Bridging the cyber and physical worlds using blockchains and smart contracts

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Motivation

- IoT devices have limitations and cannot interact with blockchains/smart contracts
  – Limited computational power and storage
  – Limited network connectivity
  – Security and trust issues
- The output of an actuation operation cannot be easily verified using cyber means

Contributions

- realistic approach for paid IoT interactions:
  - ➢ limit loss in case of disruption of actuation
    - o micro-payments for micro-transactions
    - o make blochain related micro-transactions efficient/inexpensive
- blockchain-based micro-payments to constrained IoT devices
  - – incapable of
    - performing public-key encryption
    - (directly) participating in the blockchain
    - storing blockchain-related secrets.
- enable “payment delegation”
  - – allowing users without blockchain credentials to pay
    - up to a pre-configured amount
    - for a specific service
- support many-to-one payments
  - – enabling multiple users that share the same blockchain credentials to pay for a service
- a presently feasible solution
  - – that relies on existing, already deployed technologies

H2020 SOFIE: Secure Open Federation of Internet Everywhere

- Applying Distributed Ledger Technology to
  - ➢ **securely** and **openly**

  federate IoT platforms
- *interconnected* distributed ledgers
  - – decentralized business platforms
  - – interconnection of diverse IoT systems
  - – accessible metadata
  - – open business rules on how to connect to platforms
  - – securely record audit trails to be used to resolve disputes

http://www.sofie-iot.eu/

SOFIE

A solution

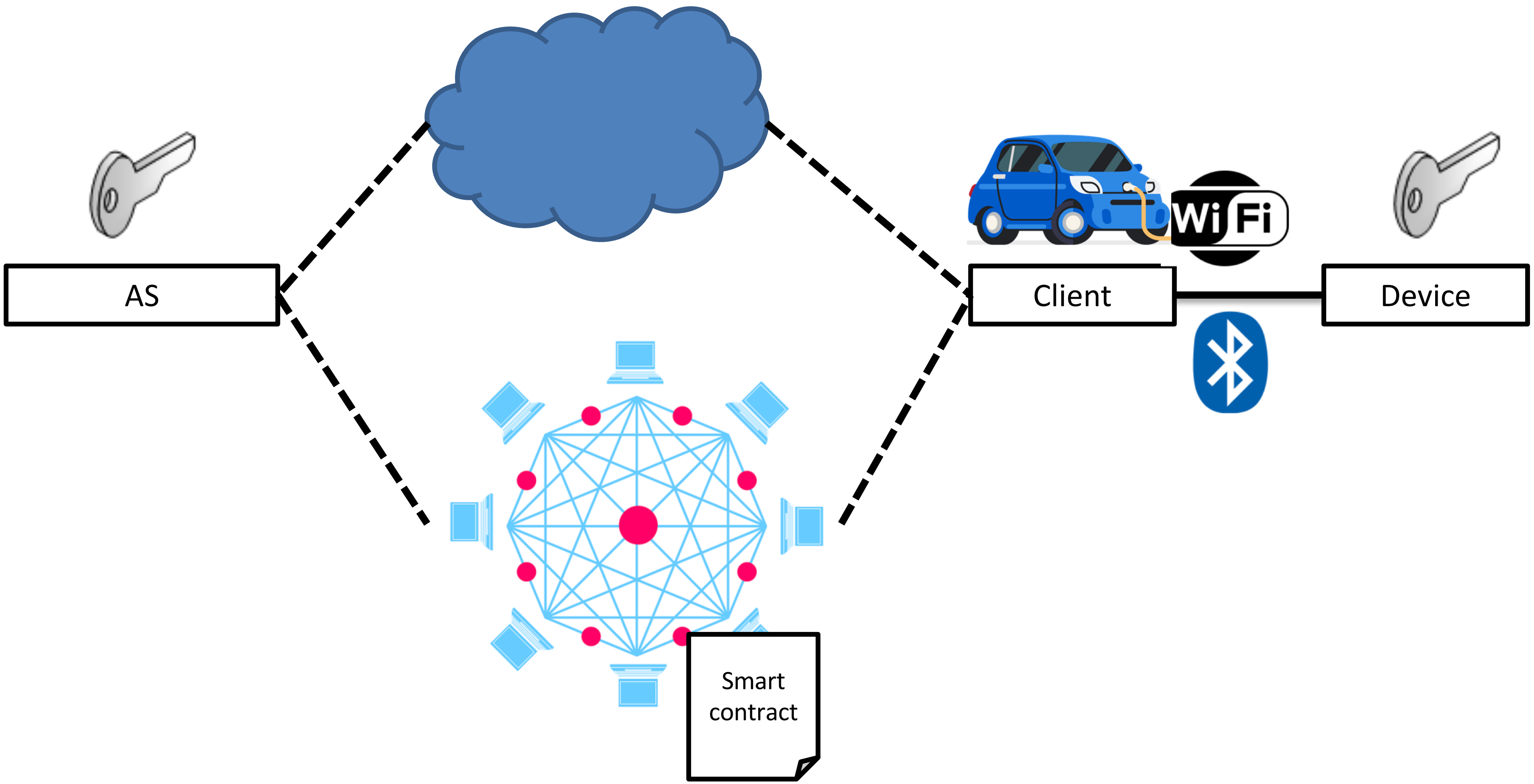
- We argue that the general cyber-real world interaction problem can not be easily solved

⇨ Damage control/limit potential loss

  – In case something goes wrong, the loss is a small pre-configured amount of money

- We leverage two existing solutions
  – Payment channels
  – Hash-based one time password (HOTP – RFC4226)

Setup



High-Level System Perspective

- A client (or his owner) makes a "deposit" to a smart contract
- The client requests from an AS an "one-time password"
  - for invoking the actuation process for 1 time slot
- The password is exchanged for a "payment receipt"
- The receipt can be used by the AS to claim, from the smart contract, (part of) the deposit
- If a client needs more passwords, it produces more receipts...

