routing attacks on Bitcoin

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outline

- **background**
- partitioning attack
- delay attack
- evaluation
- countermeasures

routing in the Internet

- routing

  *"routing is the process of selecting a path for traffic in a network, or between or across multiple networks." **

- Autonomous System (AS)

  *"an Autonomous System (AS) is a collection of routers whose prefixes and routing policies are under common administrative control." ***

  ➡ one or more IP prefixes (e.g. 128.6.0.0/16)

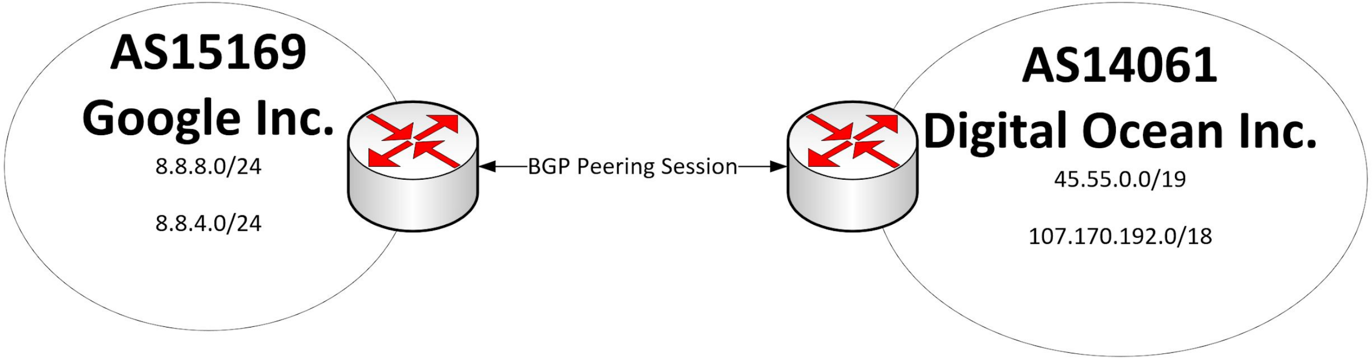
* https://en.wikipedia.org/wiki/Routing
** https://www.cs.rutgers.edu/~pxk/352/notes/autonomous_systems.html

routing in the Internet

- intra-AS / IGP (Interior Gateway Protocols)
    - OSPF (Open Shortest Path First)
    - RIP (Routing Information Protocol)
- inter-AS / EGP (Exterior Gateway Protocols):
    - **BGP (Border Gateway Protocol)**

what is BGP?

- network operators establish peers over TCP connections
- routers advertise a list of network routes they have access to
- choose from alternatives based on shortest path
- preference for more specific routes



https://blog.cdemi.io/beginners-guide-to-understanding-bgp

BGP hijacking

- ASes may announce IP ranges they do not own

  e.g. AS wants to attract traffic sent to 100.0.0.0/16

  (a) announce 100.0.0.0/16

  (b) announce a more specific range, e.g. 100.0.0.0/17, 100.0.128.0/17

  announcements more specific than /24 are usually dropped

- BGP is based on trust
- censorship, Man-in-the-Middle interception, black holes
- Pakistan's attempt to block YouTube access takes down YouTube entirely (2008)

the Bitcoin p2p protocol

- p2p broadcast/gossip network
- TCP with default port 8333
- no encryption or integrity checks
- 8 outgoing, up to 125 incoming connections by default

the Bitcoin p2p protocol

- block / transaction propagation
  - ➡ INV — "I have these blocks/transactions: …"
  - ➡ GETDATA — request a single block or transaction by hash
  - ➡ BLOCK — send a block in response to GETDATA
- by default, nodes request block from sender of first INV containing its hash
- nodes wait for 20 minutes after GETDATA before retrying

