Remote Side-Channel Attacks on Anonymous Transactions

In Zcash & Monero

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USENIX Security Symposium

Stanford University

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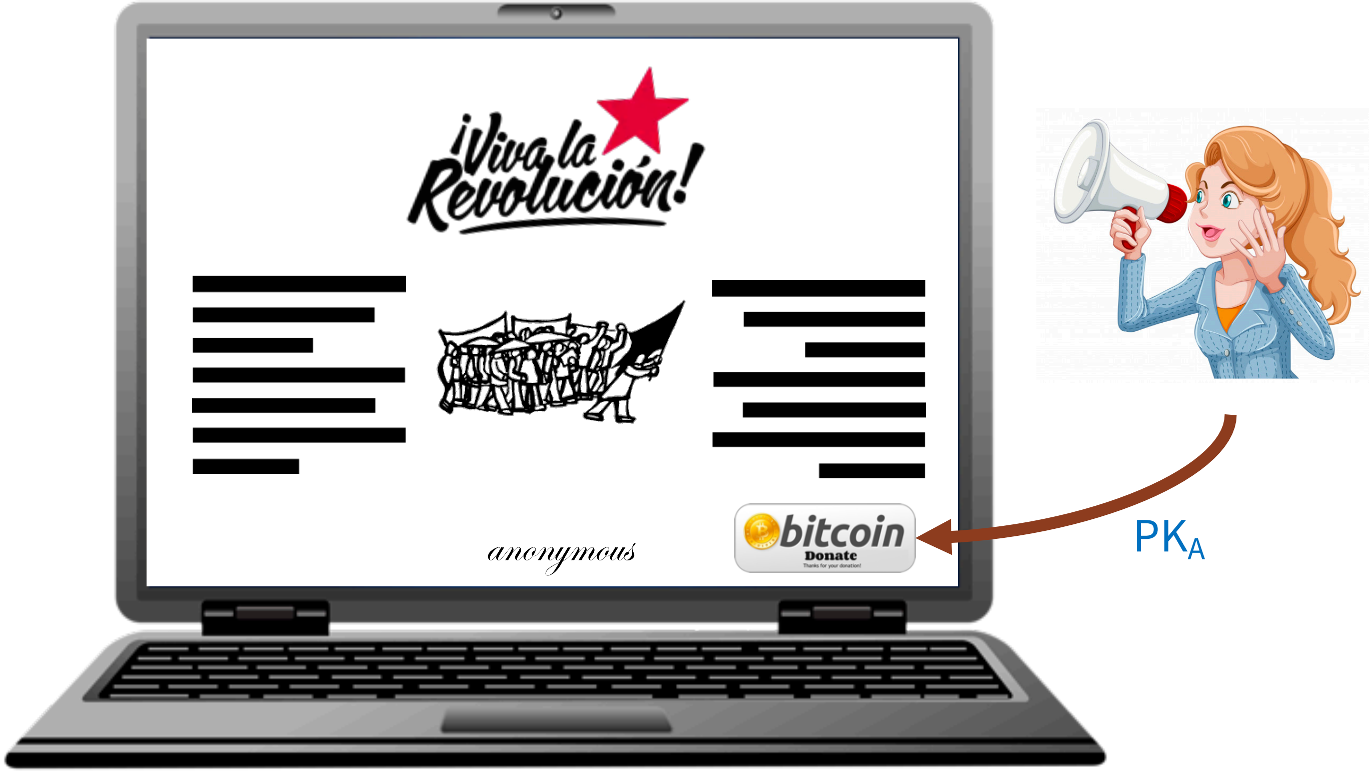
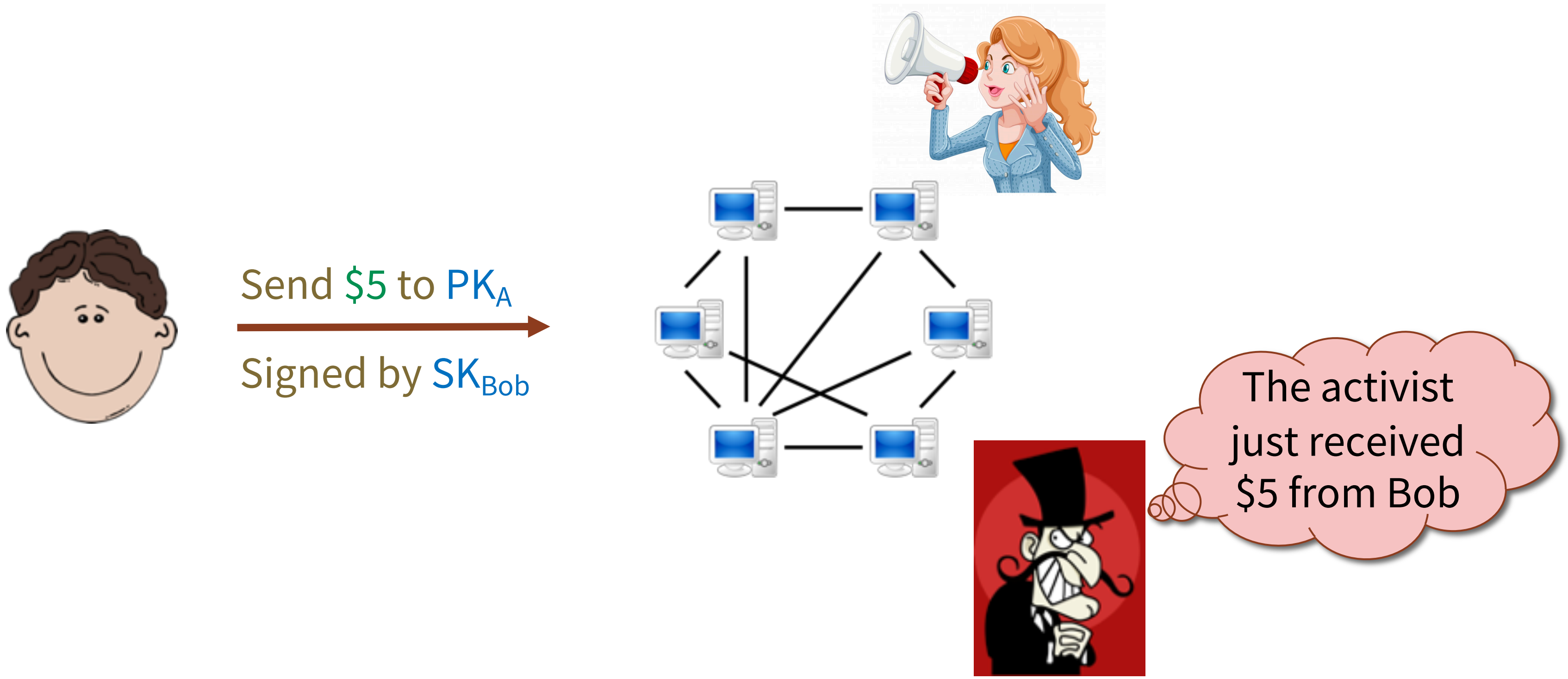
Meet Alice the Anonymous Activist Blogger



