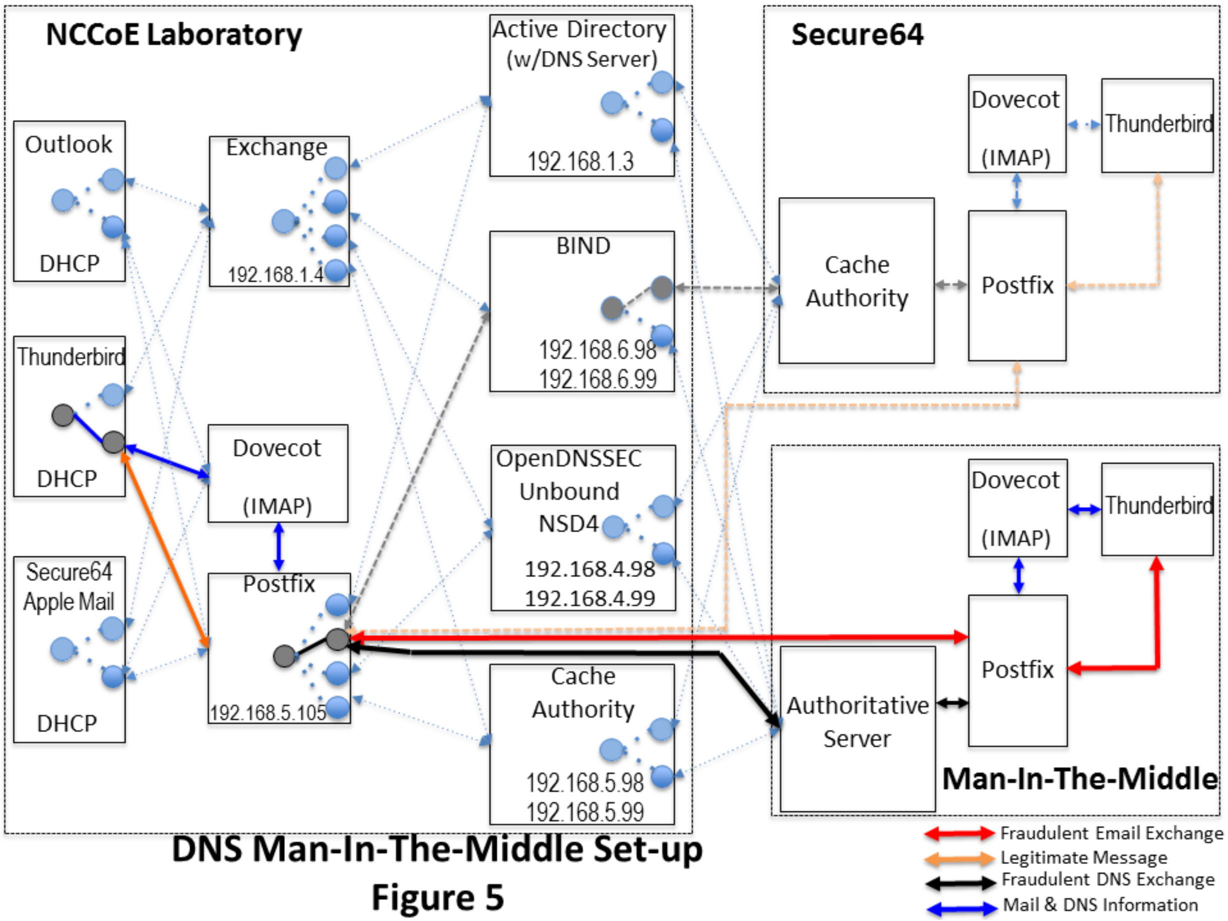
C.2.4 Sequence 4: Man-in-the-Middle Attack on Postfix-to-Postfix Connection

An NCCoE system attempted to send a TLS protected email from Exchange and Postfix MTAs (in turn) to an external Postfix MTA using DNS Authority/Cache/Signer for DNS services. The NCCoE Exchange MTA used Active Directory DNS Services, and the Postfix/Dovecot MTA used BIND and NSD4/Unbound/OpenDNSSEC DNS services. A S/MIME signed email was sent to an external Postfix MTA. Four events were conducted using Well-Known CA issued certificates, four events were conducted using Enterprise CA issued certificates (TLSA/SMIMEA RR parameter of CU=2) for TLS and S/MIME on the receiver side, and three events were conducted using self-signed certificates (TLSA/SMIMEA RR parameter of CU=3) for TLS and S/MIME on the receiver side. An Outlook/Exchange/Active Directory stack acted as a man-in-the-middle and attempted to intercept the message. Figure C.2 depicts the configuration for a man-in-the-middle demonstration. Note that the sender is being misdirected to a malicious email server only. This is to simulate a lower level attack where email is sent (via route hijacking or similar low level attack) to a Man-in-the-Middle. Figure C.2 depicts the configurations used with the Thunderbird/Postfix/Dovecot/Bind option selected.

C.2.4.1 Man-in-the-Middle Attack when Senders and Receivers use Well-Known CA Issued Certificates (CU=1)

The sender set-up was comprised of Active Directory and DNS Server, BIND DNS Service, or NLnet Labs DNS Services with Outlook and Thunderbird MUAs using an Exchange MTA. In the fourth event, the sender is a Thunderbird MUA with a Secure64 Apple Key Chain utility utilizing NSD4/Unbound/OpenDNSSEC DNS services and a Postfix/Dovecot MTA. Enterprise CA issued certificates are used on the receiver side for TLS. Each of the four configurations attempts to initiate an email exchange with an external Secure64 site. The man-in-the-middle, an Outlook/Exchange/Active Directory stack, attempts to spoof the intended receiver and accept the email. The email and DNS transactions were logged in each case, and the results are provided below.

Figure C.2 Man-in-the-Middle Event Configurations



1. **Event 19:** Outlook MUA, Exchange MTA, and Active Directory DNS Service as Sender

   Expected Outcome: The sending MTA fails to detect the spoofing. The mail connection to the MTA is established and mail is transferred.

   Observed Outcome: As expected and a log file was saved.

2. **Event 20:** Thunderbird MUA, Exchange MTA, and BIND DNS Service as Sender

   Expected Outcome: The sending MTA fails to detect the spoofing. The mail connection to the MTA is established and mail is transferred.

   Observed Outcome: As expected and a log file was saved.

3. **Event 21:** Thunderbird MUA, Postfix MTA and NSD4/Outbound/ OpenDNSSEC DNS Services as Sender

   Expected Outcome: The MUA using a SMIMEA utility was able to detect the fraudulent email and mark the email as not validated.

   Observed Outcome: As expected and a log file was saved.

4. **Event 22:** Thunderbird MUA with Secure64 Apple Key Chain Utility, Postfix/Dovecot MTA and DNS Authority/Cache/Signer DNS Services

   Expected Outcome: The MUA using a SMIMEA utility was able to detect the fraudulent email and mark the email as not validated.

   Observed Outcome: As expected and a log file was saved.

C.2.4.2 Man-in-the-Middle Attack when Senders and Receivers use Enterprise CA Issued Certificates (CU=2)

The sender set-up was composed of Active Directory and DNS Server, BIND DNS Service, or NLnet Labs DNS Services with Outlook and Thunderbird MUAs using an Exchange MTA. In the fourth event, the sender is a Thunderbird MUA with a Secure64 Apple Key Chain utility utilizing NSD4/Unbound/OpenDNSSEC DNS services and a Postfix/Dovecot MTA. Enterprise CA issued certificates are used on the receiver side for TLS. Each of the four configurations attempts to initiate an email exchange with an external Secure64 site. The man-in-the-middle, an Outlook/ Exchange/Active Directory stack, attempts to spoof the intended receiver and accept the email. The email and DNS transactions were logged in each case, and the results are provided below.

1. **Event 23:** Outlook MUA, Exchange MTA, and Active Directory DNS Service as Sender.

   Expected Outcome: The sending MTA fails to detect the spoofing. The mail connection to the MTA is established and mail transferred.

   Observed Outcome: As expected and a log file was saved.

2. **Event 24:** Thunderbird MUA, Exchange MTA, and BIND DNS Service as Sender.

   Expected Outcome: The sending MTA fails to detect the spoofing. The mail connection to the MTA is established and mail transferred.

   Observed Outcome: As expected and a log file was saved.

3. **Event 25:** Thunderbird MUA, Postifx MTA and NSD4/Outbound/OpenDNSSEC DNS Services as Sender

   Expected Outcome: The Postfix MTA detects the spoofing and closes the SMTP connection before the email is sent.

   Observed Outcome: As Expected.

4. **Event 26:** Thunderbird MUA with Secure64 Apple Key Chain Utility, Postfix/Dovecot MTA and DNS Authority/Cache/Signer DNS Services

Expected Outcome: The postfix MTA detects the spoofing and closes the SMTP connection before the email is sent.

Observed Outcome: As Expected.

C.2.4.3 Man-in-the-Middle With Self-Signed Certificates (CU=3)

The sender uses an Outlook and Thunderbird MUAs sending mail through a Postfix/Dovecot MTA and using (in turn): Active Directory and DNS Server, BIND DNS Server, and NLnet Labs DNS Services. Self-signed certificates are used on the legitimate receiver side (TLSA RR parameter CU=3) for TLS. Each of the three configurations attempts to initiate an email exchange with an external Secure64 site. The man-in-the-middle, an Outlook/Exchange/ Active Directory stack, attempts to intercept the email from the NCCoE Laboratory Configuration by acting as a Man-in-the-Middle. The email and DNS transactions were logged in each case, and the results are provided below.

1. **Event 27:** Postfix MTA Using an Active Directory DNS Service

   Expected Outcome: TLSA detects spoofing. The mail connection to the MTA is established but breaks before the mail is transferred.

   Observed Outcome: As expected and a log file was saved.

2. **Event 28:** Thunderbird MUA, Exchange MTA, and BIND DNS Service

   Expected Outcome: Exchange fails to detect the man-in-the-middle and sends the email.

   Observed Outcome: As expected and a log file was saved.

3. **Event 29:** Thunderbird MUA with Secure64 Apple Key Chain Utility, Exchange MTA and NSD4/Outbound/OpenDNSSEC DNS Services

   Expected Outcome: Exchange fails to detect the man-in-the-middle and sends the email.

   Observed Outcome: As expected and a log file was saved.

C.2.5 Sequence 5: Effects of DANE Errors

In Sequence 5, A DANE-enabled Postfix MTA sent message traffic to four other postfix MTAs. See figure C.3. A single BIND instance was set up to serve the TLSA and A RRs for the four receivers. One of the receiving MTAs did not employ DANE. The second employed DANE with a valid TLSA with the certificate usage field[1] set to 3. The third employed a TLSA with a certificate usage field of 2, but with an incomplete (i.e. bad) PKI certification path (generating a PKIX validation failure). The TLSA contained a local enterprise trust anchor, but the server did not have the full certificate chain (missing intermediate certificate). The final one employed DANE with a TLSA RR using Certificate Usage of 3, but there was a mismatch between the server cert and TLSA RR (generating a DANE validation failure).

1. RFC 6698, The DNS-Based Authentication of Named Entities (DANE) Transport Layer Security (TLS) Protocol: TLSA, Section 2.1.1. https://tools.ietf.org/html/rfc6698#section-2.1.1

C.2.5.1 Event 30: DNS/DANE Error Results

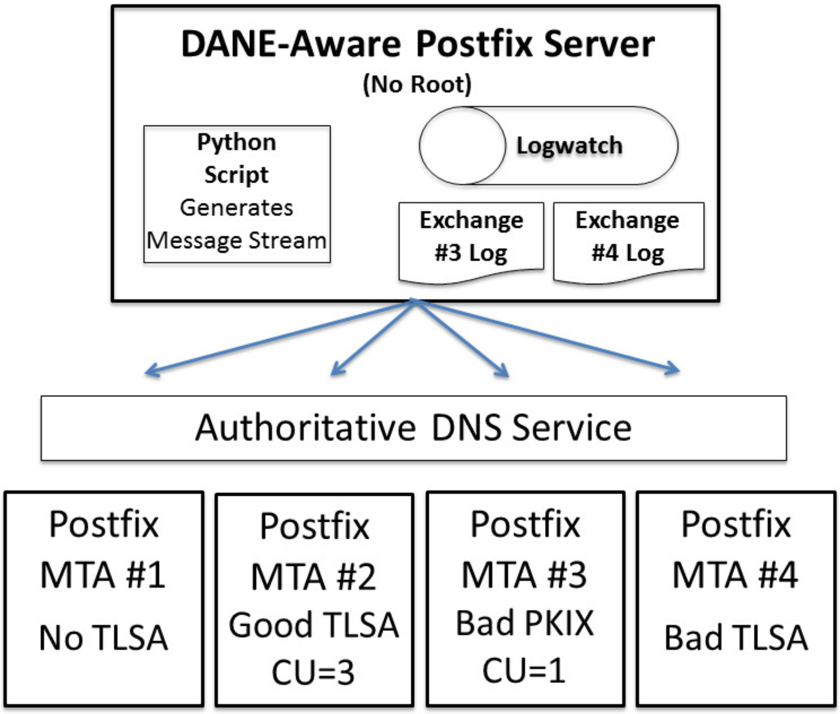
The test sequence was set up as described above. The sending MTA was set with different TLS and DANE requirements configuration. Postfix can be configured for different "levels" of TLS and DANE processing and reliance. In the Postfix configuration file (**main.cf**) the option to turn on DANE processing is:

```
smtp_tls_security_level = none | may | encrypt | dane | dane-only | fingerprint
| verify | secure
```

For this test, only **none**, **may**, **dane** and **dane-only** are relevant. These values affect how postfix establish and use TLS when sending email:

- **none:** The sender does not use TLS even when offered or available. Email is always sent in plaintext.
- **may:** The sender uses TLS opportunistically when available. No effort will be made to validate the server peer certificate, but will be used regardless.
- **encrypt:** The sender will only send mail when TLS is available, even if the server peer certificate is on validated. If STARTTLS is not offered, mail is deferred.
- **dane:** The sender attempts to use TLS when offered, and queries for TLSA RRs to help validate the server peer certificate. Mail is still sent if the validation fails, so this is sometimes referred to as "opportunistic DANE".
- **dane-only:** The sender only sends mail when TLS is offered, and there is a valid TLSA RR found. Otherwise, mail is deferred.

Figure C.3 Failed Delivery Logs



Expected Outcome: Little or nothing appears in the sender's logs for messages sent to either the MTA not employing TLS or the employing a valid TLSA. The growth rates for logs for the MTA that employs a TLSA with a certificate usage field of 1, but with a PKIX failure and the one that employs mismatched server cert/TLSA (i.e. DANE validation failure) are measured.

Observed Outcome: The delivery of the email depended on the TLS/DANE status of the receiver and the TLS/DANE configuration on the sender. The results were:

Table C.1 Transaction Results Based on Sender TLS/DANE Connection

TLS/DANE Option	Receiver TLS/DANE deployment			
	No TLS	TLS with valid DANE RR	TLS with DANE PKIX failure	TLS with DANE TLSA RR Error
none	Mail sent in plaintext	Mail sent in plaintext	Mail sent in plaintext	Mail sent in plaintext
may	Mail sent in plaintext	Mail sent over anonymous TLS (i.e., no validation of certificate)	Mail sent over anonymous TLS (i.e., no validation of certificate)	Mail sent over anonymous TLS (i.e., no validation of certificate)
dane	Mail sent in plaintext	Mail sent over TLS (with DANE validation logged)	Mail sent over anonymous TLS (i.e., no validation of certificate)	Mail sent over anonymous TLS (i.e., no validation of certificate)
dane-only	Mail not sent	Mail sent over TLS (with DANE validation logged)	Mail not sent	Mail not sent

From the above table, when the sender was configured to never use TLS, the mail was sent in plaintext regardless of the TLS/DANE configuration of the receiver. When the sender was configured to use TLS opportunistically, it used TLS regardless of the status of the certificate, or TLSA. In fact, the sender did not issue a query to find TLSA RRs even if published. When the sender used opportunistic DANE, it used TLS when available regardless of the DANE validations results. If validation failed, the mail was still sent and the result was logged as an **Untrusted** or **Anonymous** TLS connection, depending on the presence of a TLSA RR.

Of the four options used in the lab, **dane-only** was the most rigorous in what a sender will accept before sending mail. When the receiver did not offer the STARTTLS option, or lacked a TLSA RR, mail was not sent. Likewise, if a TLSA RR was present, but there was an error in validation (either the TLSA RR itself had an error, or PKIX failed), the mail was not sent. Therefore, use of this option was not recommended for general use as this resulted in the majority of email being deferred. It should only be used in scenarios where senders and receivers are coordinated and maintain a stable DANE deployment.

Appendix D Secure Name System (DNS) Deployment Checklist

The following checklist includes actions recommended by NIST SP 800-81-2, *Secure Domain Name System (DNS) Deployment Guide*. The checklist provides secure deployment guidelines for each DNS component based on policies and best practices. The primary security specifications (with associated mechanisms) on which the checklist is based are as follows:

- Internet Engineering Task Force (IETF) Domain Name System Security Extensions (DNSSEC) specifications, covered by Request for Comments (RFC) 3833, 4033, 4034, and 4035
- IETF Transaction Signature (TSIG) specifications, covered by RFCs 2845 and 3007

While not all of the checklist recommendations apply to all cases of DNS-protected email security, the checklist is a reliable guide for secure deployment of DNS components.

1. **Checklist item 1:** When installing the upgraded version of name server software, the administrator should make necessary changes to configuration parameters to take advantage of new security features.
2. **Checklist item 2:** Whether running the latest version or an earlier version, the administrator should be aware of the vulnerabilities, exploits, security fixes, and patches for the version that is in operation in the enterprise. The following actions are recommended (for BIND deployments):
    - Subscribe to ISC's mailing list called **bind-announce** or **nsd-users** for NSD
    - Periodically refer to the BIND vulnerabilities page at http://www.isc.org/products/BIND/bind-security.html
    - Refer to CERT/CC's Vulnerability Notes Database at http://www.kb/cert/org/vuls/ and the NIST NVD metabase at http://nvd.nist.gov.

    For other implementations (e.g., MS Windows Server), other announcement lists may exist.
3. **Checklist item 3:** To prevent unauthorized disclosure of information about which version of name server software is running on a system, name servers should be configured to refuse queries for its version information.
4. **Checklist item 4:** The authoritative name servers for an enterprise should be both network and geographically dispersed. Network-based dispersion consists of ensuring that all name servers are not behind a single router or switch, in a single subnet, or using a single leased line. Geographic dispersion consists of ensuring that not all name servers are in the same physical location, and hosting at least a single secondary server off-site.
5. **Checklist item 5:** If a hidden master is used, the hidden authoritative master server should only accept zone transfer requests from the set of secondary zone name servers and refuse all other DNS queries. The IP address of the hidden master should not appear in the name server set in the zone database.
6. **Checklist item 6:** For split DNS implementation, there should be a minimum of two physical files or views. One should exclusively provide name resolution for hosts located inside the firewall. It also can contain RRsets for hosts outside the firewall. The other file or view

should provide name resolution only for hosts located outside the firewall or in the DMZ, and not for any hosts inside the firewall.

7. **Checklist item 7:** It is recommended that the administrator create a named list of trusted hosts (or blacklisted hosts) for each of the different types of DNS transactions. In general, the role of the following categories of hosts should be considered for inclusion in the appropriate ACL:
   - DMZ hosts defined in any of the zones in the enterprise
   - all secondary name servers allowed to initiate zone transfers
   - internal hosts allowed to perform recursive queries
8. **Checklist item 8:** The TSIG key (secret string) should be a minimum of 112 bits in length if the generator utility has been proven to generate sufficiently random strings [800-57P1]. 128 bits recommended.
9. **Checklist item 9:** A unique TSIG key should be generated for each set of hosts (i.e. a unique key between a primary name server and every secondary server for authenticating zone transfers).
10. **Checklist item 10:** After the key string is copied to the key file in the name server, the two files generated by the dnssec-keygen program should either be made accessible only to the server administrator account (e.g., root in Unix) or, better still, deleted. The paper copy of these files also should be destroyed.
11. **Checklist item 11:** The key file should be securely transmitted across the network to name servers that will be communicating with the name server that generated the key.
12. **Checklist item 12:** The statement in the configuration file (usually found at /etc/named.conf for BIND running on Unix) that describes a TSIG key (key name (ID), signing algorithm, and key string) should not directly contain the key string. When the key string is found in the configuration file, the risk of key compromise is increased in some environments where there is a need to make the configuration file readable by people other than the zone administrator. Instead, the key string should be defined in a separate key file and referenced through an include directive in the key statement of the configuration file. Every TSIG key should have a separate key file.
13. **Checklist item 13:** The key file should be owned by the account under which the name server software is run. The permission bits should be set so that the key file can be read or modified only by the account that runs the name server software.
14. **Checklist item 14:** The TSIG key used to sign messages between a pair of servers should be specified in the server statement of both transacting servers to point to each other. This is necessary to ensure that both the request message and the transaction message of a particular transaction are signed and hence secured.
15. **Checklist item 15:** Name servers that deploy DNSSEC signed zones or query signed zones should be configured to perform DNSSEC processing.
16. **Checklist item 16:** The private keys corresponding to both the ZSK and the KSK should not be kept on the DNSSEC-aware primary authoritative name server when the name server does not support dynamic updates. If dynamic update is supported, the private key corresponding to the ZSK alone should be kept on the name server, with appropriate directory/file-level access control list-based or cryptography-based protections.