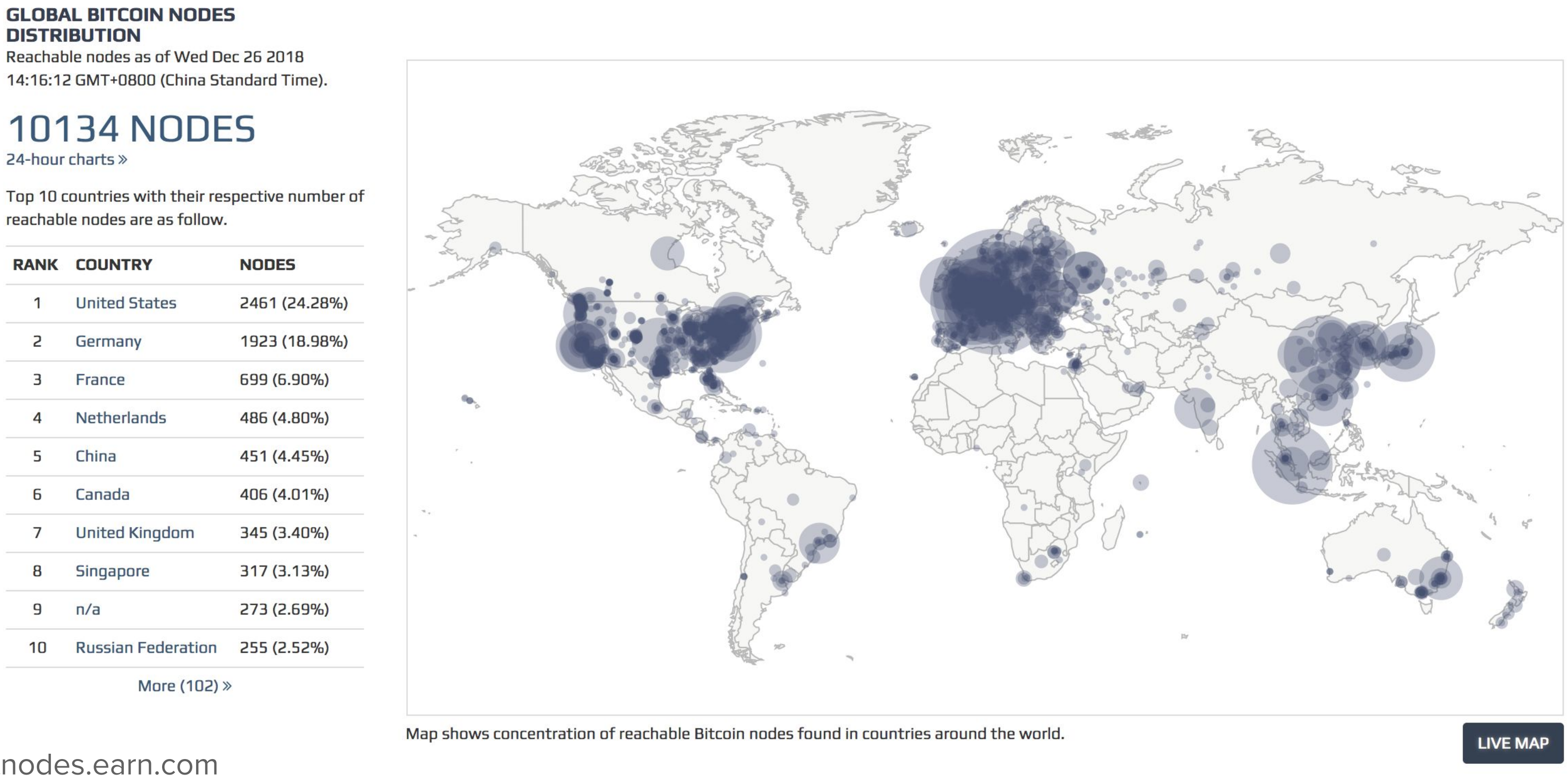
https://en.bitcoin.it/wiki/Protocol_documentation

the Bitcoin p2p protocol

- bootstrapping
  - ➡ manually provide address (command line, database, etc.)
  - ➡ ADDR message
  - ➡ DNS (seed.bitcoin.sipa.be, dnsseed.bluematt.me, seed.bitcoinstats.com, ...)
  - ➡ hardcoded default addresses / hostnames

https://en.bitcoin.it/wiki/Satoshi_Client_Node_Discovery

Bitcoin network statistics



GLOBAL BITCOIN NODES DISTRIBUTION

Reachable nodes as of Wed Dec 26 2018 14:16:12 GMT+0800 (China Standard Time).

10134 NODES

24-hour charts »

Top 10 countries with their respective number of reachable nodes are as follow.

RANK	COUNTRY	NODES
1	United States	2461 (24.28%)
2	Germany	1923 (18.98%)
3	France	699 (6.90%)
4	Netherlands	486 (4.80%)
5	China	451 (4.45%)
6	Canada	406 (4.01%)
7	United Kingdom	345 (3.40%)
8	Singapore	317 (3.13%)
9	n/a	273 (2.69%)
10	Russian Federation	255 (2.52%)

More (102) »

Map shows concentration of reachable Bitcoin nodes found in countries around the world.

https://bitnodes.earn.com

mining pools

- lower risk by increasing reward frequency
- Stratum protocol: JSON-RPC over TCP *
- multi-homing: multiple gateways to the network at multiple ISPs
- manager creates block template, miners find PoW for header
- inter-pool peering agreements

* https://slushpool.com/help/manual/stratum-protocol

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partitioning attack - overview

- AS-level adversary wants to isolate a set of nodes P from the rest of the network
  1. divert traffic destined to P
  2. identify relevant traffic
  3. drop packets crossing partition boundary
  4. isolate leaking nodes

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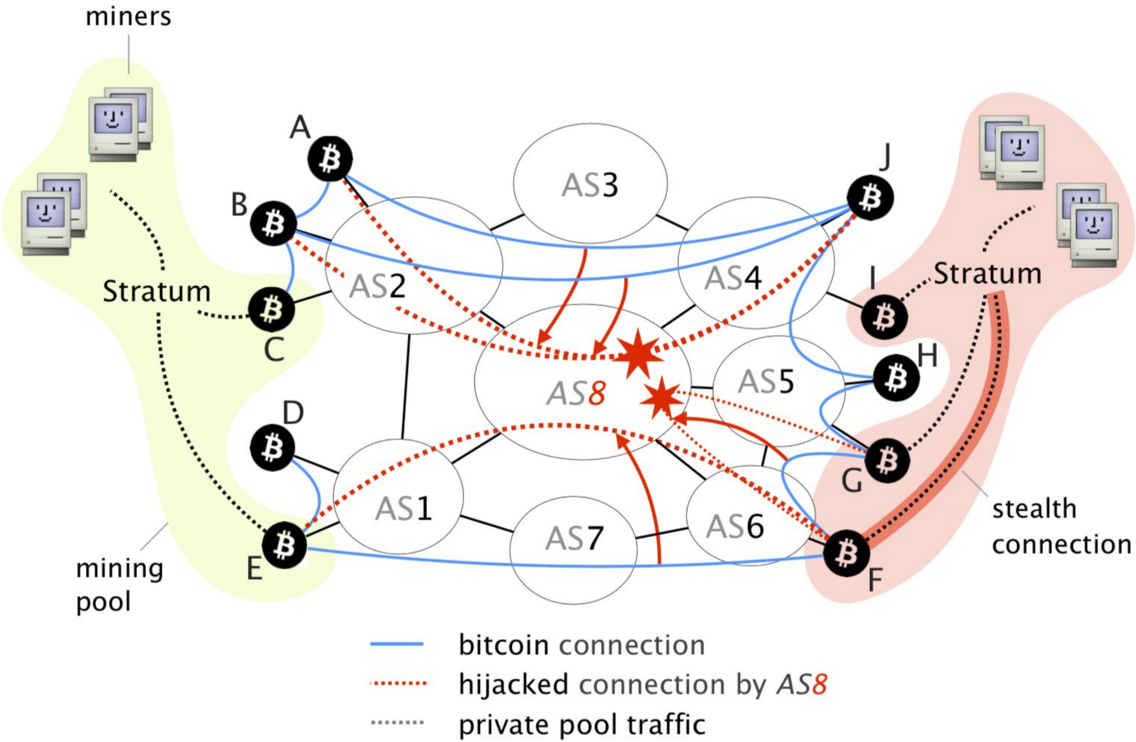
partitioning attack - overview

