Anonymously Publishing Liveness Signals with Plausible Deniability

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Problem statement

Dall-E with prompt “A picture of a brave woman blowing a whistle while holding up a document folder in film noir style”

Problem statement

- Persons might want to prove ("**Prover**") to others ("**Verifier**") that they are still alive & well ("**Signal**" received)
  - E.g. whistleblowers; to keep a "security package" stashed with third parties from being published
- If you want/need such a scheme, you implicitly want to remain **anonymous** – and in case of suspicion **be able to deny** it
  - "I am not a whistleblower" (who would be sent to jail)
  - "I am not a 'verifier' with a package" (who would have to relinquish the package – and maybe go to jail too – participation/help/…)
  - Even if the other party is discovered, all devices are obtained & analyzed, and the person (made to) cooperate, you should still be able to disclaim any participation
- We developed and implemented a protocol to support this:
  - Proving "**liveness**" + **plausible deniability**
  - Not included: data communication, security package etc.

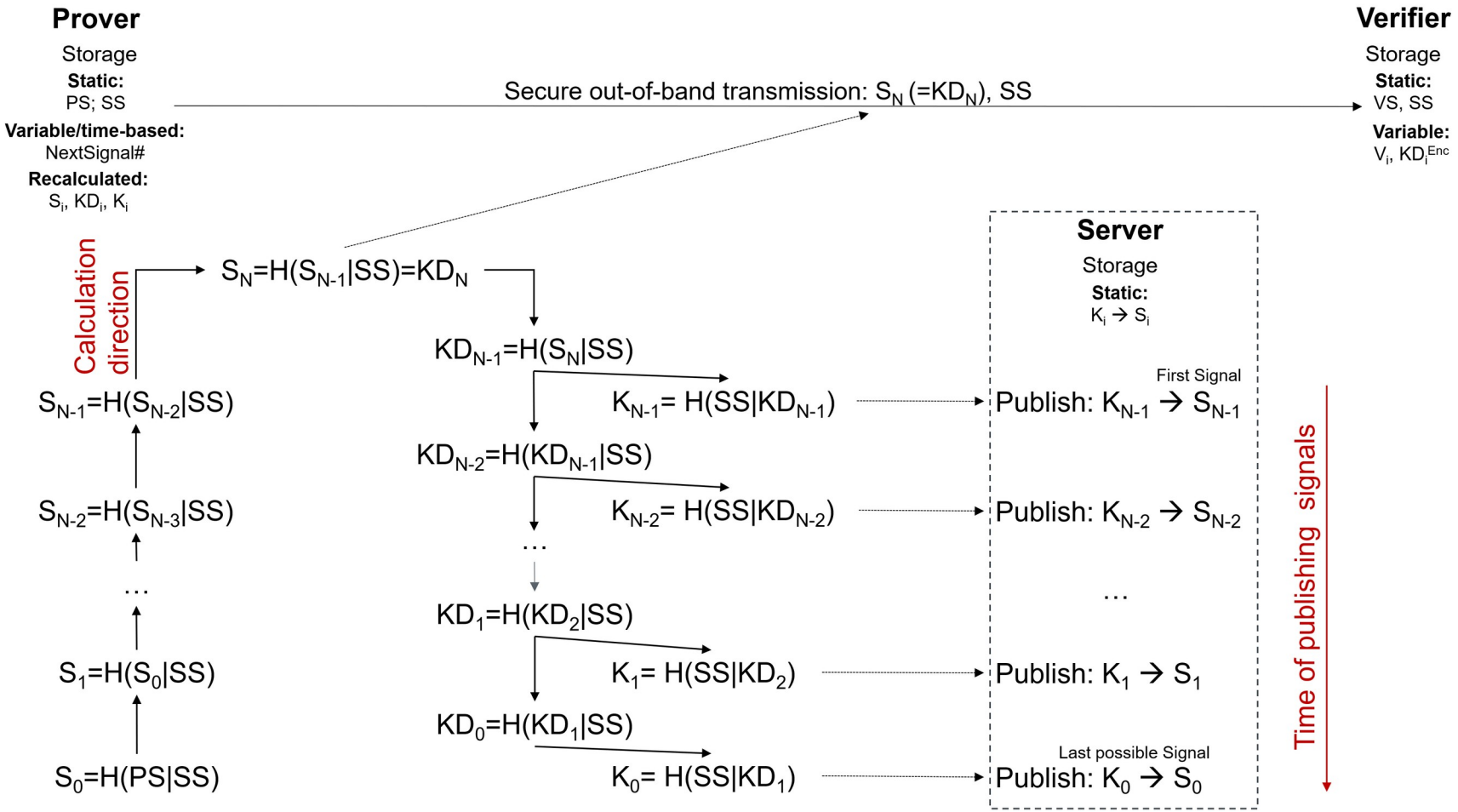
Solution outline [1]

