Hijacking Bitcoin

Routing Attacks on Cryptocurrencies

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ETH Zürich

Joint work with Aviv Zohar and Laurent Vanbever

Routing attacks quite often make the news

Russian-controlled telecom hijacks financial services' Internet traffic

Visa, MasterCard, and Symantec among dozens affected by "suspicious" BGP mishap.

DAN GOODIN - 4/27/2017, 10:20 PM

source: arstechnica.com

THREAT LEVEL

Hacker Redirects Traffic From 19 Internet Providers to Steal Bitcoins

BY ANDY GREENBERG 08.07.14 | 1:00 PM | PERMALINK

source: wired.com

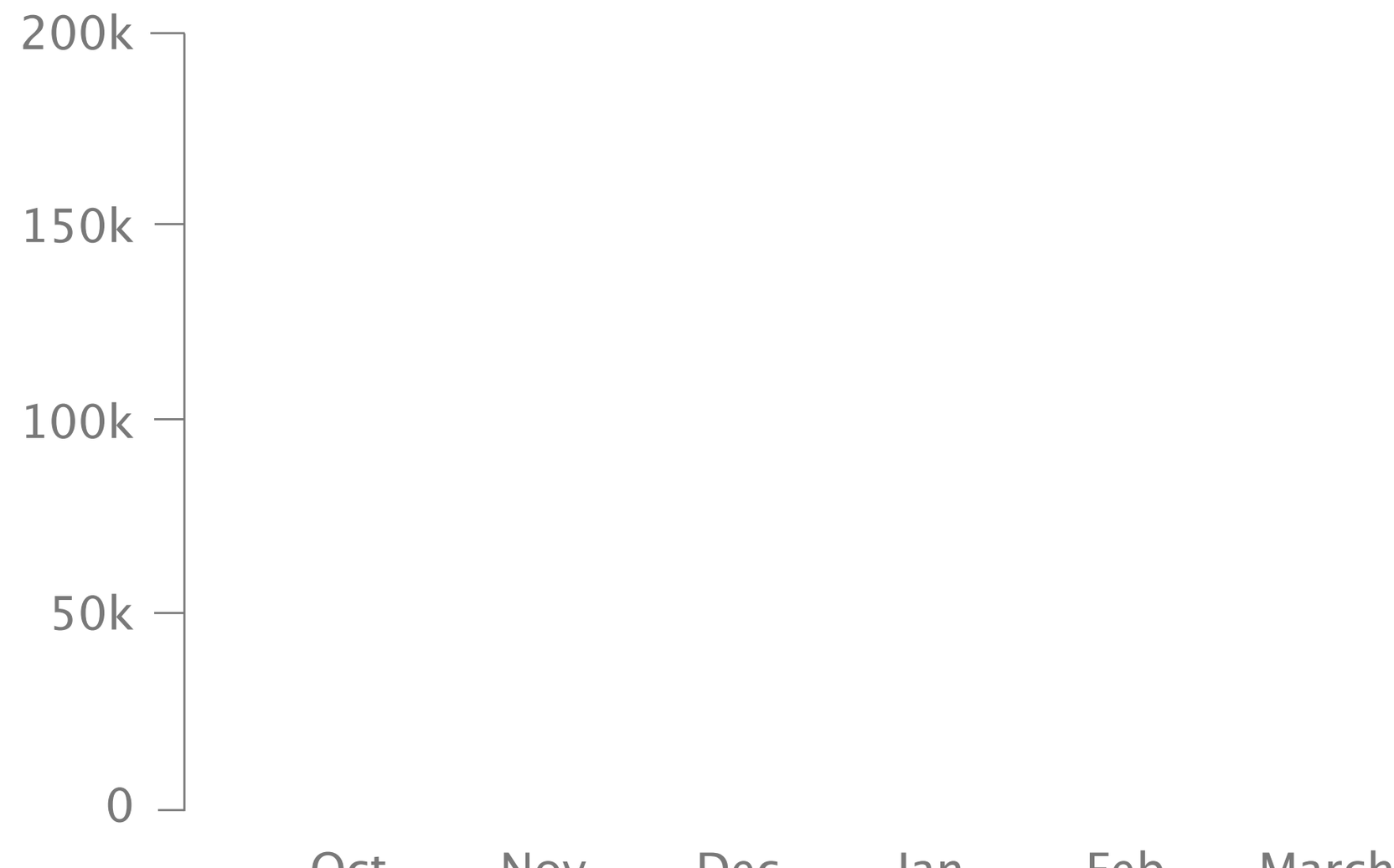
Security Blogwatch

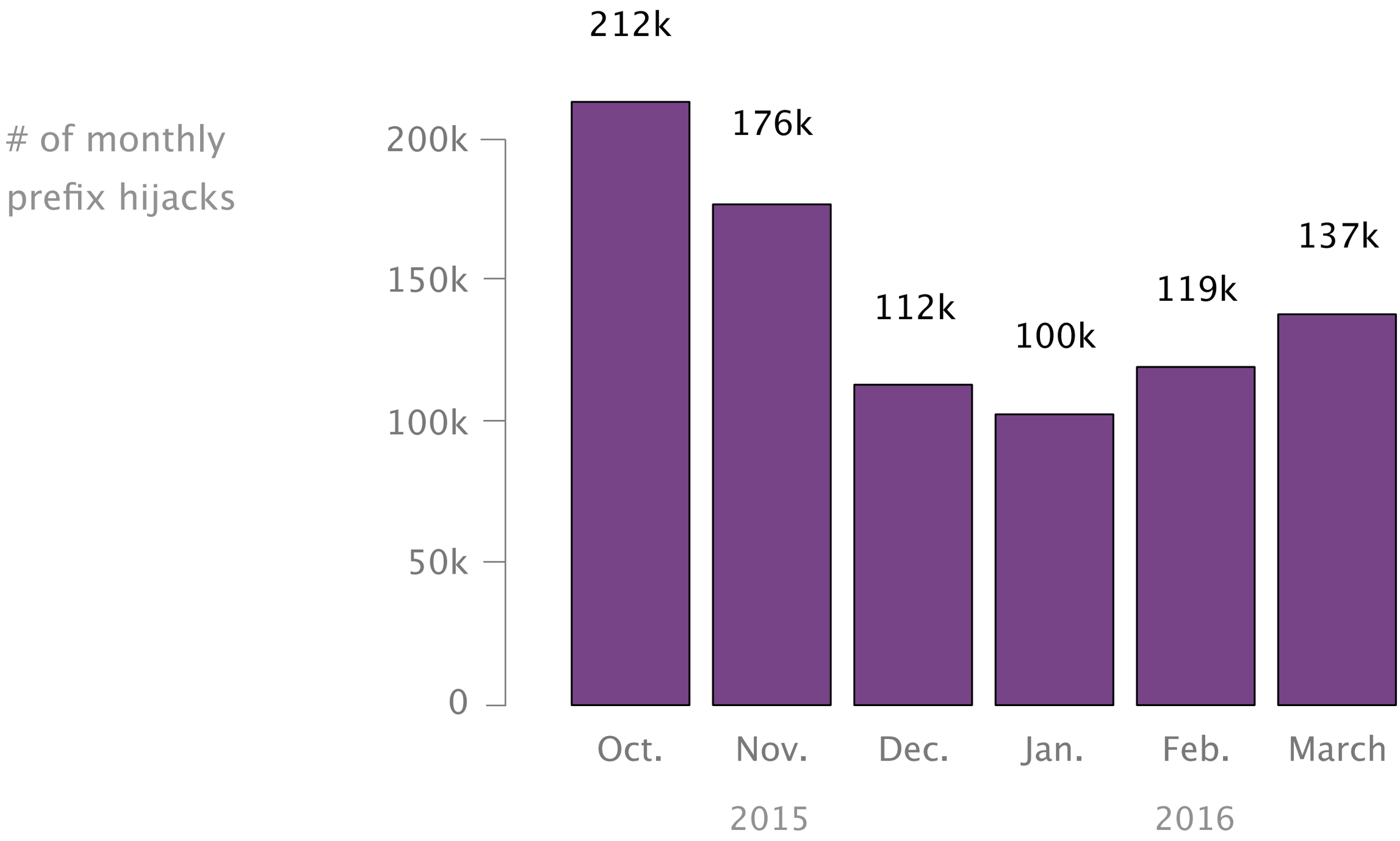
Apr 26, 2018

BGP hijack steals AWS IP range; cryptocurrency theft ensues

That is only the tip of the iceberg of routing manipulations

# of monthly prefix hijacks




# of monthly prefix hijacks
212k
176k
137k
112k
100k
119k
200k
150k
100k
50k
0
Oct.
Nov.
Dec.
Jan.
Feb.
March
2015
2016

Methodology

- 3 RIPE BGP collectors
- different origin from that seen during the previous month
- exclude prefixes with multiple origin ASes

Can routing attacks impact Bitcoin?

Bitcoin is highly decentralized

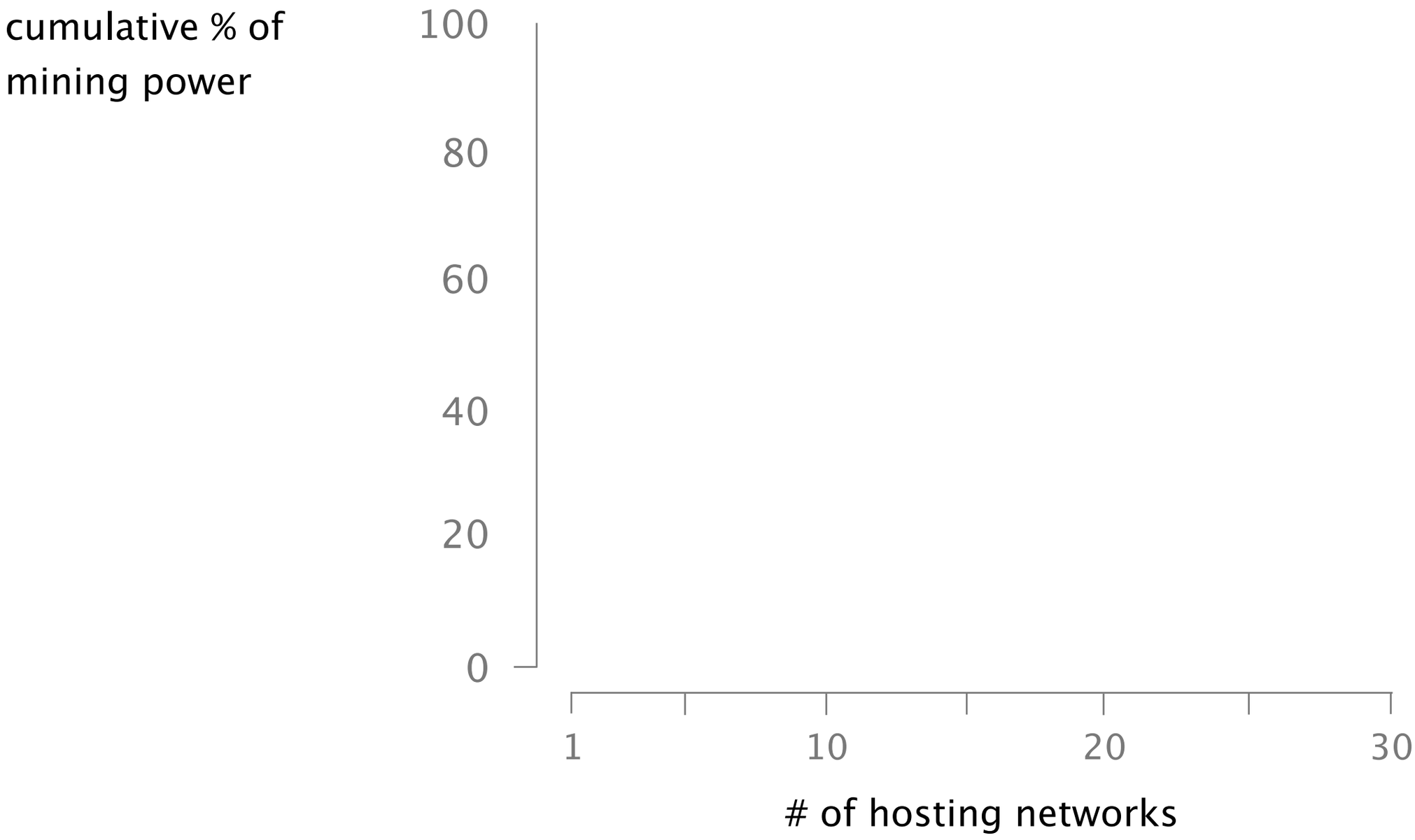
making it robust to routing attacks, in theory…

Bitcoin nodes …

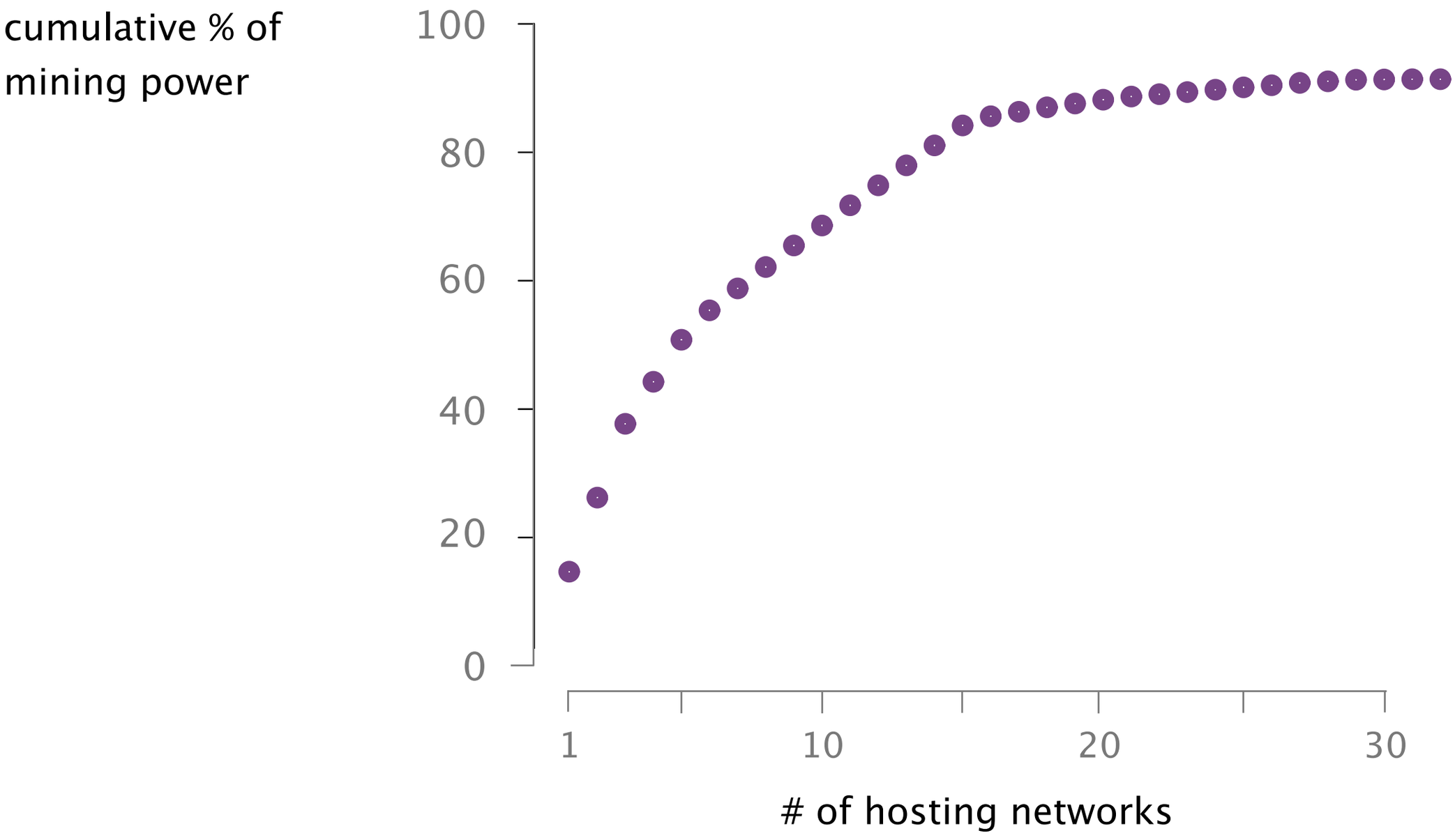
- are scattered all around the globe
- establish random connections
- use multihoming and extra relay networks

In practice, Bitcoin is highly centralized,

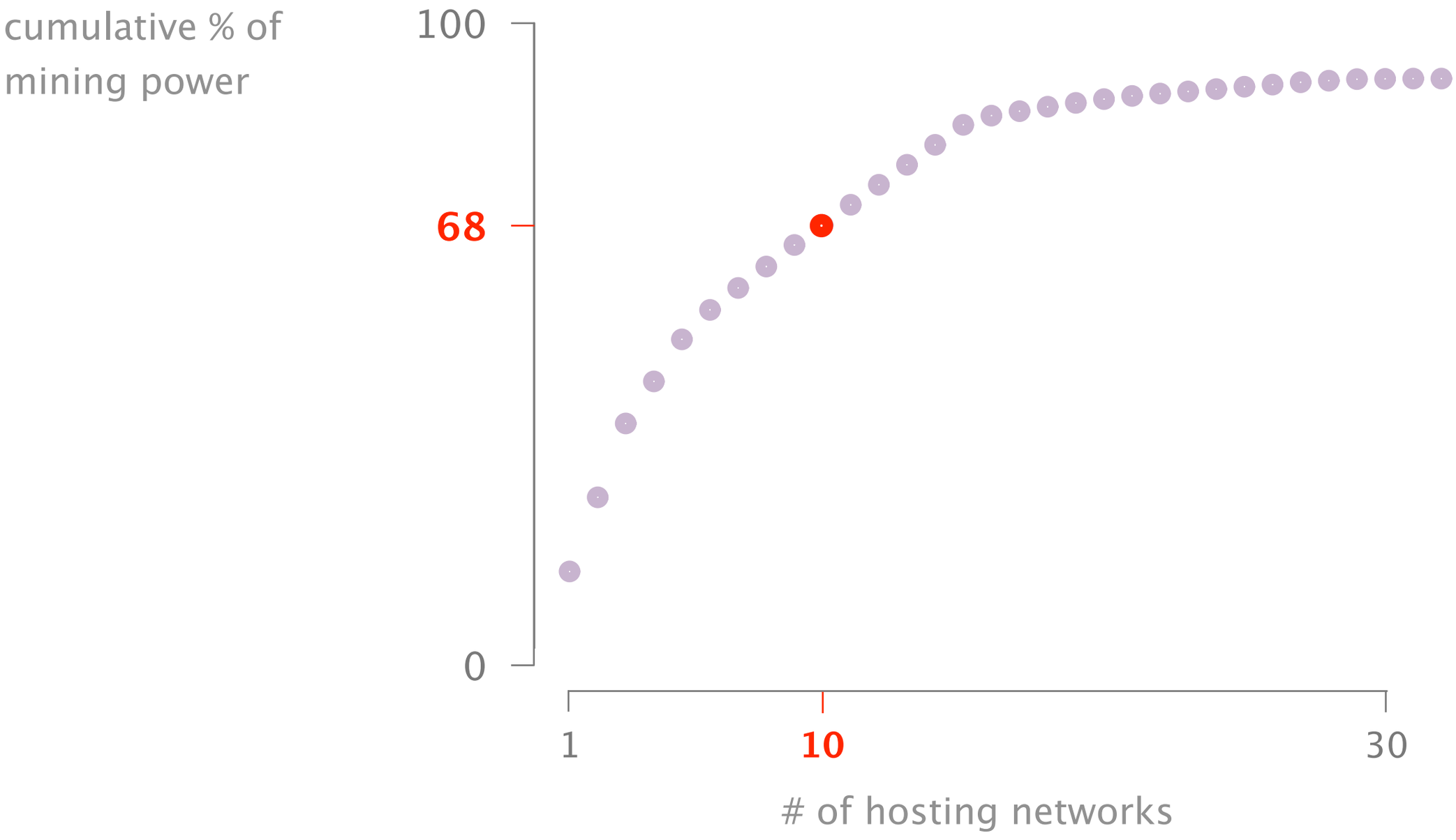
both from a routing and mining viewpoint

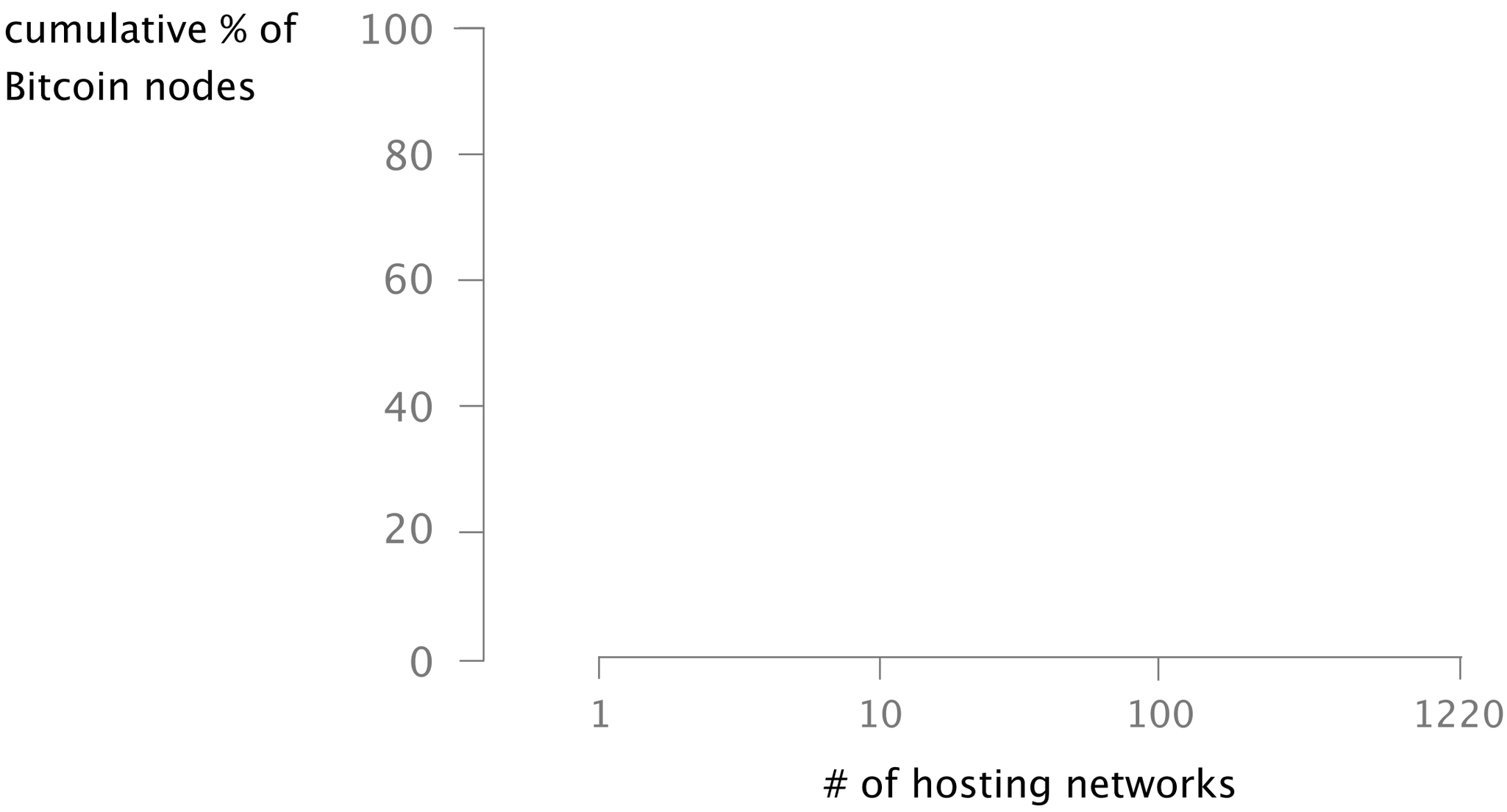

cumulative % of mining power
100
80
60
40
20
0
1
10
20
30
# of hosting networks

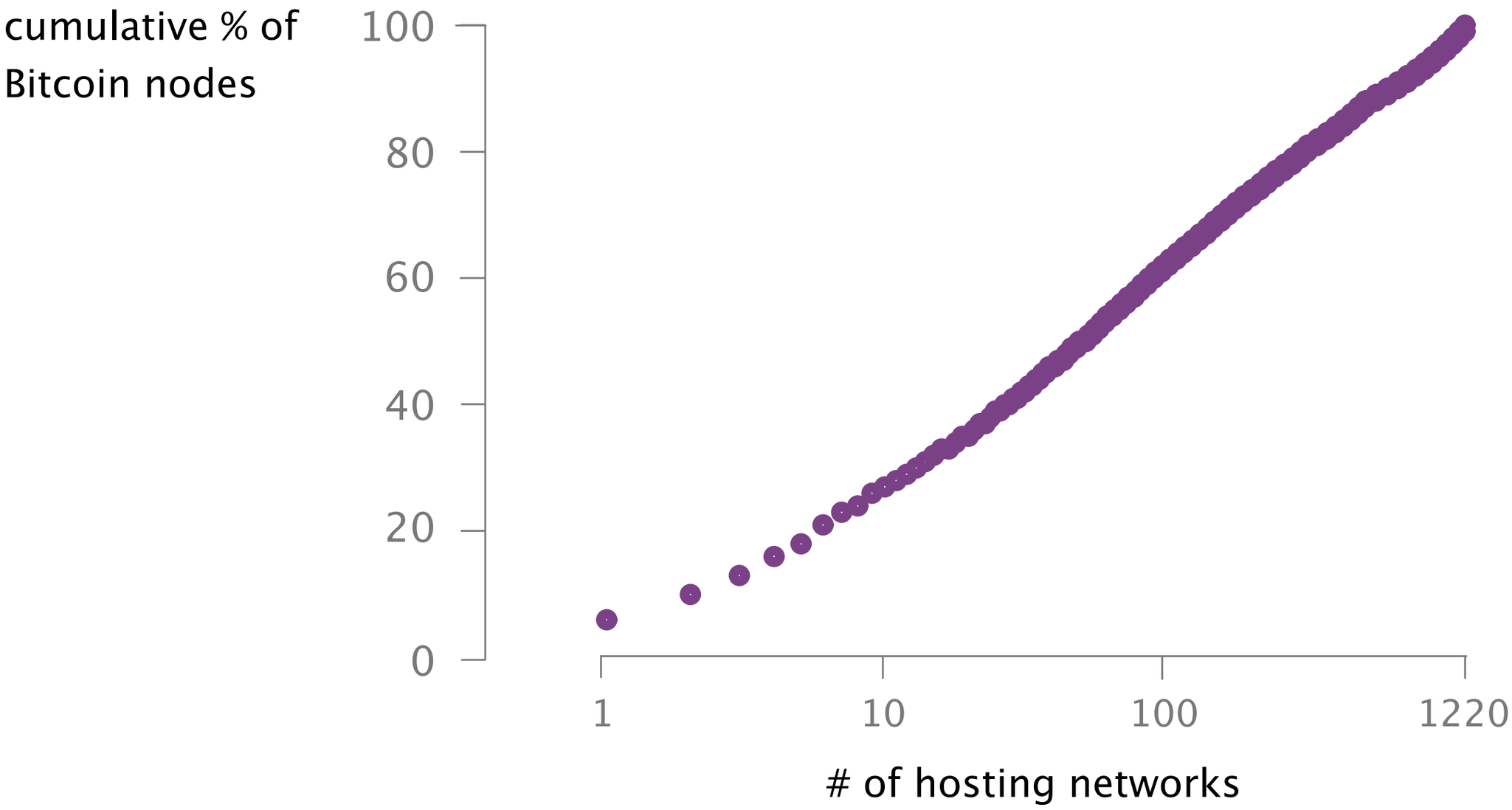
Mining power is centralized to few hosting networks



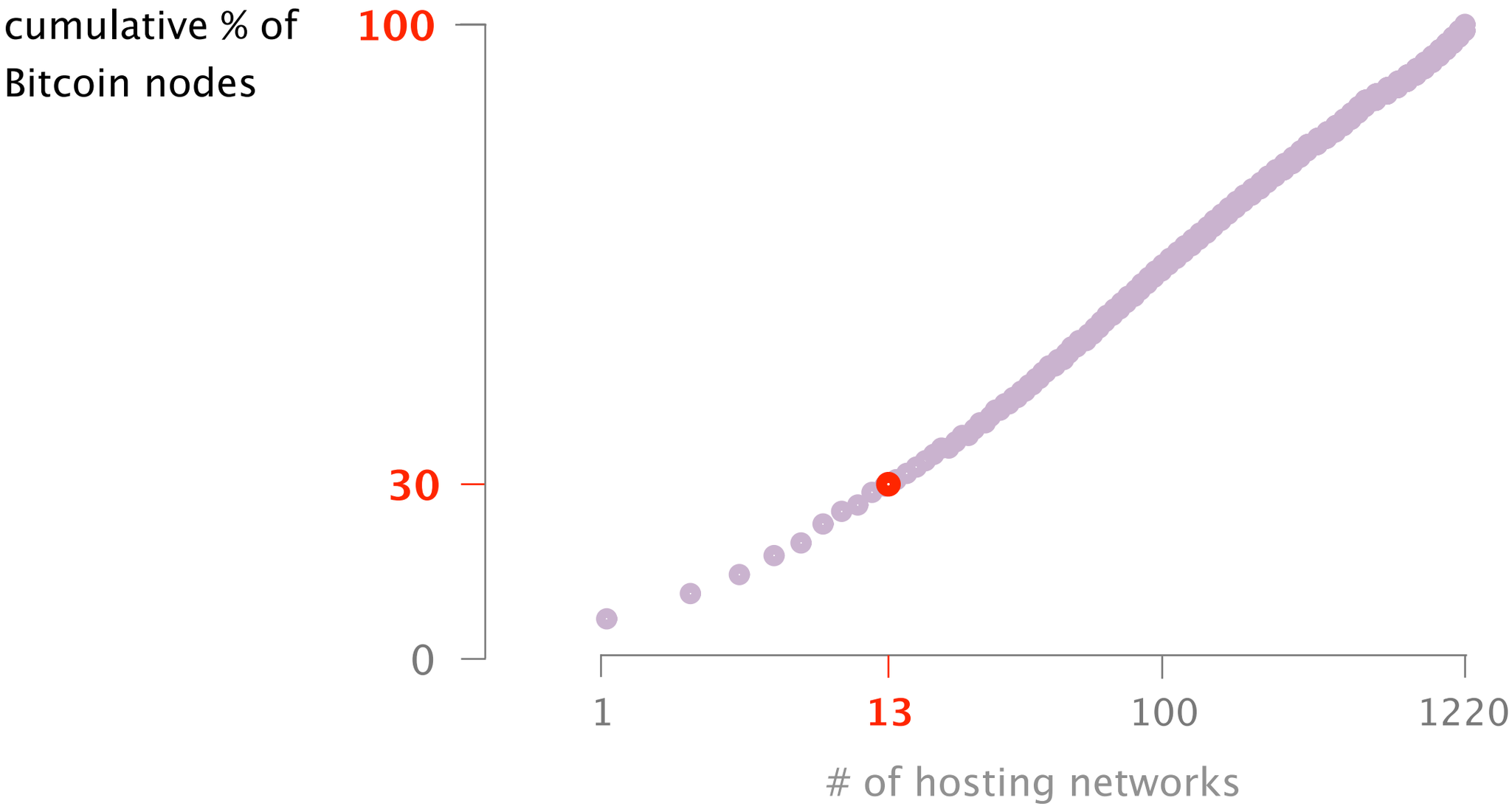
68% of the mining power is hosted in 10 networks only

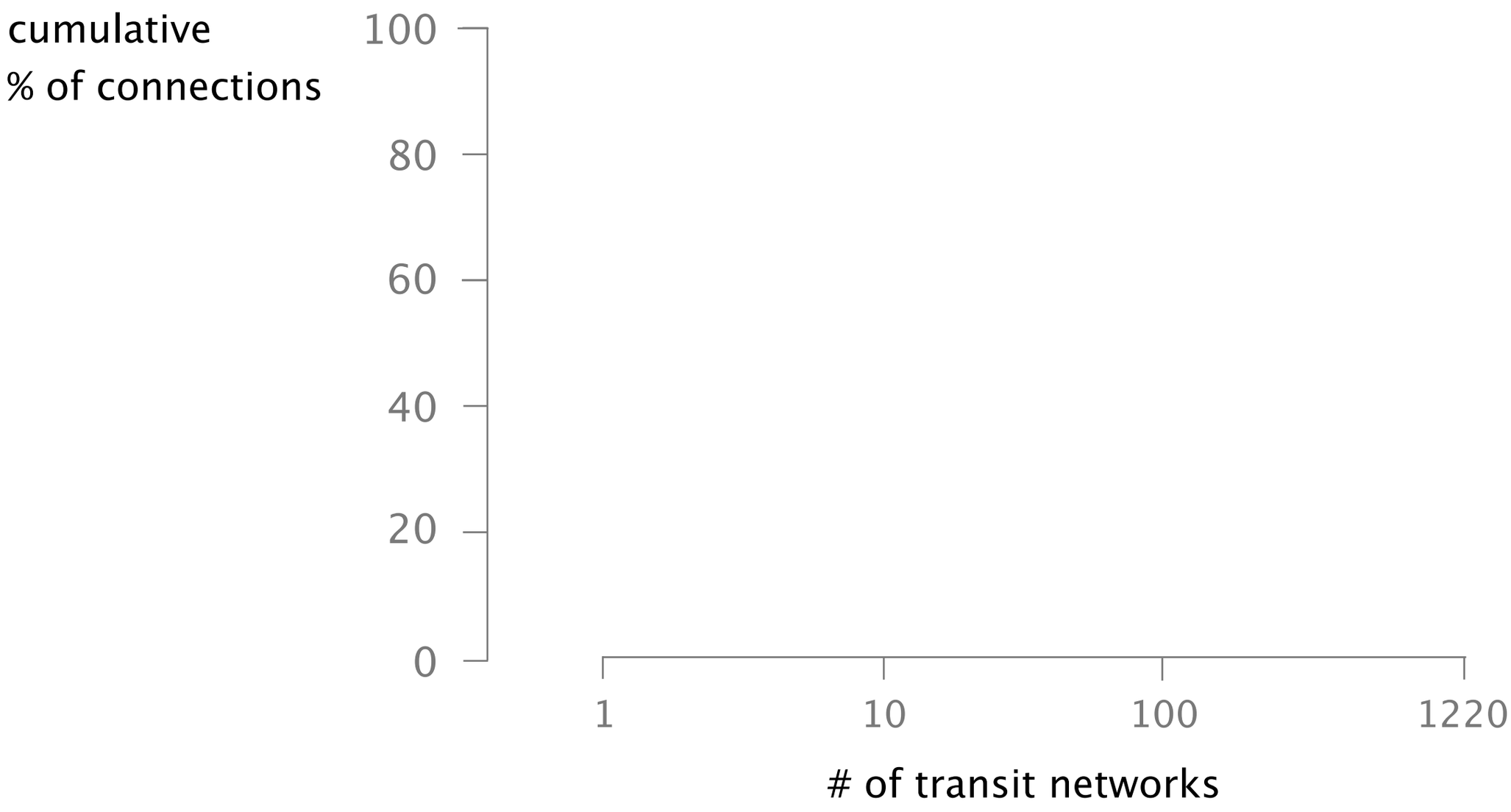



cumulative % of Bitcoin nodes
100
80
60
40
20
0
1
10
100
1220
# of hosting networks

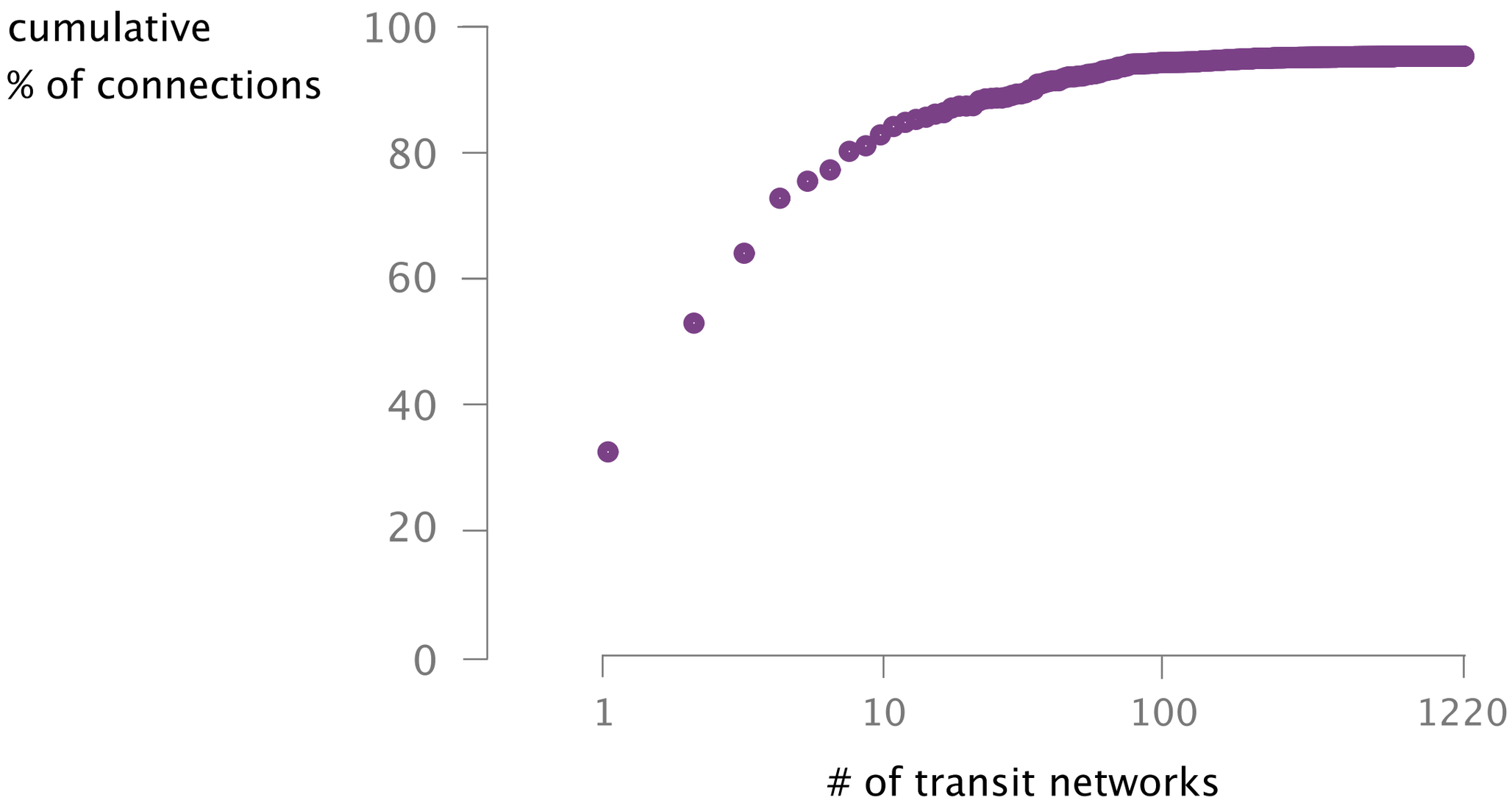

cumulative % of
Bitcoin nodes
100
80
60
40
20
0
1
10
100
1220
# of hosting networks

13 networks host **30% of all the nodes**

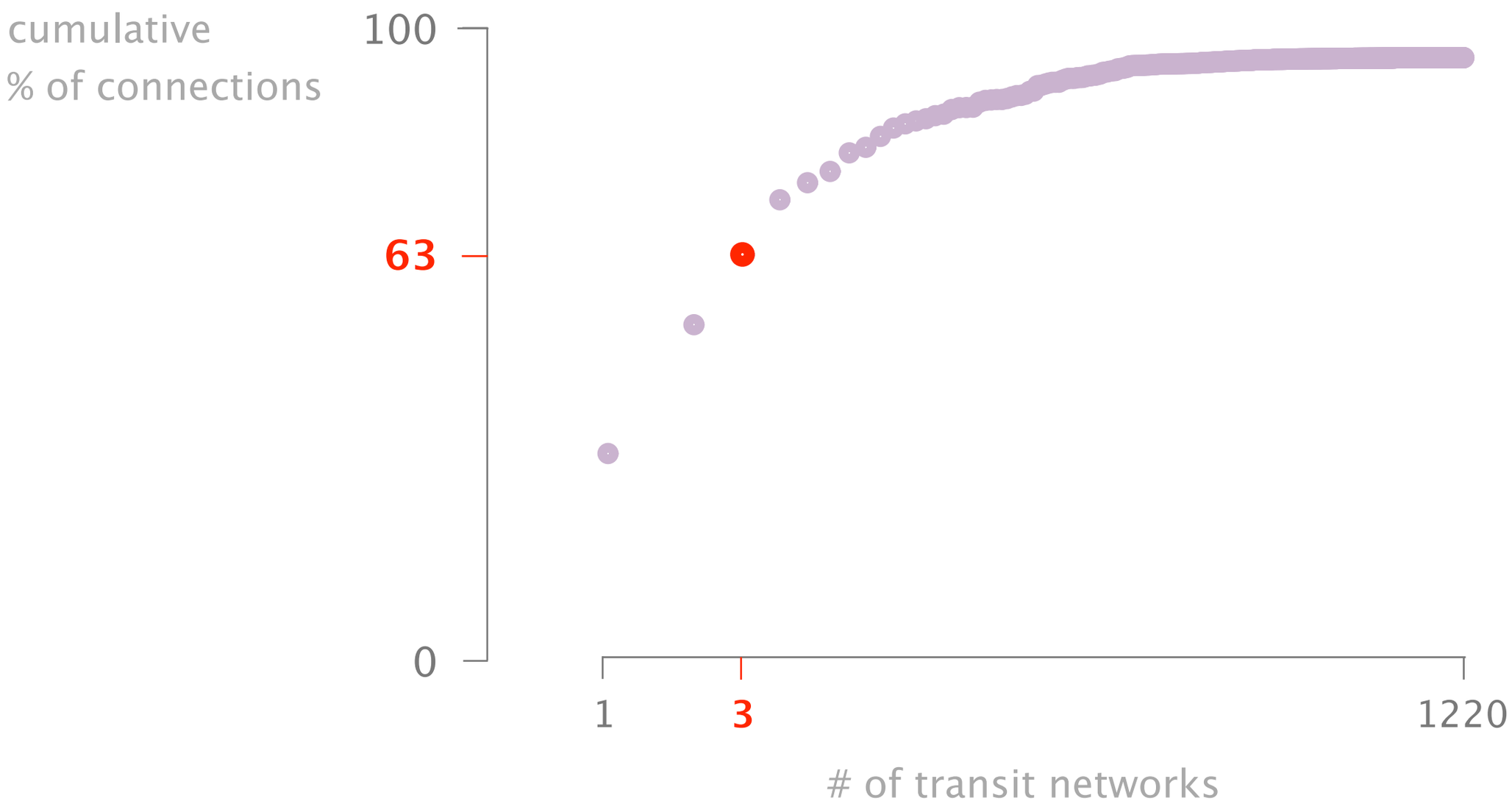



cumulative
% of connections
100
80
60
40
20
0
1
10
100
1220
# of transit networks

Likewise, a few transit networks can intercept a large fraction of the Bitcoin connections



3 transit networks see more than 60% of all connections



Because of these characteristics two routing attacks practical and effective today

Attack 1	Attack 2
Partitioning	Delay
Split the network in half	Delay block propagation

Each attack differs in terms of its visibility, impact, and targets

Attack 1

Partitioning

visible

network-wide attack

Attack 2

Delay

invisible

targeted attack (set of nodes)

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Attack 1

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targeted attack (set of nodes)

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Routing Attacks on Cryptocurrencies

