SABRE

Protecting Bitcoin against Routing Attacks

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Joint work with Gian Marti, Jan Müller and Laurent Vanbever

Partition Attack

An adversary splits the Bitcoin network
in two disjoint components

Partition attack is general, dangerous, effective, practical

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Any Blockchain system is vulnerable

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Double-spending, Revenue Loss, DoS

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50-50 partition is feasible

Partition attack is general, dangerous, effective, practical

Any Blockchain system is vulnerable

Double-spending, Revenue Loss, DoS

50-50 partition is feasible

Any network in the world is a possible attacker

In 2017 we uncovered the practicality and effectiveness of routing attacks in Bitcoin

Hijacking Bitcoin: Routing Attacks on Cryptocurrencies

https://btc-hijack.ethz.ch

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***Abstract*—As the most successful cryptocurrency to date, Bitcoin constitutes a target of choice for attackers. While many attack vectors have already been uncovered, one important vector has been left out though: attacking the currency via the Internet routing infrastructure itself. Indeed, by manipulating routing advertisements (BGP hijacks) or by naturally intercepting traffic, Autonomous Systems (ASes) can intercept and manipulate a large fraction of Bitcoin traffic.**

This paper presents the first taxonomy of routing attacks and their impact on Bitcoin, considering both small-scale attacks, targeting individual nodes, and large-scale attacks, targeting the network as a whole. While challenging, we show that two key properties make routing attacks practical: *(i)* the efficiency of routing manipulation; and *(ii)* the significant centralization of Bitcoin in terms of mining and routing. Specifically, we find that any network attacker can hijack few (<100) BGP prefixes to isolate ~50% of the mining power—even when considering that mining pools are heavily multi-homed. We also show that on-path network attackers can considerably slow down block propagation by interfering with few key Bitcoin messages.

We demonstrate the feasibility of each attack against the deployed Bitcoin software. We also quantify their effectiveness on the current Bitcoin topology using data collected from a Bitcoin supernode combined with BGP routing data.

The potential damage to Bitcoin is worrying. By isolating parts of the network or delaying block propagation, attackers can cause

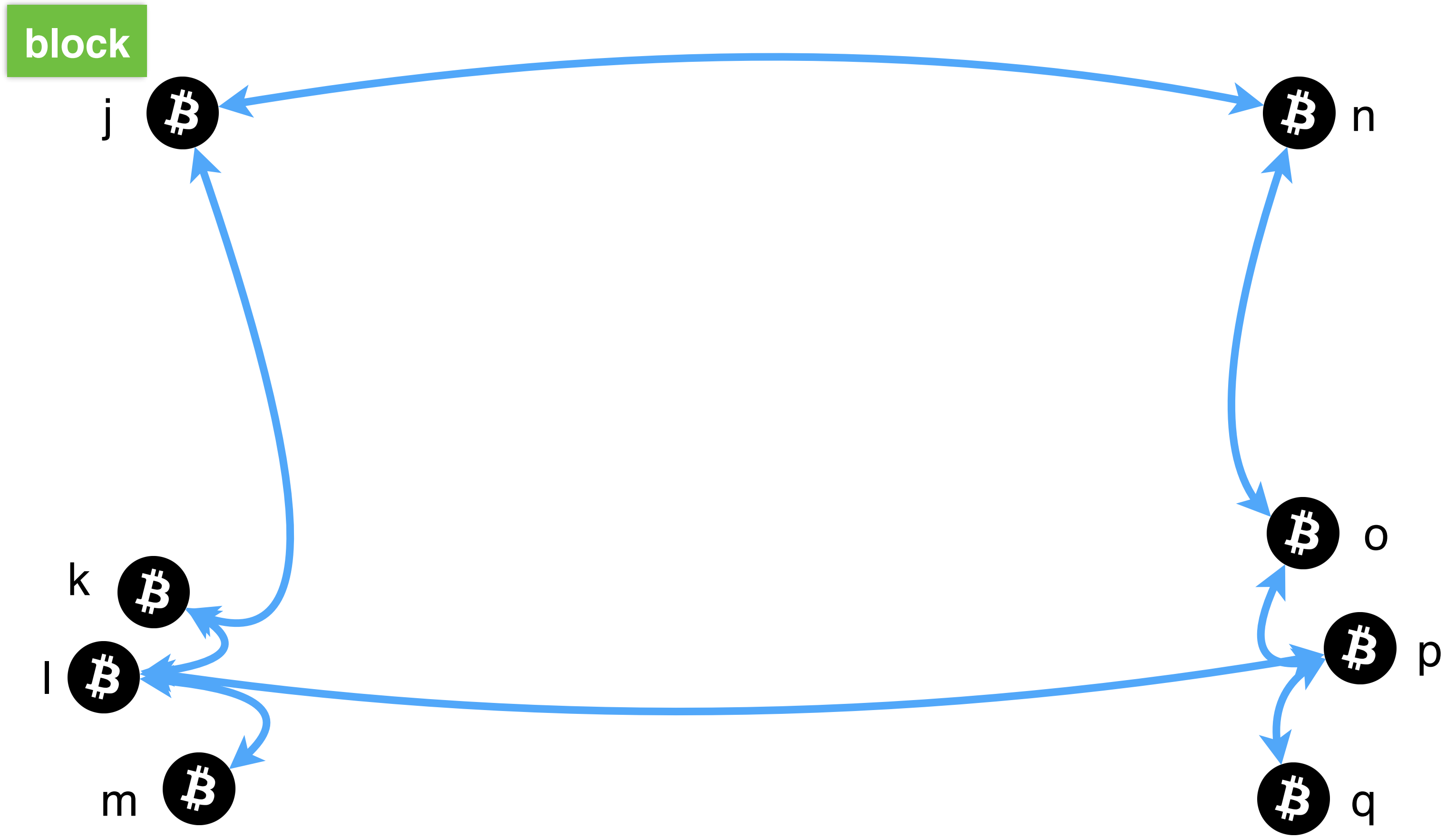
One important attack vector has been overlooked though: attacking Bitcoin via the Internet infrastructure using *routing attacks*. As Bitcoin connections are routed over the Internet—in clear text and without integrity checks—any third-party on the forwarding path can eavesdrop, drop, modify, inject, or delay Bitcoin messages such as blocks or transactions. Detecting such attackers is challenging as it requires inferring the exact forwarding paths taken by the Bitcoin traffic using measurements (e.g., traceroute) or routing data (BGP announcements), both of which can be forged [41]. Even ignoring detectability, mitigating network attacks is also hard as it is essentially a human-driven process consisting of filtering, routing around or disconnecting the attacker. As an illustration, it took Youtube close to 3 hours to locate and resolve rogue BGP announcements targeting its infrastructure in 2008 [6]. More recent examples of routing attacks such as [51] (resp. [52]) took 9 (resp. 2) hours to resolve in November (resp. June) 2015.

One of the reasons why routing attacks have been overlooked in Bitcoin is that they are often considered too challenging to be practical. Indeed, perturbing a vast peer-to-peer

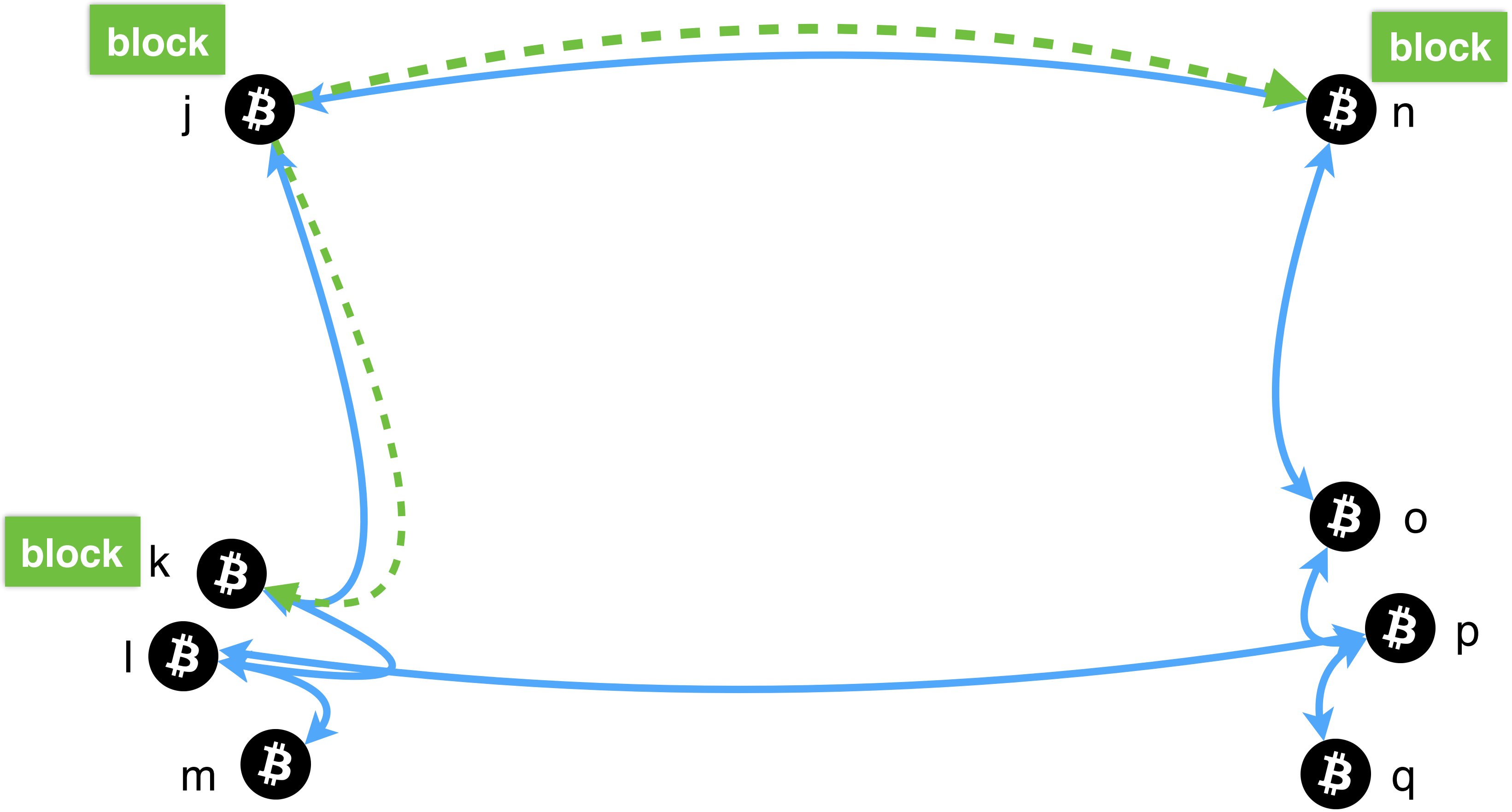
Bitcoin is a distributed network of nodes (Bitcoin clients)