Alice’s Lack of Privacy



Send \$5 to PK_A

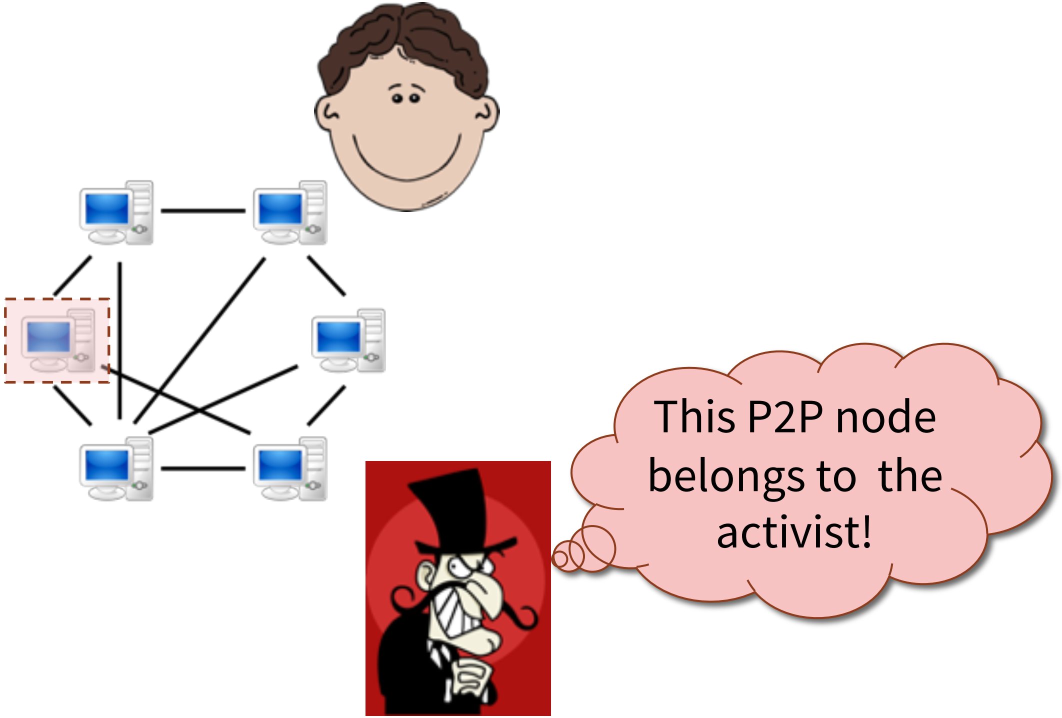
Signed by SK_Bob

The activist just received \$5 from Bob

Alice’s Lack of Privacy

Send \$5 to PK_{Bob}

Signed by SK_{A}



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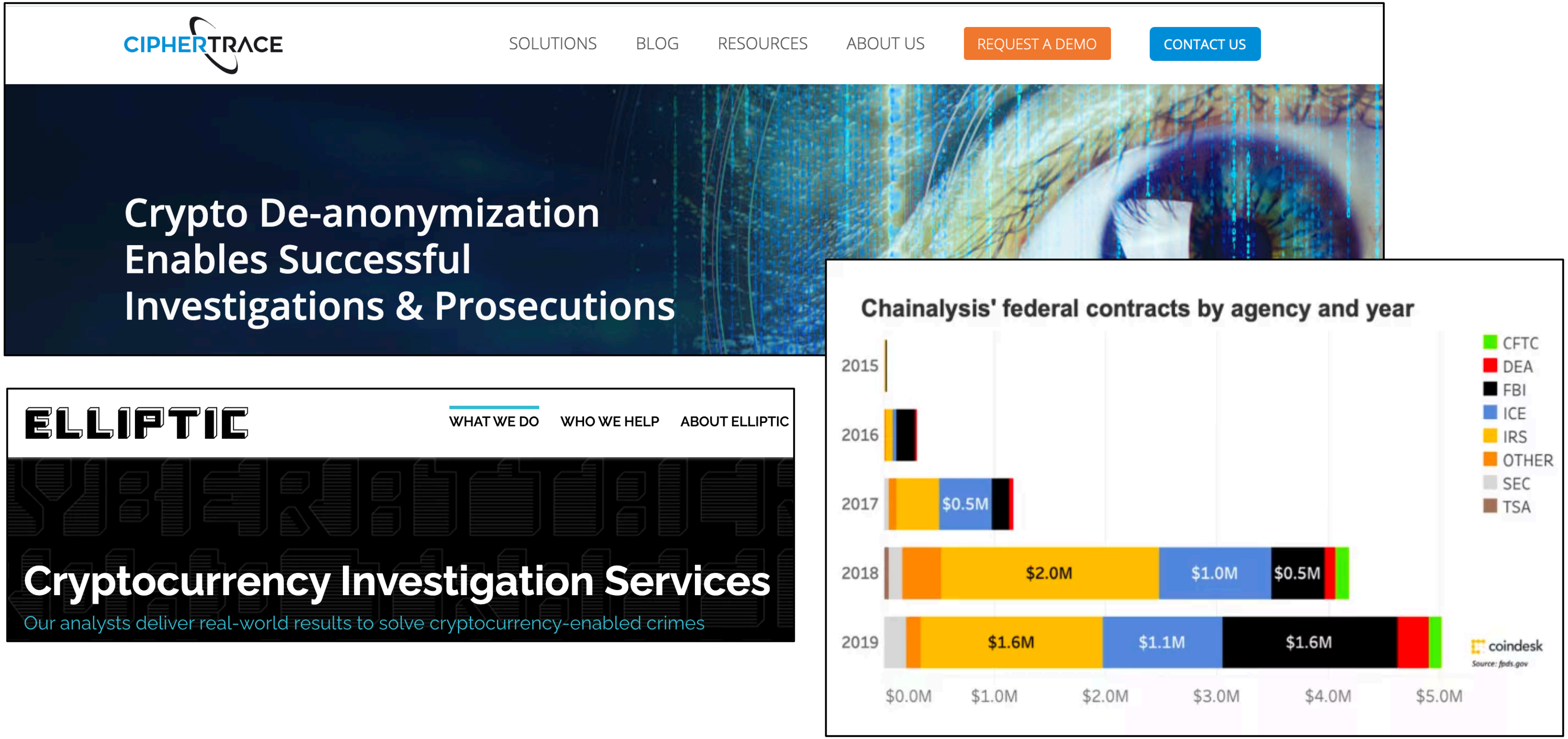