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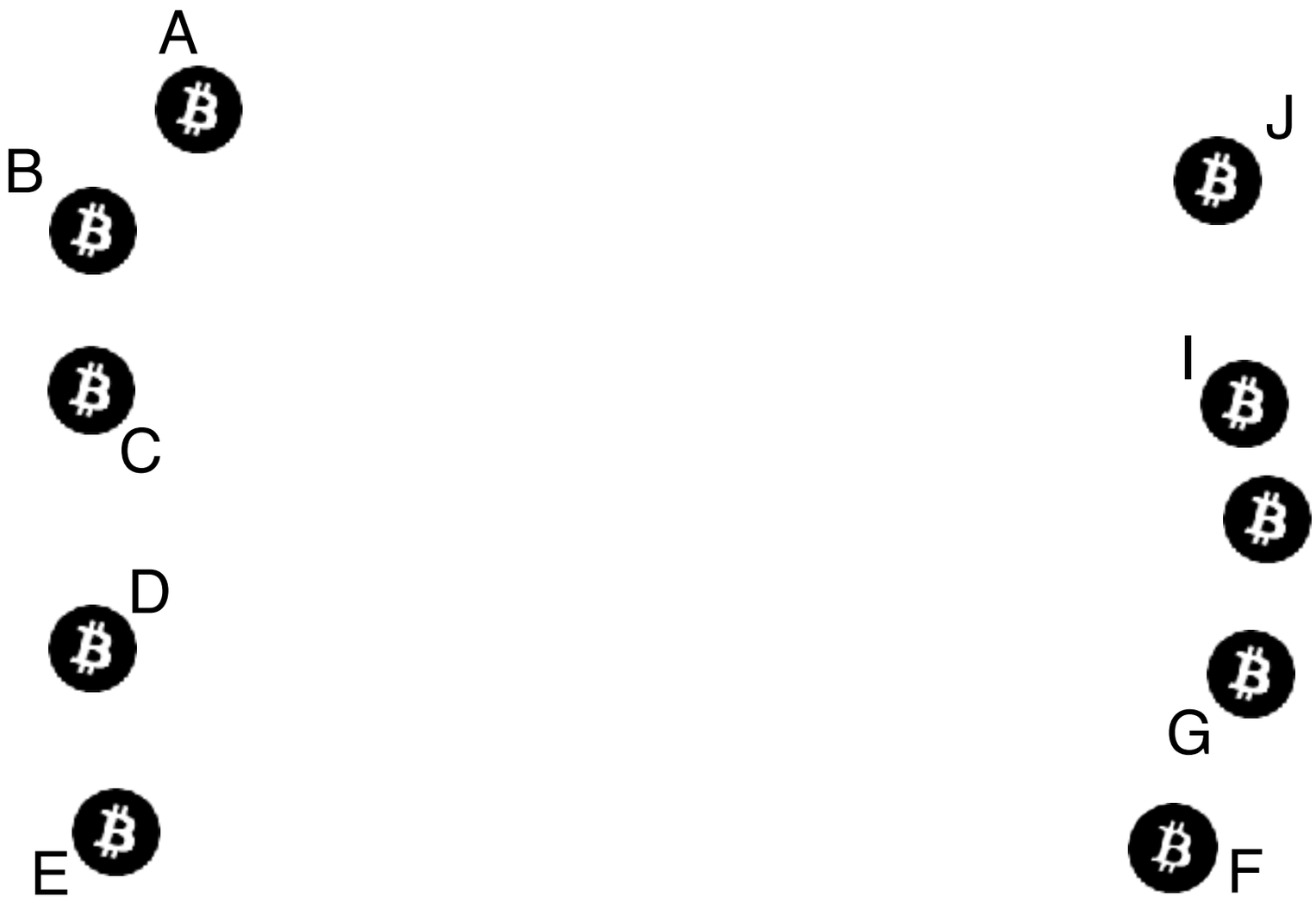
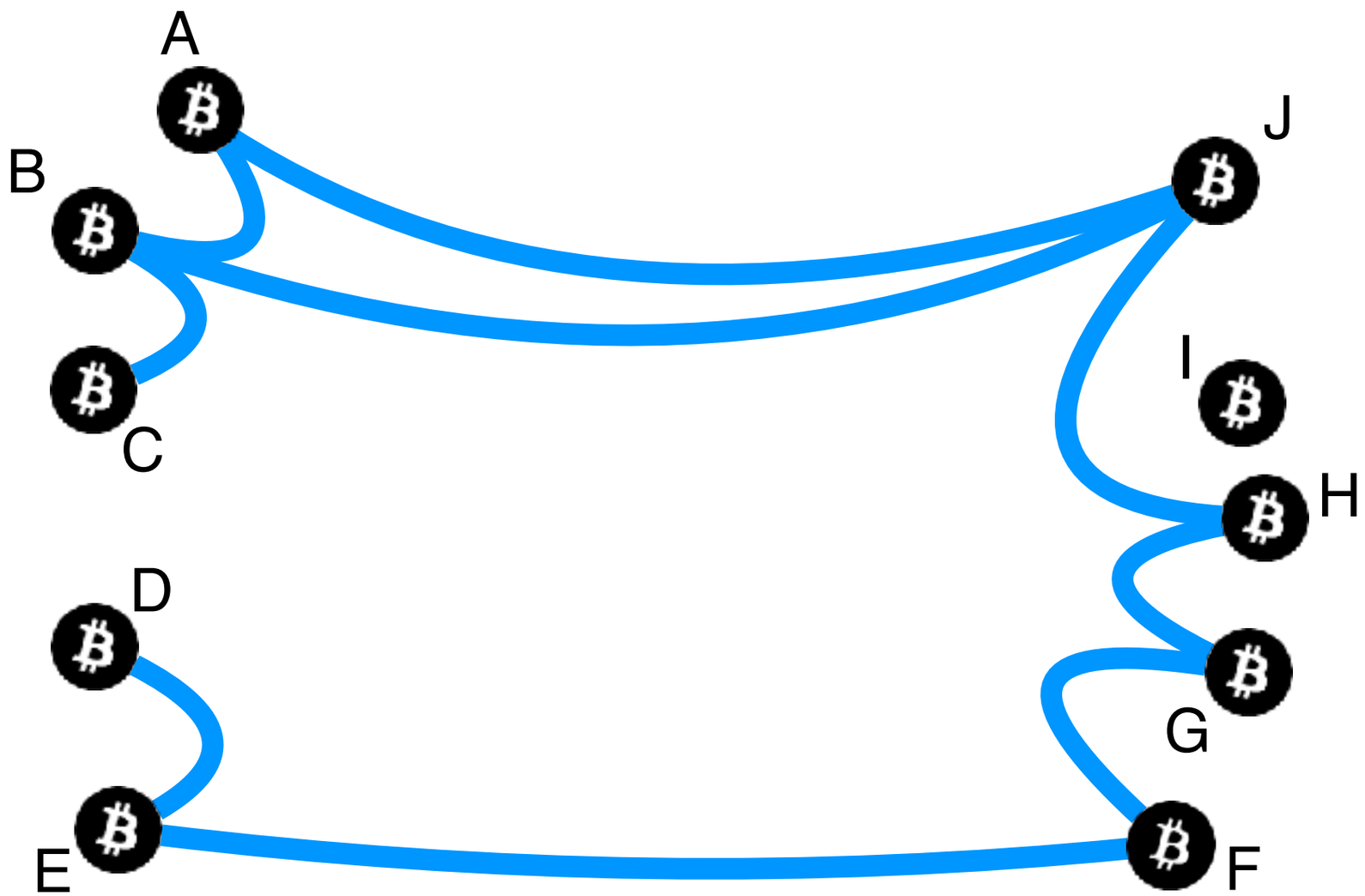
Bitcoin is a distributed network of nodes



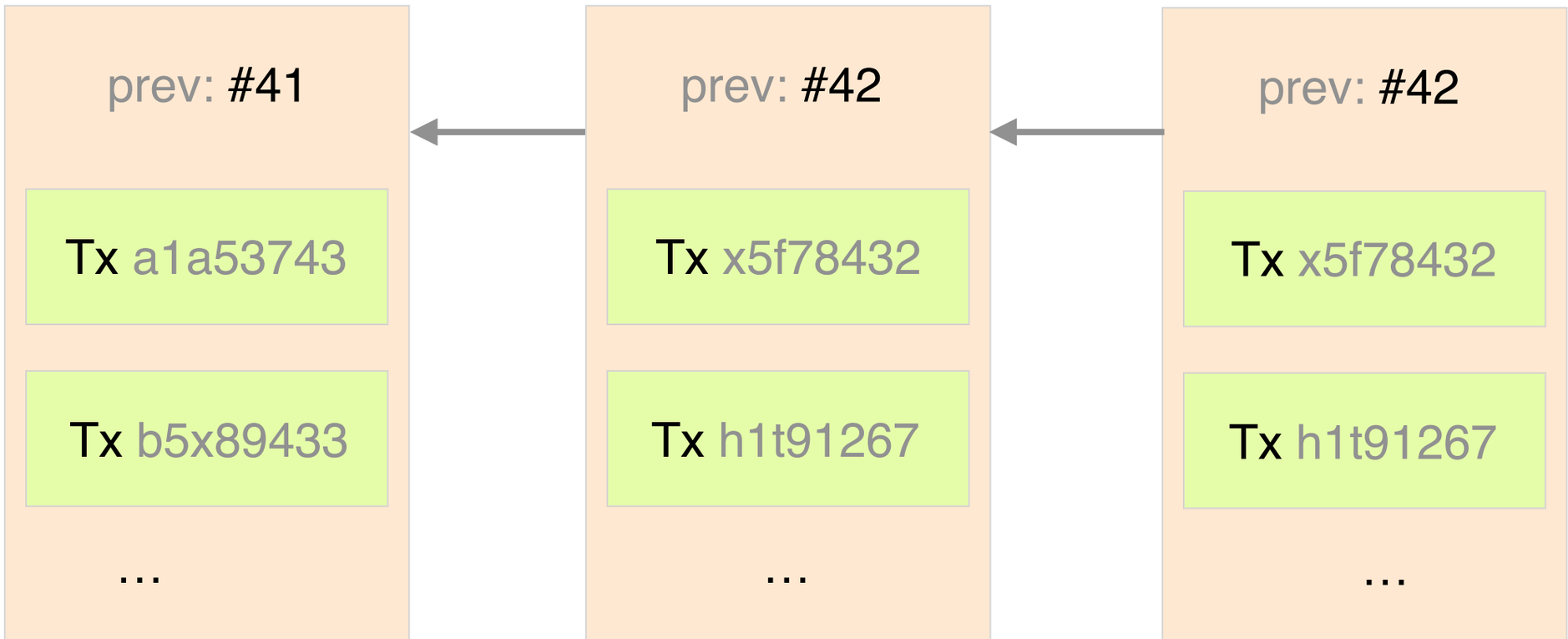
Bitcoin nodes establish random connections between each other



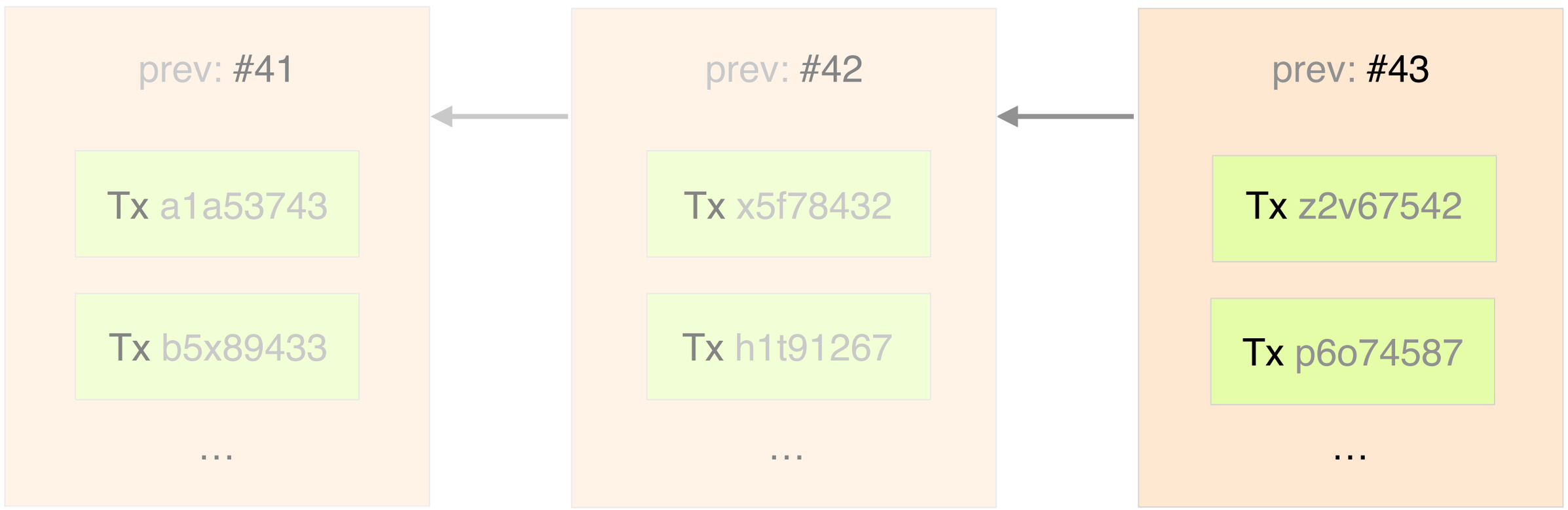
Each node keeps a ledger of all transactions ever performed: “the blockchain”

Tx a1a53743	Tx x5f78432	Tx x5f78432
Tx b5x89433	Tx h1t91267	Tx h1t91267
…	…	…

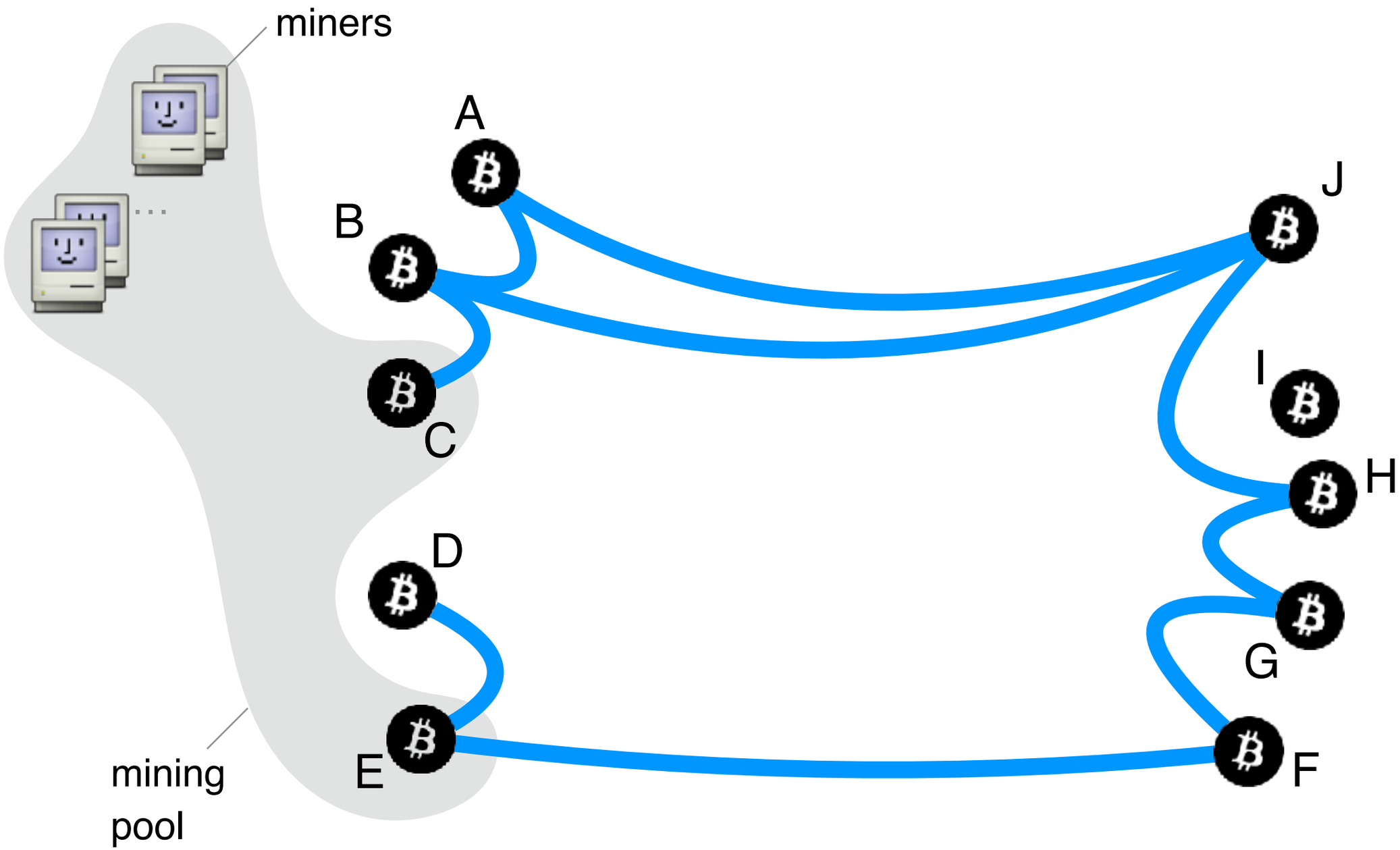
The Blockchain is a chain of Blocks



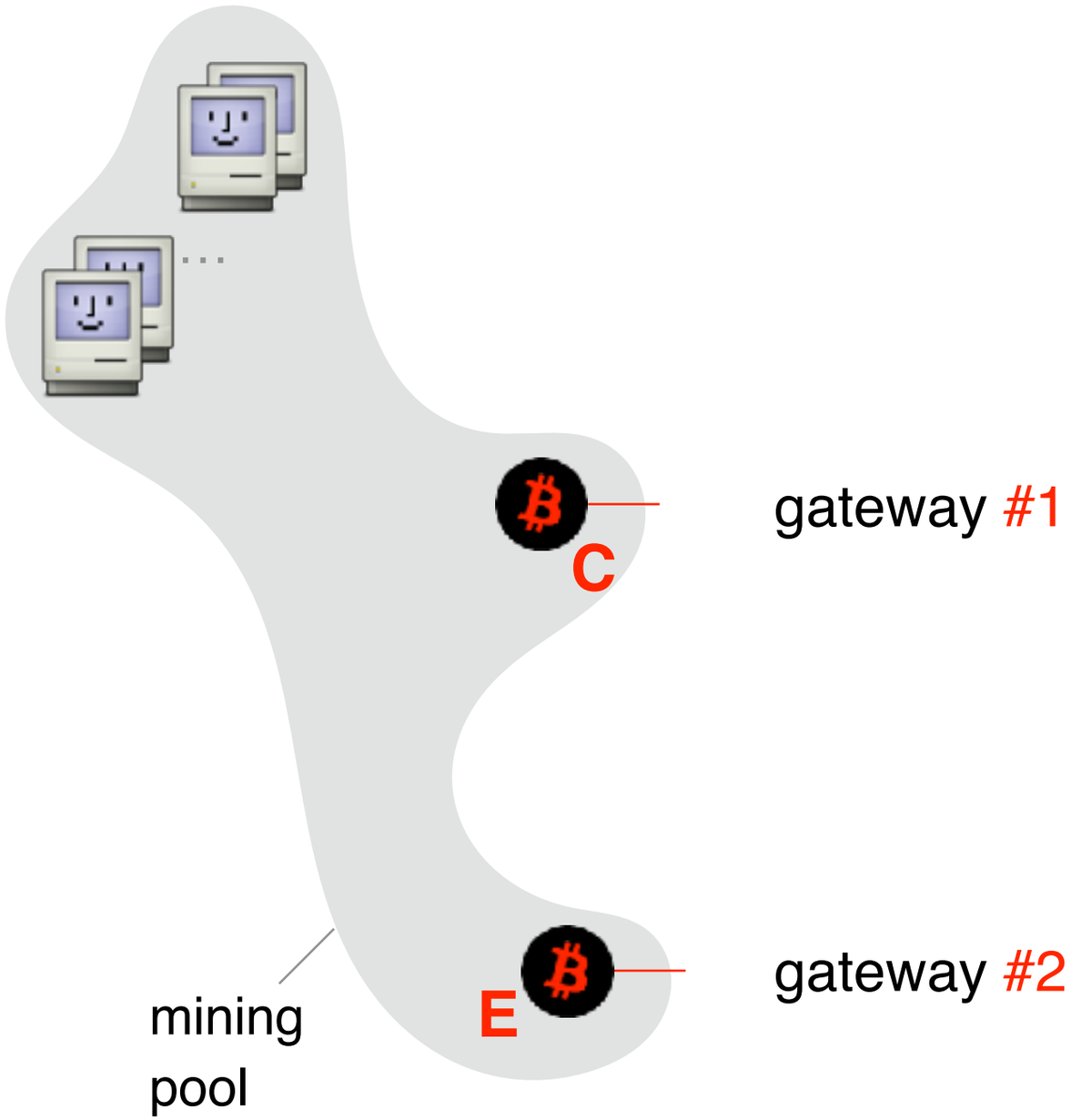
The Blockchain is extended by miners



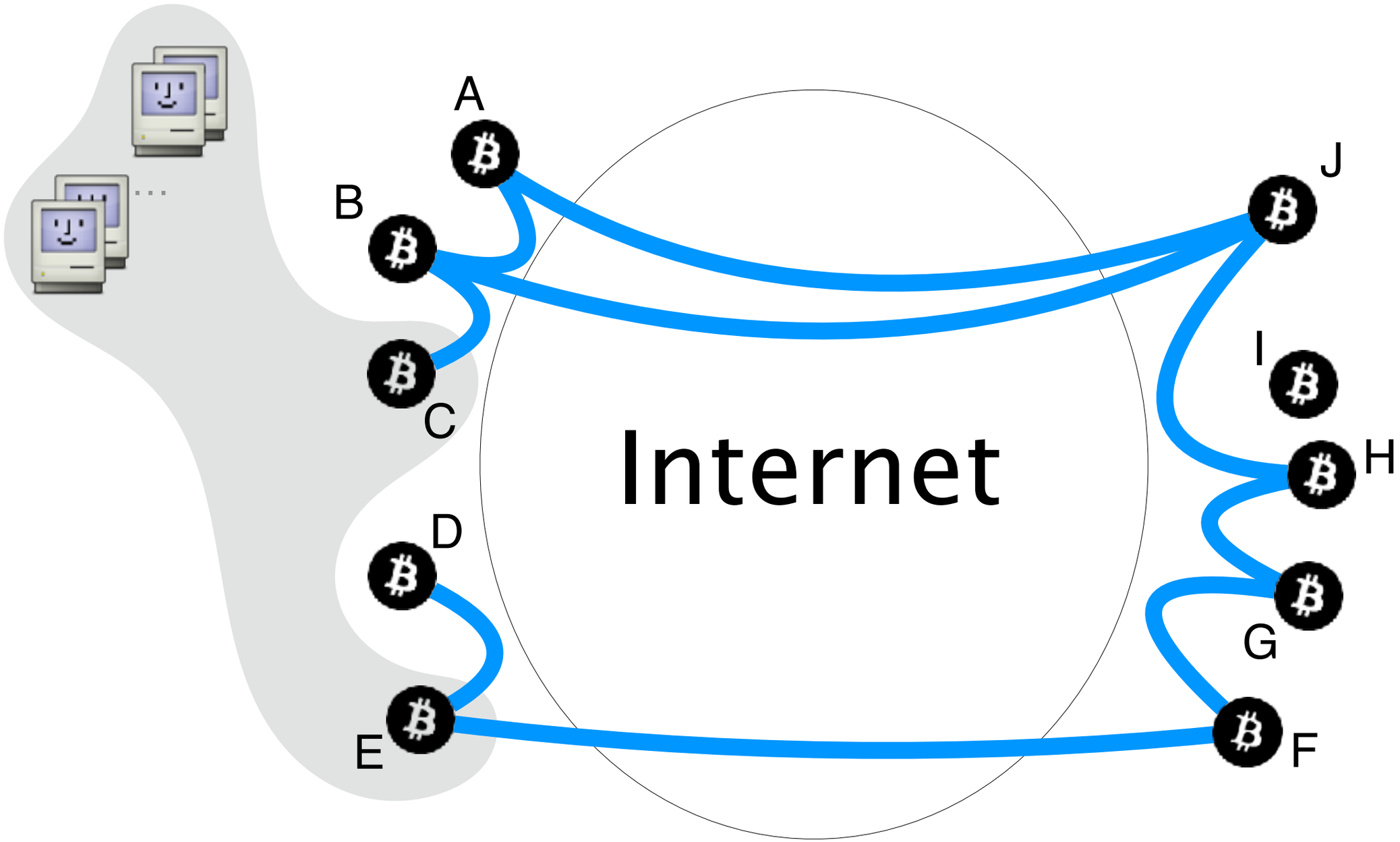
Miners are grouped in mining pools



Mining pools connect to the Bitcoin network through multiple gateways

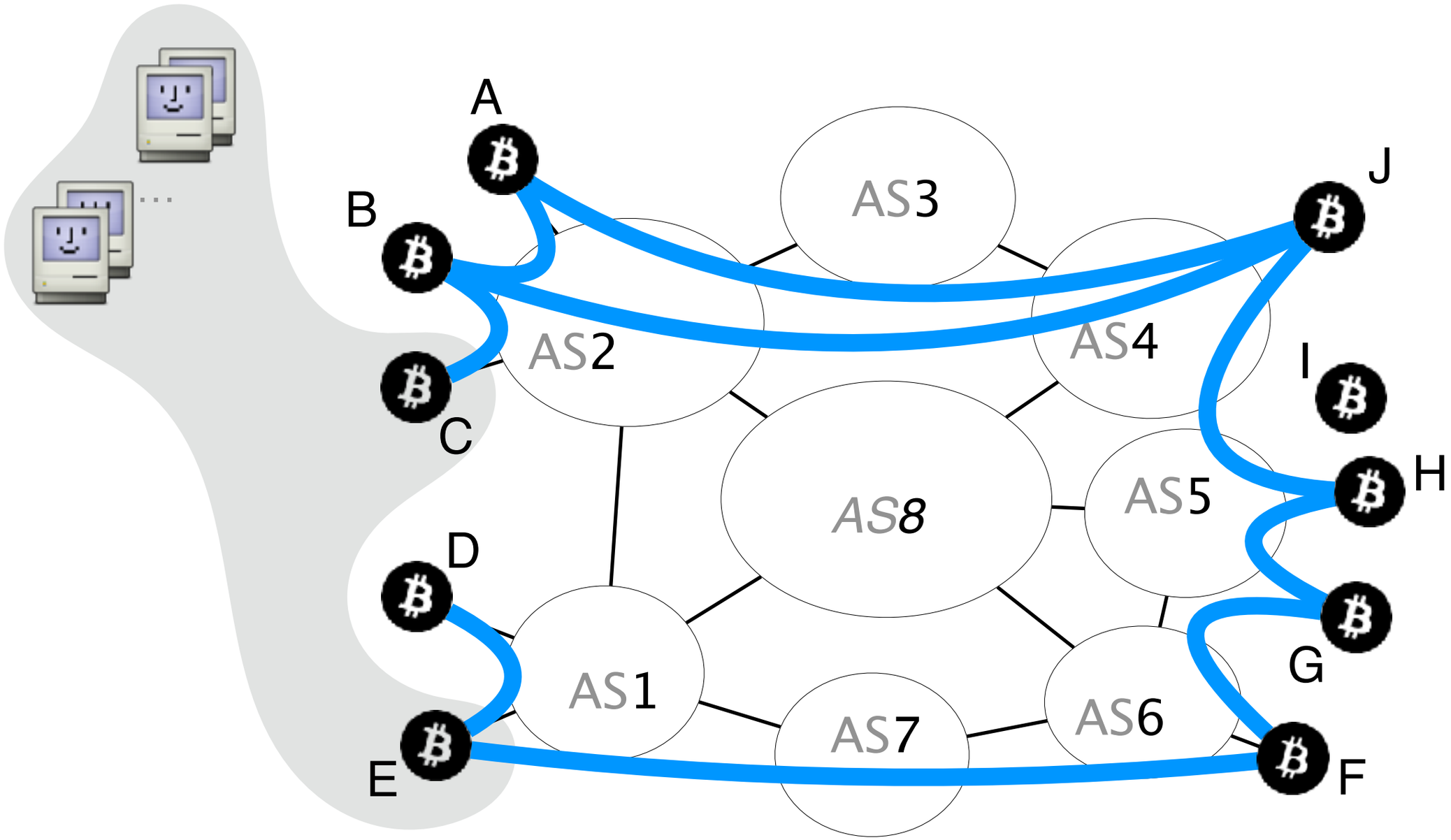


Bitcoin connections are routed over the Internet

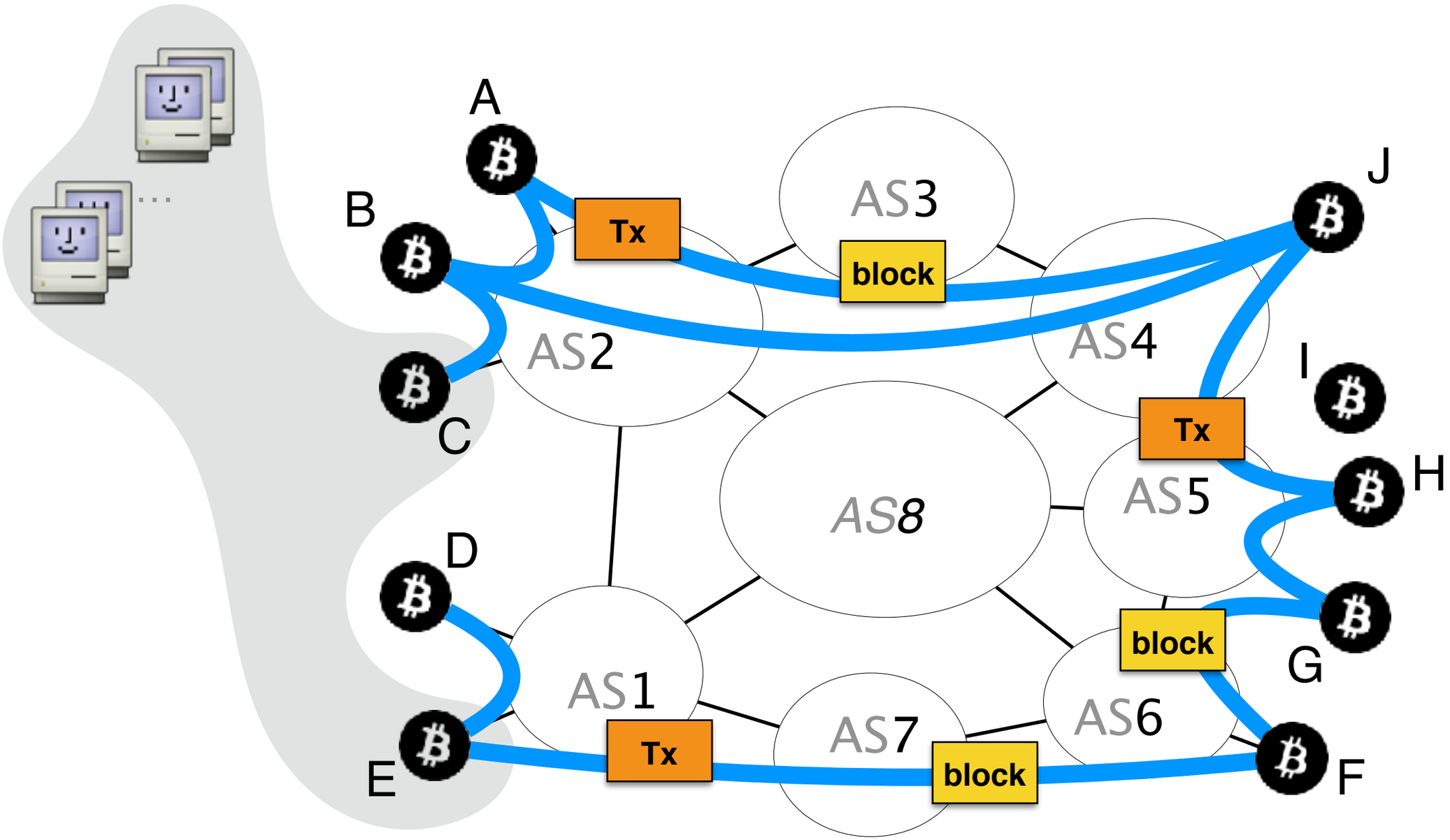


The Internet is composed of Autonomous Systems (ASes).

BGP computes the forwarding path across them



Bitcoin messages are propagated unencrypted and without any integrity guarantees



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Routing Attacks on Cryptocurrencies

Background

BGP & Bitcoin

2 Partitioning attack

splitting the network

Delay attack

slowing the network down

Countermeasures

short-term & long-term

The goal of a partitioning attack is to split
the Bitcoin network into two disjoint components

The impact of such an attack is worrying

Denial of Service

Revenue Loss

Double spending

The impact of such an attack is worrying

Denial of Service

Bitcoin clients and wallets cannot secure or propagate transactions

Revenue Loss

Double spending

The impact of such an attack is worrying

Denial of Service

Revenue Loss

Blocks in component with

less mining power are discarded

Double spending

The impact of such an attack is worrying

Denial of Service

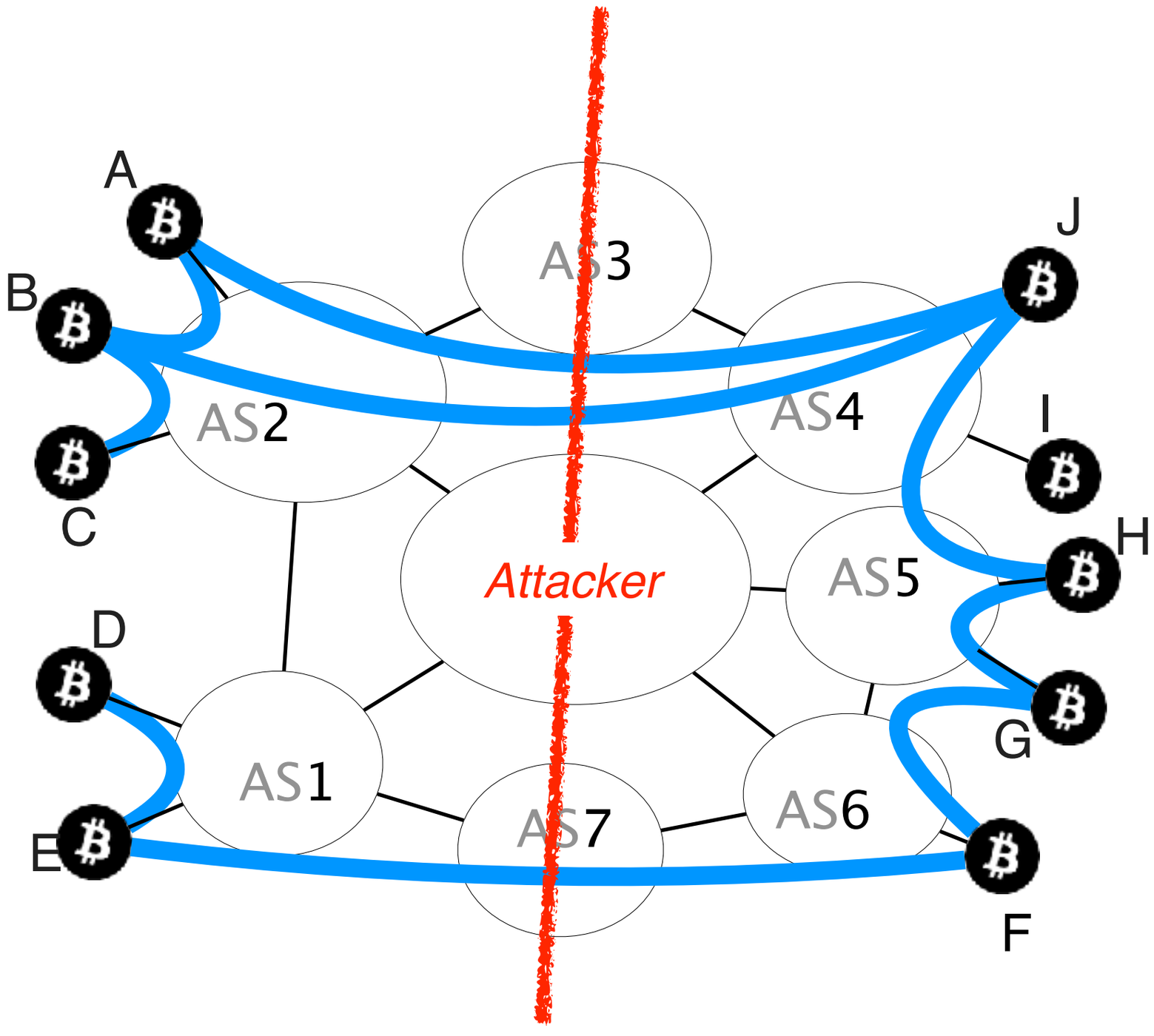
Revenue Loss

Double spending

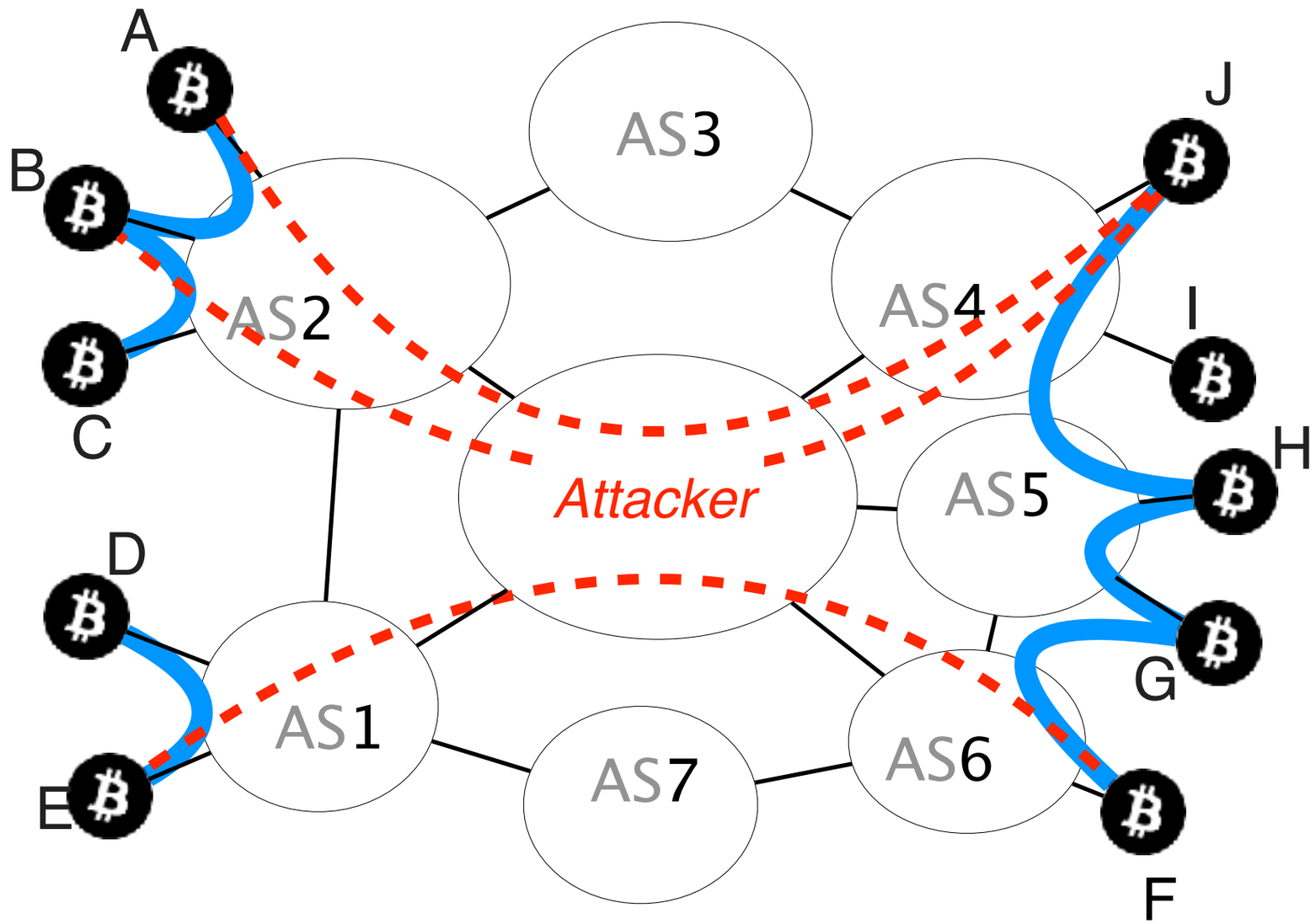
Transactions in components with less mining power can be reverted

How does the attack work?

