CSE 5095-007: Blockchain Technology

Lecture 11
Wallets and Key Management

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Outline

- Key management in cryptocurrencies.
  - Hot and cold storage.
  - Hierarchical wallets.
  - Cold info storage.
  - Splitting and sharing keys.
  - Online wallets.

Spending Coins

- Recall that coins in any cryptocurrency are virtual.
  - Strings of bits.
- Spending any amount of coins requires:
  - Some public information from the blockchain.
  - The secret key associated with the address (or public key) that owns the coins.
    - Needed to provide digital signatures.
- Losing the secret keys means losing these coins; no one will be able to spend them.

Key Management

- Storage and retrieval of secret keys.
  - Involves also when and how to generate new keys for future transactions.
- Goals:
  - Security; only the legitimate owner gets to spend a given coin.
  - Availability; coins owners can spend them whenever they wish.
  - Usability; it is relatively easy for the average user to store/retrieve/use secret keys.
- We will focus on Bitcoin in the slides.
  - The concepts we will study can be applied to any other cryptocurrency.

Wallet Software

- User (or client) software that keeps track of coins that a client owns.
- Provides a convenient user interface to simplify operations.
  - Issuing transactions.
  - Tracking total balance.
  - Generate keys when needed.
  - Bookkeeping of these keys.
- Encode addresses as text strings (Base58) or in the form of QR codes.
  - Simplifies sharing addresses with others.
- A large number of wallets is available.
  - Different flavors; desktop, mobile, web applications, etc.
  - Different vendors; metamask, jaxx, coinbase, etc.
  - Security is a driving factor of which one to choose.

Naive Solution

- Store the keys in a file on your laptop or smartphone.
  - Security is tied to your device; breaking into the device allows an attacker to steal your keys (and so your coins).
- This is called hot storage.
  - Easy to use but risky.

Hot vs. Cold Storage I

- Hot storage.
  - Storing secret keys on a device that is connected to the Internet and used frequently for variety of applications.
  - Usable/coventient.
- Cold storage.
  - Offline storage, like on a machine or memory device that is stored in some safe location.
  - Less convenient.
- Good practice: The majority of the coins are in the cold storage with a few in the hot storage.

Hot vs. Cold Storage II

- Seperate keys are needed for each.
  - Otherwise, compromising hot storage will compromise cold storage.
- But both should be aware of their addresses to allow transferring currency.
  - Cold storage stores its cold secret keys, cold addresses, and hot public addresses.
  - Hot storage stores hot secret keys and public addresses, as well as cold public addresses.

New Addresses for Cold Storage?

- A good practice in Bitcoin in order to break transaction linkability is to create a new address for each new transactions.
- How can a hot wallet learn the addresses of a cold wallet?
  - Remember cold wallet is offline, no internet connectivity.
- Even generating a large chunk of addresses at the beginning will not work.
  - Cold storage needs to connect whenever a new batch of addresses is generated.