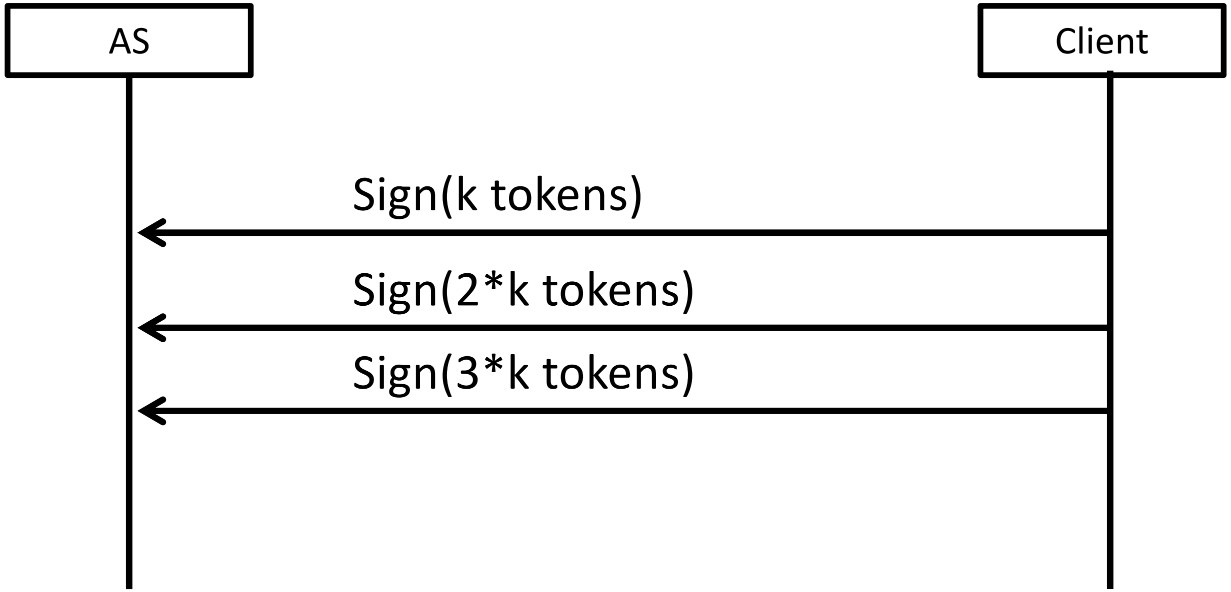
High-Level System Properties

- A deposit is claimed using only a single payment receipt
  - even in the case of many-to-one payments
  - minimizes the interactions with the smart contract and makes the smart contract implementation simpler
- Payment receipts are provided off-chain
  - generation & validation of receipts involves only digital signatures computation
  - generation & evaluation of an one-time password involves the computation of a keyed hash message authentication code (HMAC)
  - this process is fast -> small time slots can be used
    - minimizing the losses in case of service disruption
- A device and an AS have to be pre-configured with a shared secret key
  - no further interaction is required between these two entities
- The channel client-device does not have to be secure
  - as opposed to the channel between a client and an AS
- Except from the validation of an one-time password, a device does not have to perform any other operation