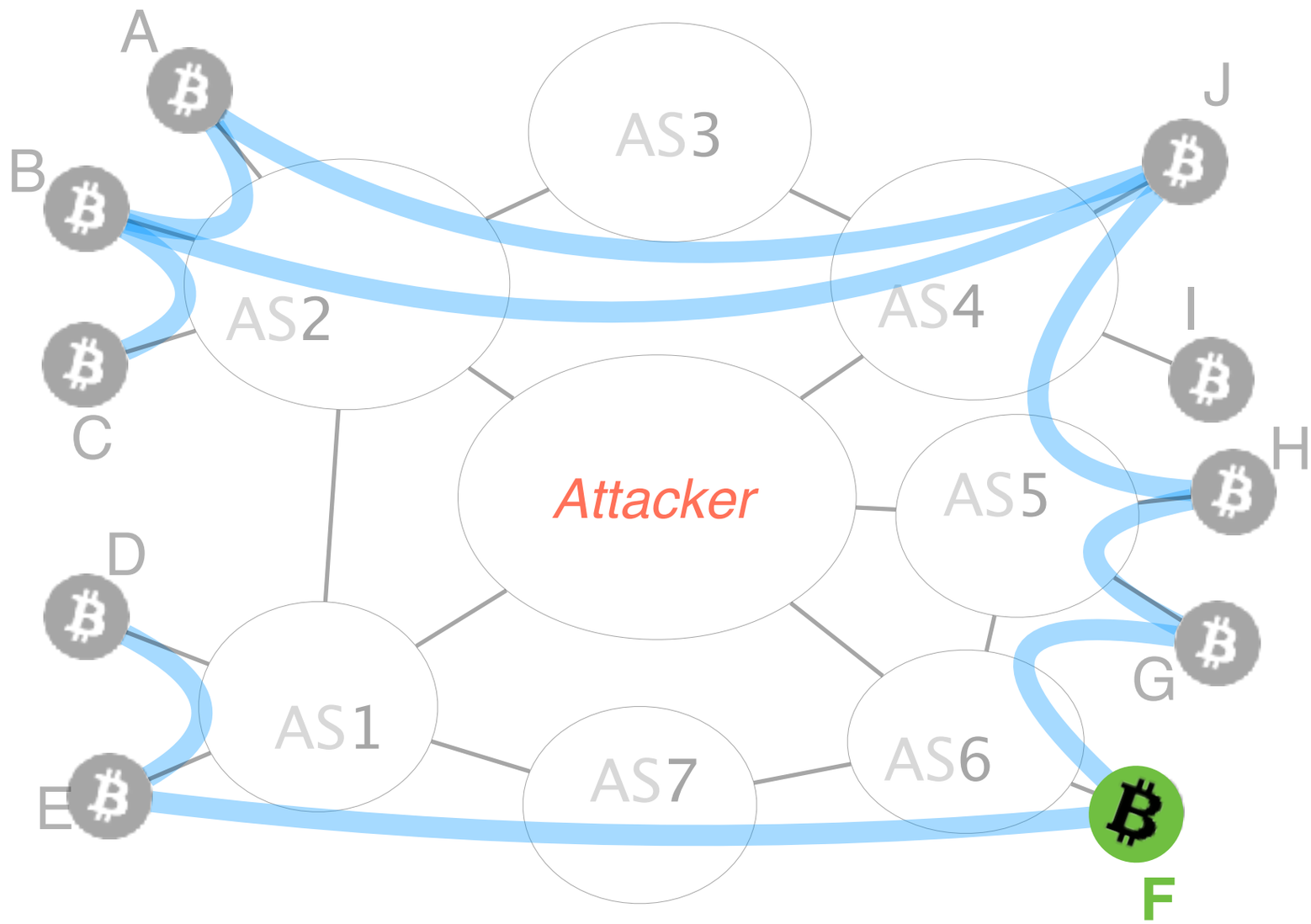
Let’s say an attacker wants to partition the network into the left and right side



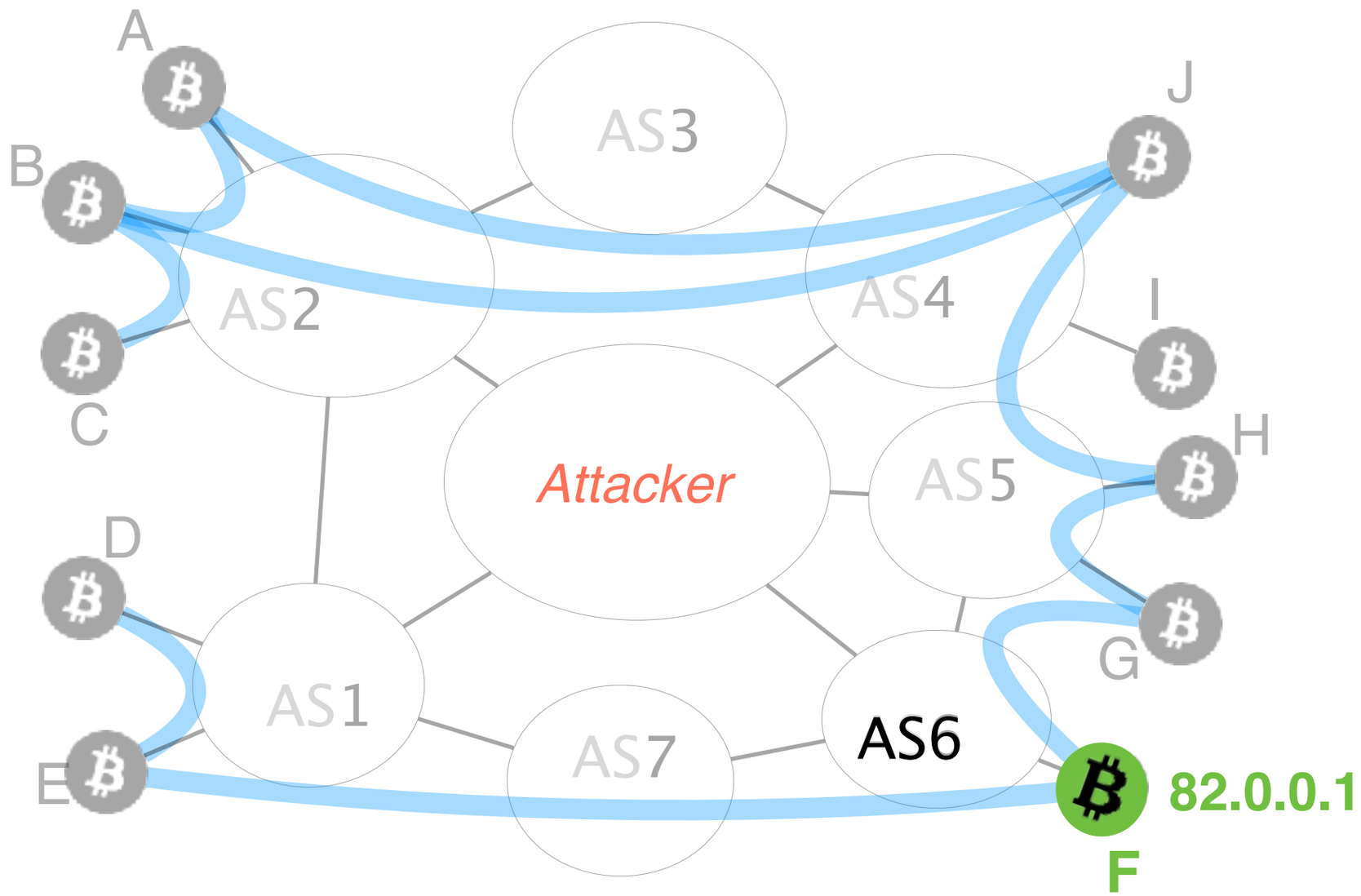
For doing so, the attacker will manipulate BGP routes to intercept any traffic to the nodes in the right



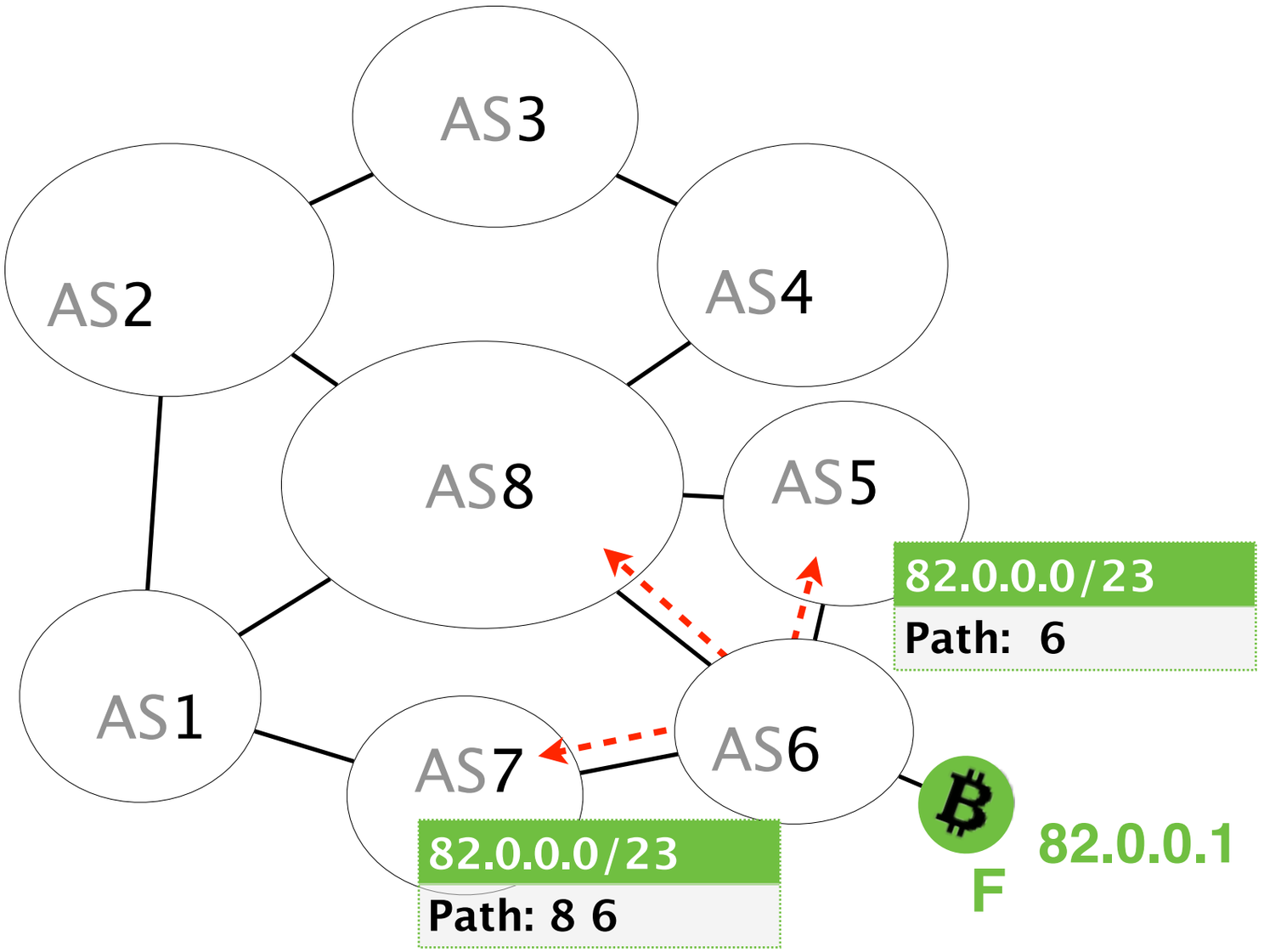
Let us focus on node F



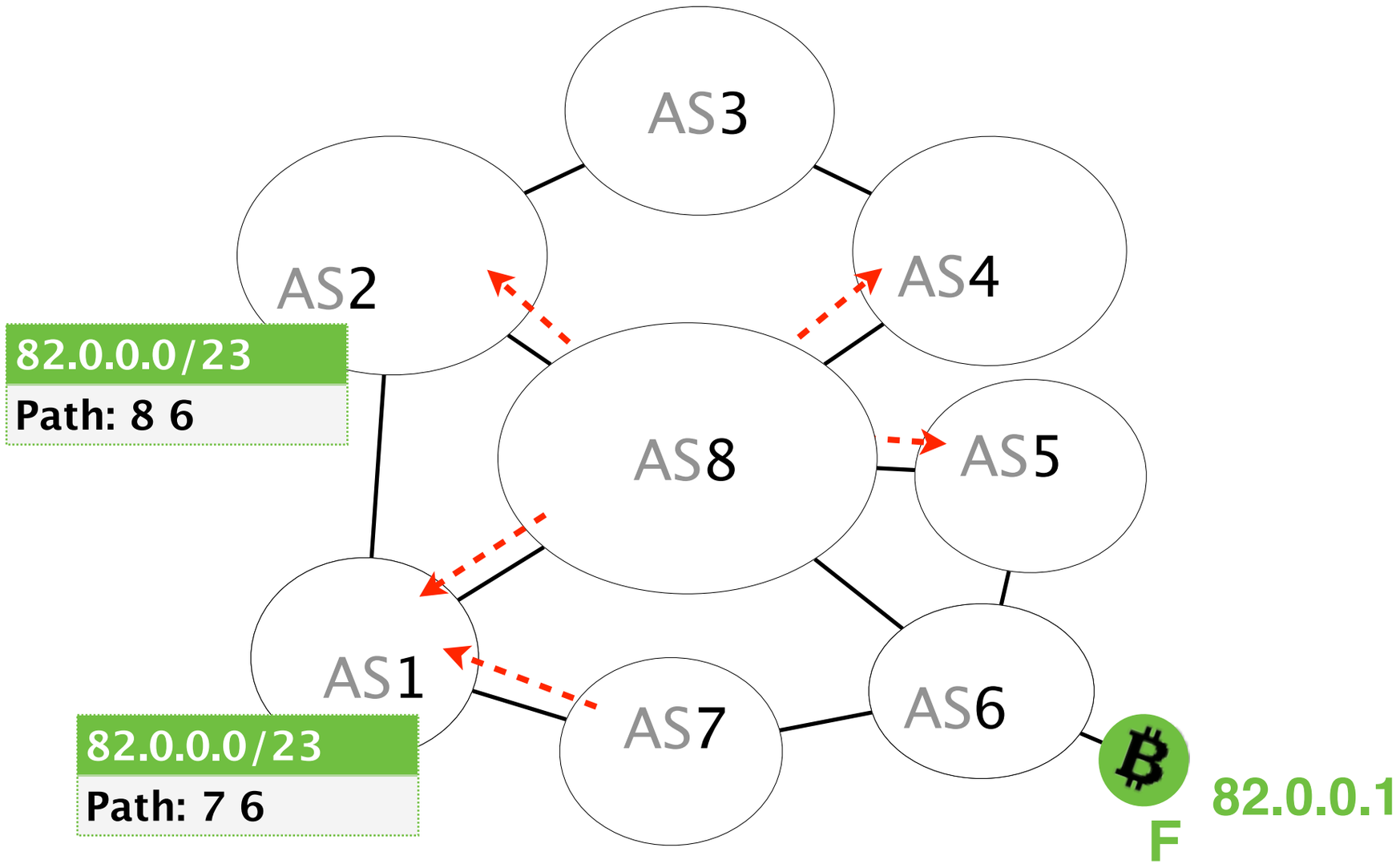
F's provider (AS6) is responsible for IP prefix



AS6 will create a BGP advertisement



AS6's advertisement is propagated AS-by-AS until all ASes in the Internet learn about it



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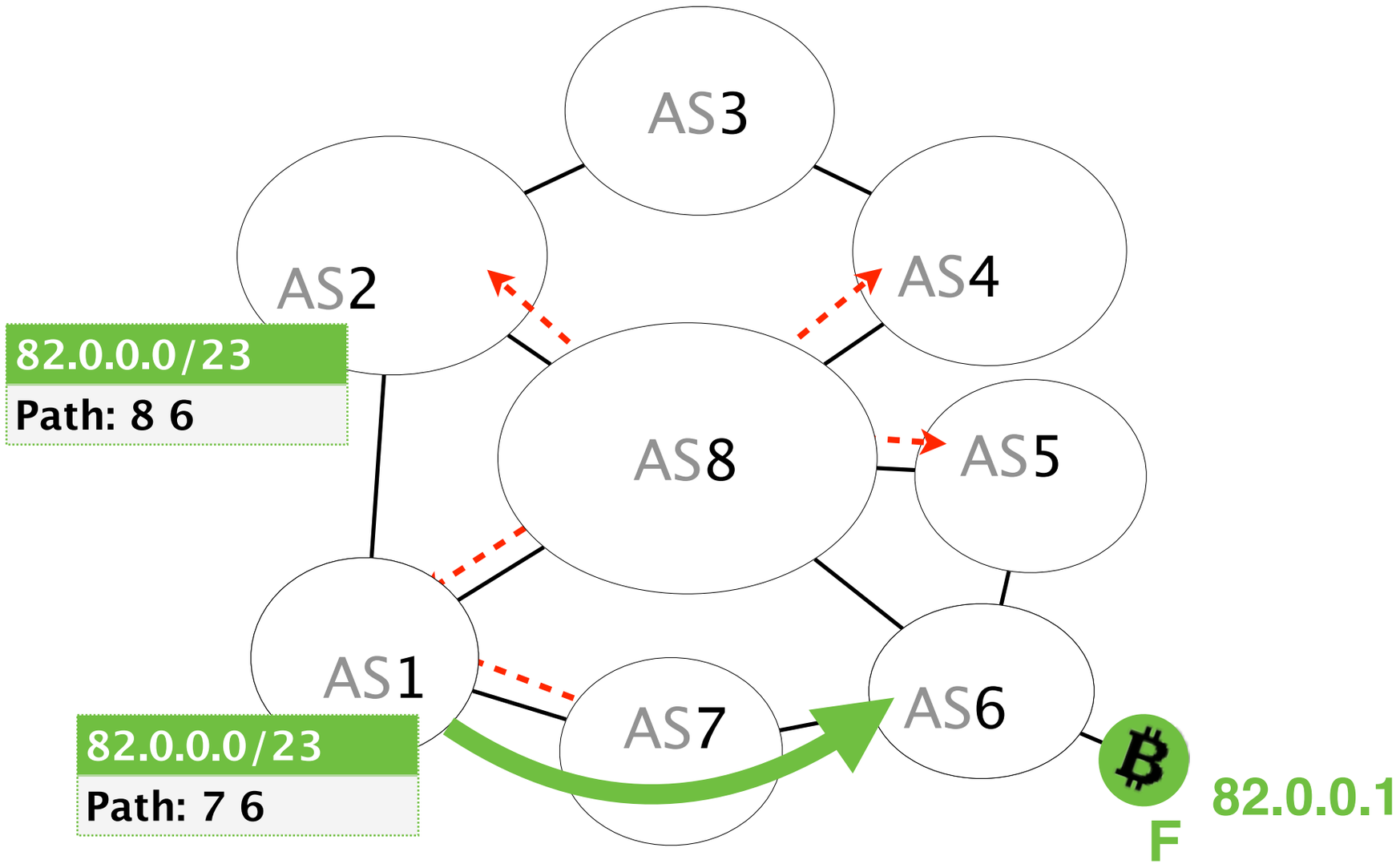
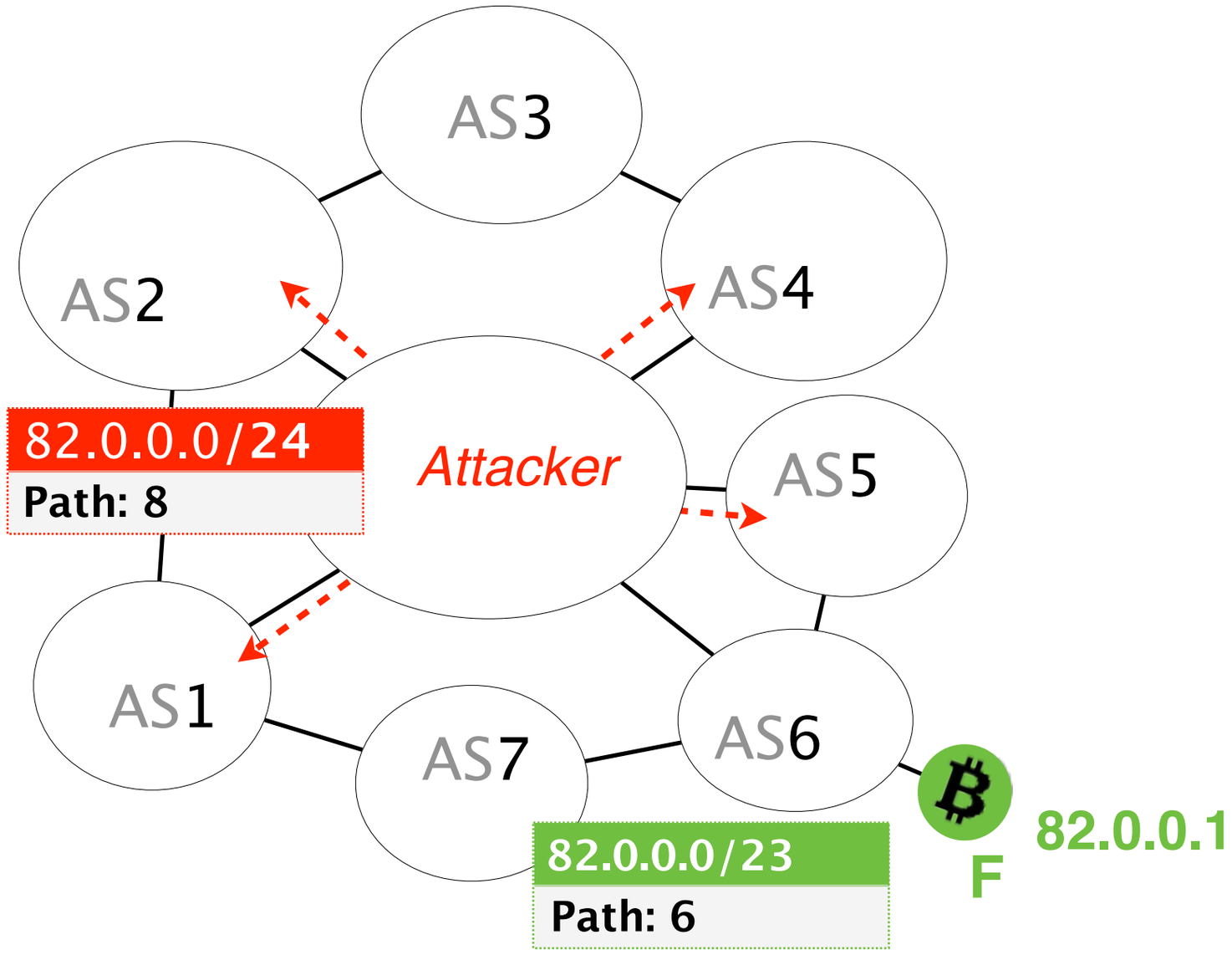
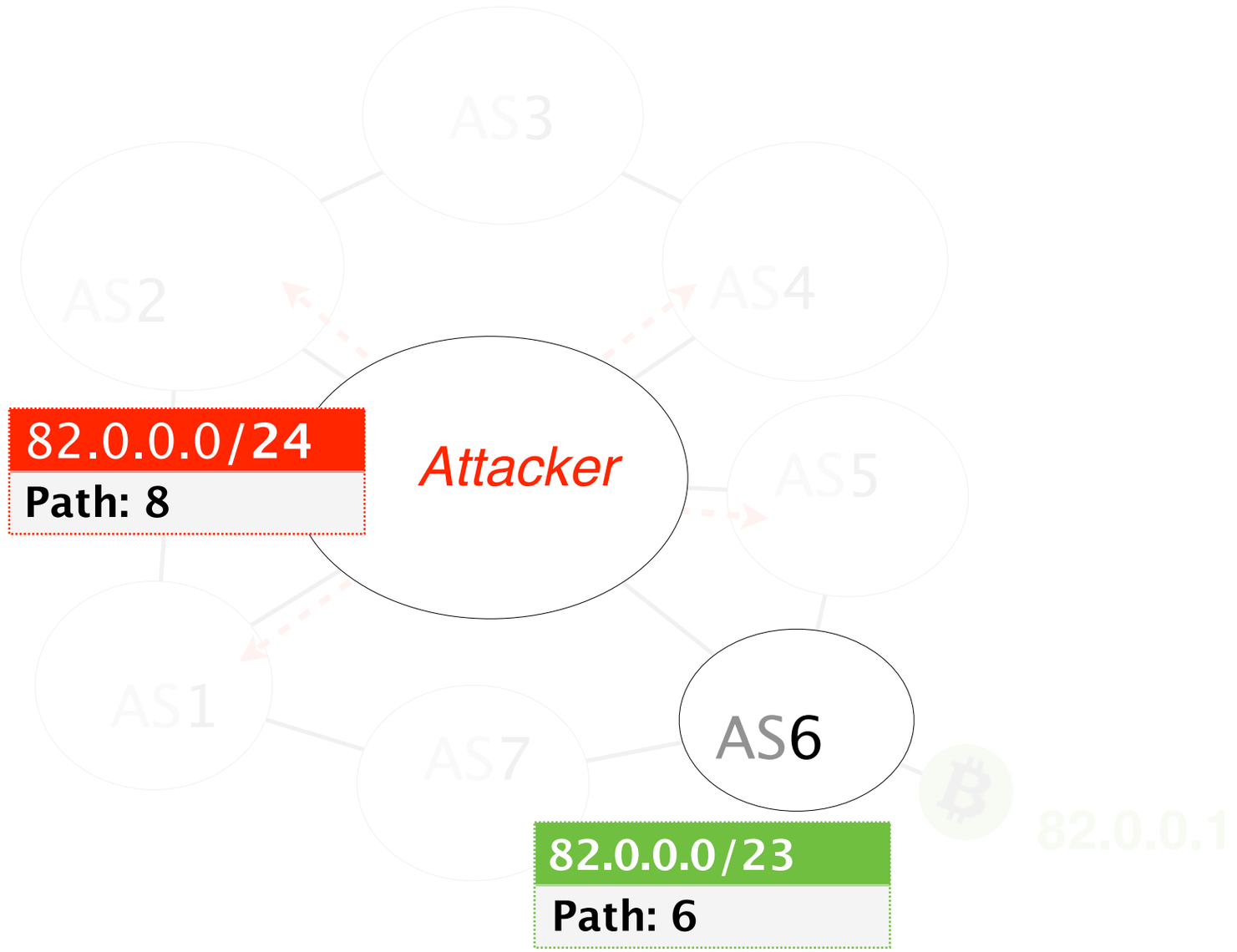


BGP does not check the validity of advertisements, meaning any AS can announce any prefix

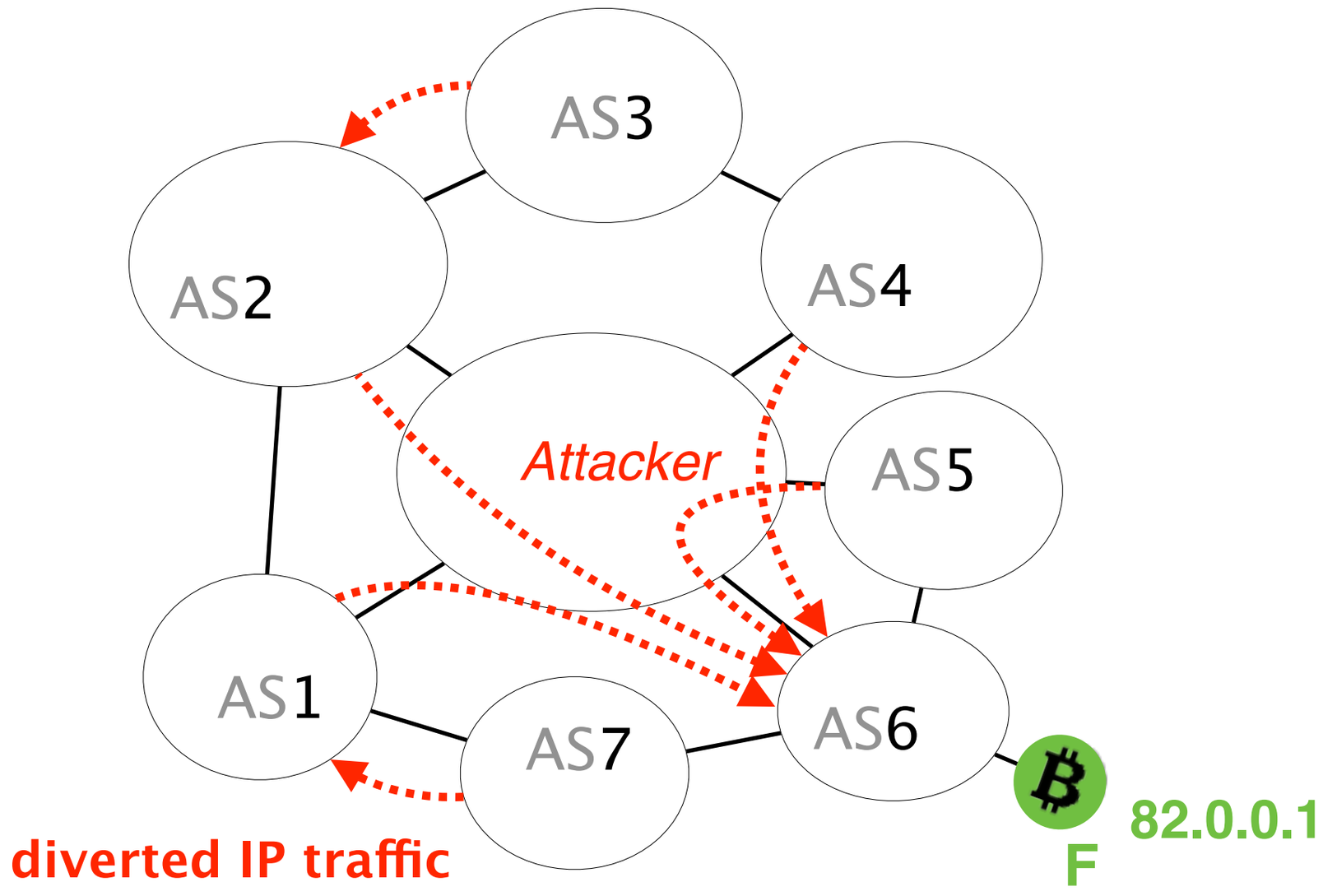
Consider that the attacker advertises a more-specific prefix covering F's IP address



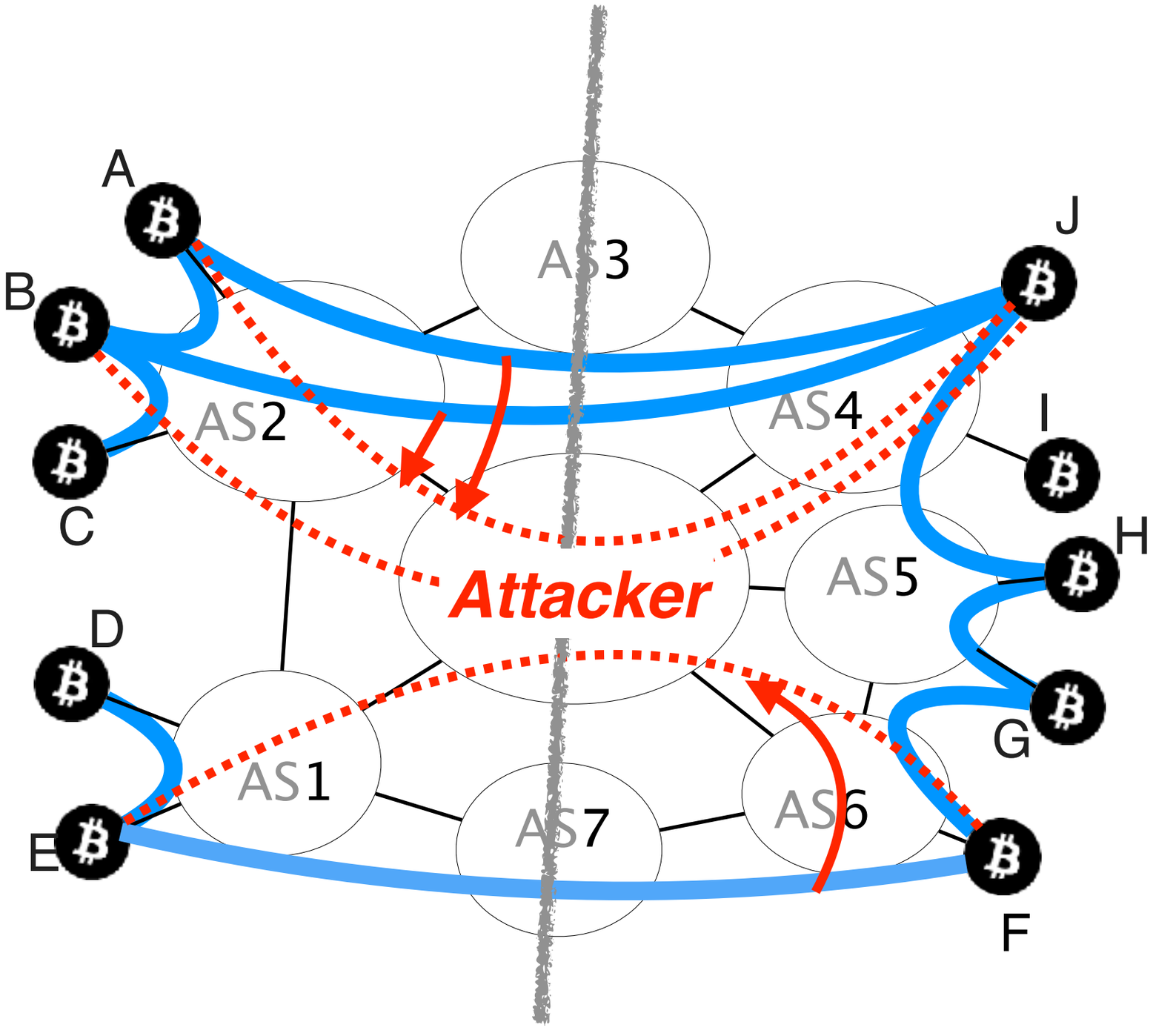
As IP routers prefer more-specific prefixes, the attacker route will be preferred



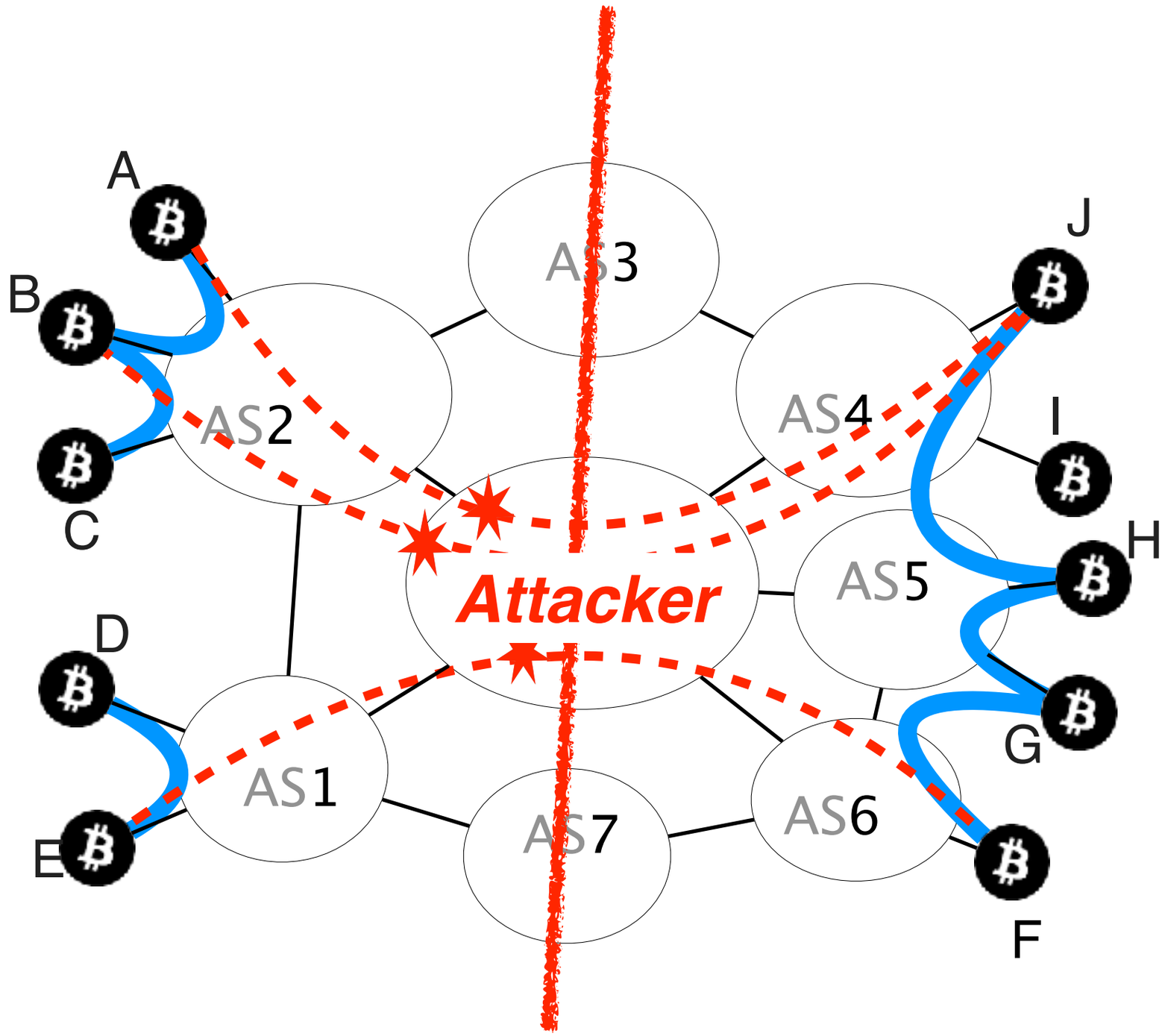
Traffic to node F is hijacked



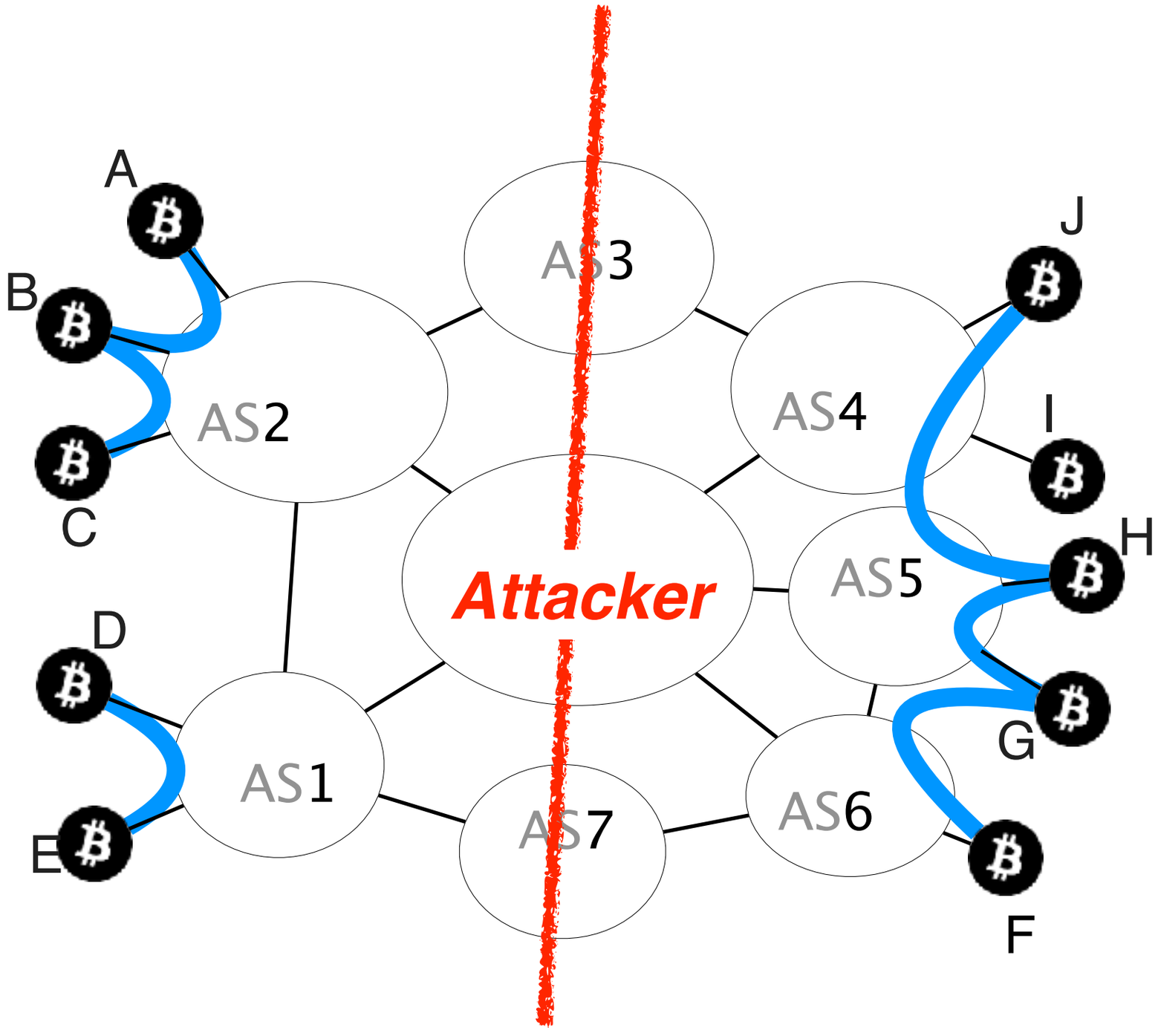
By hijacking the IP prefixes pertaining to the right nodes, the attacker can intercept all their connections



Once on-path, the attacker can drop all connections crossing the partition



The partition is created



Not all partition are feasible in practice:
some connections cannot be intercepted

Bitcoin connections established…

- within a mining pool
- within an AS
- between mining pools with private agreements

cannot be hijacked (usually)

Bitcoin connections established…

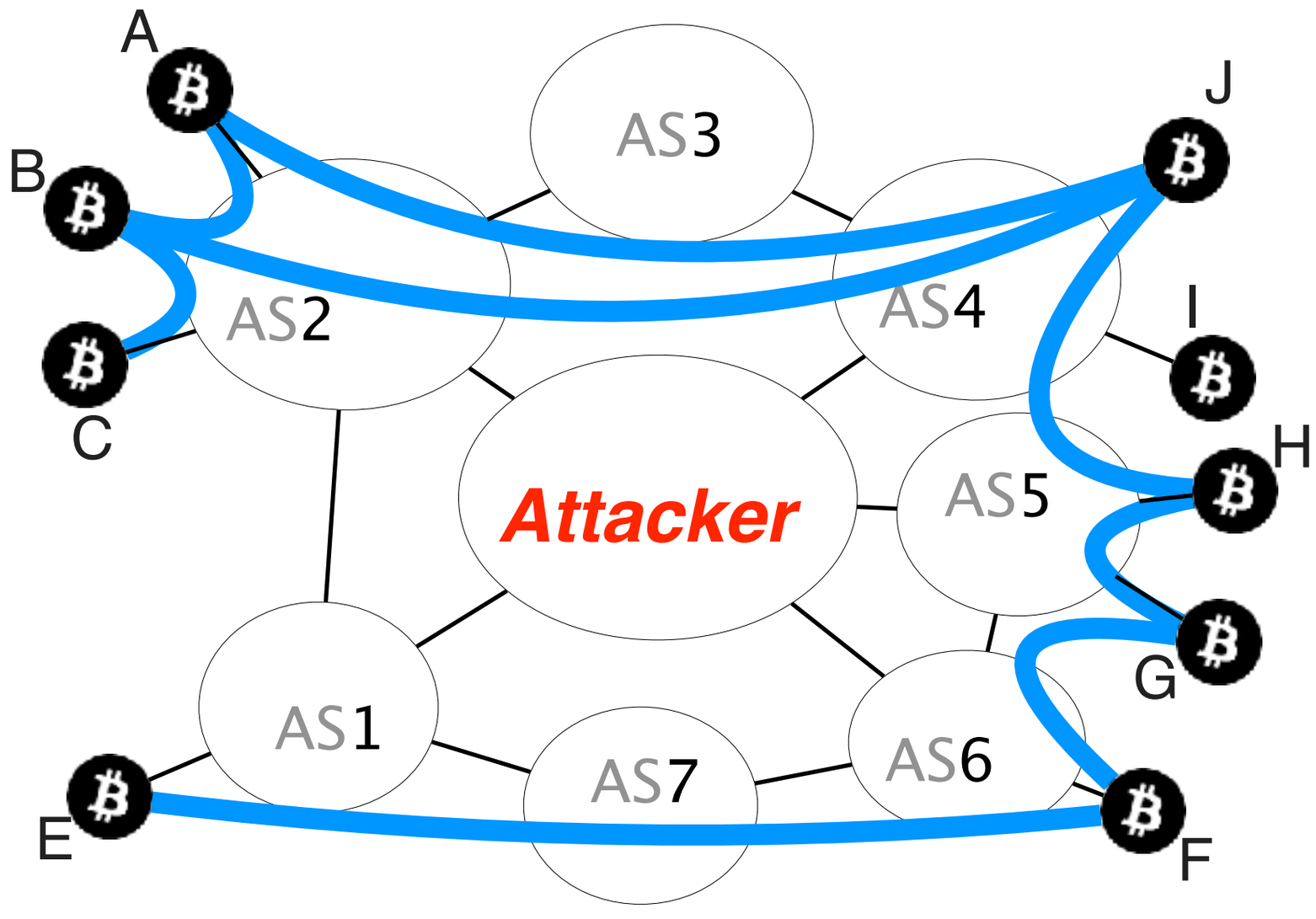
- within a mining pool
- within an AS
- between mining pools

cannot be hijacked (usually)

but can be *detected* and *located* by the attacker

enabling her to build a similar but feasible partition

Same attacker wants to create a different partition



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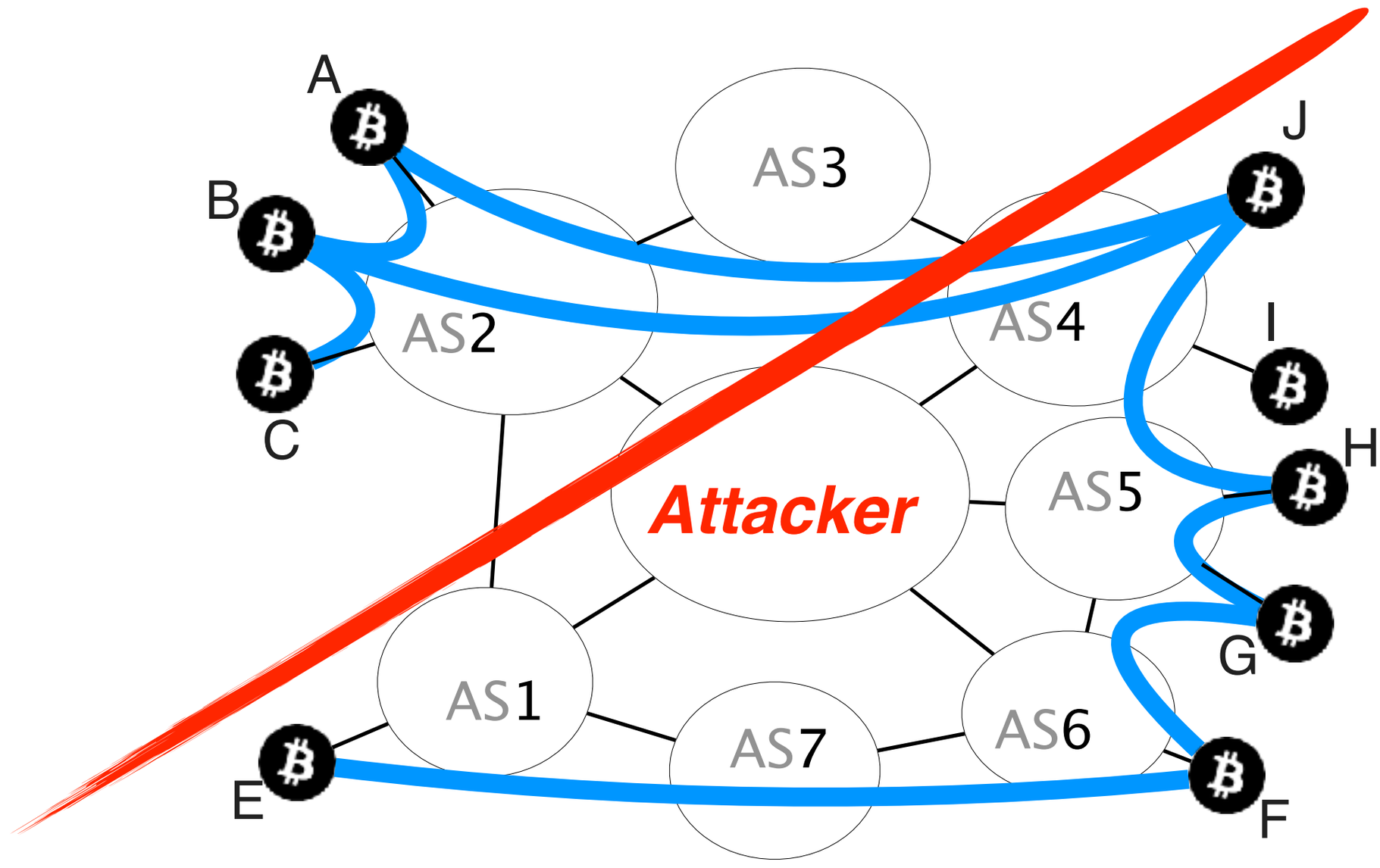
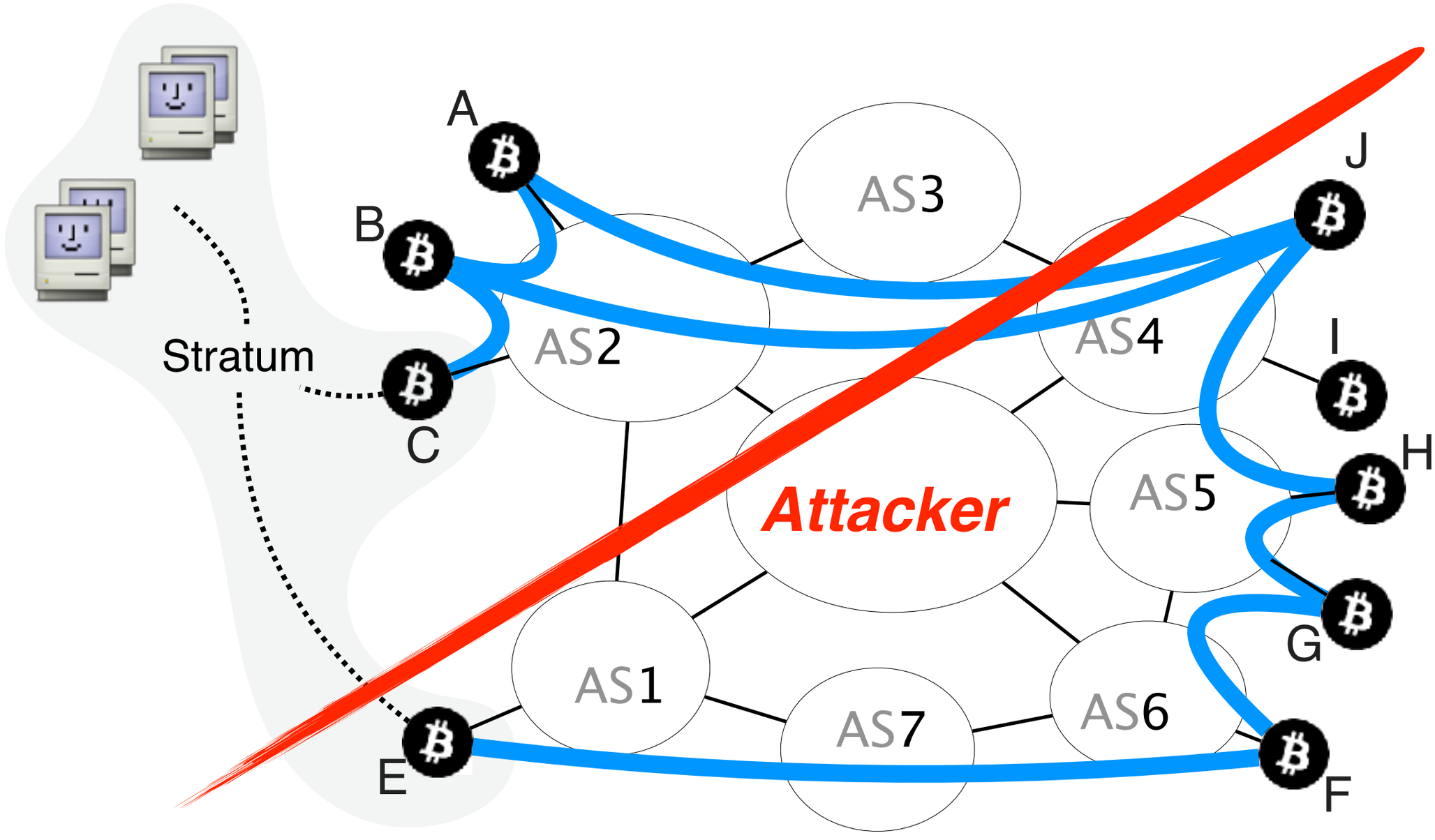
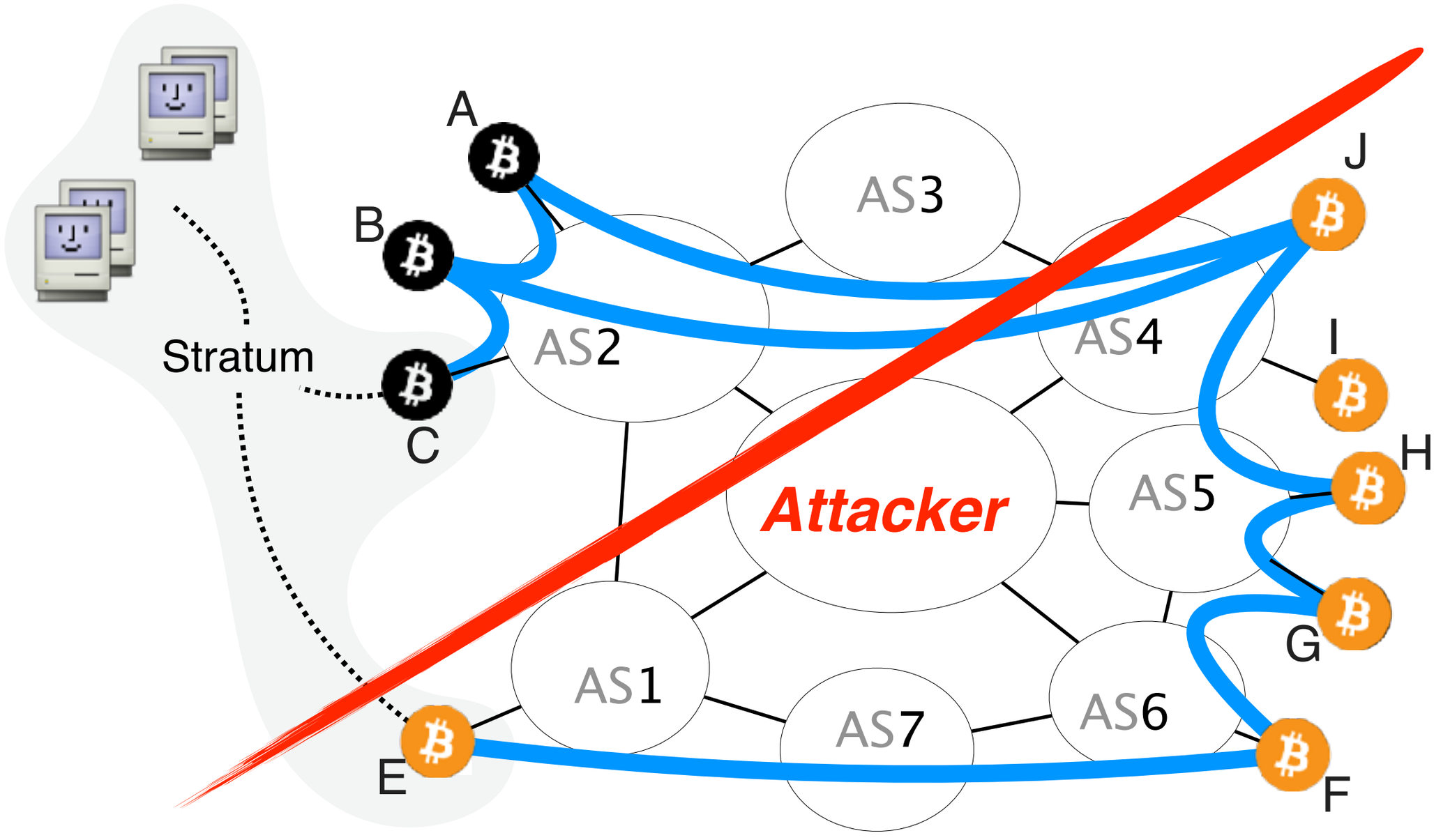


