Privacy Aspects and Subliminal Channels in Zcash

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Outline

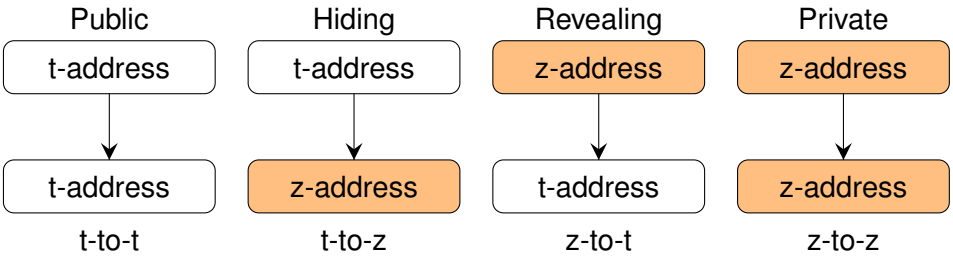
Introduction to Zcash

- Zcash is a privacy oriented digital currency.
- Built on a variety of cryptographic primitives:
  - zkSNARKs, commitment schemes, Merkle trees, encryption, etc.
- Zcash coins are called ZECs. 1 ZEC corresponds to 10^8 Zatoshis.

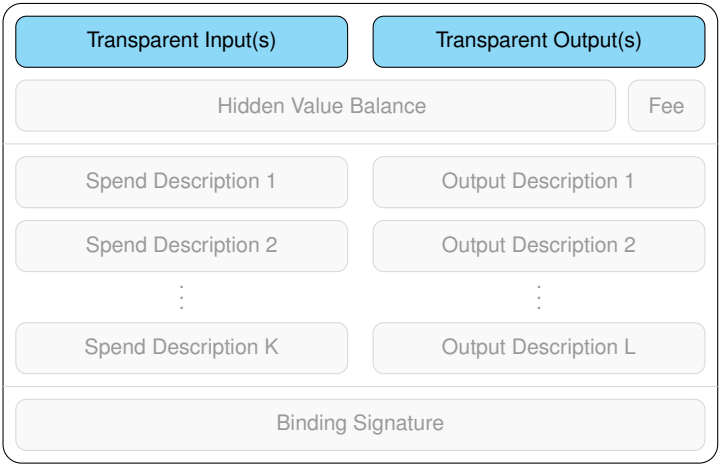
Zcash: Addresses

- Zcash offers two types of addresses:
  - *transparent* or *public*, commonly referred to as *t-addresses*.
  - *shielded* or *private*, commonly referred to as *z-addresses*.

Zcash Transaction Types



Zcash Transaction Layout



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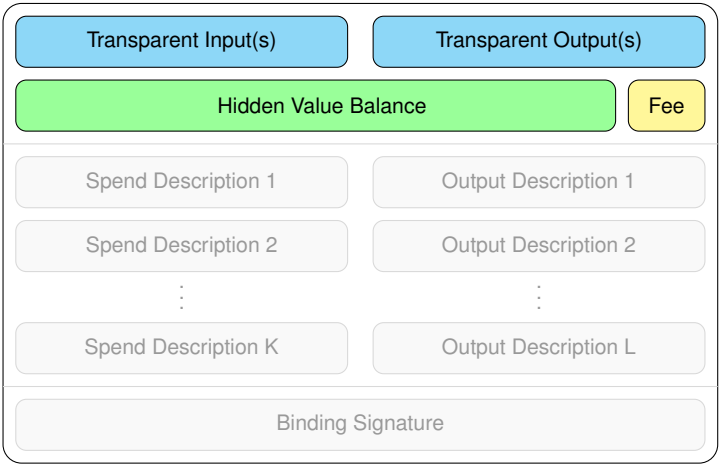
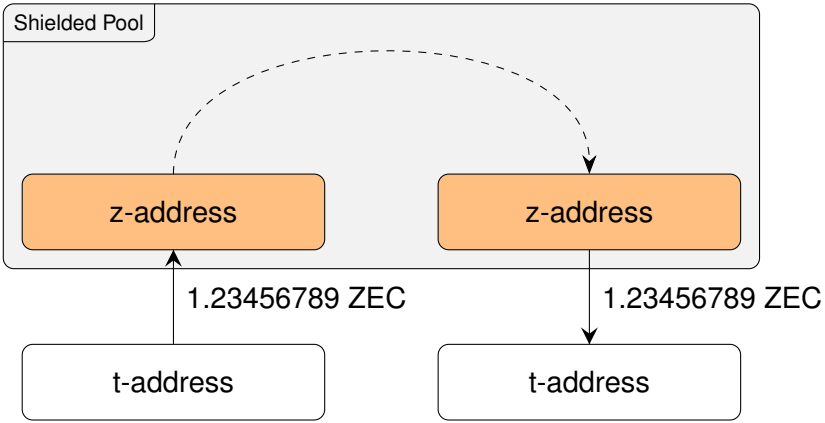