Crypto De-anonymization Enables Successful Investigations & Prosecutions

Cryptocurrency Investigation Services

Our analysts deliver real-world results to solve cryptocurrency-enabled crimes

Chainalysis' federal contracts by agency and year

Source: fpds.gov

The Solution: Anonymous Transactions

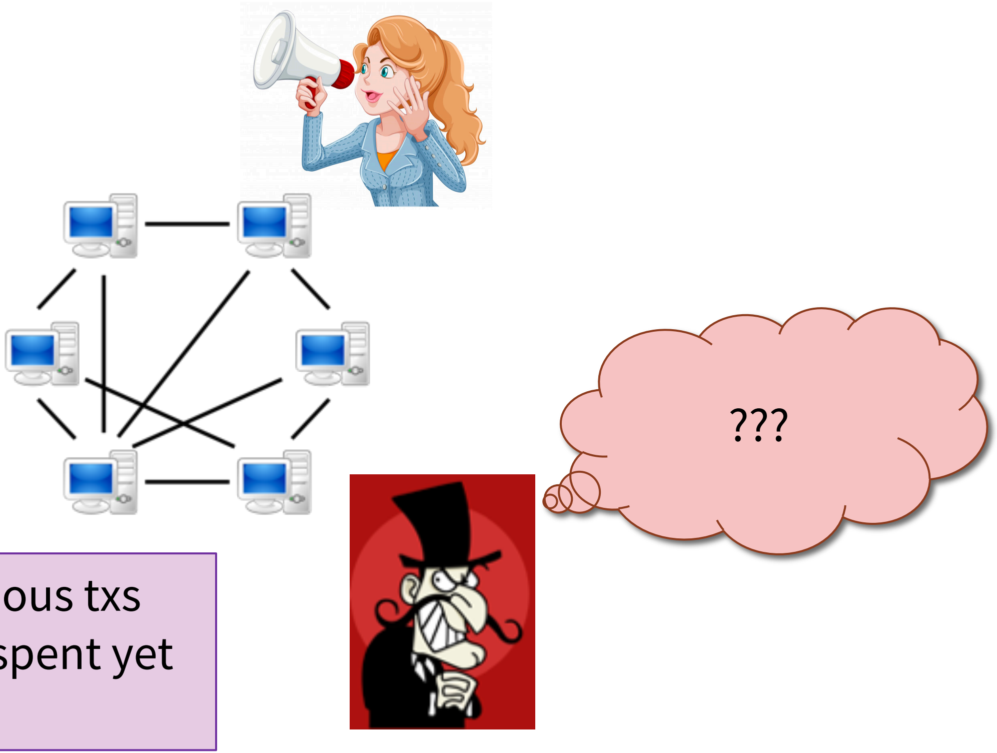
Zcash, Monero and others

Send **Enc**($5) to **Enc**($PK_A$)

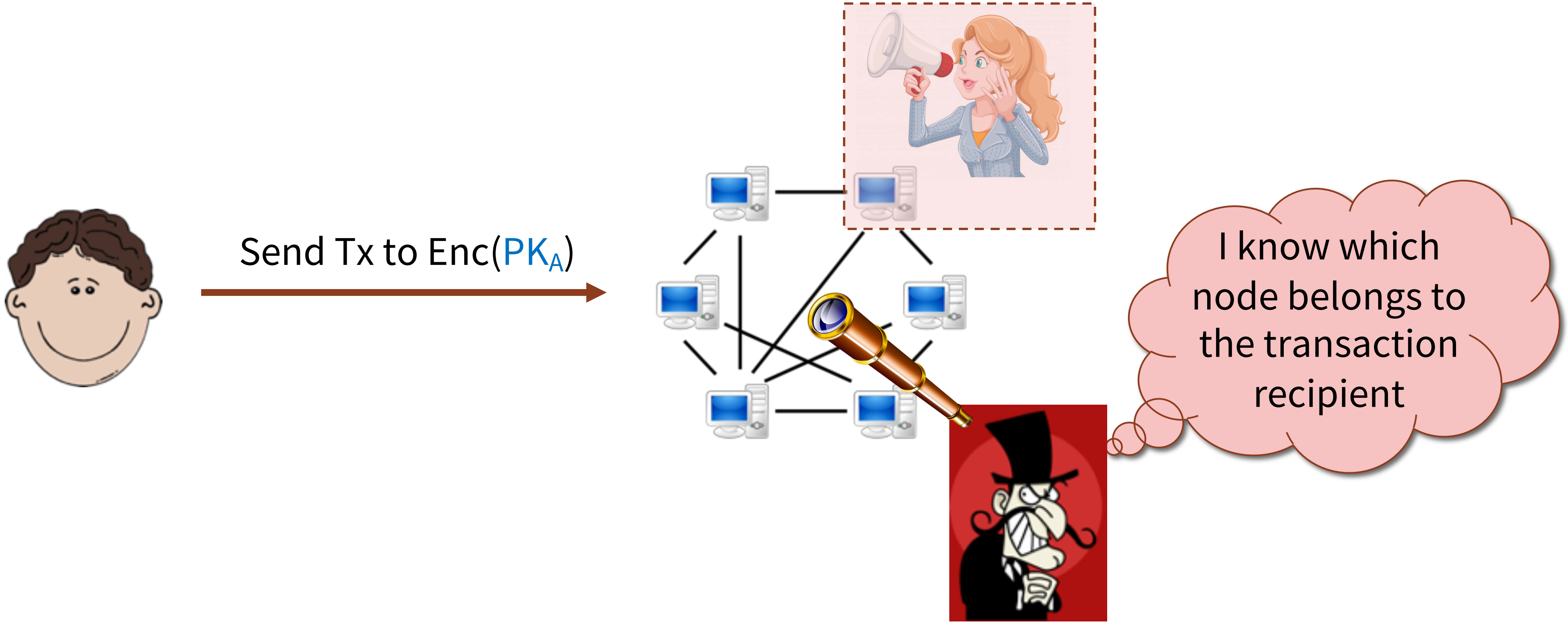
Signed by **Enc**(SK_{Bob})