There is a mining pool in the topology



Attacker hijacks all prefixes pertaining to nodes in the orange side



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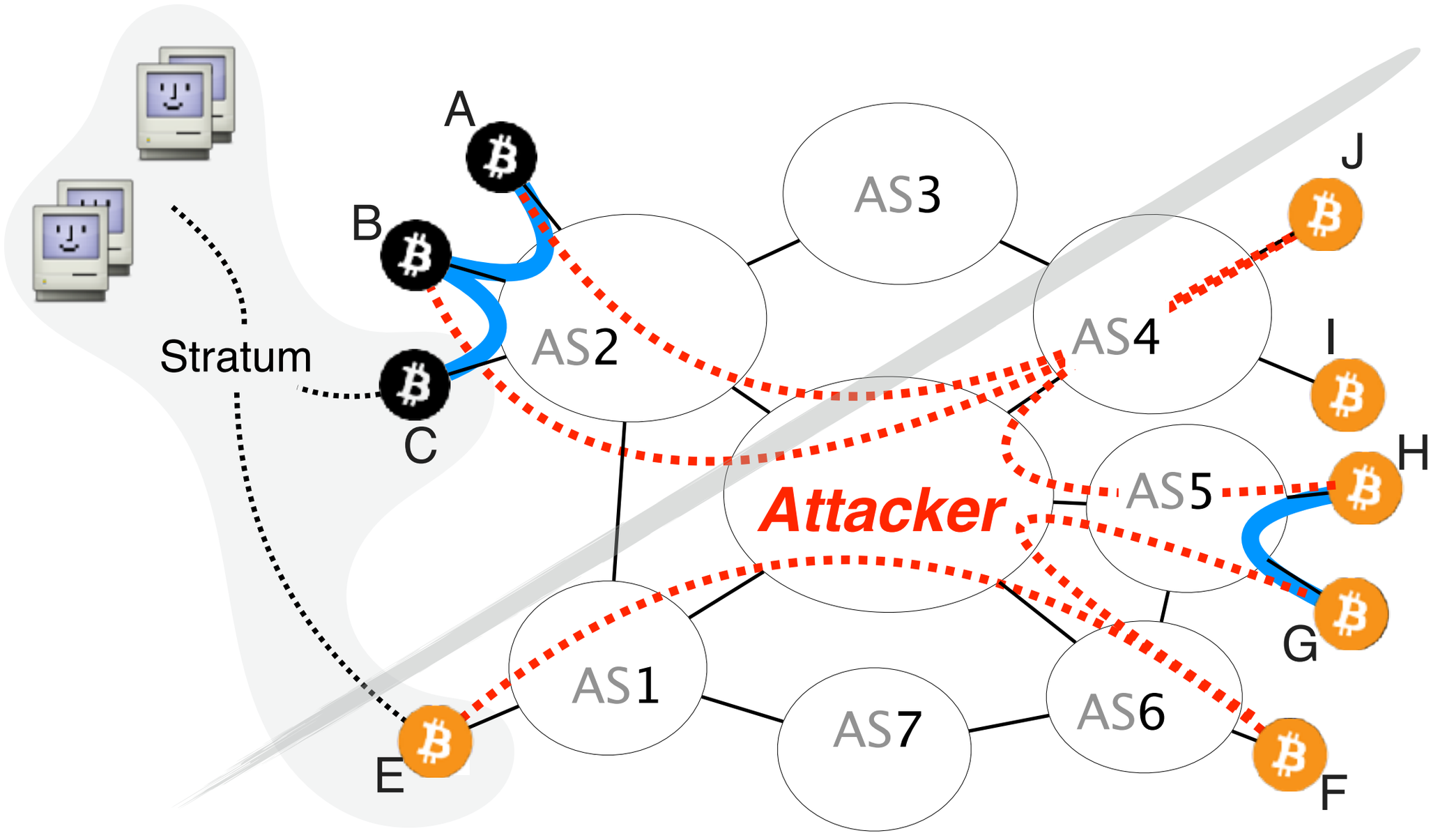
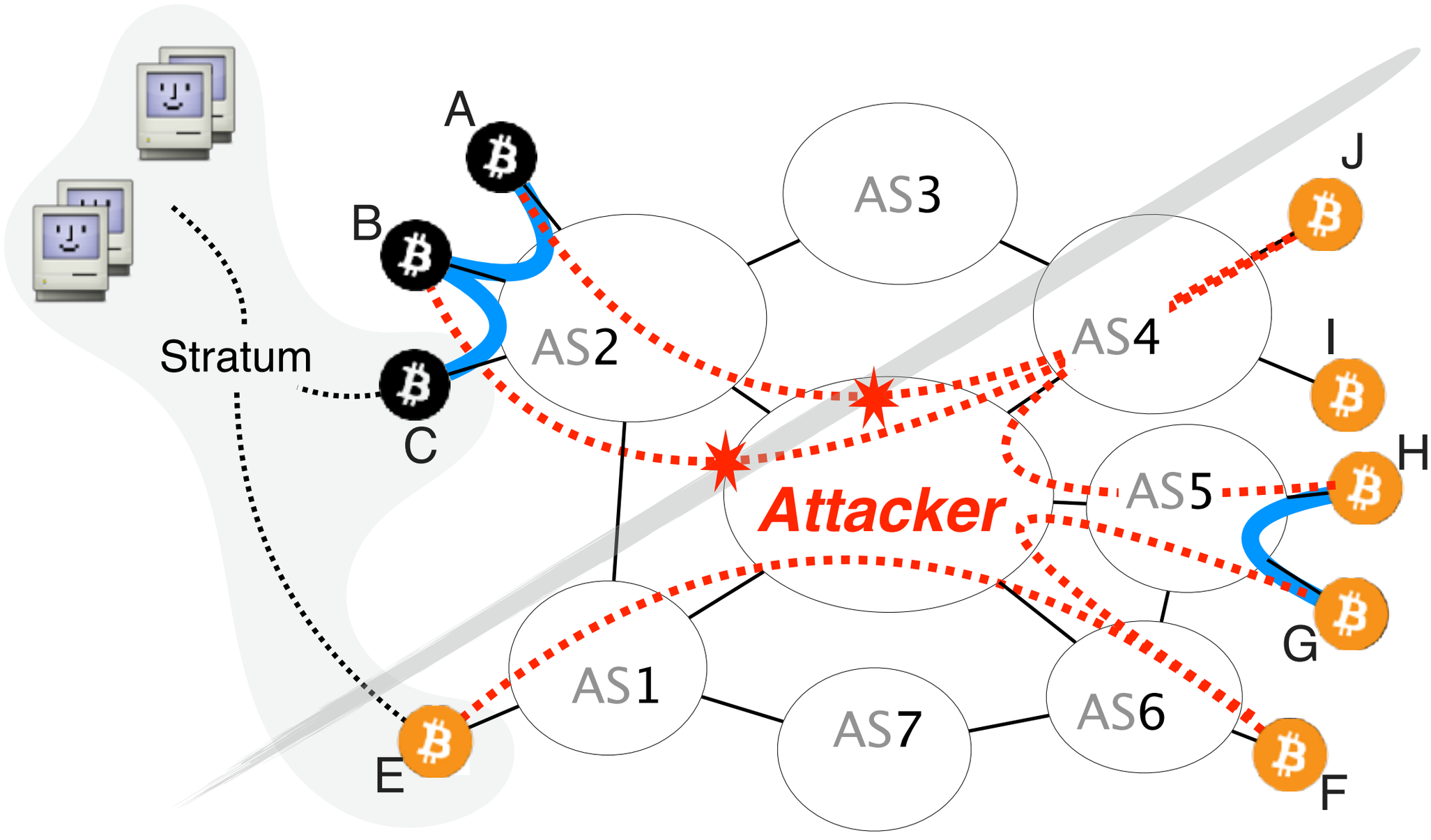
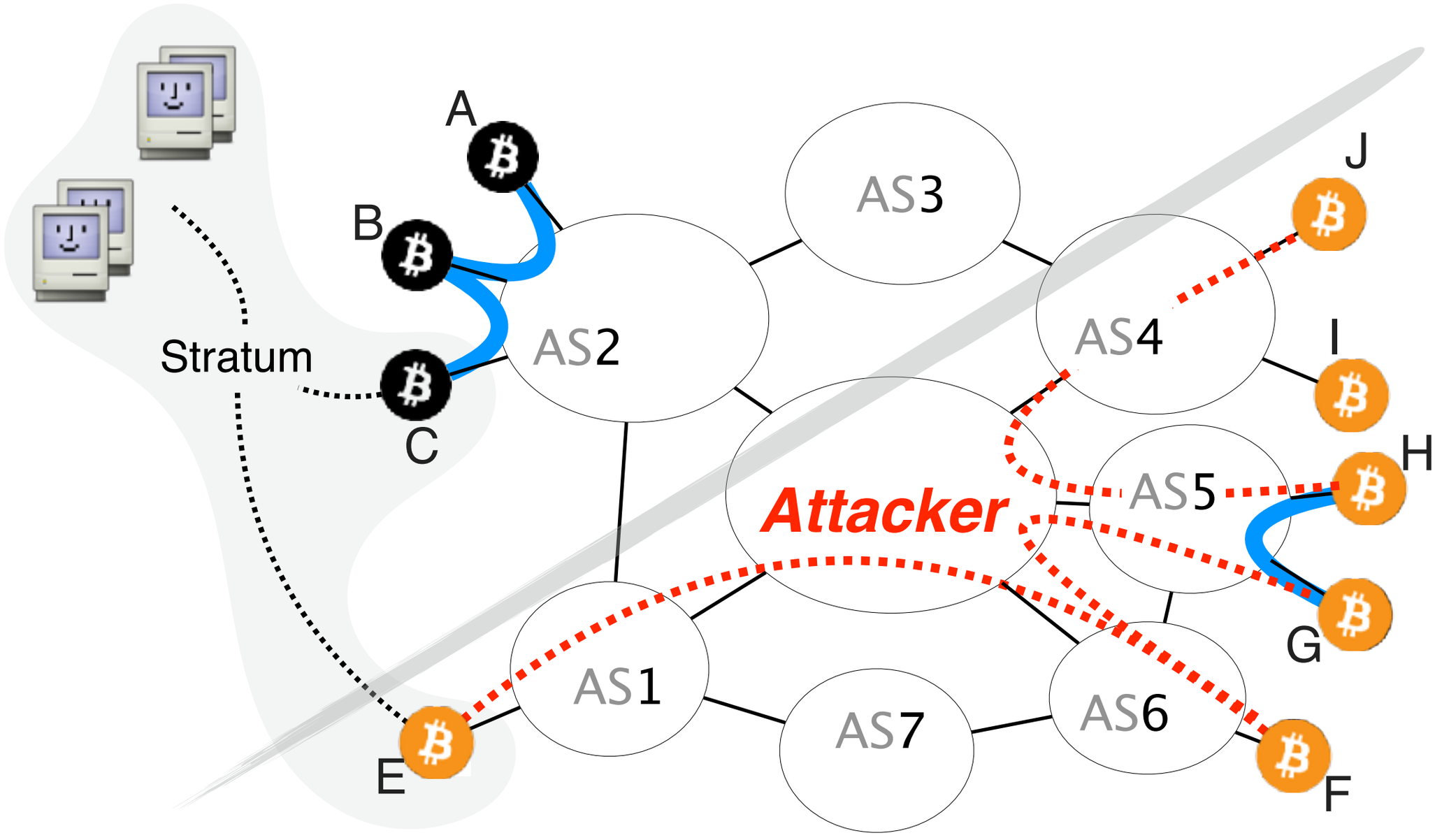


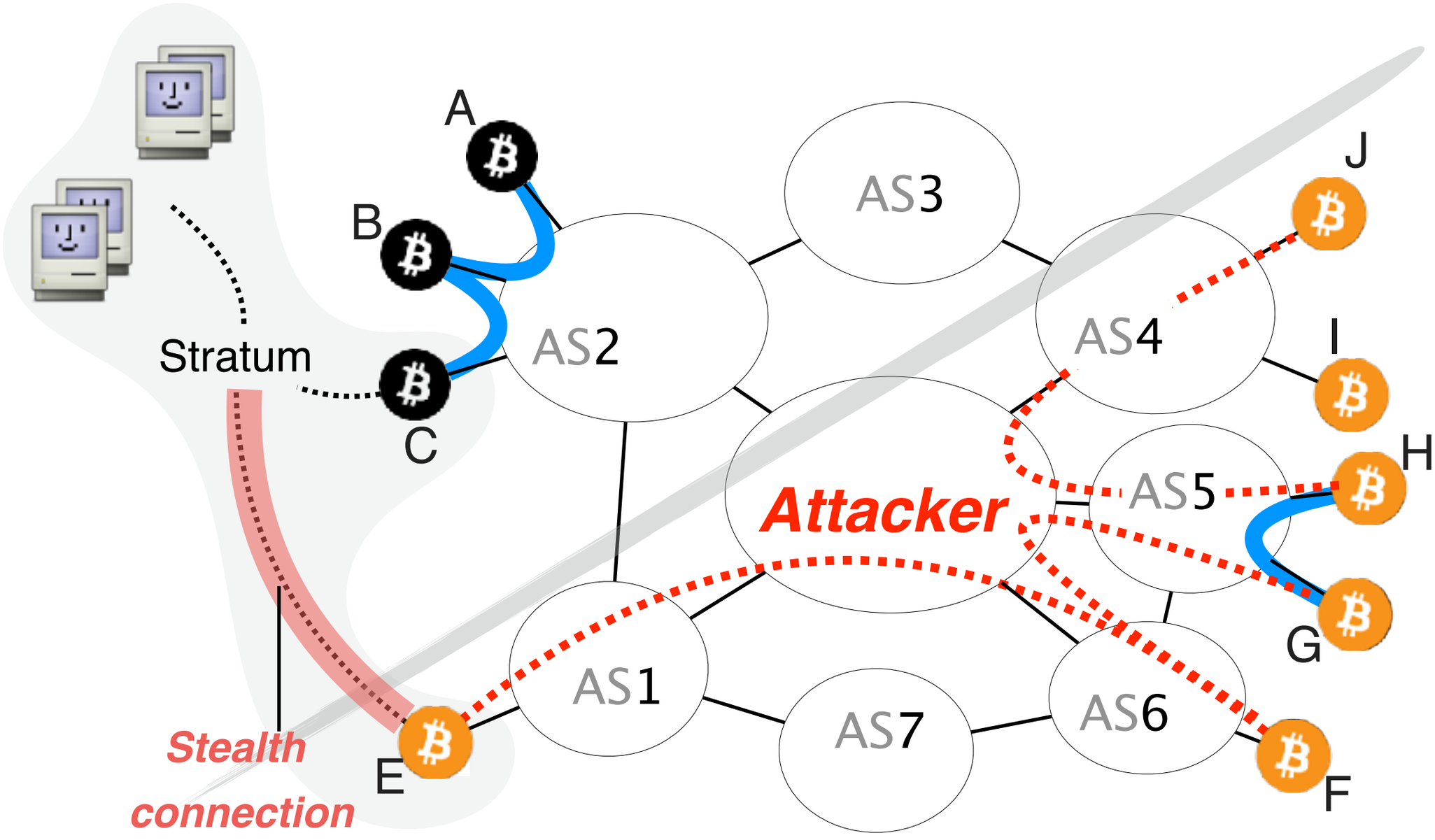
The attacker drops connections



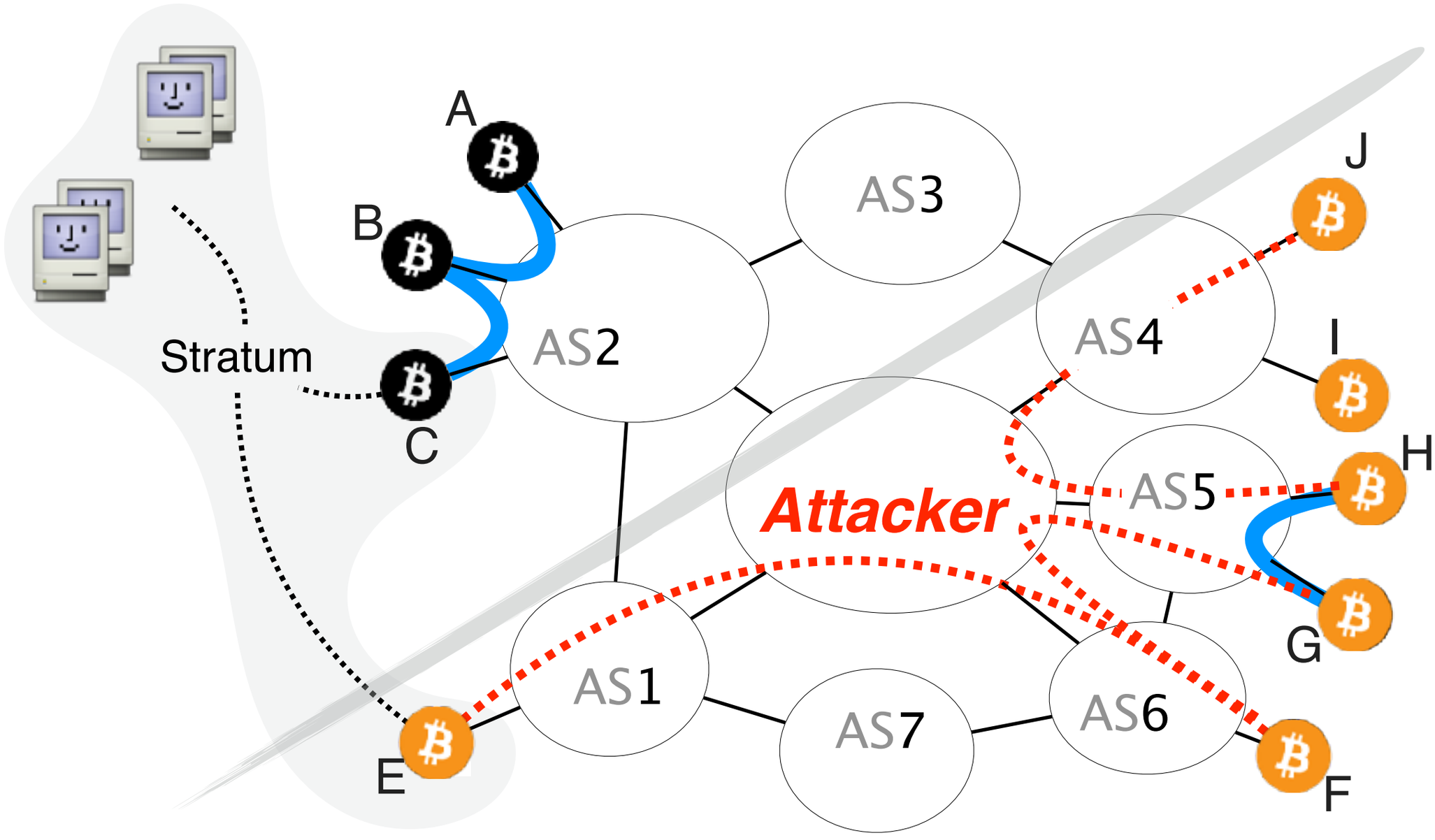
The partition is created but is ineffective



The partition is infeasible



The attacker monitors the connections and detects leakage



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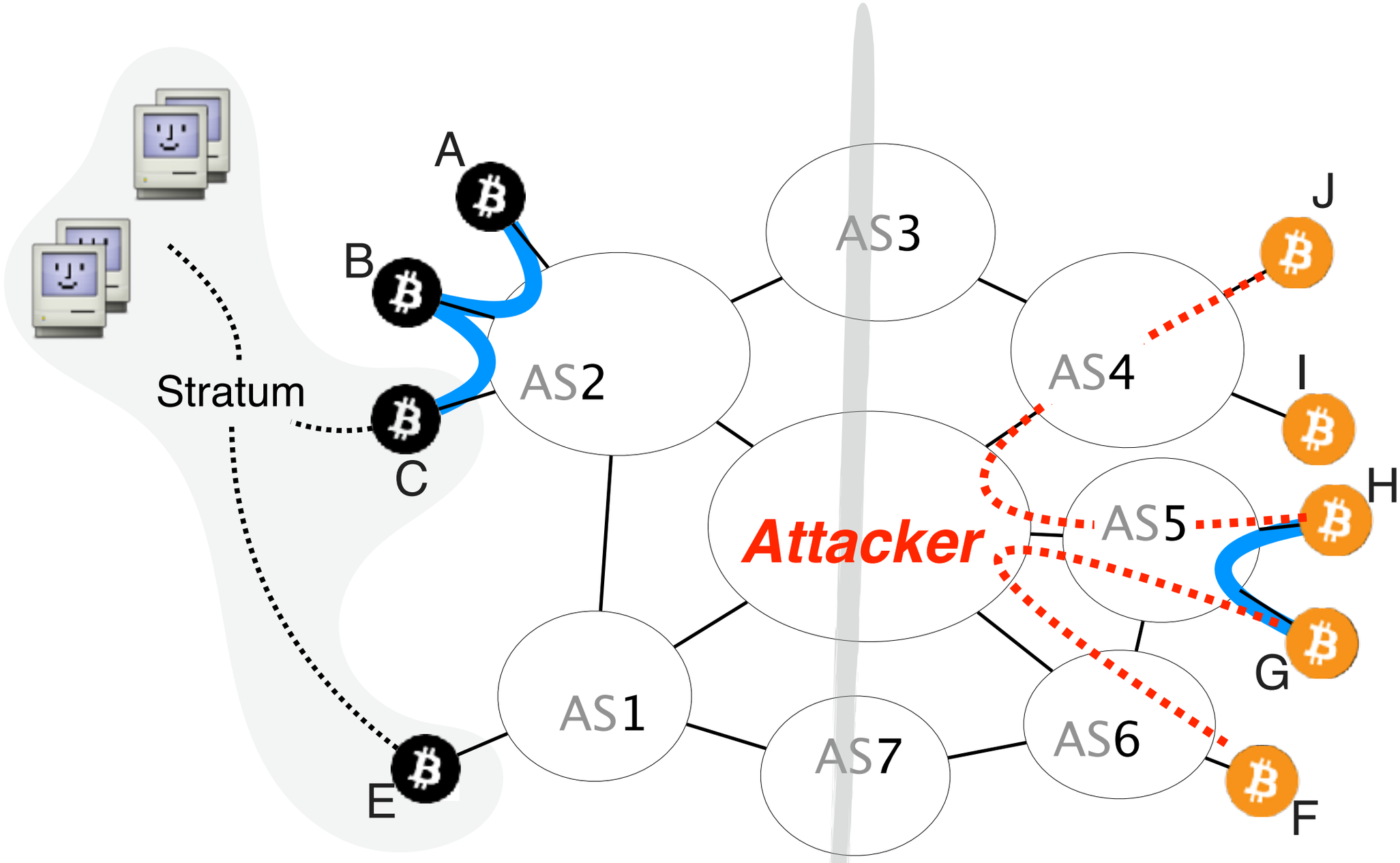

Theorem

Given a set of nodes to disconnect from the network,

there exist a unique maximal subset that can be isolated

and that the attacker will isolate.

see paper for proof

We evaluated the partition attack in terms of practicality and time efficiency

Practicality

Can it actually happen?

Time efficiency

How long does it take?

We evaluated the partition attack in terms of practicality and time efficiency

Practicality

Time efficiency

Can it actually happen?

Splitting the mining power even to half can be done by hijacking less than 100 prefixes

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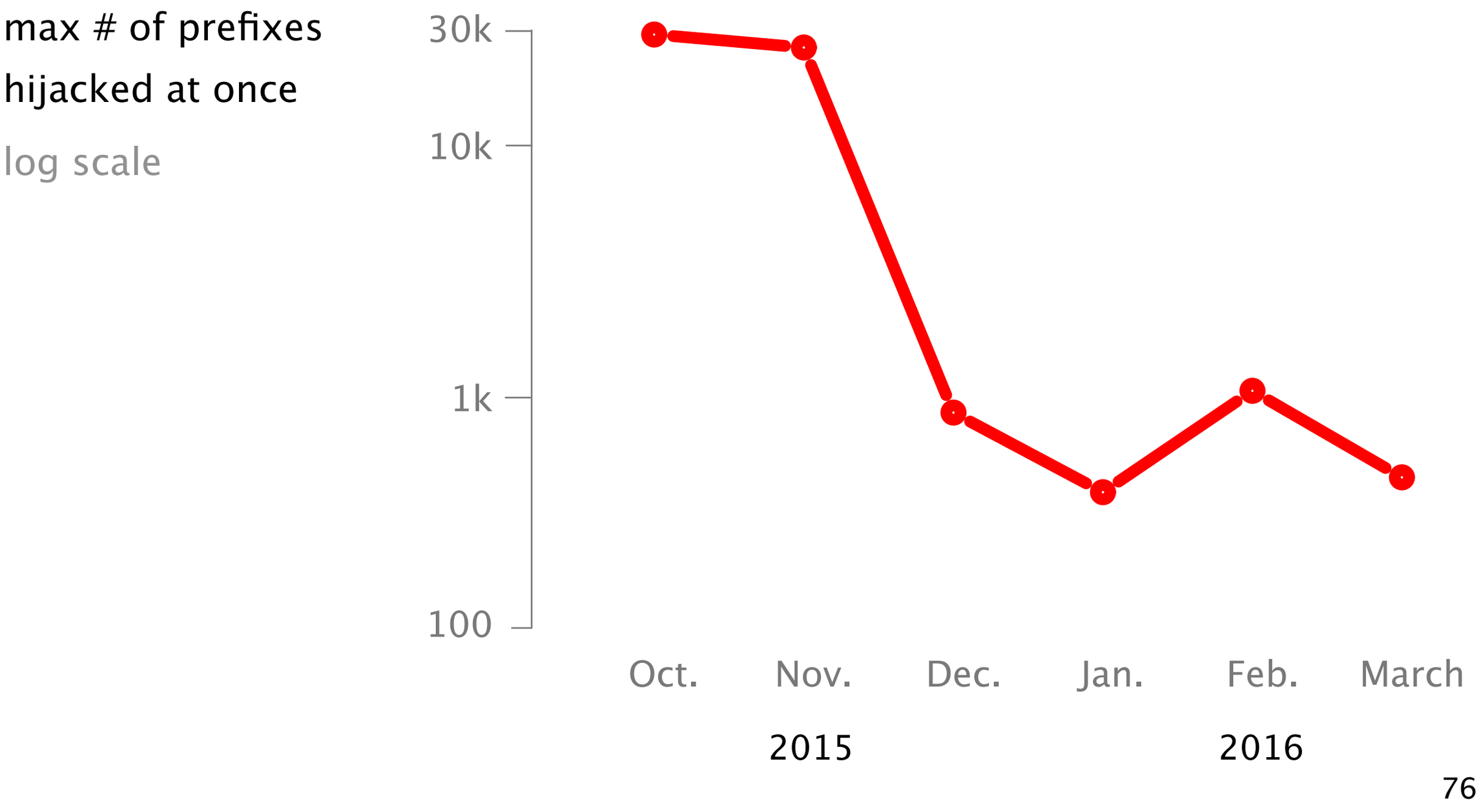
negligible with respect to routinely observed hijacks

Hijacks involving up to 1k of prefixes are frequently seen in the Internet today



We also evaluated the partition in terms of time efficiency

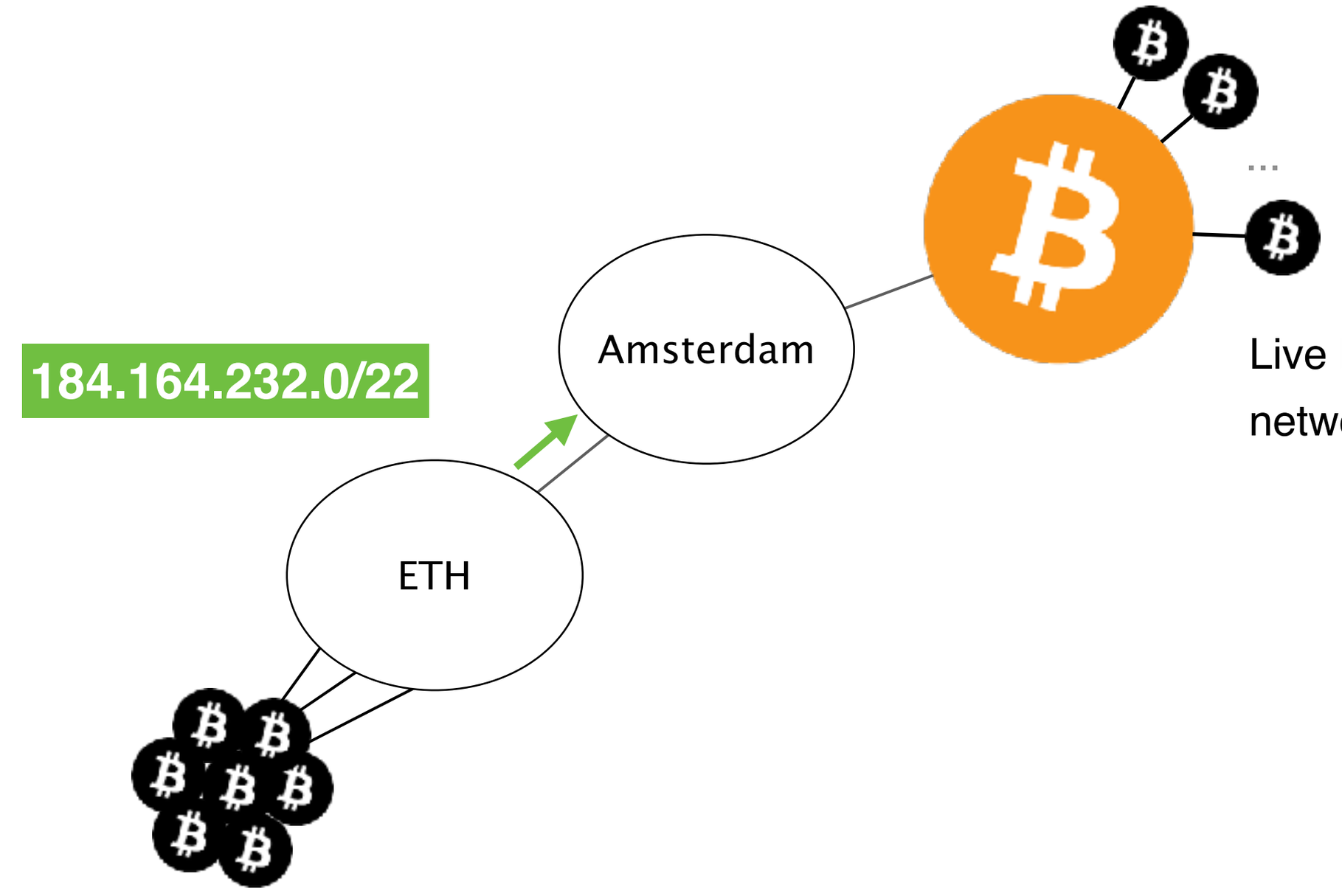
Practicality

Time efficiency

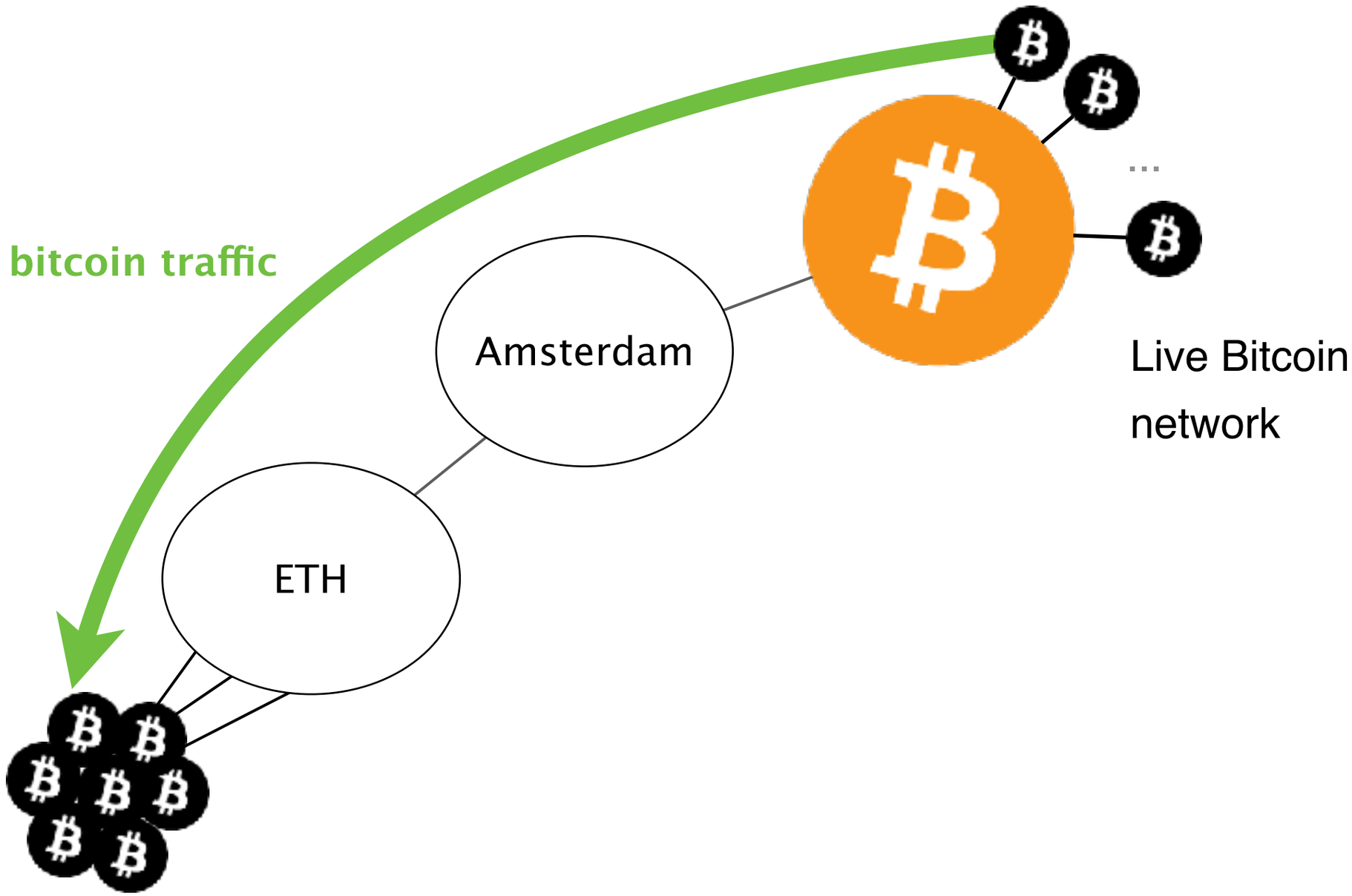
How long does it take?

