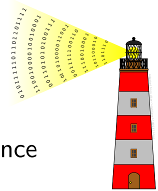
The new NIST reference for Randomness Beacons

Luís Brandão

Joint work with:
John Kelsey, René Peralta, Harold Booth

National Institute of Standards and Technology (Gaithersburg MD, USA)



Presentation at ICMC19
International Cryptographic Module Conference
May 17, 2019 @ Vancouver, Canada

Outline

1. Introduction
2. Pulse format
3. Beacon Protocol
4. Using a Beacon
5. Brief security considerations
6. Conclusion

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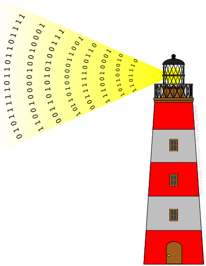
A service that produces timed outputs of fresh public randomness.



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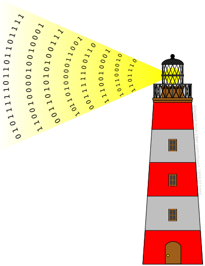
High-level description:

- Periodically *pulsates* randomness (e.g., 1 per min)



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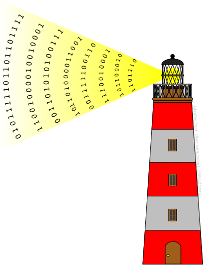

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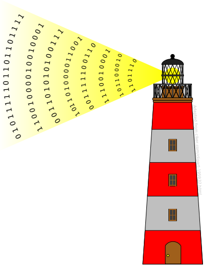

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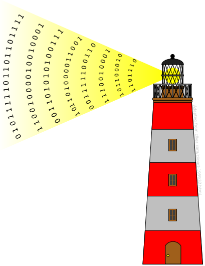

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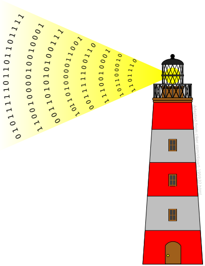

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- The sequence of pulses forms a hash-chain

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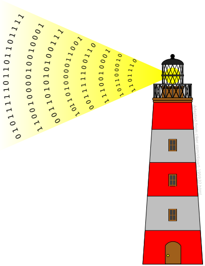

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What can it be useful for?

Not good for:

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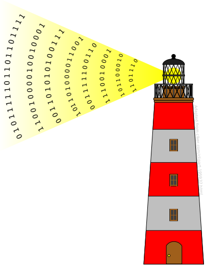

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Not good for: selecting your secret keys

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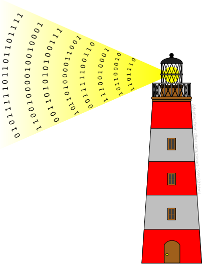

What can it be useful for?

- public auditability of randomized processes
- coordination between many parties
- prove something happened after a certain time

Not good for: selecting your secret keys

Brief historical note

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Some timeline events:

- 2013-Sep till 2018-Dec: NIST Beacon service version 1.0 online
- 2018-Jul till present: NIST Beacon service version 2.0 online
- 2019-May: “Draft NISTIR 8213” online — specifies the new (draft) *Reference for Randomness Beacons* (version 2)

Brief historical note

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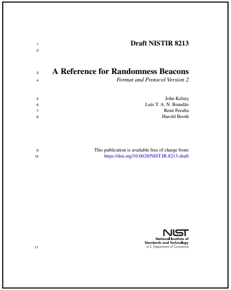
- 2019-May: "Draft NISTIR 8213" online — specifies the new (draft) *Reference for Randomness Beacons* (version 2)

The NIST Beacon will progressively implement all aspects of the Reference.