Bitcoin clients establish random connections

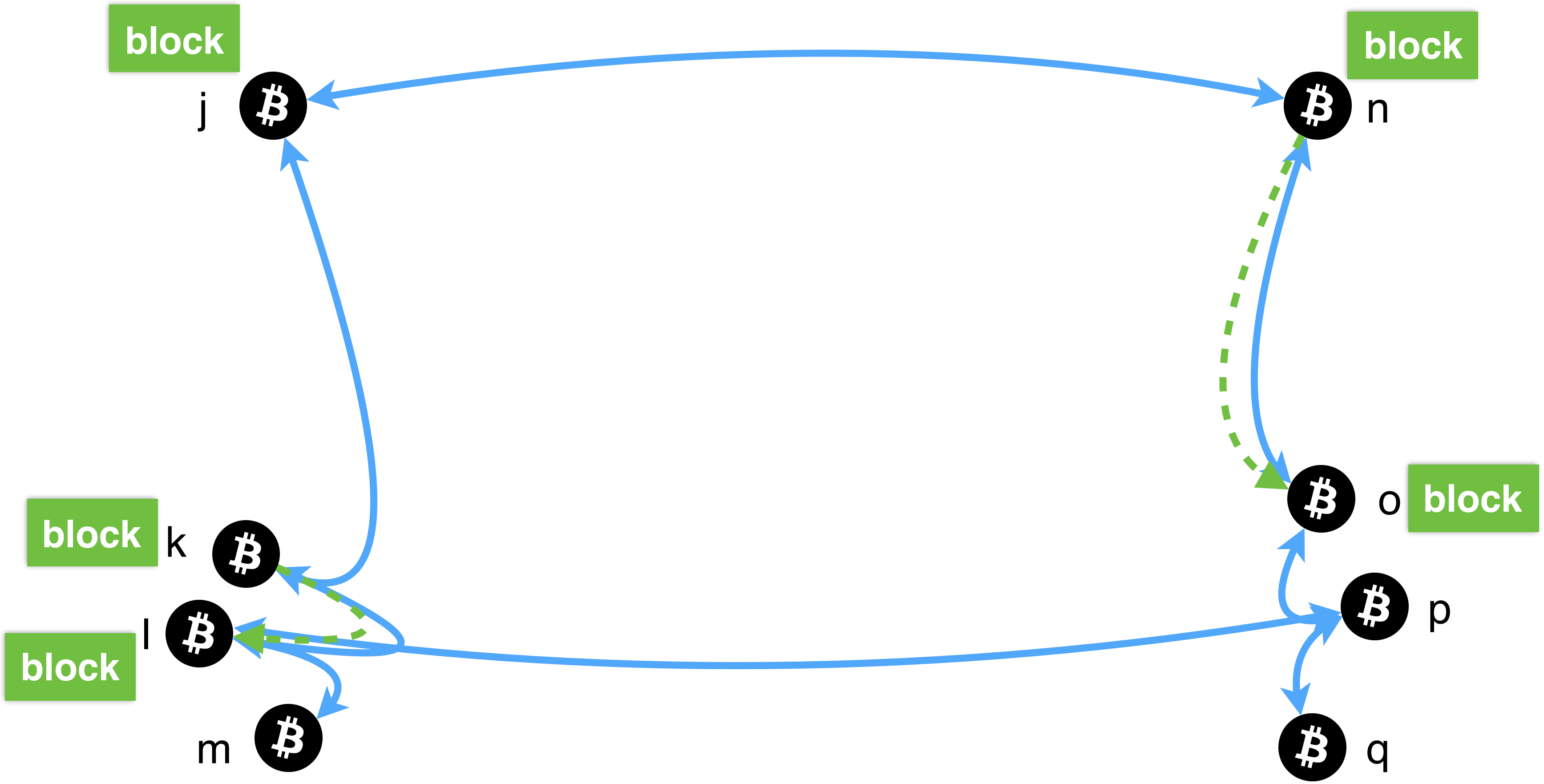
Bitcoin clients exchange Blocks



Blocks contain the latest transactions

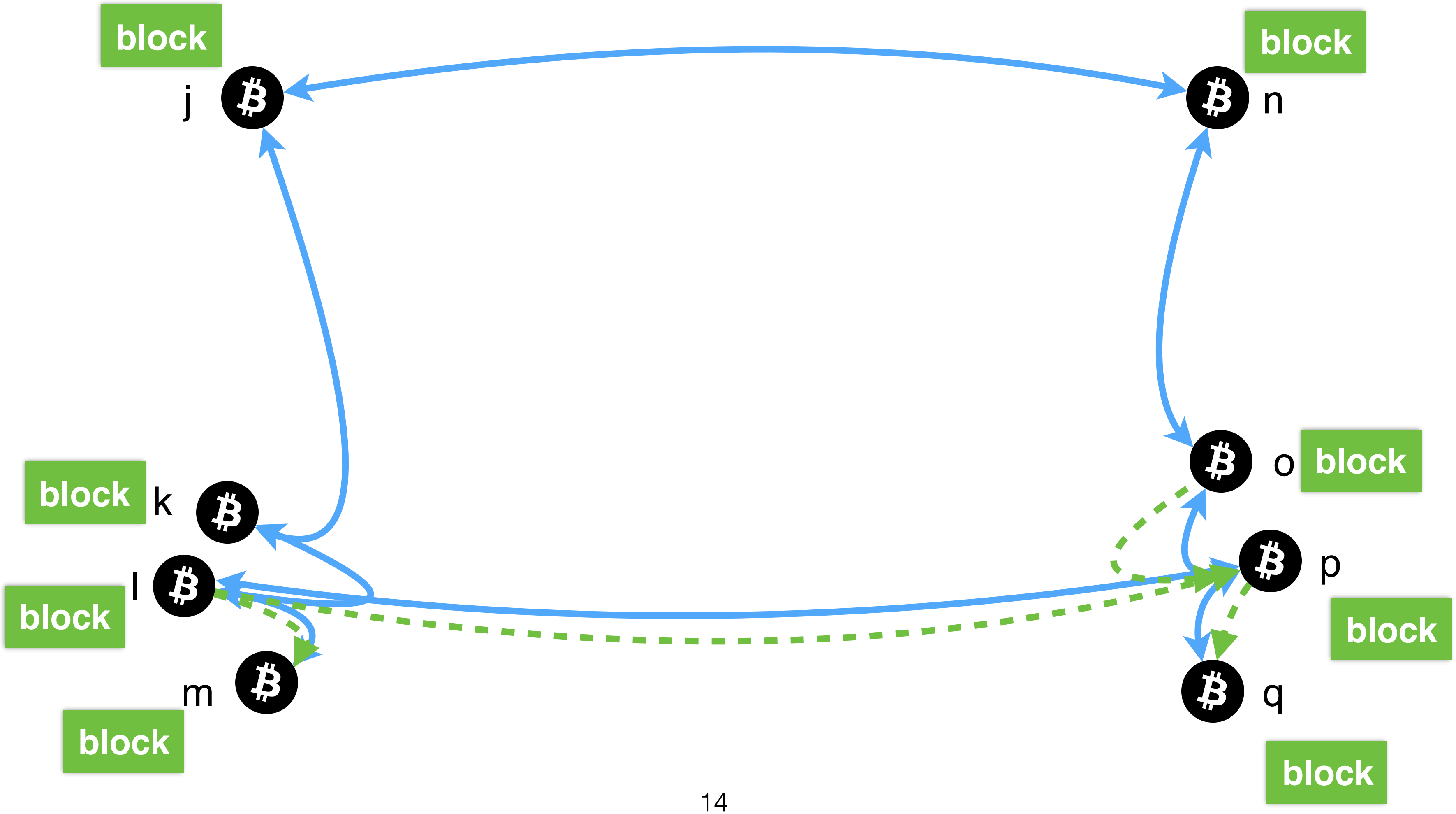


Bitcoin clients exchange Blocks



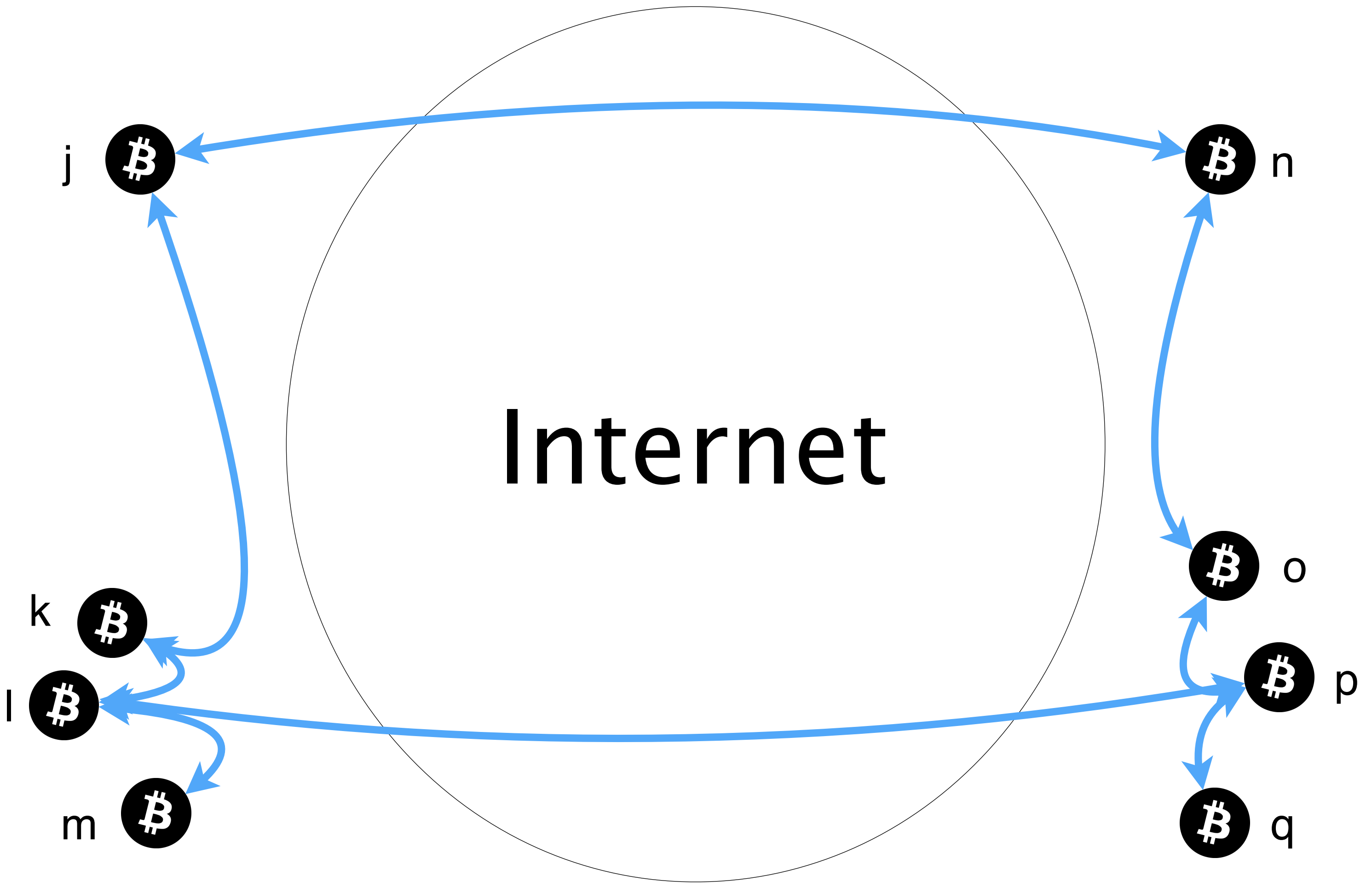
Bitcoin clients exchange Blocks