P = {A, B, C, D, E, **F**}

1. divert traffic
2. drop packets
3. isolate leaks



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attack steps

1. divert traffic destined to P
    - ➜ BGP hijack, announce more specific prefixes
2. identify relevant traffic
    - ➜ TCP:8333, specific IP addresses, Bitcoin header (unencrypted!)
3. drop packets crossing partition boundary
4. isolate leaking nodes
    - ➜ this is the main challenge

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isolating leaks - connection types

- vulnerable connection
  - ➜ can divert via BGP hijack
  - ➜ uses Bitcoin protocol
- stealth connection
  - ➜ intra-AS: cannot do BGP hijack
  - ➜ intra-pool: unique/encrypted protocol
  - ➜ pool-to-pool

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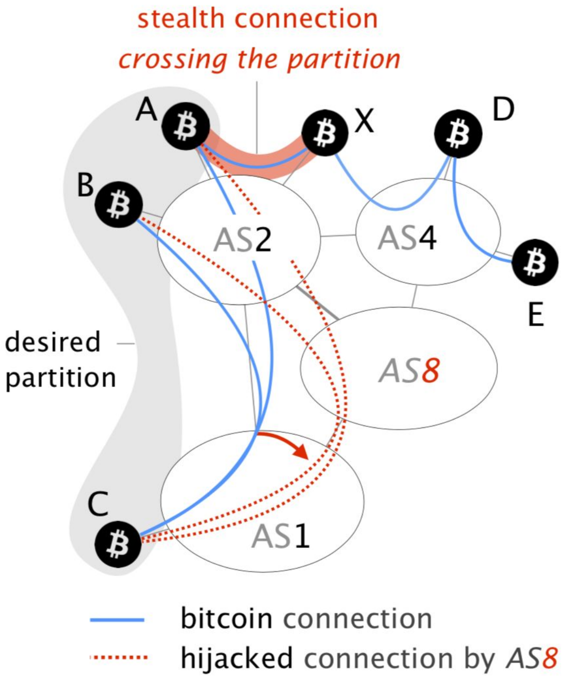
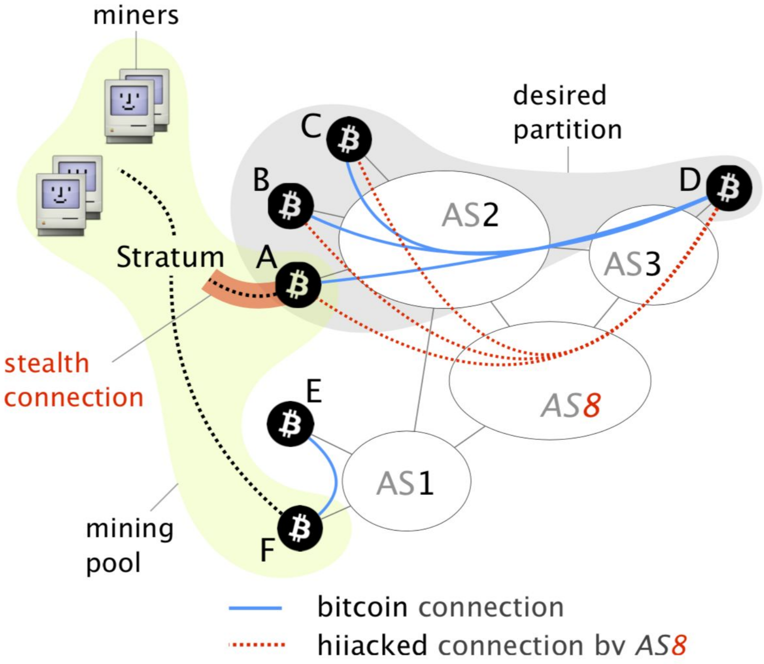
isolating leaks - connection types





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isolating leaks

1. include all or none of the nodes within the same AS

2. include all or none of the nodes within the same pool

3. **find and exclude leaking nodes**

    - inspect INV messages from nodes within P

    - if they advertise blocks mined outside P, they must have a stealth connection

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partitioning attack - impact

a. targeted attack
   - ➜ Denial-of-Service
   - ➜ double spending

b. network-wide attack
   - ➜ fork => reduced mining power on both sides
   - ➜ all blocks mined on weaker side will be discarded after the attack
   - ➜ revenue loss for miners, risk of double spend