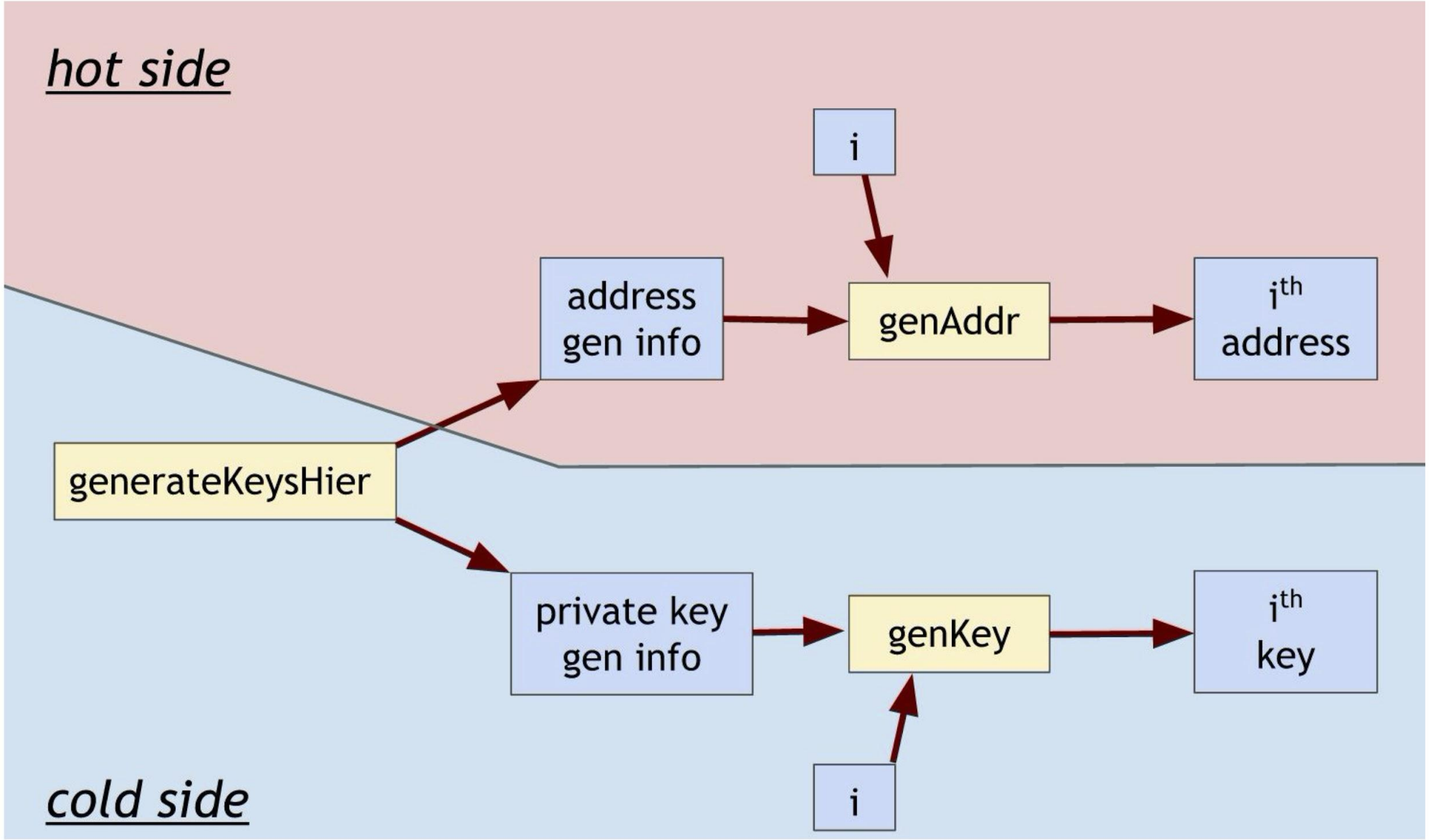
Hierarchical Key Generation I

- Allows cold storage to generate an infinite number of key pairs (or addresses).
- Usual keyGen algorithms generate a single key pair; public and private.
- Hierarchical keyGen instead generates some info that allows generating all future keys in a deterministic way.
    - Usually called master public key and master secret key.
- The master public key does not reveal any info about the master secret key or all future generated secret keys.

Hierarchical Key Generation II

- By having the operation indexed with some integer i, the master key allows generating the ith future key.
    - Works for both public and secret keys.
- Hot storage has a copy of the master public key, while the master secret key is known only to the cold storage.
- Not all digital signature schemes support this hierarchical approach.
    - ECDSA supports that, details come later.

Hierarchical KeyGen - Pictorially



*From Ch 4, Bitcoin and Cryptocurrency Technologies book.

Hierarchical KeyGen in ECDSA (BIP32)

- A group G, in which DDH is believed to be hard, of order p (where p is some large prime number) and a group generator g.
- KeyGen is extended into 3 algorithms:
  - keyGenHer(1^n): msk = x, mpk = g^x, Hash function H.
    - n is the security parameter.
    - x is some integer selected at random from Z_p.
  - addrGen(mpk, i): r = H(i || mpk), pk_i = mpk*g^r = g^{x+r}, $addr_i$= H(pk_i)
  - keyGen(msk, i): r = H(i || mpk), sk_i = msk + r = x+r
- A hot wallet will be able to generate the ith address (or public key) and a cold storage will be able to generate the ith private key.

Security Issue I

- No forward or backward security.
  - Given i, ski, mpk, it is easy to determine msk.
    - Assume an attacker compromised the hot wallet (got hold of mpk), and one secret key of the cold storage has been leaked.
    - This allows the attacker to compute msk, and hence, all previous as well as future secret keys.
    - ***Exercise:*** track the algorithms and see how to msk can be computed.
- Source of vulnerability; the way the randomness r is computed.

Security Issue II

- BIP32 gives an alternative construction that preserves forward and backward security if a private key is leaked.
  - However, no hierarchical addresses anymore, single address but hierarchical secret keys.
  - Transaction linkability!!
- Guteso et al. [Guteso et al., 2015] developed a bitcoin hierarchical wallet that tolerate leakage of m keys.
  - Drawbacks:
    - m must be fixed in advance.
    - Size of the mpk grows with m.