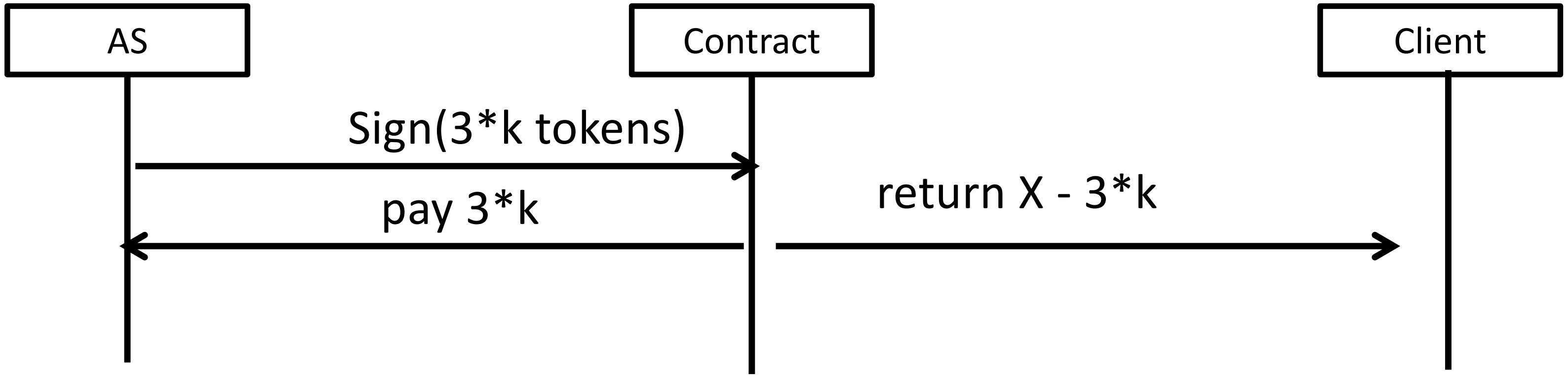
BUILDING BLOCKS

Payment channel: setup

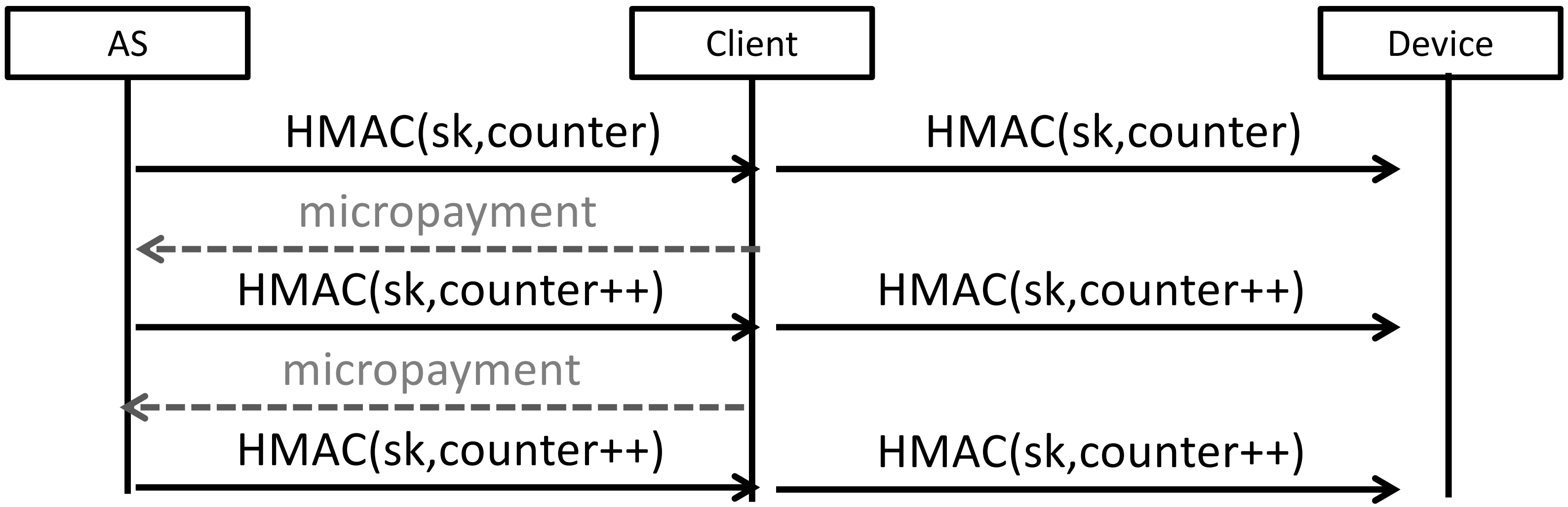
Payment channel: Micropayments



Payment channel: closing the channel

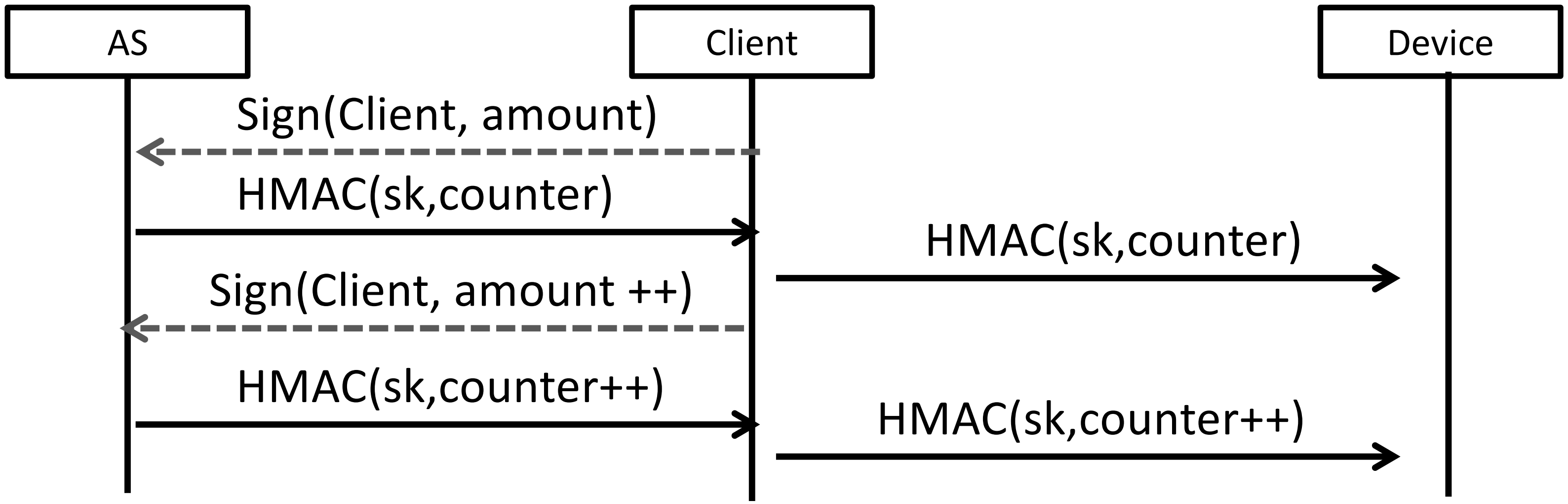


keyed **H**ash Message Authentication Code (HMAC)
One-**T**ime **P**assword (HOTP)