17. **Checklist item 17:** Signature generation using the KSK should be done offline, using the KSK-private stored offline; then the DNSKEY RRSet, along with its RRSIG RR, can be loaded into the primary authoritative name server.
18. **Checklist item 18:** The refresh value in the zone SOA RR should be chosen with the frequency of updates in mind. If the zone is signed, the refresh value should be less than the RRSIG validity period.
19. **Checklist item 19:** The retry value in a zone SOA RR should be 1/10th of the refresh value.
20. **Checklist item 20:** The expire value in the zone SOA RR should be 2 to 4 weeks.
21. **Checklist item 21:** The minimum TTL value should be between 30 minutes and 5 days.
22. **Checklist item 22:** A DNS administrator should take care when including HINFO, RP, LOC, or other RR types that could divulge information that would be useful to an attacker, or the external view of a zone if using split DNS. These RR types should be avoided if possible and only used if necessary to support operational policy.
23. **Checklist item 23:** A DNS administrator should review the data contained in any TXT RR for possible information leakage before adding it to the zone file.
24. **Checklist item 24:** The validity period for the RRSIGs covering a zone's DNSKEY RRSet should be in the range of 2 days to 1 week. This value helps reduce the vulnerability period resulting from a key compromise.
25. **Checklist item 25:** A zone with delegated children should have a validity period of a few days to 1 week for RRSIGs covering the DS RR for a delegated child. This value helps reduce the child zone's vulnerability period resulting from a KSK compromise and scheduled key rollovers.
26. **Checklist item 26:** If the zone is signed using NSEC3 RRs, the salt value should be changed every time the zone is completely resigned. The value of the salt should be random, and the length should be short enough to prevent a FQDN to be too long for the DNS protocol (i.e. under 256 octets).
27. **Checklist item 27:** If the zone is signed using NSEC3 RRs, the iterations value should be based on available computing power available to clients and attackers. The value should be reviewed annually and increased if the evaluation conditions change.
28. **Checklist item 28:** TTL values for DNS data should be set between 30 minutes (1800 seconds) and 24 hours (86400 seconds).
29. **Checklist item 29:** TTL values for RRsets should be set to be a fraction of the DNSSEC signature validity period of the RRSIG that covers the RRset.
30. **Checklist item 30:** The (often longer) KSK needs to be rolled over less frequently than the ZSK. The recommended rollover frequency for the KSK is once every 1 to 2 years, whereas the ZSK should be rolled over every 1 to 3 months for operational consistency but may be used longer if necessary for stability or if the key is of the appropriate length. Both keys should have an Approved length according to NIST SP 800-57 Part 1 [800-57P1], [800-57P3].

Zones that pre-publish the new public key should observe the following:

31. **Checklist item 31:** The secure zone that pre-publishes its public key should do so at least one TTL period before the time of the key rollover.

32. **Checklist item 32:** After removing the old public key, the zone should generate a new signature (RRSIG RR), based on the remaining keys (DNSKEY RRs) in the zone file.
33. **Checklist item 33:** A DNS administrator should have the emergency contact information for the immediate parent zone to use when an emergency KSK rollover must be performed.
34. **Checklist item 34:** A parent zone must have an emergency contact method made available to its delegated child subzones in case of emergency KSK rollover. There also should be a secure means of obtaining the new KSK.
35. **Checklist item 35:** Periodic re-signing should be scheduled before the expiration field of the RRSIG RRs found in the zone. This is to reduce the risk of a signed zone being rendered bogus because of expired signatures.
36. **Checklist item 36:** The serial number in the SOA RR must be incremented before re-signing the zone file. If this operation is not done, secondary name servers may not pick up the new signatures because they are refreshed purely on the basis of the SOA serial number mismatch. The consequence is that some security-aware resolvers will be able to verify the signatures (and thus have a secure response) but others cannot.
37. **Checklist item 37:** Recursive servers/resolvers should be placed behind an organization's firewall and configured to only accept queries from internal hosts (e.g., Stub Resolver host).
38. **Checklist Item 38:** Whenever Aggregate Caches are deployed, the forwarders must be configured to be Validating Resolvers.
39. **Checklist item 39:** Each recursive server must have a root hints file containing the IP address of one or more DNS root servers. The information in the root hints file should be periodically checked for correctness.
40. **Checklist item 40:** The root hints file should be owned by the account under which the name server software is run. The permission bits should be set so that the root hints file can be read or modified only by the account that runs the name server software.
41. **Checklist item 41:** Administrators should configure two or more recursive resolvers for each stub resolver on the network.
42. **Checklist item 42:** Enterprise firewalls should consider restricting outbound DNS traffic from stub resolvers to only the enterprise's designated recursive resolvers.
43. **Checklist item 43:** Each recursive server must have a root hints file containing the IP address of one or more DNS root servers. The information in the root hints file should be periodically checked for correctness.
44. **Checklist item 44:** The root hints file should be owned by the account under which the name server software is run. The permission bits should be set so that the root hints file can be read or modified only by the account that runs the name server software.
45. **Checklist item 45:** Administrators should configure two or more recursive resolvers for each stub resolver on the network.
46. **Checklist item 46:** Enterprise firewalls should consider restricting outbound DNS traffic from stub resolvers to only the enterprise's designated recursive resolvers.
47. **Checklist item 47:** Non-validating stub resolvers (both DNSSEC-aware and non-DNSSEC-aware) must have a trusted link with a validating recursive resolver.

48. **Checklist item 48:** Validators should routinely log any validation failures to aid in diagnosing network errors.
49. **Checklist item 49:** Mobile or nomadic systems should either perform their own validation or have a trusted channel back to a trusted validator.
50. **Checklist item 50:** Mobile or nomadic systems that perform its own validation should have the same DNSSEC policy and trust anchors as validators on the enterprise network.
51. **Checklist item 51:** Validator administrator must configure one or more trust anchors for each validator in the enterprise.
52. **Checklist item 52:** The validator administrator regularly checks each trust anchor to ensure that it is still in use, and updates the trust anchor as necessary.

Appendix E Overview of Products Contributed by Collaborators

Components provided by collaborators included Mail User Agents (MUAs), Mail Transfer Agents (MTAs), and DNS Services. Most of the products included were DNS service components, but these DNS service components were initially provided with MUAs and MTAs in all cases. Where the MUA and MTA components employed are not part of the collaborator's standard offering, open source MUA and MTA components were included in the initial collaborator installation. Component overviews follow:

E.1 Open Source MUA and MTA Components

E.1.1 Thunderbird Mail User Agent

Mozilla Thunderbird is a free, open source, cross-platform email, news, and chat client developed by the Mozilla Foundation. Thunderbird is an email, newsgroup, news feed, and chat (XMPP, IRC, Twitter) client. The Mozilla Lightning extension, which is installed by default, adds PIM functionality. Thunderbird can manage multiple email, newsgroup, and news feed accounts and supports multiple identities within accounts. Features such as quick search, saved search folders (virtual folders), advanced message filtering, message grouping, and labels help manage and find messages. On Linux-based systems, system mail (movemail) accounts are supported. Thunderbird incorporates a Bayesian spam filter, a whitelist based on the included address book, and can also understand classifications by server-based filters such as SpamAssassin.

Thunderbird has native support for RFC 3851 S/MIME, but RFC 5757 (S/MIME version 3.2) is not supported. Support for other security systems can be added by installing extensions (e.g, the Enigmail extension adds support for PGP). S/MIME and PGP cannot both be used in the same message. SSL/TLS is also supported, but it is used only to temporarily encrypt data being send and received between an email client and server. SSL/TLS can work in combination with S/MIME or OpenPGP.

Thunderbird supports POP and IMAP. It also supports LDAP address completion. Thunderbird supports the S/MIME standard, extensions such as Enigmail add support for the OpenPGP standard. A list of supported IMAP extensions can be found at wiki.mozilla.org. Since version 38, Thunderbird has integrated support for automatic linking of large files instead of attaching them directly to the mail message.

Thunderbird runs on a variety of platforms. Releases available on the primary distribution site support Linux, Windows, and OS X operating systems. Unofficial ports are available for FreeBSD, OpenBSD, OpenSolaris, OS/2, and eComStation.

E.1.2 Dovecot

Dovecot is used in the DNS-Based Email Security project to permit MUA access to the Postfix MTA. Dovecot is an open source IMAP[1] and POP3 email server for Linux/UNIX-like systems, written with security primarily in mind. Dovecot is used in both small and large installations. It is compact and requires no special administration and it uses very little memory. Dovecot supports the standard mbox and Maildir formats. The mailboxes are transparently indexed and provide full compatibility with existing mailbox handling tools. Dovecot v1.1 passes all IMAP server standard compliance tests. Dovecot allows mailboxes and their indexes to be modified by multiple computers at the same time, providing compatibility with clustered file systems. Caching problems can be worked around with director proxies. Postfix 2.3+ and Exim 4.64+ users can do SMTP authentication directly against Dovecot's authentication backend without having to configure it separately, and Dovecot supports easy migration from many existing IMAP and POP3 servers, allowing the change to be transparent to existing users.

Dovecot currently offers IMAP4rev1, POP3, IPv6, SSL and TLS support. It supports multiple commonly used IMAP extensions, including SORT, THREAD and IDLE. Shared mailboxes are supported in v1.2+. Maildir++ quota is supported, but hard file system quota can introduce problems. Dovecot is commonly used with Linux, Solaris, FreeBSD, OpenBSD, NetBSD and Mac OS X. See the Dovecot Wiki page (http://wiki2.dovecot.org/OSCompatibility) about OS compatibility for more.

E.1.3 Postfix

Postfix is a free and open-source mail transfer agent (MTA) that routes and delivers electronic mail. Postfix is released under the IBM Public License 1.0 which is a free software license. As an SMTP client, Postfix implements a high-performance parallelized mail-delivery engine. Postfix is often combined with mailing-list software (such as Mailman).

Postfix consists of a combination of server programs that run in the background, and client programs that are invoked by user programs or by system administrators. The Postfix core consists of several dozen server programs that run in the background, each handling one specific aspect of email delivery. Examples are the SMTP server, the scheduler, the address rewriter, and the local delivery server. For damage-control purposes, most server programs run with fixed reduced privileges, and terminate voluntarily after processing a limited number of requests. To conserve system resources, most server programs terminate when they become idle.

Client programs run outside the Postfix core. They interact with Postfix server programs through mail delivery instructions in the user's ~/.forward file, and through small “gate” programs to submit mail or to request queue status information.

As an SMTP server, Postfix implements a first layer of defense against spambots and malware. Administrators can combine Postfix with other software that provides spam/virus filtering (e.g., Amavisd-new), message-store access (e.g., Dovecot), or complex SMTP-level access-policies (e.g., postfwd, policyd-weight or greylisting).

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1. The Internet Message Access Protocol (IMAP) is a mail protocol used for accessing email on a remote web server from a local client. IMAP and POP3 are the two most commonly used Internet mail protocols for retrieving emails. Both protocols are supported by all modern email clients and web servers.

Features include:

- standards-compliant support for SMTPUTF8, SMTP, LMTP, STARTTLS encryption including DANE protocol support and “perfect” forward secrecy, SASL authentication, MIME encapsulation and transformation, DSN delivery status notifications, IPv4, and IPv6
- configurable SMTP-level access policy that automatically adapts to overload
- virtual domains with distinct address-namespaces
- UNIX-system interfaces for command-line submission, for delivery to command, and for direct delivery to message stores in mbox and maildir format
- light-weight content inspection based on regular expressions
- database lookup mechanisms including Berkeley DB, CDB, OpenLDAP LMDB, Memcached, LDAP and multiple SQL database implementations
- a scheduler that implements parallel deliveries, with configurable concurrency and back-off strategies
- a scalable zombie blocker that reduces SMTP server load due to botnet spam

Postfix extensions use the SMTP or Milter (Sendmail mail filter) protocols which both give full control over the message envelope and content, or a simple text-based protocol that enables complex SMTP-level access control policies. Extensions include:

- deep content inspection before or after a message is accepted into the mail queue
- mail authentication with DMARC, DKIM, SPF, or other protocols
- SMTP-level access policies such as greylisting or rate control

Postfix runs on BSD, GNU/Linux, OS X, Solaris and most other Unix-like operating system, generally ships with a C compiler, and delivers a standard POSIX development environment. It is the default MTA for the OS X, NetBSD and Ubuntu operating systems.

E.2 Microsoft Windows-Based Components

Microsoft's contribution includes a complete MUA, MTA, and DNS service stack, though each of the components can be integrated into systems provided by other contributors.

E.2.1 Outlook

Microsoft Outlook is a personal information manager from Microsoft, available as a part of the Microsoft Office suite. Although often used mainly as an email application, it also includes a calendar, task manager, contact manager, note taking, journal, and web browsing. It can be used as a stand-alone application, or can work with Microsoft Exchange Server and Microsoft SharePoint Server for multiple users in an organization, such as shared mailboxes and calendars, Exchange public folders, SharePoint lists, and meeting schedules. Microsoft has also released mobile applications for most mobile platforms, including iOS and Android. Developers can also create their own custom software that works with Outlook and Office components using Microsoft Visual Studio. In addition, mobile devices can synchronize almost all Outlook data to Outlook Mobile. Microsoft Outlook mail system uses the proprietary Messaging

Application Programming Interface (MAPI) to access Microsoft Exchange electronic mail servers.

Outlook supports S/MIME (Secure/Multipurpose Internet Mail Extensions) is a standard for public key encryption and signing of MIME data. S/MIME is on an IETF standards track and defined in a number of documents, most importantly RFCs 3369, 3370, 3850 and 3851.

E.2.2 Exchange

Microsoft Exchange Server is a calendaring and mail server developed by Microsoft that runs exclusively on the Microsoft Windows Server product line. Exchange Server was initially Microsoft's internal mail server but is now published outside Microsoft. It uses the Active Directory directory service. It is bundled with the Outlook email client.

Exchange Server supports POP3, IMAP, SMTP and EAS. It also supports IPv6, SMTP over TLS, PoP over TLS, NNTP, and SSL. Exchange Server is licensed both in the forms of on-premises software and software as a service. In the on-premises form, customer purchase client access licenses (CALs). In the software as a service form, Microsoft receives a monthly service fee instead (see https://en.wikipedia.org/wiki/Office_365).

E.2.3 Server DNS Services

Windows Server 2016 is a server operating system developed by Microsoft as part of the Windows NT family of operating systems, developed concurrently with Windows 10. Microsoft Server features server virtualization, networking, server management and automation, a web and application platform, access and information protection, and virtual desktop infrastructure. Key operating system elements for the DNS-Based Email Security project are Active Directory and DNS Server.

E.2.3.1 Active Directory

Active Directory (AD) is a directory service that Microsoft developed for Windows domain networks. It is included in most Windows Server operating systems as a set of processes and services. Initially, Active Directory was only in charge of centralized domain management. Active Directory is an umbrella title for a broad range of directory-based identity-related services. A server running Active Directory Domain Services (AD DS) is called a domain controller. It authenticates and authorizes all users and computers in a Windows domain type network-assigning and enforcing security policies for all computers and installing or updating software. For example, when a user logs into a computer that is part of a Windows domain, Active Directory checks the submitted password and determines whether the user is a system administrator or normal user.

Active Directory uses Lightweight Directory Access Protocol (LDAP) versions 2 and 3, Microsoft's version of Kerberos, and DNS. Active Directory Domain Services (AD DS) is the cornerstone of every Windows domain network. It stores information about members of the domain, including devices and users, verifies their credentials and defines their access rights. The server (or the cluster of servers) running this service is called a domain controller. A domain controller is contacted when a user logs into a device, accesses another device across the network, or runs a line-of-business Metro-style application side loaded into a device. Other Active Directory services (excluding LDS, as well as most of Microsoft server technologies rely on or use Domain

Services; examples include Group Policy, Encrypting File System, BitLocker, Domain Name Services, Remote Desktop Services, Exchange Server and SharePoint Server.

Active Directory Certificate Services (AD CS) establishes an on-premises public key infrastructure. It can create, validate and revoke public key certificates for internal uses of an organization. These certificates can be used to encrypt files (when used with Encrypting File System), emails (per S/MIME standard), network traffic (when used by virtual private networks, Transport Layer Security protocol or IPSec protocol).

E.2.3.2 DNS Server

Microsoft Windows server operating systems can run the DNS Server service, a monolithic DNS server that provides many types of DNS service, including caching, Dynamic DNS update, zone transfer, and DNS notification. DNS notification implements a push mechanism for notifying a select set of secondary servers for a zone when it is updated. DNS Server has improved interoperability with BIND and other implementations in terms of zone file format, zone transfer, and other DNS protocol details.

Microsoft's DNS server supports different database back ends. Microsoft's DNS server supports two such back ends. DNS data can be stored either in master files (also known as zone files) or in the Active Directory database itself. In the latter case, since Active Directory (rather than the DNS server) handles the actual replication of the database across multiple machines, the database can be modified on any server (multiple-master replication), and the addition or removal of a zone will be immediately propagated to all other DNS servers within the appropriate Active Directory “replication scope”. (Contrast this with BIND, where when such changes are made, the list of zones, in the /etc/named.conf file, has to be explicitly updated on each individual server.)

Microsoft's DNS server can be administered using either a graphical user interface, the DNS Management Console, or a command line interface, the dnscmd utility. New to Windows Server 2012 is a fully featured PowerShell provider for DNS server management.

E.3 NLnet Labs Name Server Daemon-Based Components

E.3.1 NSD4 Authoritative Name Server

Name Server Daemon (NSD) is an open-source DNS server. It was developed from scratch by NLnet Labs of Amsterdam in cooperation with the RIPE NCC, as an authoritative name server (i.e., not implementing the recursive caching function by design). The intention of this development is to add variance to the “gene pool” of DNS implementations originally intended for root servers, top-level domains (TLDs) and second-level domains (SLDs), thus increasing the resilience of DNS against software flaws or exploits.

NSD uses BIND-style zone-files (zone-files used under BIND can usually be used unmodified in NSD, once entered into the NSD configuration).

The collection of programs/processes that make-up NSD are designed so that the NSD daemon itself runs as a non-privileged user and can be easily configured to run in a Chroot jail, such that security flaws in the NSD daemon are not so likely to result in system-wide compromise as without such measures.

The latest current stable release is NSD 4.1.13. Download the latest version here: https://www.nlnetlabs.nl/downloads/nsd/nsd-4.1.10.tar.gz.

NSD is thoroughly tested, there is a regression tests report available.

For NSD 4, the memory estimation tool can be compiled in the source tarball with **`make nsd-mem`** and running it on a config file with the zone files in question.

NLnet Labs has a long-term commitment for supporting NSD. There will be an advanced notice when the organization's commitment ends. The latest NSD release will supported for at least two years after an end-of-life notification has been sent to the community.

Manual pages are installed, they can also be viewed:

1. nsd(8) man page: https://www.nlnetlabs.nl/projects/nsd/nsd.8.html
2. nsd-control(8) man page: https://www.nlnetlabs.nl/projects/nsd/nsd-control.8.html
3. nsd-checkconf(8) man page: https://www.nlnetlabs.nl/projects/nsd/nsd-checkconf.8.html
4. nsd-checkzone(8) man page: https://www.nlnetlabs.nl/projects/nsd/nsd-checkzone.8.html
5. nsd.conf(5) man page: https://www.nlnetlabs.nl/projects/nsd/nsd.conf.5.html

NSD users can subscribe to nsd-users and browse the archives of nsd-users here http://open.nlnetlabs.nl/mailman/listinfo/nsd-users/.

The repository of NSD is available at /svn/nsd/, the NSD 4.x.x development tree is located in trunk/.

E.3.2 OpenDNSSEC Domain Name Security Manager

OpenDNSSEC software manages the security of domain names on the Internet. The OpenDNSSEC project is a cooperative effort intended to drive adoption of Domain Name System Security Extensions (DNSSEC) in order to further enhance Internet security. OpenDNSSEC was created as an open-source turn-key solution for DNSSEC. It secures DNS zone data just before it is published in an authoritative name server. OpenDNSSEC takes in unsigned zones, adds digital signatures and other records for DNSSEC and passes it on to the authoritative name servers for that zone. OpenDNSSEC will furthermore take care of the key management and roll-over procedure to replace keys. It acts as a bump in the wire, where it will fit in an existing DNS tool chain without modification in that tool chain. Incrementally incorporating changes and re-using already signed zones to perform a constant up-to-date zone.

All keys are stored in a hardware security module and accessed via PKCS #11, a standard software interface for communicating with devices which hold cryptographic information and perform cryptographic functions. OpenDNSSEC uses SoftHSM, OpenSSL, the Botan cryptographic library, and SQLite or MySQL as database back-end. It is used on the .se, .dk, .nl .ca, .za, .uk, and other top-level domains. OpenDNSSEC can be downloaded from:

- https://dist.opendnssec.org/source/opendnssec-2.0.1.tar.gz
- https://dist.opendnssec.org/source/opendnssec-2.0.1.tar.gz.sig

- Checksum SHA256: bf874bbb346699a5b539699f90a54e0c15fff0574df7a3c118abb30938b7b346

In August of 2014, NLnet Labs took responsibility for continuing the OpenDNSSEC activities of both the OpenDNSSEC software project and the Swedish OpenDNSSEC AB.