This talk is about the NISTIR 8213 (draft)

“A **Reference** for Randomness Beacons: Format and Protocol Version 2”

https://doi.org/10.6028/NIST.IR.8213-draft



Draft NISTIR 8213

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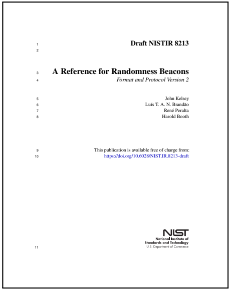

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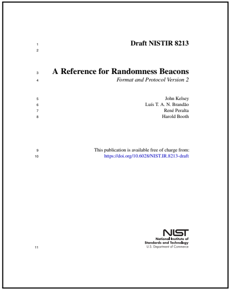

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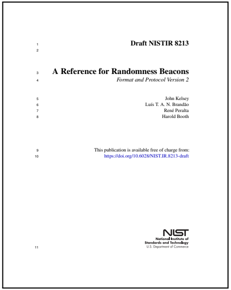

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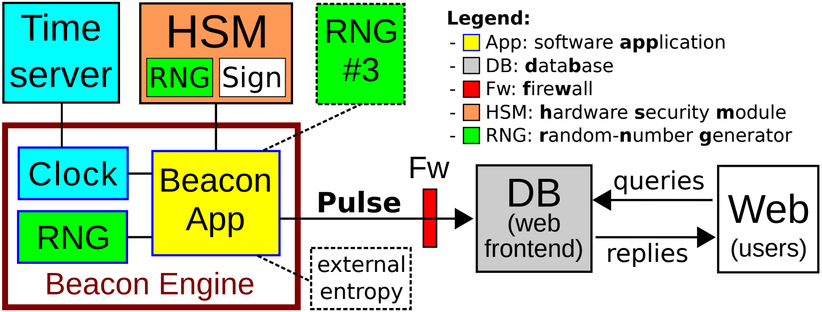
Two goals in this presentation:

- Provide an overview of the new reference
- Motivate engagement: NISTIR feedback, new beacons and apps

Components of the Beacon service, at a high level



Time server

HSM

RNG

Sign

RNG #3

Clock

RNG

Beacon App

Beacon Engine

Pulse

Fw

external entropy

DB (web frontend)

queries

replies

Web (users)

Legend:

- 🟨 App: software **app**lication
- ⬜ DB: **d**ata**b**ase
- 🟥 Fw: **f**ire**w**all
- 🟧 HSM: **h**ardware **s**ecurity **m**odule
- 🟩 RNG: **r**andom-**n**umber **g**enerator

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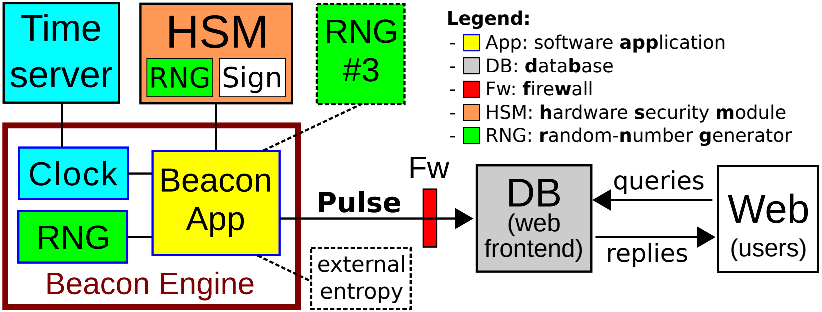

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But what exactly is a *pulse*, what is its randomness, ...?