until all clients have the same view of the transactions

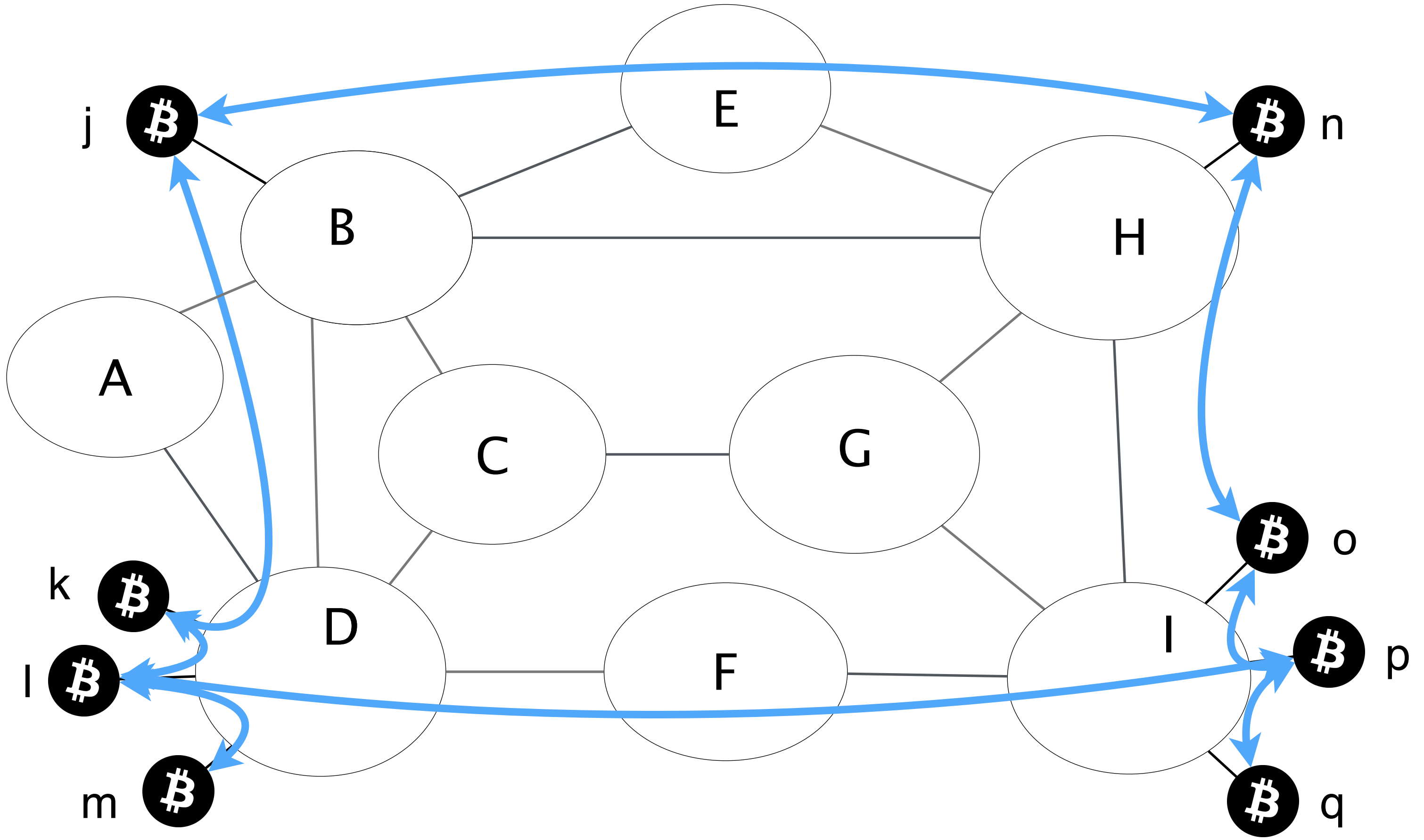


What can go wrong?

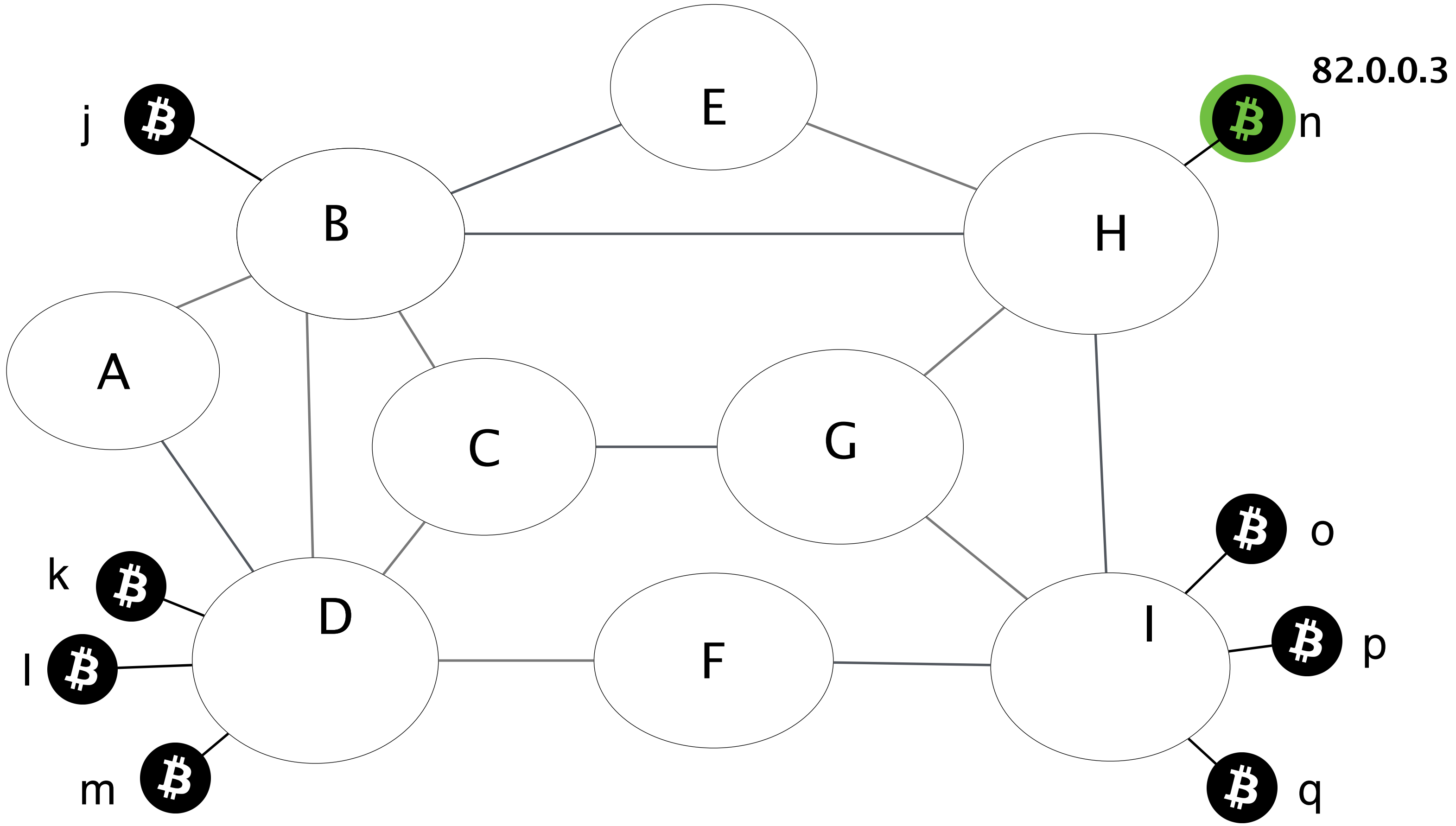
Bitcoin connections are routed over the Internet using BGP, the default Internet routing protocol



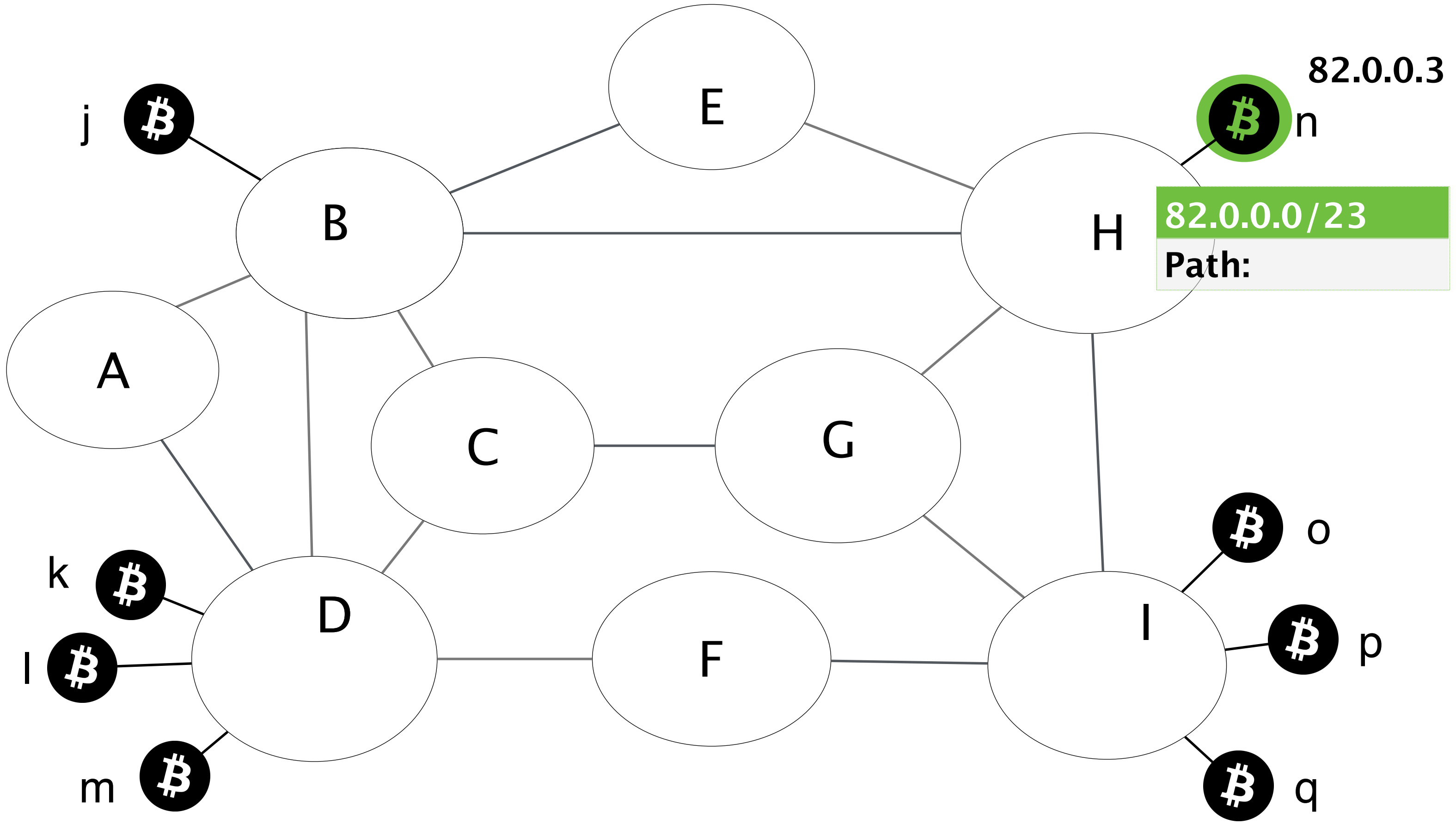
The Internet is composed of Autonomous Systems



