Employing quantum cryptography for providing Byzantine fault-tolerance

2-nd International workshop "Mathematical Methods in the Problems of Quantum Technologies"

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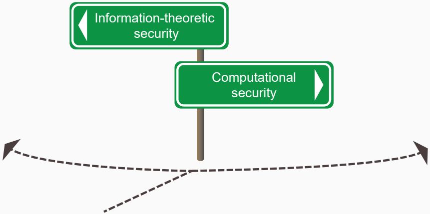
Introduction

There are two main approaches to protection against "quantum threat"



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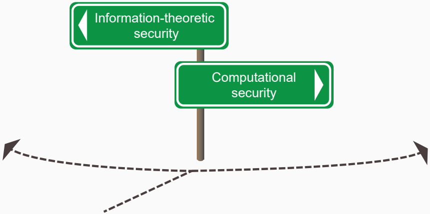

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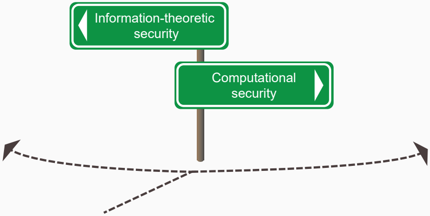

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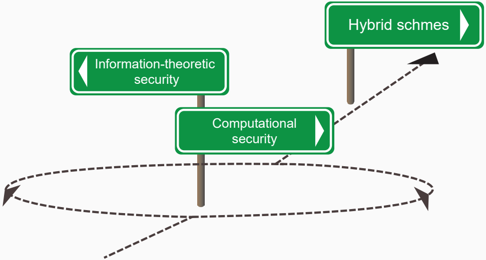

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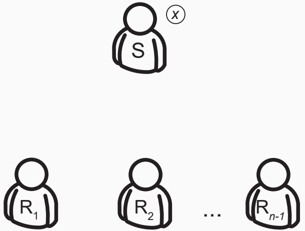
Here we consider these two approaches in the framework of providing Byzantine fault-tolerance, and show how they can be combined together in hybrid scheme in order to get benefits from both of them.

Byzantine agreement problem

[L. Lamport, R. Shostak, and M. Pease, ACM T. Progr. Lang. Sys. 4 382 (1982)]



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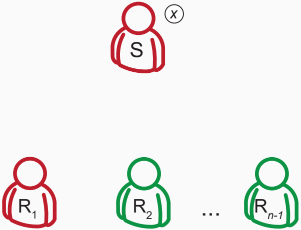

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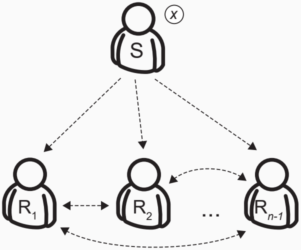

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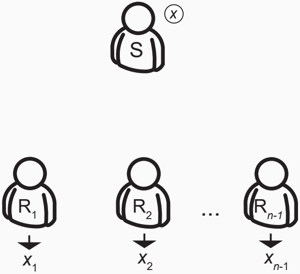

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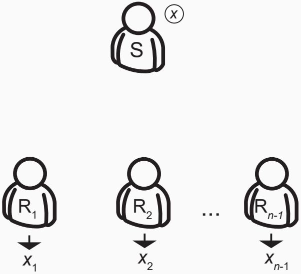

Required properties

A1. All honest receivers R_i decide the same output value $x_i = \overline{x}$ (consistency).

A2. If the sender is honest then all honest receivers R_i agree on sender's value $\overline{x} = x$ (validity).

Information-theoretic treatment

- Basic assumption: all players are connected with pair-wise authentic channels.

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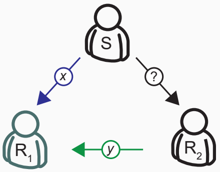

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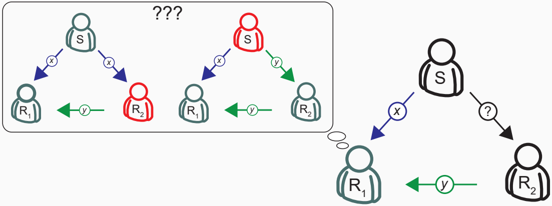

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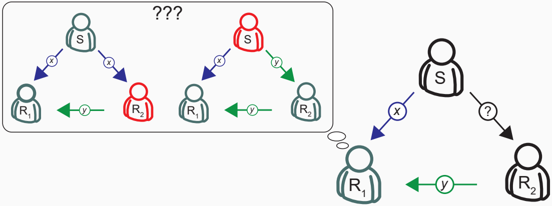

- ITS pair-wise authentication is possible with QKD.