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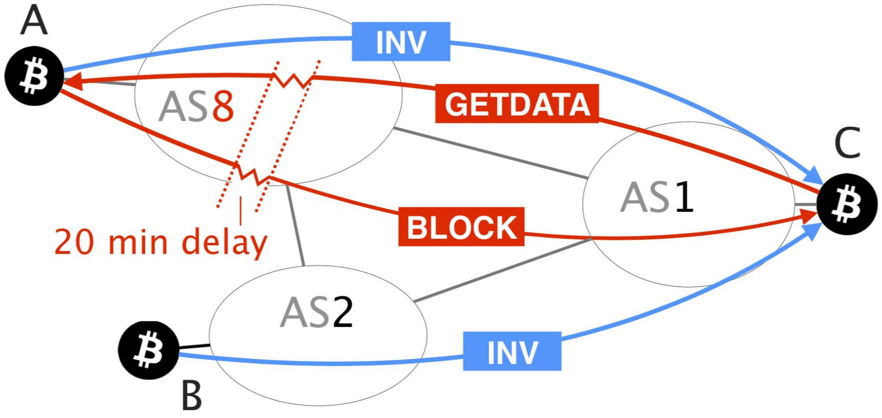
- **delay attack**
- evaluation
- countermeasures

delay attack - overview

- slow down block propagation
- tamper with traffic in a way that
  1. prevents node from receiving correct information
  2. but keeps connection alive



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delay attack - overview

a. intercept outgoing connection (block #42)

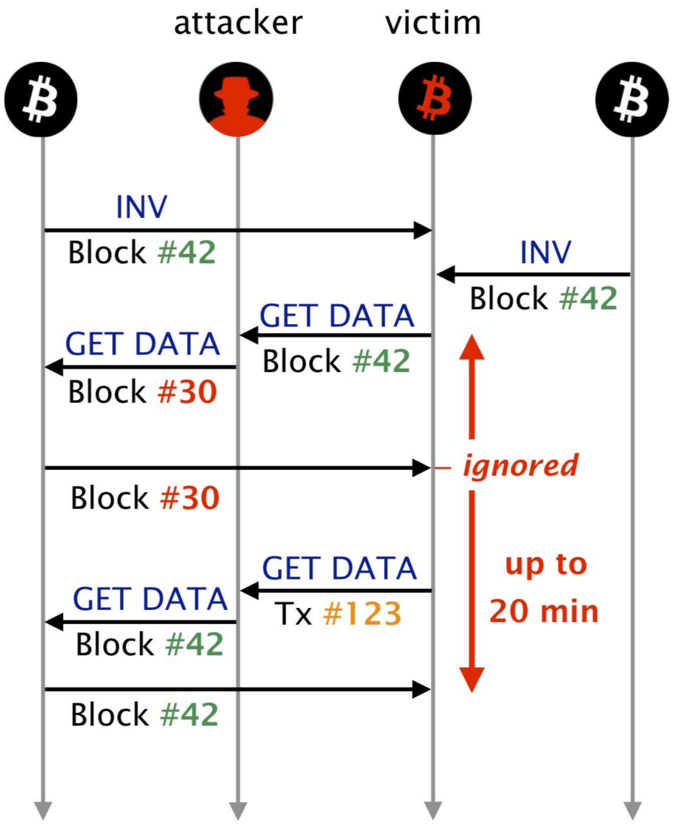
→ change block hash in GETDATA to #30

→ victim gets wrong block (#30); keeps waiting

→ change another GETDATA to #42 this time

→ victim gets #42 with a large delay

- why not just drop?
- why change the second time?



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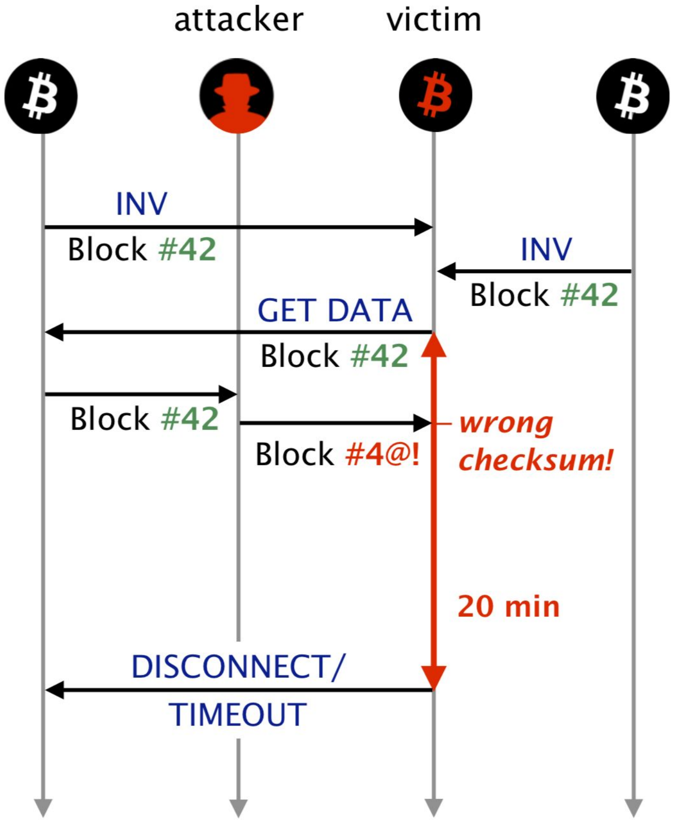
delay attack - overview

a. intercept incoming connection

- ➡ change data in BLOCK
- ➡ victim drops it; keeps waiting
- ➡ timeout after 20 minutes