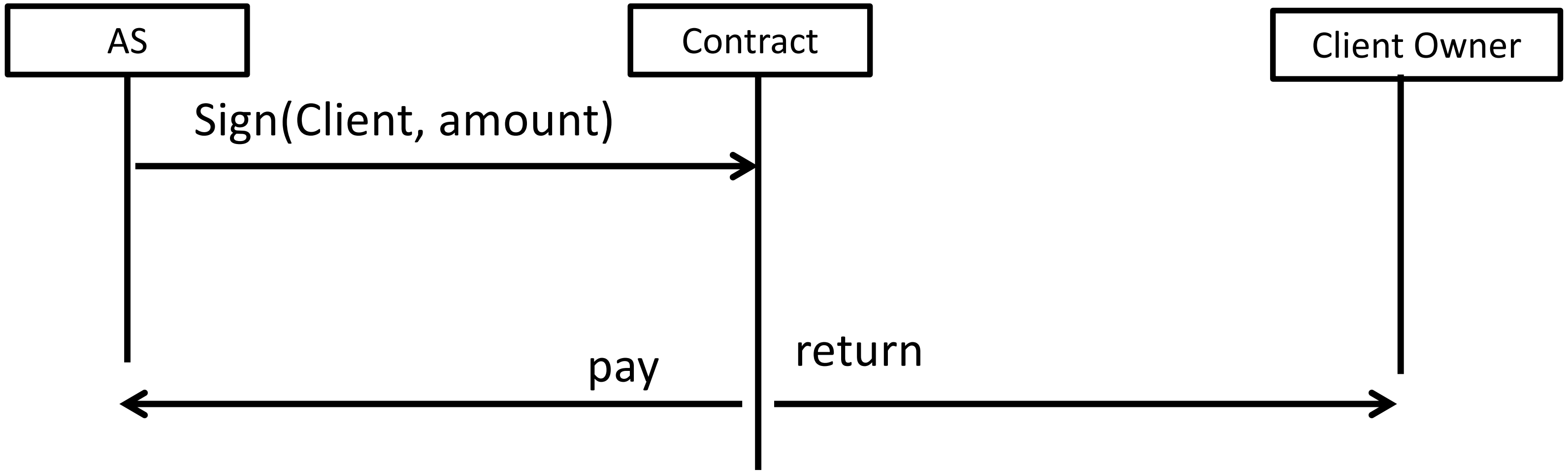


TRIVIAL CONSTRUCTION

Device access

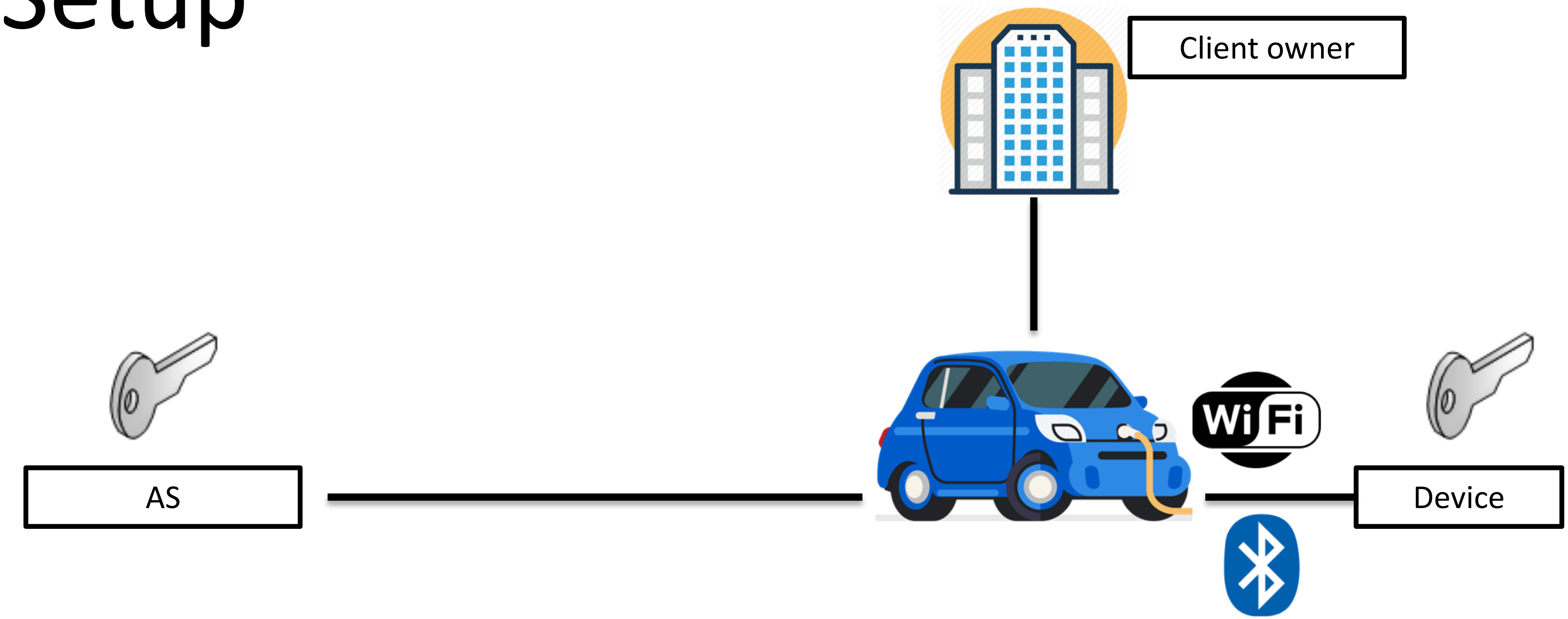


Channel close

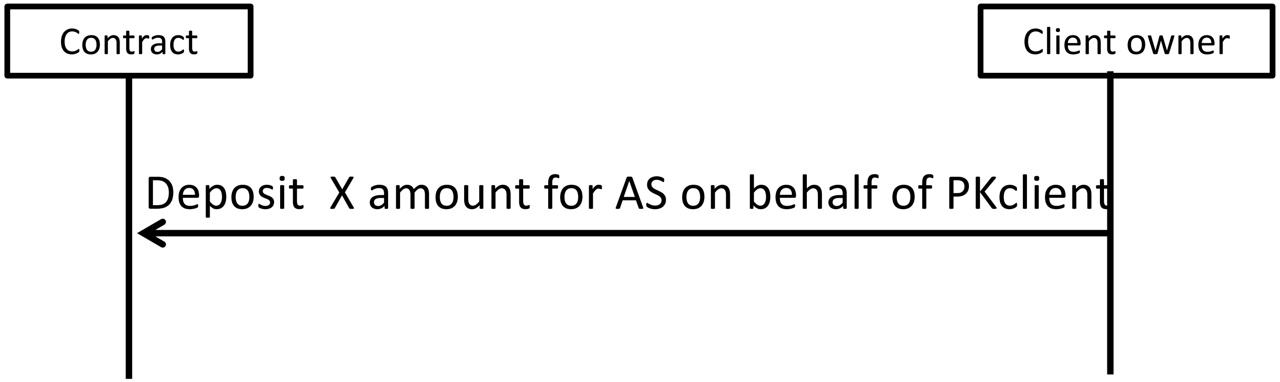


CLIENTS WITHOUT ACCESS TO THE BLOCKCHAIN

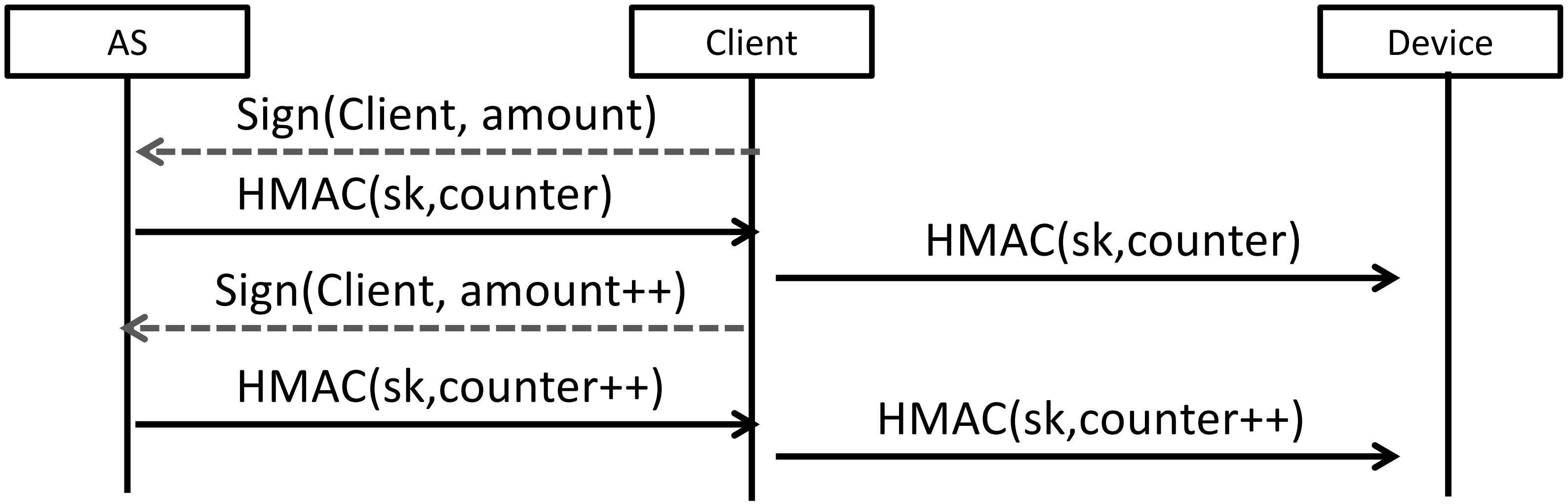
Setup



Payment channel setup