Quantum-secured blockchain

[E.O.K., N.O. Pozhar, M.N. Anufriev, A.S. Trushechkin, R.R. Yunusov, Y.V. Kurochkin, A.I. Lvovsky, and A.K. Fedorov, Quantum Sci. Technol. 3, 035004 (2018)]

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- ITS broadcast protocol based on pair-wise authentic channels only.
- No signature schemes are used.
- The broadcast protocol is launching for unconfirmed transaction appeared during fixed period of time.
- The "block" with newly confirmed transactions is constructed for all users simultaneously.

Some technical details

[E.O.K., N.O. Pozhar, M.N. Anufriev, A.S. Trushechkin, R.R. Yunusov, Y.V. Kurochkin, A.I. Lvovsky, and A.K. Fedorov, Quantum Sci. Technol. 3, 035004 (2018)]

Number of nodes in the network	$n = 4$
Upper bound on the number of faulty nodes	$m = 1$
Number of rounds in the broadcast protocol	2
Duration of broadcast protocol	$<$ 10 sec
Time between block generation events	5 min
Authentication hash length	40 bit
Quantum key consumption in the initial broadcast of a transaction	40 bit
Quantum key consumption in the broadcast protocol	80 bit
Average quantum key consumption required for a transaction rate of 10 per minute	$<$ 7 bit/s

Employing signatures

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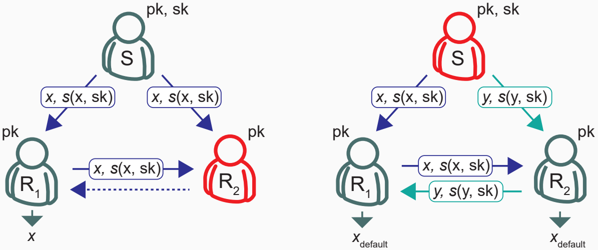

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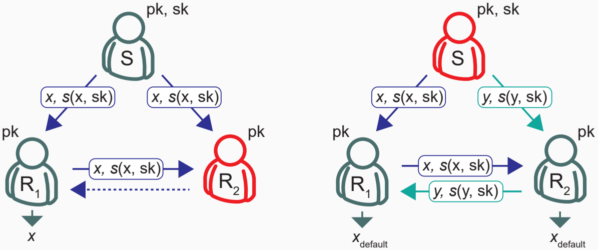

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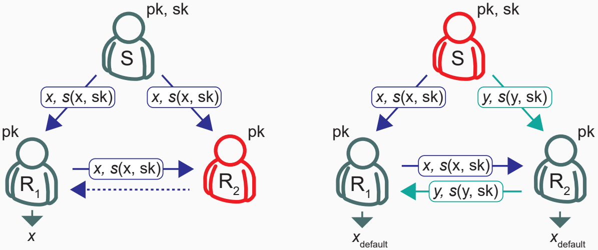

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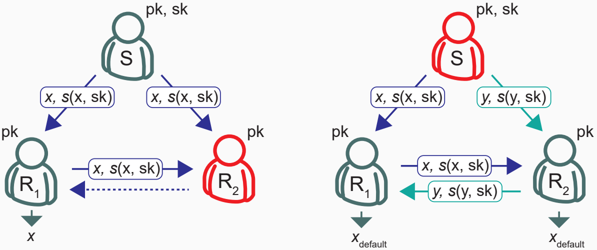

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- Can be established using common or post-quantum CS algorithms or ITS schemes (e.g. see [B. Pfitzmann, M. Waidner Reserch reprot (#908RZ 2882 (#90830)) (1996)]).
- Of particular interest are the post-quantum hash-based signatures.

Lamport one-time signature

[L. Lamport, Technical Report SRI-CSL-98, SRI International Computer Science Laboratory (1979)]

Let $H : \{0, 1\}^* \to \{0, 1\}^n$ be a cryptographic hash function. Consider a following variation of L-OTS.