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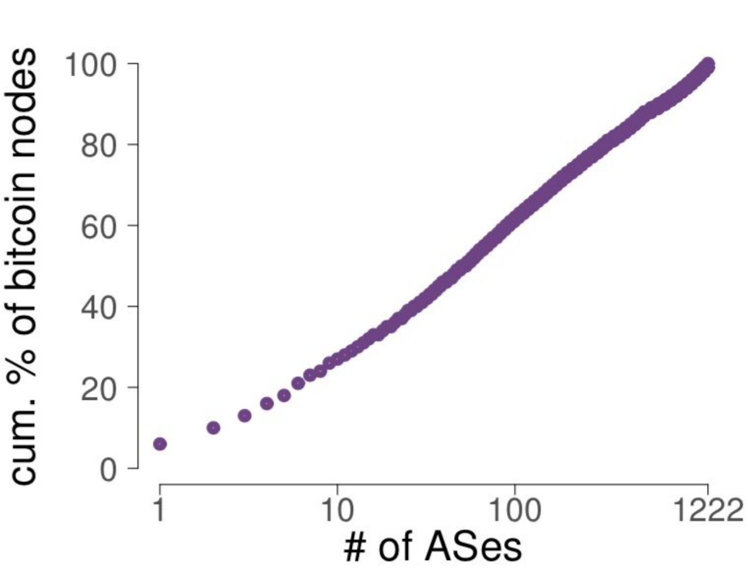
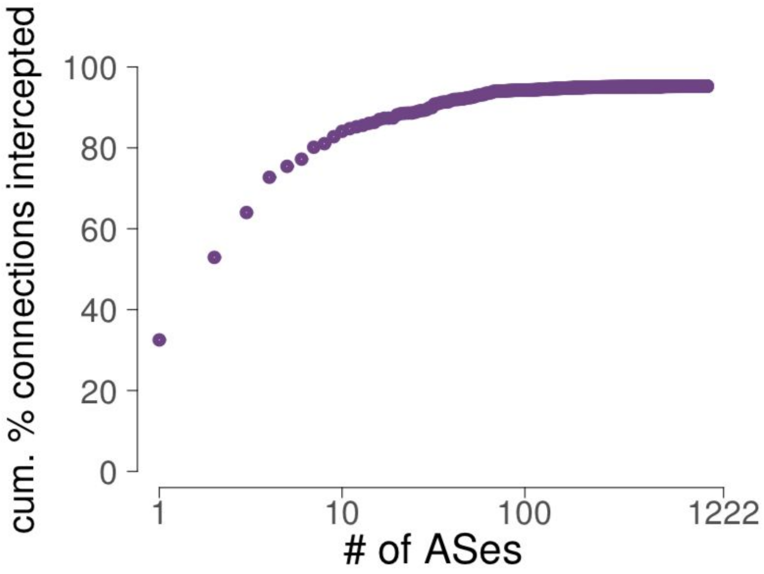
network topology





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network topology

- a few ASes host most Bitcoin nodes
- a few ASes intercept the majority of Bitcoin traffic
- most Bitcoin nodes are susceptible to BGP hijacks
- mining pools are distributed and multi-homed (2-5)
- Bitcoin routing properties are stable over time

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partitioning - speed

- host six Bitcoin nodes under 184.164.232.0/22
- advertise 184.164.232.0/22 using a virtual AS
- advertise 184.164.235.0/24 via another (malicious) virtual AS
- divert all traffic within 90 seconds

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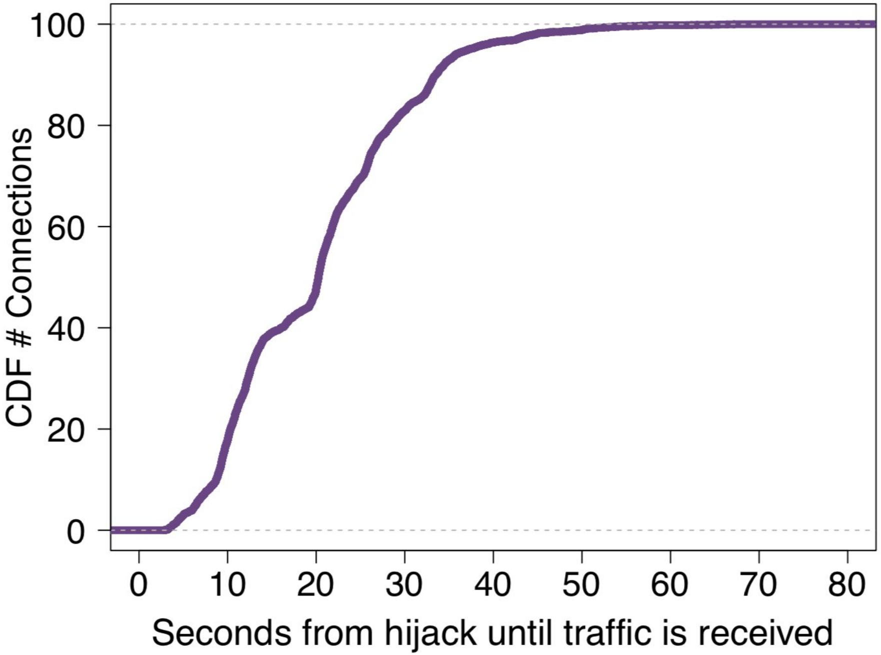
partitioning - speed