Introduction to Zcash

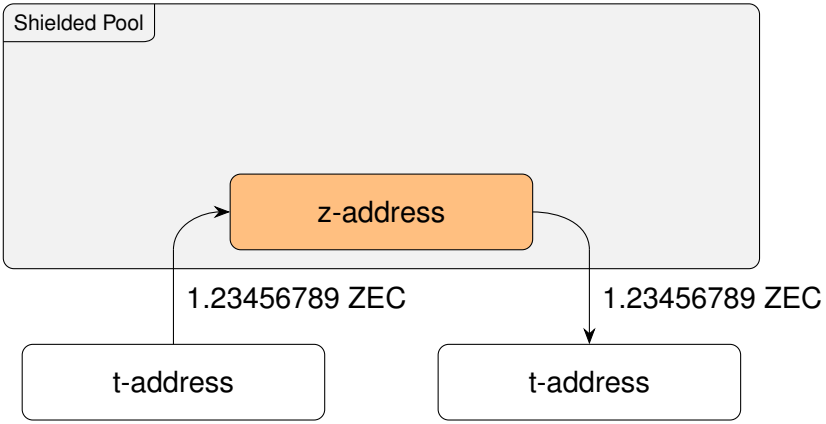
Transaction Linking

Subliminal Channels

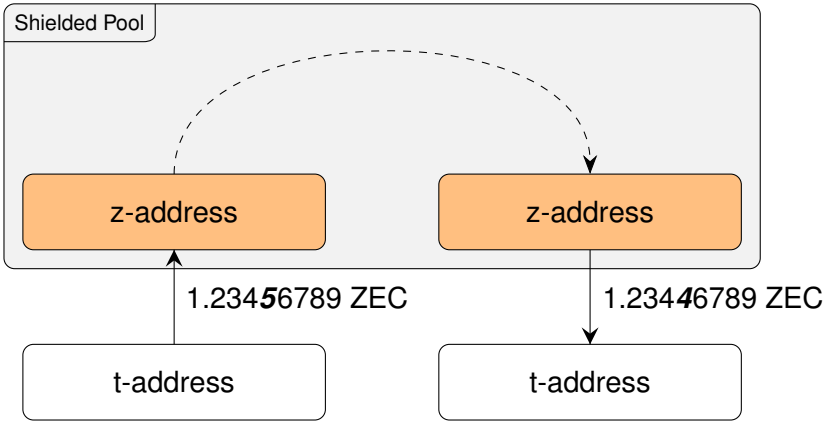
Transaction Linking v1



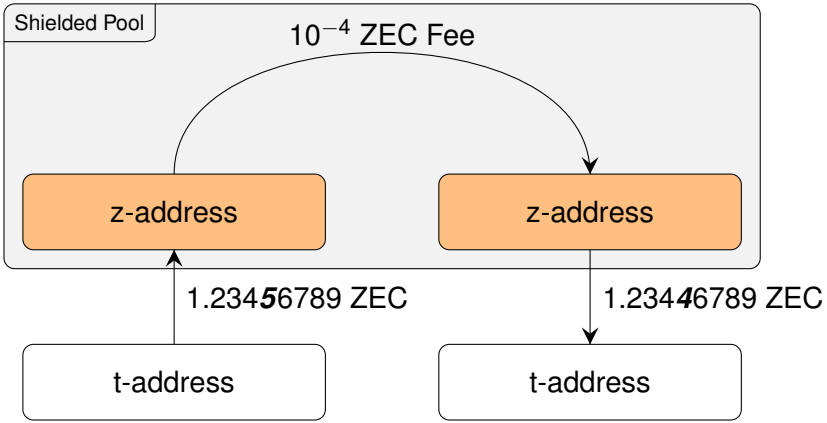
Transaction Linking v1



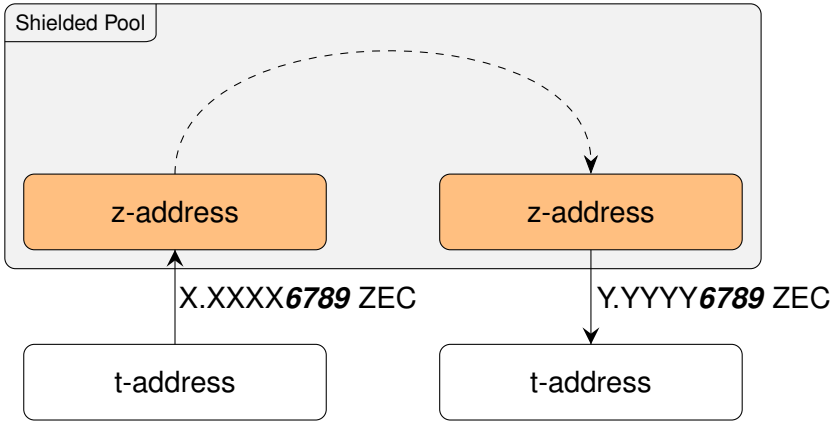
Transaction Linking v2



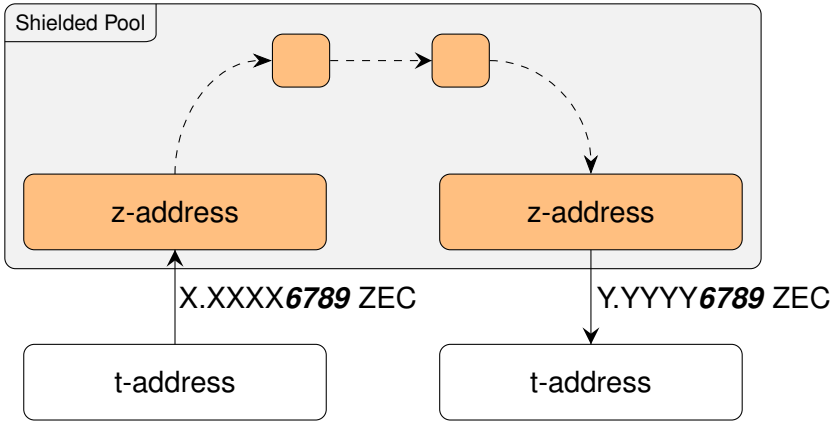
Transaction Linking v2



Transaction Linking v3



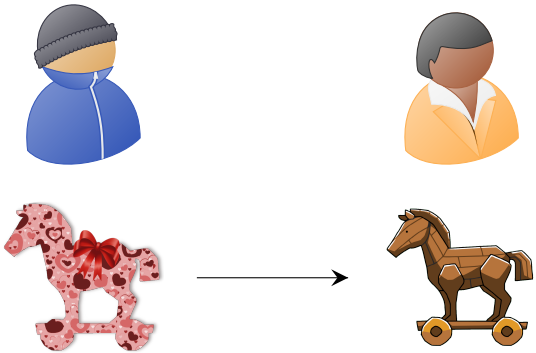
Transaction Linking v3



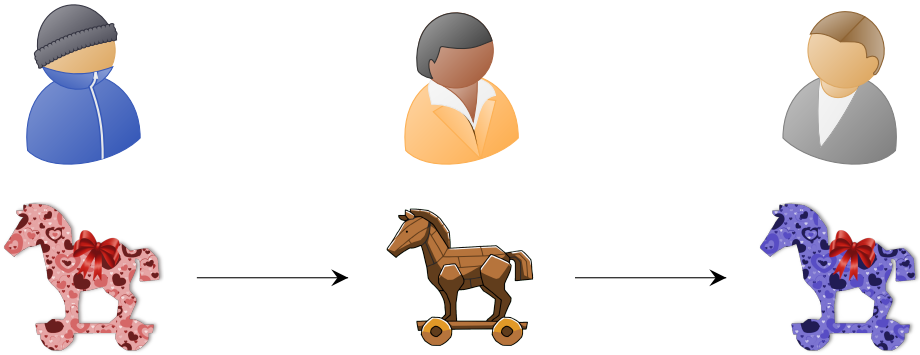
Value Fingerprints