We measured the time required to perform a partition attack by attacking our own nodes

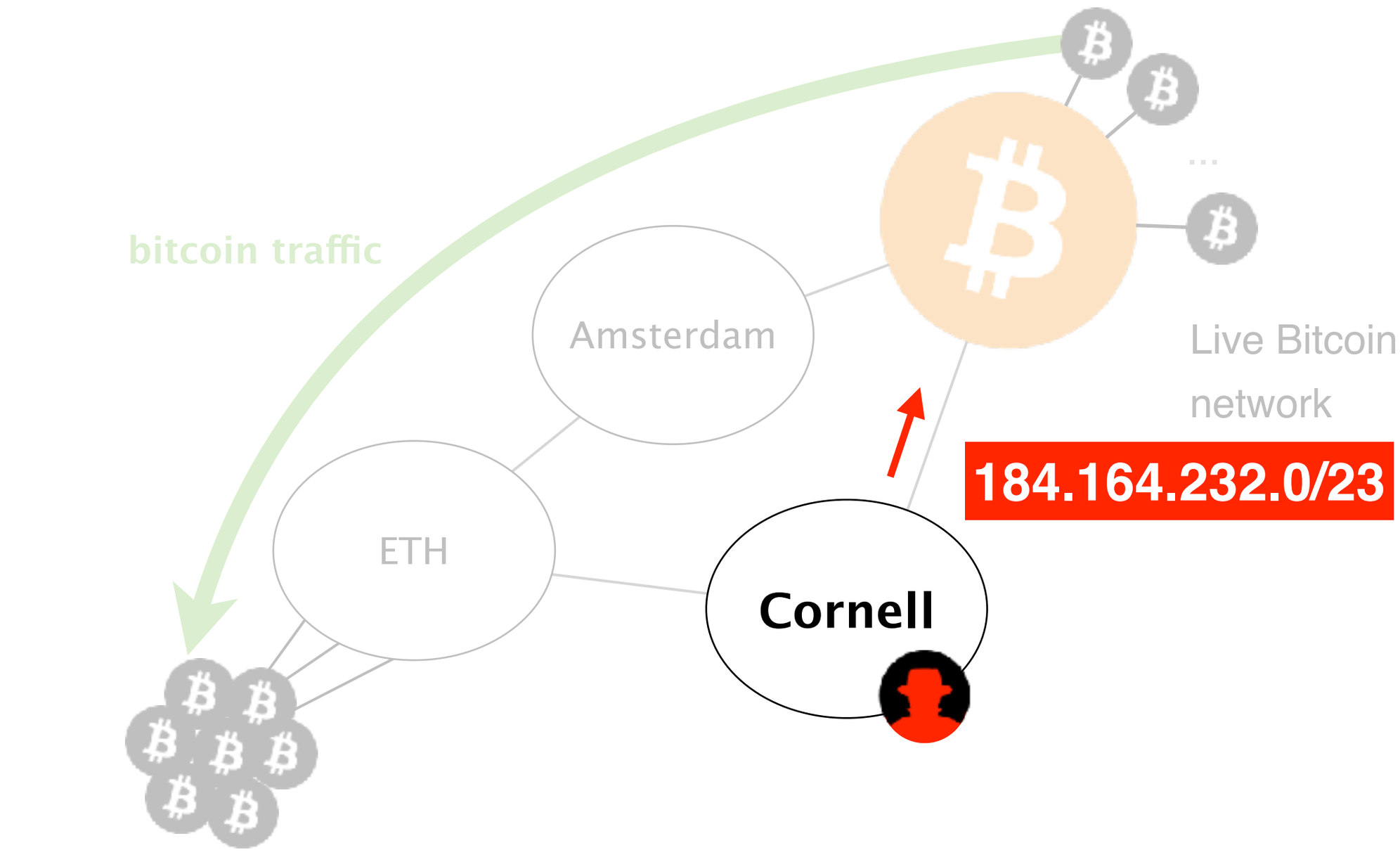
We hosted a few Bitcoin nodes at ETH and advertised a covering prefix via Amsterdam



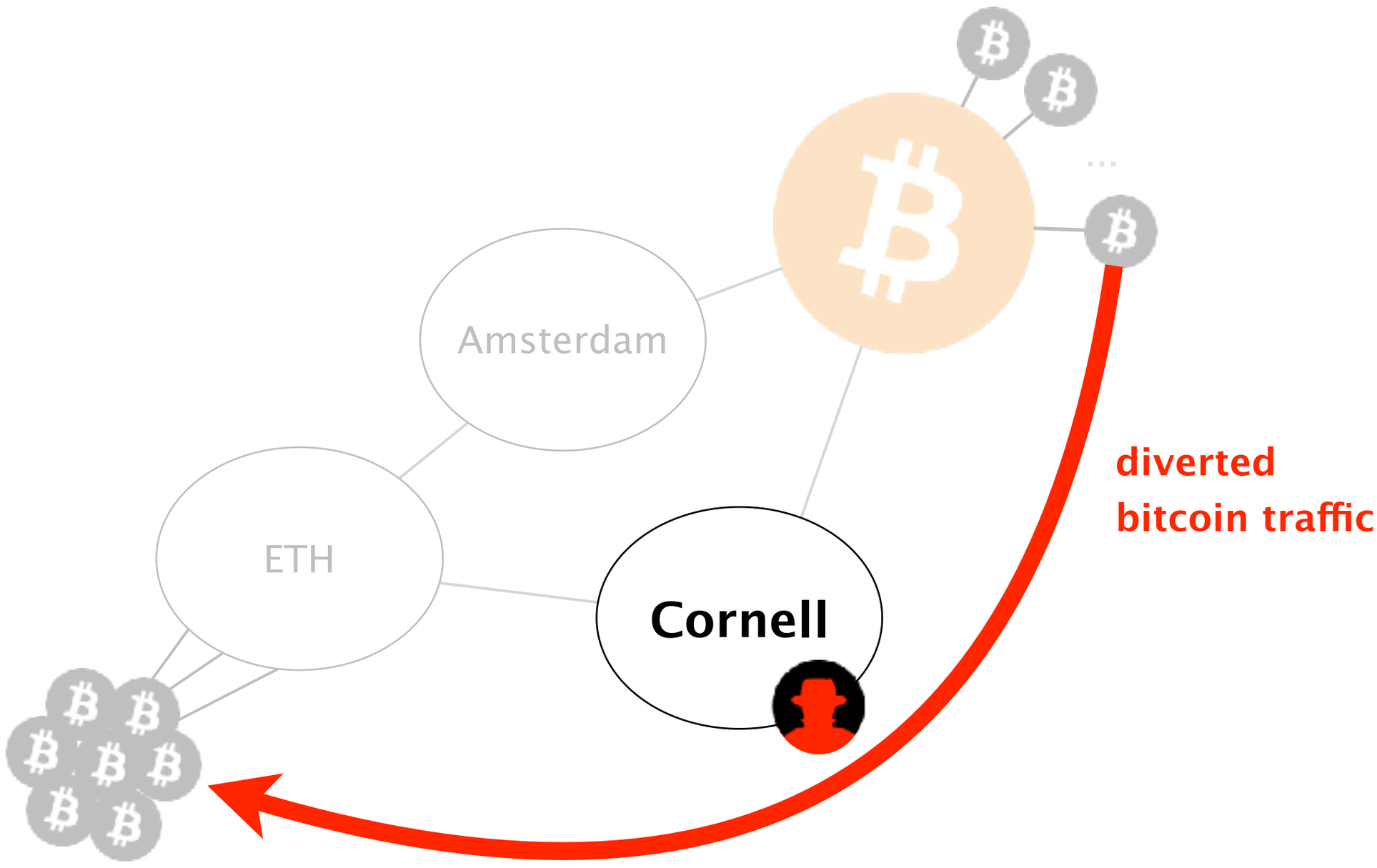
Initially, all the traffic to our nodes transits via Amsterdam

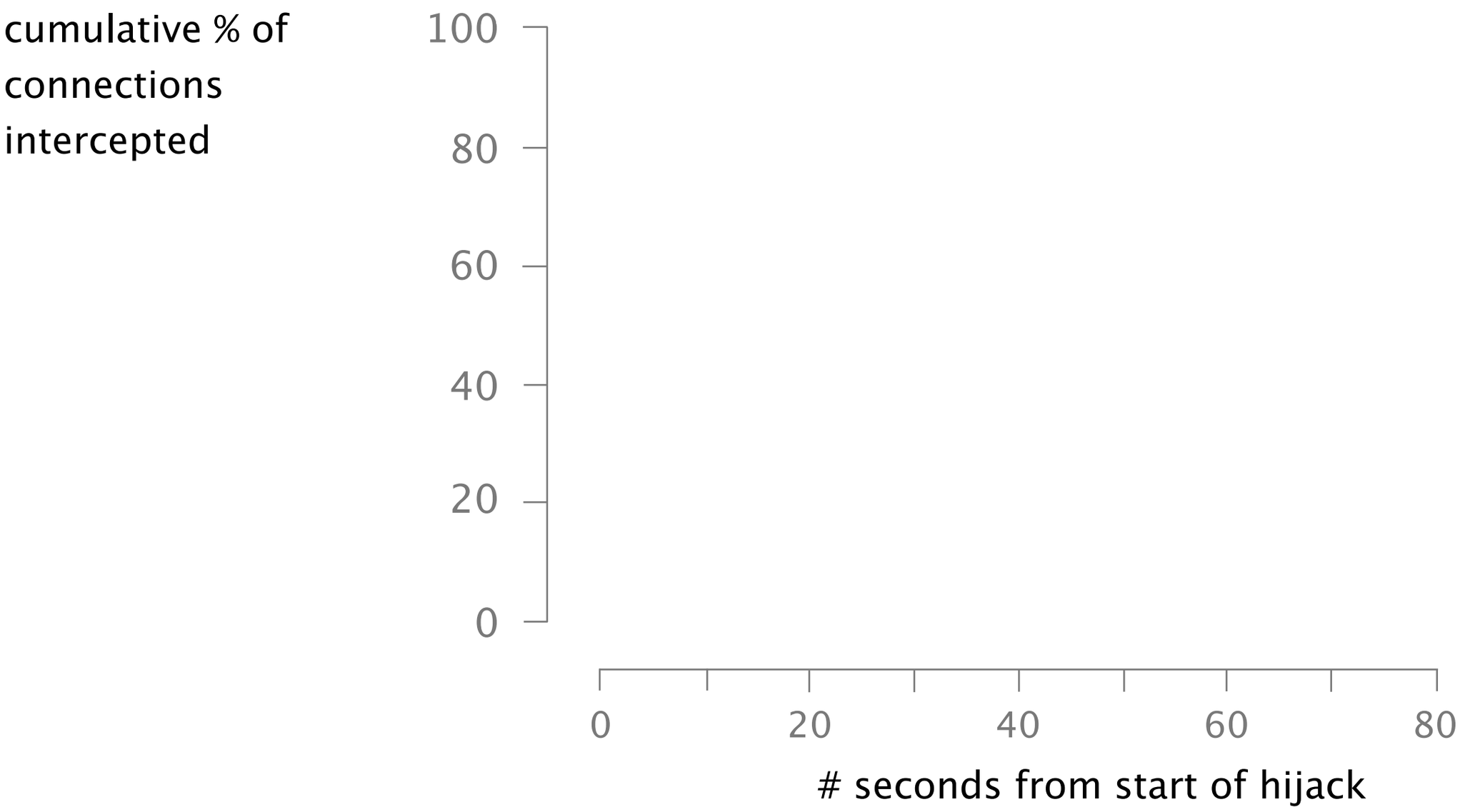


We hijacked our nodes

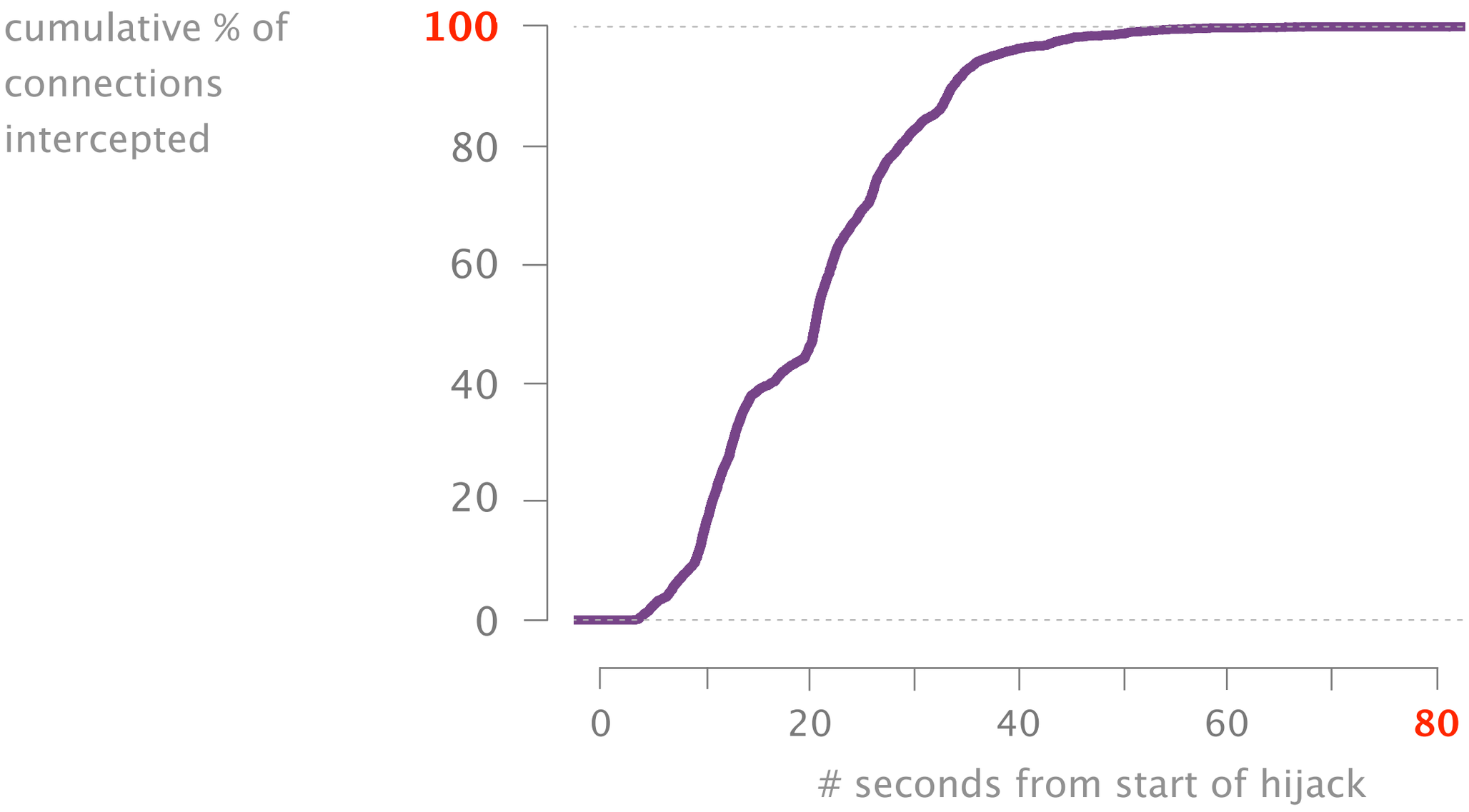


We measured the time required for a rogue AS to divert all the traffic to our nodes




cumulative % of connections intercepted
100
80
60
40
20
0
0
20
40
60
80
seconds from start of hijack

It takes less than 2 minutes for the attacker to intercept all the connections



Mitigating a hijack is a human-driven process,
as such it often takes hours to be resolved

Mitigating a hijack is a human-driven process,
as such it often takes hours to be resolved

It took Google close to 3h
to mitigate a large hijack in 2008 [6]

(same hold for more recent hijacks)

We measured the healing time of the partition in a testbed of 1050 Bitcoind clients

The Bitcoin network will regain connectivity in seconds after the hijack stops

The two components will be loosely connected for hours

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Hijacking Bitcoin

Routing Attacks on Cryptocurrencies

The goal of a delay attack is to keep the victim uninformed of the latest Block

The impact of delay attacks is worrying and depends on the victim

Merchant

Mining pool

Regular node

The impact of delay attacks is worrying and depends on the victim

Merchant

Mining pool

Regular node

susceptible to be the victim
of double-spending attacks

The impact of delay attacks is worrying and depends on the victim

Merchant

Mining pool

Regular node

waste their mining power by mining on an obsolete chain

The impact of delay attacks is worrying and depends on the victim

Merchant

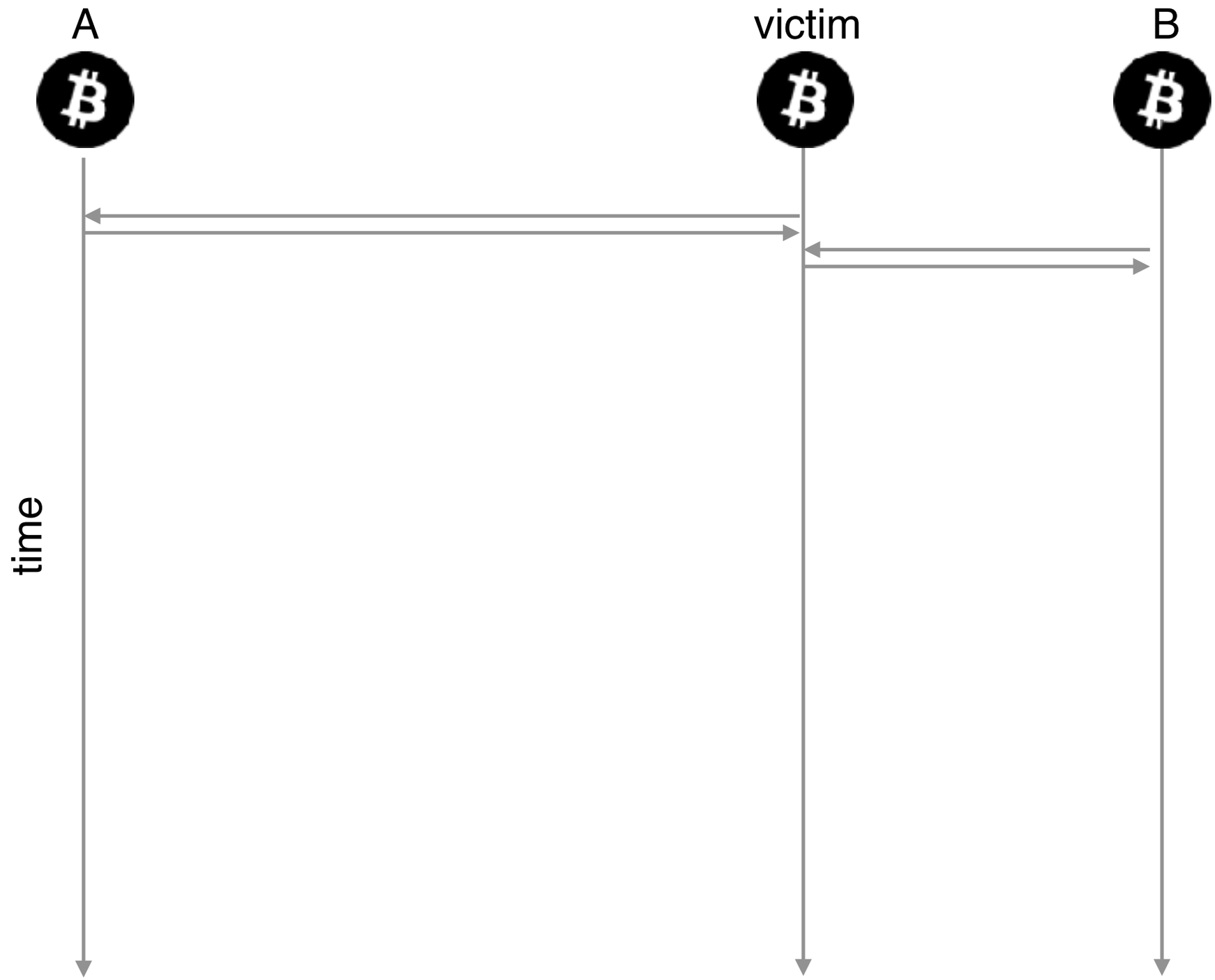
Mining pool

Regular node

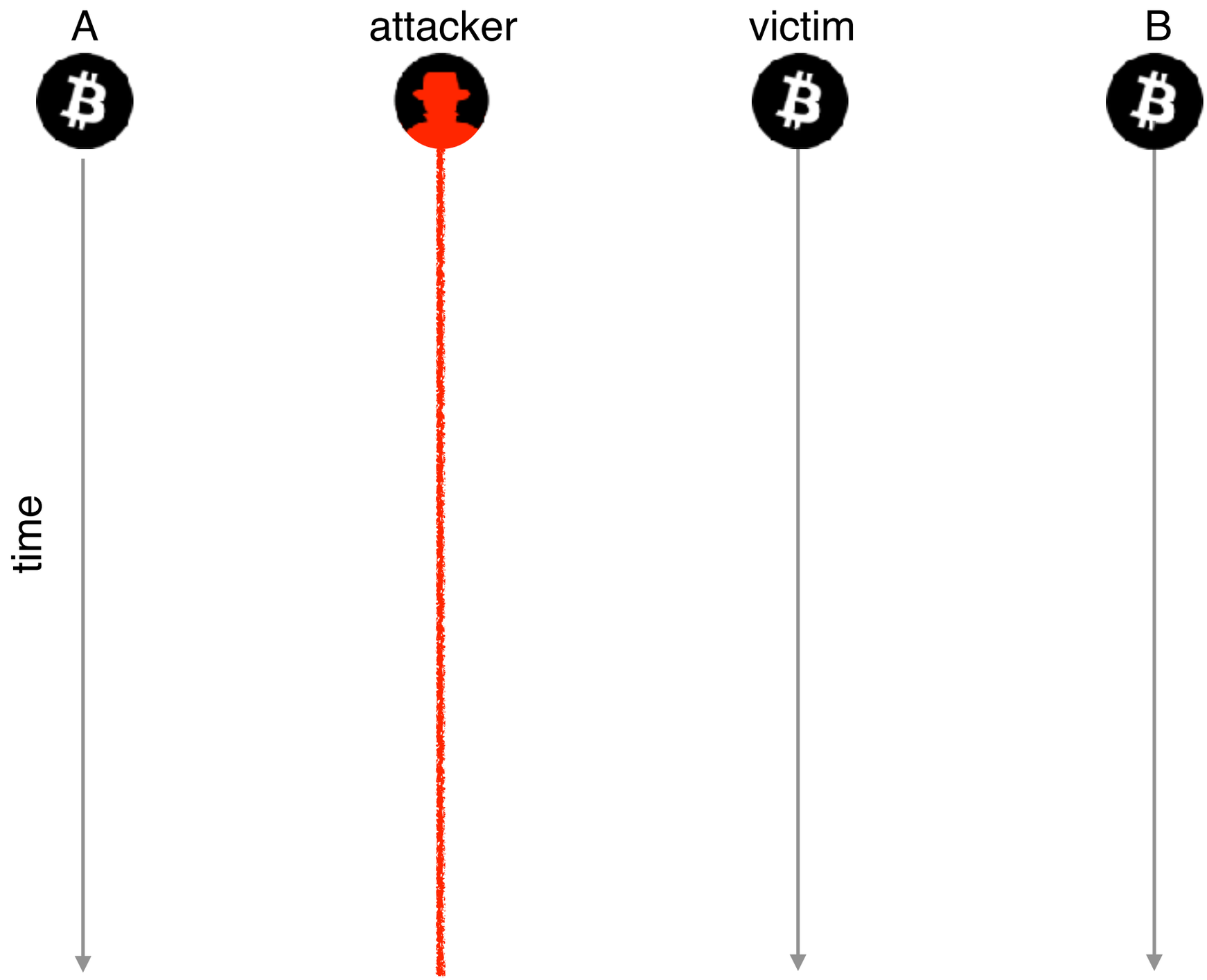
unable to collaborate to the peer-to-peer network

How does a delay attack work?

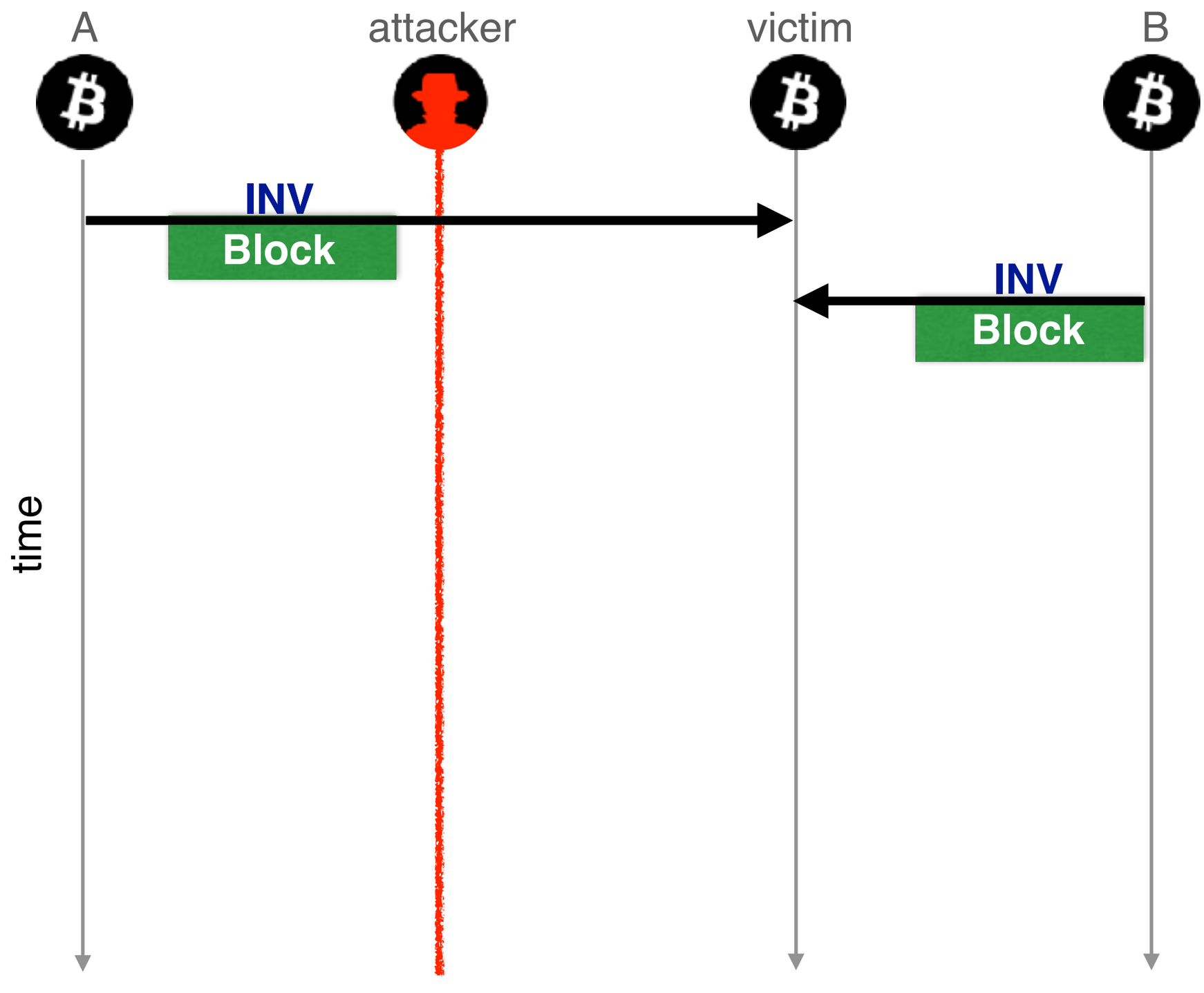
Consider these three Bitcoin nodes



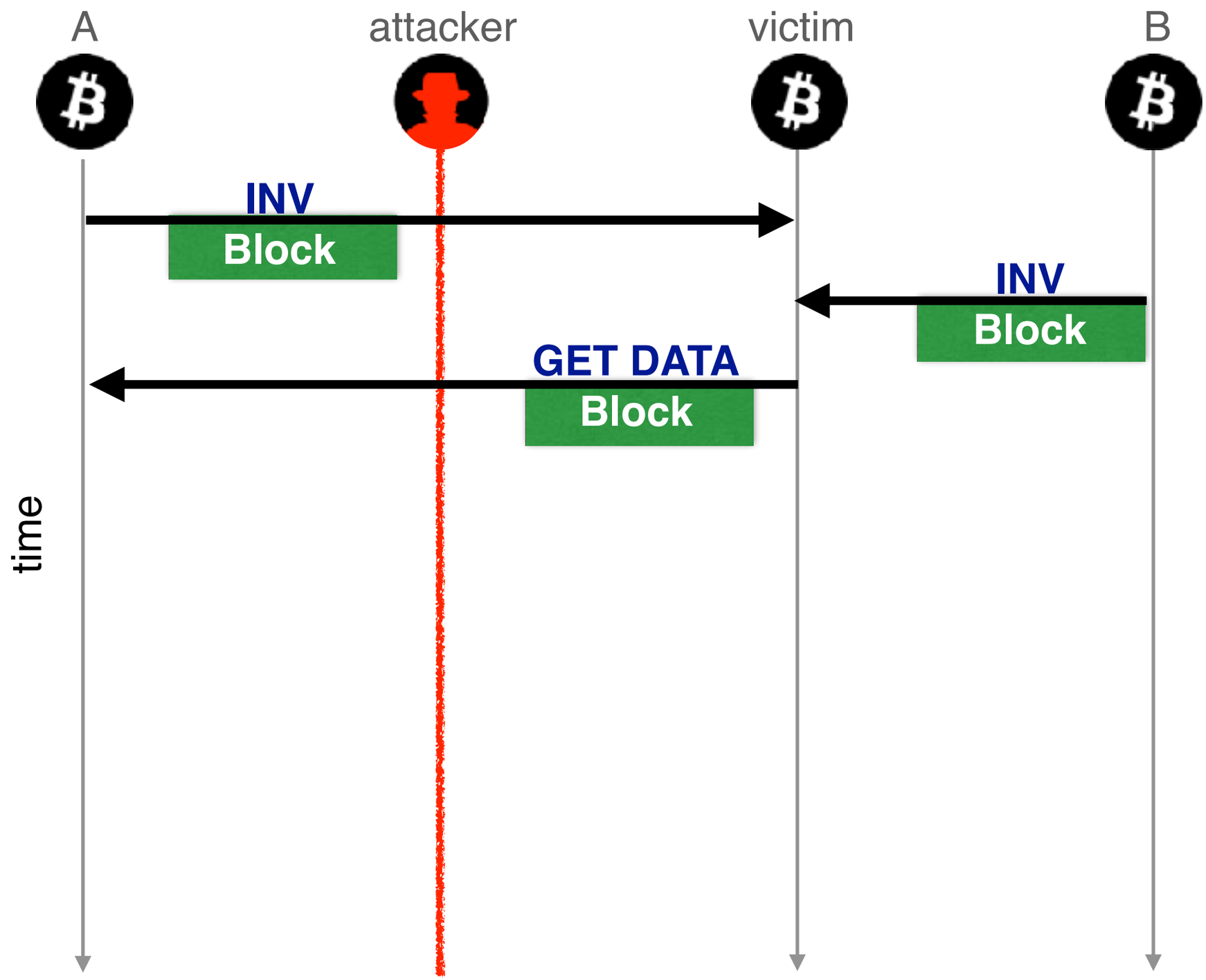
An attacker wishes to delay the block propagation towards the victim



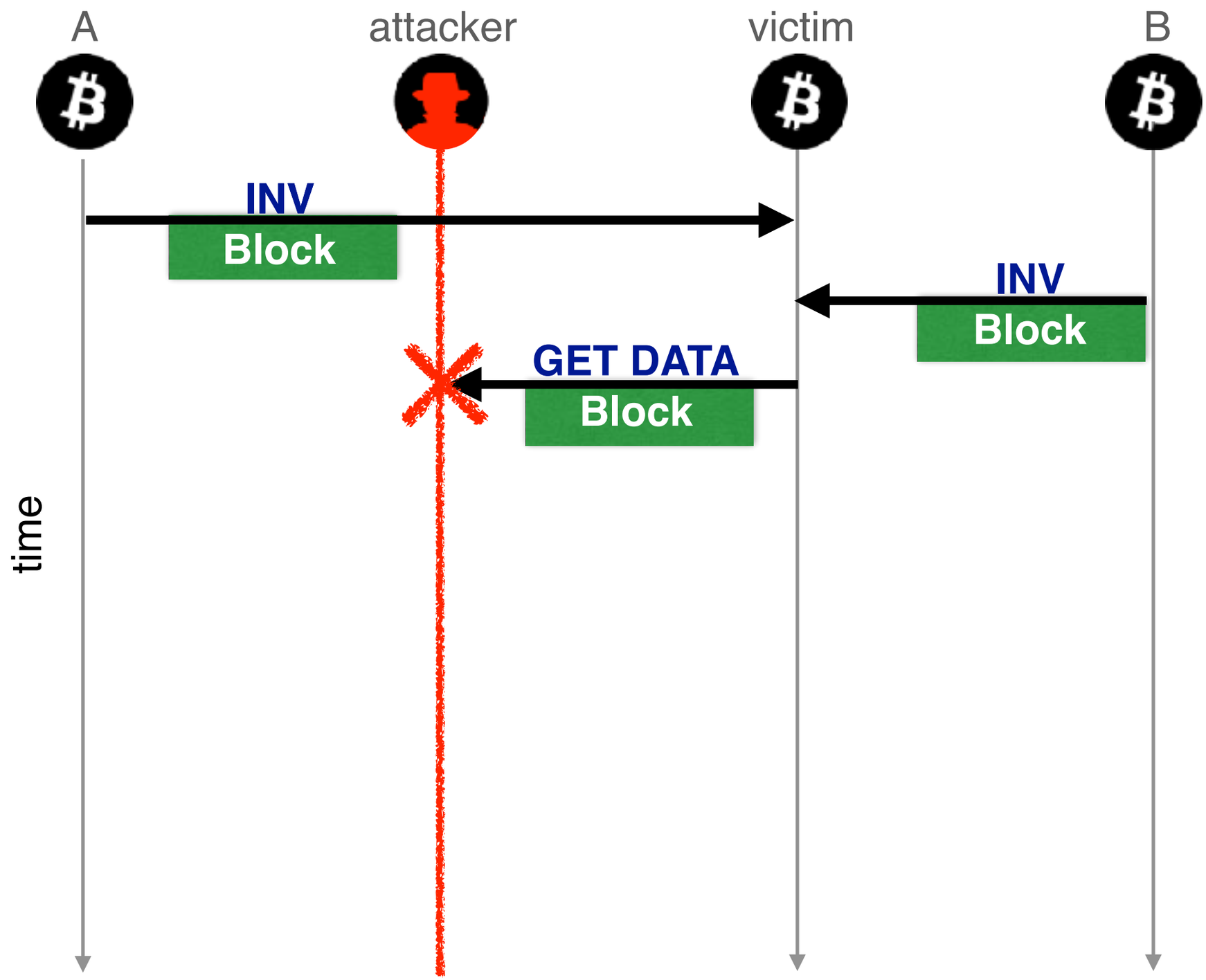
The victim receives two advertisement for the **block**



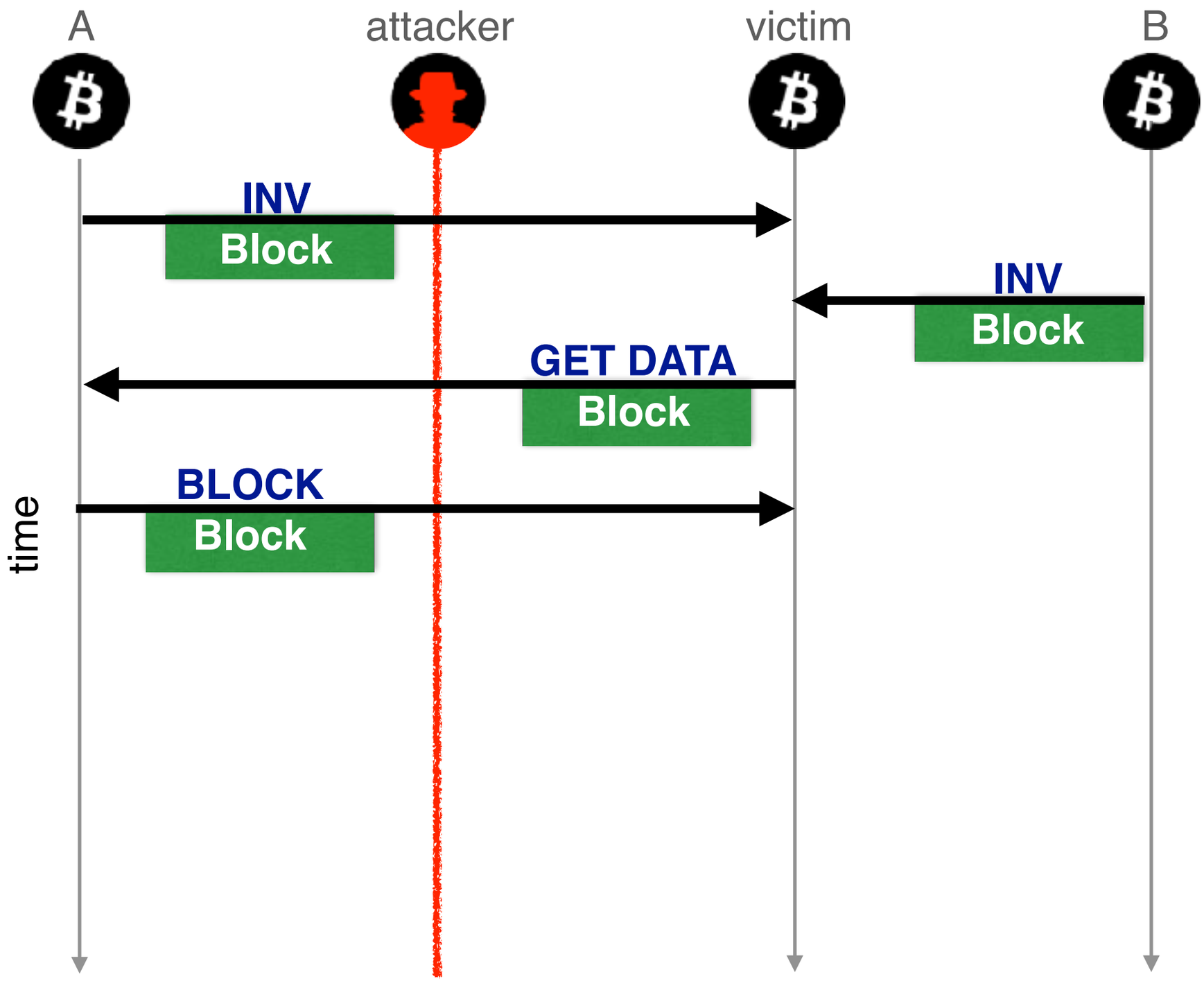
The victim requests the **block** to one of its peer, say A



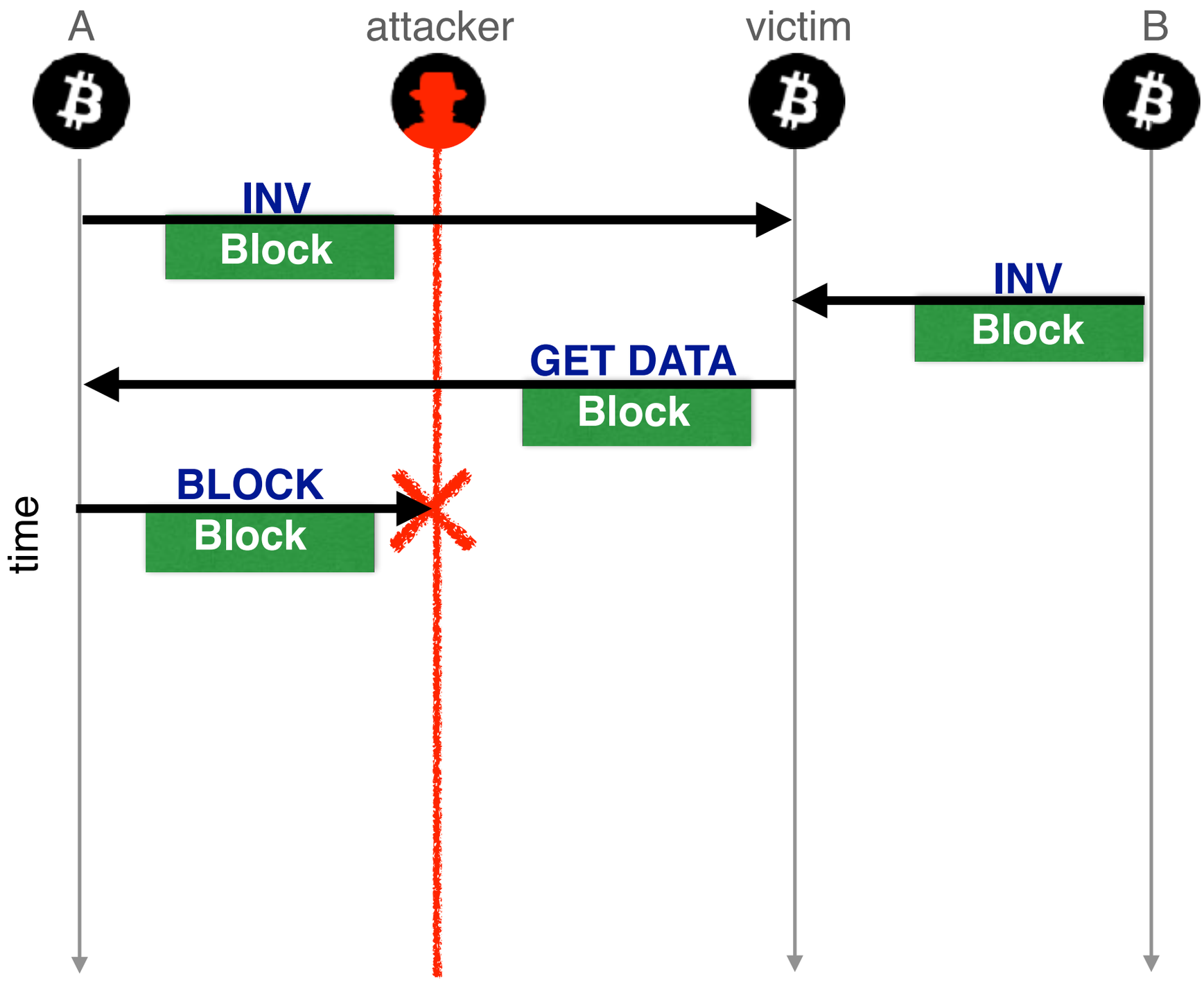
As a MITM, the attacker could drop the **GETDATA** message



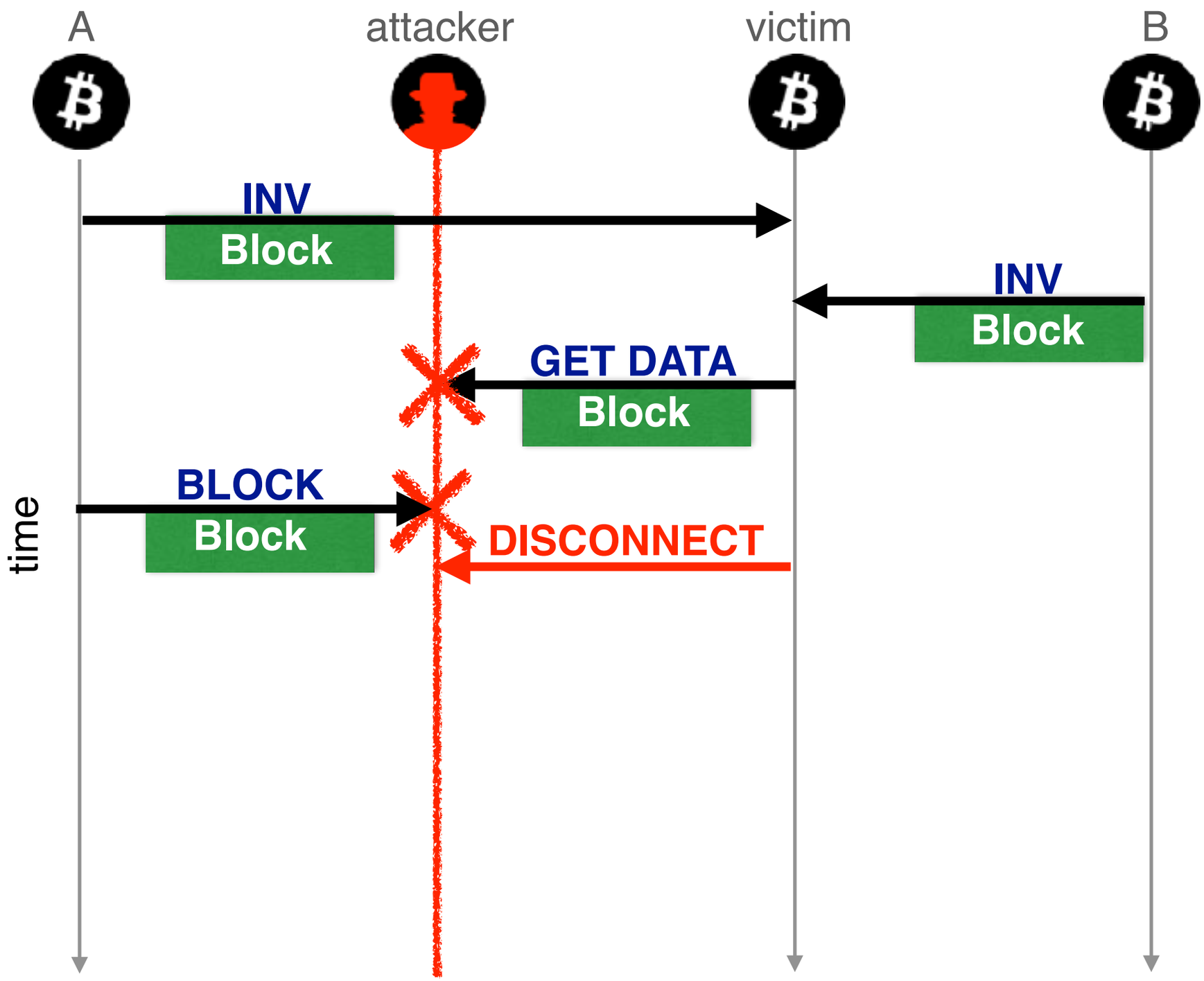
Similarly, the attacker could drop the delivery of the **block** message



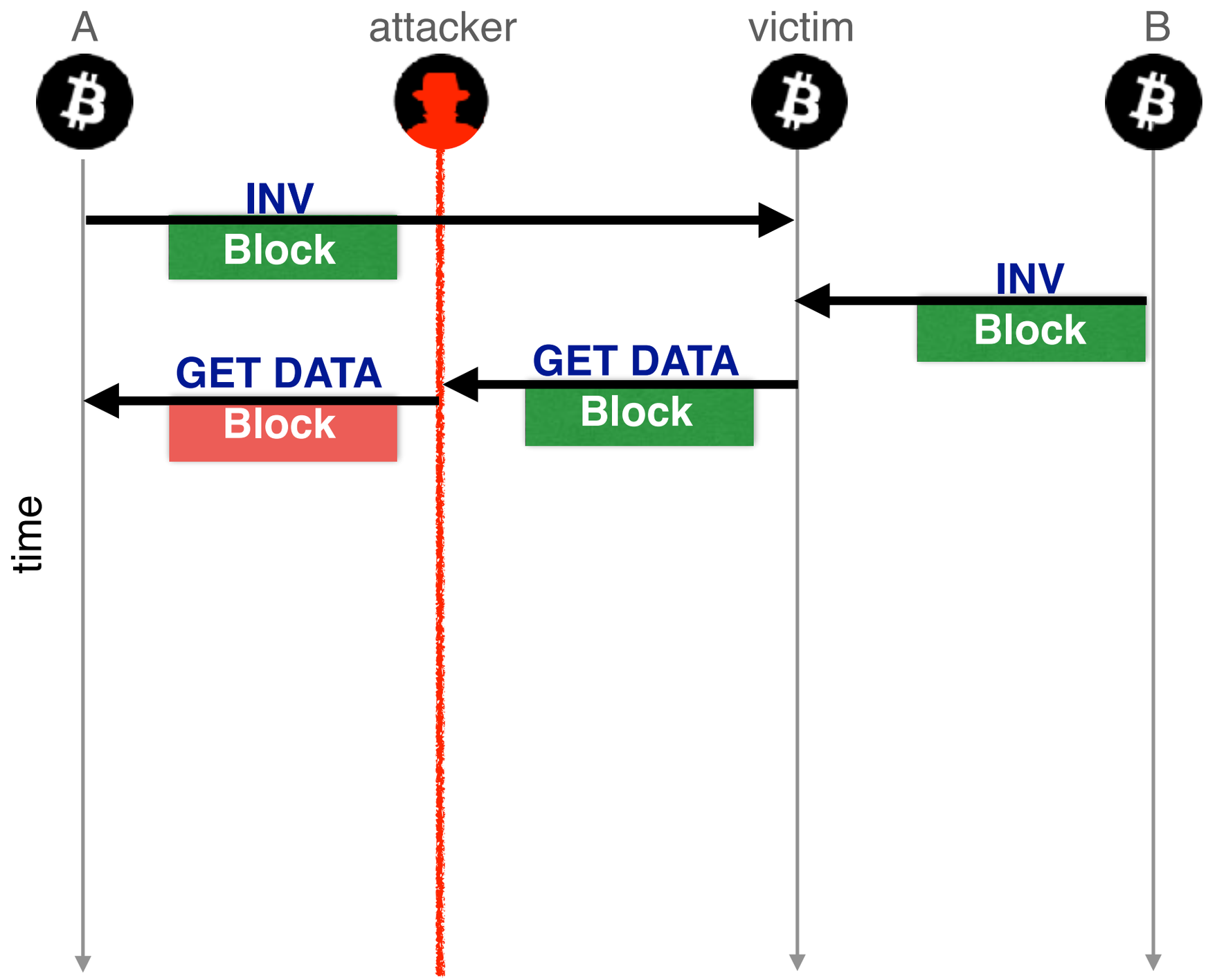
Similarly, the attacker could drop the delivery of the **block** message