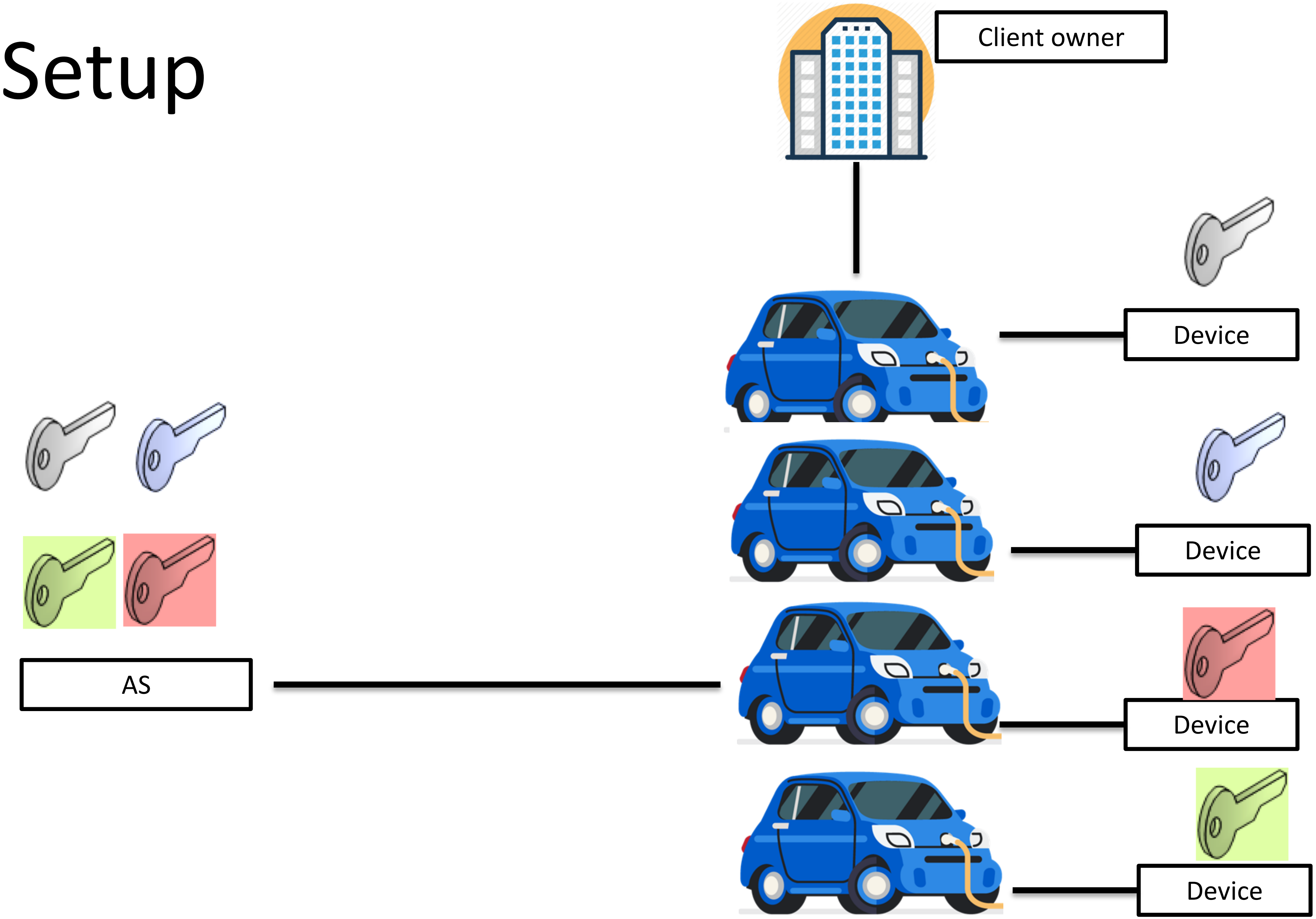


Device access



ONE CLIENT OWNER
MULTIPLE CLIENTS

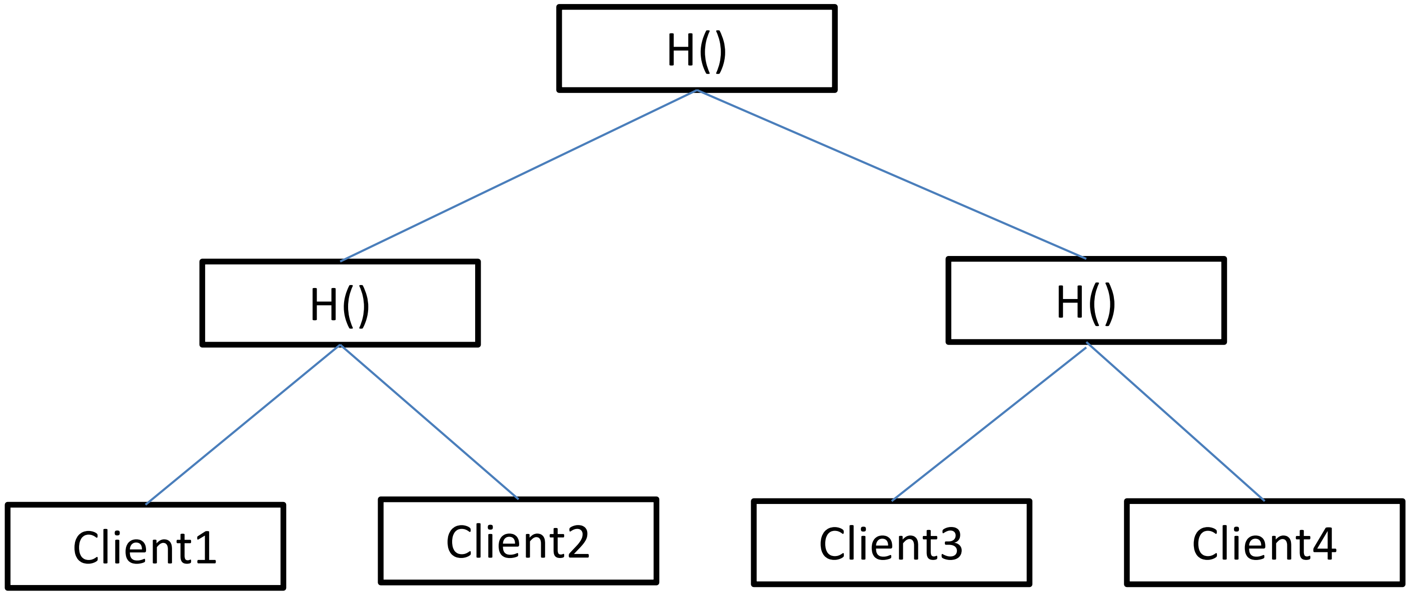
Setup



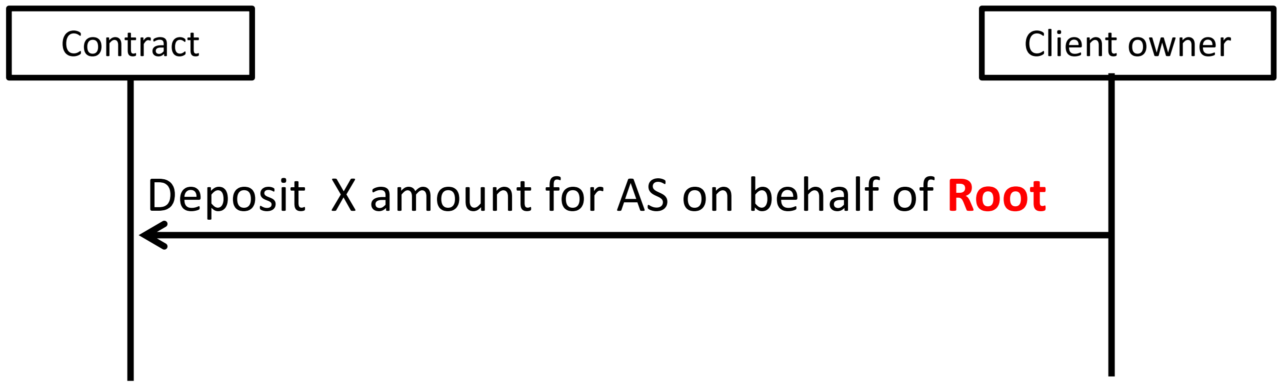
Challenges

- 1. Store all legitimate public keys
- 2. Close the channel with a single transaction