- ~97% of shielded transactions use 10^4 Zatoshis as fee.
- Last 4 digits are not changed by the fee.
- Can be used maliciously

Danaan-Gift Attack



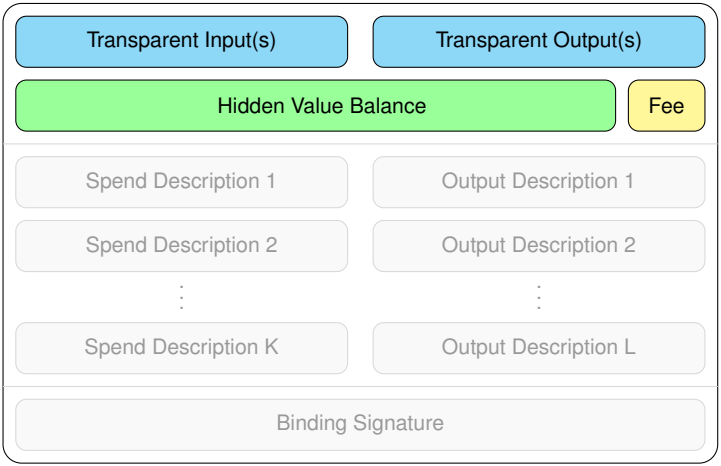
Danaan-Gift Attack



Danaan-Gift Attack

- What is the success ratio of the attack?
- What is the likelihood of a fingerprint surviving?

Zcash Transaction Layout



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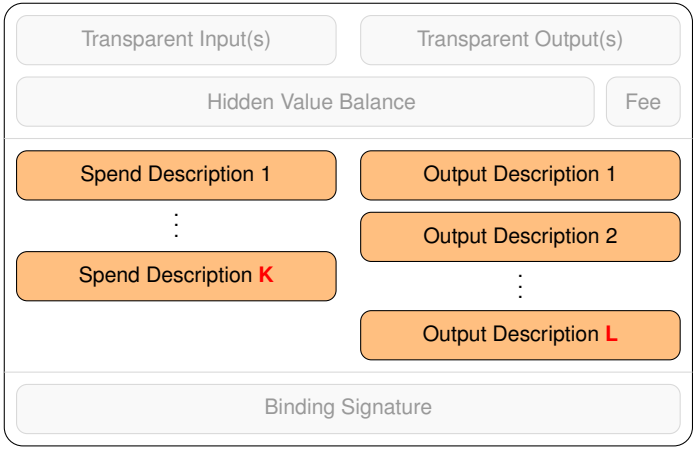

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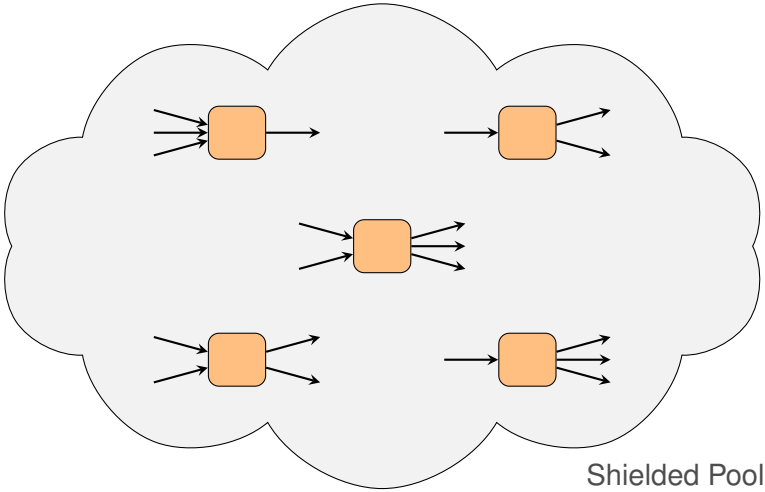