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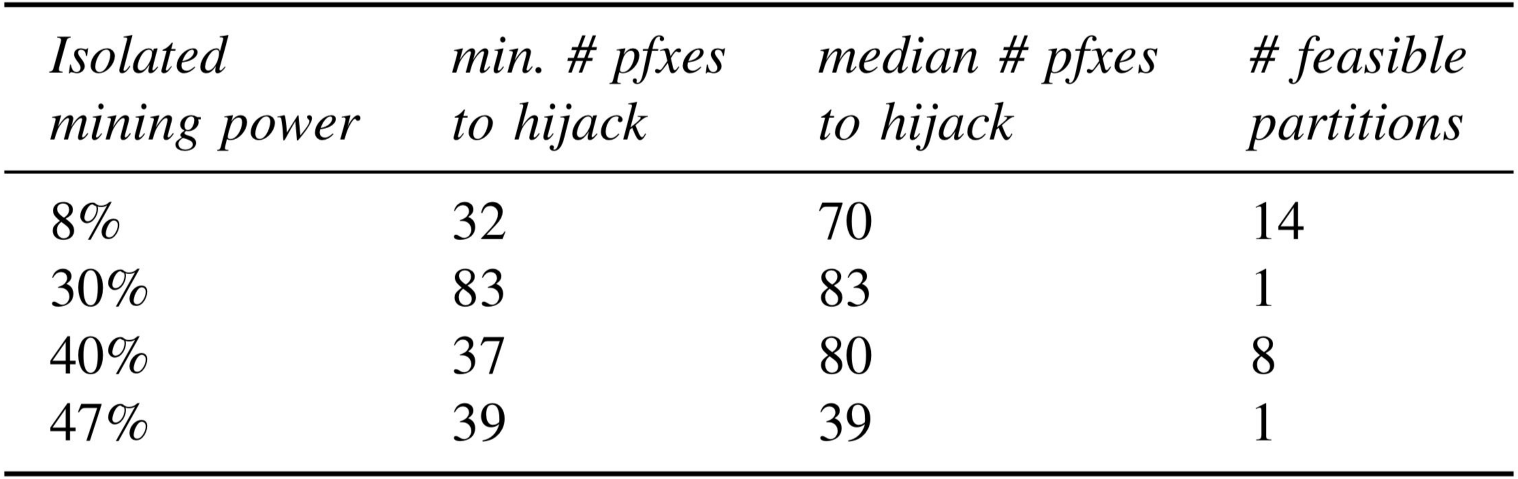
partitioning - impact



Isolated mining power	*min. # pfxes to hijack*	*median # pfxes to hijack*	*# feasible partitions*
8%	32	70	14
30%	83	83	1
40%	37	80	8
47%	39	39	1

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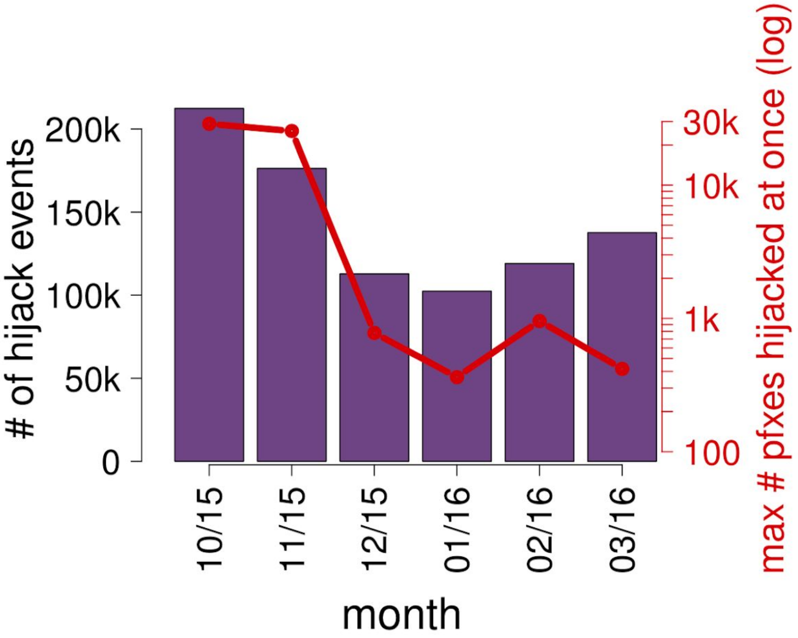
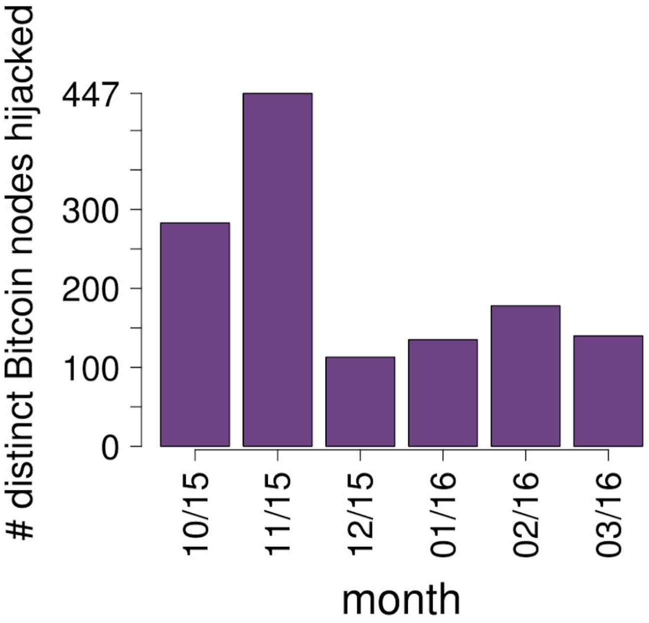
partitioning - frequency