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A pulse (simplified example)

```
uri:str="https://beacon.nist.gov/beacon/2.0/chain/1/pulse/220394"
version:str="2.0"
...
period:dec="60000"
...
chainId:dec="1"
pulseId:dec="220394"
time:str="2018-12-26T16:07:00.000Z"
randLocal:hex="5FF1E0C019C42C77FA72D522...(512 bits total)"
...
out.Prev:hex="BA646CC4E7AE195D2C85E9D3...(512 bits total)"
...
preCom:hex="269908B840E79BE71CEC4EBA...(512 bits total)"
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sig:hex="17943D886DA8C7C24B9244BE...(4096 bits total)"
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- Two main random values (“rands”): `randLocal` and `randOut`.
- Other features: signature, precommit `randLocal`, chain `randOut`, ...

The two “rands” in a pulse

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randLocal (a.k.a. local random value):

randOut (a.k.a. output value):

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- Hash (SHA512) of randomness output by ≥ 2 RNGs
- Pre-committed 1 minute in advance of release
- Useful for combining beacons

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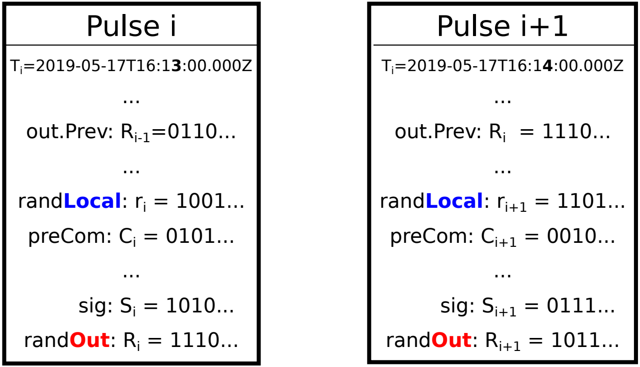
- Hash (SHA512) of randomness output by ≥ 2 RNGs
- Pre-committed 1 minute in advance of release
- Useful for combining beacons

randOut (a.k.a. output value):

- Hash of all other fields
- **Fresh** at the time of release
- The actual randomness to be used by applications

The two “rands” in a pulse



Pulse i

T_i=2019-05-17T16:1**3**:00.000Z

...

out.Prev: $R_{i\text{-}1}$=0110...

...

rand**Local**: r_i = 1001...

preCom: C_i = 0101...

...

sig: S_i = 1010...

rand**Out**: R_i = 1110...

Pulse i+1

T_i=2019-05-17T16:1**4**:00.000Z

...

out.Prev: R_i = 1110...

...

rand**Local**: r_{i+1} = 1101...

preCom: C_{i+1} = 0010...

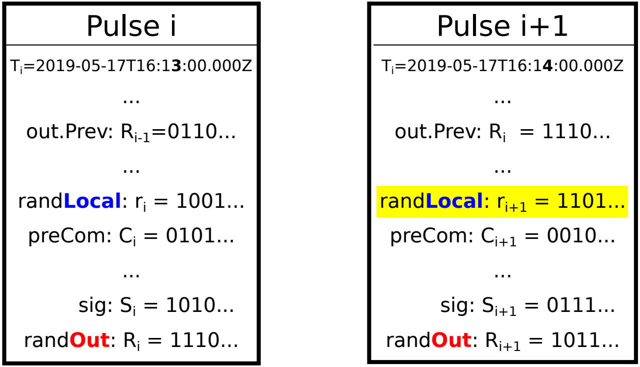
...

sig: S_{i+1} = 0111...

rand**Out**: R_{i+1} = 1011...

The two “rands” in a pulse

`randLocal:` $r_{i+1} = \text{Hash}(\rho_{1,i} \mid\mid \rho_{2,i} \ [\mid\mid \ \rho_{3,i}])$, with random $\rho_{j,i}$ from i^{th} RNG



Pulse i

T_i=2019-05-17T16:1**3**:00.000Z

...

out.Prev: R_{i-1}=0110...

...

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preCom: C_i = 0101...