Dust Attack

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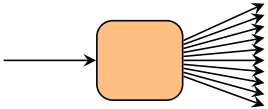

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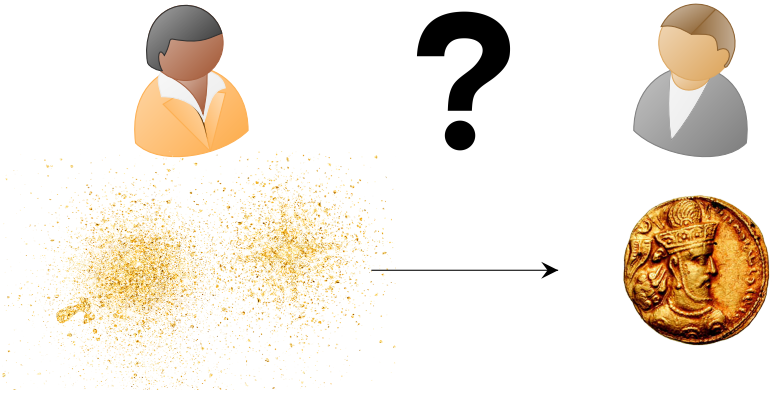

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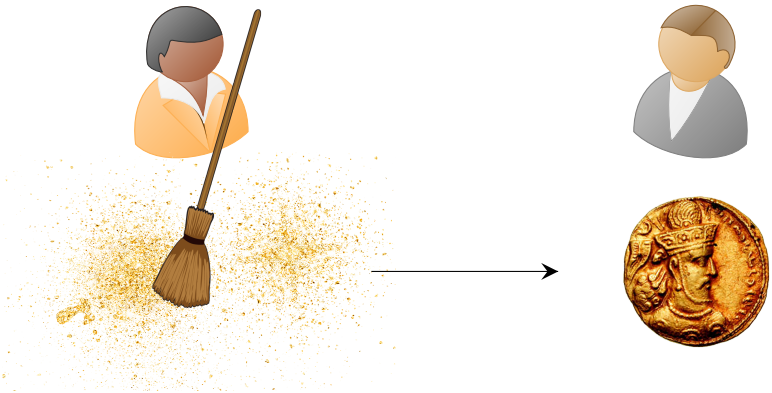
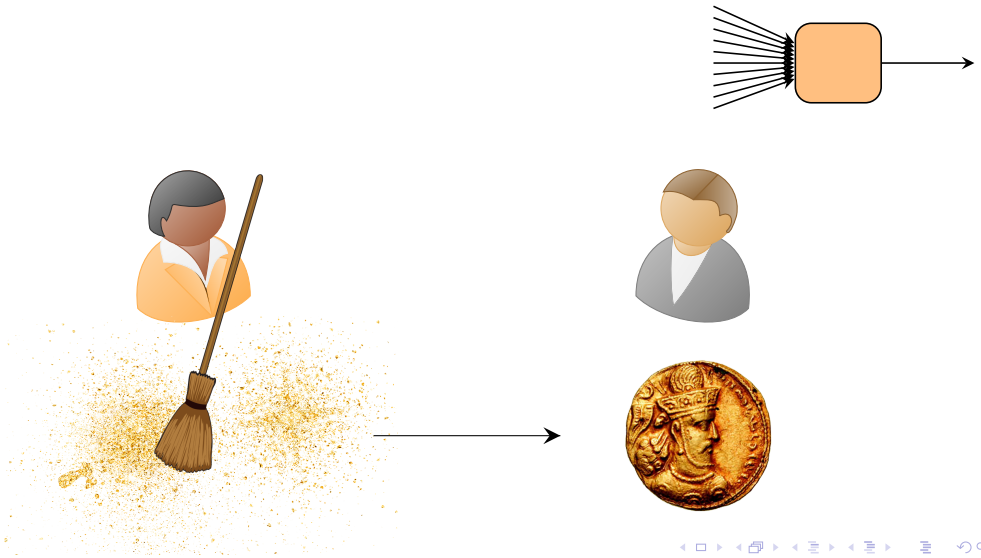


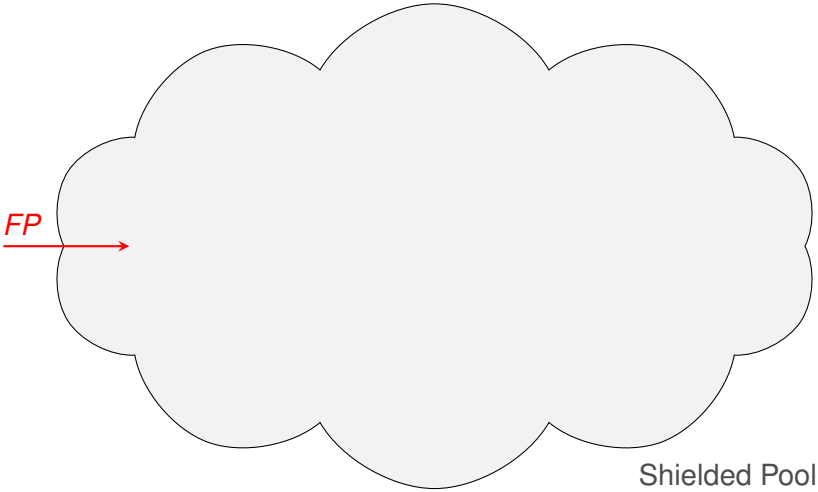
Dust Attack



The Survival Probability of Fingerprints

- We have developed a statistical model for the shielded pool.
- Based on the number of inputs and outputs in a shielded transaction.
- Markov-chain of all possible scenarios.
- Sample data based on characteristically the same public transactions.