E.3.3 Unbound DNS Resolver

Unbound is a validating, recursive, and caching DNS resolver. The C implementation of Unbound is developed and maintained by NLnet Labs. It is based on ideas and algorithms taken from a Java prototype developed by Verisign labs, Nominet, Kirei and ep.net. Unbound is designed as a set of modular components, so that also DNSSEC (secure DNS) validation and stub-resolvers (that do not run as a server, but are linked into an application) are easily possible.

The source code is under a BSD License.

Release 1.5.9 of Unbound was released June 9, 2016. The repository for unbound is available https://unbound.nlnetlabs.nl/svn/. The development tree is located in trunk/.

The latest source code tarball is available for download.

Unbound problems can be reported through the NLnet Labs bugzilla web interface. In the case NLnet Labs will stop supporting the product, and they will announce such two years in advance. Unbound is subject to NLnet Labs Security Patch Policy. Commercial support for Unbound is available from several organizations.

E.4 ISC BIND Component

Internet Systems Consortium, Inc., also known as ISC, is a non-profit corporation that supports the infrastructure of the Internet by developing and maintaining core production-quality software, protocols, and operations. ISC has developed several key Internet technologies that enable the global Internet, including BIND.

BIND is open source software that implements the Domain Name System (DNS) protocols for the Internet. It is a reference implementation of those protocols, but it is also production-grade software, suitable for use in high-volume and high-reliability applications. The acronym BIND stands for Berkeley Internet Name Domain, because the software originated in the early 1980s at the University of California at Berkeley.

BIND is widely used DNS software that provides a stable platform on top of which organizations can build distributed computing systems that are fully compliant with published DNS standards.

BIND is transparent open source. If an organization needs some functionality that is not in BIND, it is possible to modify it, and contribute the new feature back to the community by sending ISC its source. It is possible to download a tar ball from the ISC web site (https://www.isc.org/downloads/), ftp.isc.org (http://ftp.isc.org/isc/bind9/cur/), or a binary from an organization's operating system repository.

The BIND software distribution has three parts:

E.4.1 Domain Name Resolver

The BIND resolver is a program that resolves questions about names by sending those questions to appropriate servers and responding appropriately to the servers' replies. In the most common application, a web browser uses a local stub resolver library on the same computer to look up names in the DNS. That stub resolver is part of the operating system. (Many operating system distributions use the BIND resolver library.) The stub resolver usually will forward queries to a caching resolver, a server or group of servers on the network dedicated to DNS services. Those resolvers will send queries to one or multiple authoritative servers in order to find the IP address for that DNS name.

DNS authoritative operations include the following features:

1. **NXDOMAIN Redirect:** When a user searches for a non-existent domain, (NXDOMAIN response) the user can be redirected to another web page. This is done using the BIND DLZ feature.
2. **Flexible Cache Controls:** From time to time users can get incorrect or outdated records in the resolver cache. BIND gives users the ability to remove them selectively or wholesale.
3. **Split DNS:** BIND provides the ability to configure different views in a single BIND server. This allows users to give internal (on-network) and external (from the Internet) users different views of DNS data, keeping some DNS information private.
4. **Cache Hit Rate Optimization:** BIND is designed to be persistent and resilient in resolving queries even when there is a delay in responding, in order to populate the cache for later requests. DNS Pre-fetch is a technique for continuously refreshing the cached records for popular domains, reducing the time the user has to wait for a response.
5. **Resolver Rate-limiting:** Beginning with BIND 9.10.3, two new configuration parameters were added, *fetches-per-zone* and *fetches-per-server*. These features enable rate-limiting queries to authoritative systems that appear to be under attack. These features have been successful in mitigating the impact of a DDOS attack on resolvers in the path of the attack.
6. **DNSSEC Validation:** DNSSEC validation protects clients from impostor sites. In BIND, this is enabled with a single command. BIND supports RFC 5011 maintenance of root key trust anchors. BIND also has a Negative Trust Anchor feature (introduced in the 9.9 subscription branch), which temporarily disables DNSSEC validation when there is a problem with the authoritative server's DNSSEC support.
7. **Geo IP:** GeoIP, or Geographic IP, allows a BIND DNS server to provide different responses based on the network information about the recursive DNS resolver that a user is using. There is an active Internet Draft describing another mechanism for providing location information, called EDNS-Client-Subnet-Identifier. This requires the resolver to cache multiple different addresses for a given DNS record, depending on the address of the requester. This feature has not been added to the BIND9 resolver, although the corresponding feature has been developed for the BIND9 authoritative server.
8. **Response Policy Zone:** A Response Policy Zone or RPZ is a specially-constructed zone that specifies a policy rule set. The primary application is for blocking access to zones that are believed to be published for abusive or illegal purposes. There are companies who specialize in identifying abuse sites on the Internet, who market these lists in the form of RPZ feeds. For more information on RPZ, including a list of DNS reputation feed providers, see https://dnsrpz.info.

E.4.2 Domain Name Authority Server

The authoritative DNS server answers requests from resolvers, using information about the domain names it is authoritative for. Enterprises can provide DNS services on the Internet by installing this software on a server and giving it information about the enterprise's domain names.

1. **Response Rate Limiting:** An enhancement to the DNS protocol to reduce the problem of “amplification attacks” by limiting DNS responses. Response rate limiting is on by default.
2. **Dynamically-Loadable Zones:** enable BIND9 to retrieve zone data directly from an external database. This is not recommended for high-query rate authoritative environments.
3. **Reload Time Reduction:** BIND server zone files can be updated via nsupdate, and 'dynamic' zone files can be added via RNDC, both without restarting BIND. For those times when it is necessary to restart, the **MAP** zone file format can speed up re-loading a large zone file into BIND, such as on restart.
4. **Hardware Security Modules:** BIND supports the use of Hardware Security Modules through either a native PKCS#11 interface, or the OpenSSL PKCS#11 provider. HSMs are used to store key material outside of BIND for security reasons.
5. **DNSSEC With In-line Signing:** BIND fully supports DNSSEC With In-line Signing and has an easy-to use implementation. Once an enterprise has initially signed its zones, BIND can automatically re-sign the records as they are updated with in-line signing, maintaining the DNSSEC validity of the records. BIND supports both NSEC and NSEC3 and inline signing works with NSEC3.
6. **Catalog Zones:** Catalog Zones were introduced in BIND 9.11.0 to facilitate the provisioning of zone information across a nameserver constellation. Catalog Zones are particularly useful when there are a large number of secondary servers. A special zone of a new type, a catalog zone, is set up on the master. Once a catalog zone is configured, when an operator wishes to add a new zone to the nameserver constellation s/he can provision the zone in one place only, on the master server and add an entry describing the zone to the catalog zone. As the secondary servers receive the updated copy of the catalog zone data they will note the new entry and automatically create a zone for it. Deletion of a zone listed in a catalog zone is done by deleting the entry in the catalog zone on the master.
7. **Scalable Master/Slave Hierarchy:** A DNS authoritative system is composed of a zone primary or master with one or more slave servers. Zones files are established and updated on a master BIND server. Slaves maintain copies of the zone files and answer queries. This configuration allows scaling the answer capacity by adding more slaves, while zone information is maintained in only one place. The master signals that updated information is available with a notify message to the slaves, and the slaves then initiate an update from the master. BIND fully supports both the AXFR (complete transfer) and IXFR (incremental transfer) methods, using the standard TSIG security mechanism between servers. There are a number of configuration options for controlling the zone updating process.

E.4.3 Tools

ISC includes a number of diagnostic and operational tools. Some of them, such as the popular DIG tool, are not specific to BIND and can be used with any DNS server.

E.5 Secure64 Component

The Secure64 contributions included an automated online Secure64 DNS Signer delivered on dedicated hardware and DNSSEC-capable VM images of DNS Cache, DNS Authority, and DNS Manager. DNS Manager provided centralized management of Secure64 DNS Cache software and configurations and provided network-wide monitoring of key performance indicators. DNS Manager allowed creation of groups of servers and assignment of configurations to a group, a single server, or all servers. DNS Authority is an authoritative signer and server as a single platform. This stack was able to demonstrate Outlook, Thunderbird, or Apple Mail as MUAs and uses Postfix as an MTA and Dovecot to provide IMAP for clients. Descriptions of the DNS service components follow:

E.5.1 DNS Signer

Secure64 DNS Signer is DNSSEC key management and zone signing software that is designed to facilitate and provide security for DNSSEC implementation. Secure64 DNS Signer fully automates DNSSEC key generation, key rollover, zone signing and re-signing processes, It is designed to scale to large, dynamic environments by maintaining DNSSEC signing keys securely online while providing incremental zone signing and high signing performance. Signer integrates into existing infrastructures configurations. It is fully compatible with Secure64 DNS Authority, BIND, NSD, and Microsoft DNS masters and slaves. Signer supports all of the RFCs and best practices required to deploy DNSSEC.

E.5.2 DNS Authority

Secure64 DNS Authority is a name server software product. It provides built-in DoS protection that identifies and blocks TCP or UDP attack traffic. It is designed to respond to legitimate queries, even while under attack. DNS Authority provides real-time alerts and attack characteristics through syslog and SNMP traps in order to enable remedial action. Authority is also designed to be anycasted in any data center, even for enterprises that don't operate the routing infrastructure. The administrator can insert and withdraw servers without requiring router changes or deploying dedicated router hardware. Authority directly reads existing BIND configuration files and is interoperable with name servers running BIND, NSD, or Microsoft Windows DNS software. Some specific features include the following:

1. **IPv6 support:** Authority supports IPv6 in either dual stack or IPv6-only mode.
2. **PipeProtector:** Authority's PipeProtectorTM feature protects networks by automatically identifying the sources of amplified flood attacks and communicating with the upstream router to blackhole the attack traffic.
3. **Built-in BGP:** Built-in Border Gateway Protocol (BGP) permits Authority to be set up in an anycast configuration, which provides greater resiliency against denial-of-service attacks and improved performance. After BGP is initially configured, the administrator can insert and withdraw the server from the anycast cluster without making router changes.
4. **Secured runtime environment:** Authority is designed to run on a SourceT operating system and to utilizes server hardware security capabilities to eliminate all paths for injection or execution of malicious code at runtime.

5. **System Authentication:** Digital signatures of the firmware, operating system and application code are all validated during the boot process. This protects against the operating system and the application code images on disk from being compromised by a rootkit.
6. **Secured zone data:** Authority provides end-to-end integrity protection of zone data by supporting DNSSEC, TSIG and ACLs for queries, notifies and zone transfers.
7. **Synthesized PTR records:** Reverse DNS records for IPv6 addresses or other large address blocks can be generated on the fly where necessary to preserve compatibility with other systems that rely upon the existence of these reverse records.
8. **Standards support:** Authority supports ENUM standards, including RFC 3163 (SIP initiation protocol), RFC 6116 (storage of data for E.164 numbers in the DNS) and 3GPP TS 29.303 (DNS procedures for the Evolved Packet System).
9. **Split horizon DNS:** Views permit configuration of an authoritative server to provide different functionality and responses based on characteristics of the requesting client.

E.5.3 DNS Cache

Secure64 DNS Cache is scalable, secure, caching DNS software designed to provide built-in protection against high volume denial-of-service attacks and immunity to BIND-specific security vulnerabilities. DNS Guard is a family of security services that protect users and the network from malicious activity, while the Web Error Redirection Module allows service providers to improve the end user's experience while generating incremental revenues that flow right to the bottom line. Some specific features include the following:

1. **IPv6 Support:** DNS Cache supports both dual stack and deployment of a pure IPv6 network while providing compatibility with IPv4 networks.
2. **Built-In DDoS Protection:** Built-in DDoS detection and mitigation allows DNS Cache to continue to respond to legitimate queries while fending off high volume denial-of-service-attacks. This combats a common issue with DNS solutions that crash or become unavailable at lower levels of attack traffic. In addition to mitigating high volume attacks, DNS Cache automatically detects cases of individual clients exceeding a user-defined query threshold and temporarily blacklists them while logging information about the offending client. This helps prevent inadvertent participation in a denial-of-service attack.
3. **SNMP:** DNS Cache provides several MIBs, that allow monitoring of the chassis, network, operating system and application in real time and support a variety of network monitoring systems. In addition, DNS Cache directly provides alerts of critical operational conditions through SNMP traps without requiring special configuration within the network monitoring system.
4. **Centralized management:** DNS Cache servers can be managed individually, or can be centrally managed and monitored through Secure64 DNS Manager.
5. **Scalable performance:** At a 90% cache hit rate, DNS Cache delivers over 125,000 queries per second, which can easily be increased to 280,000 queries per second through the optional software-based Capacity Expansion Module.
6. **DNSSEC validation overrides:** DNS Cache can configured to validate DNSSEC signed answers. Because DNSSEC configuration errors are not uncommon, operators can readily

identify domains failing validation and specify which of these should be allowed to resolve normally.

7. **Merge Zones:** DNS Cache's merge zones feature allows a number of dynamic authoritative zones to be split up among different authoritative servers, each of which is queried for a response to a query for that zone until an answer is received.
8. **Web Error Redirection Module:** The optional Web Error Redirection Module allows service providers to redirect NXDOMAIN responses from authoritative servers to a provider-branded search portal that helps guide users to their intended designation.
9. **Rules engine:** DNS Cache's rules engine provides fine-grained control over which responses are redirected, and includes built-in support for opt-out.

E.5.4 DNS Manager

DNS Manager provides centralized management of Secure64 DNS Cache software and configurations and provides network-wide monitoring of key performance indicators. This GUI based application can configure, manage, and monitor a set of Secure64 DNS Cache servers from one central point. In an environment consisting of many DNS servers, there are likely to be differences in configurations. Some servers may be anycasted, while others are load balanced, for example. Or servers located in different geographies may have different values for local DNS data. DNS Manager allows creation of groups of servers and assigns configurations to a group, a single server, or all servers. Groups may be arranged hierarchically. Common configuration parameters may be assigned to all servers in the network, whereas settings specific to subsets of servers may be assigned at the group level, and IP addresses and other server-specific information are assigned to each specific server. All actions to modify configuration files or software versions are revision controlled and logged. Authorized users can rollback to previous software versions or configurations if necessary. DNS Manager is able to monitor key performance indicators across the DNS network, including queries per second, CPU, disk and memory utilization.

E.5.5 Secure64 Apple Key Chain Utility

The Apple Key Chain Utility is a Secure64 utility for Public Key Retrieval into the Apple Key Chain. This utility is delivered on a MacBook loaded with Apple Mail and is a program for the MacBook that will fetch SMIMEA records and put them in the keystore so that we can demonstrate end-to-end security.