- Store “Signal” on a third-party server, so communication is completely **asynchronous** → no correlation attacks
  - Communication should be explainable as “normal usage”, too
- Use Tor & **Onion services** to hide participants
  - Large foreign public Onion services (= Signal storage) preferable
  - Querying non-existing signals: random generation
- Roles are **symmetrical** regarding stored data
  - Each one can claim to be the other (if desirable)
- **No identical data** stored at participants
  - Exception: a single shared secret kept in (human) memory
  - Prover: nothing related found at Verifier, even if all secrets (incl. shared one) are disclosed correctly
  - Verifier: vice versa
  - Both: Lying about anything provides valid values indistinguishable from those based on correct disclosure

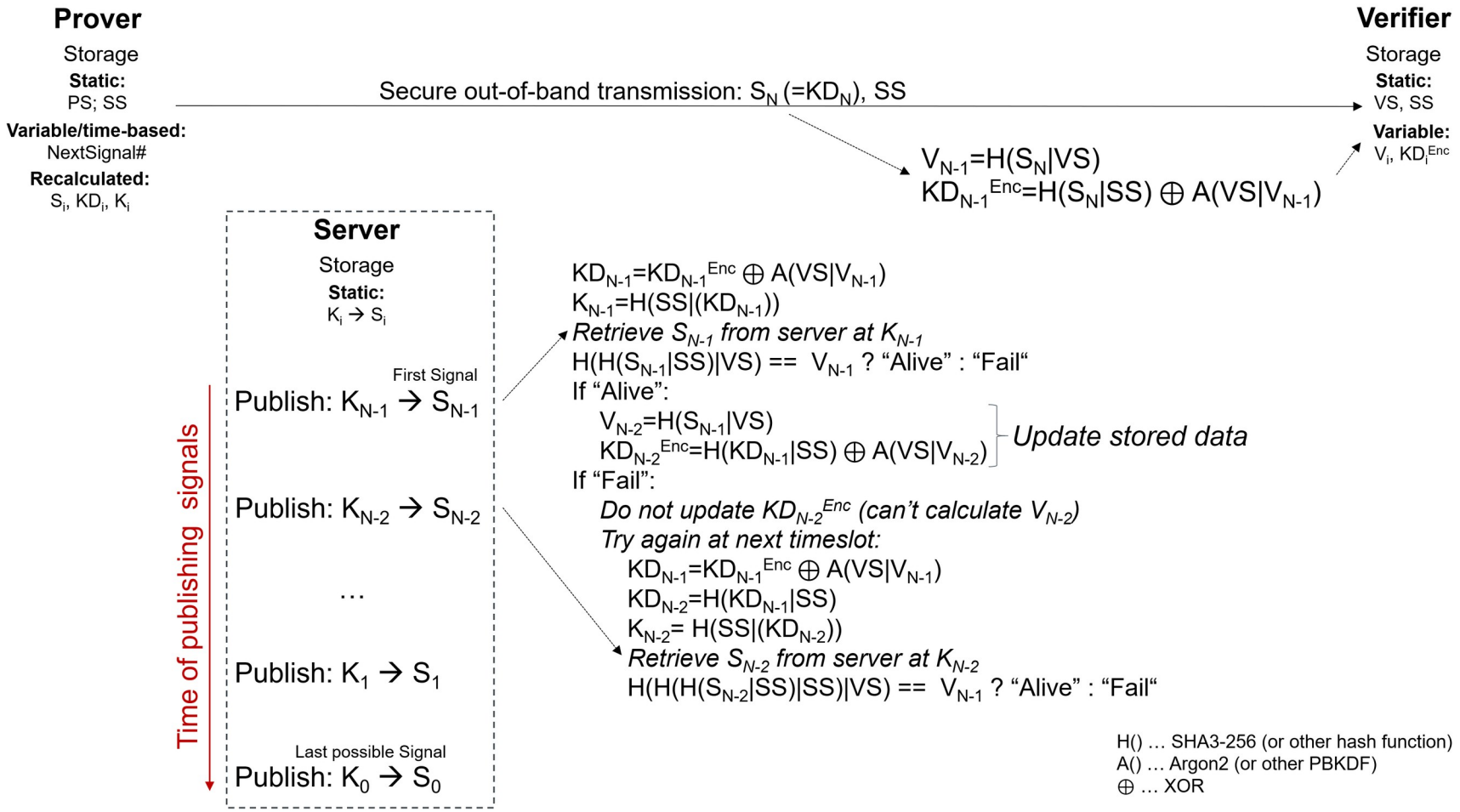
Solution outline [2]