+ zk-proof π

- Bob received $5 from previous txs
- These funds haven't been spent yet
- Bob knows SK_{bob}



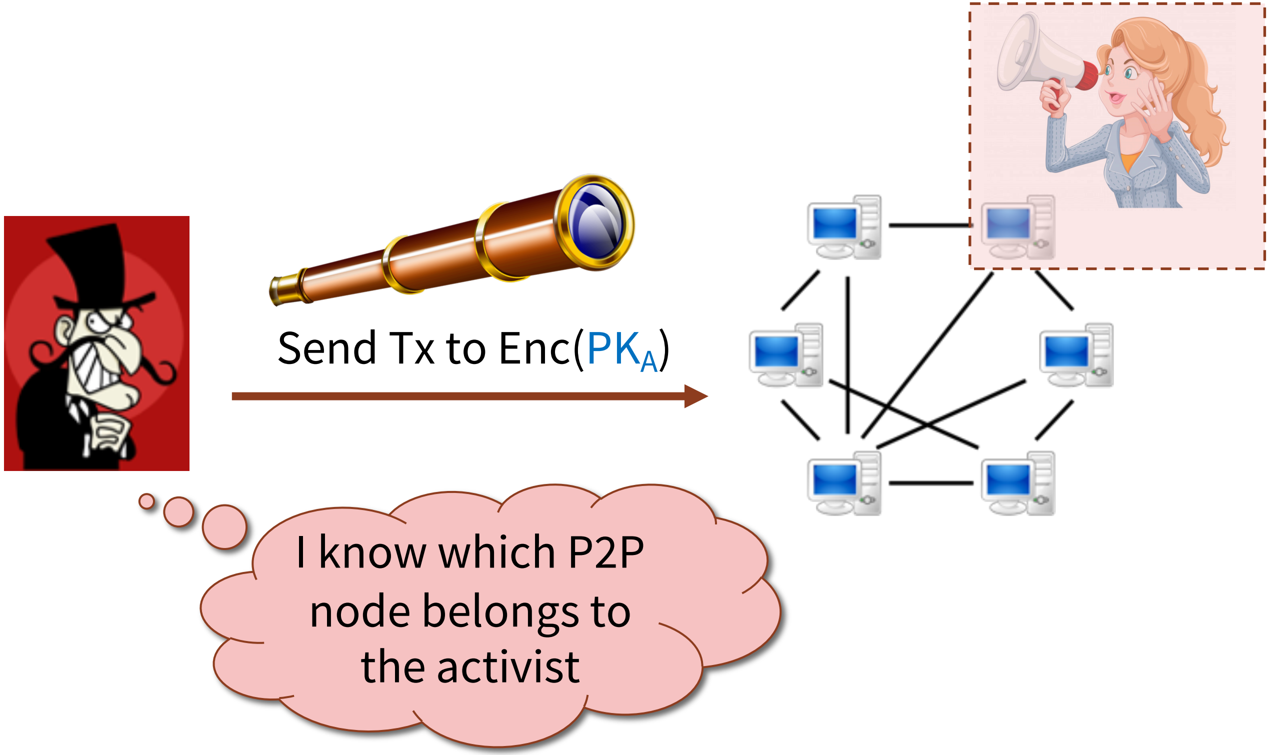
Our Attacks: Identifying Transaction Recipients



Send Tx to Enc(PK_A)

I know which node belongs to the transaction recipient

Our Attacks: Linking an Address to a Node



Send Tx to Enc(PK_A)