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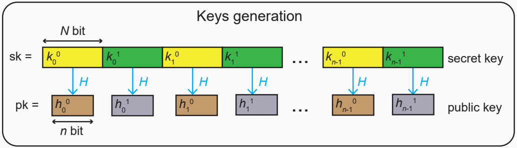

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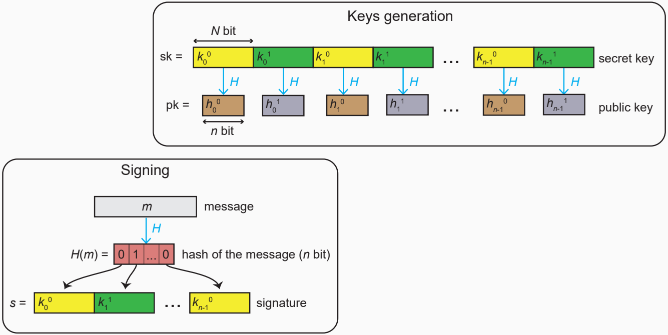

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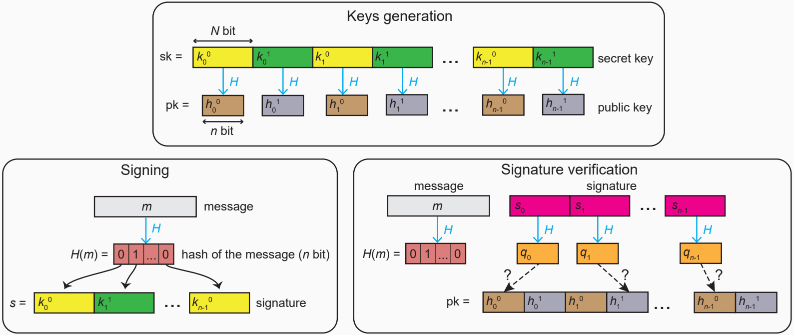

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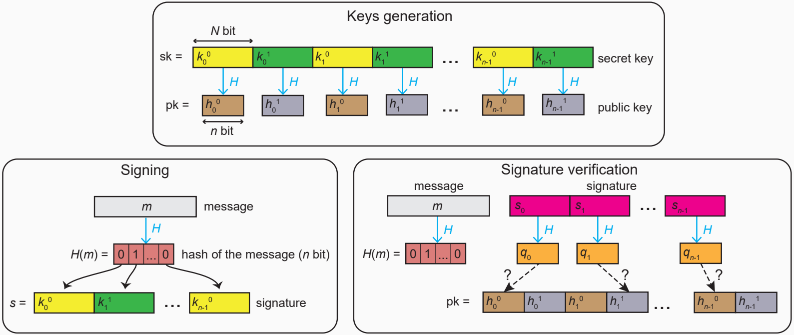

Note: signature includes a half of secret key!

Security of hash-based signatures

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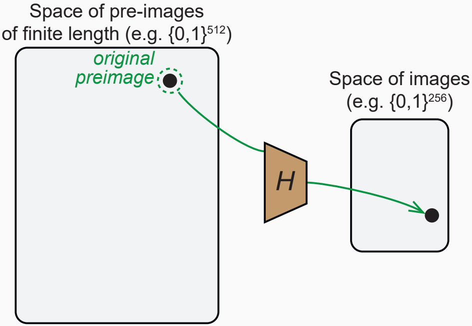

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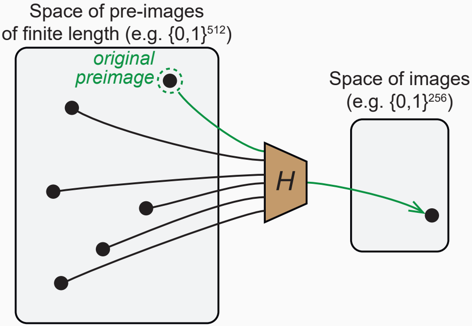

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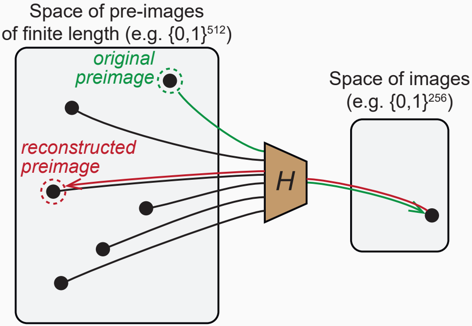

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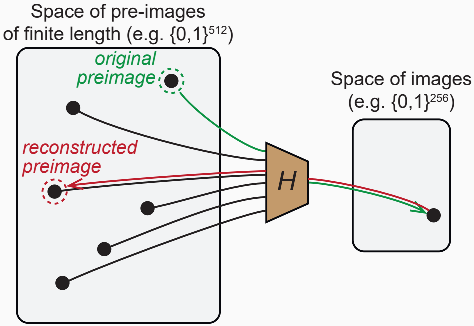
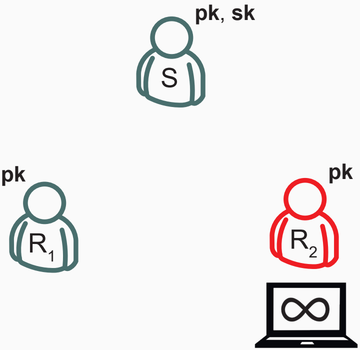


- We can use a resulting collision as an evidence of a forgery event.