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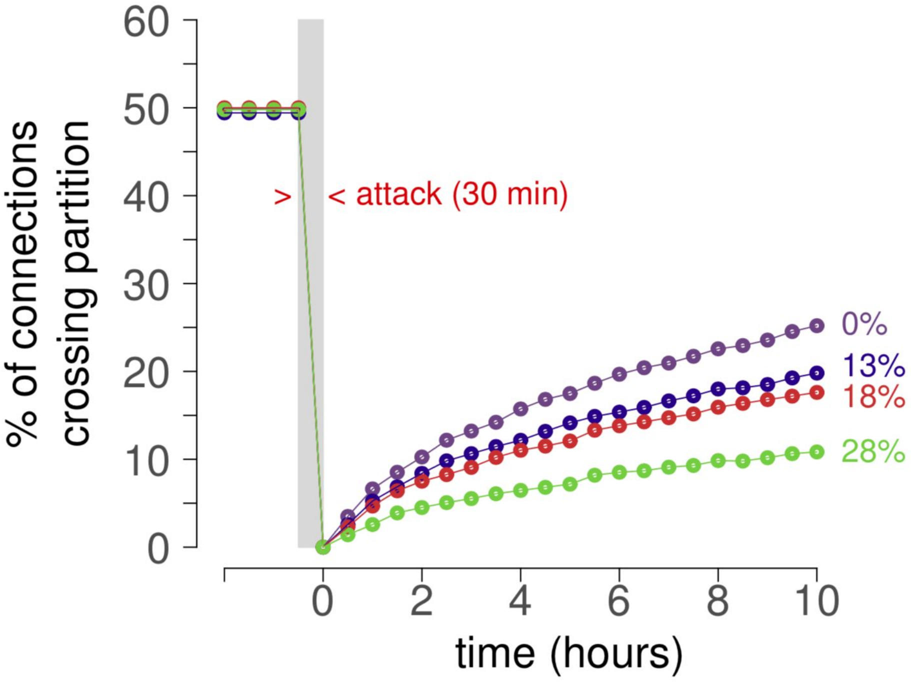
partitioning - recovery



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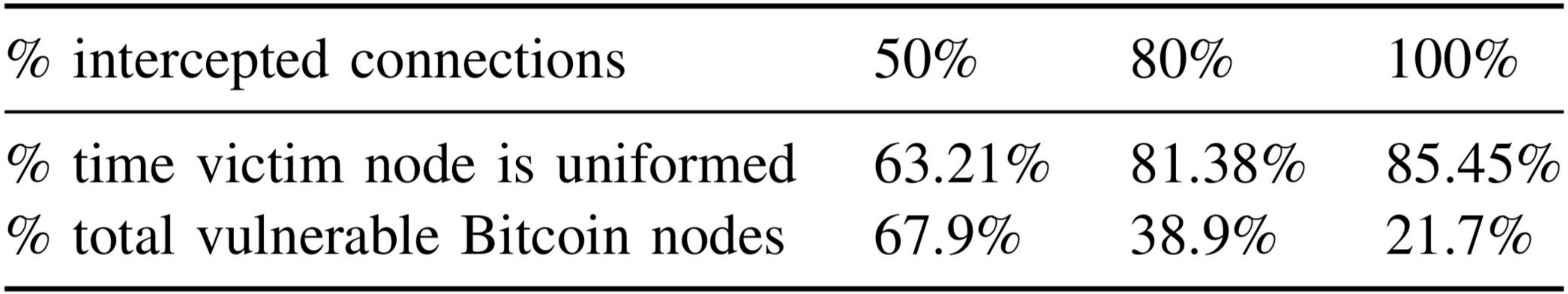
delay - impact (single node)



% intercepted connections	50%	80%	100%
% time victim node is uniformed	63.21%	81.38%	85.45%
% total vulnerable Bitcoin nodes	67.9%	38.9%	21.7%

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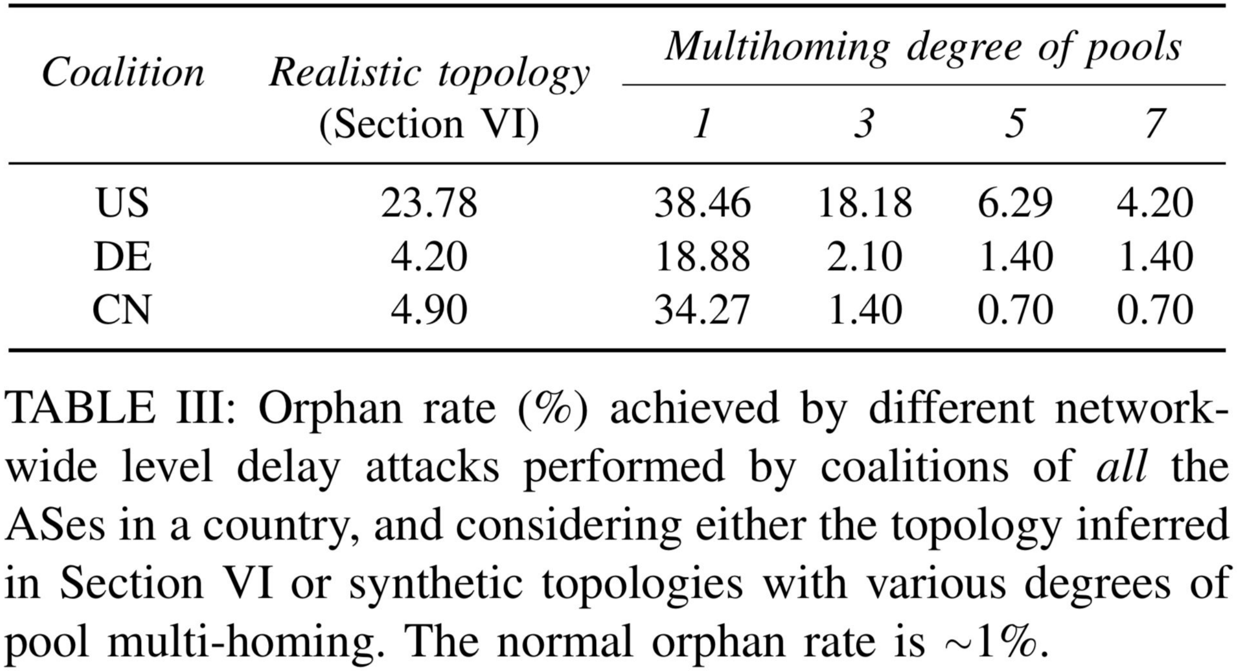
delay - impact (whole network)