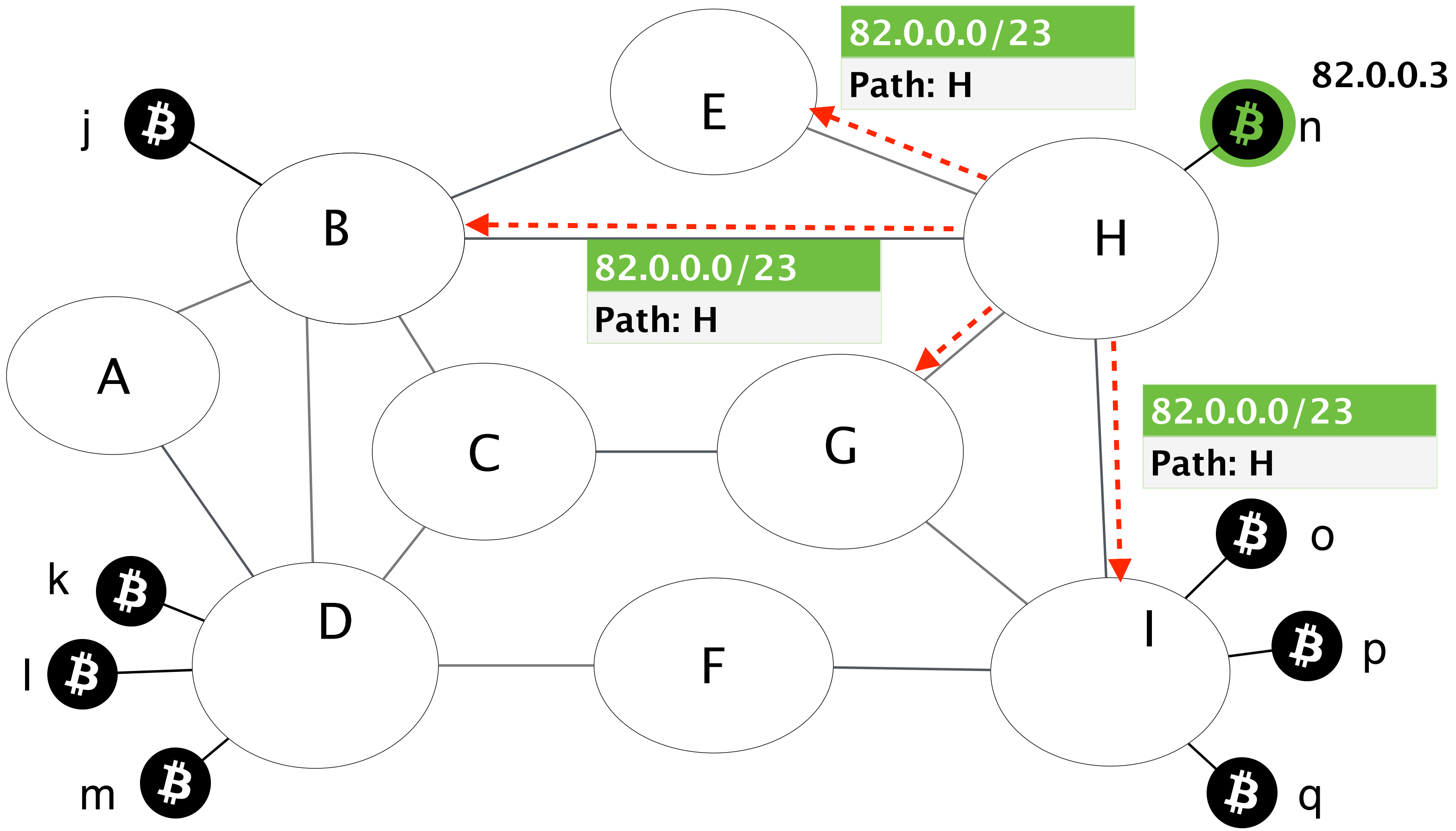
Each Bitcoin client n has an IP



AS H creates a BGP advertisement for n's IP prefix



BGP propagates advertisements in the Internet



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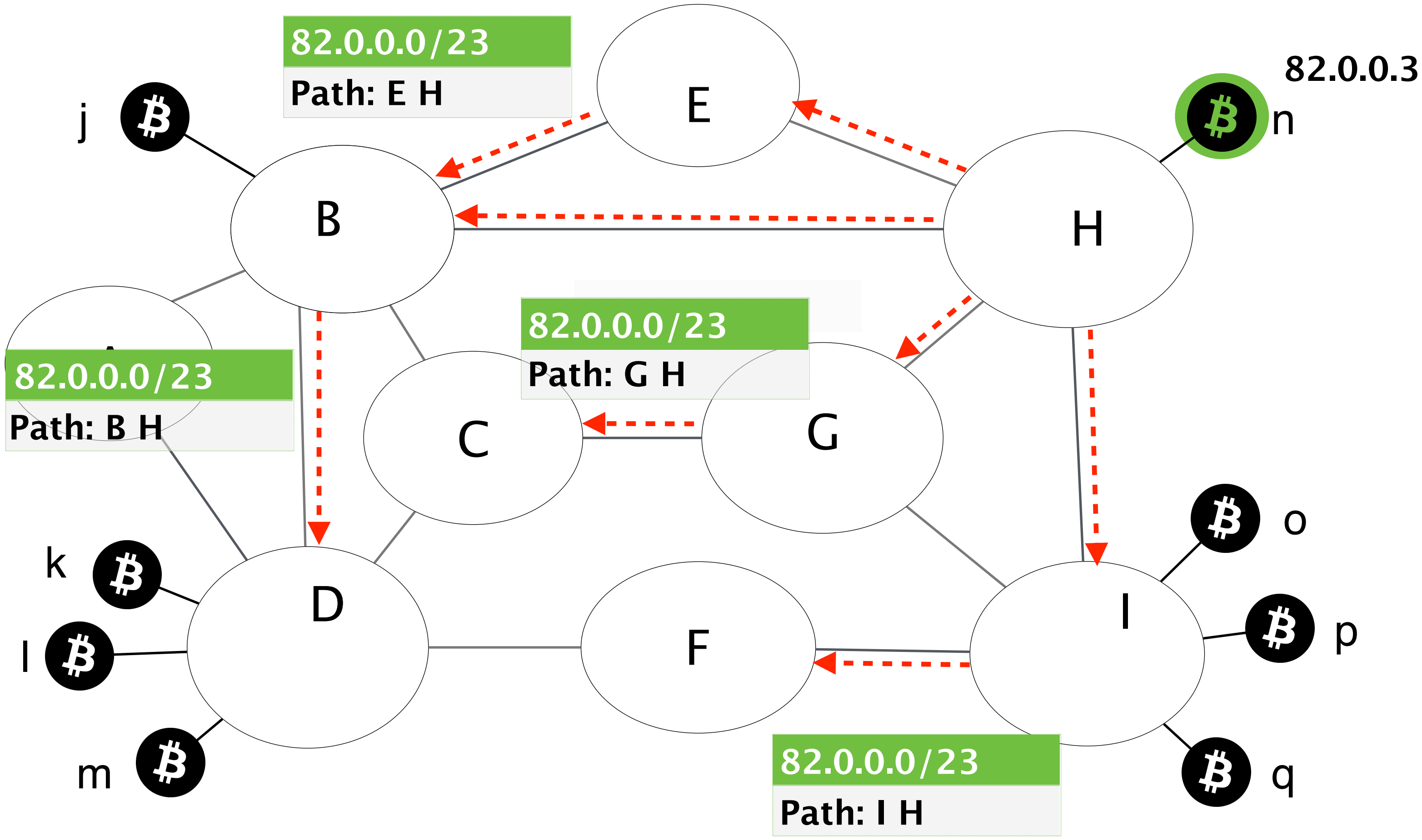
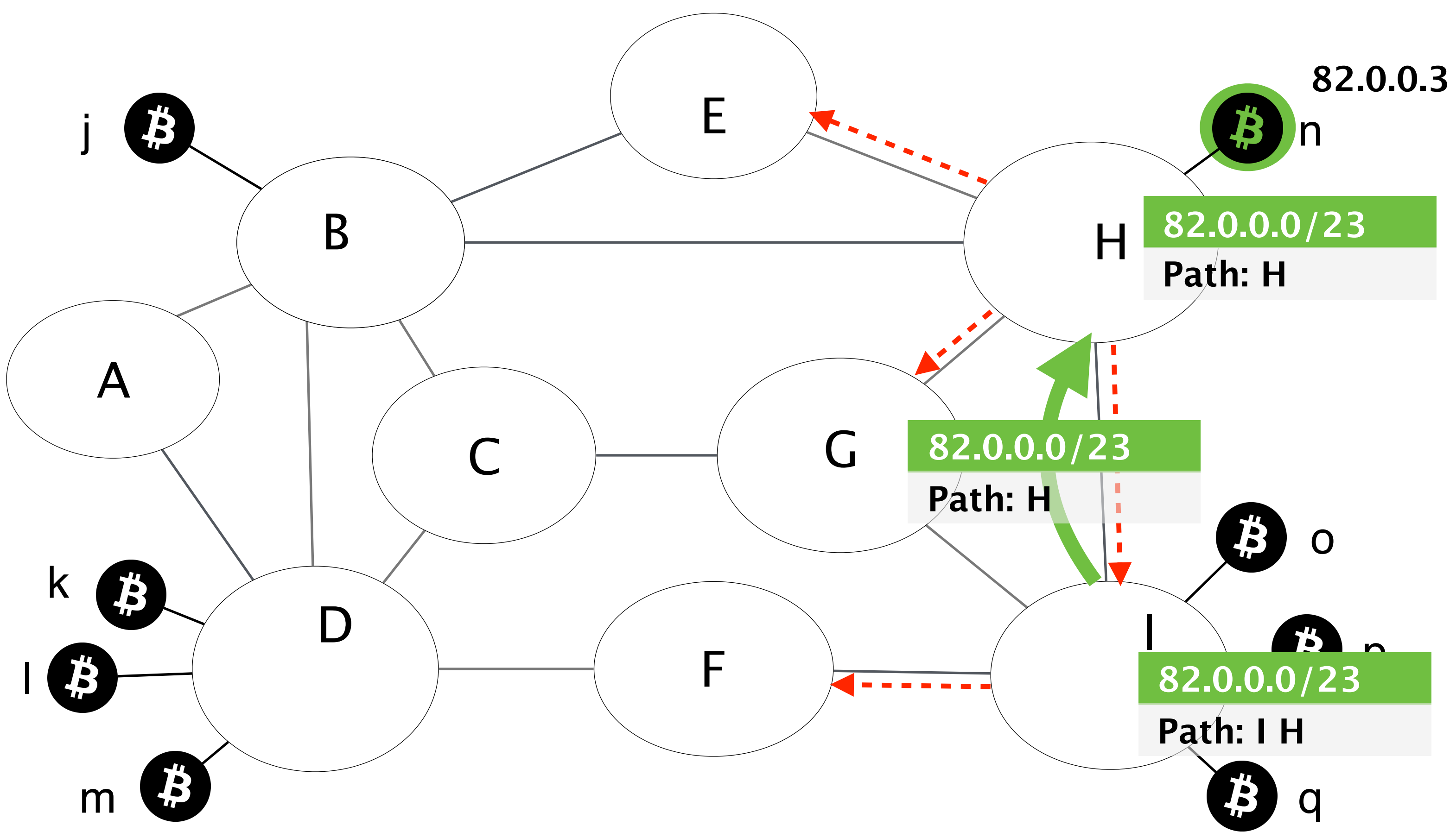
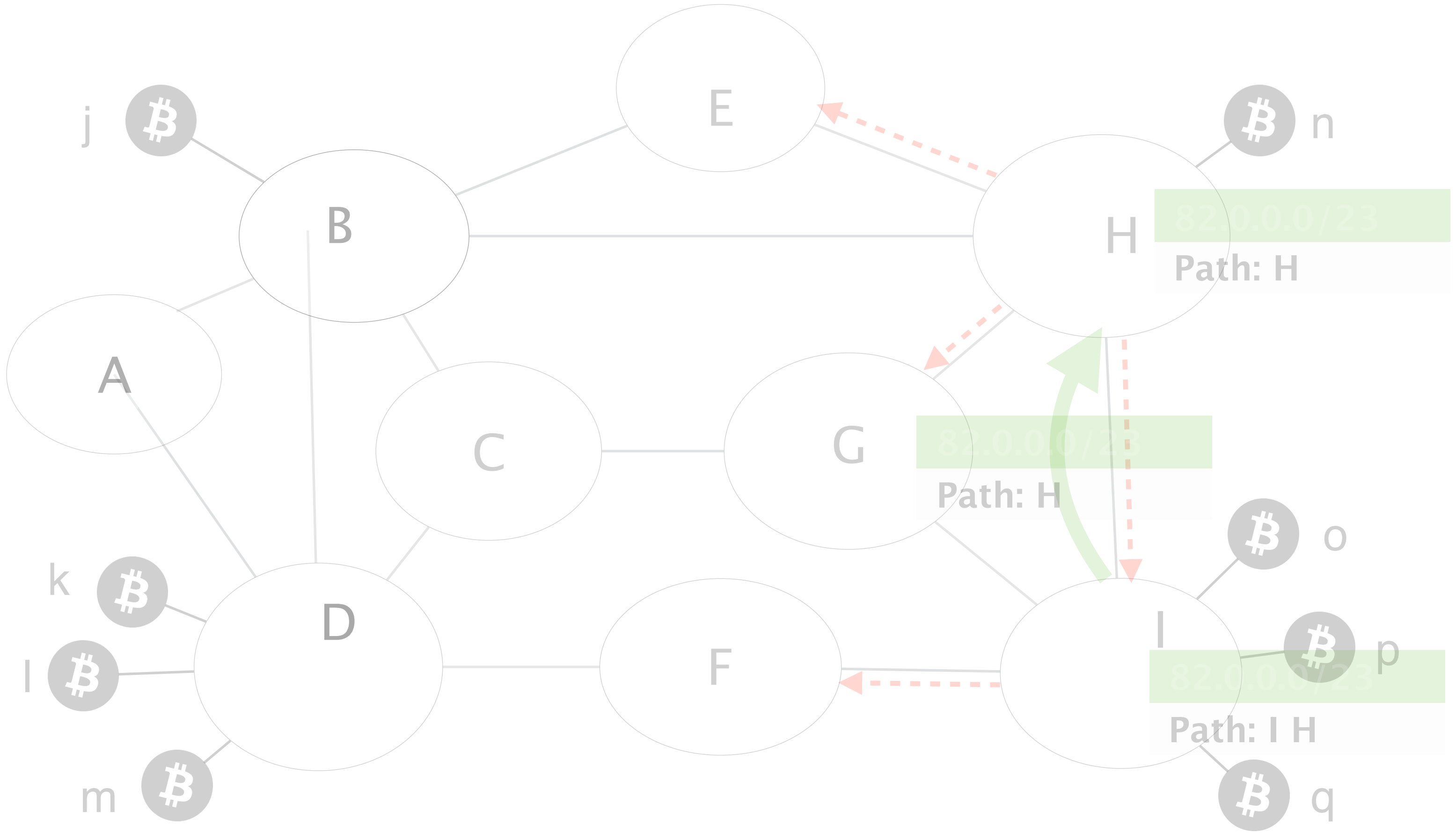