- No danger from attackers for storage server
  - Proof of Work for querying and submission (DoS prevention)
    - No DoS regarding signals or protocol; requires only limited storage
  - No registration, payment, etc. needed
- A “key” is used to distinguish multiple provers on a single server
  - Derived from the same values; properties as before
- Signals may be missed: participants can calculate/verify forward, but not backwards
  - Based on a hash chain → no reversing (computational limits)
  - The prover can stop calculation early to create “old” keys/signals, but that doesn’t help with identifying/proving a verifier
  - After a freely set number of missed signals the verifier considers the prover “dead” → can delete data, publish security package, ...
    - And should stop verification attempts!

Prover side


Prover
Storage
Static:
PS; SS
Variable/time-based:
NextSignal#
Recalculated:
S_i, KD_i, K_i
Secure out-of-band transmission: S_N (=KD_N), SS
Verifier
Storage
Static:
VS, SS
Variable:
V_i, KD_i^{Enc}
Server
Storage
Static:
$K_i \rightarrow S_i$
Calculation direction
$S_N=H(S_{N-1}|SS)=KD_N$
$KD_{N-1}=H(S_N|SS)$
$S_{N-1}=H(S_{N-2}|SS)$
$K_{N-1}= H(SS|KD_{N-1})$
First Signal
Publish: $K_{N-1} \rightarrow S_{N-1}$
$KD_{N-2}=H(KD_{N-1}|SS)$
$S_{N-2}=H(S_{N-3}|SS)$
$K_{N-2}= H(SS|KD_{N-2})$
Publish: $K_{N-2} \rightarrow S_{N-2}$
$KD_1=H(KD_2|SS)$
$S_1=H(S_0|SS)$
$K_1= H(SS|KD_2)$
Publish: $K_1 \rightarrow S_1$
$KD_0=H(KD_1|SS)$
$S_0=H(PS|SS)$
$K_0= H(SS|KD_1)$
Last possible Signal
Publish: $K_0 \rightarrow S_0$
Time of publishing signals