...

sig: S_i = 1010...

rand**Out**: R_i = 1110...

Pulse i+1

T_i=2019-05-17T16:1**4**:00.000Z

...

out.Prev: R_i = 1110...

...

rand**Local**: r_{i+1} = 1101...

preCom: C_{i+1} = 0010...

...

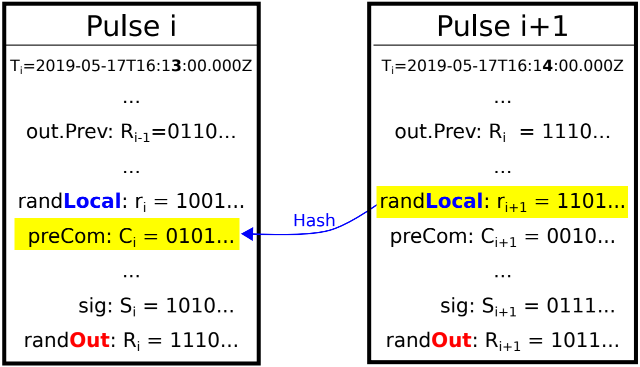
sig: S_{i+1} = 0111...

rand**Out**: R_{i+1} = 1011...

The two "rands" in a pulse

randLocal: $r_{i+1} = \text{Hash}(\rho_{1,i} \mid\mid \rho_{2,i} \; [\mid\mid \rho_{3,i}])$, with random $\rho_{j,i}$ from i^{th} RNG

preCom: $C_i = \text{Hash}(r_{i+1})$, released 1 min before r_{i+1}



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preCom: C_i = 0101...

...

sig: S_i = 1010...

rand**Out**: R_i = 1110...

Hash

Pulse i+1

T_i=2019-05-17T16:1**4**:00.000Z

...

out.Prev: R_i = 1110...

...

rand**Local**: r_{i+1} = 1101...

preCom: C_{i+1} = 0010...

...

sig: S_{i+1} = 0111...

rand**Out**: R_{i+1} = 1011...

The two "rands" in a pulse

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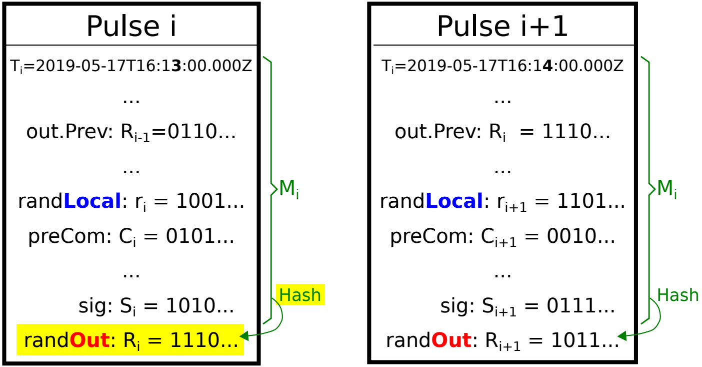

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...

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preCom: C_i = 0101...

...

sig: S_i = 1010...

rand**Out**: R_i = 1110...

Pulse i+1

T_i=2019-05-17T16:1**4**:00.000Z

...

out.Prev: R_i = 1110...

...

rand**Local**: r_{i+1} = 1101...

preCom: C_{i+1} = 0010...

...

sig: S_{i+1} = 0111...

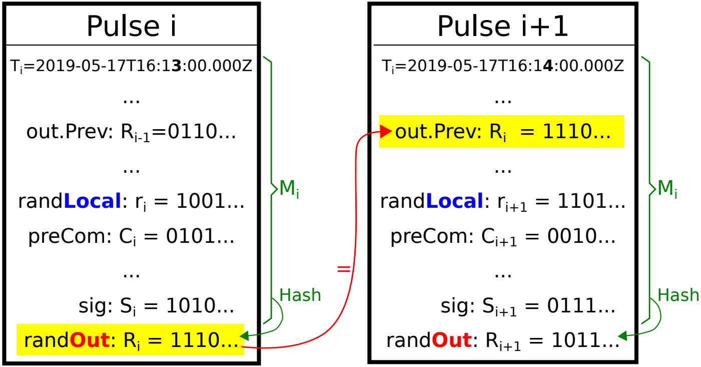
rand**Out**: R_{i+1} = 1011...

`randOut`: R_i $= \text{Hash}(M_i)$, with M_i being the serialization of all previous fields

The two “rands” in a pulse

`randLocal`: $r_{i+1} = \text{Hash}(\rho_{1,i} \mid\mid \rho_{2,i} \; [\mid\mid \; \rho_{3,i}])$, with random $\rho_{j,i}$ from i^{th} RNG

`preCom`: $C_i = \text{Hash}(r_{i+1})$, released 1 min before r_{i+1}



Pulse i

T_i=2019-05-17T16:1**3**:00.000Z

...

out.Prev: R_{i-1}=0110...

...

rand**Local**: r_i = 1001...

preCom: C_i = 0101...

...

sig: S_i = 1010...

rand**Out**: R_i = 1110...

M_i

Hash

=

Pulse i+1

T_i=2019-05-17T16:1**4**:00.000Z

...

out.Prev: R_i = 1110...

...

rand**Local**: r_{i+1} = 1101...

preCom: C_{i+1} = 0010...

...

sig: S_{i+1} = 0111...

rand**Out**: R_{i+1} = 1011...

M_i

Hash