Cold Info Storage

- On a device, and lock that device in a safe.
- Brain wallets:
  - Encrypt under a password that the user memorizes.
  - Security issue: offline password cracking.
- Paper wallet:
  - Print the key material and store the paper in a safe.
- Tamper resistant hardware device.
  - Either the device generates the secret key and stores it, or just use it to store the private key.
  - The device signs the transactions; it does not allow retrieving the secret key at all.

Splitting and Sharing Keys

- Distribute the trust of storing a key among multiple devices/locations instead of one.
- Works by creating several shares of the key and store each share at a different place.
  - Usually a threshold is used, meaning that having t out of n shares allows constructing the secret key, and hence, use it to sign transactions.
- Good for both availability and security.
  - Any t shares can be used.
  - As long as less than t shares are revealed, no information will be leaked about the secret key.
    - Much better than having singe key stored at a single location.

Shamir Secret Sharing

- A widely used scheme to share secrets.
- A (t, n)-secret sharing scheme consists of two algorithms:
    - Share(s): Outputs shares s1, s2, …, sn.
    - Reconstruct(x1, …, xt): Outputs s.
        - x1, …, xt: any t subset of the shares s1, …, sn
- t-privacy:
    - For any two secrets s, s’, and any subset X of size < t, the shares of s are indistinguishable from the shares of s’.

Example - (2, 2) Secret Sharing

- $n = 2$ and $t = 2$.
- A prime $p = 11$, so we work in Zp (the integers 0, …, 10).
- To share a secret s, first choose some r at random from Zp
- Share(s):
  - $s_i = (s + i*r) \bmod p$ for i in {1, 2}
- Reconstruct(s1, s2):
  - $s = (2x_1 - x_2) \bmod p$
- 2-privacy: each si is uniformly distributed over Zp.
- The basic idea of Shamir Secret Sharing:
  - Generate a polynomial of degree (t-1) with the free factor set as the secret key. Each share is simply the evaluation of the polynomial at the share index. Reconstruct is computing the free factor using lagrange interpolation.

Mulitsig and Threshold Signatures

- Multisig:
  - No need to reconstruct the key, keep the random shares apart.
    - Or simply generate multiple keys instead of one.
  - To authorize a transaction, all devices (or t of them) need to sign.
  - If collective signing is used, one signature will be produced.
- Threshold signatures:
  - A signing key is divided among several parties such that any t subset of them can jointly produce a signature.
  - Produce a single signature instead of many.
    - More efficient, signature verification algorithm will be executed once.
  - There is an increasing interest of threshold signatures these days across a large number of cryptocurrency systems.
    - Among them, the BLS scheme is a popular one (check https://crypto.stanford.edu/~dabo/pubs/papers/BLSmultisig.html).

Online Wallets

- A wallet in the form of a web app.
  - The site stores keys.
  - The site issues transactions when the users asks for that.
  - The user logs in using some credentials.
- High usability level; log in using any device connected to the Internet.
- Site compromised, wallet is compromised.
- Usually used when trading on exchanges.

Cryptocurrency Exchanges

- Pretty much a centrally managed bank system.
  - Accept deposits in cryptocurrency or fiat currency.
    - With a promise to pay back when a client ask for any withdrawal.
  - Allow customers to pay in cryptocurrency, receive payments, and trade cryptocurrencies.
    - Mainly match buyers with sellers at the exchange rate along with charging fees.
  - Nothing goes to the network, it is just that the exchange makes a different promise to the customers.
    - Everything is local.

Cryptocurrency Exchanges - Issues

- Highly convenient.
  - Several services at the same place.
  - Very close to the traditional banking systems already in use.
  - Gives a direct value for cryptocurrency in terms of fiat currency.
- High risk.
  - Requires pre-identification - know your customer policy.
    - Any anonymity aspect promised by a cryptocurrency is taken away!
  - Security risks - a target for attackers.
    - Exchanges accumulate currency of all customers.
- Regulation issues.
  - Traditional banks has to prove holding a specific fraction of money in reserve.

References

- [Guteso et al., 2015] Gutoski, Gus, and Douglas Stebila. "Hierarchical deterministic bitcoin wallets that tolerate key leakage." In International Conference on Financial Cryptography and Data Security, pp. 497-504. Springer, Berlin, Heidelberg, 2015.