The Survival Probability of Fingerprints



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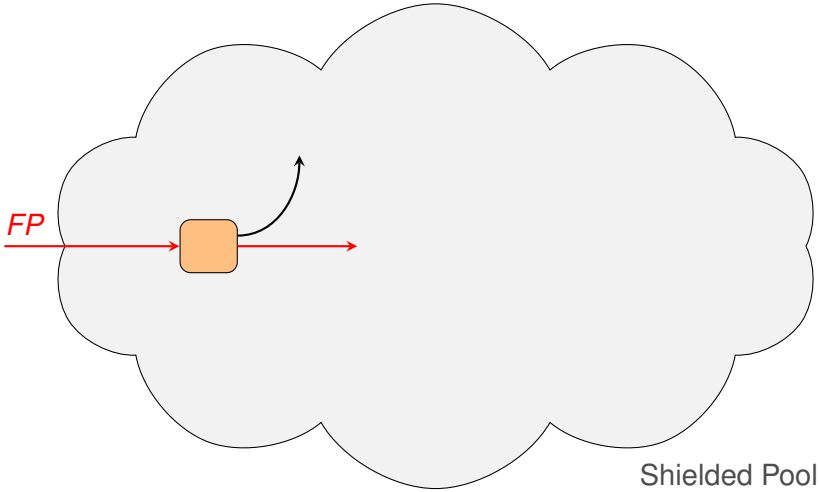

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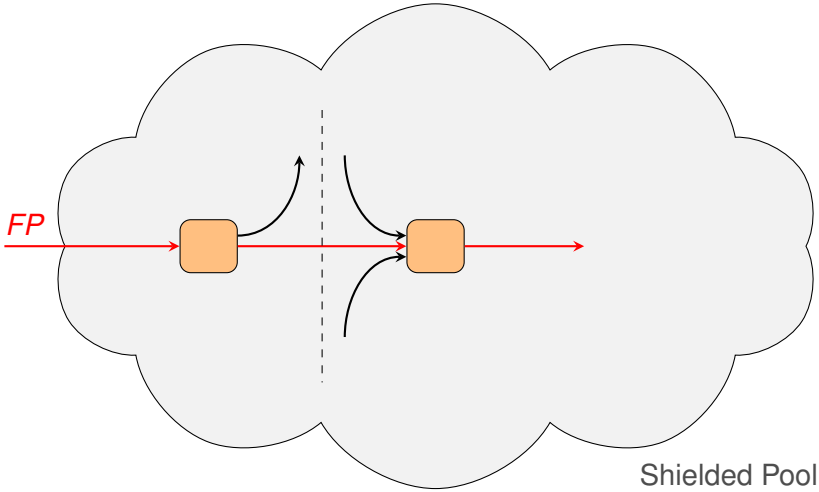

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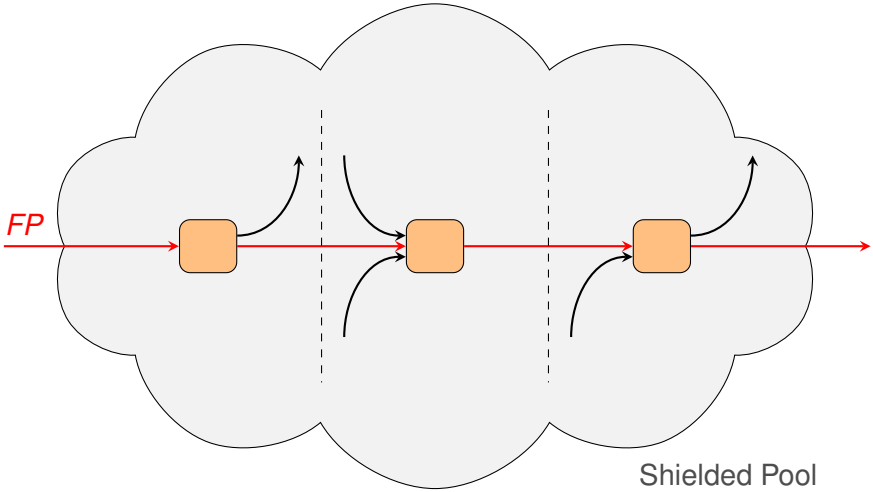


The Survival Probability of Fingerprints

- The average number of hops a path goes through inside the shielded pool is only 1.42.
- The survival probability of *good* fingerprints is ~16.6%.
- The survival probability of fingerprints corresponds, in turn, to the success probability of Danaan-gift Attack.