`randOut`: $R_i = \text{Hash}(M_i)$, with M_i being the serialization of all previous fields

`out.Prev` has the output value (R_i) of the previous pulse

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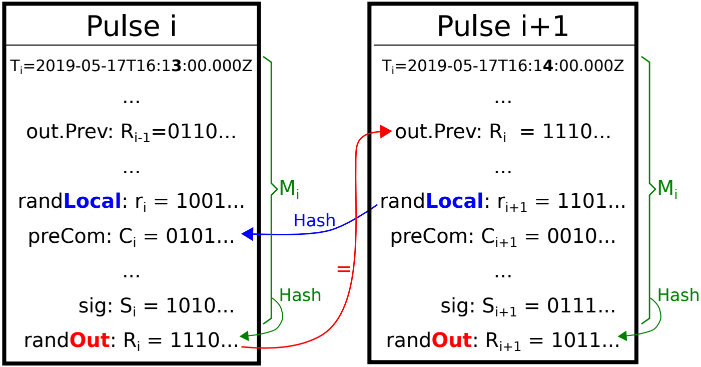

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Pulse i+1

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Outline

1. Introduction
2. Pulse format
3. Beacon Protocol
4. Using a Beacon
5. Brief security considerations
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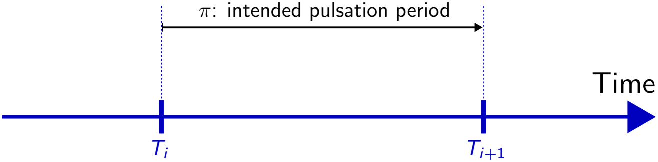
Beacon proper operation

- Timing and entropy requirements
- Beacon interface: getting pulses and skiplists
- Others (not here): external values, status fields, ...

Timing requirements for generation and release



Timing requirements for generation and release

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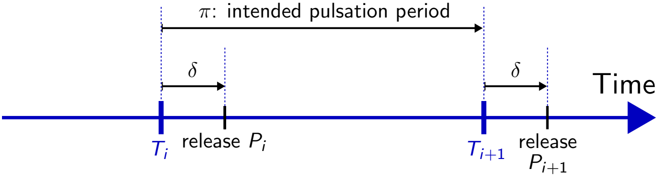
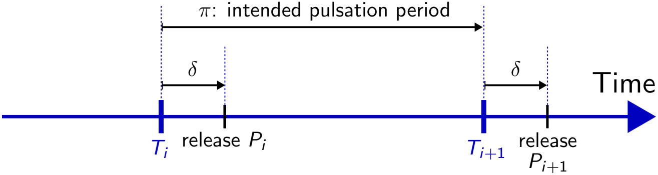


Timing requirements for generation and release

$$\left.\begin{array}{l}\text{1. No advanced release of pulse } (\delta \geq 0) \\ \text{2. Generate with entropy } (\geq 2 \text{ RNGs})\end{array}\right\} \Rightarrow \textbf{Unpredictability}$$



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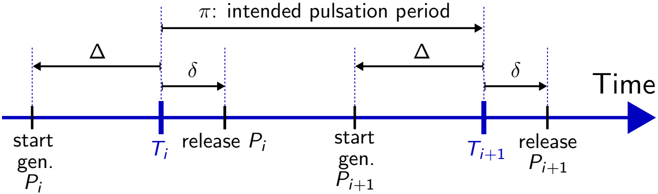

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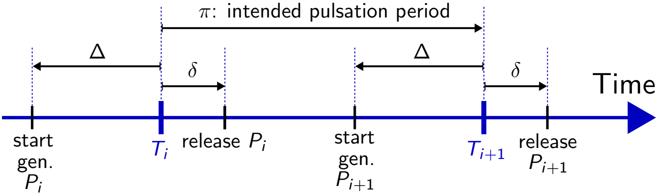
1. No advanced release of pulse ($\delta \geq 0$)
2. Generate with entropy (≥ 2 RNGs)

$\Big\} \Rightarrow$ **Unpredictability**

3. Generate not too in advance (small Δ) $\Rightarrow$ **Freshness**



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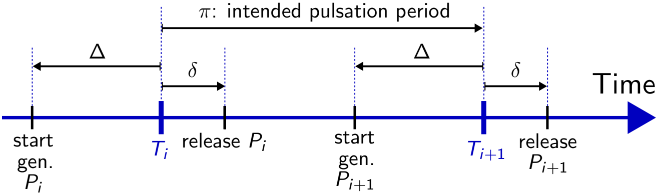

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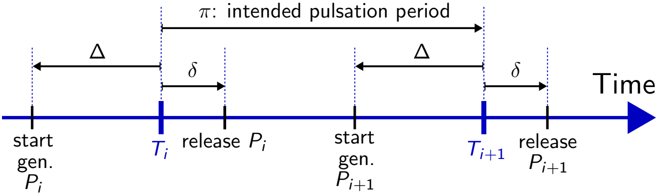

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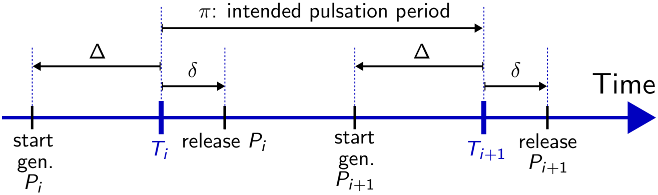

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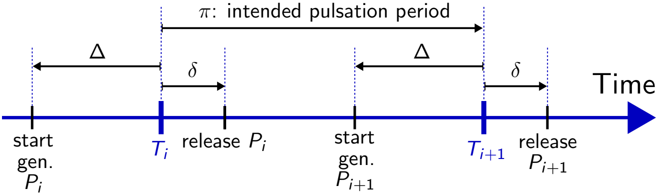

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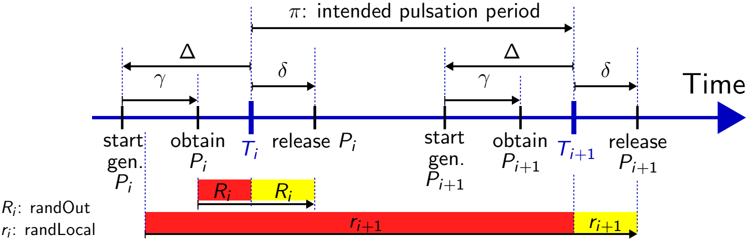

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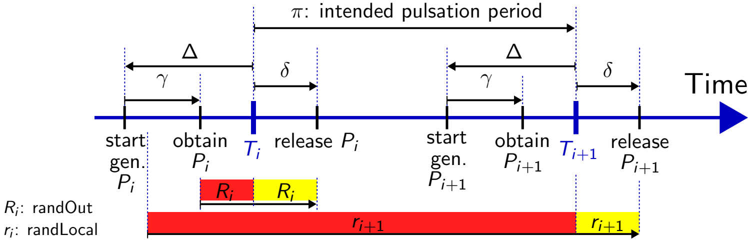

(The reference document specifies allowed intervals for δ and Δ, relative to π)

