Stamp & Extend - Instant but Undeniable Timestamping based on Lazy Trees

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According to the recent proposal for a regulation of the European Parliament and of the Council on electronic identification and trust services for electronic transactions in the internal market:

"electronic time stamp" means data in electronic form which binds other electronic data to a particular time establishing *evidence* that these data existed at that time

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2. Signing time is crucial for the legal consequences - e.g., in administrative procedures a party has a limited period of time to perform a legally valid action.
3. The recent proposal states that "Qualified electronic time stamp shall enjoy a *legal* presumption of ensuring the time it indicates and the integrity of the data to which the time is bound".

Trusted services

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But:

- Certification process is only a process of checking of some properties against a certain list (a Protection Profile) that may ignore or overlook some important issues.
- TSA may itself be interested to retrieve the keys stored in the device to be able to backdate certain documents.

Honesty of TSA forced by the protocol

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- Each element of the chain contains a signature of TSA on:
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- The very first element of the chain is the certificate of TSA's public key.
- Disadvantage: verification time is linear in the number of time stamps issued.

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Round schemes

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Construction of a single round

one-way accumulators, aggregated signatures, Merkle trees.

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- For each request m a value r is generated by the service in such a way $h_c(m, r)$ fits the first unused hash value generated in advance.
- A trapdoor necessary to generate values r is distributed between a few servers. They must collude to backdate a document.

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- **If the same randomness is used to sign answers to two different requests then the private key of TSA leaks.**
- Accordingly, we have an undeniable evidence that: private key of TSA is used outside the TSA, or TSA is misbehaving.

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- Costly certification process of the time-stamping device is not necessary - the protocol provides evidence of a fraud.
- Each request is served instantly.
- Any two timestamps are comparable with respect to the order they were requested.

Protocol's Building Blocks - Schnorr Signatures

Keys

Private key: x, public key: g^x, where $\langle g \rangle$ is a group of prime order q, in which DLP is hard.

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1. the signer chooses an integer $k \in [1, q-1]$ uniformly at random,
2. $r := g^k$,
3. $e := H(M||r)$ ($||$ stands for concatenation),
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Note: **if the same** k **is used twice, for different** M, M', **then key** x **leaks!**

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Let $h \in \langle g \rangle$ such that $\log_g h$ is known to nobody.

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Commitment

- Commitment c to k is obtained by choosing $\ell \in \{0, 1, \ldots, q-1\}$ uniformly at random and assigning:

$$c := g^k \cdot h^\ell.$$

- Commitment c reveals no information about k.
- Changing the commitment c to a k' such that $k' \neq k$ implies knowledge of $\log_g h$. Therefore it is infeasible to replace k by k'.

The protocol

Certificate HS_0 of TSA contains y, and c_1 where:

- $y = g^x$ is TSA's public, signature verification key,
- $c_1 = g^{k_1} h^{\ell_1}$ is the first commitment, where k_1, ℓ_1 are uniformly chosen.

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Data stored by TSA

- the index of the last timestamp issued $i - 1$ (initially $i = 1$),
- a private list P of pairs of exponents $[(k_i, \ell_i), \ldots, (k_{2i-1}, \ell_{2i-1})]$
- a public file C with the list of Pedersen commitments $[c_1, \ldots, c_{2i-1}]$,
- a public file HS that includes an initial value HS_0 and timestamps HS_j for $j = 1, \ldots, i - 1$.

The protocol - processing a request H_i by TSA

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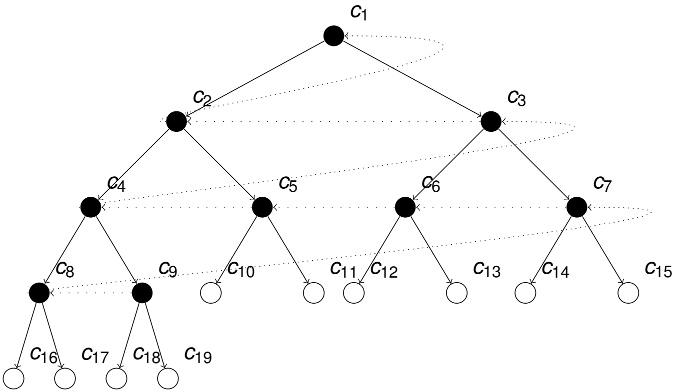
6. return the sequence of records to the requester

$$((e_i, s_i), H(\mathrm{HS}_{j-1}), \mathrm{H}_j, c_{2j}, c_{2j+1}, \ell_j, j) \tag{1}$$

for $j = \lfloor i/2^\alpha \rfloor$, where $\alpha = 0, 1, \ldots, \lfloor \log_2 i \rfloor$.

Two structures fused, $i = 9$



The protocol: the main trick ...

- If the same commitment c_i is utilized twice for signing two different requests H_i, H_i' then the private key leaks (see the second component of Schnorr signatures).
- "An escape route" for the forger would be to change commitments, but then . . .

The protocol: ... the main trick ...

- Assign $c'_j := g^{e_j} y^{s_j} h^{\ell_j}$ for $j = \lfloor i/2^\alpha \rfloor$, where $\alpha = 0, 1, \ldots, \lfloor \log_2 i \rfloor$ - see records (1).
- Note that if the sequence

$$c'_i, c'_{\lfloor i/2 \rfloor}, \ldots, c'_{\lfloor i/2^{\lfloor \log_2 i \rfloor - 2} \rfloor}, c'_{\lfloor i/2^{\lfloor \log_2 i \rfloor - 1} \rfloor}, c_1$$

is different from the publicly available sequence

$$c_i, c_{\lfloor i/2 \rfloor}, \ldots, c_{\lfloor i/2^{\lfloor \log_2 i \rfloor - 2} \rfloor}, c_{\lfloor i/2^{\lfloor \log_2 i \rfloor - 1} \rfloor}, c_1$$

then there is some index for which the sequences differ. By β denote the first such index counting from the right.
- Then $c_\beta \neq c'_\beta$, but $c_{\lfloor \beta/2 \rfloor} = c'_{\lfloor \beta/2 \rfloor}$ (at worst $\lfloor \beta/2 \rfloor = 1$).

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- But the randomness used to make the signatures under the "messages" is the same, because $c_{\lfloor \beta/2 \rfloor} = c'_{\lfloor \beta/2 \rfloor}$.
- Assuming that Schnorr signatures are hard to repudiate this leads to leakage of key x.

The protocol: requester's actions

- Each requester receiving a timestamp (i.e., each client application) should always verify *a constant* number n_{ver} of timestamps: the one received and $n_{ver} - 1$ consecutive predecessors of a randomly chosen timestamp in the chain (the random choice is made by the requester).

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- We may assume that a local copy of all timestamps received is maintained by the requester, and a locally stored timestamp is compared with the newly received one if both are on the same position in the hash chain.

Thanks for your attention!

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