Appendix F Installation and Configuration Log for NSD4, Unbound, and OpenDNSSEC

The following log captures the installation and configuration process for NSD4, Unbound, and OpenDNSSEC for the NCCoE's DNS-Based Email Security project. Please note that the IP addresses, domain names, and mail addresses are for the NCCoE laboratory and must not be used in actual implementations.

```
####
# Unbound installation log for 10.33.XX.XX
###


# Unbound does not depend on a resolver for its installation. However, I
# configure one here so I can use yum from installation of the dependencies.
[rdolmans@unbound ~]$ sudo cp /etc/resolv.conf /etc/resolv.conf.orig
[rdolmans@unbound ~]$ echo "nameserver 10.97.XX.X" | sudo tee -a /etc/resolv.conf


# Install build tools
[rdolmans@unbound ~]$ sudo yum group install "Development Tools"


# Install unbound dependencies: openssl, expat
[rdolmans@unbound ~]$ sudo yum install openssl-devel expat-devel


# Download Unbound and verify
[rdolmans@unbound ~]$ curl https://unbound.net/downloads/unbound-1.5.8.tar.gz -o unbound-
1.5.8.tar.gz
[rdolmans@unbound ~]$ cat unbound-1.5.8.tar.gz | openssl sha256
(stdin)= 33567a20f73e288f8daa4ec021fbb30fe1824b346b34f12677ad77899ecd09be


# We do not need a nameserver anymore, move back old resolv.conf
[rdolmans@unbound ~]$ sudo mv /etc/resolv.conf.orig /etc/resolv.conf


# extract, ./configure, compile and install Unbound
[rdolmans@unbound ~]$ tar xvzf unbound-1.5.8.tar.gz
[rdolmans@unbound ~]$ cd unbound-1.5.8
[rdolmans@unbound unbound-1.5.8]$ ./configure
[rdolmans@unbound unbound-1.5.8]$ make
[rdolmans@unbound unbound-1.5.8]$ sudo make install


# Add system user and group
```

```
[rdolmans@unbound unbound-1.5.8]$ sudo groupadd -r unbound
[rdolmans@unbound unbound-1.5.8]$ sudo useradd -r -g unbound -s /sbin/nologin -c "unbound name
daemon" unbound


# Setup unbound-control, get trust anchor
[rdolmans@unbound ~]$ sudo unbound-control-setup
[rdolmans@unbound ~]$ sudo unbound-anchor


# Config changes:
# 1. Specify the interfaces to listen on
# 2. Allow second host to use this resolver (ACL)
# 3. Load DNSSEC trust anchor obtained using unbound-anchor
# 4. Enable remote-control (for unbound-control command, limited to localhost)


[rdolmans@unbound ~]$ diff -u /usr/local/etc/unbound/unbound.conf.orig /usr/local/etc/unbound/
unbound.conf
--- /usr/local/etc/unbound/unbound.conf.orig    2016-05-10 09:22:13.917495389 -0400
+++ /usr/local/etc/unbound/unbound.conf 2016-05-12 06:34:02.660574284 -0400
@@ -34,6 +34,9 @@
         # specify 0.0.0.0 and ::0 to bind to all available interfaces.
         # specify every interface[@port] on a new 'interface:' labelled line.
         # The listen interfaces are not changed on reload, only on restart.
+        interface: 192.168.3.98
+        interface: ::1
+        interface: 127.0.0.1
         # interface: 192.0.2.153
         # interface: 192.0.2.154
         # interface: 192.0.2.154@5003
@@ -197,6 +200,7 @@
         # access-control: ::0/0 refuse
         # access-control: ::1 allow
         # access-control: ::ffff:127.0.0.1 allow
+        access-control: 192.168.3.0/23 allow


         # if given, a chroot(2) is done to the given directory.
         # i.e. you can chroot to the working directory, for example,
@@ -376,7 +380,7 @@
         # you start unbound (i.e. in the system boot scripts).  And enable:
         # Please note usage of unbound-anchor root anchor is at your own risk
         # and under the terms of our LICENSE (see that file in the source).
-        # auto-trust-anchor-file: "/usr/local/etc/unbound/root.key"
+        auto-trust-anchor-file: "/usr/local/etc/unbound/root.key"



         # File with DLV trusted keys. Same format as trust-anchor-file.
```

```
 	# There can be only one DLV configured, it is trusted from root down.
@@ -614,7 +618,7 @@
 remote-control:
 	# Enable remote control with unbound-control(8) here.
 	# set up the keys and certificates with unbound-control-setup.
-	# control-enable: no
+	control-enable: yes

 	# Set to no and use an absolute path as control-interface to use
 	# a unix local named pipe for unbound-control.


# Start daemon
[rdolmans@unbound ~]$ sudo unbound-control start


# add local resolver to resolv.conf
[rdolmans@unbound ~]$ echo "nameserver ::1" | sudo tee -a /etc/resolv.conf

# Install ldns tools (incl. drill)
[rdolmans@unbound ~]$ sudo yum install ldns


# Test DNSSEC validation
# 1. resolve bogus record with CD bit set, should result in answer
# 2. resolve bogus record with CD bit unset, should result in SERVFAIL

# CD set:
[rdolmans@unbound ~]$ drill txt bogus.nlnetlabs.nl @::1 -o CD
;; ->>HEADER<<- opcode: QUERY, rcode: NOERROR, id: 36453
;; flags: qr rd cd ra ; QUERY: 1, ANSWER: 1, AUTHORITY: 4, ADDITIONAL: 2
;; QUESTION SECTION:
;; bogus.nlnetlabs.nl.	IN	TXT


;; ANSWER SECTION:
bogus.nlnetlabs.nl.	59	IN	TXT	"will be Bogus"


;; AUTHORITY SECTION:
nlnetlabs.nl.	10200	IN	NS	sec2.authdns.ripe.net.
nlnetlabs.nl.	10200	IN	NS	anyns.pch.net.
nlnetlabs.nl.	10200	IN	NS	ns.nlnetlabs.nl.
nlnetlabs.nl.	10200	IN	NS	ns-ext1.sidn.nl.

;; ADDITIONAL SECTION:
ns.nlnetlabs.nl.	9831	IN	A	185.49.140.60
ns.nlnetlabs.nl.	9831	IN	AAAA	2a04:b900::8:0:0:60
```

```
;; Query time: 581 msec
;; SERVER: ::1
;; WHEN: Thu May 12 05:58:20 2016
;; MSG SIZE  rcvd: 209


# CD unset:
[rdolmans@unbound ~]$ drill txt bogus.nlnetlabs.nl @::1
;; ->>HEADER<<- opcode: QUERY, rcode: SERVFAIL, id: 14388
;; flags: qr rd ra ; QUERY: 1, ANSWER: 0, AUTHORITY: 0, ADDITIONAL: 0
;; QUESTION SECTION:
;; bogus.nlnetlabs.nl.  IN      TXT

;; ANSWER SECTION:

;; AUTHORITY SECTION:

;; ADDITIONAL SECTION:

;; Query time: 0 msec
;; SERVER: ::1
;; WHEN: Thu May 12 05:59:06 2016
;; MSG SIZE  rcvd: 36



####
# NSD installation log for 10.33.XX.XX
###

# Add 192.168.3.98 to resolv.conf
[rdolmans@nsd ~]$ echo "nameserver 192.168.3.98" | sudo tee -a /etc/resolv.conf

# install openssl, libevent
[rdolmans@nsd ~]$ sudo yum install openssl-devel libevent-devel

# SoftHSM
[rdolmans@nsd ~]$ tar xvzf softhsm-2.1.0.tar.gz
[rdolmans@nsd ~]$ cat softhsm-2.1.0.tar.gz | openssl sha256
(stdin)= 0399b06f196fbfaebe73b4aeff2e2d65d0dc1901161513d0d6a94f031dcd827e
[rdolmans@nsd softhsm-2.1.0]$ cd softhsm-2.1.0
[rdolmans@nsd softhsm-2.1.0]$ autoreconf -i -f
# openssl version has no gost support, disable
[rdolmans@nsd softhsm-2.1.0]$ ./configure --disable-gost
[rdolmans@nsd softhsm-2.1.0]$ make
[rdolmans@nsd softhsm-2.1.0]$ sudo make install
[rdolmans@nsd softhsm-2.1.0]$ sudo softhsm2-util --init-token --slot 0 --label "OpenDNSSEC"

# LDNS (incl. examples and drill)
```

```
[rdolmans@nsd ~]$ curl https://nlnetlabs.nl/downloads/ldns/ldns-1.6.17.tar.gz -o ldns-
1.6.17.tar.gz
[rdolmans@nsd ~]$ cat ldns-1.6.17.tar.gz | openssl sha1
(stdin)= 4218897b3c002aadfc7280b3f40cda829e05c9a4
[rdolmans@nsd ~]$ tar xvzf ldns-1.6.17.tar.gz
[rdolmans@nsd ~]$ cd ldns-1.6.17
[rdolmans@nsd ldns-1.6.17]$ ./configure --with-examples --with-drill
[rdolmans@nsd ldns-1.6.17]$ make
[rdolmans@nsd ldns-1.6.17]$ sudo make install

# OpenDNSSEC
# install dependencies: SQLite3, libxml2, java (for now)
[rdolmans@nsd ~]$ sudo yum install libxml2-devel sqlite-devel java-1.8.0-openjdk-devel
[rdolmans@nsd ~]$ git clone https://github.com/opendnssec/opendnssec.git
[rdolmans@nsd ~]$ cd opendnssec
[rdolmans@nsd opendnssec]$ sh autogen.sh
[rdolmans@nsd opendnssec]$ ./configure
[rdolmans@nsd opendnssec]$ make
[rdolmans@nsd opendnssec]$ sudo make install


# Setup SQLite db
[rdolmans@nsd opendnssec]$ sudo ods-enforcer-db-setup

# Use SoftHSM2, reload NSD zone after signing
[rdolmans@nsd ~]$ sudo diff -u /etc/opendnssec/conf.xml.sample /etc/opendnssec/conf.xml
--- /etc/opendnssec/conf.xml.sample     2016-05-12 10:53:35.154584441 -0400
+++ /etc/opendnssec/conf.xml    2016-05-17 12:03:20.719795941 -0400
@@ -5,9 +5,9 @@
        <RepositoryList>

                <Repository name="SoftHSM">
-                       <Module>/usr/local/lib/softhsm/libsofthsm.so</Module>
+                       <Module>/usr/local/lib/softhsm/libsofthsm2.so</Module>
                        <TokenLabel>OpenDNSSEC</TokenLabel>
-                       <PIN>1234</PIN>
+                       <PIN>**********</PIN>
                        <SkipPublicKey/>
                </Repository>

@@ -87,9 +87,7 @@
 <!--
                     <              NotifyCommand>/usr/local/bin/my_nameserver_reload_command</
NotifyCommand>
 -->
-<!--
-               <NotifyCommand>/usr/sbin/rndc reload %zone</NotifyCommand>
--->
+               <NotifyCommand>/usr/local/sbin/nsd-control reload %zone</NotifyCommand>
        </Signer>
```

```
</Configuration>


# Add policy to KASP config file. We use a policy named dnslab here, which is based on policy
default (but uses NSEC).
# See /etc/opendnssec/kasp.xml

[rdolmans@nsd ~]$ sudo ods-enforcer update all
Created policy dnslab successfully
Policy dnslab already up-to-date
update all completed in 0 seconds.
[rdolmans@nsd ~]$ sudo ods-enforcer policy list
Policy:                         Description:
dnslab                          Policy used for the NCCOE dnslab
policy list completed in 0 seconds.
[rdolmans@nsd ~]$ sudo ods-enforcer zone add --zone nev1.dnslab.nccoe.nist.gov --policy dnslab
Zone nev1.dnslab.nccoe.nist.gov added successfully
zone add completed in 1 seconds.



# NSD
# Download, verify checksum, extract, configure, compile and install NSD
[rdolmans@nsd ~]$ curl https://nlnetlabs.nl/downloads/nsd/nsd-4.1.9.tar.gz -o nsd-4.1.9.tar.gz
[rdolmans@nsd ~]$ cat nsd-4.1.9.tar.gz | openssl sha256
(stdin)= b811224d635331de741f1723aefc41adda0a0a3a499ec310aa01dd3b4b95c8f2
[rdolmans@nsd ~]$ tar xvzf nsd-4.1.9.tar.gz
[rdolmans@nsd ~]$ cd nsd-4.1.9
[rdolmans@nsd nsd-4.1.9]# ./configure --with-pidfile=/var/run/nsd/nsd.pid
[rdolmans@nsd nsd-4.1.9]$ make
[rdolmans@nsd nsd-4.1.9]$ sudo make install
[rdolmans@nsd ~]$ sudo nsd-control-setup

# enable in config
[rdolmans@nsd ~]$ sudo cp /etc/nsd/nsd.conf.sample /etc/nsd/nsd.conf
[rdolmans@nsd ~]$ diff -u /etc/nsd/nsd.conf.sample /etc/nsd/nsd.conf
--- /etc/nsd/nsd.conf.sample    2016-05-17 11:46:58.379795464 -0400
+++ /etc/nsd/nsd.conf   2016-05-18 07:06:14.861829191 -0400
@@ -23,6 +23,9 @@
        # ip-address: 1.2.3.4
        # ip-address: 1.2.3.4@5678
        # ip-address: 12fe::8ef0
+       ip-address: 192.168.3.99
+       ip-address: ::1
+       ip-address: 127.0.0.
        # Allow binding to non local addresses. Default no.
        # ip-transparent: no
@@ -62,7 +65,7 @@
```

```

         # the database to use
         # if set to "" then no disk-database is used, less memory usage.
-        # database: "/var/db/nsd/nsd.db"
+        database: ""

         # log messages to file. Default to stderr and syslog (with
         # facility LOG_DAEMON).  stderr disappears when daemon goes to bg.
@@ -141,7 +144,7 @@
 remote-control:
         # Enable remote control with nsd-control(8) here.
         # set up the keys and certificates with nsd-control-setup.
-        # control-enable: no
+        control-enable: yes

         # what interfaces are listened to for control, default is on localhost.
         # control-interface: 127.0.0.1
@@ -249,4 +252,10 @@
         # zonefile: "example.com.zone"
         # request-xfr: 192.0.2.1 example.com.key

-
+pattern:
+        name: "local-signed"
+        zonefile: "/var/opendnssec/signed/%s"
+
+zone:
+        name: "nev1.dnslab.nccoe.nist.gov"
+        include-pattern: "local-signed"


[rdolmans@nsd ~]$ sudo groupadd -r nsd
[rdolmans@nsd ~]$ sudo useradd -r -g nsd -s /sbin/nologin -c "nsd daemon" nsd

# Make user nsd the owner of the nsd db and run directories
[rdolmans@nsd ~]# sudo chown nsd:nsd /var/db/nsd/
[rdolmans@nsd ~]# sudo chown nsd:nsd /var/run/nsd

# Start NSD
[rdolmans@nsd ~]$ sudo nsd-control start

# Export DS
[rdolmans@nsd ~]$ sudo ods-enforcer key export --zone nev1.dnslab.nccoe.nist.gov --ds
;ready KSK DS record (SHA1):
nev1.dnslab.nccoe.nist.gov.     3600    IN      DS      35674 8 1
79ee1e53ce23658b6d5632297336b3067a80e329
;ready KSK DS record (SHA256):
nev1.dnslab.nccoe.nist.gov.     3600    IN      DS      35674 8 2
0bd77d723e0a6d602a82bf0173a32a8286cfa4d602100e716192425544fb43a2
key export completed in 0 seconds.
```

```
Generate key + selfsigned cert:

[rdolmans@unbound cert]$ sudo openssl req -newkey rsa:2048 -nodes \
-keyout nev1.dnslab.nccoe.nist.gov.key -x509 -days 365 -out nev1.dnslab.nccoe.nist.gov.crt
Generating a 2048 bit RSA private key
...................+++
.....................................+++
writing new private key to 'nev1.dnslab.nccoe.nist.gov.key'
-----
You are about to be asked to enter information that will be incorporated into your certificate
request.
What you are about to enter is what is called a Distinguished Name or a DN.
There are quite a few fields but you can leave some blank
For some fields there will be a default value,
If you enter '.', the field will be left blank.
-----
Country Name (2 letter code) [XX]:NL
State or Province Name (full name) []:
Locality Name (eg, city) [Default City]:Amsterdam
Organization Name (eg, company) [Default Company Ltd]:NLnet Labs
Organizational Unit Name (eg, section) []:
Common Name (eg, your name or your server's hostname) []:nev1.dnslab.nccoe.nist.gov
Email Address []:


# Generate TLSA record for cert:

[rdolmans@unbound cert]$ ldns-dane create nev1.dnslab.nccoe.nist.gov 25 3 1 1 -c
nev1.dnslab.nccoe.nist.gov.crt
_25._tcp.nev1.dnslab.nccoe.nist.gov.    3600    IN      TLSA    3:
 1 1 0e8f0af01ea3c87bb5647de3f36cd7ab1eedf5ae466edf5a8800f6174884f60d

# Add TLSA and MX records to zone:

[rdolmans@nsd unsigned]$ diff -u nev1.dnslab.nccoe.nist.gov.old nev1.dnslab.nccoe.nist.gov
--- nev1.dnslab.nccoe.nist.gov.old      2016-05-31 10:13:17.728379254 -0400
+++ nev1.dnslab.nccoe.nist.gov  2016-05-31 10:13:21.403379256 -0400
@@ -9,7 +9,10 @@


                 NS      ns.nev1.dnslab.nccoe.nist.gov.
                 A       192.168.3.99
+                MX      10 192.168.3.98


                 TXT "dnslab test zone."
```

```
 ns      IN      A       192.168.3.99
+
+_25._tcp  IN      TLSA    3 1 1 0e8f0af01ea3c87bb5647de3f36cd7ab1eedf5ae466edf5a8800f6174884f60d

# Resign
[rdolmans@nsd unsigned]$ sudo ods-signer sign nev1.dnslab.nccoe.nist.gov
Zone nev1.dnslab.nccoe.nist.gov scheduled for immediate re-sign.
```

Appendix G Microsoft Installation for the NCCoE

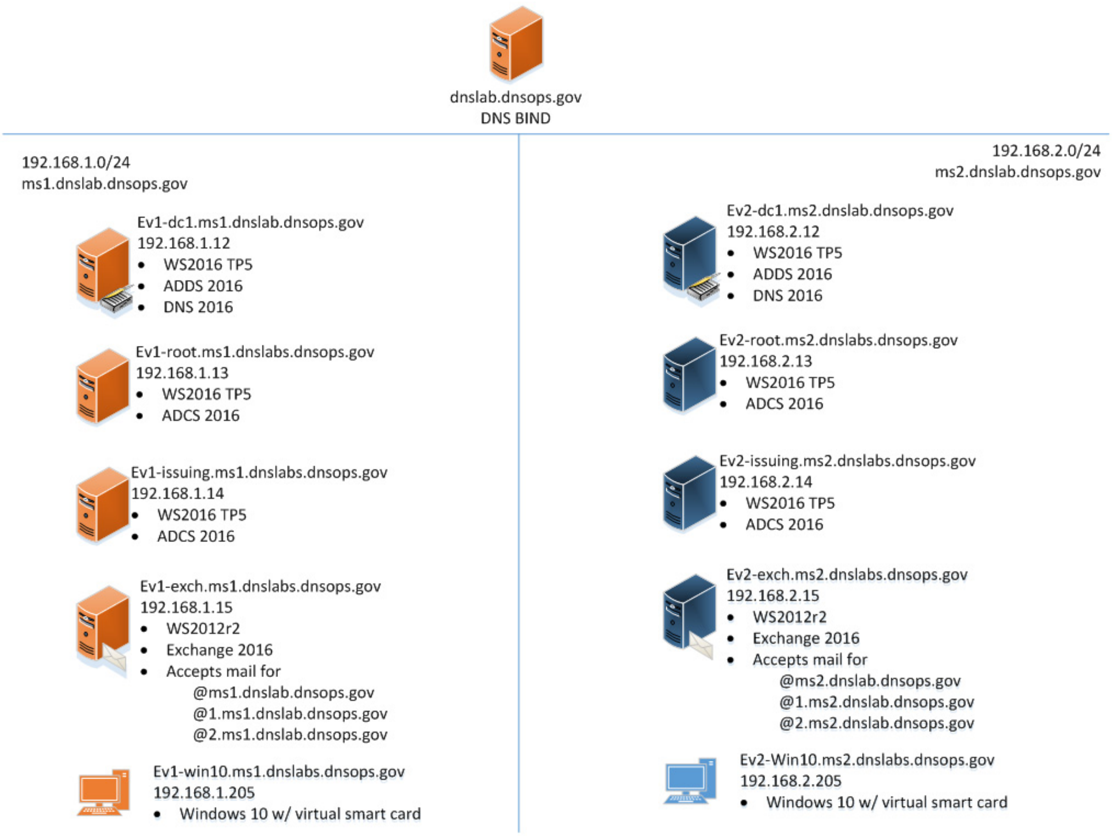
The following log captures the installation and configuration process for Microsoft system and applications software for the NCCoE's DNS-Based Email Security project. Please note that the IP addresses, domain names, and mail addresses are for the NCCoE laboratory and must not be used in actual implementations.

G.1 Microsoft Server

Two Microsoft Active Directory domains were built for this project. MS1.DNSLAB.DNSOPS.GOV and MS2.DNSLAB.DNSOPS.GOV domains. Two versions of Windows Server were used. Windows Server 2016 Technical Preview 5, Standard GUI edition (WS2016TP5) which is available from the Microsoft Evaluation Center (https://www.microsoft.com/en-us/evalcenter/evaluate-windows-server-technical-preview); and Active Directory Domain Services with integrated Domain Name Services and Certificate Services run on WS2016TP5. Currently, Exchange 2016 runs on Windows Server 2012R2 due to Exchange requirements (https://technet.microsoft.com/en-us/library/aa996719(v=exchg.160).aspx).

The procession of Microsoft Services to be installed and configured is as follows:

1. Active Directory Domain Services
2. Active Directory Certificate Services - Root Certification Authority
3. Active Directory Certificate Services - Issuing Certification Authority
4. Active Directory Domain Name Services
5. Exchange 2016

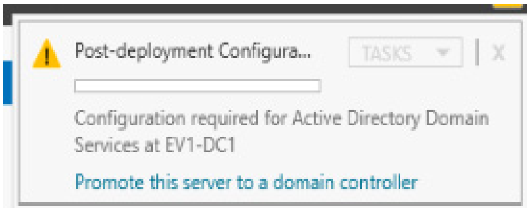


G.2 Active Directory Domain Services

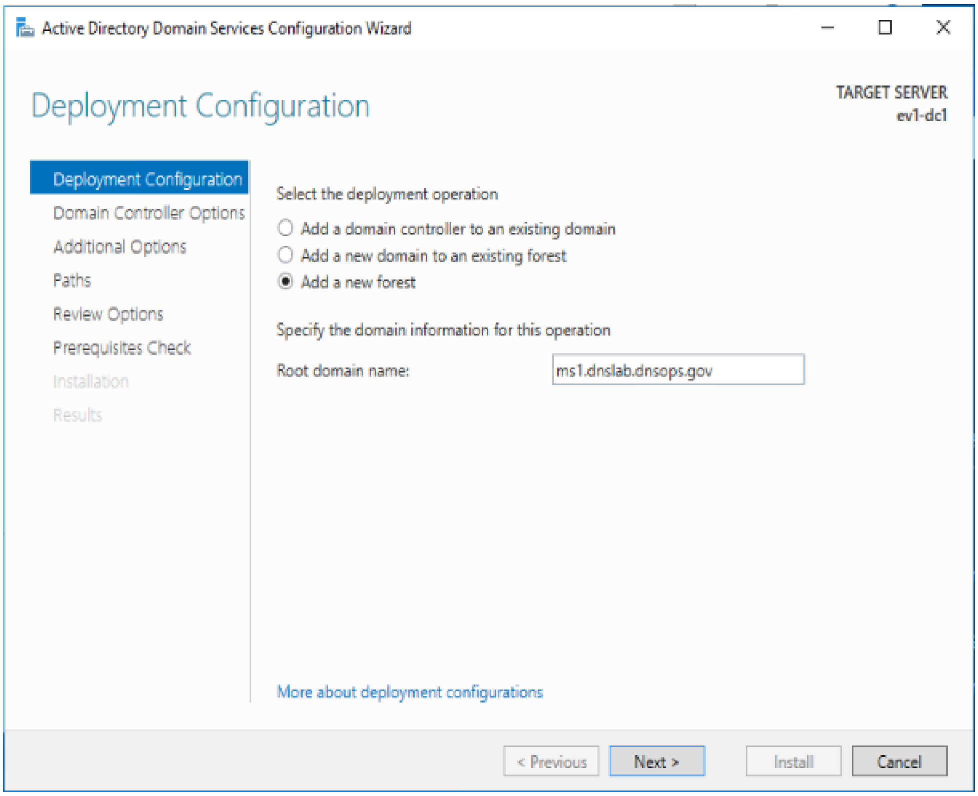
The following procedures were used for the creation of the MS1.DNSLAB.DNSOPS.GOV Active Directory domain on the EV1-DC1.MS1.DNSLAB.DNSOPS.GOV WS2016TP5 server.

1. Statically assign IP address of the Domain Controller. This domain controller serves as the DNS server for the MS1.DNSLAB.DNSOPS.GOV Active directory domain:
    a. IP Address: 192.168.1.12
    b. Netmask: 255.255.255.0
    c. Gateway: 192.168.1.1
    d. DNS Server 192.168.1.12
2. Install Active Directory Domain Services (ADDS) role:
    a. **Server Manager -> Manage -> Add Roles and Features**
    b. **Installation type -> Role-based or feature based installation**
    c. **Server Selection -> local server**
    d. **Server Roles ->** Select **Active Directory Domain Services**, accept the Features to be added with the installation of ADDS.
    e. On the **Features** selection menu click **Next**.

   f. Click **Install**.
   g. Once installation is complete click **Close**.
3. Configure the Active Directory Domain Services.
   a. In Server Manager click the **exclamation mark** underneath the flag icon and click on **Promote this server to a domain controller**.



   b. **Deployment Configuration -> Add a new forest** and specify the root name of **MS1.DNSLAB.DNSOPS.GOV**.



   c. In **Domain Controller Options** select the defaults and set the **Directory Services Restore Mode (DSRM) password**.
   d. DNS Options - parent zone could not be found, click **Next**.
   e. The NetBios domain name will default to the lowest level of the FQDN of the Forest, i.e. **MS1**.
   f. Accept the default paths for the ADDS Database, Log and SysVol folders. If running on a virtual machine, follow the recommended practice of the virtualization host.

g. In the Prerequisites Check you will be notified that the DNS cannot be delegated. The DNS server will be hosted on this domain controller.

G.3 Active Directory Certificate Services: Microsoft Certificate Authority

Windows Server 2016 TP5 Active Directory Certificate Services (ADCS) serves as the Public Key Infrastructure for the MS1.DNSLAB.DNSOPS.GOV namespace. It is a two-tier hierarchy with EV1-ROOT.MS1.DNSLAB.DNSOPS.GOV as the root Certification Authority (CA) trust point, and EV1-ISSUING.MS1.DNSLAB.DNSOPS.GOV as the domain joined enterprise issuing CA.

G.3.1 Root CA Installation

The installation of Active Directory Certificate Services must be performed by an enterprise administrator.