Fetching pulses

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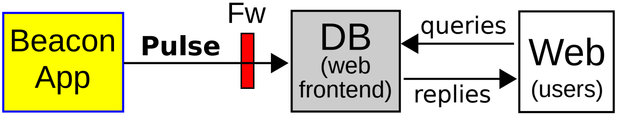
Beacon App: a *pulse release* means *sending the pulse to the database*



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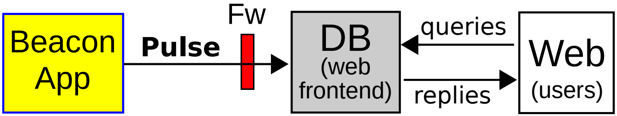

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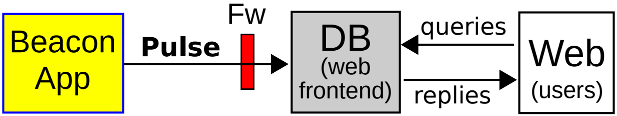

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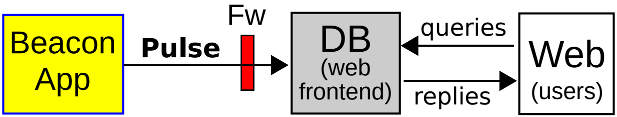

How do users request pulses from the database? uri/url

https://beacon.nist.gov/beacon/2.0/chain/last/pulse/last
Example: URI for the latest pulse in chain 1 of the NIST randomness Beacon (version 2)

Skiplists — efficient chain verification

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Efficient: check the hash-chaining in a **skiplist** ($<$ 125 pulses).

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Use the 5 *past output* fields in the pulse format:

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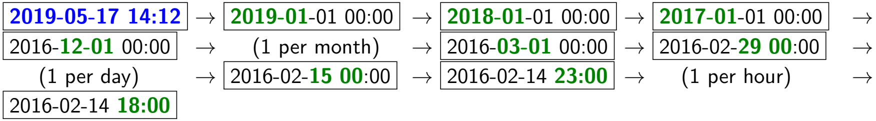

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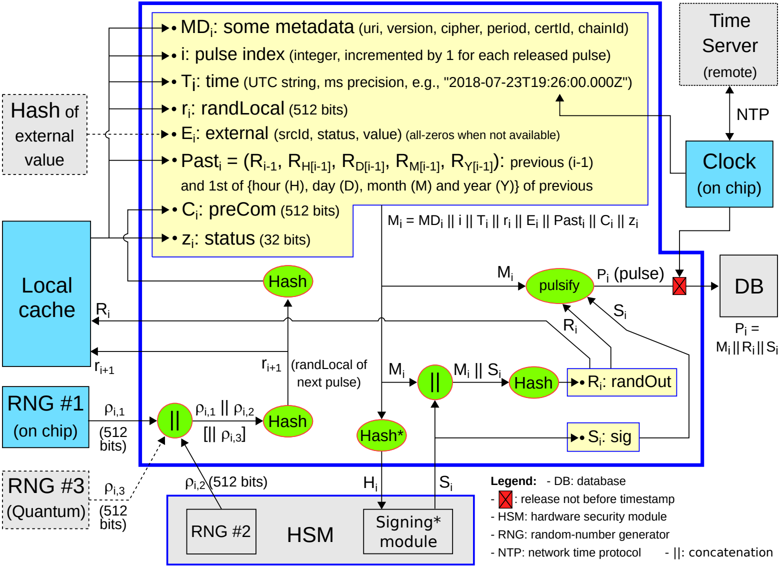
(1 per day) → 2016-02-**15 00**:00 → 2016-02-14 **23:00** → (1 per hour) →
2016-02-14 **18:00** → 2016-02-14 17:**59** → (1 per minute) → **2016-02-14 17:45**

A possible diagram of pulse generation



- MD_i: some metadata (uri, version, cipher, period, certId, chainId)
- i: pulse index (integer, incremented by 1 for each released pulse)
- T_i: time (UTC string, ms precision, e.g., "2018-07-23T19:26:00.000Z")
- r_i: randLocal (512 bits)
- E_i: external (srcId, status, value) (all-zeros when not available)
- $Past_i = (R_{i-1}, R_{H[i-1]}, R_{D[i-1]}, R_{M[i-1]}, R_{Y[i-1]})$: previous (i-1) and 1st of {hour (H), day (D), month (M) and year (Y)} of previous
- C_i: preCom (512 bits)
- z_i: status (32 bits)

$M_i = MD_i \,||\, i \,||\, T_i \,||\, r_i \,||\, E_i \,||\, Past_i \,||\, C_i \,||\, z_i$

$P_i = M_i \,||\, R_i \,||\, S_i$

Legend:
- DB: database
- ☒: release not before timestamp
- HSM: hardware security module
- RNG: random-number generator
- NTP: network time protocol
- ||: concatenation