Countermeasures

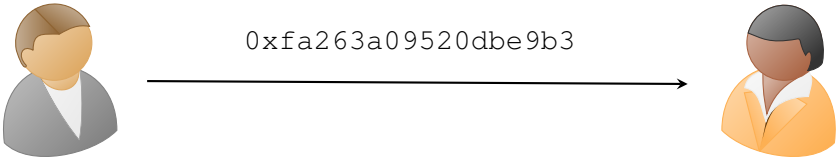
- Dust Attack is recognizable: move funds once.
- Danaan-gift Attack *manual defense*: do not use default fees.
- Danaan-gift Attack *built-in defense*: default fee is a random value between 0.00009500 ZEC and 0.00010500 ZEC.

Introduction to Zcash

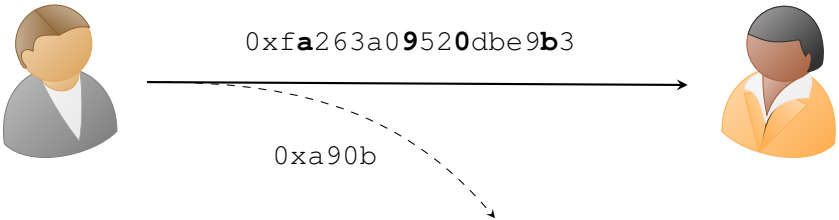
Transaction Linking

Subliminal Channels

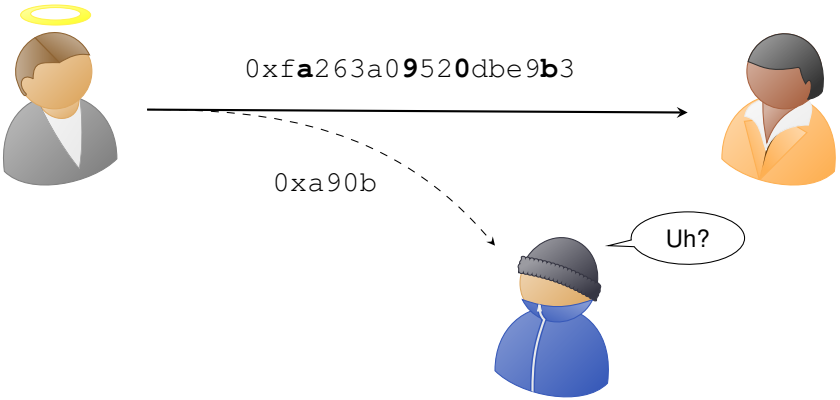
Subliminal Channels



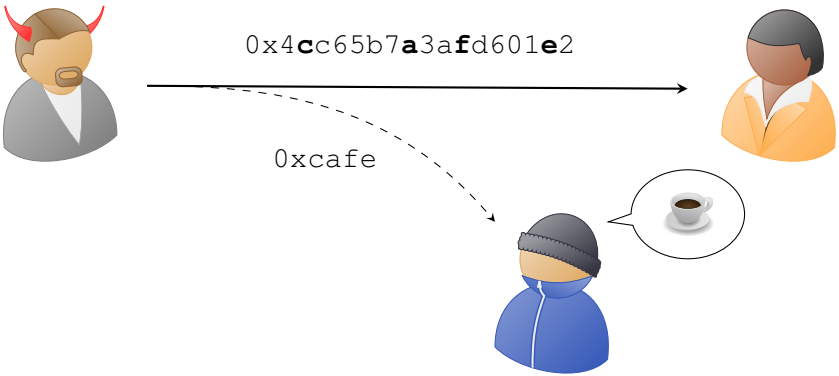
Subliminal Channels



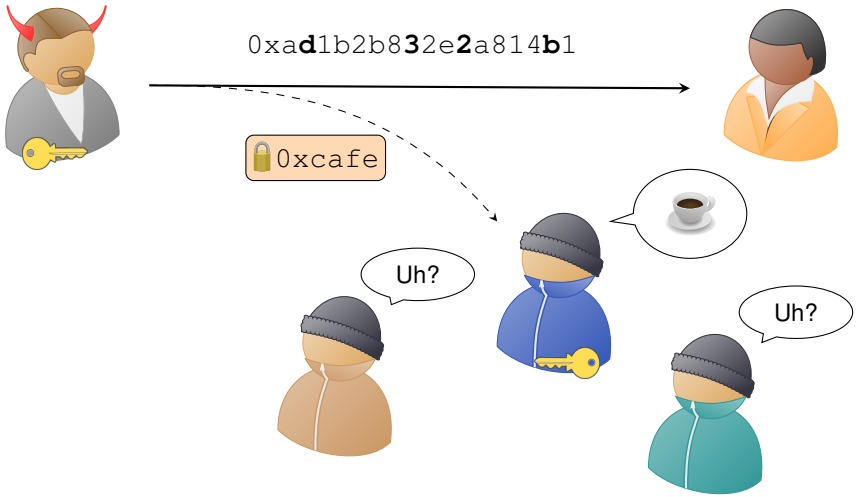
Subliminal Channels



Subliminal Channels



Subliminal Channels

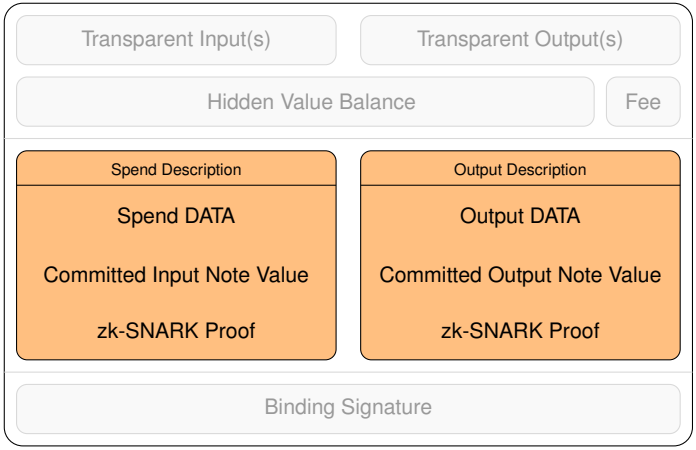


Subliminal Channels

- We found 3 subliminal channels by exploiting malleability of Pedersen's commitments and Groth16's zkSNARKs proofs:
  1. *Pedersen Subliminal Channel (commitment scheme)*
  2. *Inner Subliminal Channel (zkSNARK)*
  3. *Outer Subliminal Channel (zkSNARK)*