1. Copy **CAPolicy.inf** to the **c:\windows** directory:

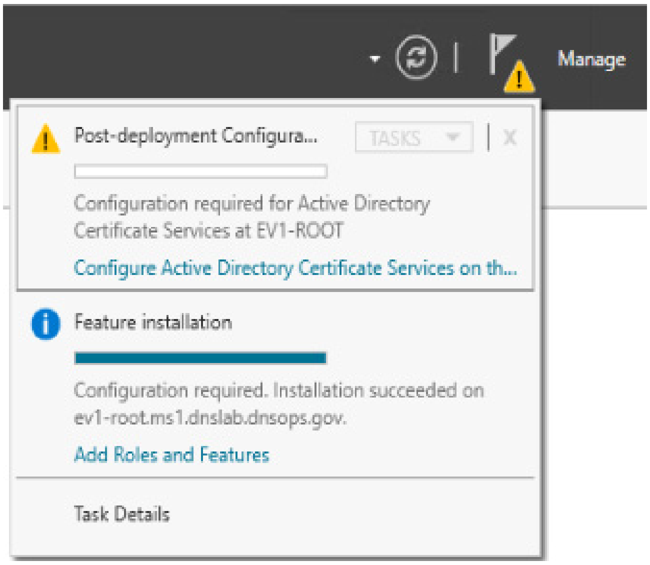
```
; NCCoE DANE DNSSEC Building Block

[Version]
Signature= "$Windows NT$"

; Configures CA to allow only a single tier of CAs below it
[BasicConstraintsExtension]
PathLength = 1

; Allows all issuance policies, sets HTTP pointer for CPS
[PolicyStatementExtension]
Policies = AllIssuancePolicy, LegalPolicy
Critical = 0

[AllIssuancePolicy]
OID = 2.5.29.32.0

[LegalPolicy]
OID = 1.1.1.1.1
Notice = "http://pki.ms1.dnslab.dnsops.gov/CPS.htm"
URL = "http://pki.ms1.dnslab.dnsops.gov/CPS.htm"

; Sets key renewal and CRL publication parameters
[Certsrv_Server]
RenewalKeyLength = 4096
RenewalValidityPeriod = Years
RenewalValidityPeriodUnits = 20
CRLPeriod = days
CRLPeriodUnits = 180
CRLDeltaPeriodUnits = 0
```

```
CRLDeltaPeriod = days

; Makes the CDP and AIA pointer for the root CA cert blank
[CRLDistributionPoint]
Empty = True

[AuthorityInformationAccess]
Empty = True

; NCCoE DANE DNSSEC Building Block

[Version]
Signature= "$Windows NT$"

; Configures CA to allow only a single tier of CAs below it
[BasicConstraintsExtension]
PathLength = 1

; Allows all issuance policies, sets HTTP pointer for CPS
[PolicyStatementExtension]
Policies = AllIssuancePolicy, LegalPolicy
Critical = 0

[AllIssuancePolicy]
OID = 2.5.29.32.0

[LegalPolicy]
OID = 1.1.1.1.1
Notice = "http://pki.ms1.dnslab.dnsops.gov/CPS.htm"
URL = "http://pki.ms1.dnslab.dnsops.gov/CPS.htm"

; Sets key renewal and CRL publication parameters
[Certsrv_Server]
RenewalKeyLength = 4096
RenewalValidityPeriod = Years
RenewalValidityPeriodUnits = 20
CRLPeriod = days
CRLPeriodUnits = 7
CRLDeltaPeriodUnits = 0
CRLDeltaPeriod = days

; Makes the CDP and AIA pointer for the root CA cert blank
[CRLDistributionPoint]
Empty = True

[AuthorityInformationAccess]
Empty = True
```

2. **Server Manager -> Manage -> Add Roles and Features**.
3. **Installation type -> Role-based** or **feature based** installation.
4. **Server Selection -> local server**.
5. **Server Roles ->** Select **Active Directory Certificate Services**, accept the Features to be added with the installation of ADCS.
6. On the **Features** selection menu click **Next**.
7. Click **Install**.
8. Once installation is complete click **Close**.

G.3.1.1 Configure Root CA

1. **Run post install configuration wizard**, click on **Configure Active Directory Certificate Services** link:

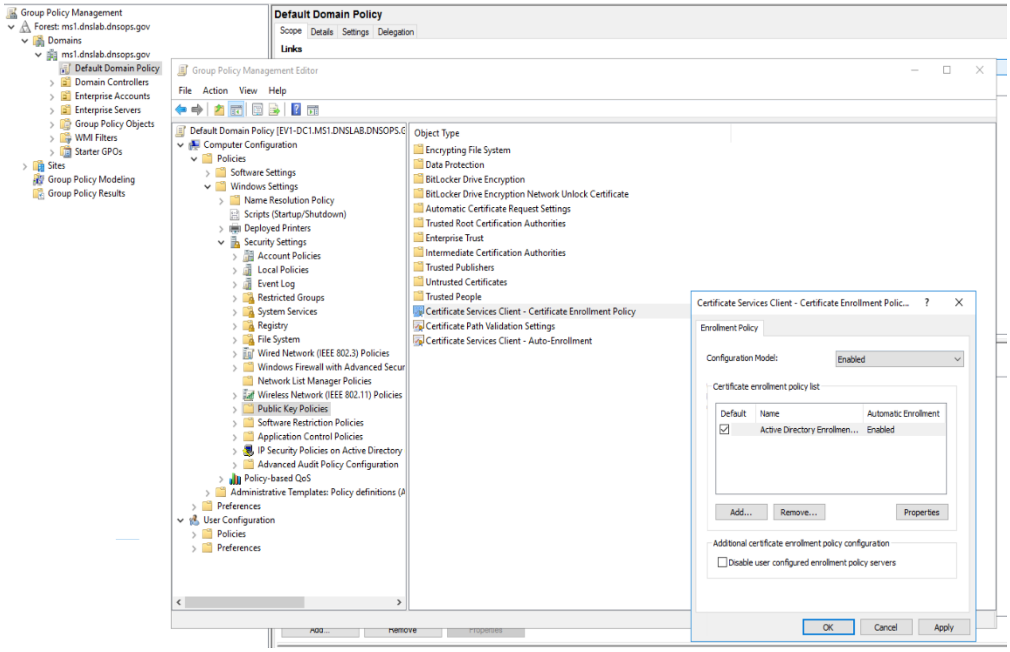


2. Select **Role Services to configure ->** select **Certification Authority**.
3. Setup Type = **Standalone CA**.
4. CA Type = **Root CA**.
5. Private Key = **Create a new private key**.
6. Cryptography:
   a. Cryptographic provider -> **RSA#Microsoft Software Key Storage Provider**
   b. Hashing Algorithm = **SHA256**
   c. Key Length **2048**
7. CA Name = **EV1-Root**
8. Once completed, **run the post install script**.

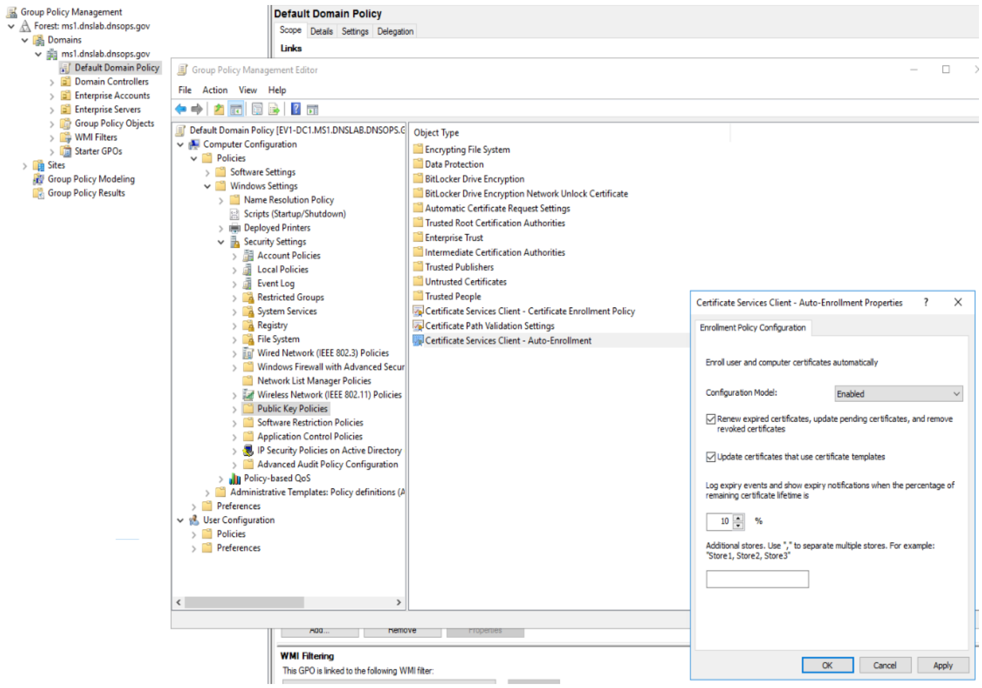
```
:: NCCoE DANE DNSSEC Building Block

:: Declares configuration NC
certutil -setreg CA\DSConfigDN CN=Configuration,DC=ms1,DC=dnslab,DC=dnsops,DC=gov

:: Defines CRL publication intervals
certutil -setreg CA\CRLPeriodUnits 7
certutil -setreg CA\CRLPeriod "Days"
certutil -setreg CA\CRLDeltaPeriodUnits 0
certutil -setreg CA\CRLDeltaPeriod "Days"

:: Specifies CDP attributes
certutil -setreg CA\CRLPublicationURLs
"65:%windir%\system32\CertSrv\CertEnroll\%%3%%8%%9.crl\n6:http://pki.ms1.dnslab.dnsops.gov/
%%3%%8%%9.crl\n14:ldap:///CN=%%7%%8,CN=%%2,CN=CDP,CN=Public Key Services,CN=Services,%%6%%10\n"

:: Specifies AIA attributes
certutil -setreg CA\CACertPublicationURLs
"1:%windir%\system32\CertSrv\CertEnroll\%%7.crt\n2:http://pki.ms1.dnslab.dnsops.gov/
%%7.crt\n3:ldap:///CN=%%7,CN=AIA,CN=Public Key Services,CN=Services,%%6%%11\n"

:: Enables auditing all events for the CA
certutil -setreg CA\AuditFilter 127

:: Sets validity period for issued certificates
certutil -setreg CA\ValidityPeriodUnits 10
certutil -setreg CA\ValidityPeriod "Years"

:: Restarts Certificate Services
net stop certsvc & net start certsvc

:: Republishes the CRL; sometimes this gets an access denied (error 5) because the service is not
ready after restart, in this case, manually execute
certutil -crl
```

G.3.1.2 Enable Certificate Services Auto Enrollment within the Active Directory Domain

1. Log on to the domain controller EV1-DC1.MS1.DNSLAB.DNSOPS.GOV.
2. Start **Group Policy Management console** (gpmc.msc).
3. Navigate to the **Default Domain Policy**.
4. Within the Default Domain Policy go to **Computer Configuration -> Policies -> Windows Settings -> Security Settings -> Public Key Policies**
5. Select the **Certificate Services Client - Certificate Enrollment Policy** setting.
6. Set to **Enabled**, ensure the **default Active Directory Enrollment Policy** is selected and click **OK**.



7. Select **Certificate Services Client - Auto-Enrollment** setting.



8. Set **Configuration Model** to **Enabled**.

9. Enable **Renew Expired Certificates** and **Update certificates that use certificate templates** radio buttons.

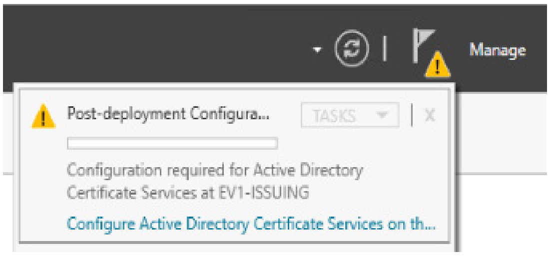
G.3.2 Issuing a CA Installation

1. Start administrative command prompt as an Enterprise Administrator.
2. Publish the EV1-Root CA certificate to Active Directory for dissemination to all systems within the MS1.DNSLAB.DNSOPS.GOV Active Directory domain. From an administrative command prompt, type **`certutil -dspublish -f ev1-root.crt rootca`**.
3. From the administrative command prompt, type **`certutil -pulse`** followed by **`gpupdate /force`**.
4. Copy **CAPolicy.inf** to the **c:\windows** directory.

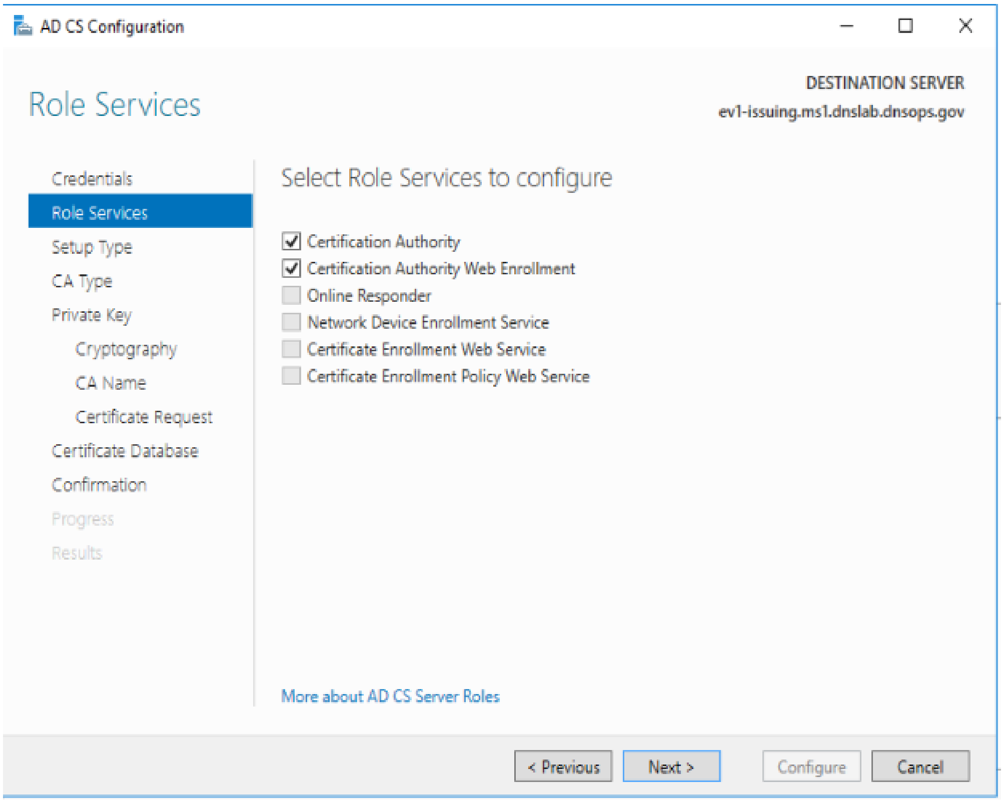
```

; NCCoE DANE DNSSEC Building Block

[Version]
Signature= "$Windows NT$"

; Allows all issuance policies, sets HTTP pointer for CPS
[PolicyStatementExtension]
Policies = AllIssuancePolicy, LegalPolicy
Critical = 0

[AllIssuancePolicy]
OID = 2.5.29.32.0

[LegalPolicy]
OID = 1.1.1.1.1
Notice = "http://pki.ms1.dnslab.dnsops.gov/cps.htm"
URL = "http://pki.ms1.dnslab.dnsops.gov/CPS.htm"

; Sets key renewal and CRL publication parameters
[certsrv_server]
renewalkeylength = 2048
RenewalValidityPeriodUnits = 10
RenewalValidityPeriod = years
CRLPeriod = hours
CRLPeriodUnits = 36
CRLDeltaPeriod = hours
CRLDeltaPeriodUnits = 0

```

5. **Server Manager -> Manage -> Add Roles and Features**.
6. **Installation type -> Role-based** or f**eature based installation**.
7. **Server Selection -> local server**.
8. **Server Roles -> Select Active Directory Certificate Services**, accept the Features to be added with the installation of ADCS.
9. Features = **Certification Authority** and **Certification Authority Web Enrollment** (this will add the required IIS features).
10. On the **Features** selection menu click **Next**.

11. Click **Install**.
12. Once installation is complete click **Close**.
13. Run the **Post-Deployment configuration for the ADCS role**.



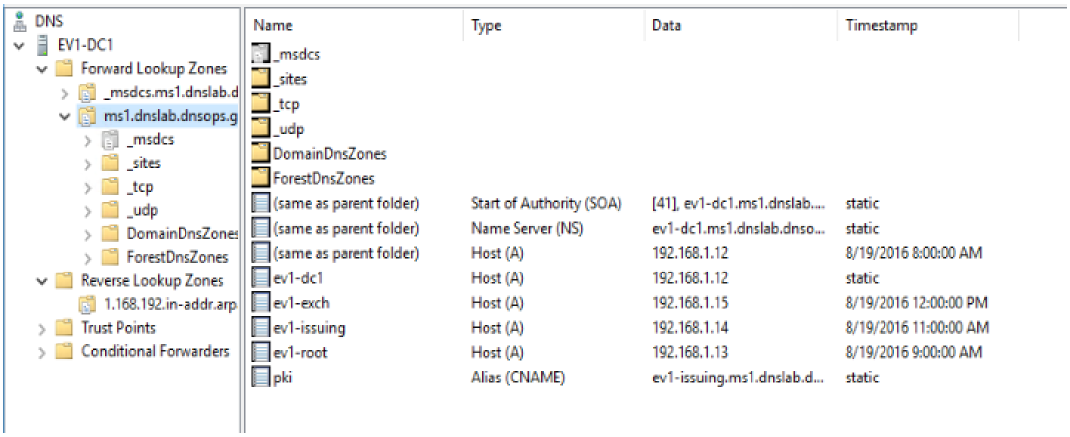
14. Select both **Certification Authority** and **Certification Authority Web Enrollment**.



15. Setup Type = **Enterprise CA**
16. CA Type = **Subordinate CA**
17. **Create new key** (same as above).
18. CA Name = **EV1-Issuing**
    a. Private Key = **Create a new private key**
    b. Cryptography:
        i. Cryptographic provider -> **RSA#Microsoft Software Key Storage Provider**
        ii. Hashing Algorithm = **SHA256**

iii. Key Length **2048**

19. **Save** the request file to the **c:\ drive**.
20. **Copy** request file to **root ca**.
21. On Root CA, **issue certificate**.
22. Import **ev1-issuing.ca** into the **Certification Authority**.
23. Create a **CNAME** record for PKI.MS1.DNSLAB.DNSOPS.GOV to point to ev1-issuing.ms1.dnslab.dnsops.gov.