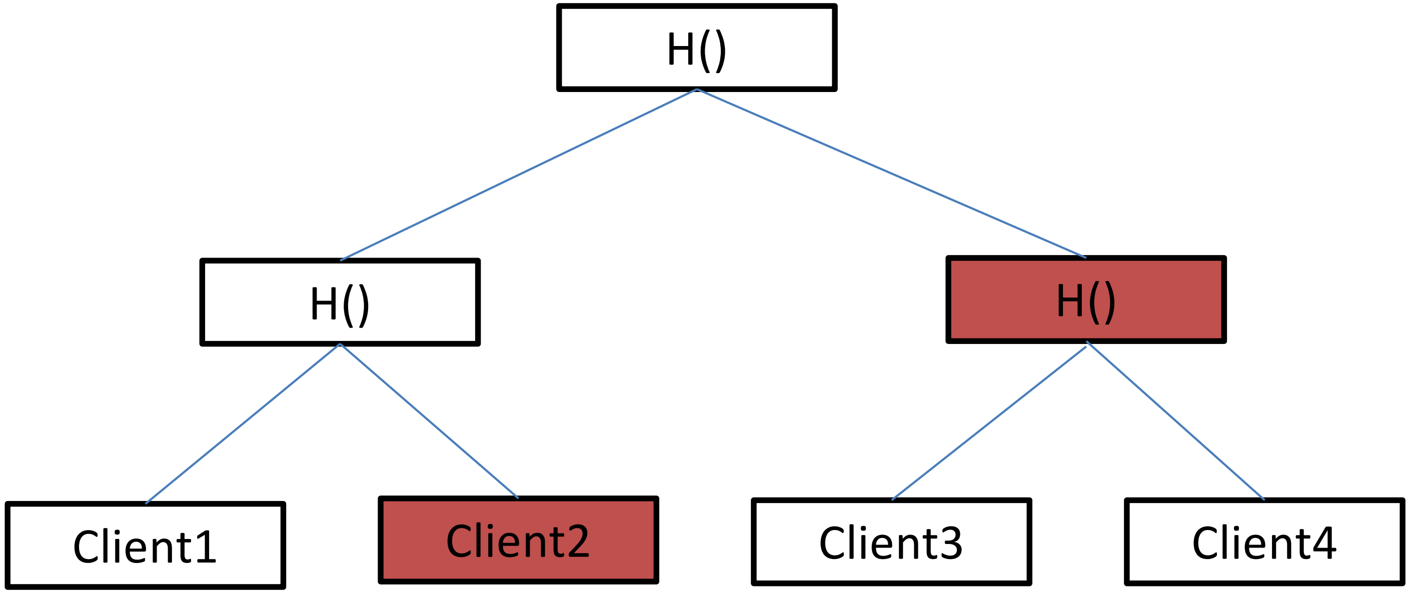
Store all client keys in a Merkle tree



Payment channel setup



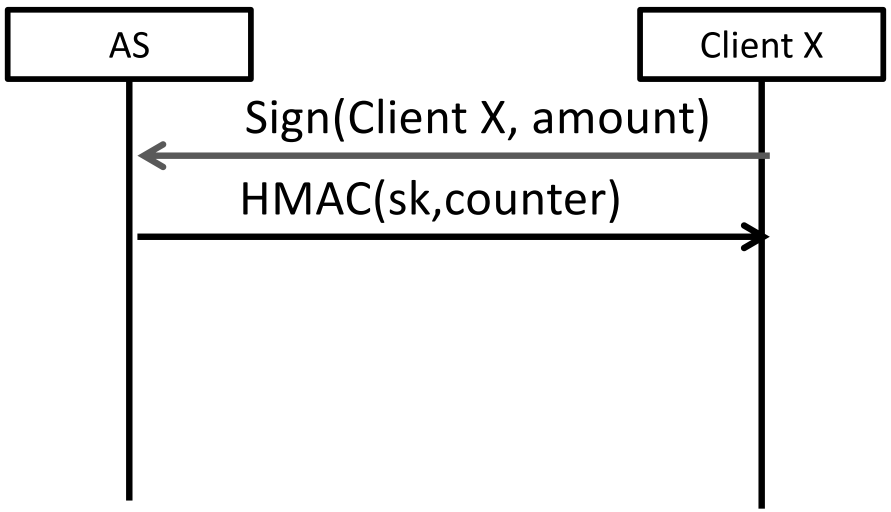
Prove membership



Challenges

- 1st Store all legitimate public keys
- 2nd Close the channel with a single transaction

The straw man ledger



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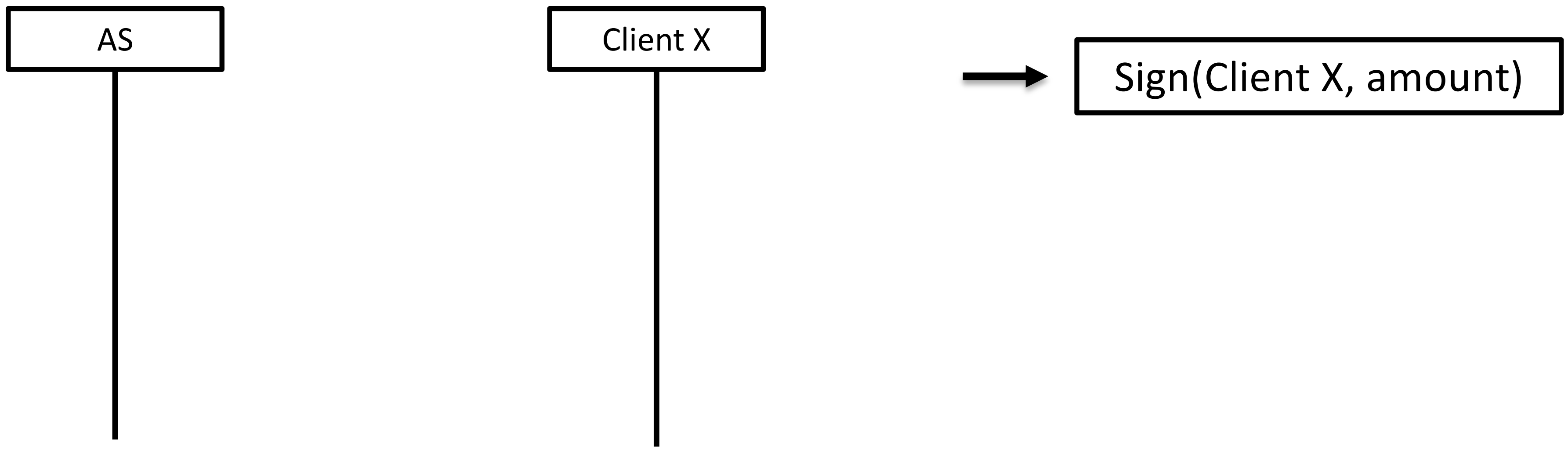