For simplicity, the diagram omits serialization details (e.g., field lengths and padding) and some metadata fields.

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(some simplifications for presentation purpose)

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We defer reference guidance to complementary future documentation

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Also need to check:

- reception of $A[t-\pi].\mathit{randOut}$ and $B[t-\pi].\mathit{randOut}$ before time T
- correctness of standalone pulses: $A[t-\pi], B[t-\pi], A[t], B[t]$
- hash-chaining (e.g., $A[t].\texttt{out.Prev} = A[t-\pi].\texttt{randOut}$)
- pre-commitments (e.g., $\text{Hash}(\text{A}[\text{t}].\texttt{randLocal}) = A[t-\pi].\texttt{preCom}$)

Some Beacons in development

Three countries are developing Beacons to match the current reference:

United States
Brazil
Chile

- (United States) NIST Randomness Beacon
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We would like others to join

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- Select test and control groups for clinical trials
- Select random government officials for financial audits
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Some generic goals:

- Prevent auditors from biasing selections (or being accused of it)
- Prevent auditees from addressing only the items to-be sampled
- Enable public verifiability of correct sampling

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2. Pulse format

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5. Brief security considerations

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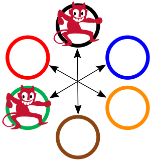
Why considering intrusions?

1. We want trust to be leveled with trustworthiness — a security analysis enables reflecting on meaningful security claims.
2. *Even if operators believe in uncompromised components at launch day, we want security in the long run, against conceivable adversarial threats (goals and capabilities).*



Types of security properties (informal)

- **Relational**: correct hash chain, signatures, timestamps, consistent record (immutable past), ...
- **Availability:** *timely* pulse releases; *accessible* past pulses; *automatic* operation (reduced human operator intervention); ...