Verifier side

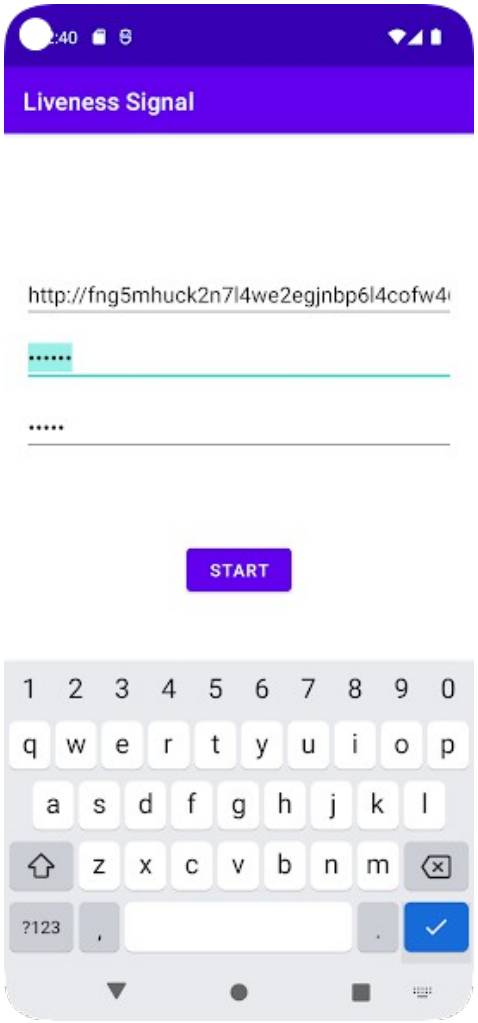


Data “stored” by participants

- Prover & Verifier:
  - Onion address of storage server(s): public site, human memory, …
  - Shared secret (human memory only)
- Prover:
  - Prover secret (human memory only) for signal/key generation
  - Number of the next signal
    - Or some method of deriving it, e.g. starting time + current date/time
  - Arbitrary data looking like current key generation/verification data
- Verifier:
  - Verifier secret (human memory only)
  - Current key generation data
    - Encrypted via XOR with data derived from verifier secret and verification data during storage & ratcheted forward after each sending
  - Verification data for verifying the next signal value
- Onion service operator: Map[Key → Signal]