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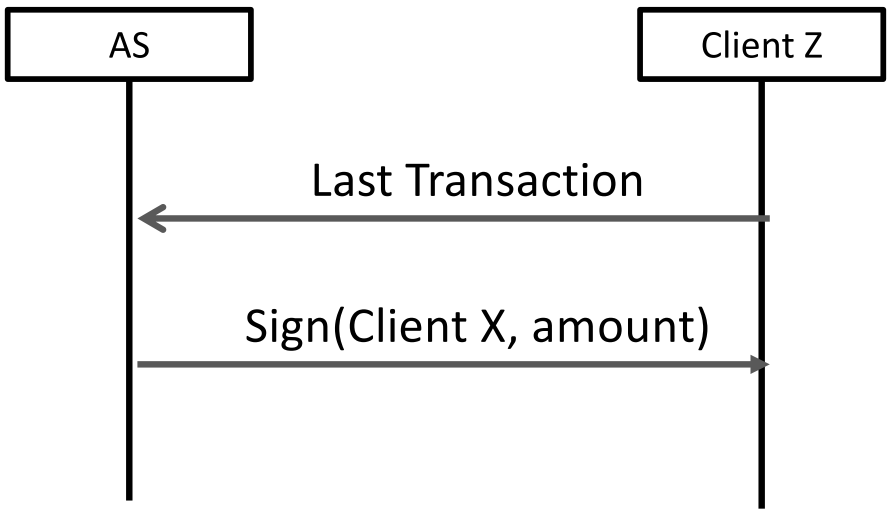

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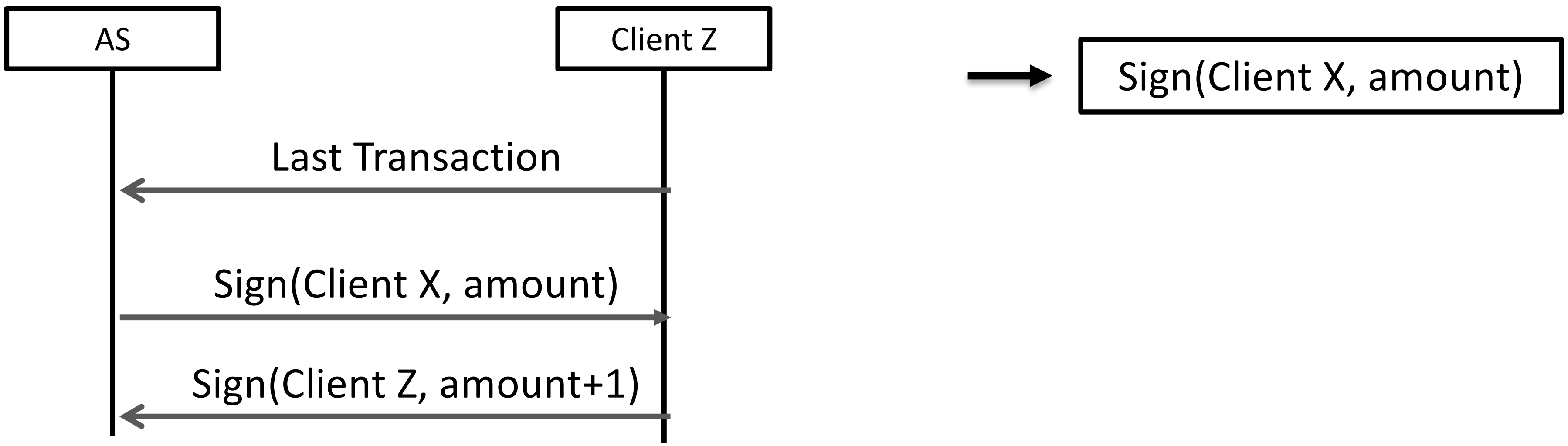