Proving the fact of a forgery



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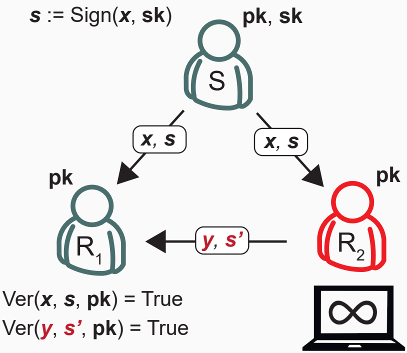

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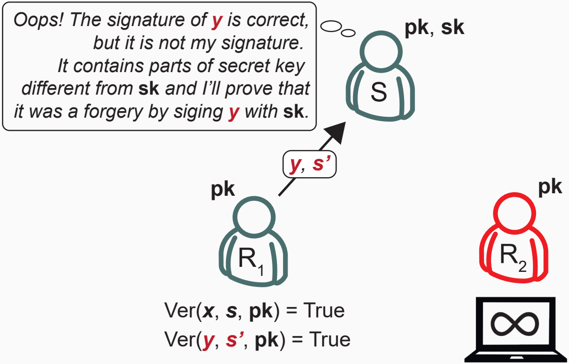

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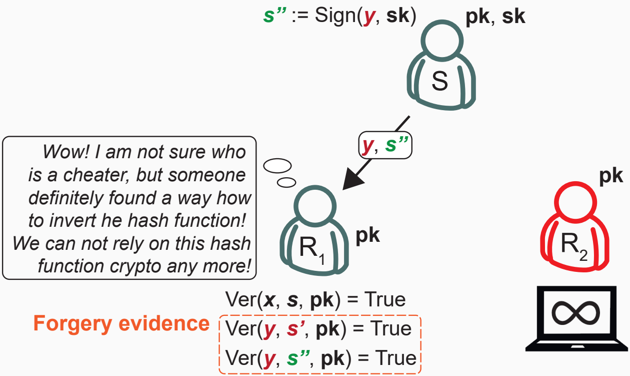

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Required properties

B1. If no one has an ability to forge anyones signature, then the standard broadcast Byzantine agreement properties (consistency and validity) hold, and all the honest players end protocol with $\texttt{forgery\_detected}_i = 0$.

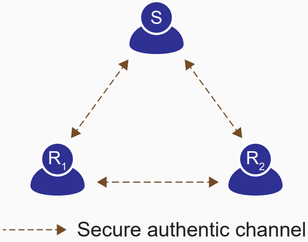
B2. If anyone applies the ability to forge signature, then all the honest players end up the protocol with flags $\texttt{forgery\_detected}_i = 1$.

Sketch of the protocol for tripartite case

Main ideas

1. Using hash-based signatures (PQC) + ITS authentication (provided with QKD);
2. Making a check if there is suspicion of a forgery.
3. Using ITS (pseudo-)signatures (provided with QKD) for broadcasting the evidence.

Pre-broadcast stage: establishing PKI and keys for ITS signatures.



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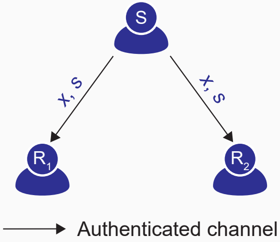

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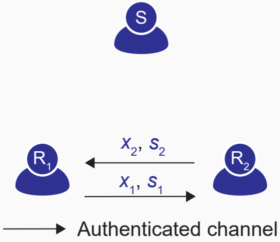
Step 2: exchanging messages by Receivers.



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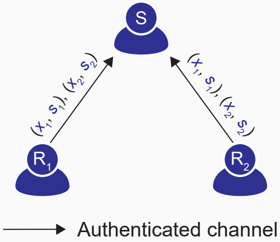
Step 3: asking for clarifications (if needed).



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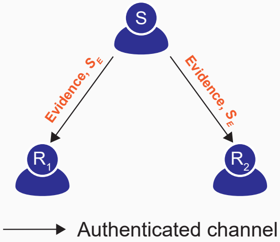
Step 4: sending the evidence of forgery (if available).