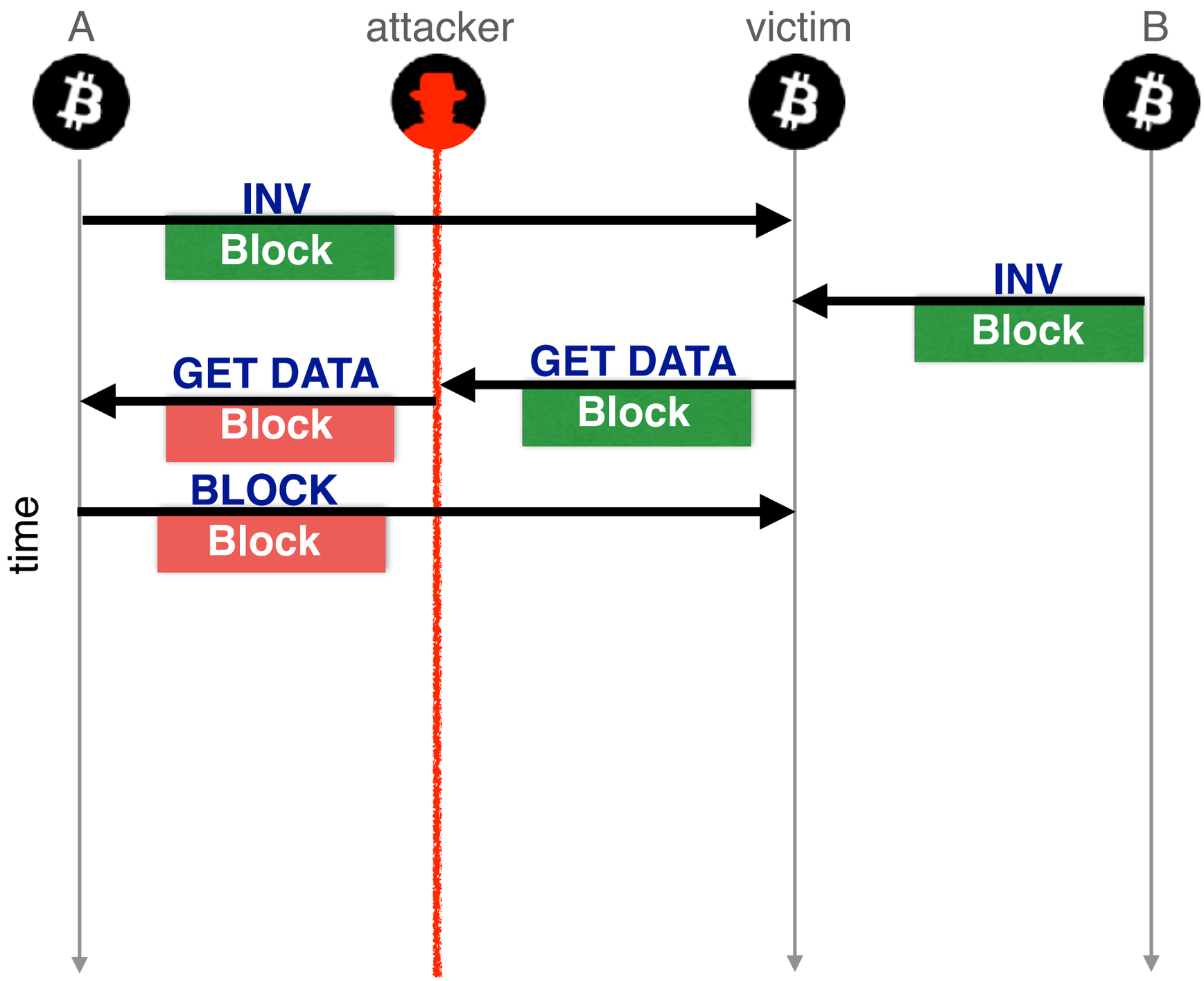
Yet, both cases will lead to the victim killing the connection (by the TCP stack on the victim)



Instead, the attacker could intercept the **GETDATA** and modifies its content

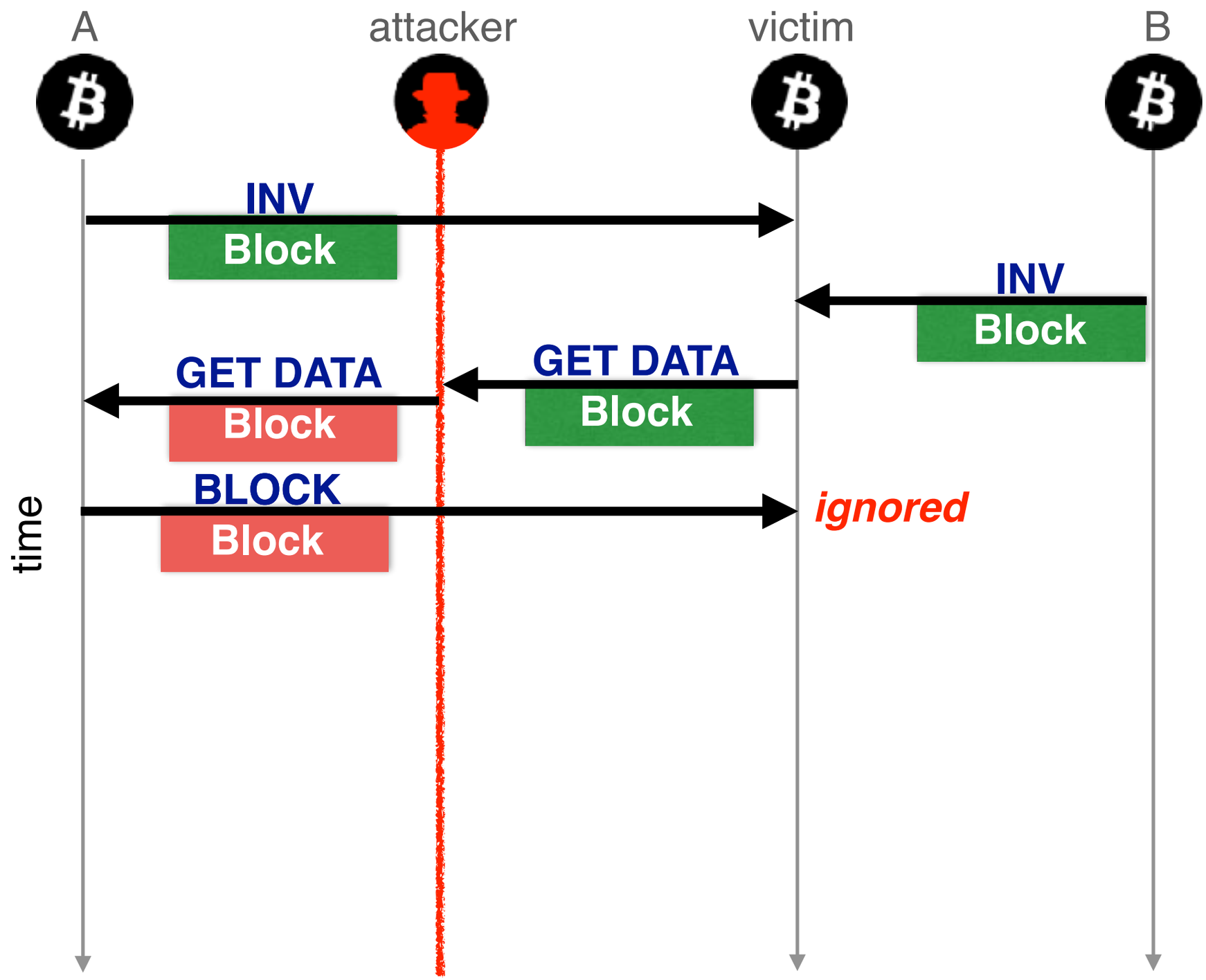


By modifying the ID of the requested block,
the attacker triggers the delivery of an older **block**

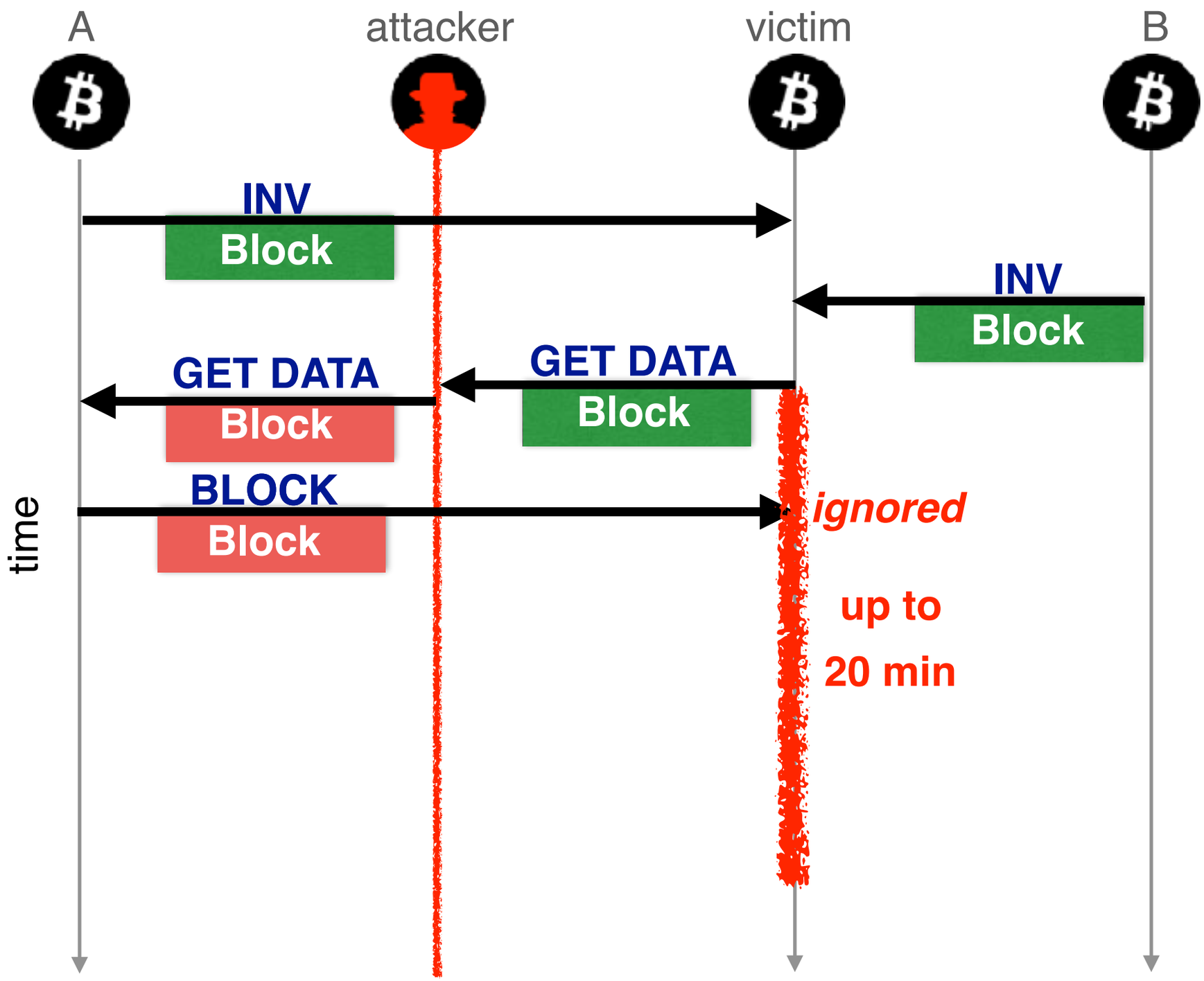


The delivery of an older block triggers

no error message at the victim



From there on, the victim will wait for 20 minutes for the actual block to be delivered



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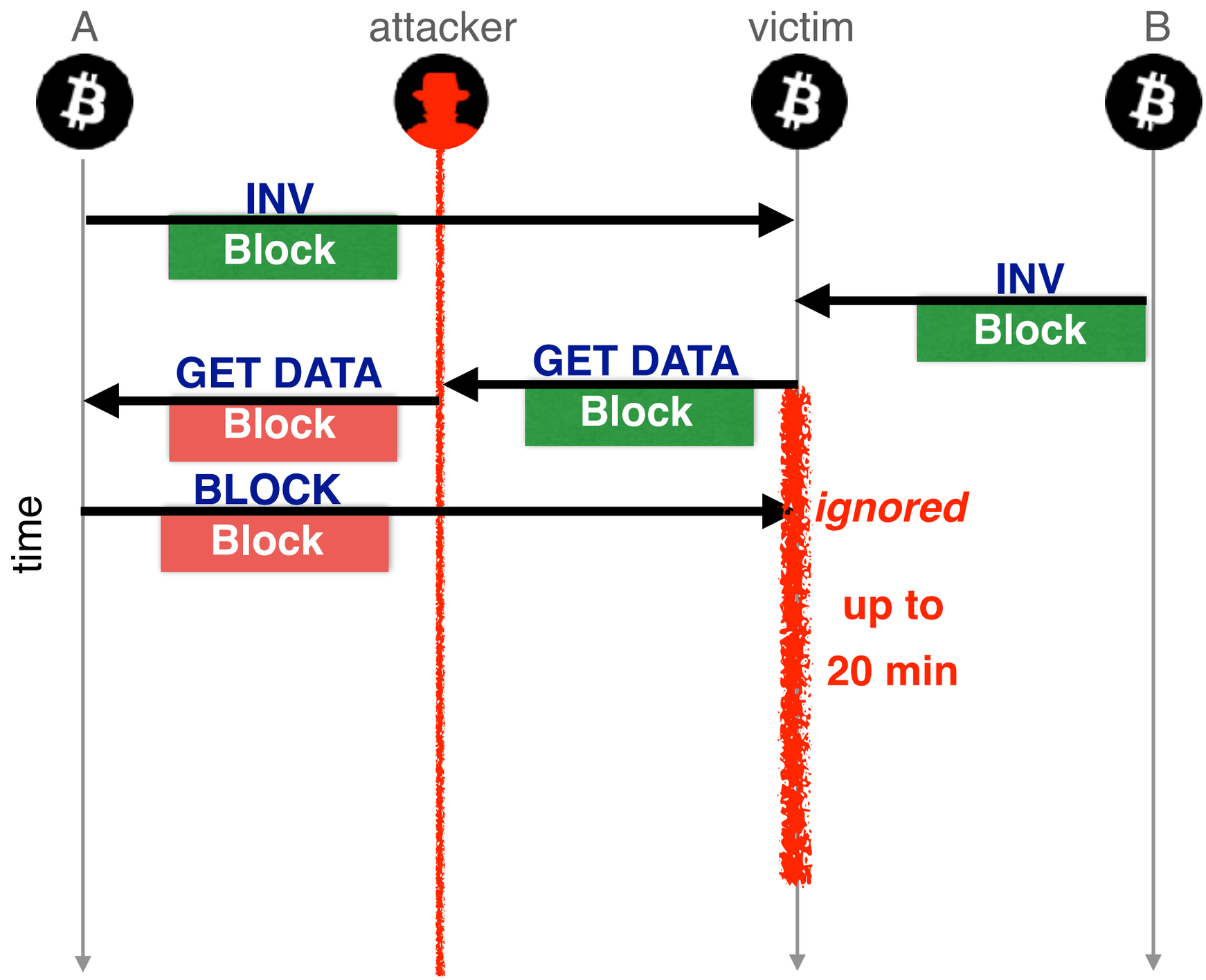
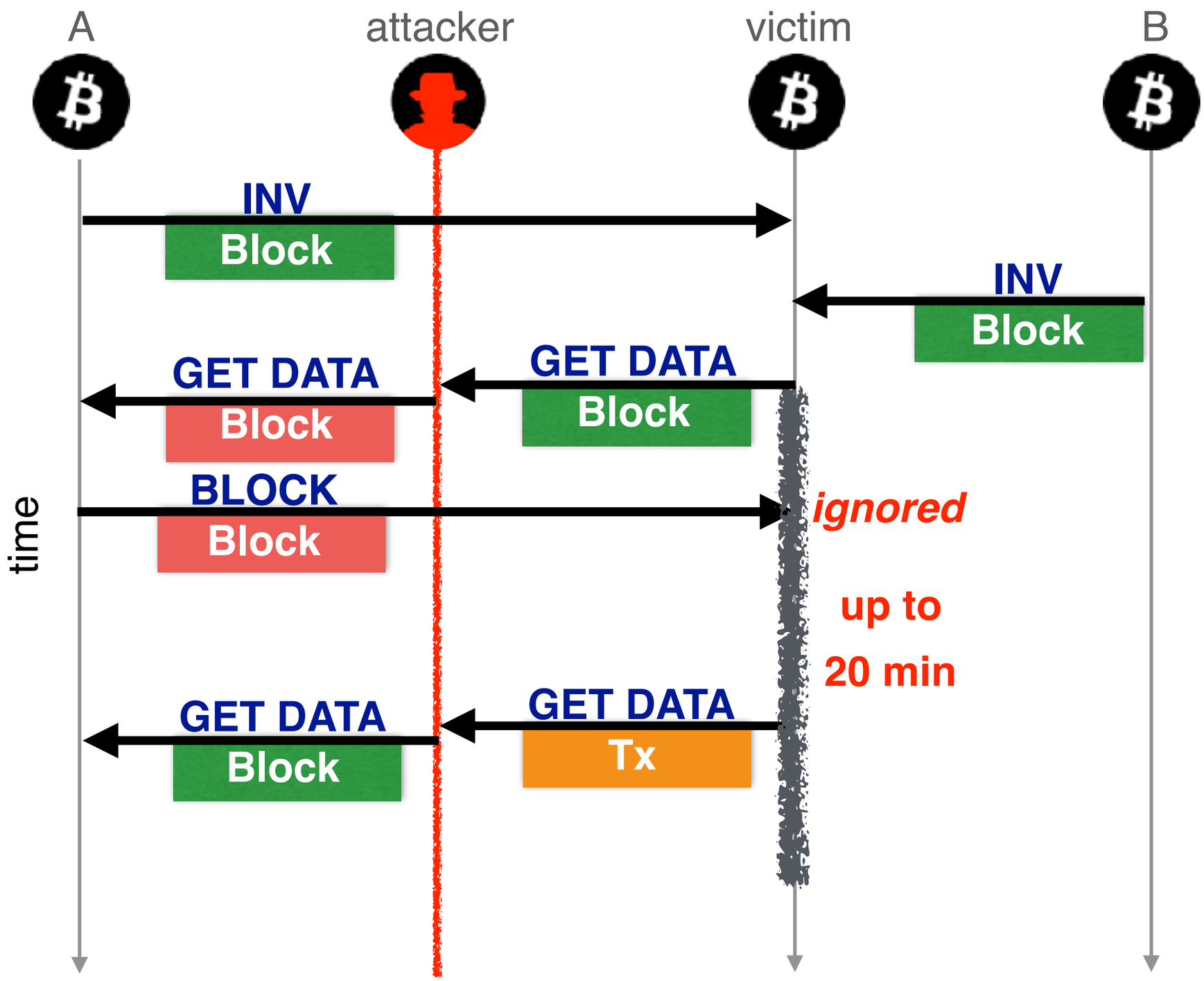
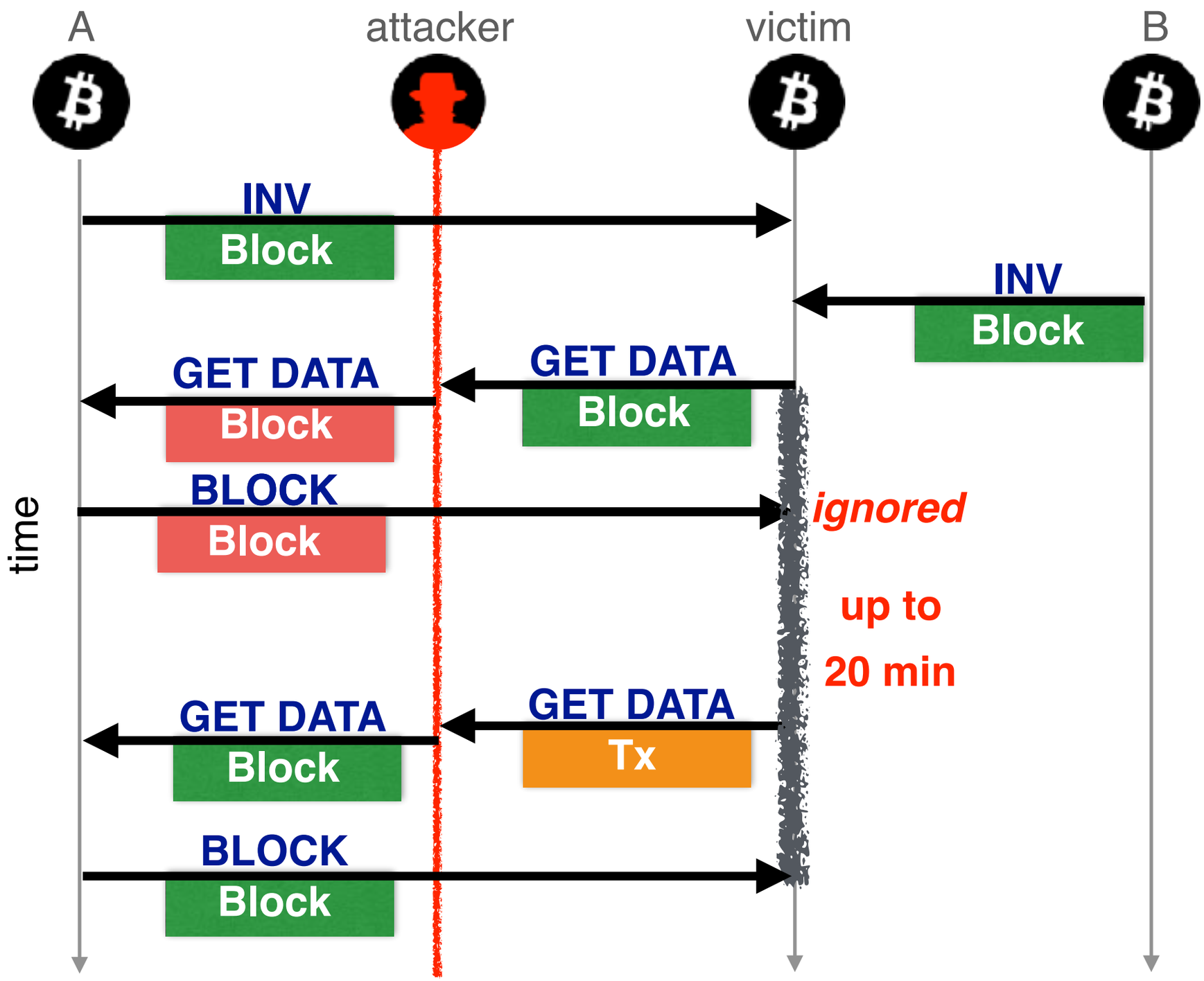


To keep the connection alive, the attacker can trigger the block delivery by modifying another **GETDATA** message



Doing so, the block is delivered before the timeout and the attack goes undetected (and could be resumed)



We evaluated the delay attack in terms of effectiveness and practicality

Effectiveness

How much time does the victim stay uniformed?

Practicality

Is it likely to happen?

We performed the attack
on a percentage of a node's connections (*)

(*) software available online: https://btc-hijack.ethz.ch/

The attacker can keep the victim uninformed
for most of its uptime while staying under the radar

The attacker can keep the victim uninformed

for most of its uptime while staying under the radar

even if the attacker intercepts

a fraction of the node connection

% intercepted connections 50%

% intercepted connections	50%
% time victim does not have the most recent block	63.2%

The vast majority of the Bitcoin network is at risk

% intercepted connections	50%
% time victim does not have the most recent block	63.2%
% nodes vulnerable to attack	67.9%

Hijacking Bitcoin

Routing Attacks on Cryptocurrencies

Countermeasures exist for both types of attacks

Delay attacks could be prevented with short and long-term countermeasures

Long-term	Use end-to-end encryption or MAC

prevent delay attacks (not partition attacks)

Delay attacks could be prevented with short and long-term countermeasures

Long-term	Use end-to-end encryption or MAC prevent delay attacks (not partition attacks)
Short-term	Routing-aware peer selection reduce risk of having one ISP seeing all connections

Countermeasures against partition attacks exist

Short-term	Host all Bitcoin clients in /24 prefixes
	reduce of a successful hijack

Countermeasures against partition attacks exist

Short-term	Host all Bitcoin clients in /24 prefixes reduce chances of a successful hijack
Long-term	Deploy secure routing protocols prevent partition attacks

Countermeasures against partition attacks exist

But are impractical

Host all Bitcoin clients in /24 prefixes

Deploy secure routing protocols

Countermeasures against partition attacks exist

But are impractical

Host all Bitcoin clients in /24 prefixes

increase BGP routing tables

Deploy secure routing protocols

Countermeasures against partition attacks exist

But are impractical

Host all Bitcoin clients in /24 prefixes
increase BGP routing tables

Deploy secure routing protocols

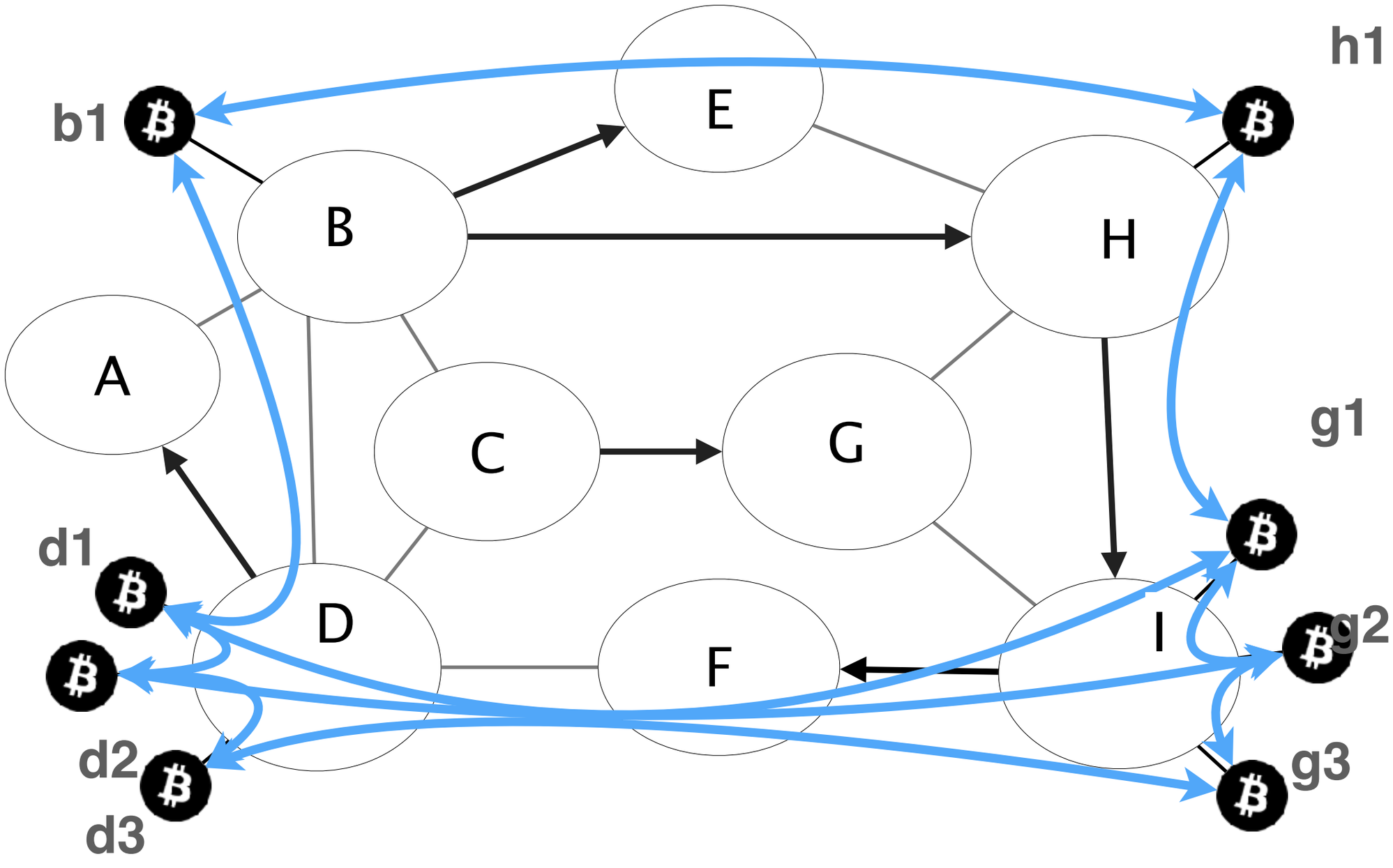
ISP collaboration required

Build additional secure channel to allow communication even if the Bitcoin network is partitioned

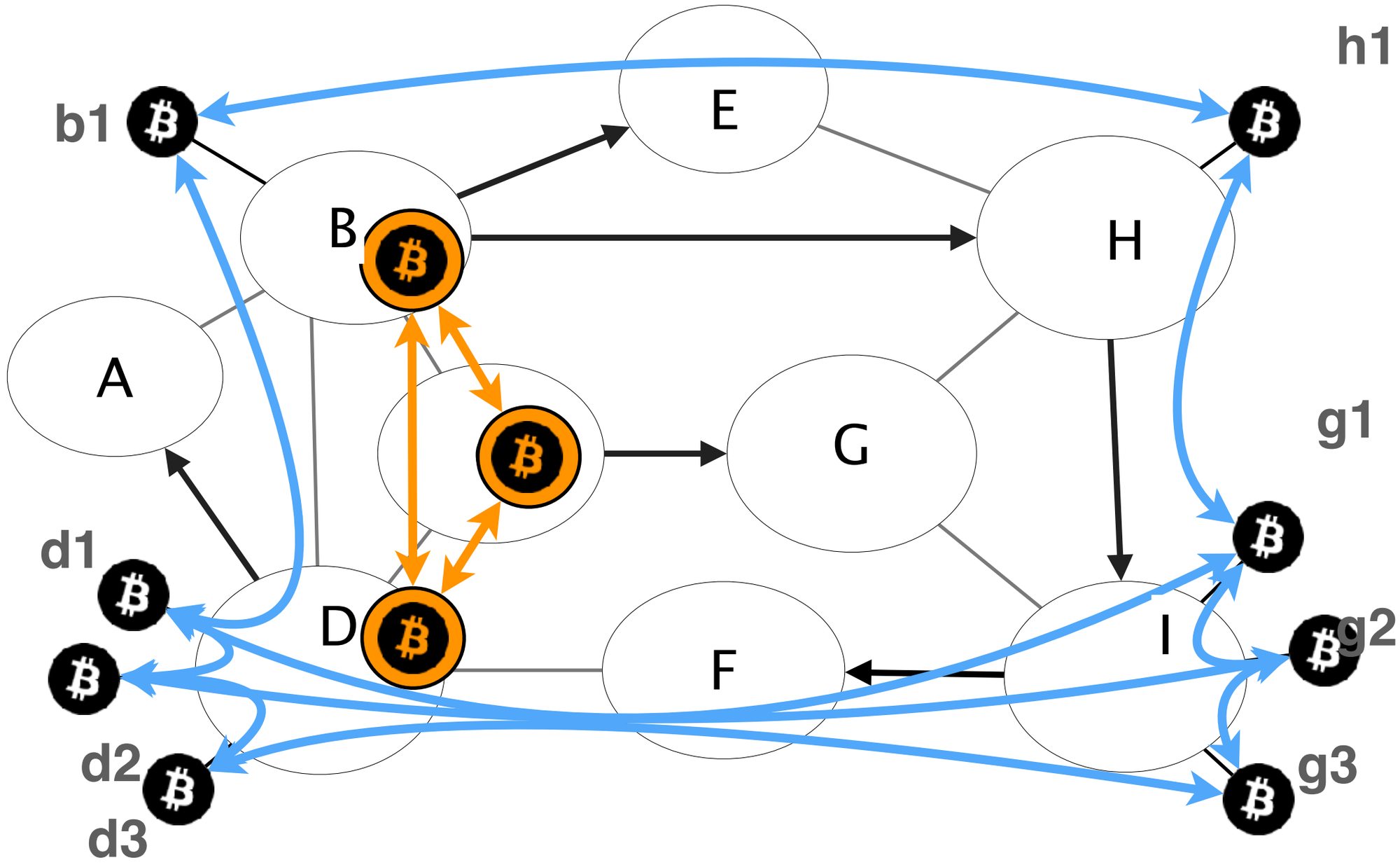
SABRE = Secure Relay Location + Robust Design

SABRE = Secure Relay Location + Robust Design

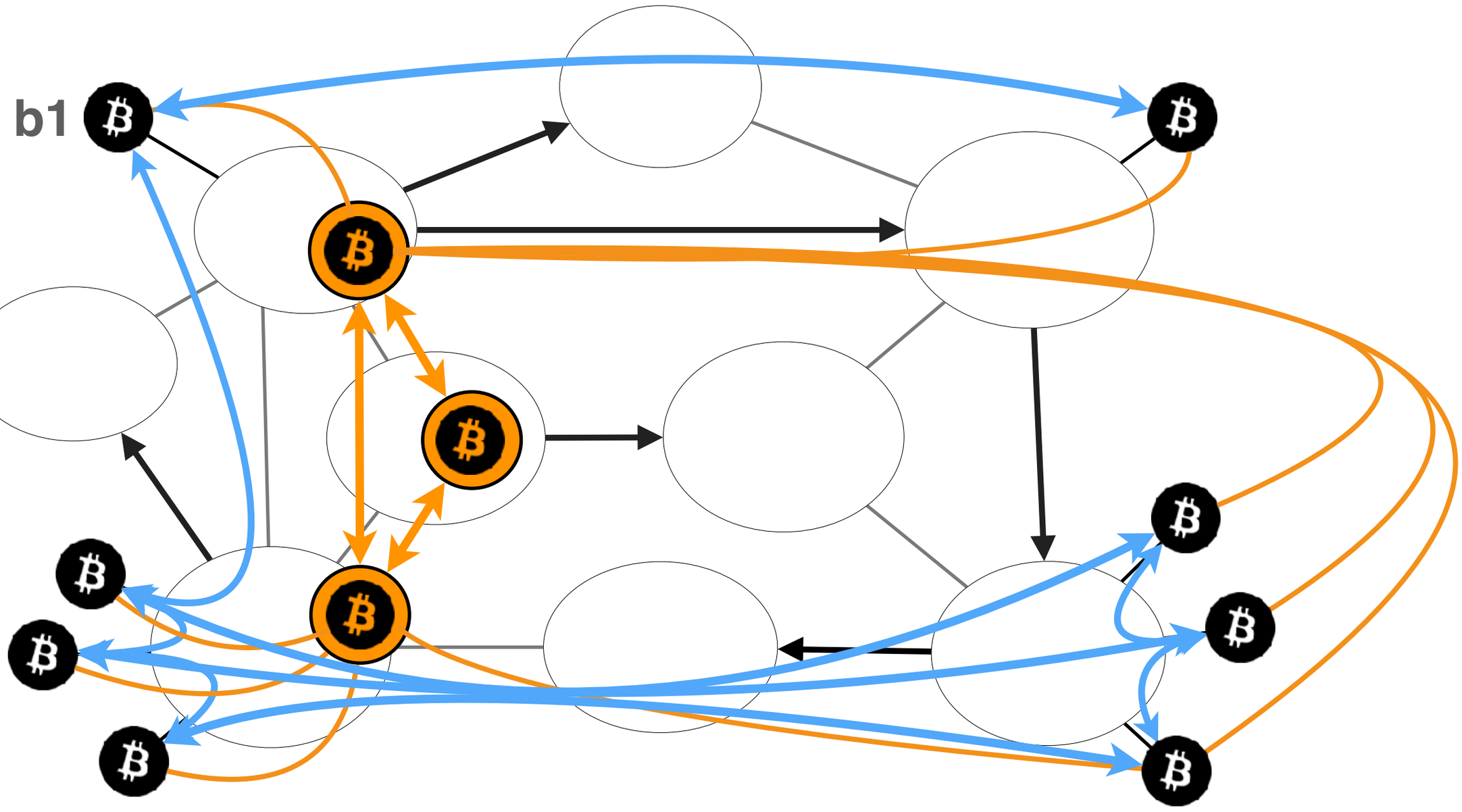
add few clients that connect to
each other and to all other clients


b1
h1
E
B
H
A
C
G
g1
d1
D
F
I
g2
d2
g3
d3

SABRE: Additional relay network of relay nodes



Clients connect to at least one relay node



SABRE = Secure Relay Location + Robust Design

SABRE = Secure Relay Location + Robust Design

additional nodes protected against hijacking attacks

SABRE = Secure Relay Location + Robust Design

Open and Resilient against DDoS attacks

SABRE = Secure Relay Location + Robust Design

Secure Relay Placement

nodes in /24 prefix

peering ASes with no customers

k-connected graph of relays

relays cover most clients

Secure Relay Placement

nodes in /24 prefix

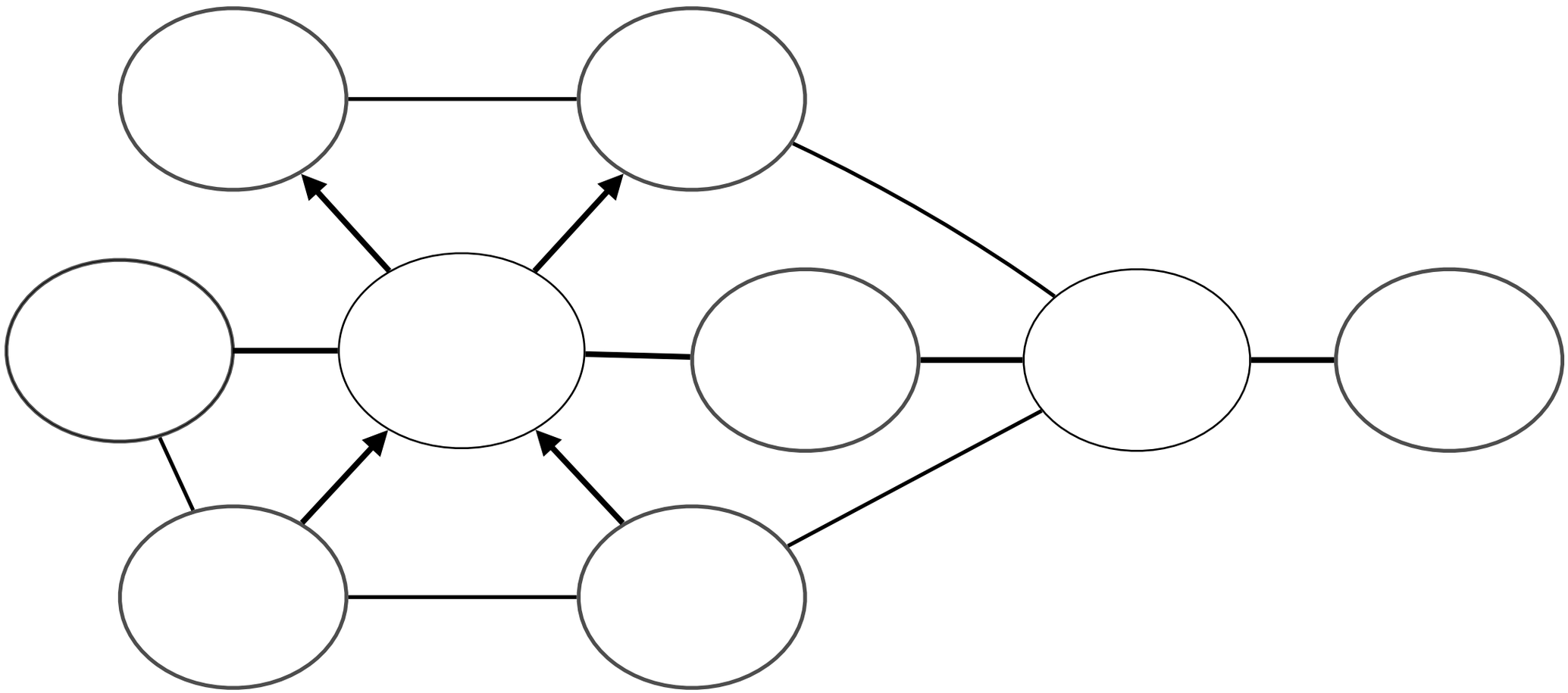
peering ASes with no customers

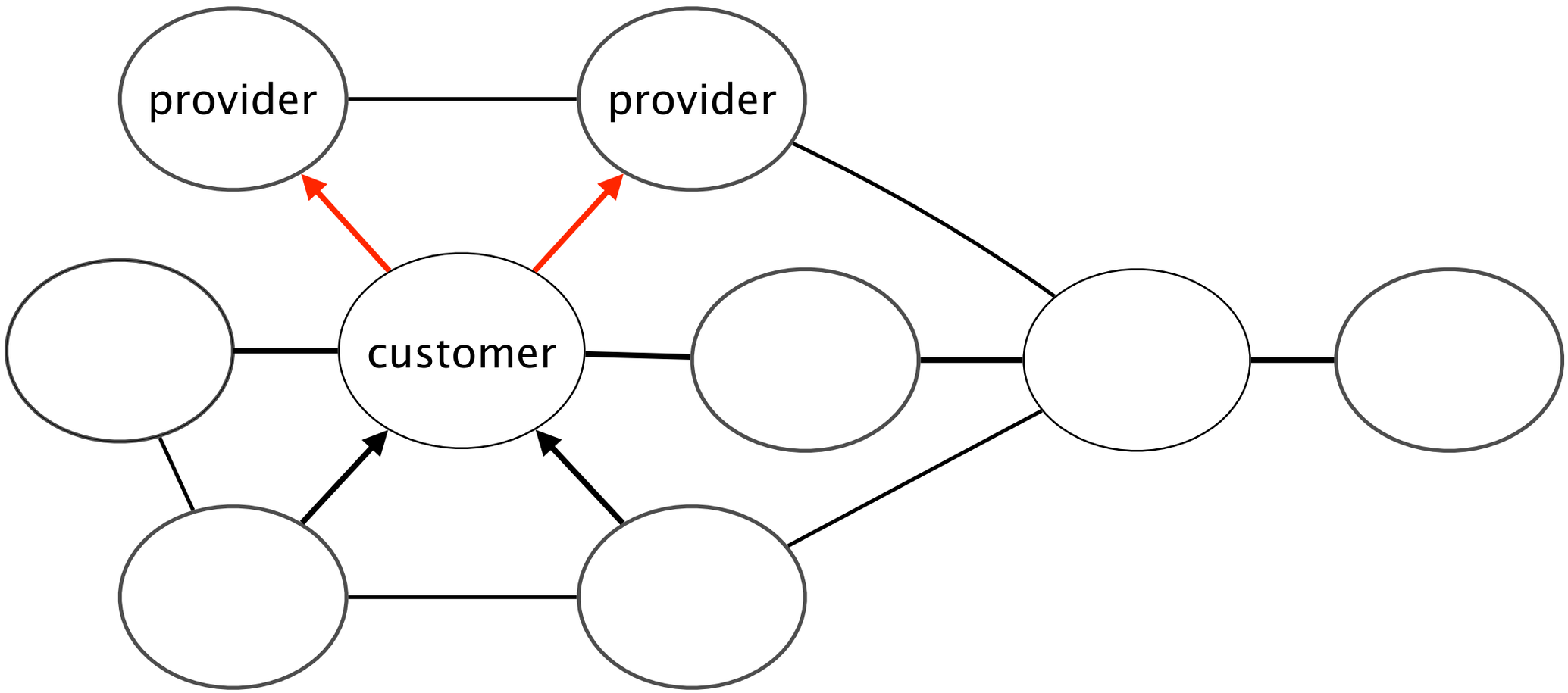
k-connected graph of relays

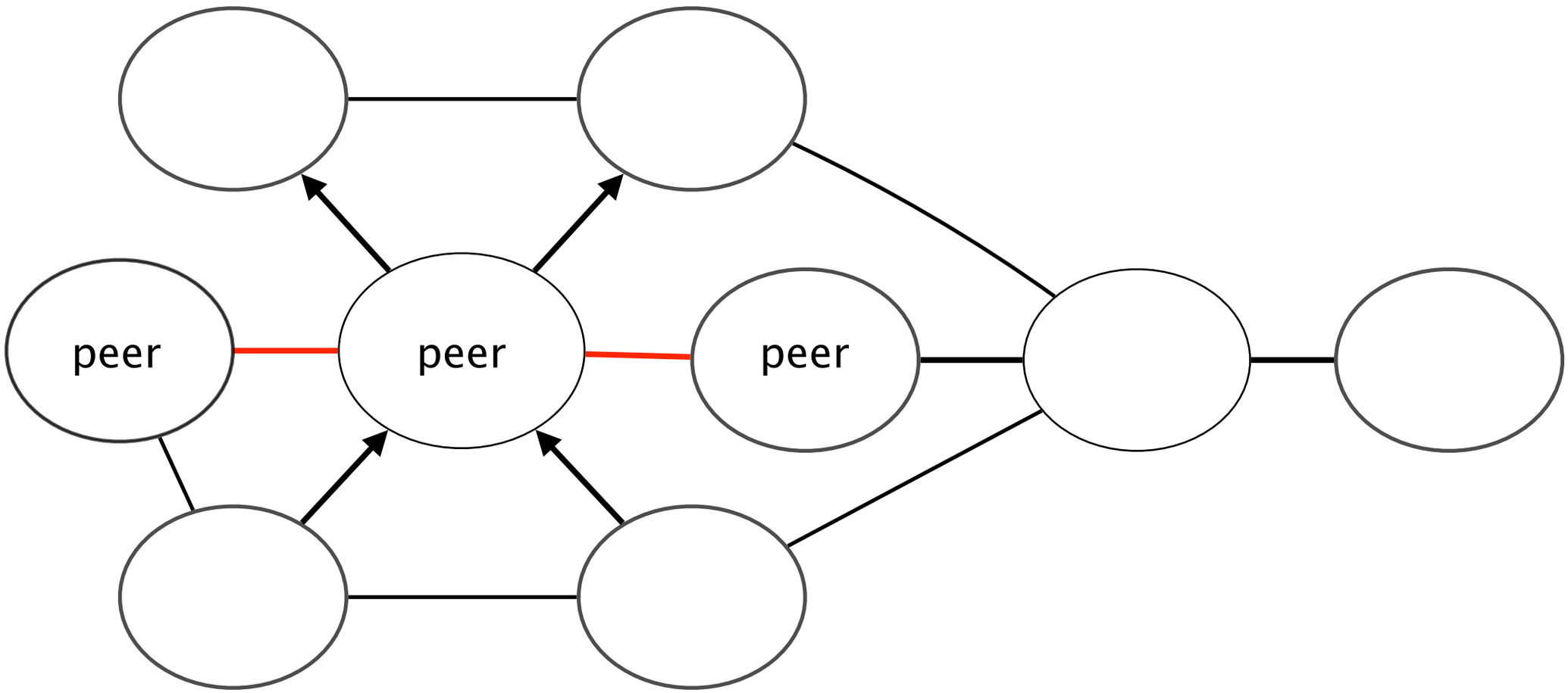
relays cover most clients

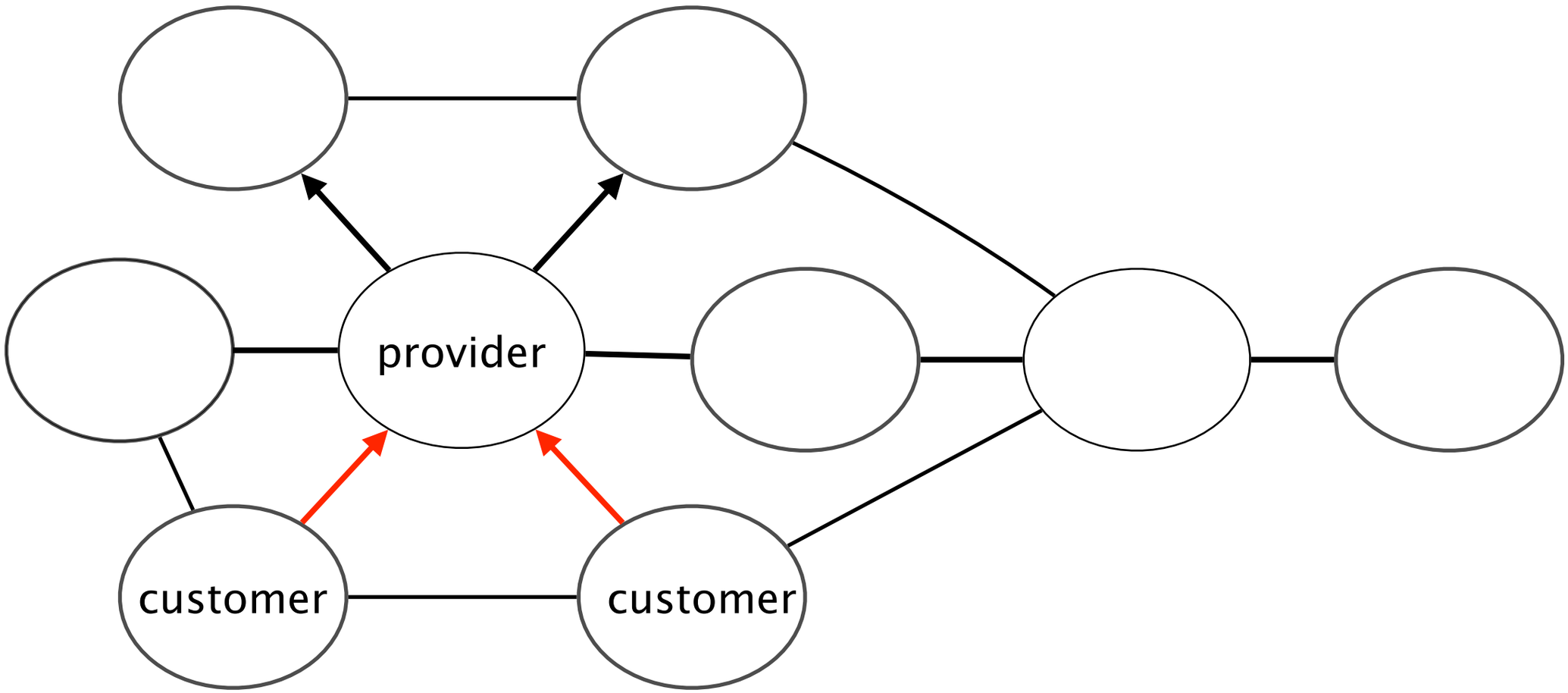
malicious prefix in competition with legitimate ones