- **Key Idea:** use re-randomization until a desired *subliminal message* is successfully embedded.

Shielded Transaction Layout



Pedersen Subliminal Channel

- A note value v is committed to c with randomness r as

$$v \longrightarrow c = g^v h^r = \texttt{0xf2c71e906}$$

- c can be re-randomized to c' as

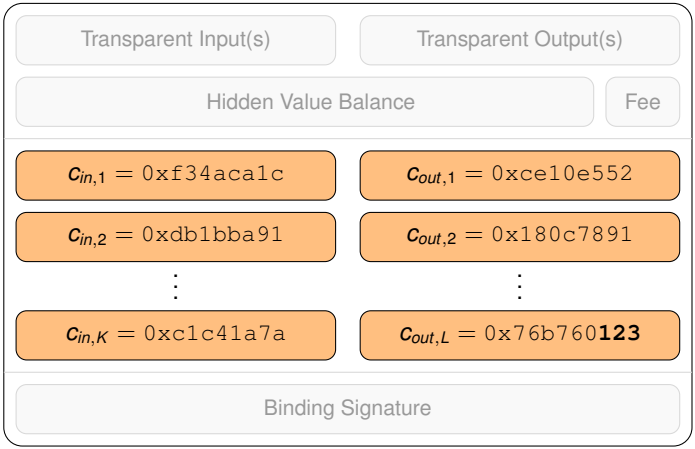
$$c \longrightarrow c' = c \cdot h^s = g^v h^{r+s}$$

- By selecting different random values s, we found that

$$c' = c \cdot h^s = \texttt{0x76b760}\mathbf{123}$$

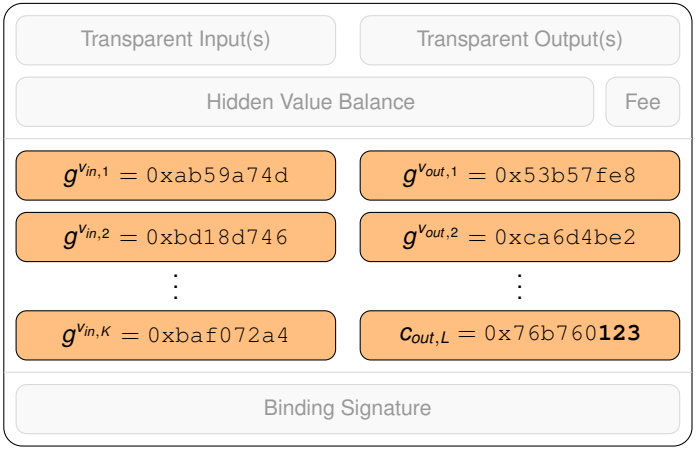
- c' embeds the message `123`.

Pedersen Subliminal Channel



Detect tag $\longrightarrow$ *Partial decommitment* $\longrightarrow$ *Dictionary attack* $\longrightarrow$ *Full decommitment*

Pedersen Subliminal Channel



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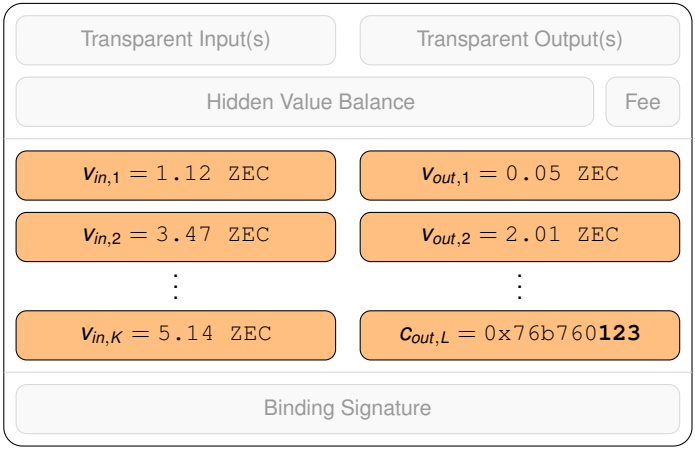
Pedersen Subliminal Channel