I know which P2P node belongs to the activist

Summary of Results

Remote side-channel attacks on various system components of anonymous transactions

1. A general attack framework for any anonymous transaction system
2. Specific attack instantiations for Zcash and Monero
   - Determine the P2P node of *any* transaction recipient
   - Link a (diversified) public key to an IP address
3. Attacks beyond de-anonymization (for Zcash):
   - Remotely crash user nodes
   - ~ Remotely extract a user’s secret viewing key
   - ~ Learn transaction amounts by timing a zk-proof generation

Summary of Results

Remote side-channel attacks on various system components of anonymous transactions

We have disclosed these vulnerabilities to Zcash and Monero and they have all been fixed!

The general issues we found, and the lessons we learned, extend to other anonymous payment systems

⇒ **Getting the cryptography right is not enough!**

Summary of Results

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De-anonymizing Zcash Transactions

Receiving Transactions in Zcash

Commitment to a “coin”

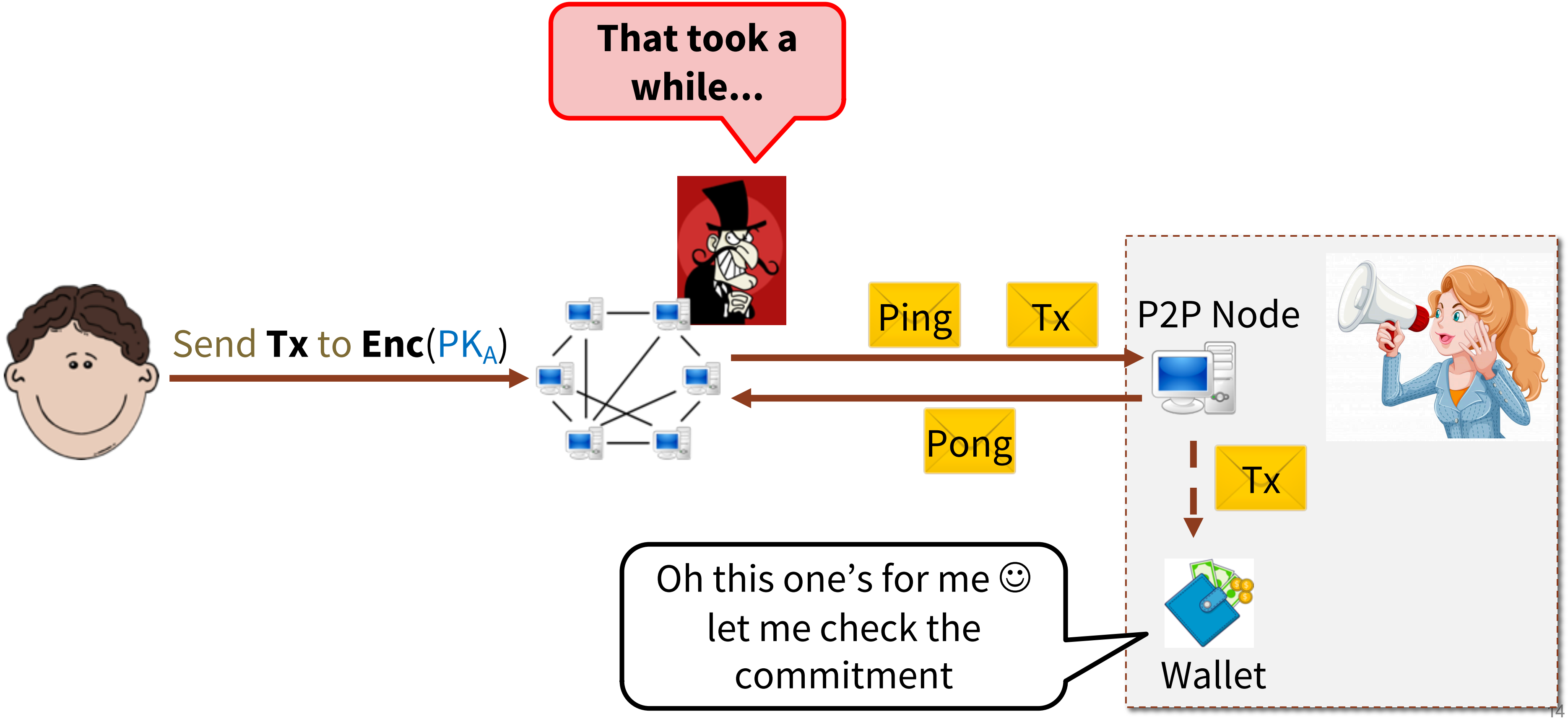
Commitment opening encrypted under the recipient’s public key

```
OnReceive(Tx={Comm,C,...}):
    1) Note = Decrypt(SK_A, C)
    2) if Note = ⊥, return
    3) ($v, r) = Note
    4) Check that Comm = Commit(PK_A, $v; r)
```

This check ensures that the coin is spendable

(public key crypto)

The PING Attack



That took a while...