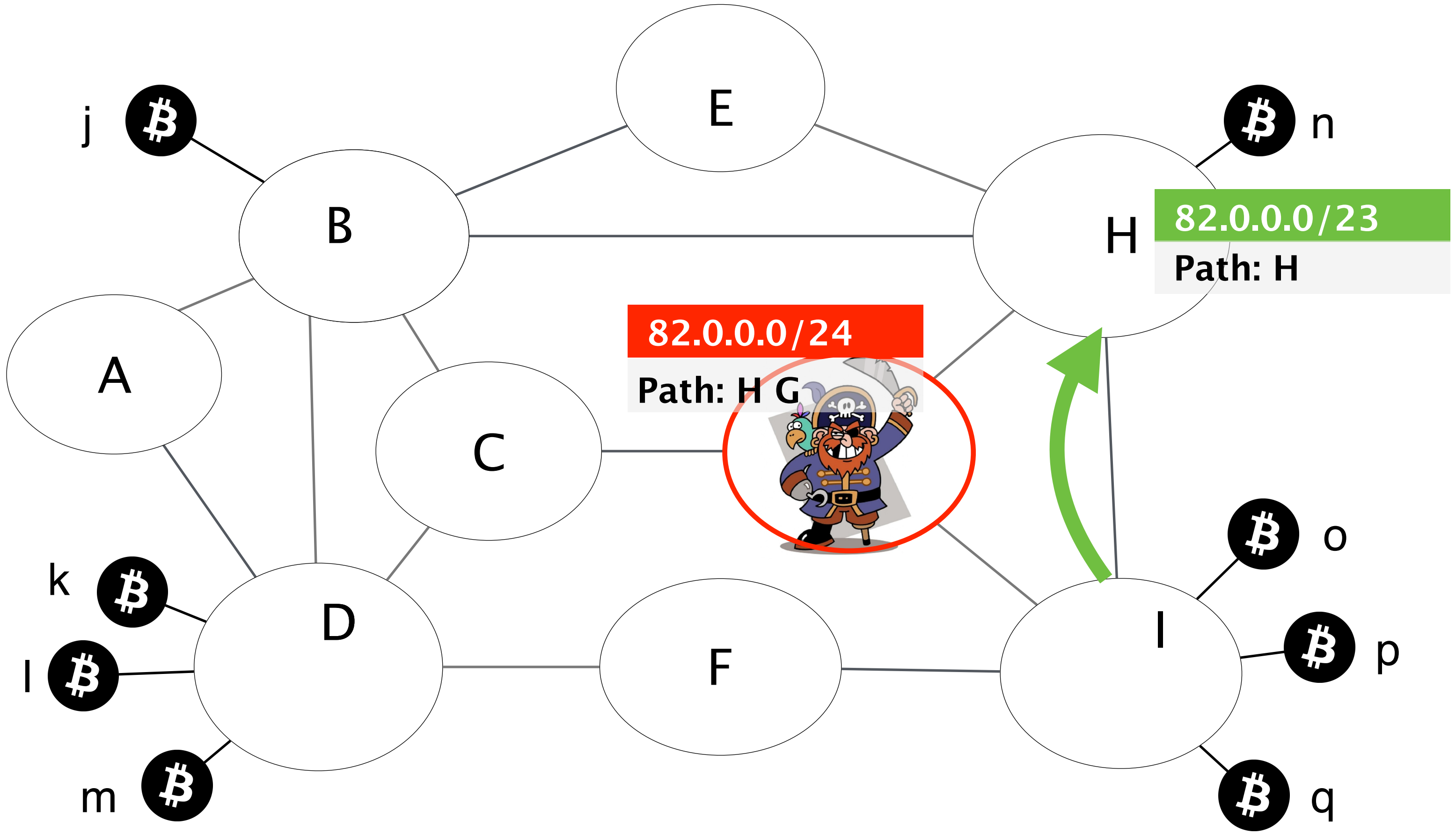
AS I can directly reach AS H



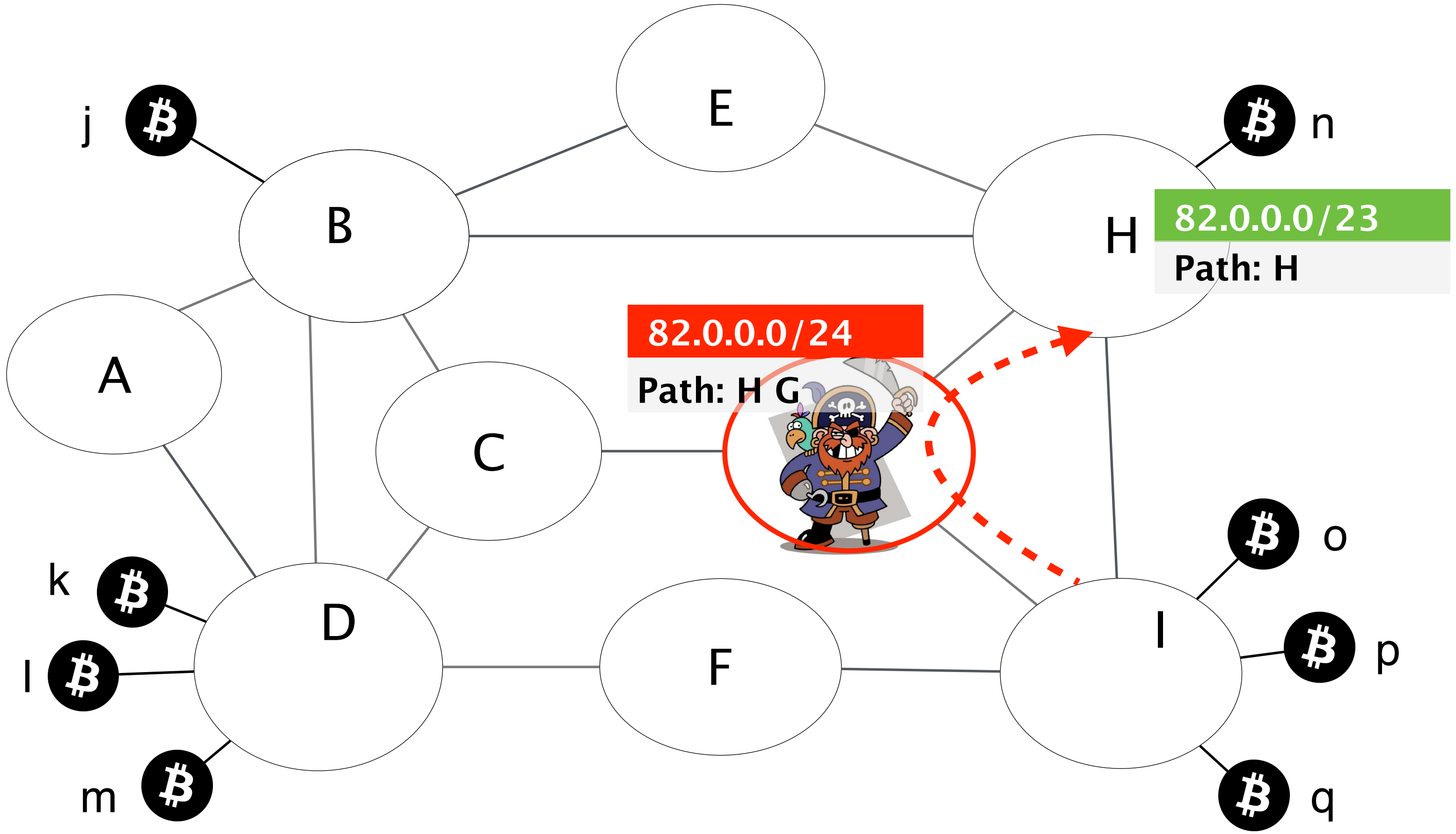
BGP does not check the legitimacy of advertisements