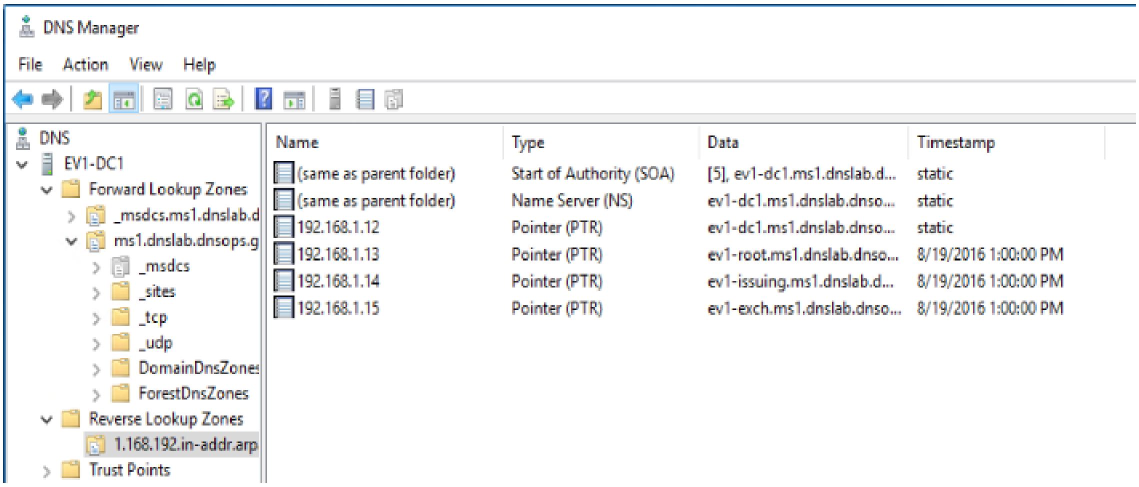
24. Open **Internet Information Service Manager**.
25. Go to the **Default Web Site**.
26. Bindings: edit the existing default HTTP binding and add **pki.ms1.dnslab.dnsops.gov**.
27. Click on the **Filter requests ->** Select **Allow File name Extension** and add .**crl**, .**crt** and **.cer**.
28. From an administrative command prompt type **`iisreset`**.
29. On the Issuing CA run the post install script.

```
:: NCCoE DANE DNSSEC Building Block

:: Declares configuration NC
certutil -setreg CA\DSConfigDN CN=Configuration,DC=MS1,DC=DNSLAB,DC=DNSOPS,DC=GOV

:: Defines CRL publication intervals
certutil -setreg CA\CRLPeriodUnits 3
certutil -setreg CA\CRLPeriod "days"
certutil -setreg CA\CRLDeltaPeriodUnits 0
certutil -setreg CA\CRLDeltaPeriod "Hours"

:: Specifies CDP attributes
certutil -setreg CA\CRLPublicationURLs
"65:%windir%\system32\CertSrv\CertEnroll\%%3%%8%%9.crl\n6:http://pki.ms1.dnslab.dnsops.gov/
%%3%%8%%9.crl\n79:ldap:///CN=%%7%%8,CN=%%2,CN=CDP,CN=Public Key Services,CN=Services,%%6%%10\n"

:: Specifies AIA attributes
```

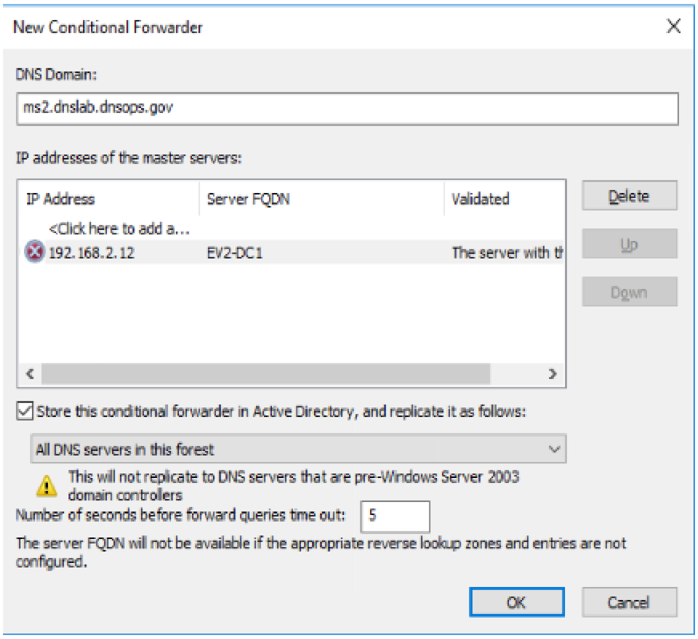
```
certutil -setreg CA\CACertPublicationURLs
"1:%windir%\system32\CertSrv\CertEnroll\%%7.crt\n2:http://pki.ms1.dnslab.dnsops.gov/
%%7.crt\n3:ldap:///CN=%%7,CN=AIA,CN=Public Key Services,CN=Services,%%6%%11\n"

:: Enables  auditing all events for the CA
certutil -setreg CA\AuditFilter 127

:: Sets maximum validity period for issued certificates
certutil -setreg CA\ValidityPeriodUnits 5
certutil -setreg CA\ValidityPeriod "Years"

:: Restarts Certificate Services
net stop certsvc & net start certsvc

:: Republishes the CRL; sometimes this gets an access denied (error 5) because the service is not
ready after restart, in this case, manually execute
certutil -CRL
```

G.4 Microsoft Domain Name Services: DNS Domain Server

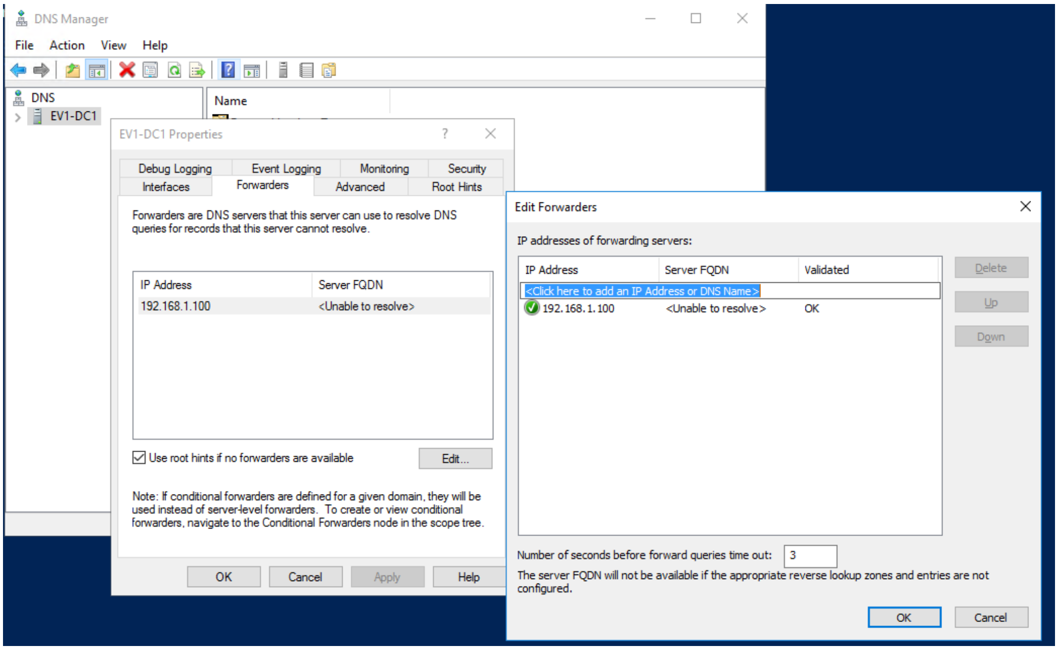
Active Directory Domain Services installation installs and configures the ms1.dnslab.dnsops.gov Forward lookup zone. It is recommended to create a Reverse lookup zone for the subnets used.



1. Create a conditional forwarder for the other name spaces:



2. Create forwarded to dnslab.dnsops.gov.



G.5 Microsoft Exchange

Exchange 2016 was installed on a Windows Server 2012R2 Standard (Server with a GUI). Exchange 2016 is currently not supported on Windows Server 2016 Technical Preview 2016 https://technet.microsoft.com/en-us/library/aa996719(v=exchg.160).aspx.

Exchange 2016 prerequisites can be found here: https://technet.microsoft.com/en-us/library/bb691354(v=exchg.160).aspx.

Download for .Net 4.5.2: https://www.microsoft.com/en-us/download/details.aspx?id=42642.

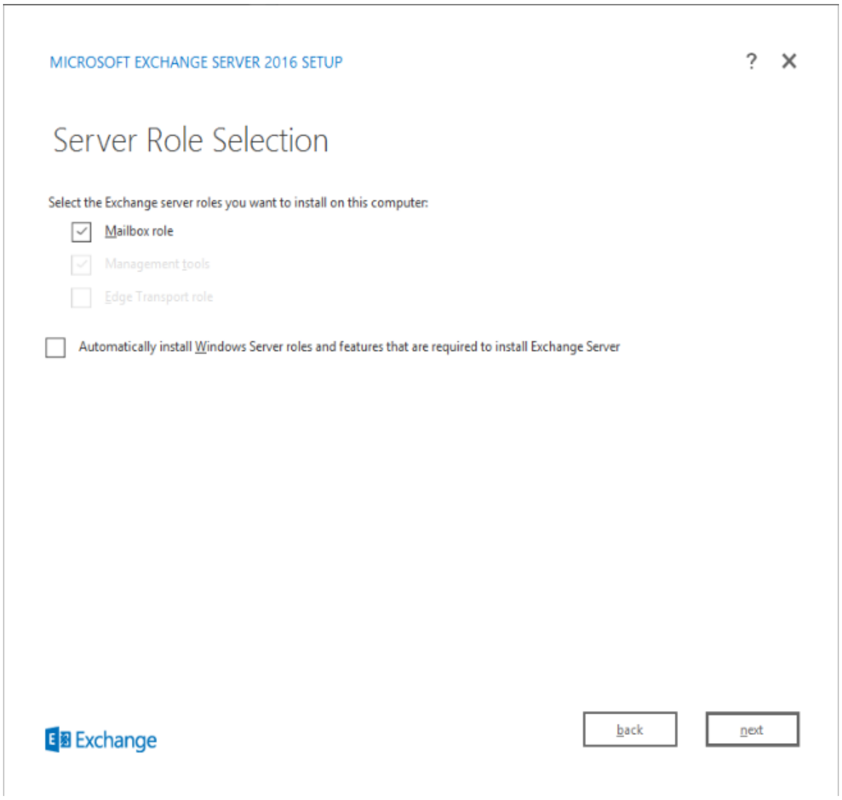
1. Install the Remote Tools Administration Pack using the following powershell command: `Install-WindowsFeature RSAT-ADDS`.

2. Install Exchange 2016 prerequisites with the following powershell command:

```
Install-WindowsFeature AS-HTTP-Activation, Desktop-Experience, NET-Framework-45-Features, RPC-over-HTTP-proxy, RSAT-Clustering, RSAT-Clustering-CmdInterface, RSAT-Clustering-Mgmt, RSAT-Clustering-PowerShell, Web-Mgmt-Console, WAS-Process-Model, Web-Asp-Net45, Web-Basic-Auth, Web-Client-Auth, Web-Digest-Auth, Web-Dir-Browsing, Web-Dyn-Compression, Web-Http-Errors, Web-Http-Logging, Web-Http-Redirect, Web-Http-Tracing, Web-ISAPI-Ext, Web-ISAPI-Filter, Web-Lgcy-Mgmt-Console, Web-Metabase, Web-Mgmt-Console, Web-Mgmt-Service, Web-Net-Ext45, Web-Request-Monitor, Web-Server, Web-Stat-Compression, Web-Static-Content, Web-Windows-Auth, Web-WMI, Windows-Identity-Foundation
```

3. Perform Active Directory Schema update following the Technet article, “Prepare Active Directory and Domains”: https://technet.microsoft.com/en-us/library/bb125224(v=exchg.160).aspx.

4. Install the **Mailbox role**.

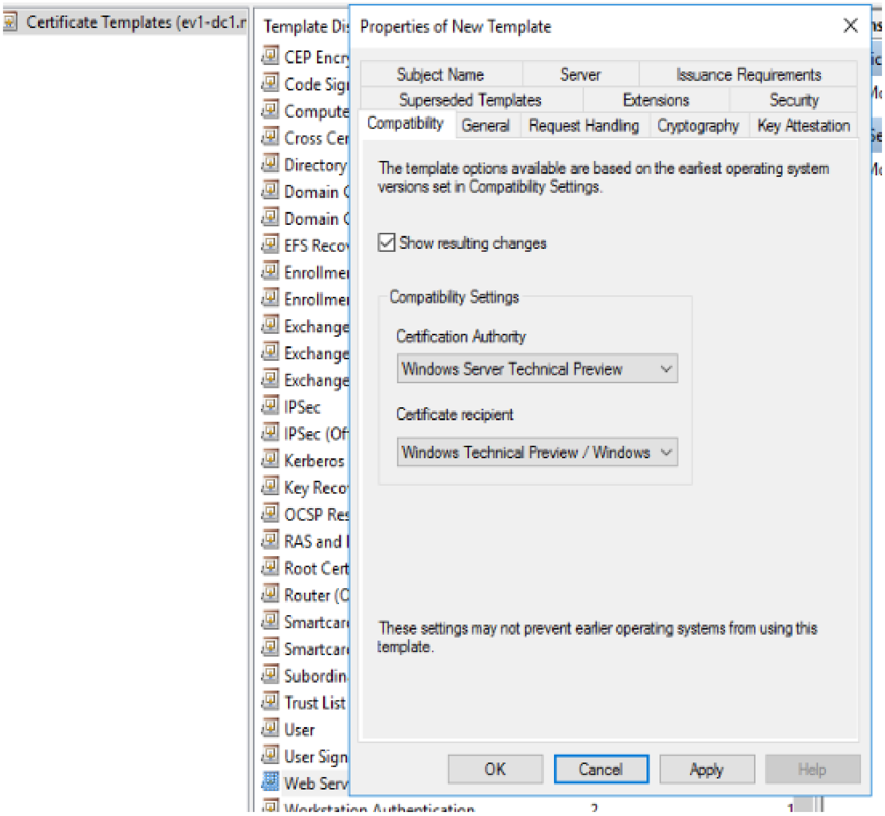


5. Once the installation is completed go to the **Exchange Admin console**: https://ev1-exch.ms1.dnslab.dnsops.gov/ECP.

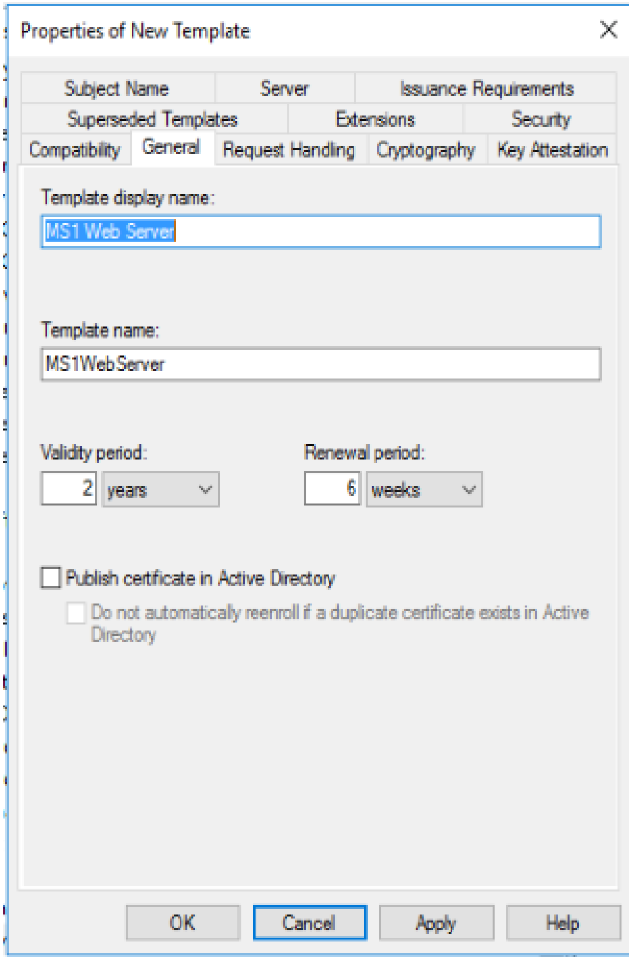
6. Create an **Internet send connector** following this Technet article: https://technet.microsoft.com/en-us/library/jj657457(v=exchg.160).aspx.

7. Create an **SSL certificate** for the Exchange services.

8. On the Issuing CA (ev1-issuing), open **Certification Authority -> Certificate Templates**.
9. **Right click -> Manage**.
10. Right click on the **Web Server template** and select **duplicate**.
11. Compatibility = **Windows Server Technical Preview**

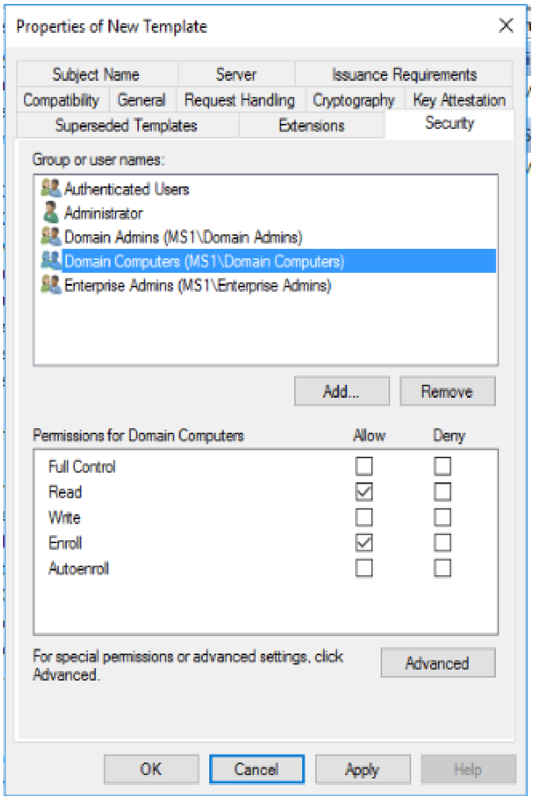


12. **General -> Template Display Name MS1 Web Server**

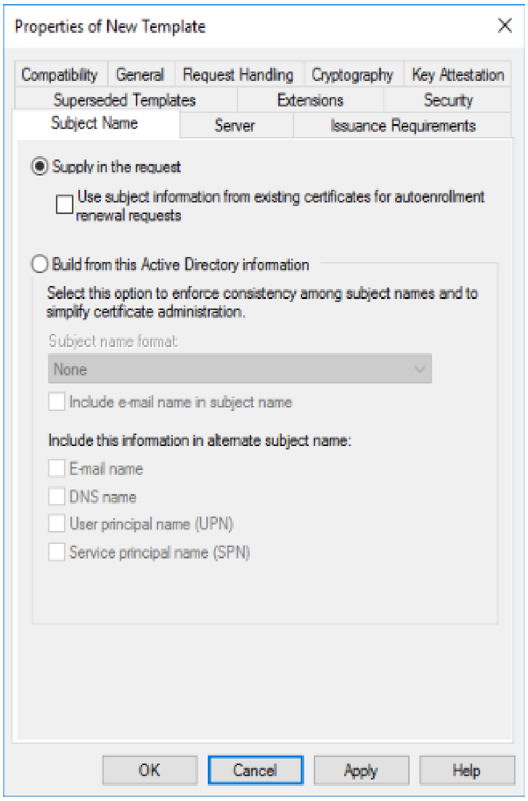


368

369 13. **Security -> Domain Computers allowed to Enroll for certificate**

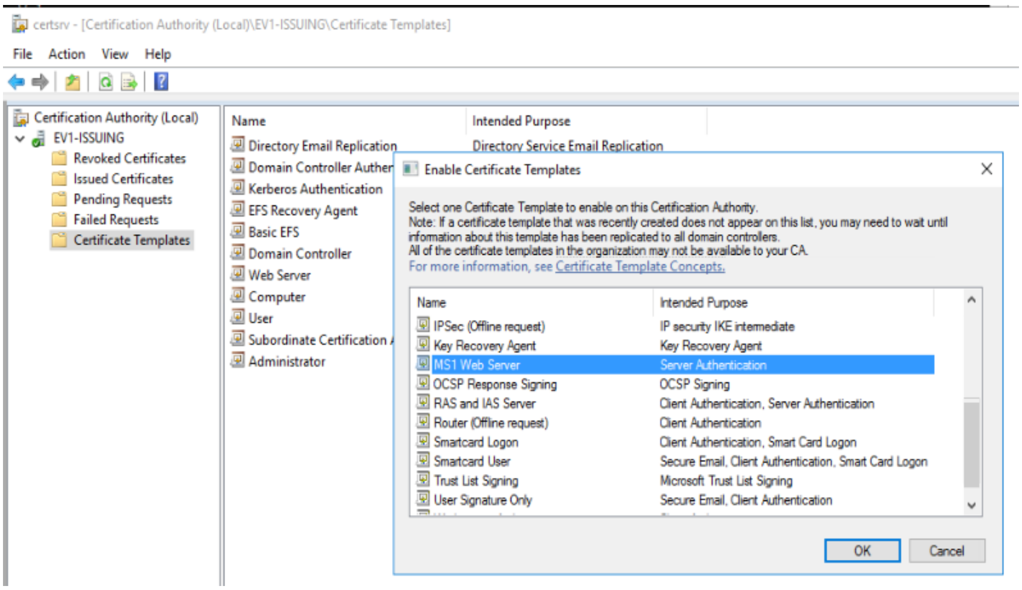


14. **Subject Name -> Supply in Request**



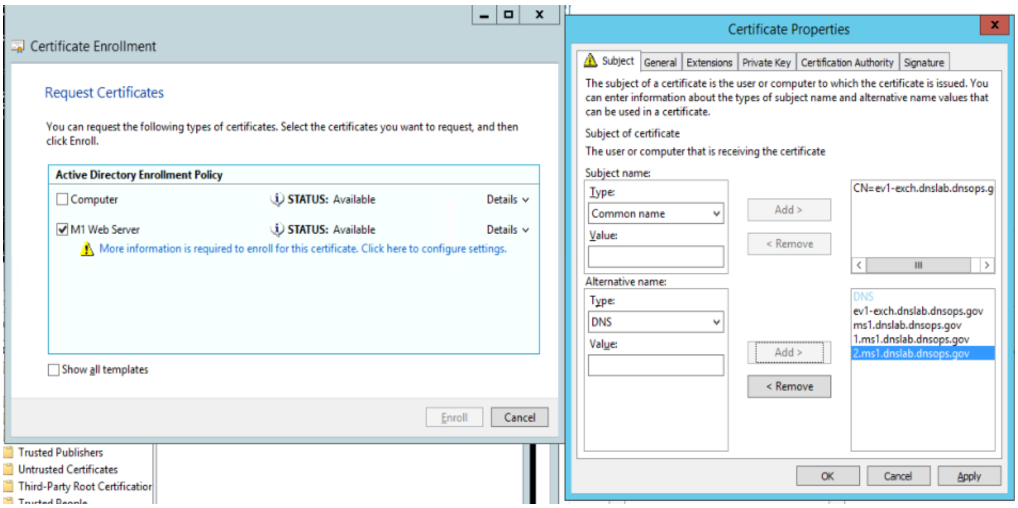
15. Click **OK** to save the new MS1 Web Server certificate template.

16. Back in the Certification Authority snap-in, right click on **Certificate Templates -> Certificate to Issue**, then select the **MS1 Web Server** certificate template.