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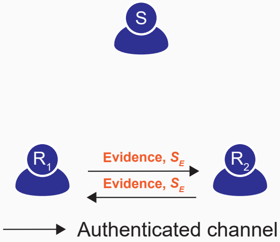
Step 5: exchanging the evidence between Receivers (if available).



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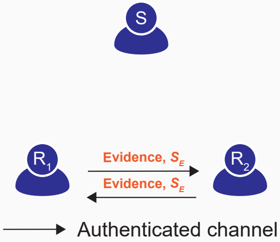

Details to appear on arXiv soon!

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- Features of hash-based post-quantum signatures allows proving event of their forgery.

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- Features of hash-based post-quantum signatures allows proving event of their forgery.
- Combining with ITS cryptographic primitives, provided with QKD, allows constructing new type of broadcast protocol with detection of signature forgery (detailed description of the protocol with its security proof to appear on arXiv soon).

Conclusion

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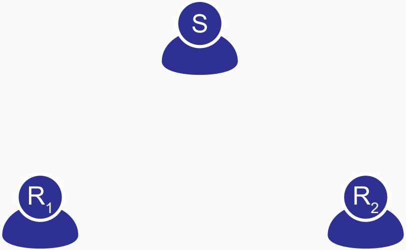
- Combining with ITS cryptographic primitives, provided with QKD, allows constructing new type of broadcast protocol with detection of signature forgery (detailed description of the protocol with its security proof to appear on arXiv soon).
- Open questions:
  - extending protocol on arbitrary number of players;
  - employing modern hash-based many-time signatures (`SPHINCS`, `XMSS`, etc.).

Thank You!
Any questions?

e.kiktenko@rqc.ru

ITS signature scheme

[P. Wallden, V. Dunjko, A. Kent, E. Andersson Phys. Rev. A 91, 042304 (2014)]



ITS signature scheme

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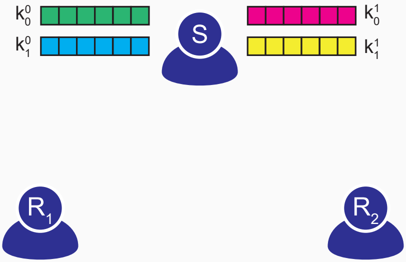

ITS signature scheme

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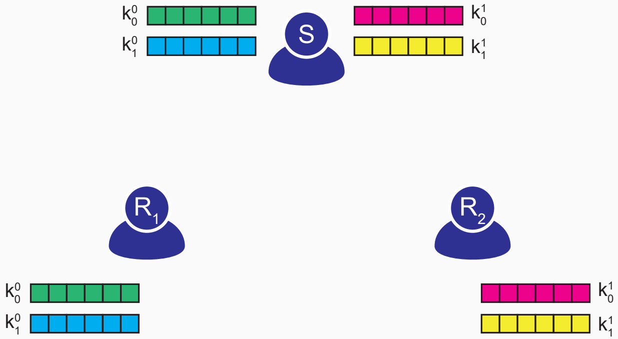

ITS signature scheme

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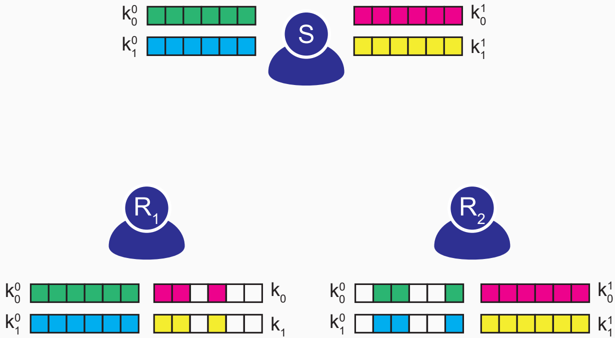

ITS signature scheme

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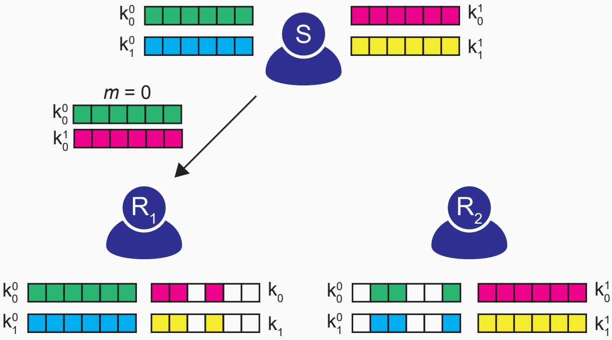

ITS signature scheme

[P. Wallden, V. Dunjko, A. Kent, E. Andersson Phys. Rev. A 91, 042304 (2014)]