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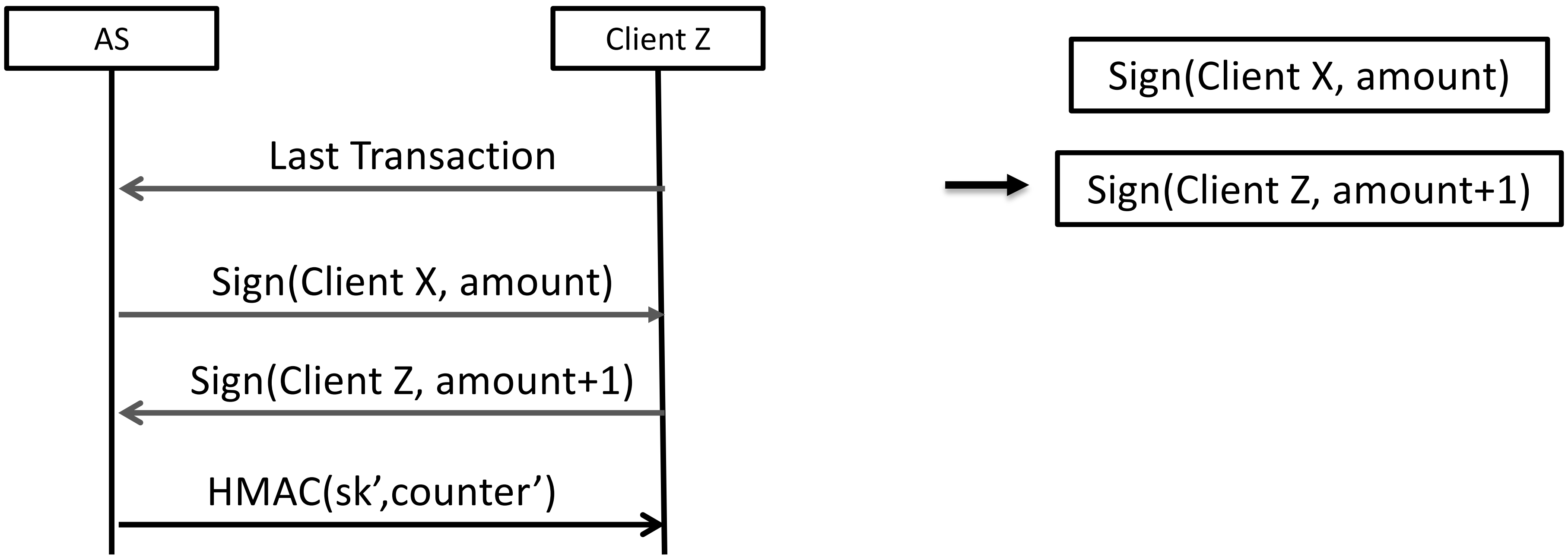
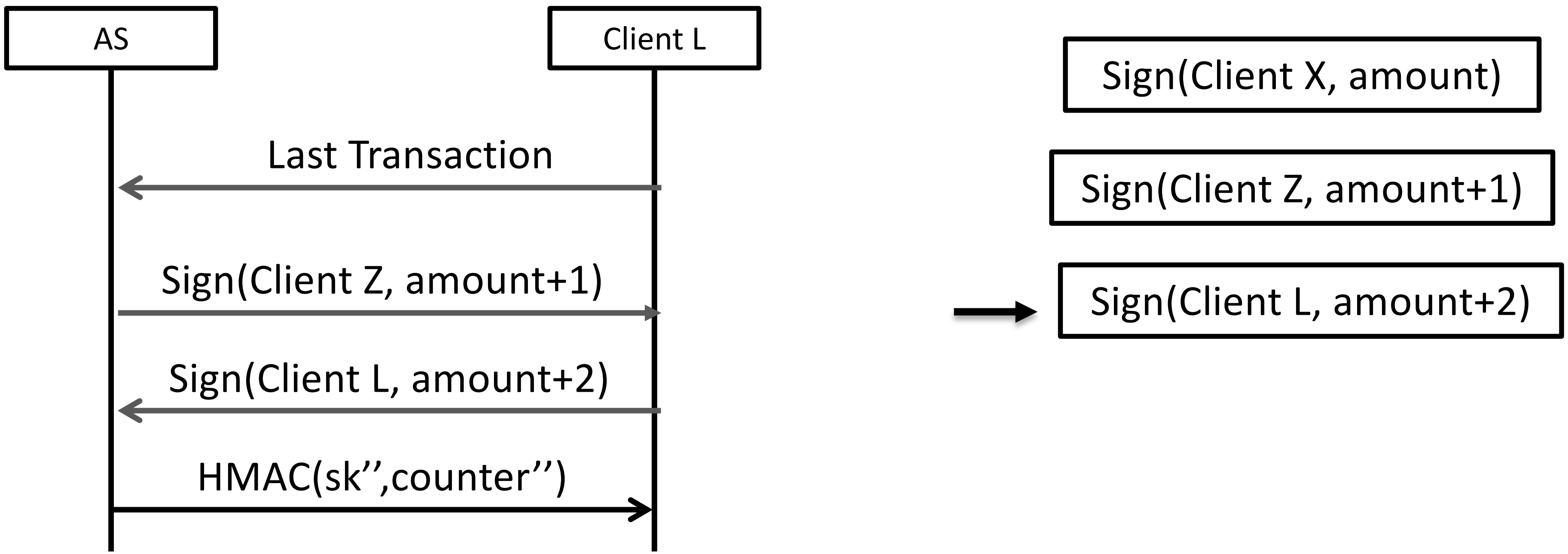
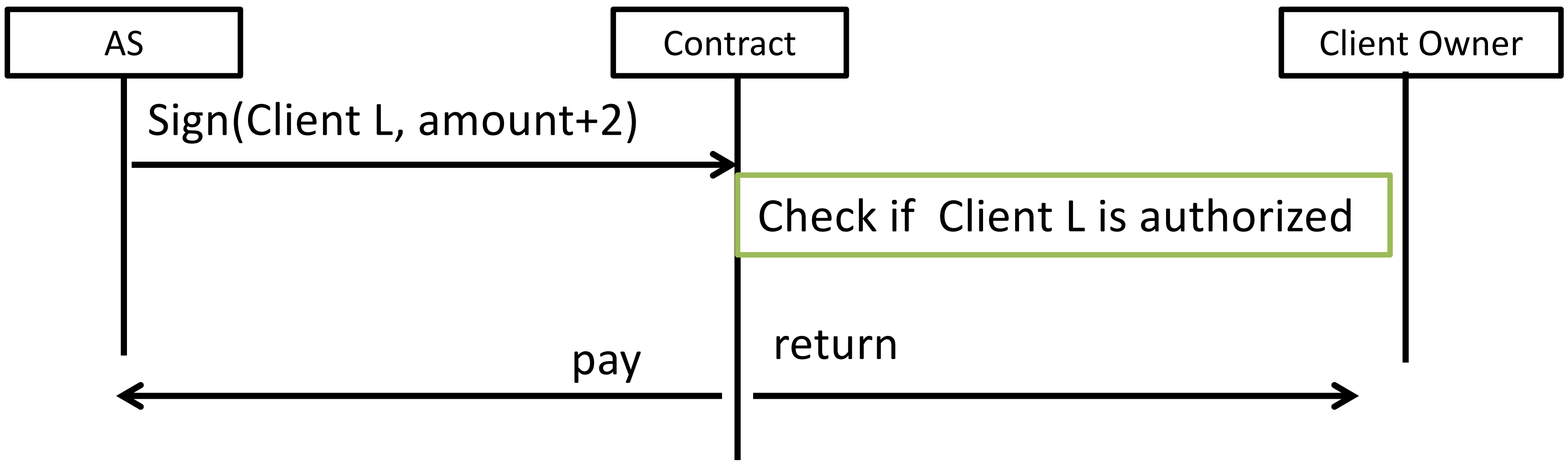


The straw man ledger



Channel close



Implementation and Evaluation

- Implementation with Ethereum smart contracts
- Public-private key pairs with secp256k1
- HMAC with SHA256
- Merkle tree with keccak256
  - Hash function recommended for Ethereum Smart Contracts
- Cost of Open and Close:
  - 3rd construction: 4 cars
- Opening deposit: 14.5 sec

First construction		
Operation	**Cost measured in gas**	
open channel	43700	€0,05
close channel	36258	€0,04
Second construction		
Operation	**Cost measured in gas**	
open channel	50388	€0,06
close channel	36258	€0,04
Third construction		
Operation	**Cost measured in gas**	
open channel	50388	€0,06
close channel	36330	€0,04

Conclusions

- realistic approach for paid IoT interactions:
- blockchain-based micro-payments to constrained IoT device owners
  - payment delegation
- efficiently support groups of clients (1 owner)
- a presently feasible solution

Future Work

- Advanced Ledger and ILP
- Key revocation

Thanks!

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SOFIE

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