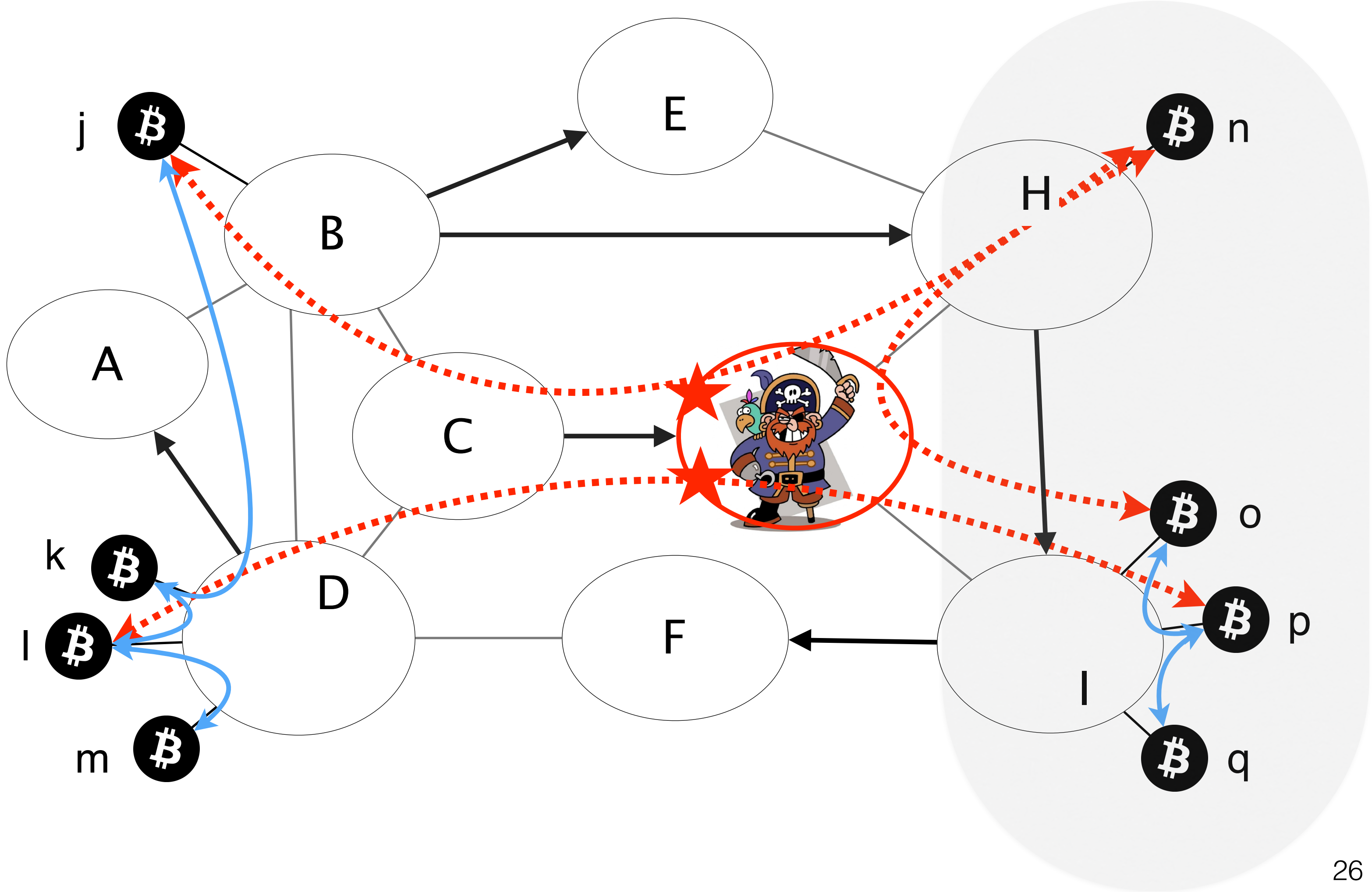
Attacker creates a fake BGP advertisement



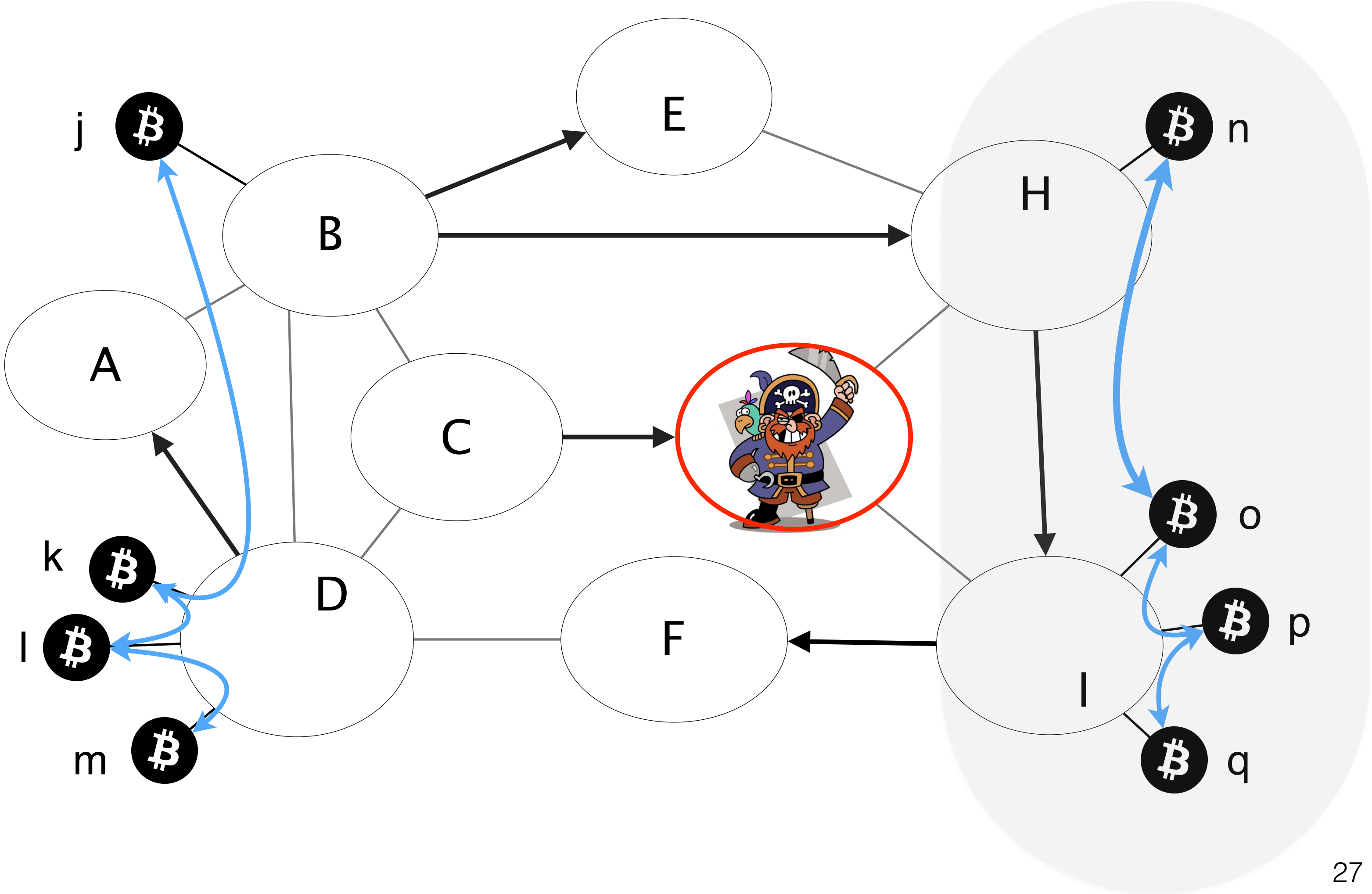
Attacker attracts traffic destined to AS H using BGP hijacking



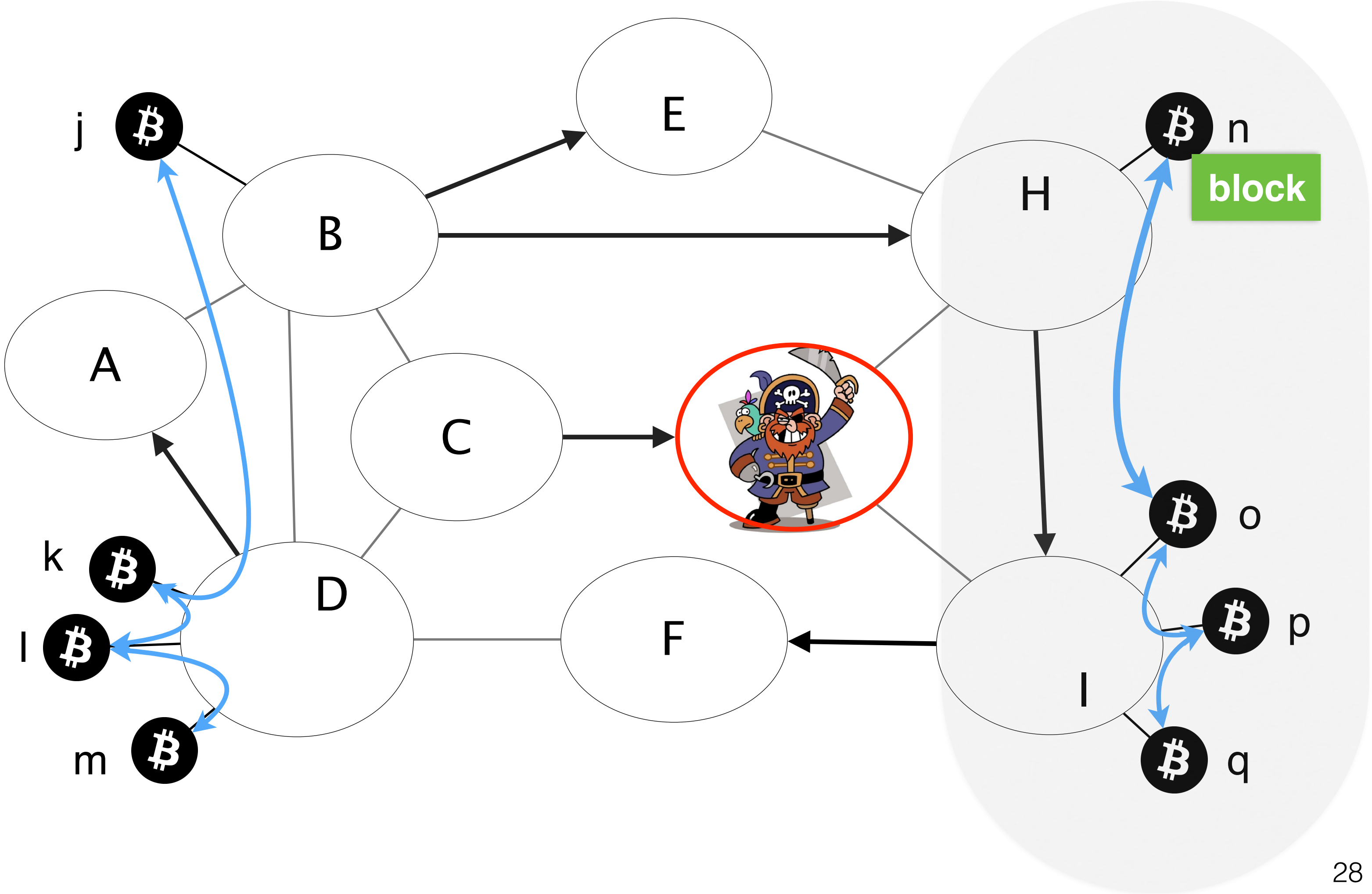
Attacker attracts connections with BGP hijacking



Attacker drops connections crossing the partition



A new block in the grey zone cannot be propagated further



SABRE:

Additional channel that is engineered
to allow clients to exchange blocks,
even if the Bitcoin network is partitioned