Coalition	*Realistic topology* (Section VI)	*Multihoming degree of pools*			
		1	*3*	*5*	*7*
US	23.78	38.46	18.18	6.29	4.20
DE	4.20	18.88	2.10	1.40	1.40
CN	4.90	34.27	1.40	0.70	0.70

TABLE III: Orphan rate (%) achieved by different network-wide level delay attacks performed by coalitions of *all* the ASes in a country, and considering either the topology inferred in Section VI or synthetic topologies with various degrees of pool multi-homing. The normal orphan rate is ~1%.

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countermeasures (short-term)

- increase diversity of node connections
  - ➜ use multiple ASes (directly or through VPN)
- take routing into consideration when establishing connections
  - ➜ use traceroute, check BGP traffic
  - ➜ prevent a single AS from appearing in all paths
- monitor sudden change in round-trip time (RTT) and other anomalies
- prefer peers in same AS and in /24 prefixes

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countermeasures (long-term)

- use encryption and/or integrity checks (BIP-151)
- use port negotiation or randomized port
- use UDP heartbeats
- request blocks on multiple connections

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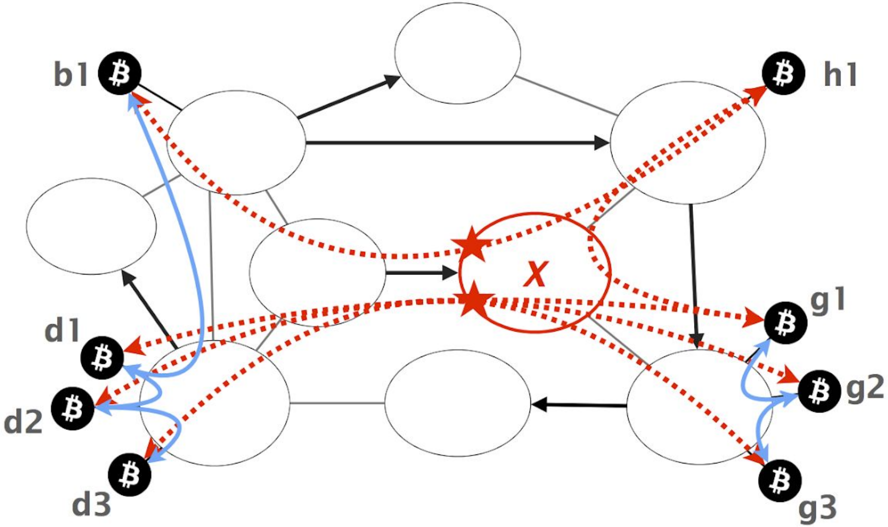
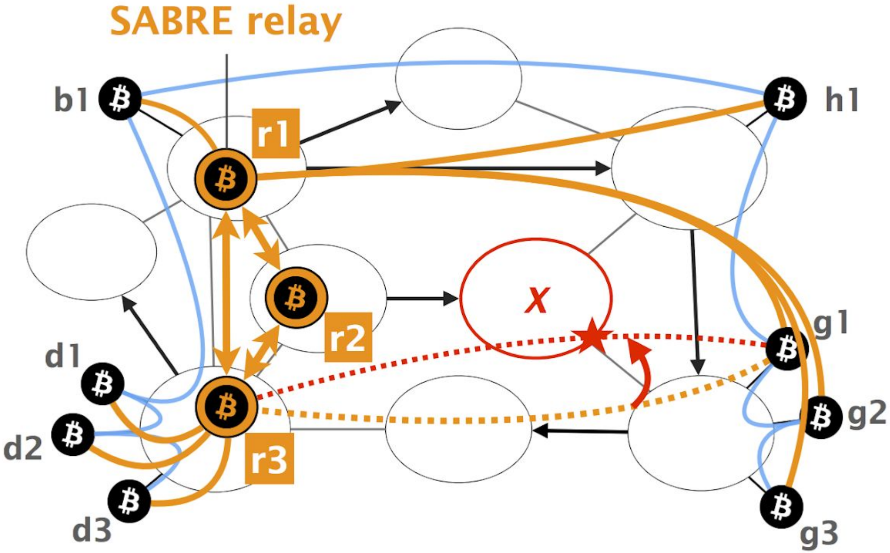
SABRE





Apostolaki, M., Marti, G., Müller, J., & Vanbever, L. (2018). SABRE: Protecting Bitcoin against Routing Attacks

references

Apostolaki, M., Zohar, A., & Vanbever, L. (2017). Hijacking Bitcoin: Routing Attacks on Cryptocurrencies
https://btc-hijack.ethz.ch/files/btc_hijack.pdf

Apostolaki, M., Marti, G., Müller, J., & Vanbever, L. (2018). SABRE: Protecting Bitcoin against Routing Attacks
https://arxiv.org/pdf/1808.06254