17. On the Exchange server (ev1-exch), log on as an administrator and type `certlm.msc`.

18. Go to **Personal -> Certificates -> right click -> request new certificate**.



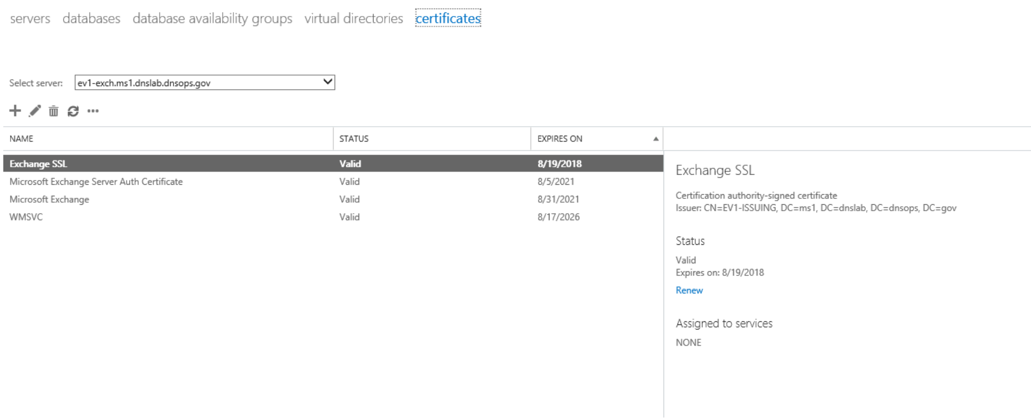
19. Subject Name: **Common Name = ev1-exch.ms1.dnslab.dnsops.gov**

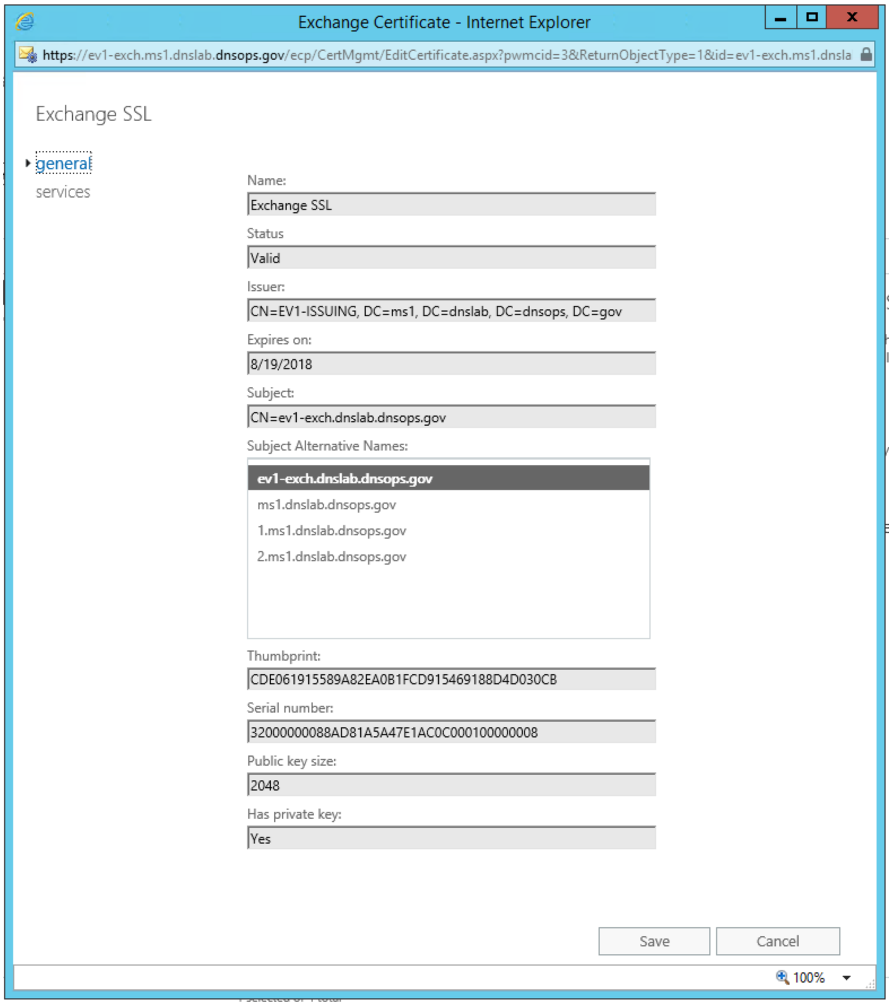
20. Alternative Name: **DNS = ev1-exch.ms1.dnslab.dnsops.gov, ms1.dnslab.dnsops.gov, 1.ms1.dnslab.dnsops.gov, 2.ms1.dnslab.dnsops.gov**

21. Click **OK** and then select **enroll**.

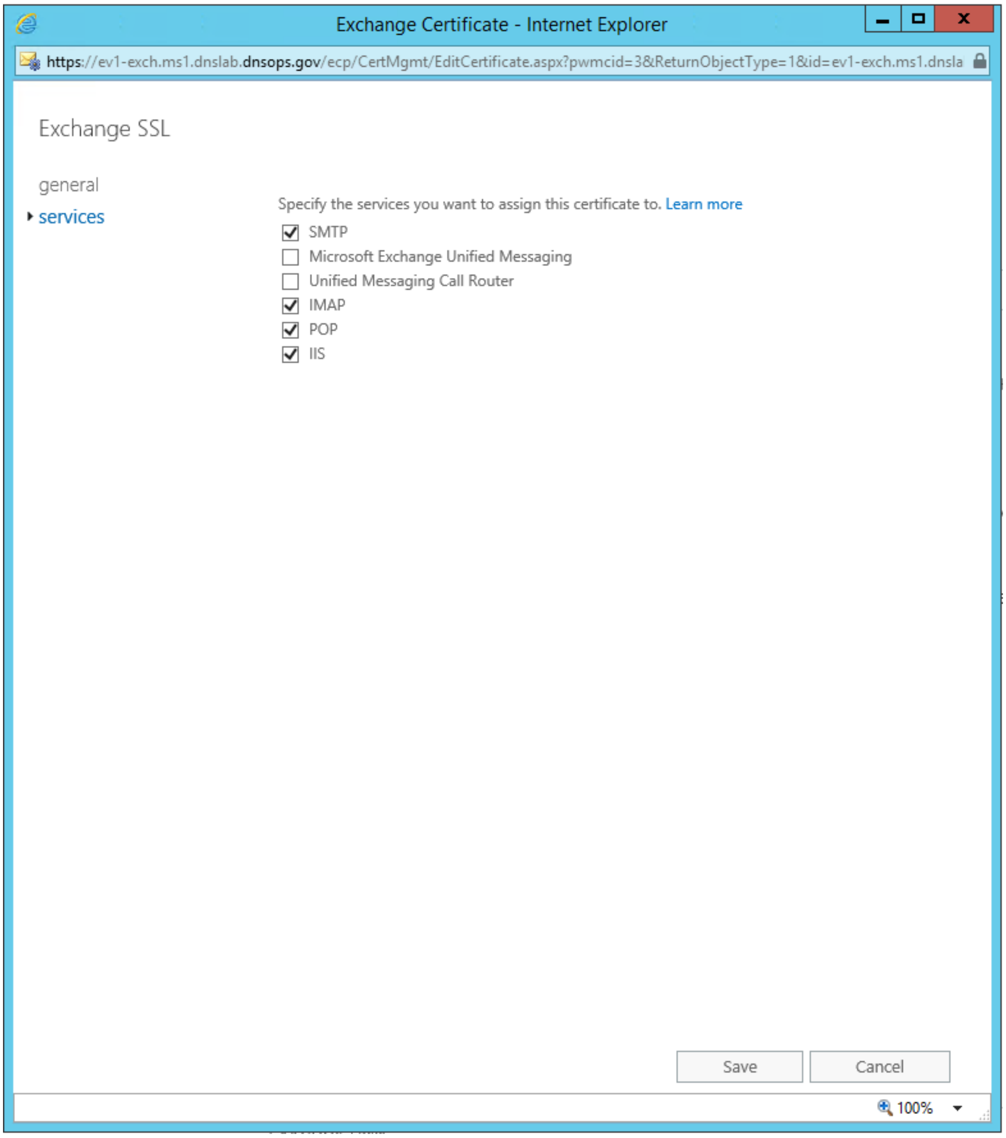
22. Use this certificate to protect the Exchange services.

23. Within the Exchange Admin console (https://ev1-exch.ms1.dnslab.dnsops.gov/ECP), select **Server -> Certificates**, then change all services to use the issued SSL certificate.



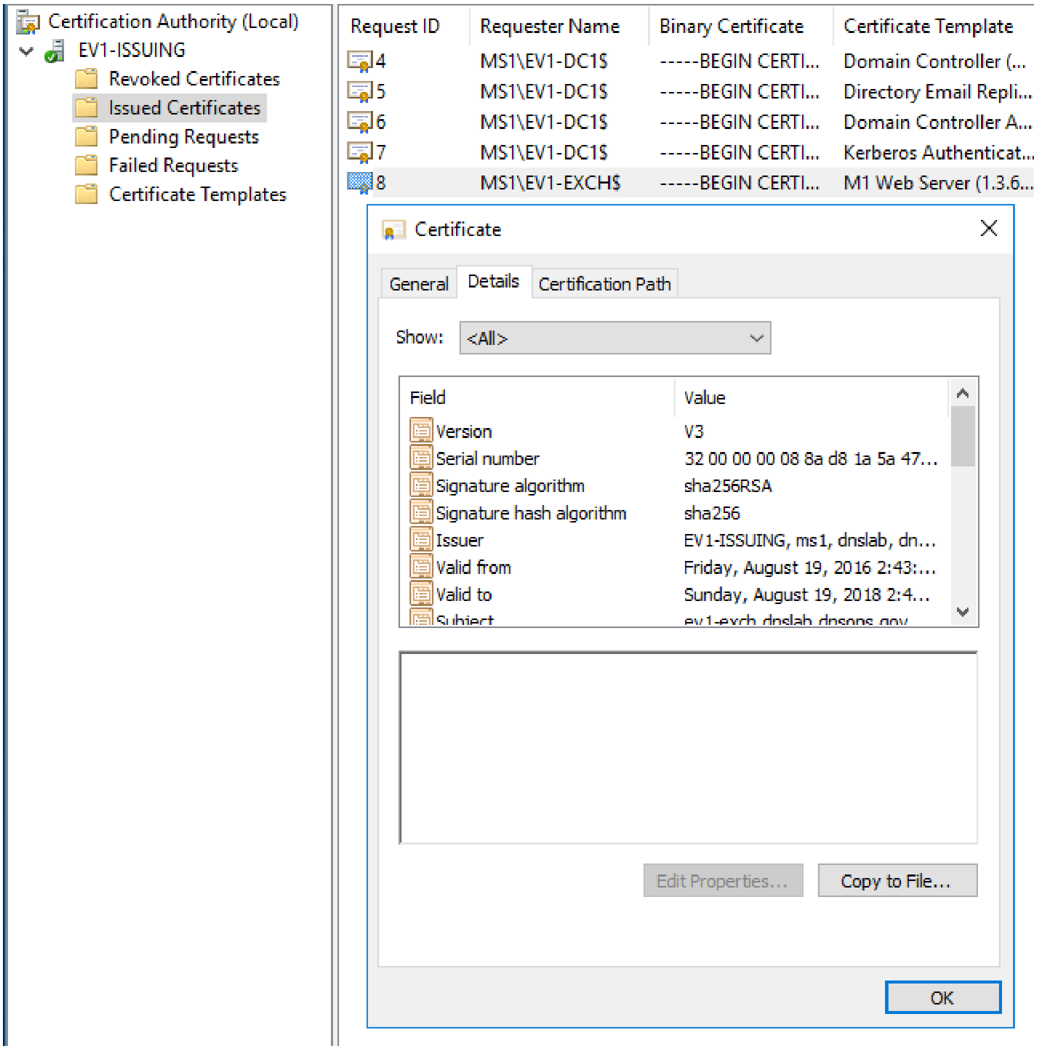


24. Select all the services **except** for **Unified Messaging**.

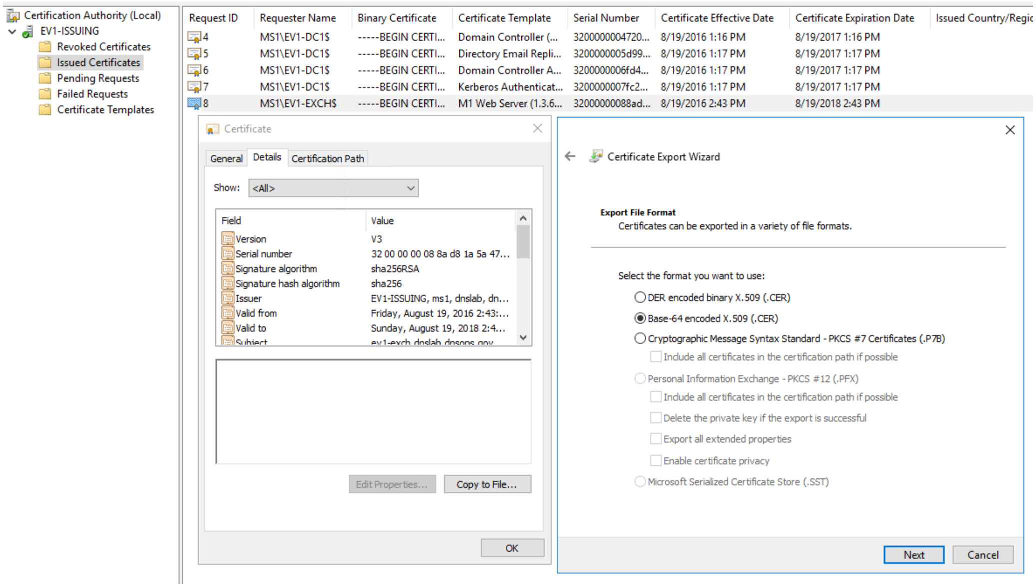


G.5.1 Generate the TLS DNS Record

1. Sign the ms1.dnslab.dnsops.gov zone by following the Technet article for enabling DNSSEC https://technet.microsoft.com/en-us/library/hh831411.aspx.
2. **Export** the **Exchange SSL certificate** to a **.cer** file. Find the certificate on the Issuing CA (ev1-issuing) within the **Issued Certificates** group.

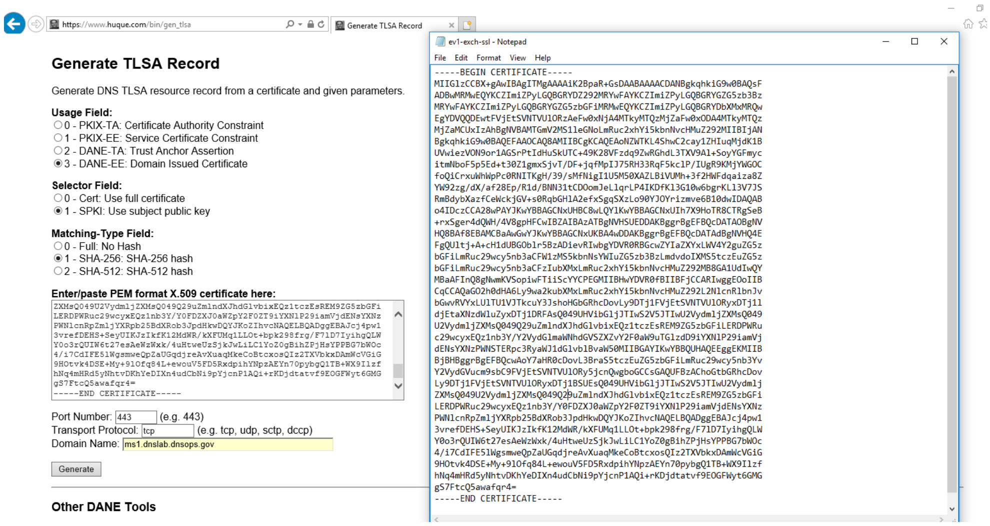


3. Click on the **Details** tab and select **Copy to File**. **Save** as a **base64 (.cer)** file.



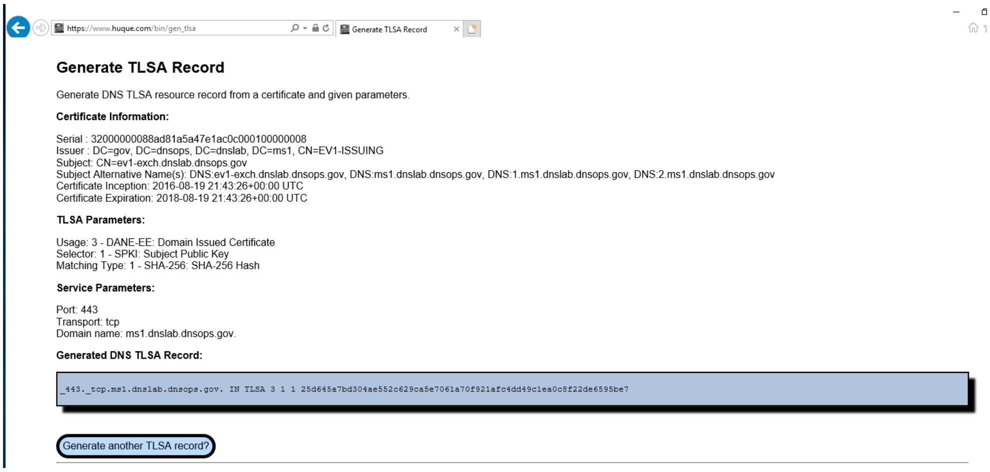
4. Go to https://www.huque.com/bin/gen_tlsa. **Open** the exported certificate into notepad, the **copy and paste** into the **Enter/paste PEM format X.509 certificate here** field.

5. Fill in the name space specific information.



6. Select **Generate** and the TLSA record string is presented back.

```
_443._tcp.ms1.dnslab.dnsops.gov. IN TLSA 3 1 1
25d645a7bd304ae552c629ca5e7061a70f921afc4dd49c1ea0c8f22de6595be7
```



7. To register this TLSA record within Windows Server 2016 Active Directory Domain Name Services, issue the following powershell command on the Domain Controller as Administrator:

```
add-dnsserverresourcerecord -TLSA -CertificateAssociationData
"25d645a7bd304ae552c629ca5e7061a70f921afc4dd49c1ea0c8f22de6595be7" -
CertificateUsage DomainIssuedCertificate -MatchingType Sha256Hash -Selector
FullCertificate -ZoneName ms1.dnslab.dnsops.gov -Name _25._tcp.ev1-
exch.ms1.dnslab.dnsops.gov.
```

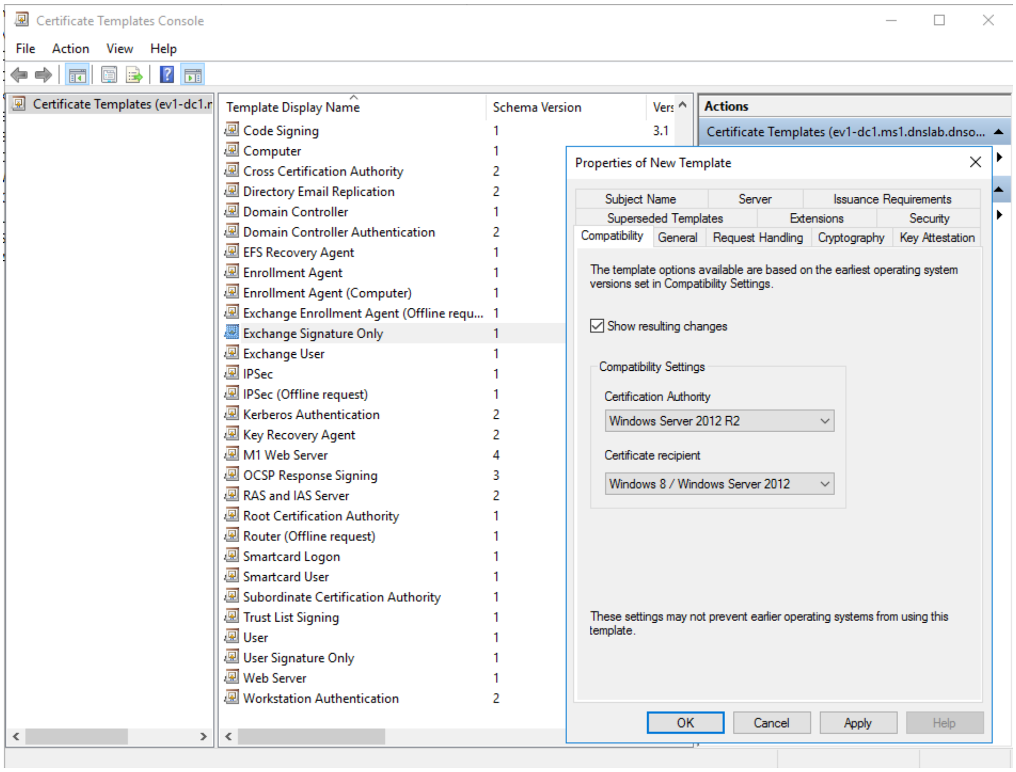
8. To get the zone output, issue the following powershell command:

```
Resolve-DnsName ev1-dc1.ms1.dnslab.dnsops.gov -type soa -server ev1-dc1 -
DnssecOk
```

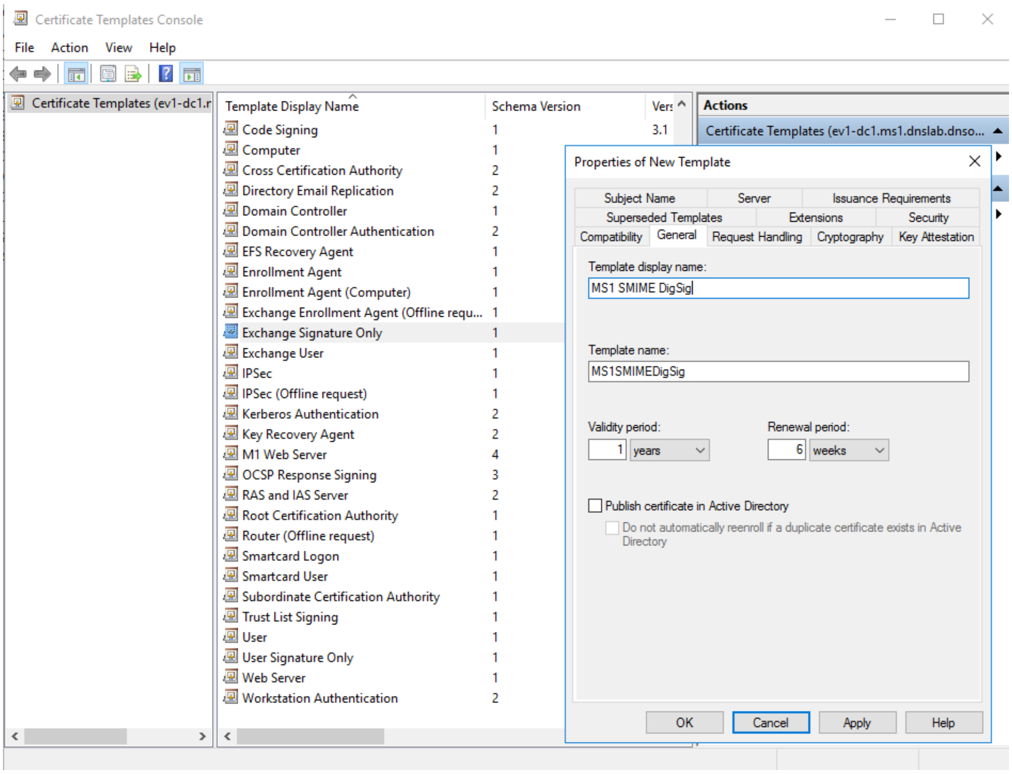
G.5.2 Issue S/MIME Certificates and Configure Outlook

To issue an S/MIME Digital Signature certificate to the user, go to the Issuing CA (ev1-issuingca).