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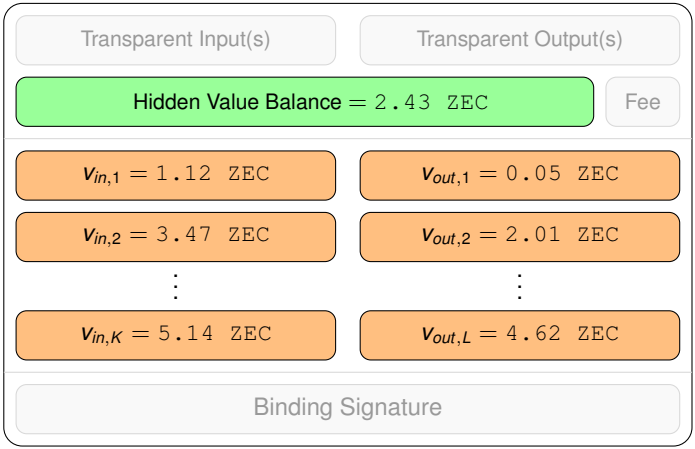

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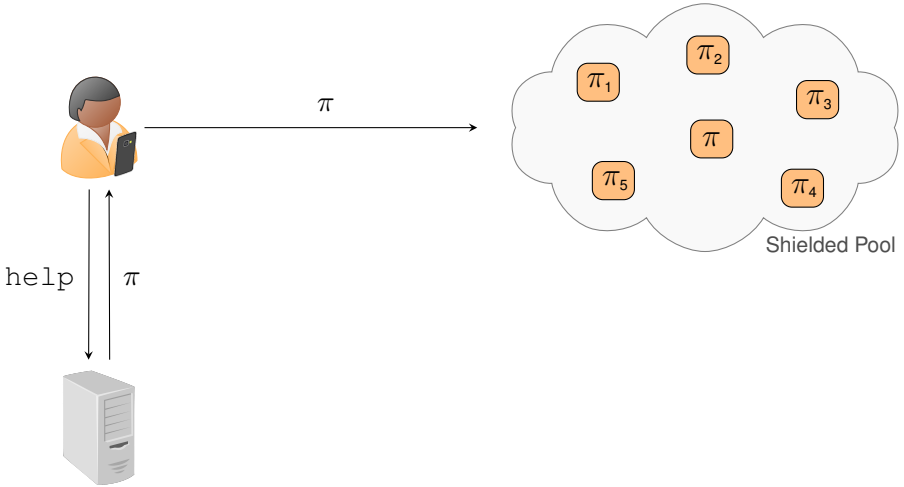
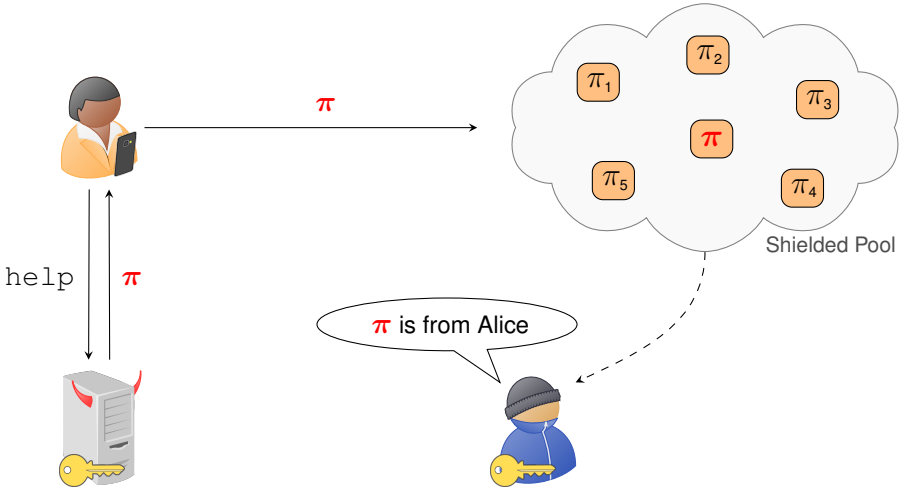
Decoupled Spend Authority

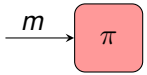


Decoupled Spend Authority



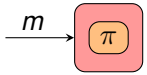
The Inner Subliminal Channel

- A zkSNARK proof is generated by choosing two different random values.
- A malicious proving system can iteratively select different randomness until the resulting π embeds the subliminal message.
- *'Inner'* because a message is embedded *before* π is finalized.



The Outer Subliminal Channel

- A proof π can be re-randomized using some non-expensive elliptic curve operations and without knowing any witness.
- π is iteratively re-randomized until the subliminal message is embedded.
- *'Outer'* because re-randomization is done on an already generated proof.

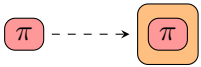


Implementation Results

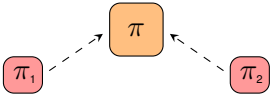
- We embedded 9 bytes in a fully shielded transaction with 1 shielded input and 2 shielded outputs (3 bytes per description).
- On a standard laptop, it took on average 3.0087s compared to 2.8412s normally needed (just a 6% increase).
- Our tagged transaction has a confirmed status on the Zcash testnet:

Countermeasures

- Use proof re-randomization to disrupt any embedded subliminal message.



- Combine two (even tagged) proofs for the same statement.



- Trusted Execution Environments could help to mitigate trust issues in proof delegation and transaction generation.

Summary

- Two different approaches for transaction tagging and linking in Zcash:

1. **Transaction Linking Attacks:**
   - Based on interplay of transparent and hidden transactions;
   - Verified with a rigorous statistical model.
2. **Subliminal Channels:**
   - Based on discovery of subliminal channels in cryptographic primitives used to build hidden transactions;
   - Embedded 3 bytes per description.