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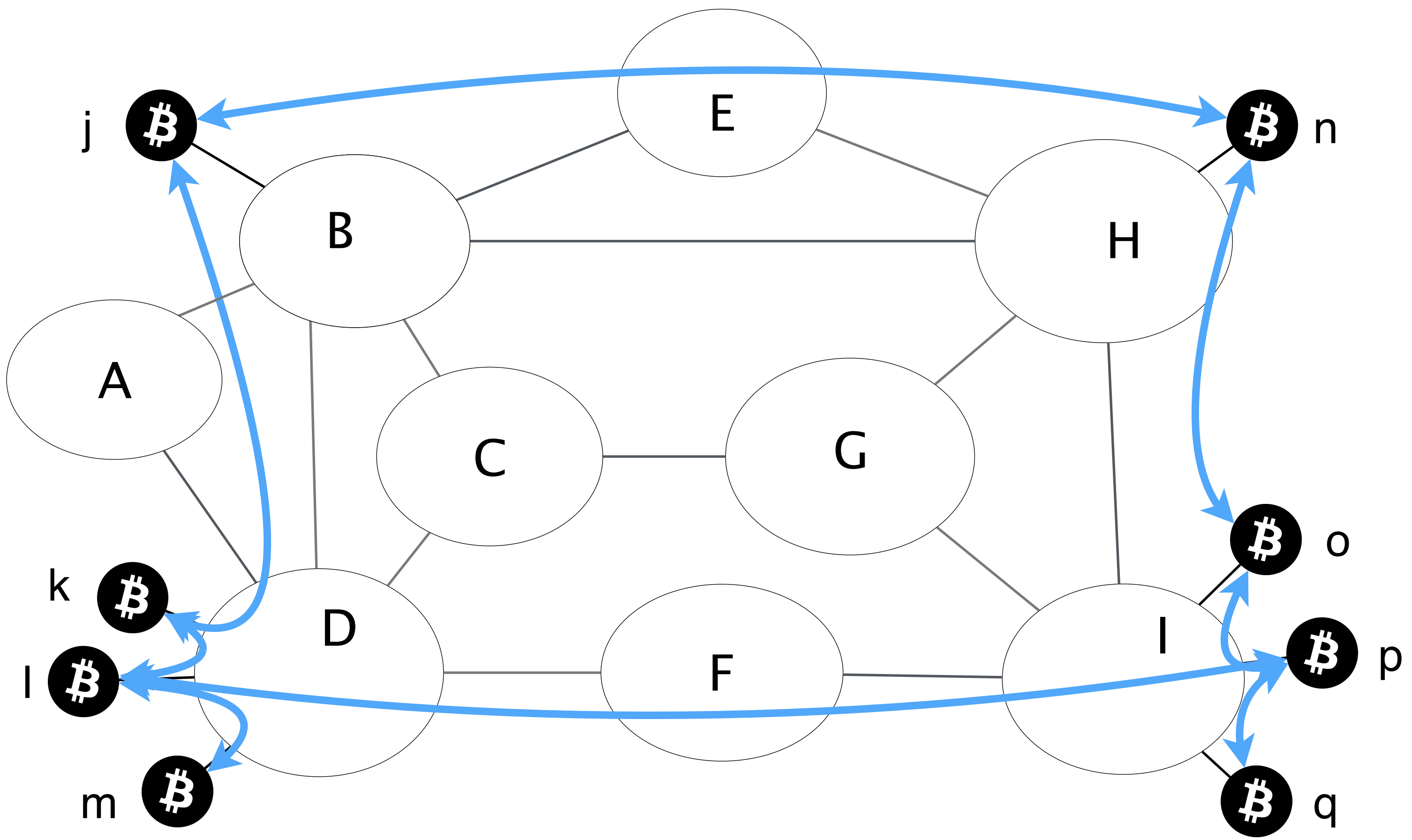
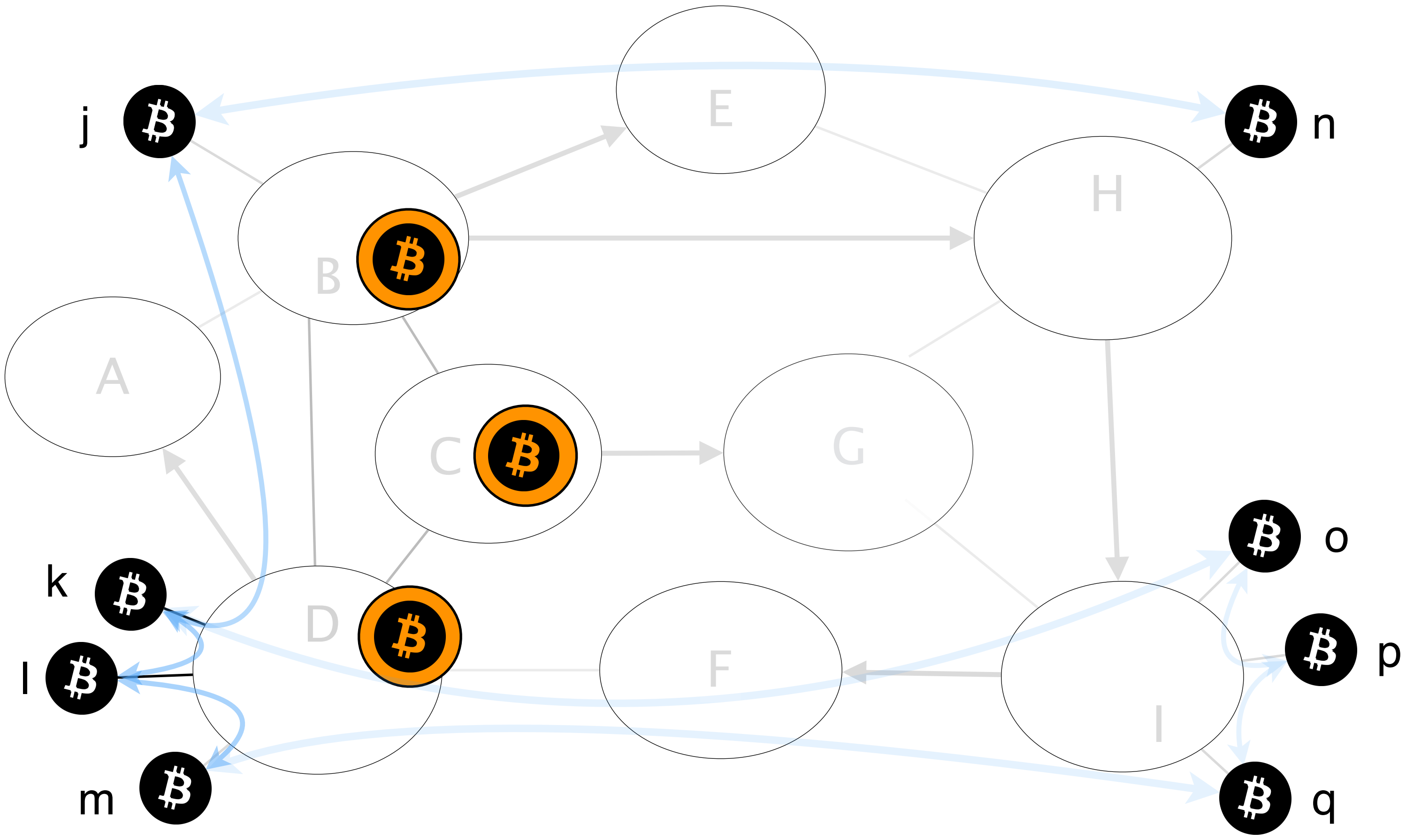
Additional channel that is engineered to allow clients to exchange blocks, even if the Bitcoin network is partitioned

… without the need to deploy secure routing protocols

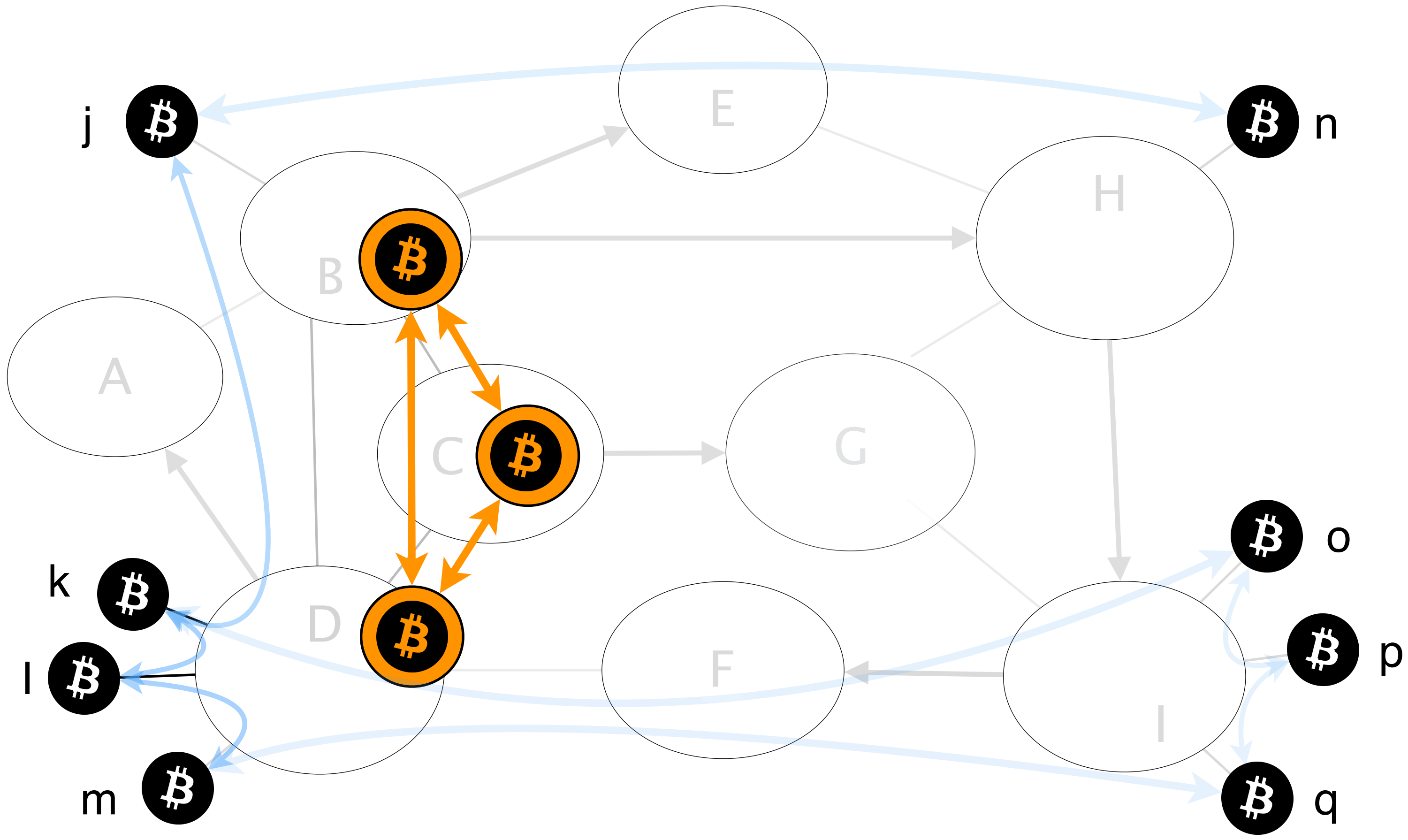
SABRE does not affect any of the regular Bitcoin clients