Single hash value each

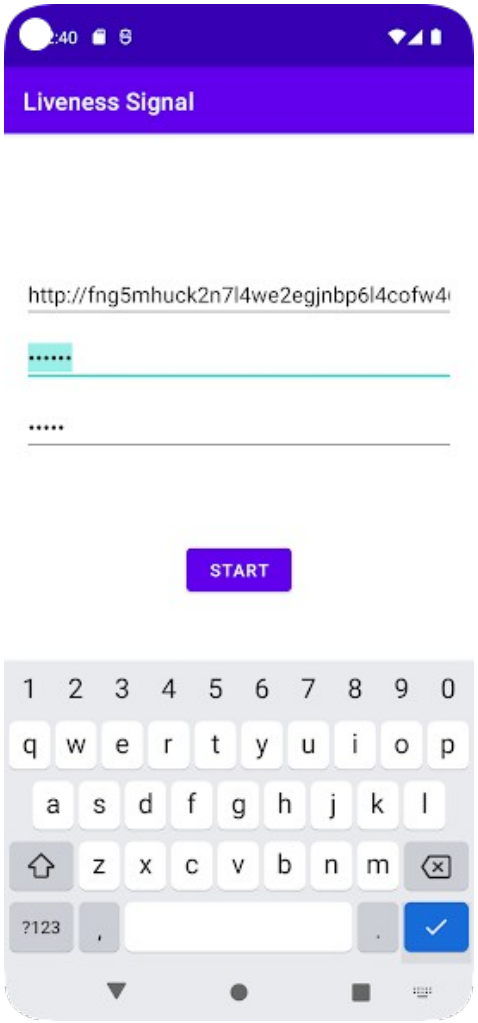
Exemplary implementation

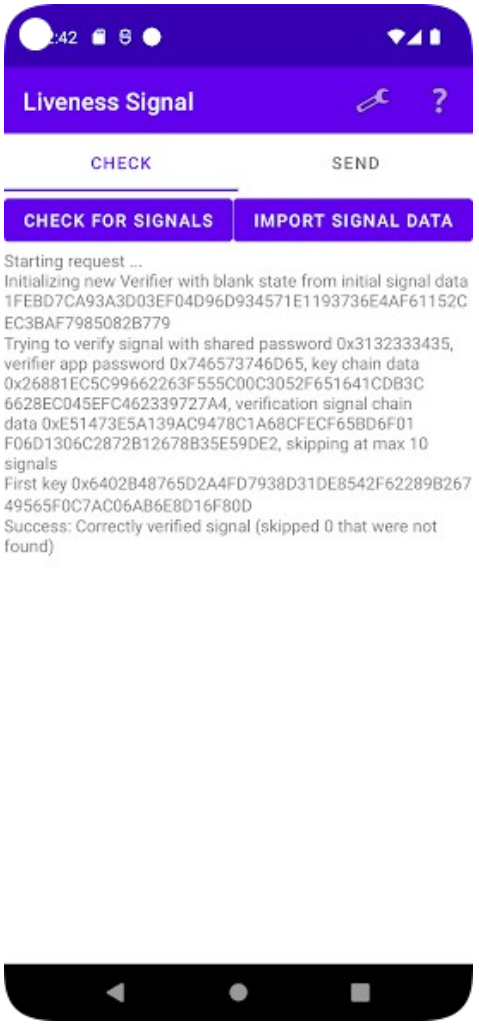


Exemplary implementation

- Same Android app for Prover & Verifier:
  - Default onion address for storage server (run by INS at JKU)
  - App secret specific to each user, used for local storage encryption
  - Shared secret (human memory only) for signal creation+verification

Exemplary implementation





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- Synchronizing Prover & Verifier:
  - One-time initial synchronization, assisted by displaying a QRcode at Prover and scanning with Verifier
  - After that first synchronization, completely asynchronous communication through the Onion service
- Core cryptographic protocol implemented in Java-only library
  - Minor dependencies (mostly logging)
  - Can be easily used in other apps, e.g. standard news organizations apps with integrated messaging functionality

Plausible deniability achieved? [1]

- Prover cooperates and discloses prover and shared secret
  - Future keys and signals can be calculated
    → Prover can be impersonated
  - None of that data is found at the verifier on any device, neither the shared secret nor any of the future key or verification data
  - Calculating older keys does not help, as servers do not store when/whether the data was retrieved – and would they, this would not help either with identifying/proving a Verifier because of Tor
  - Lying about the shared secret produces valid values that can be stored (but will not validate); previous ones (allegedly published in the past) are no longer stored by the server and enumeration by attacker in advance is impossible
  - Correlation attacks can be performed, but require cooperation of the storage server → pre-calculate the key and wait for check(s)

Plausible deniability achieved? [2]

- Prover can claim to be a verifier: With an invented (or correct) shared secret signals can be successfully retrieved, but none will validate
  - Some delay required to convincingly tell “prover is already dead”
  - Old signals cannot be generated, so it is impossible to prove that there never was a valid signal
- Verifier: Situation is symmetric
  - Verifier can be impersonated if disclosing all values
    - Verifying liveness becomes possible for the attacker
  - No help identifying/proving the Prover
    - No matching data found there; no access to previous keys or signals as this would require reversing the hash function
  - Verifier could claim to be a prover: that no one verifies this could only be proven together with the storage server & if quick
    - Or prover would already consider him dead and checks no longer

Summary

- We provide a scheme to prove a “recent activity” by “someone knowing a shared secret”
  - But without the ability for attackers to identify any participant, knowing such a scheme is going on, and even if all (other) participants cooperate fully, the last one can still deny involvement
    - Or claim a different role, if desirable
- Open problems:
  - Separate app needed: integration (tiny part) into a widely-used app would remove this sign of participation
    - Alternative: Download JavaScript from trusted website and calculate locally; difficult to verify this is secure (unchanged code); requires lots of trust in the site
  - Third party needed for storage
    - Load is low: practically no computational effort required
    - Storage: 1 attacker doing 24/7 nothing else: ≈ 15 MB storage

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THANK YOU FOR YOUR ATTENTION!

Questions?

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