Arrows show the money flow

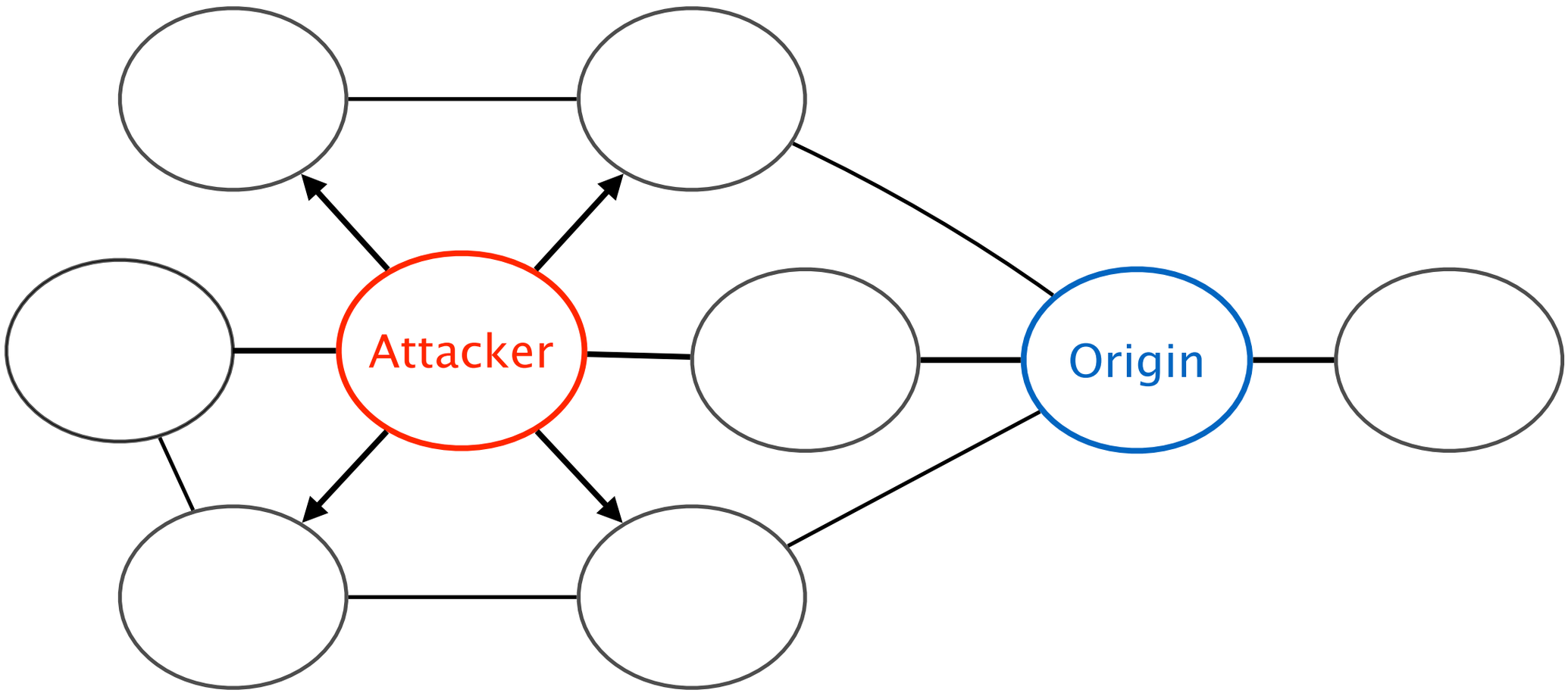



provider
provider
customer

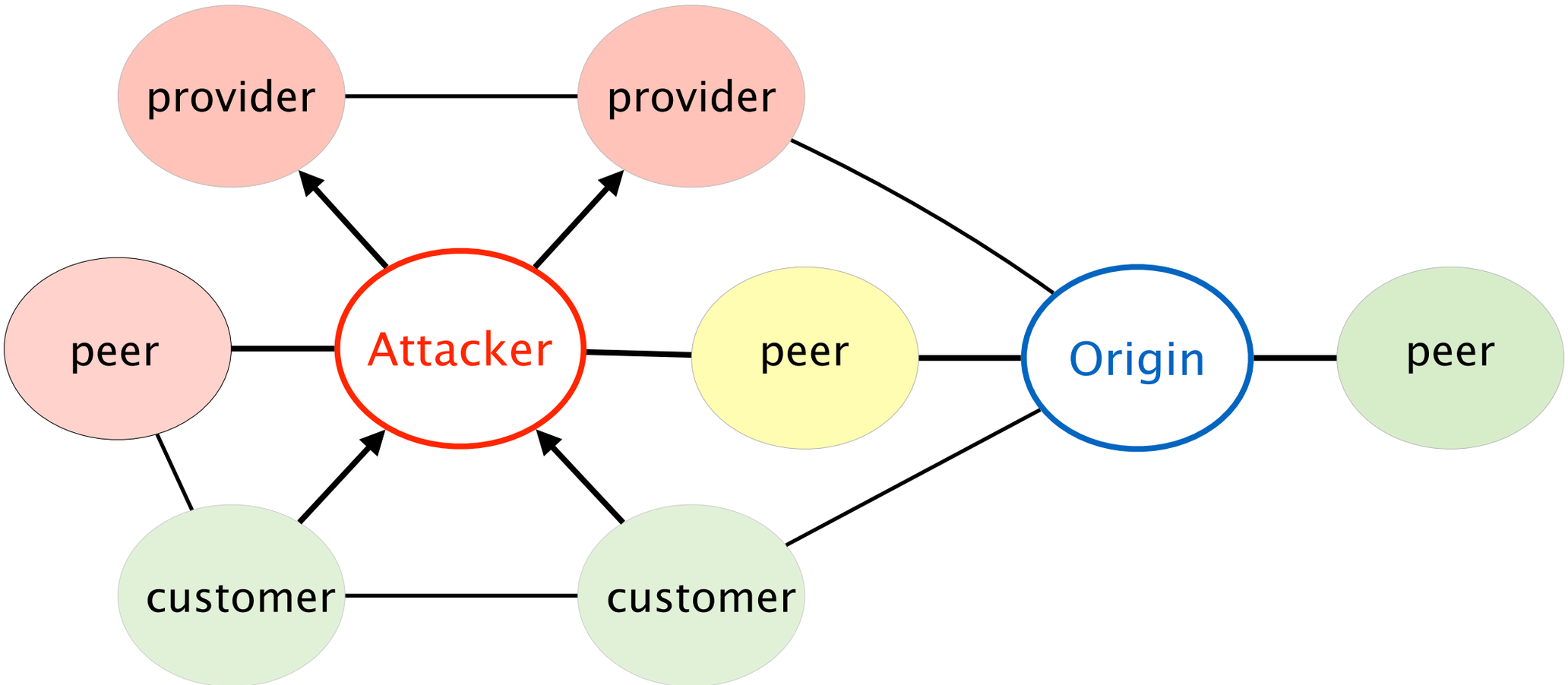

peer
peer
peer


provider
customer
customer

The attacker advertises same length prefix as the origin



~50% ASes would follow the attacker's advertisement



Secure Relay Placement

nodes in /24 prefix

peering ASes with no customers

k-connected graph of relays

relays cover most clients

Secure Relay Placement

nodes in /24 prefix

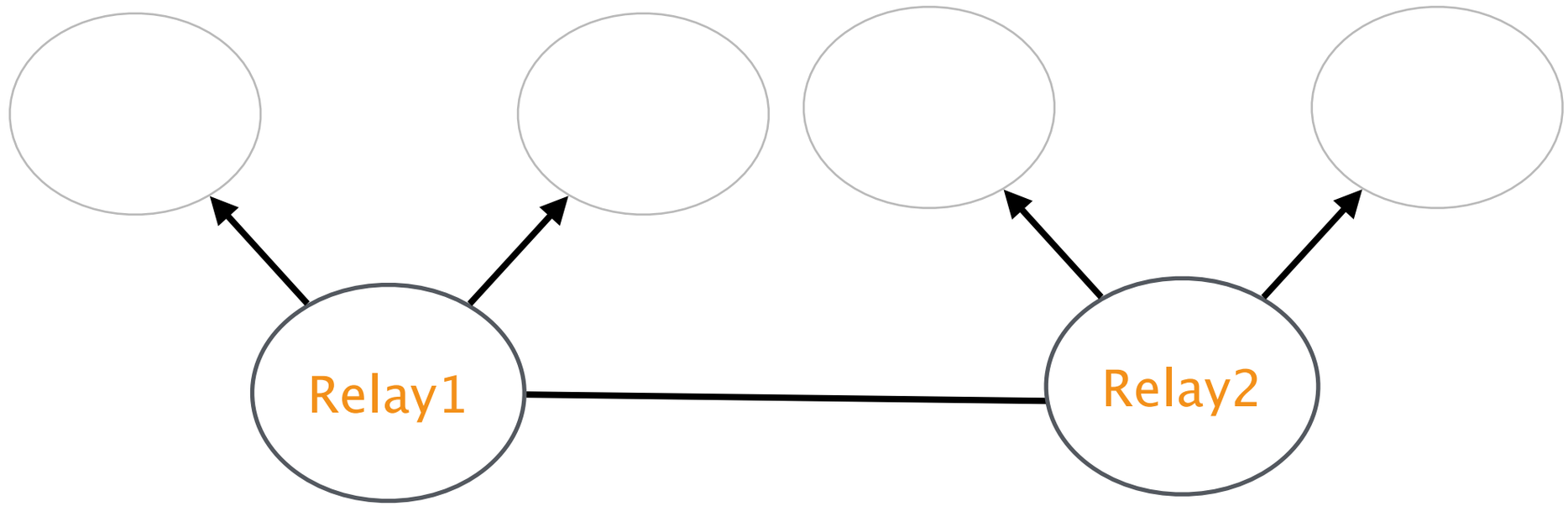
peering ASes with no customers

k-connected graph of relays

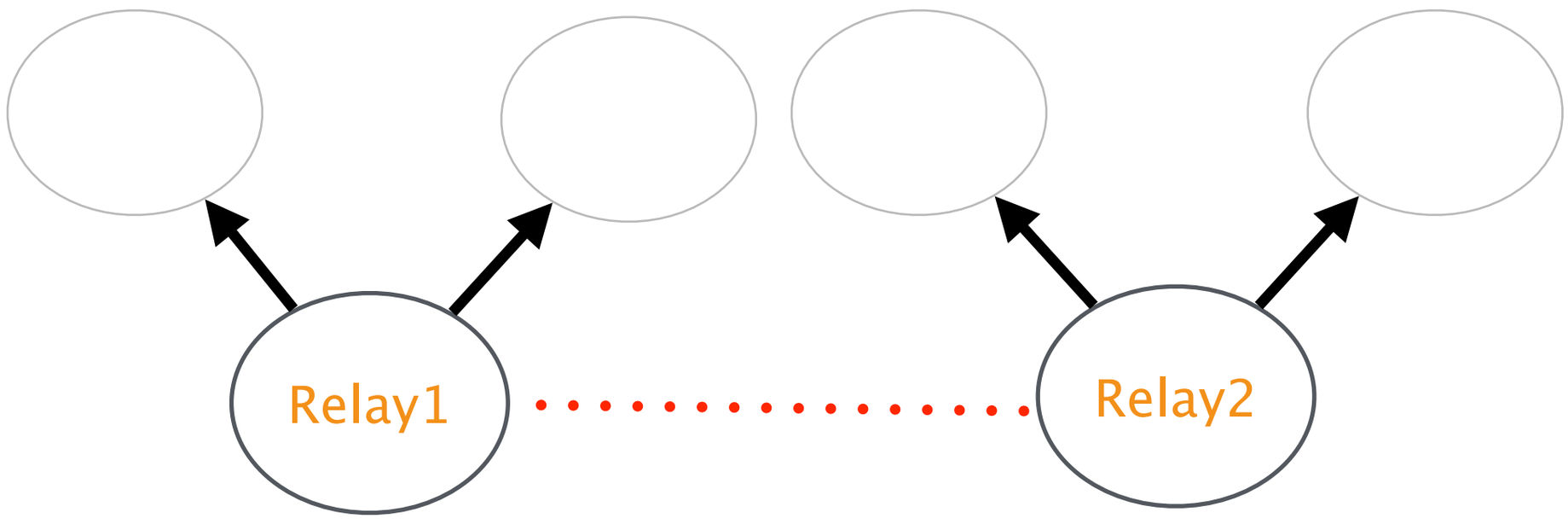
relays cover most clients

no strictly better prefix advertisement exists

No strictly better advertisement exist



Peering agreement can be revoked



Secure Relay Placement

nodes in /24 prefix

peering ASes with no customers

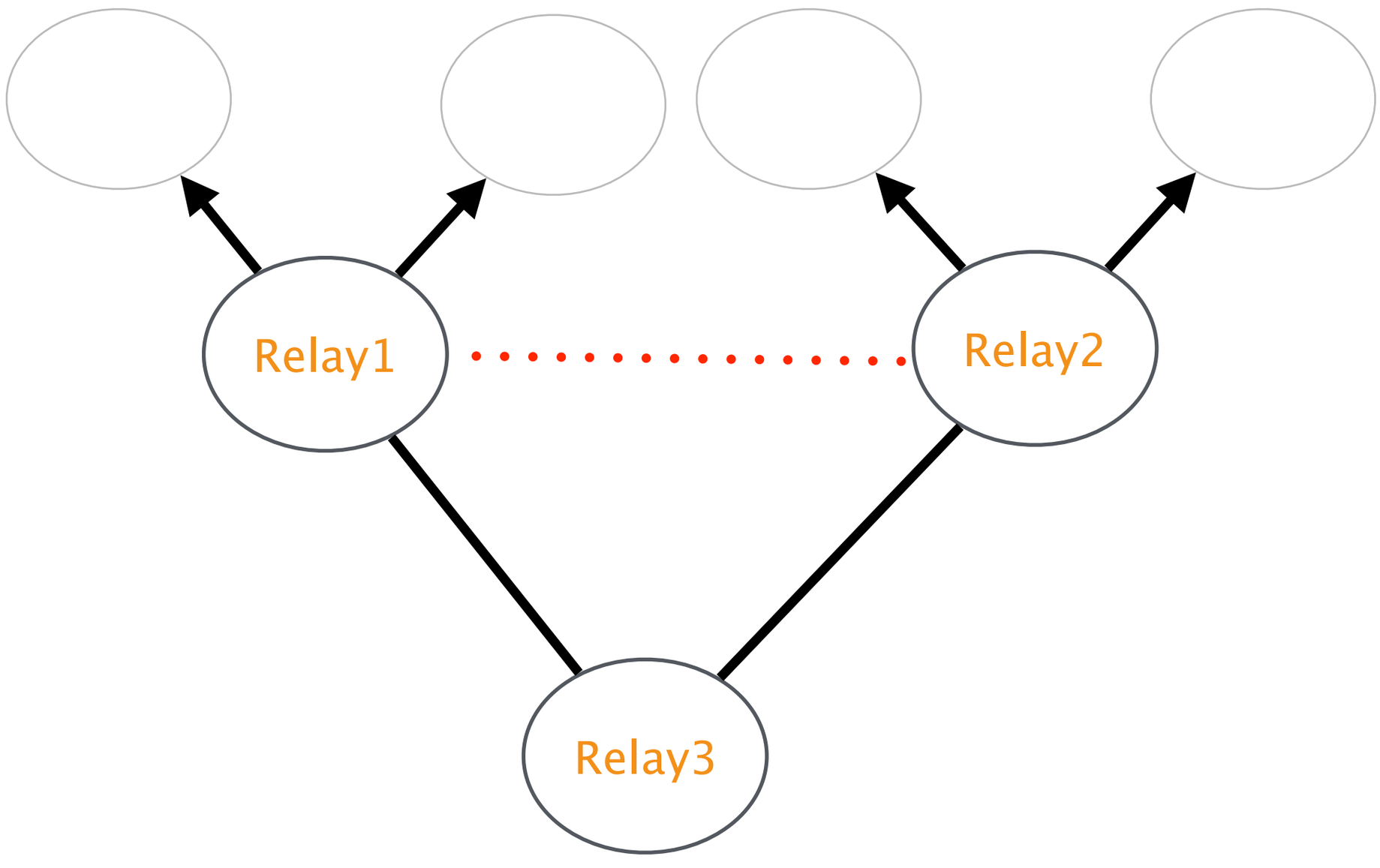
k-connected graph of relays

relays cover most clients

relay connectivity

is not affected by any k cuts

2-k connected graph retains connectivity



Secure Relay Placement

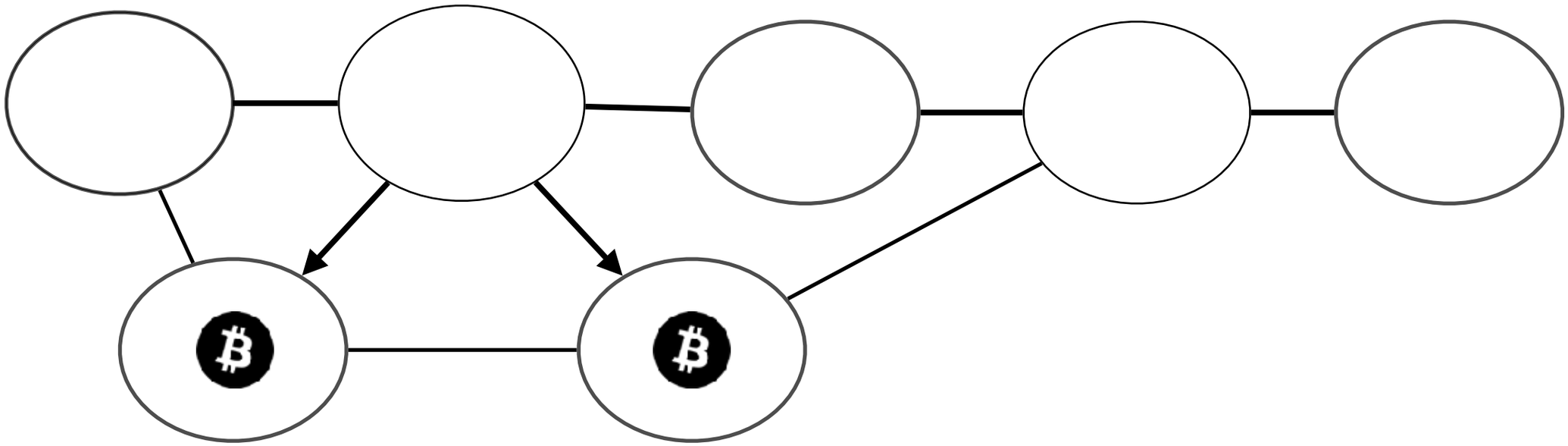
nodes in /24 prefix

peering ASes with no customers

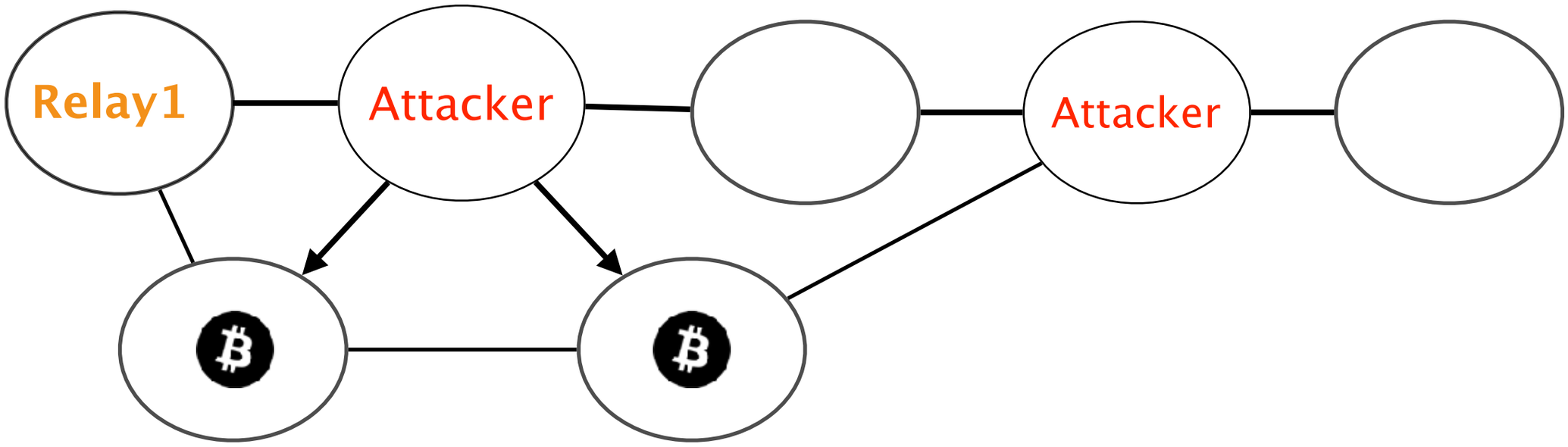
k-connected graph of relays

relays cover most clients

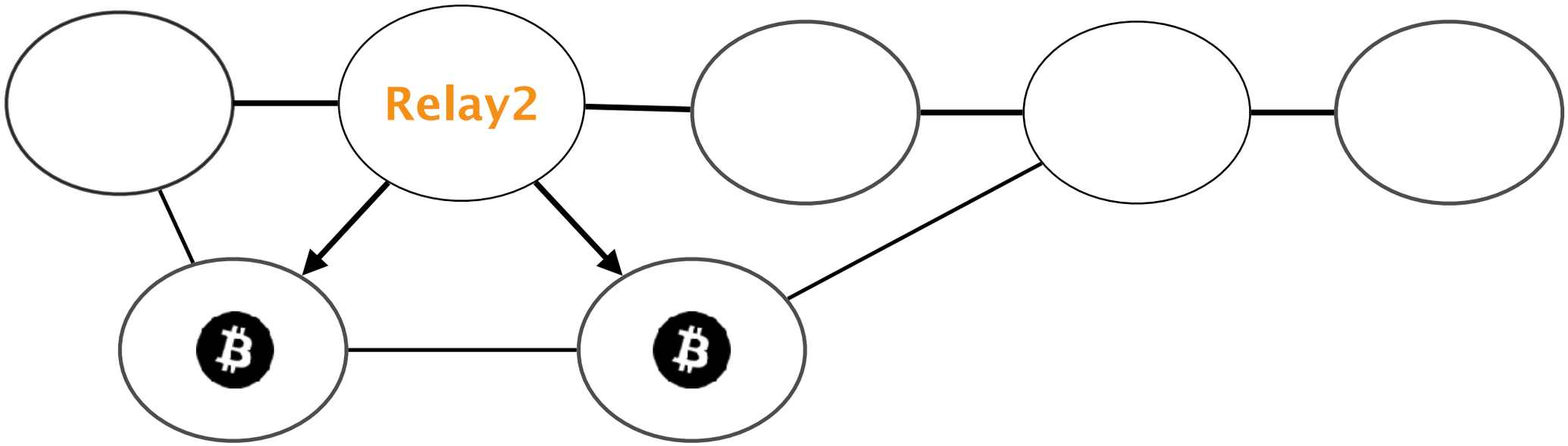
relays are in path that are more preferred than any alternative



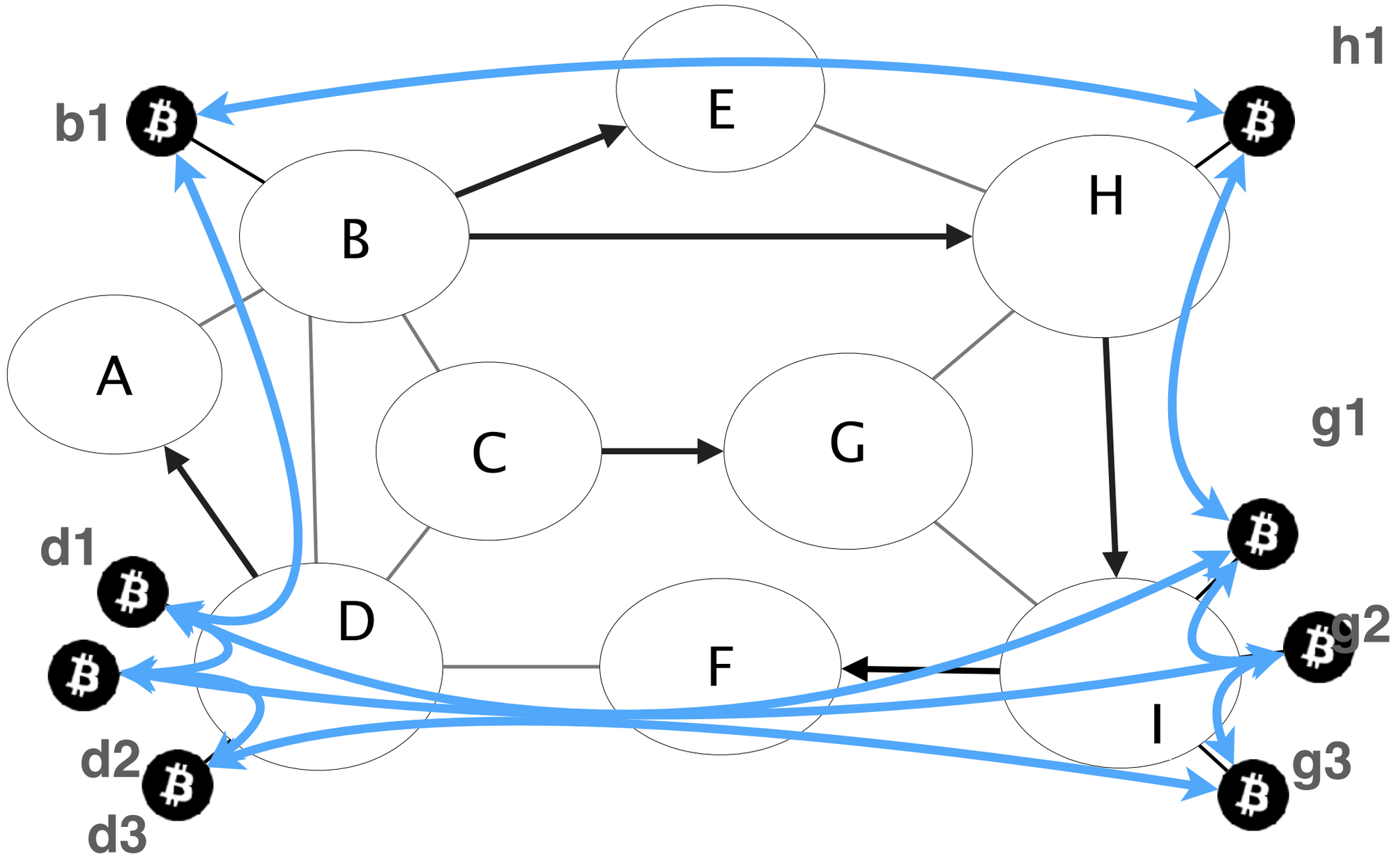
Two effective attackers against Relay1



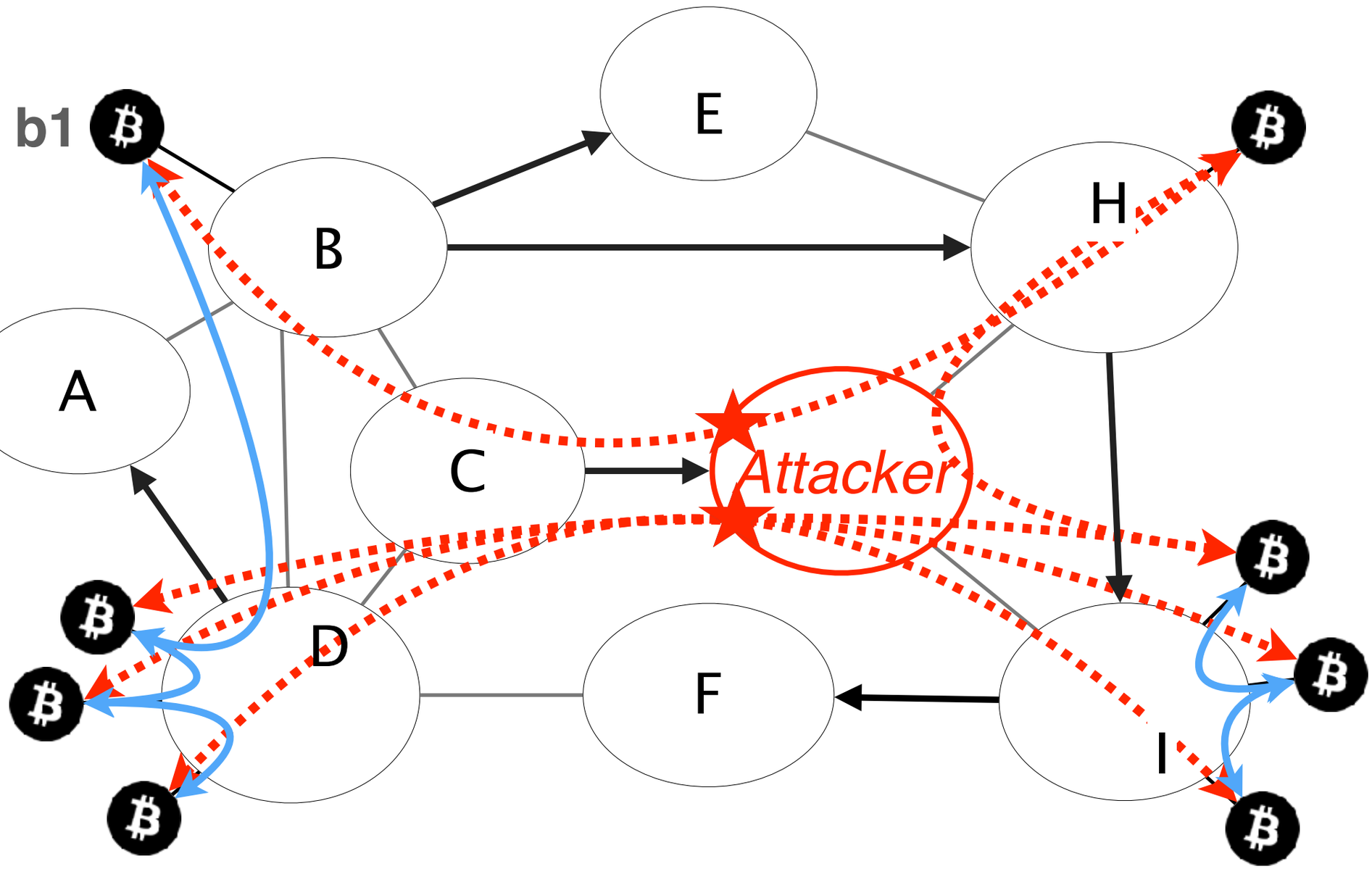
Relay2 protects the Bitcoin clients better



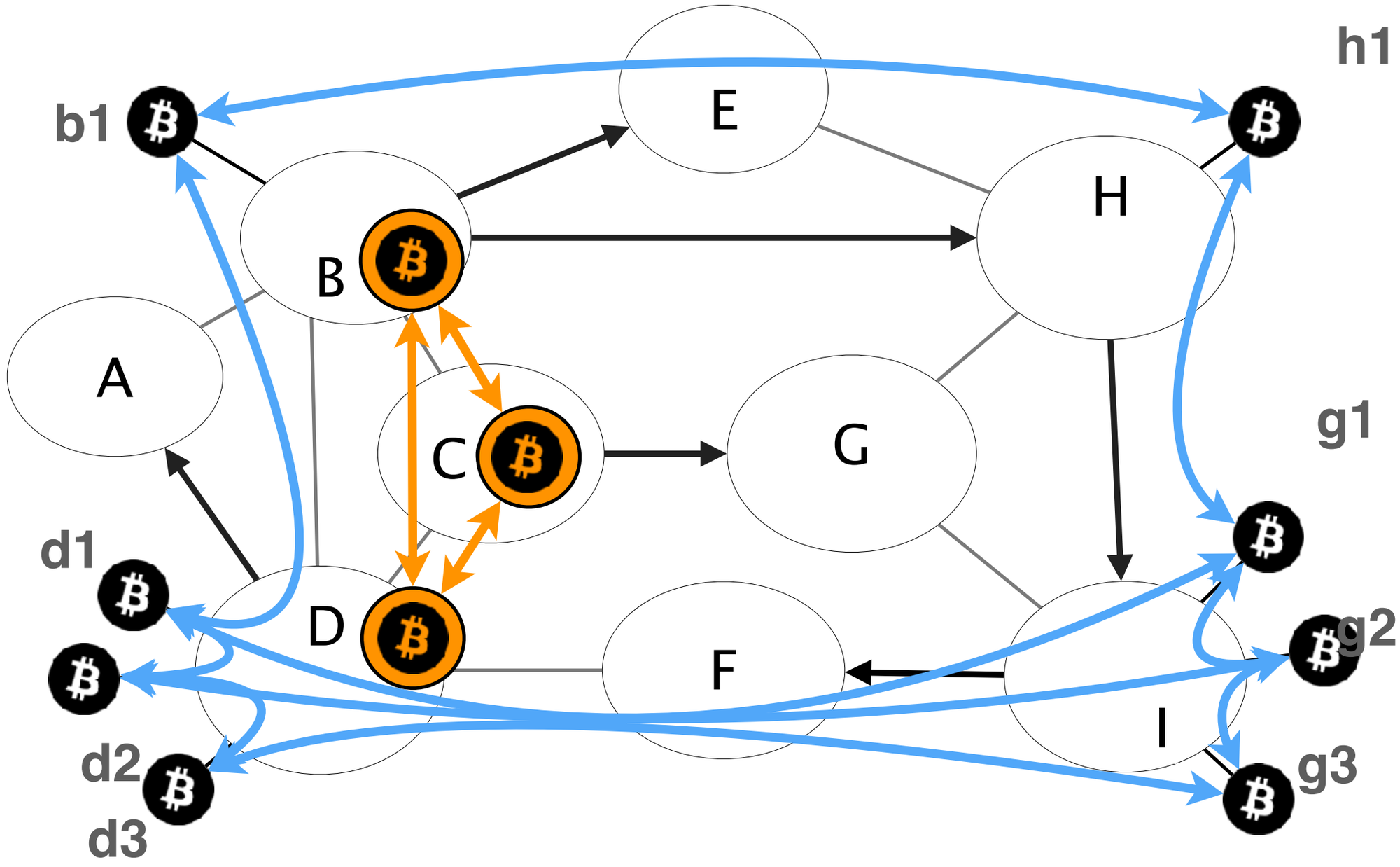
Let’s see SABRE in practice



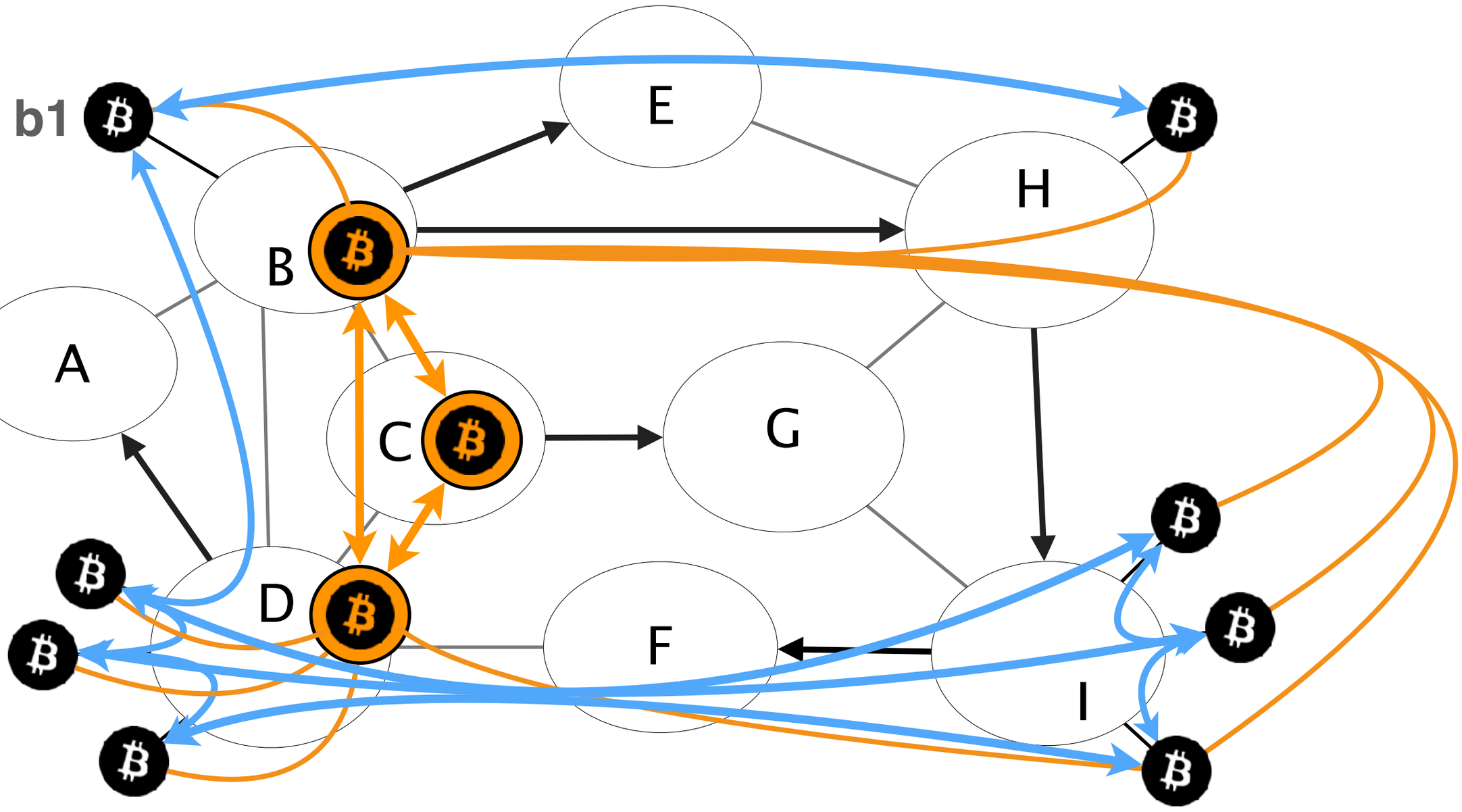
Attacker hijacks and drops connection between components



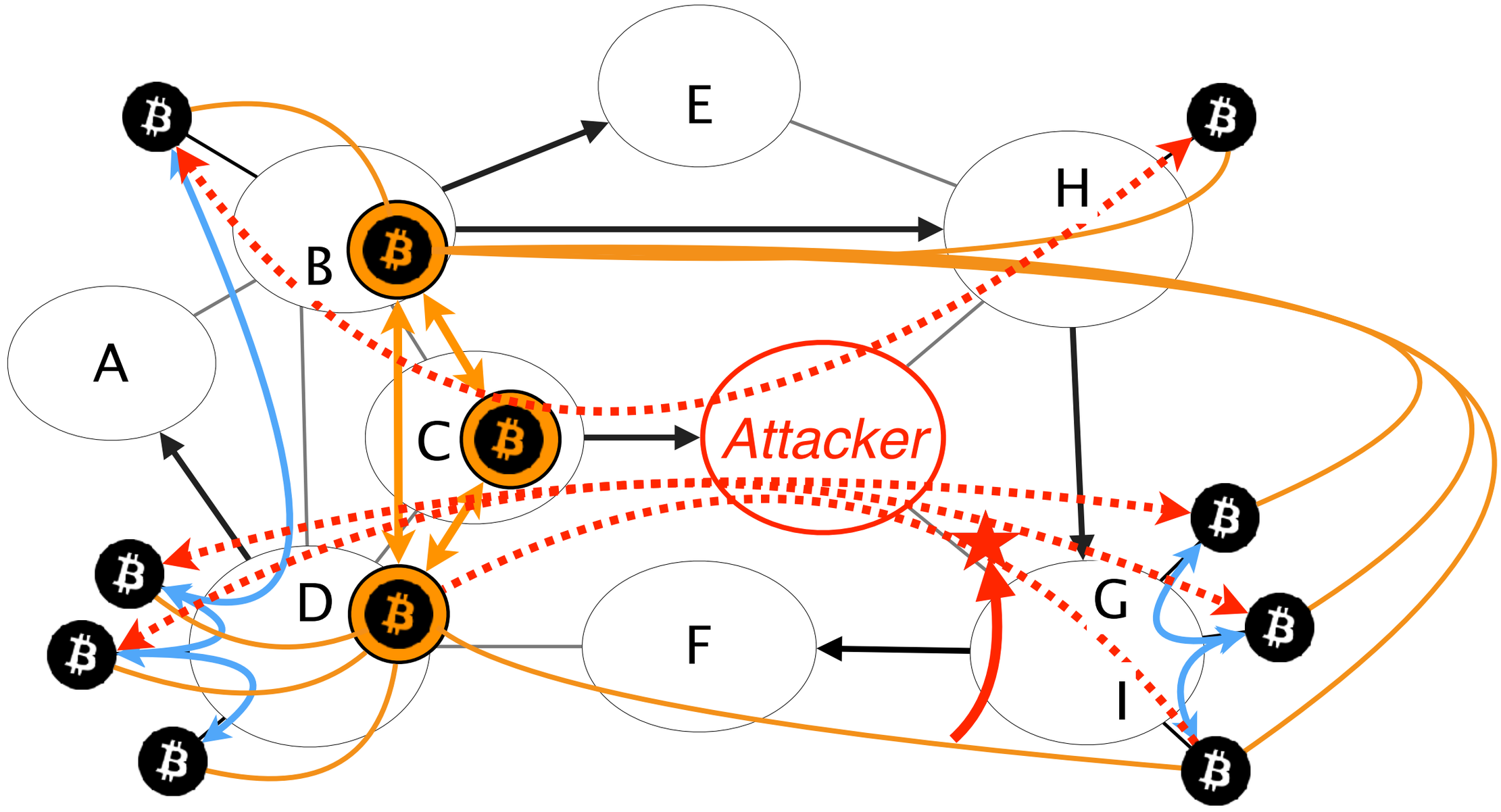
SABRE: Additional relay network of relay nodes