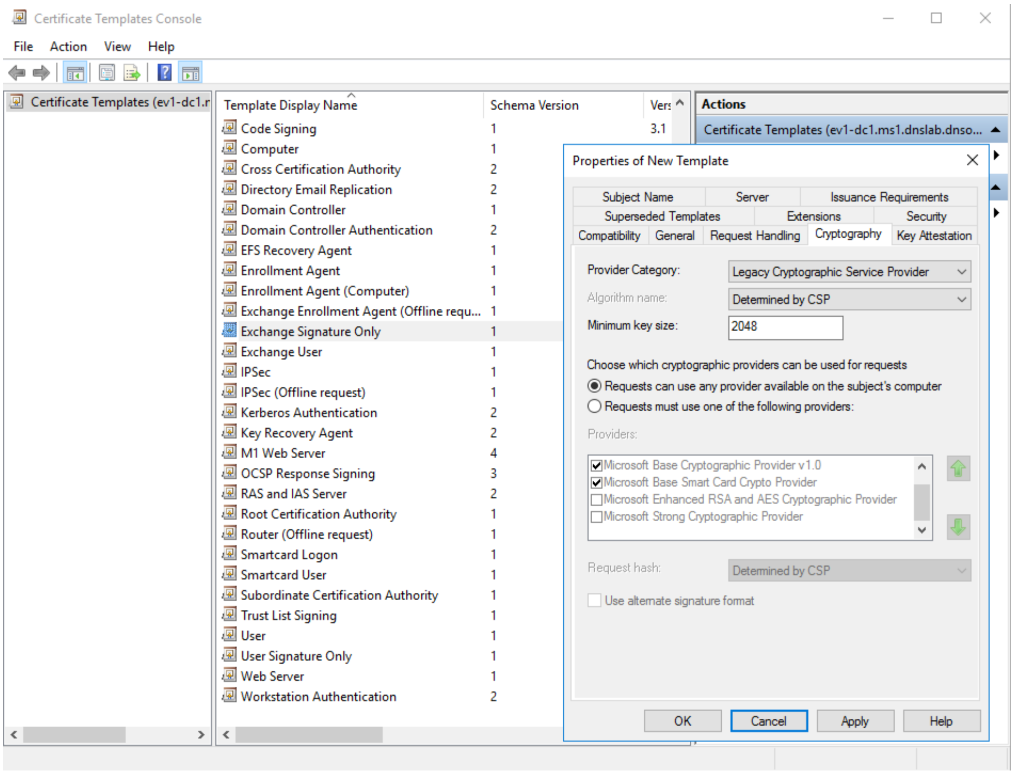
1. Open the **Certification Authority** snap-in, right click on **Certificate Templates** and select **Manage**.
2. Find the **Exchange Signature Only** certificate template, right click and select **duplicate**.
3. Set **Compatibility** to **Windows Server 2012 R2**.



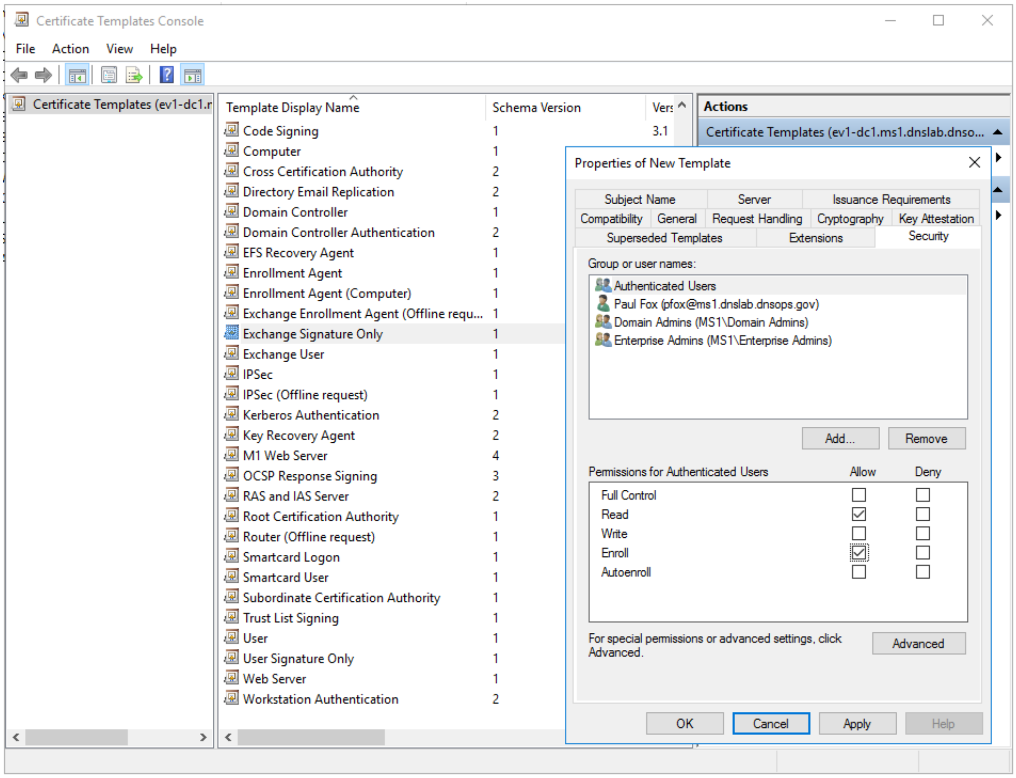
4. Within the **General** tab provide a name for the new template.



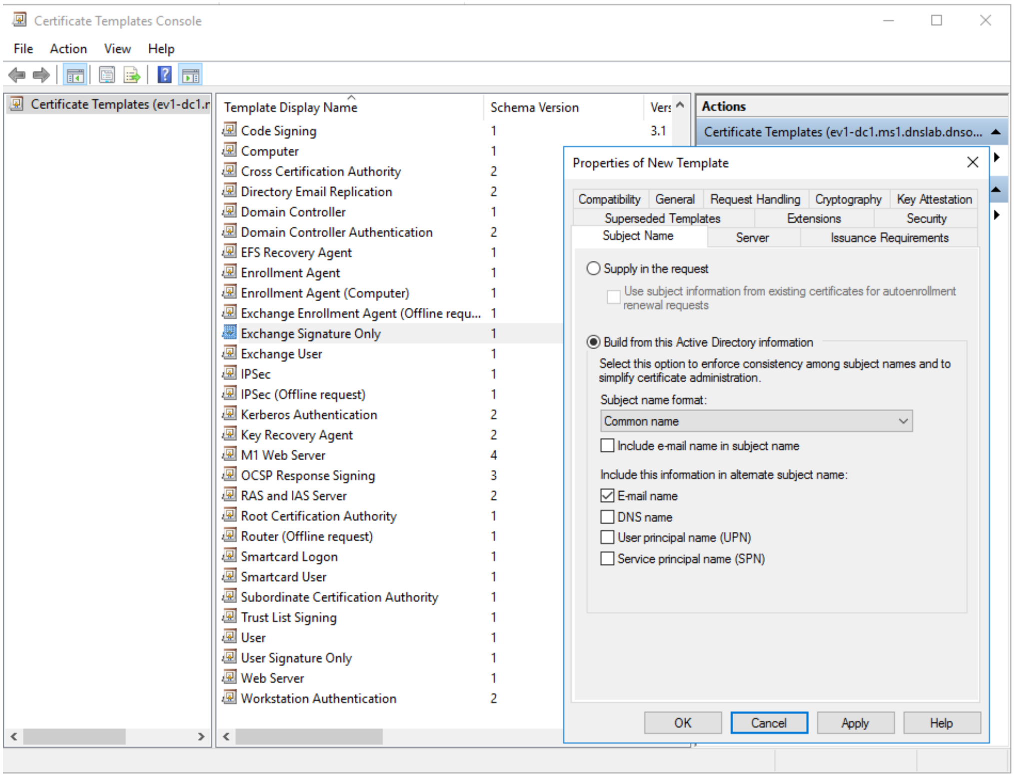
5. In the **Cryptography** tab select **Request can use any provider available on the subject's computer**.



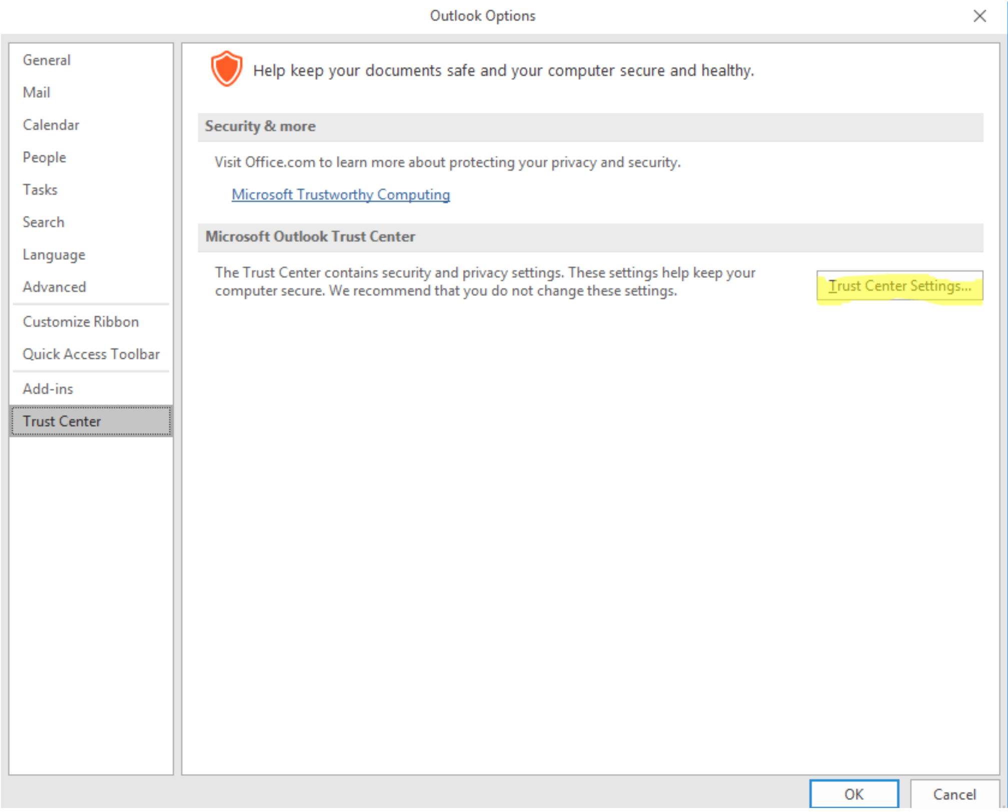
6. In the **Security** tab, select **Authenticated Users** from **Group or user names**, and allow **Read** and **Enroll**.



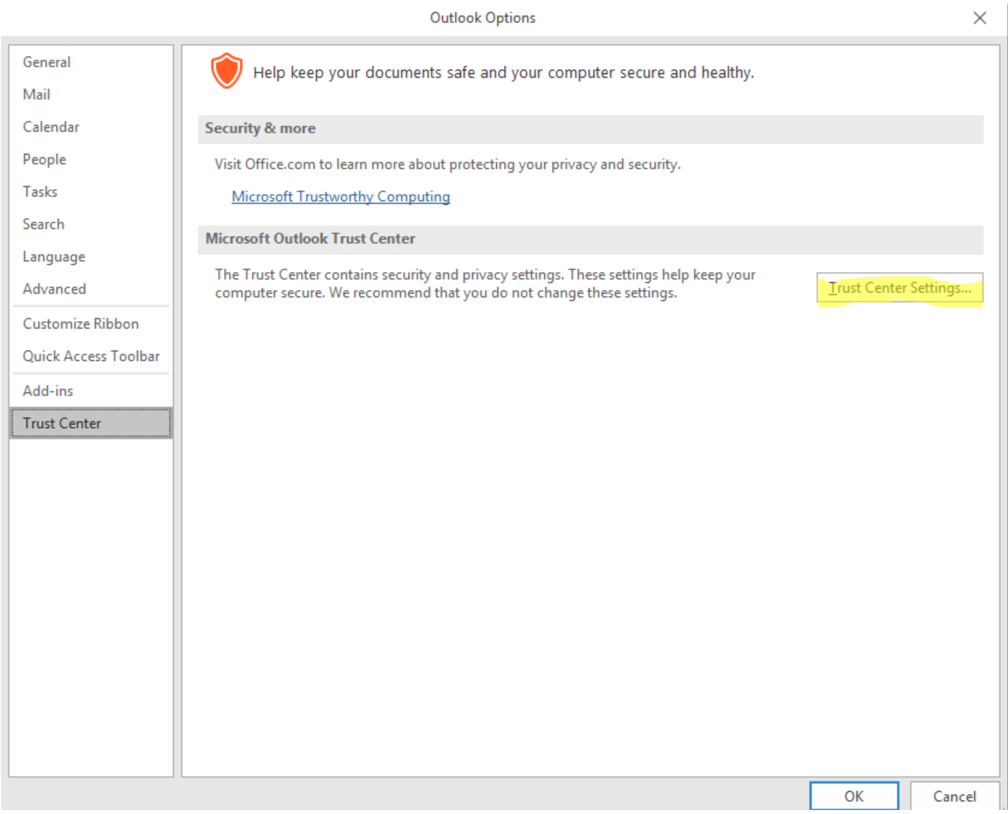
7. In the **Subject Name** tab, select **Build for this Active Directory information -> Email name** (note: make sure the mail attribute on the recipient's Active Directory object is populated with the correct email address)



8. On the Windows 10 workstation, log on as the user that will receive the S/MIME Digital Signature certificate. Start **certmgr.msc -> Personal -> right click: all tasks -> request new certificate**.
9. Select the **Active Directory Enrollment Policy ->** select the certificate template that was just created and follow the prompts.
10. Once completed, the S/MIME digital signature certificate will be in the user's Personal -> Certificate store and can be used for S/MIME digital signature within Outlook.
11. To configure Outlook to use the new S/MIME certificate:
    a. Open **Outlook 2016**.
    b. Click on **File**, and then **Options**.
    c. In the left-hand menu click on **Trust Center**.
    d. Click on the **Trust Center Settings** box.



e. Click **Email Security** in the left-hand menu.



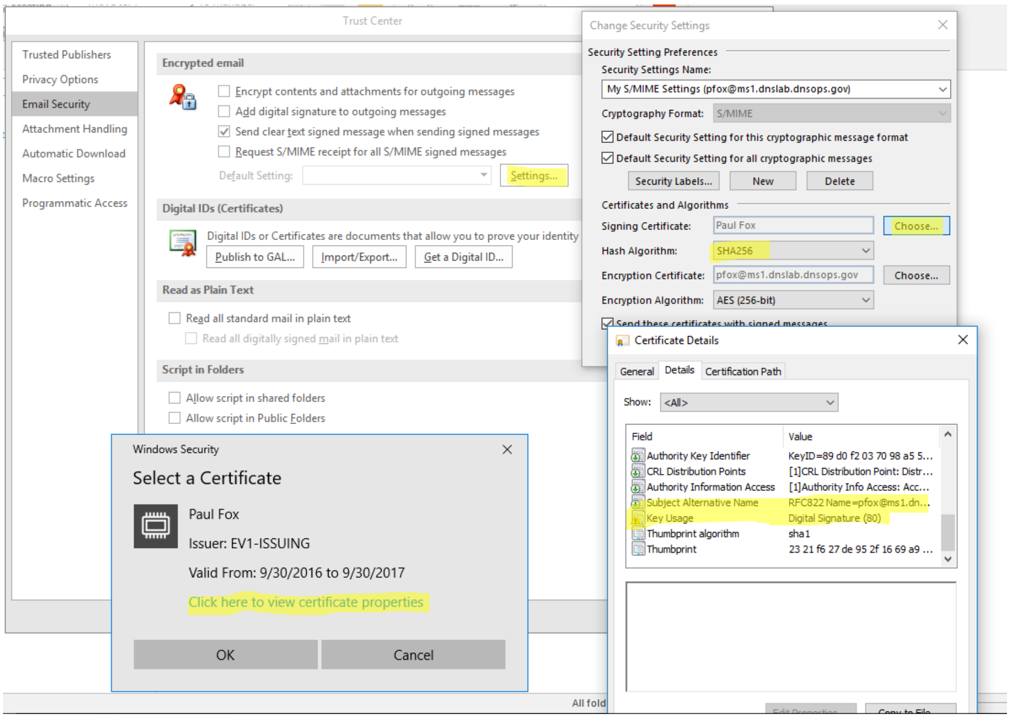
f. Click the **Settings** button within the **Encrypted Email** section.

g. Enter a name within the **Security Settings Name** field.

h. Select the **Signing Certificate** by clicking on the **Choose** button for the signing certificate, and select the **Hash Algorithm**.

i. If you have an S/MIME encryption certificate select the **Choose** button for the encryption certificate and select the **Encryption Algorithm**.

j. Select the radio button **Send these certificates with signed messages**.



Appendix H Installation and Configuration of DNS Authority, DNS Cache, and DNS Signer at the NCCoE

The NCCoE lab contained one DNS Signer appliance, and one VM instance each of DNS Authority and DNS Cache. These systems were not subject to special configurations beyond normal network configuration. The normal installation and setup for Secure64 products is found in the documentation (online at: https://support.secure64.com/).

There are no special configuration options needed for supporting DANE aware mail servers or clients with Secure64 DNS products. DANE Resource Record types are treated as any other valid DNS RRtype.

H.1 DNS Signer

Once the DNS Signer appliance is installed and initially set up, there are no special configuration options needed when deploying DANE to support email. Once a certificate is obtained (or generated) for the SMTP server, a TLSA RR needs to be generated and added to the zone. This can be done using one of the tools or websites described in Section 3.4 above. Once the TLSA RR is generated, the zone can be manually updated by editing the zone file or updated via dynamic update. Enterprises should follow any established procedure.

H.2 DNS Authority

Like DNS Signer, above, there is no difference between a standard setup of the authoritative server, and an authoritative server that hosts DANE RRtypes. Secure64 users should consult their product documentation on how to set up a DNS Authority instance.

H.3 DNS Cache

Like DNS Signer and DNS Authority, there are not additional steps in configuring a DNS Cache instance for supporting DANE. However, DANE requires the use of DNSSEC validation, so DNS Cache administrators (i.e. those that can enable the **cachdnsadmin** role) must enable DNSSEC validation and insure that the DNS Cache has a set of initial trust anchors.