Send **Tx** to **Enc**(PK_A)

Ping

Tx

P2P Node

Pong

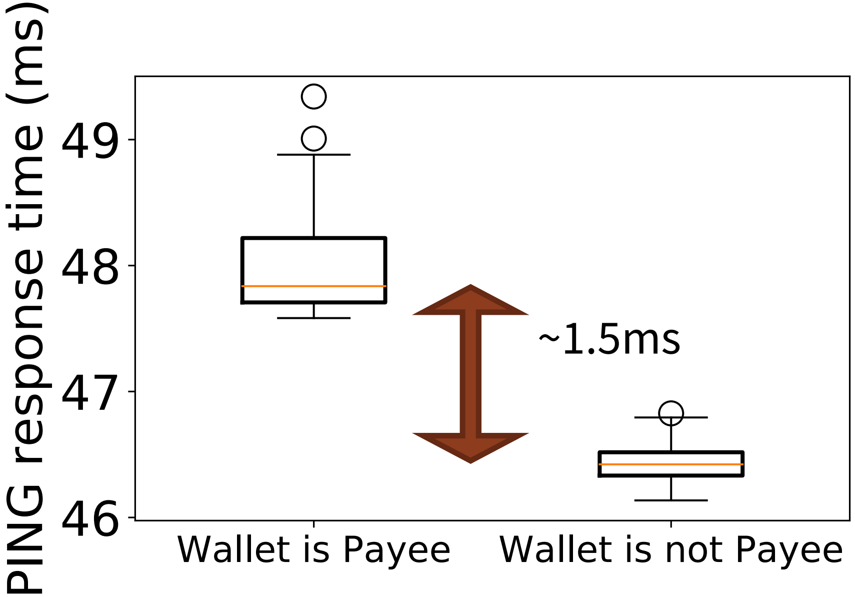
Tx

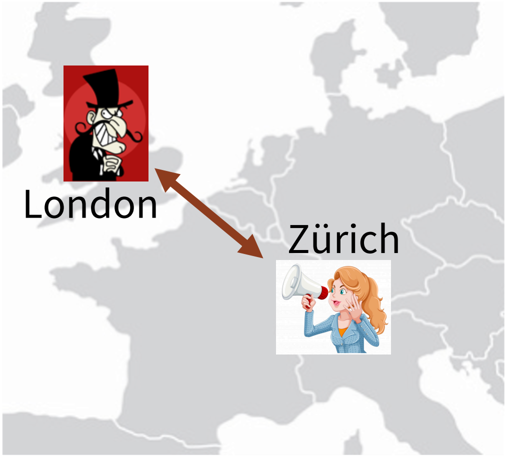
Oh this one’s for me ☺ let me check the commitment

Wallet

The PING Attack

Adversary can use timing side-channel
to infer receiver of **any** Tx





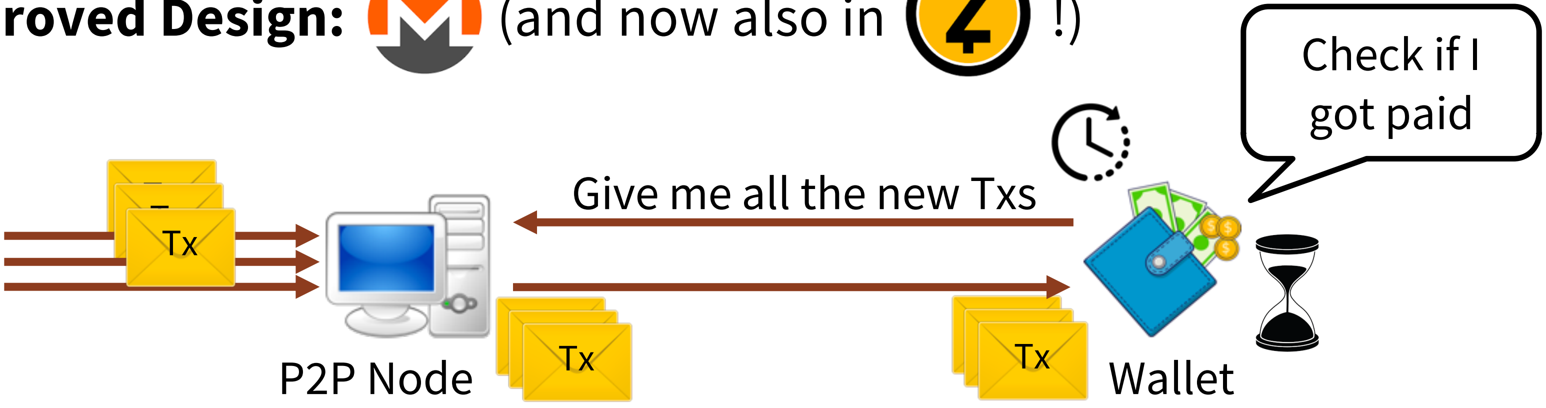
What Went Wrong?