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Attack consequences:

- breaking *relational* or *availability* properties typically leads to detectable errors, e.g., incorrect signatures or hash-chaining, delayed releases, ...
- next slides mention a few examples of attacks to the *"rands" quality*

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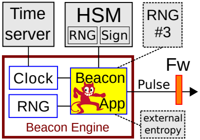

Legend: Mal=malicious

The red dancing devil clipart is from clker.com/clipart-13643.html

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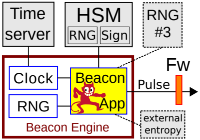

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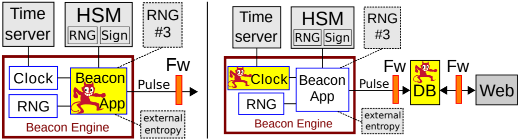

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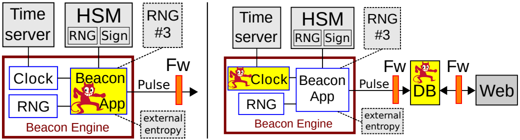

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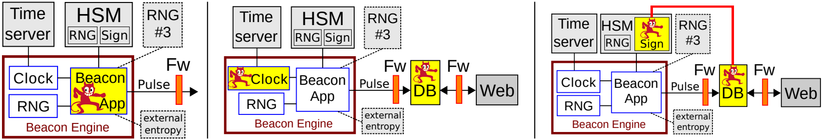
- I5. Mal DB with HSM sign key → change-history attack



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Conceivable mitigations

The NISTIR mentions some mitigations

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For example, some could be based on the use of:

- publicly-verifiable external entropy (to reduce pre-computation window)
- verifiable delay functions
- secure time synchronization
- a different `randLocal` computation, with non controllable value
- different signature (e.g., $>$ bit-strength, post-quantum, or/and threshold)
- a forward-chaining mechanism

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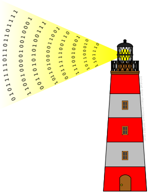
- **We would like to have your collaboration:**
  - public feedback on the NISTIR 8213
  - more deployed beacons
  - external apps using Beacon randomness

- Draft NISTIR 8213: https://doi.org/10.6028/NIST.IR.8213-draft
- Email for feedback on the NISTIR 8213: beacon-nistir@nist.gov
- Beacon project: https://www.nist.gov/programs-projects/nist-randomness-beacon



Thank you for your attention

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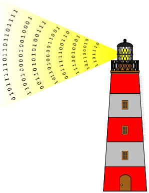

Presentation at the International Cryptographic Module Conference

May 17, 2019 @ Vancouver, Canada

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