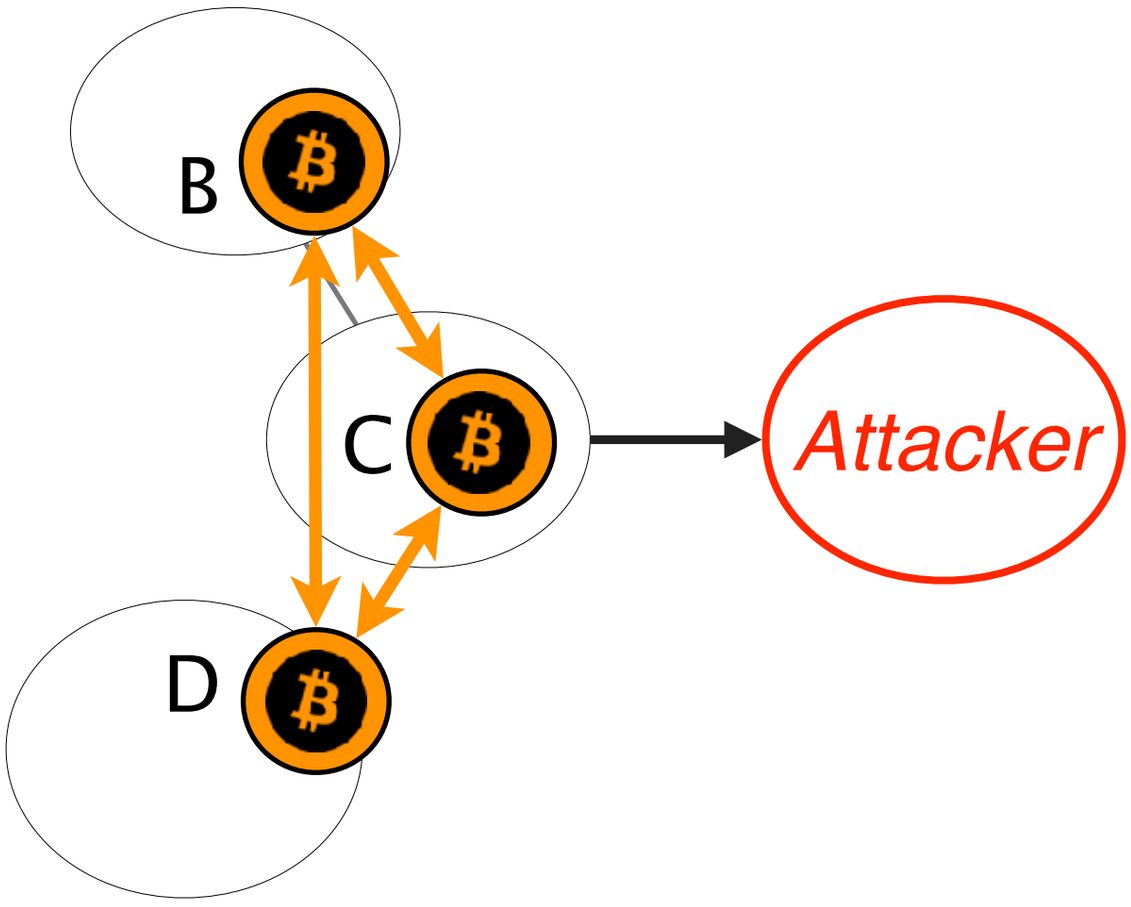
Clients connect to at least one relay node



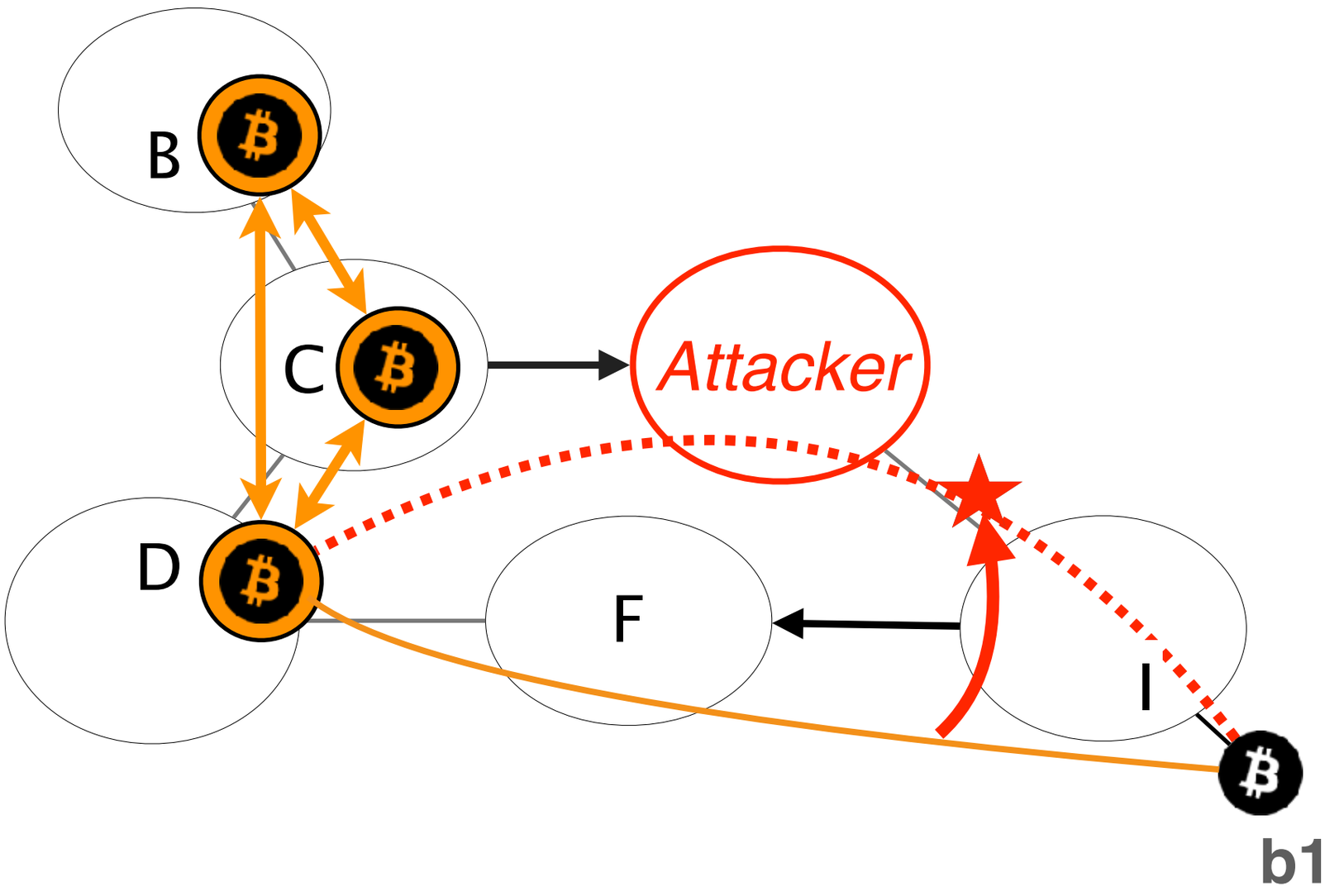
Intra-relay & some inter-relay connection survive



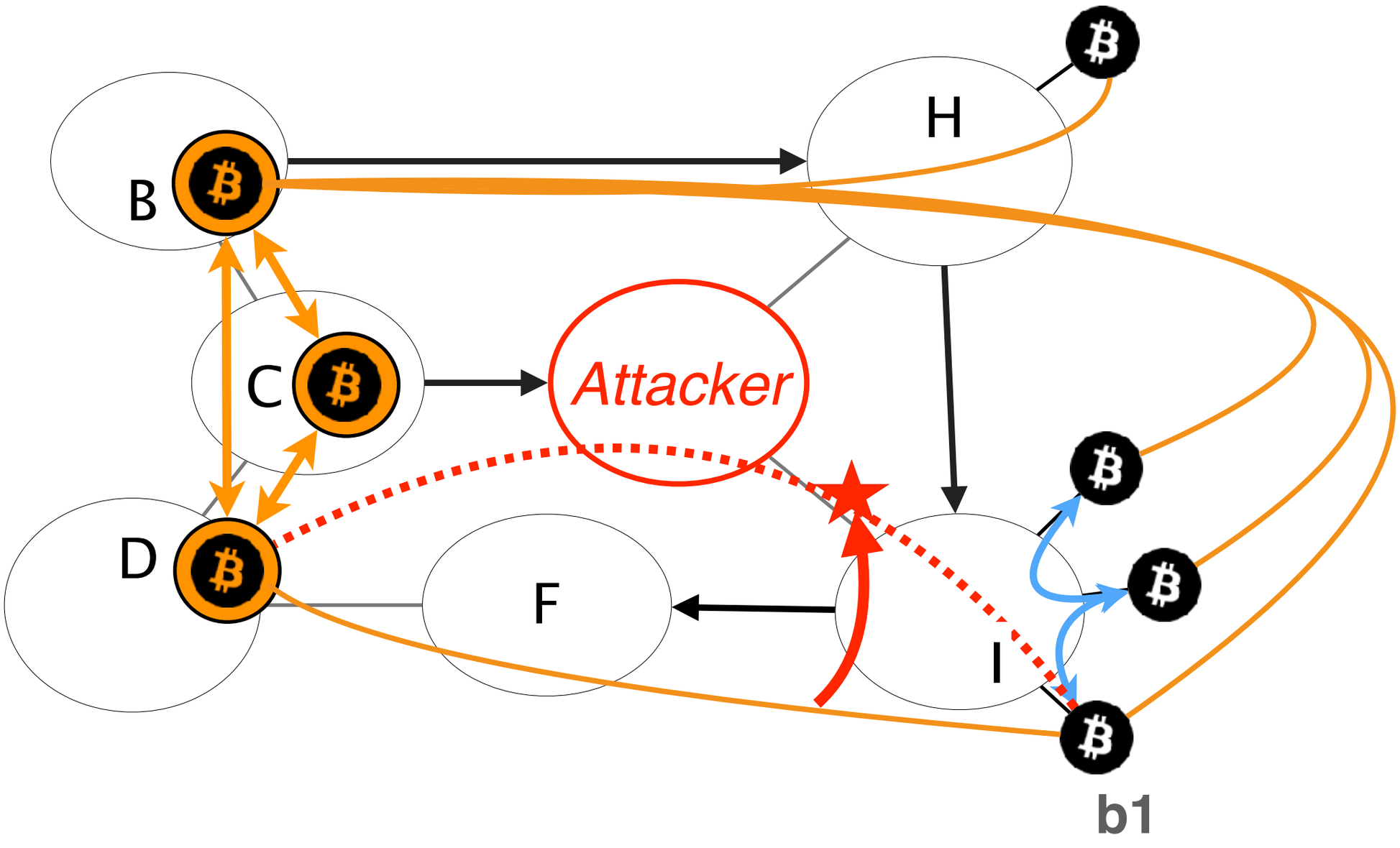
Attacker cannot attract traffic from ASC to ASB



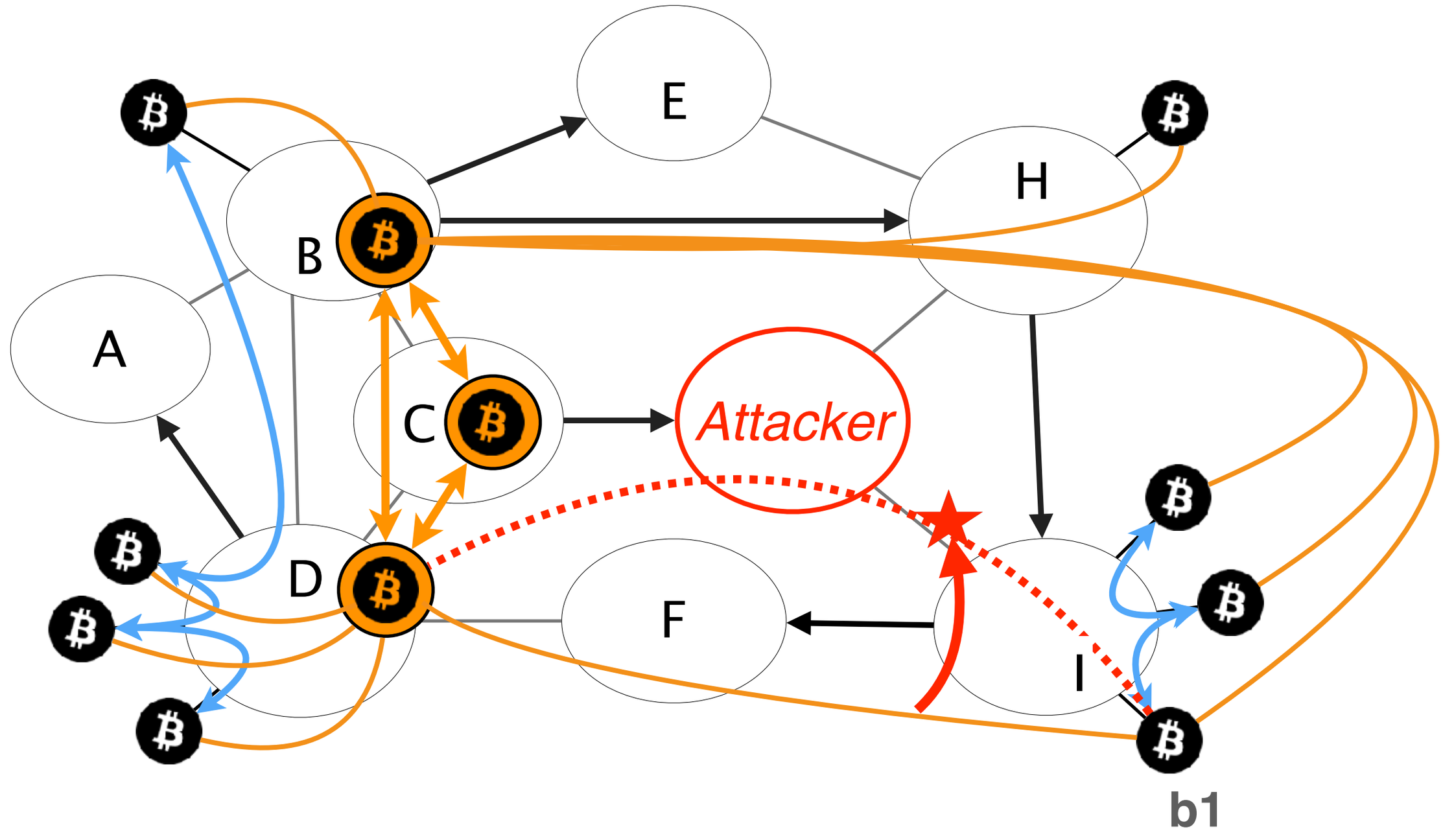
The attacker manage to attract traffic ASI to ASD



The attacker failed to attract traffic ASI to ASB

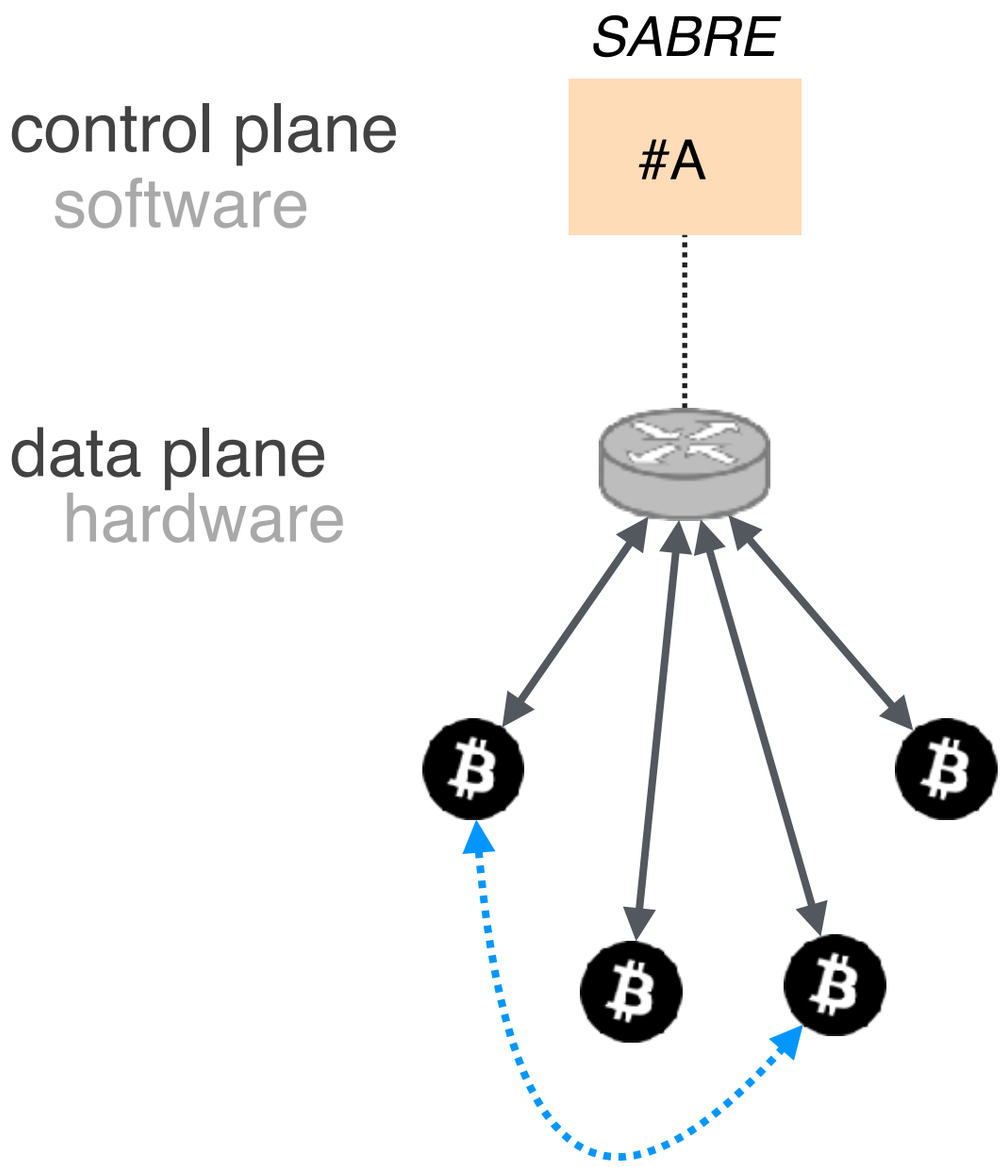


Partition attack failed



SABRE = Secure Relay Location + Robust Design

Software/Hardware co-design



Software/Hardware co-design

communication heavy protocol

simple computations,

many message exchanges

rarely updated state

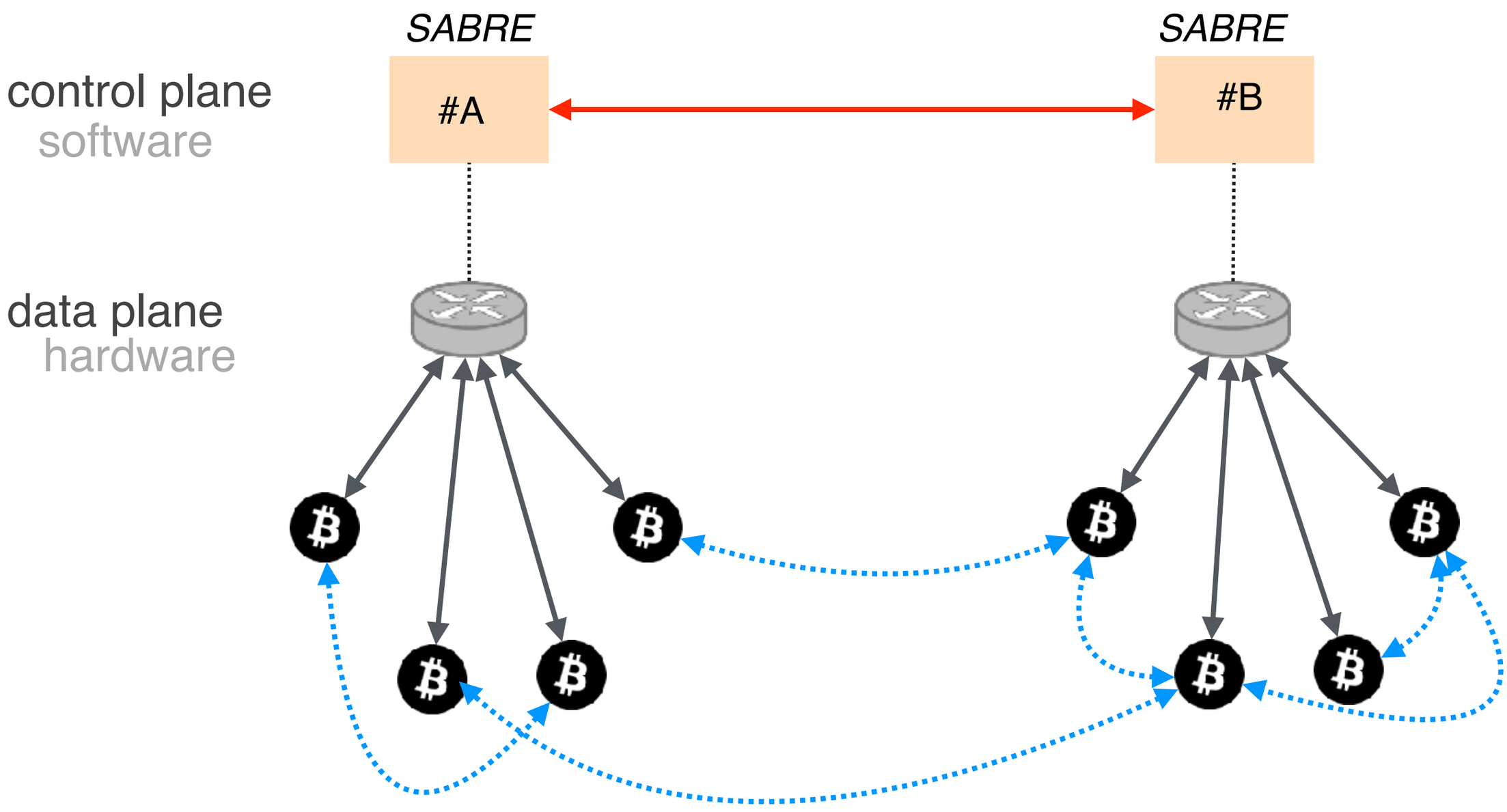
Software/Hardware co-design

communication heavy protocol

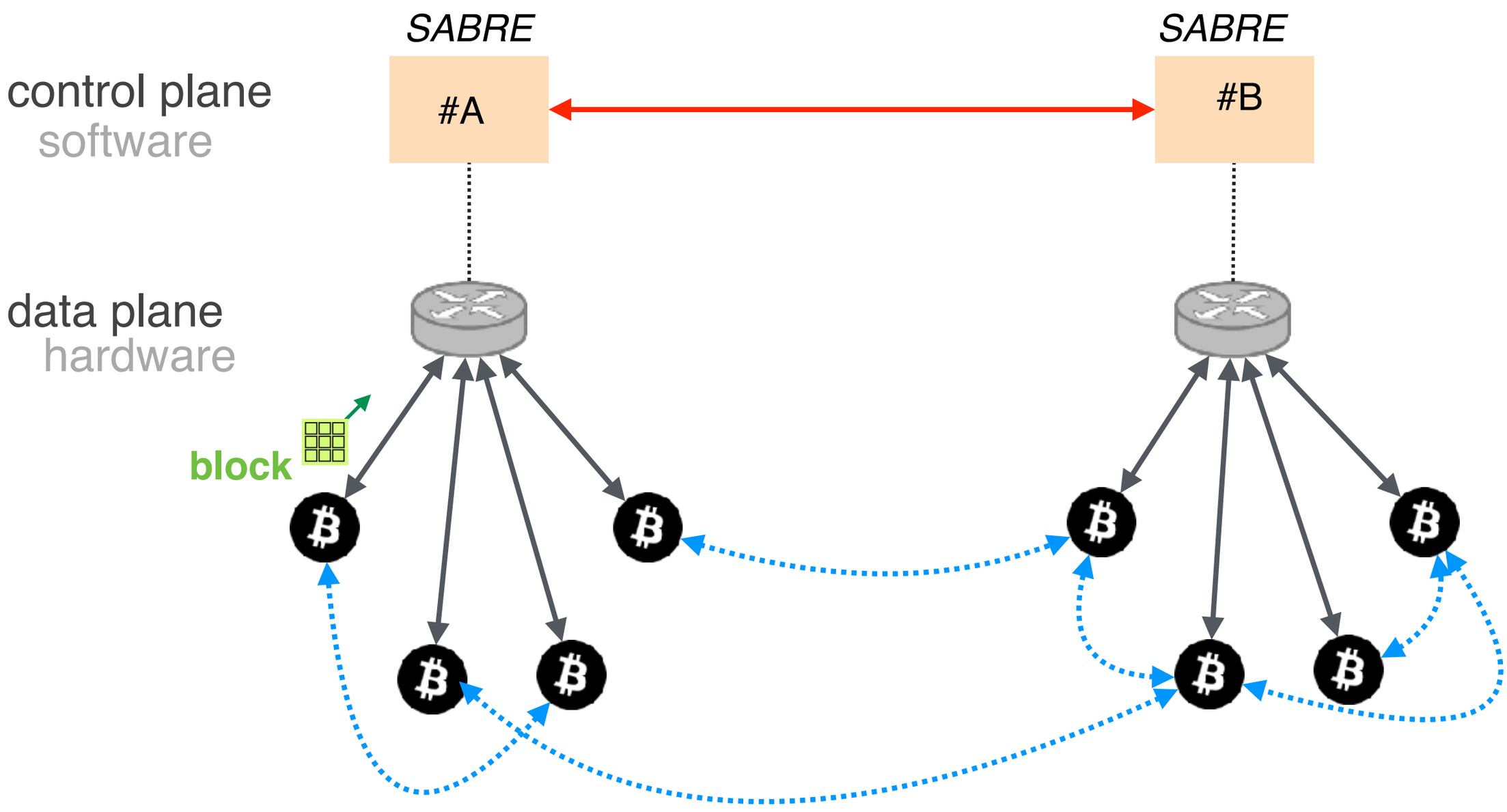
rarely updated state

New Blocks are found every 10 minutes

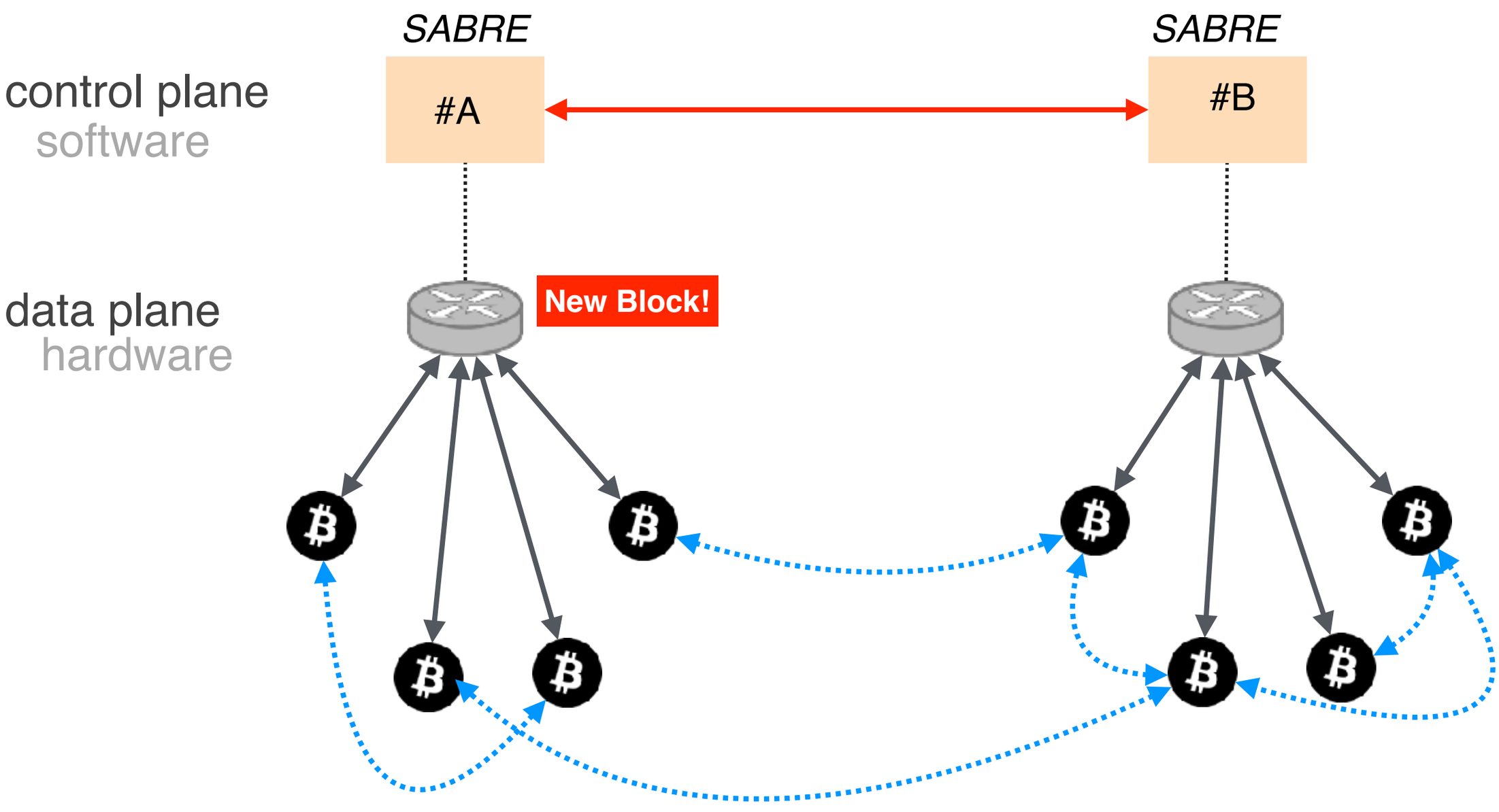
Let’s see how it works in practice



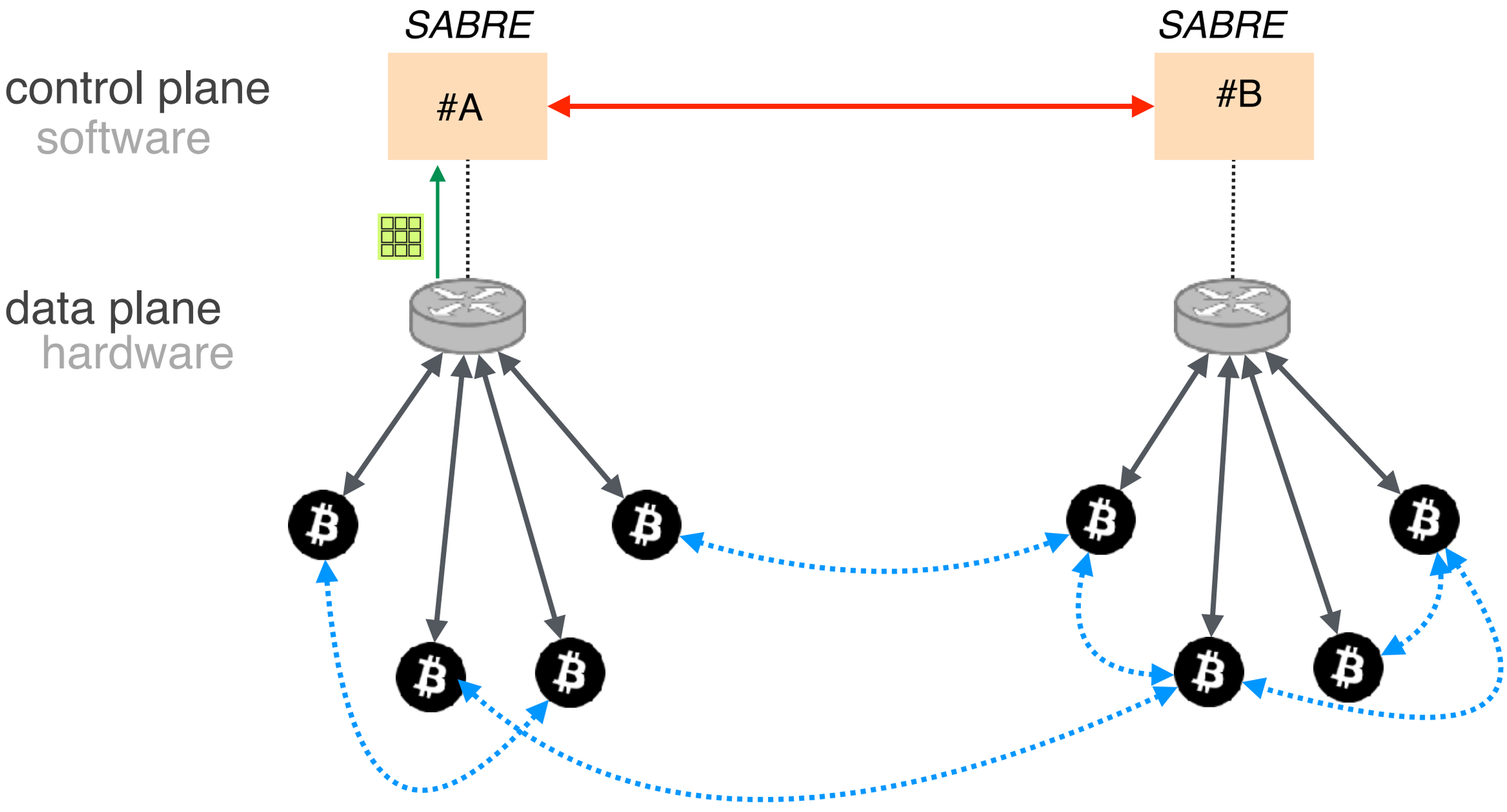
New block sent to SABRE node



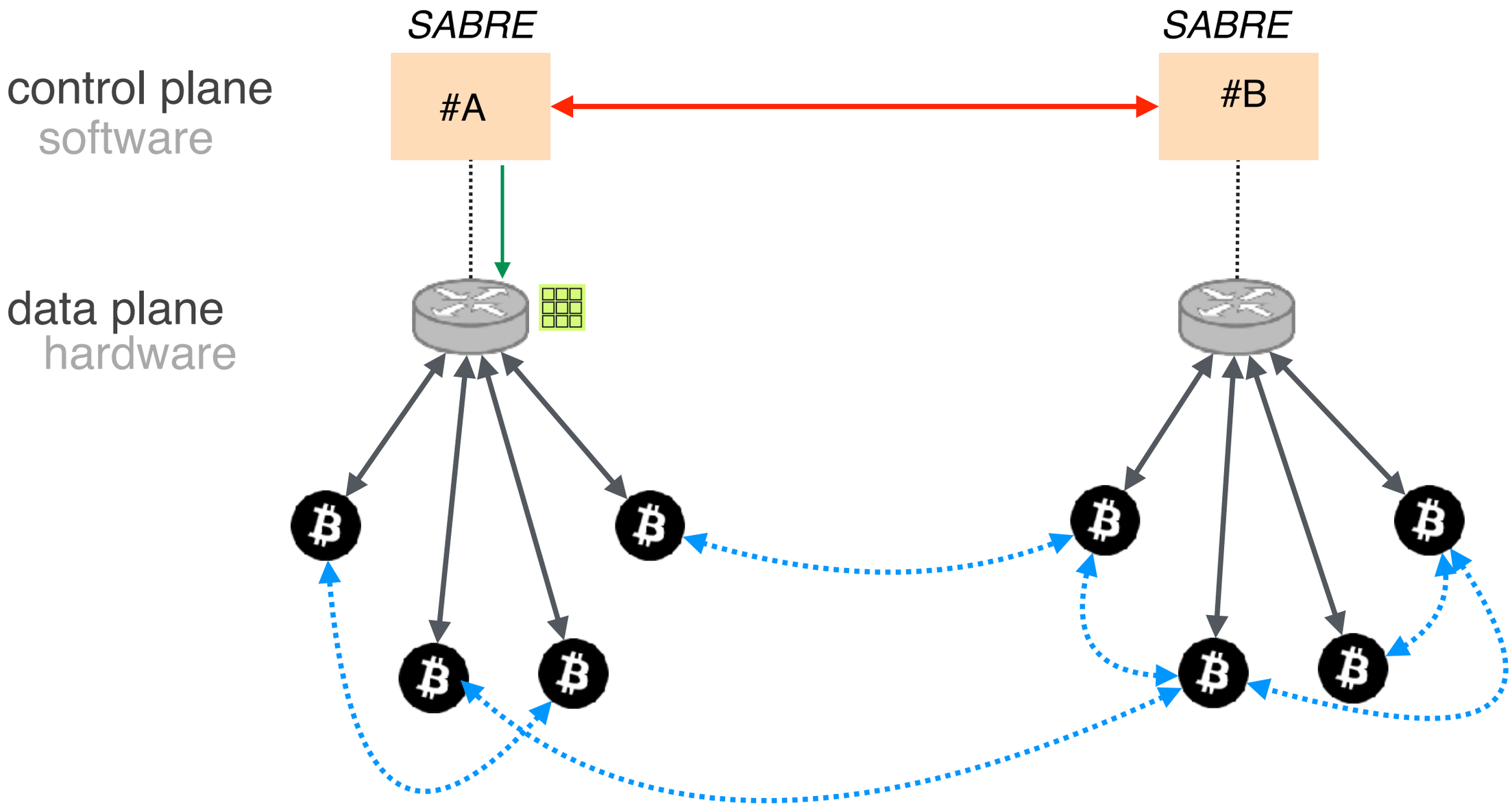
Block is forwarded to the control plane for validation



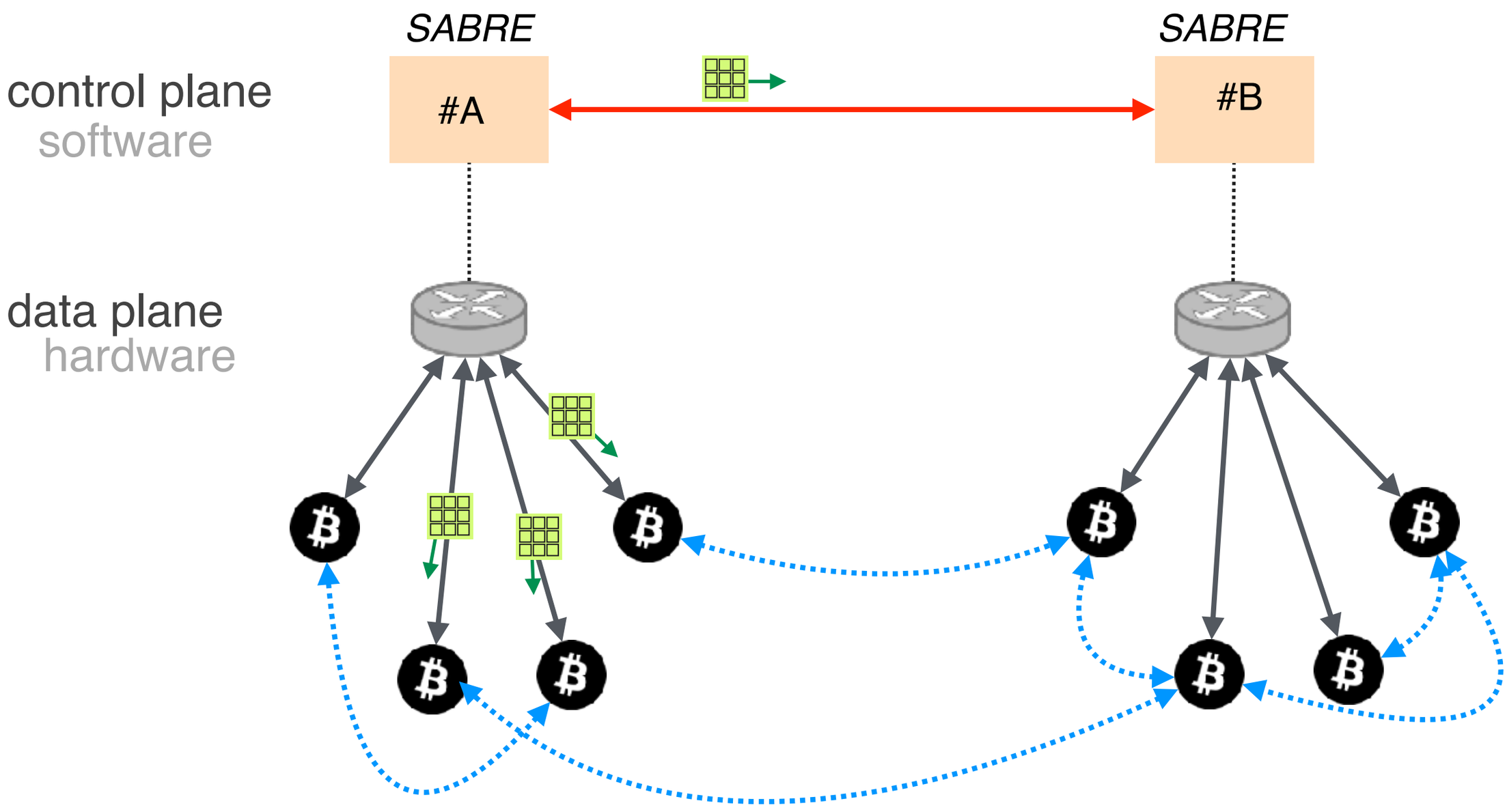
Block is forwarded to the control plane for validation



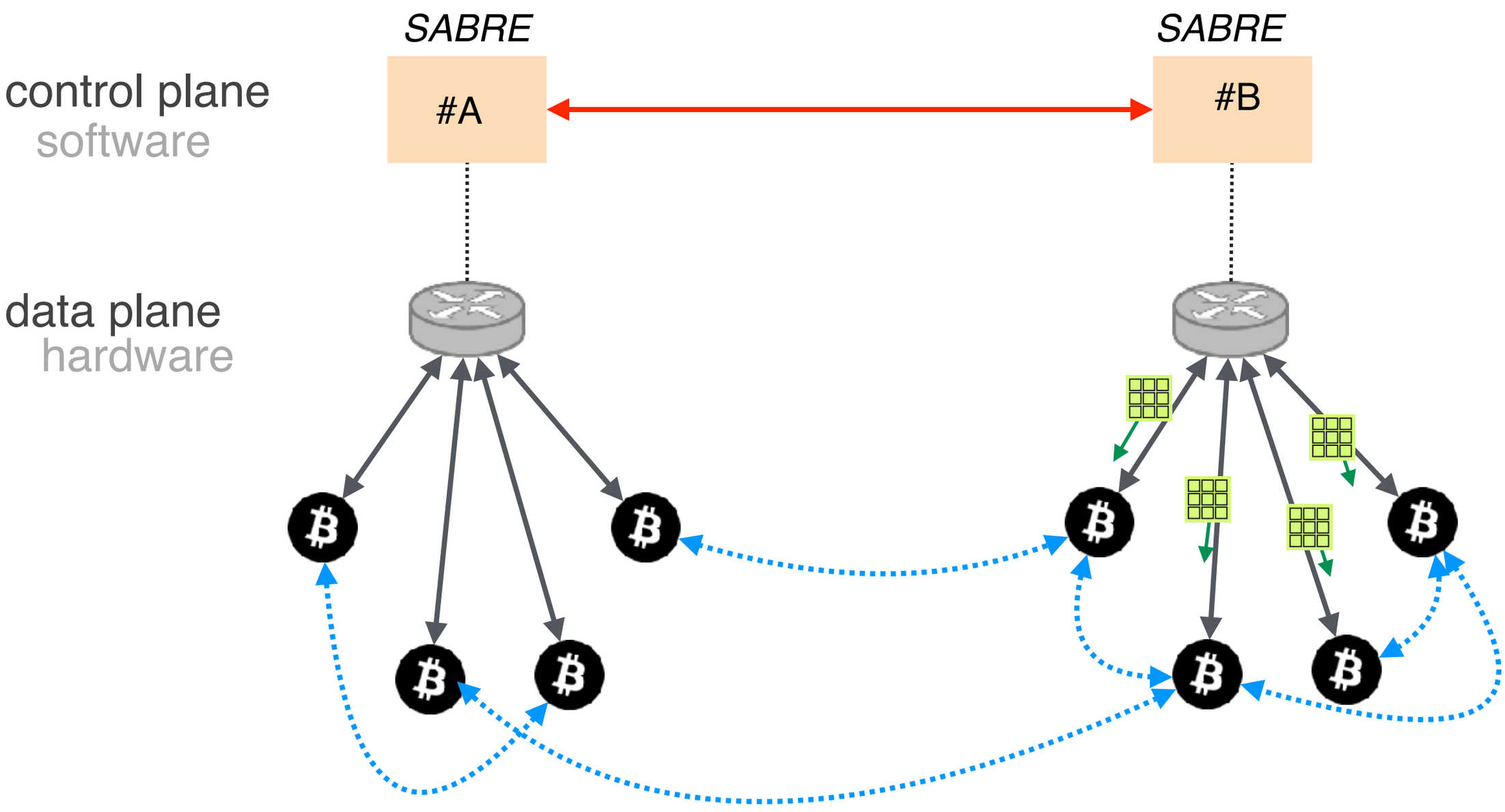
Block is forwarded to the control plane for validation



Update control switch's memory



Update control switch's memory



Hijacking Bitcoin

Routing Attacks on Cryptocurrencies

Background

BGP & Bitcoin

Partitioning attack

splitting the network

Delay attack

slowing the network down

Countermeasures

short-term & long-term

Hijacking Bitcoin

Routing Attacks on Cryptocurrencies

Bitcoin is vulnerable to routing attacks

both at the network and at the node level

The potential impact on the currency is worrying

DoS, double spending, loss of revenues, etc.

Countermeasures exist (we worked on it!)

some of which can be deployed today