P2P node and wallet are tightly decoupled

⇒ Node & wallet are in completely different layers of the protocol stack

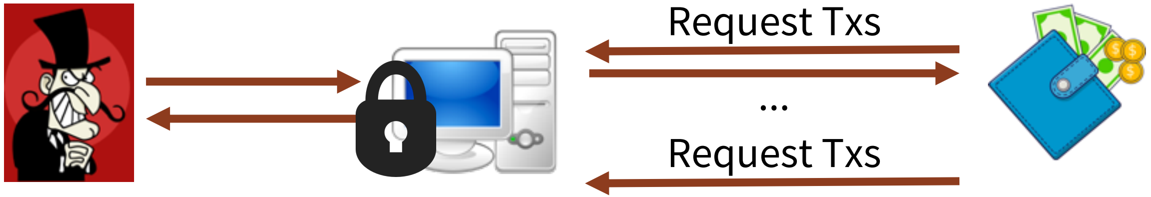
⇒ The P2P node should just act as a DB for the wallet

Improved Design: M (and now also in Ƶ !)



So why was Monero also vulnerable?

Exploiting Leaks at Synchronization Points



✗ *Timing of wallet's requests leaks wallet's processing time*

Time between requests = 60s + time to process txs →

```
while True:
  txs = request_txs()
  process(txs)
  sleep(60)
```

✗ *Monero P2P node acquires **global mutex** to process a request*

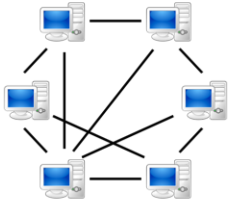
Fixed!

Timing side channels in zkSNARK proof generation

Send Enc($5) to Enc($PK_{Bob}$)

Signed by Enc(SK_A)

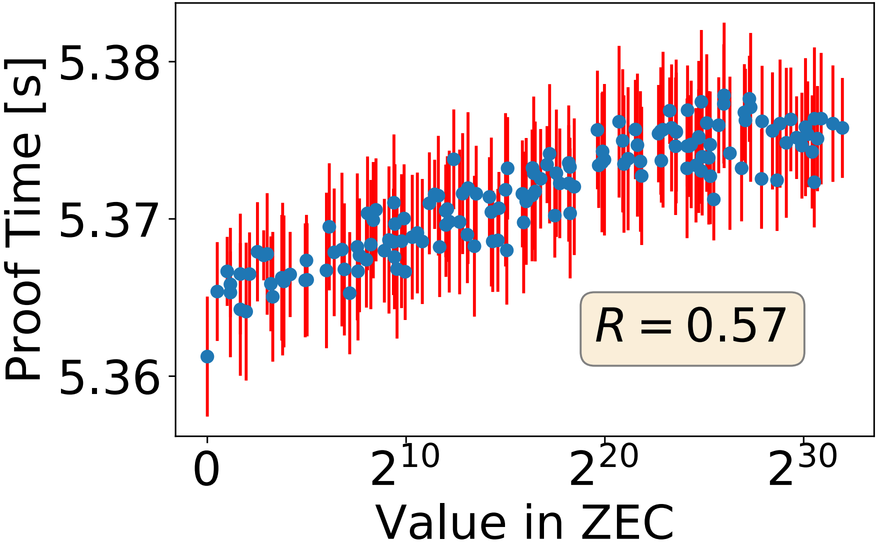
+ zk-proof π



Cryptographic proof that the transaction is valid

Zero-knowledge: proof leaks nothing
about PK_{Bob}, SK_A, $5, ..., right?

Timing side channels in zkSNARK proof generation



Transaction generation time leaks (some) information about value!

Conclusions and Lessons Learned

Anonymity is hard!

- Flaws are not (only) in the complicated cryptography
- Be careful when inheriting designs from non-anonymous currencies (e.g., Bitcoin → Zcash)
- Develop constant-time crypto implementations

Anonymity = good crypto + good systems design

https://crypto.stanford.edu/timings tramer@cs.stanford.edu