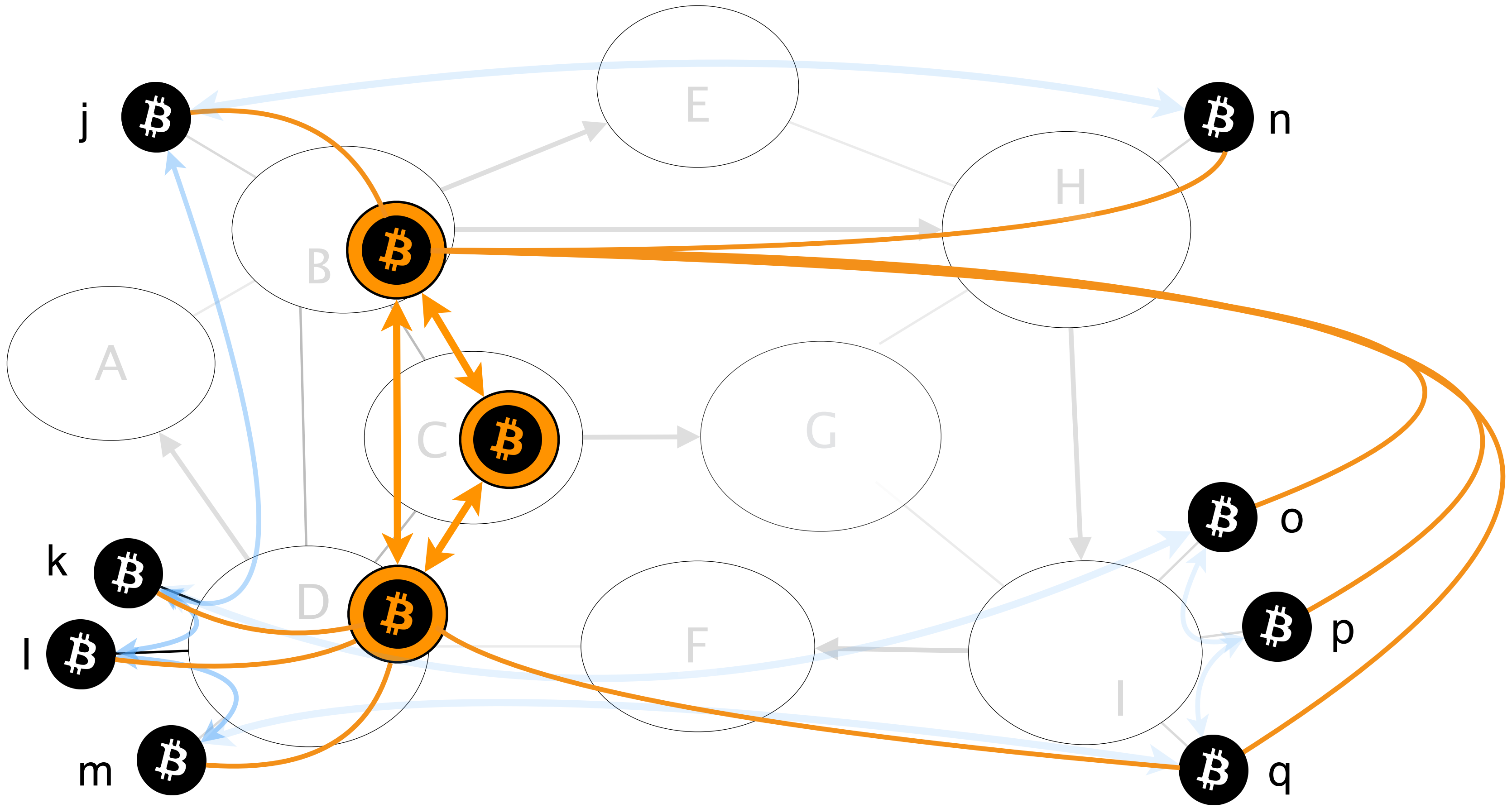
SABRE is an overlay network of special Bitcoin clients



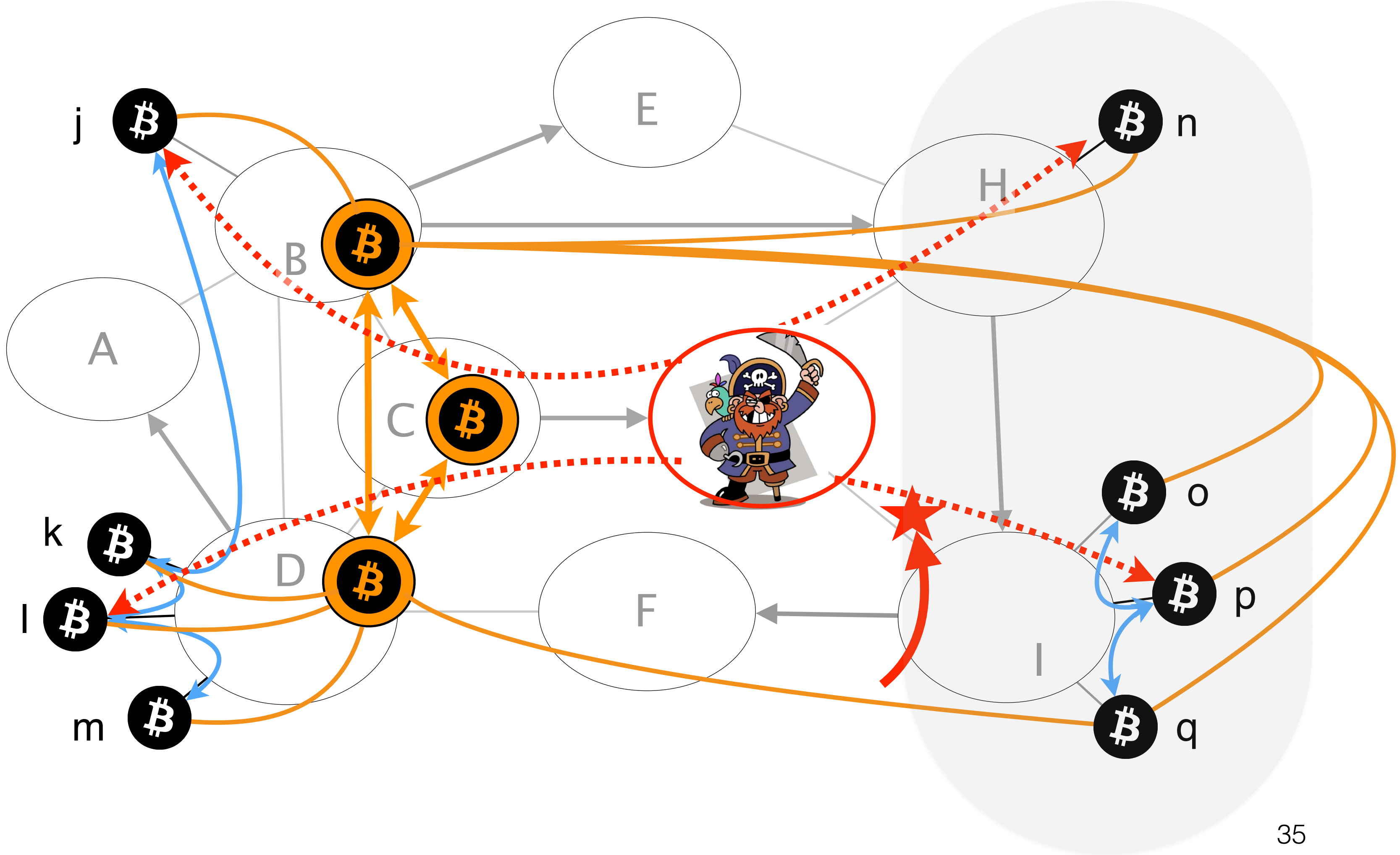
SABRE nodes are connected to each other



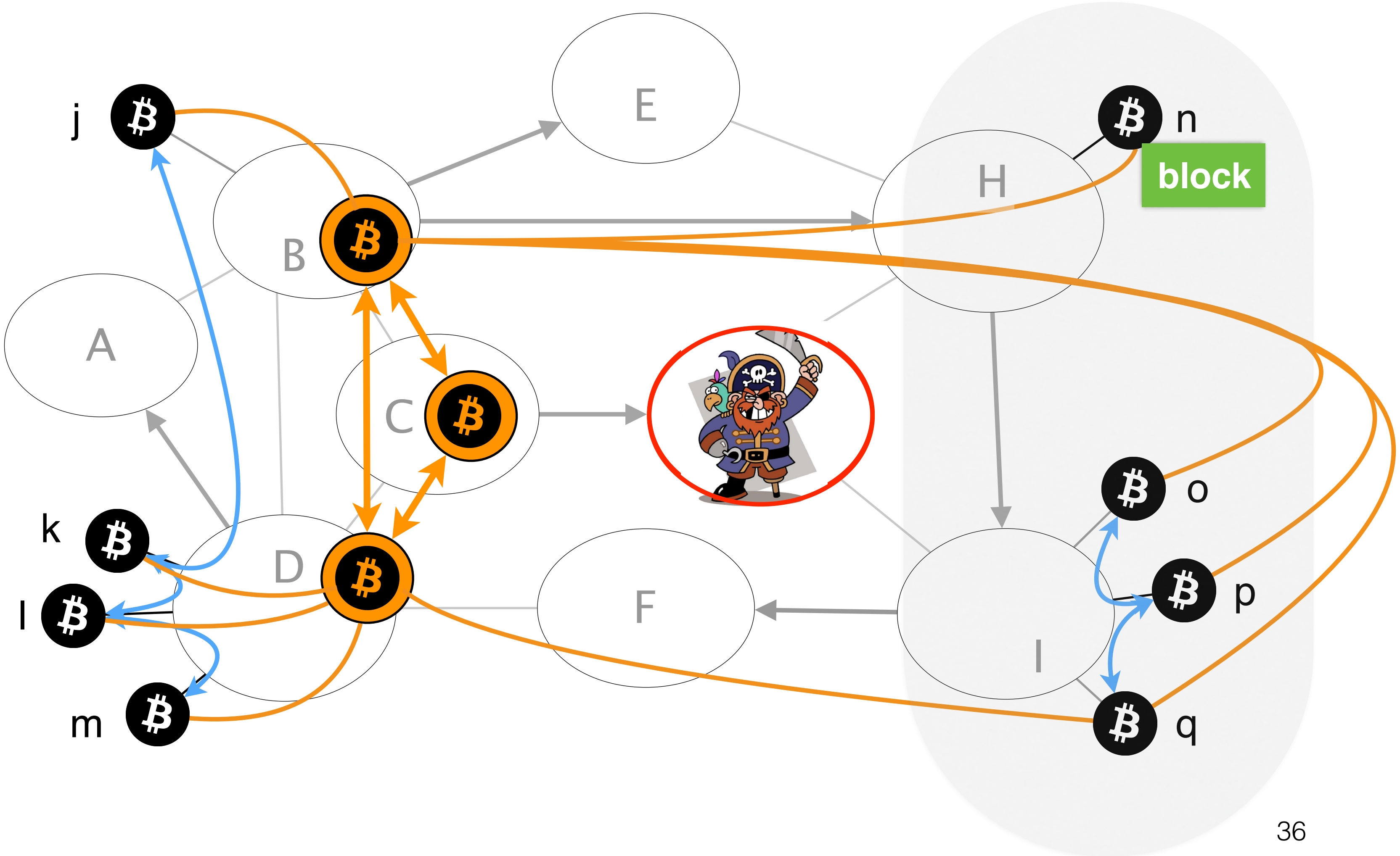
Each Bitcoin client connects to at least one SABRE node



SABRE protects the Bitcoin network from partition attacks



Block is propagated via the SABRE network



The attacker might try to fight back by attacking SABRE itself

The attacker might try to fight back by attacking SABRE itself

Attacker knows SABRE's locations and code

- BGP hijacks against SABRE nodes
- malicious requests to take down SABRE nodes

SABRE is an additional overlay network which allows communication, even if the Bitcoin network is partitioned

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SABRE needs to…

- [ ] secure relay-to-relay connections

SABRE is an additional overlay network which allows communication, even if the Bitcoin network is partitioned

SABRE needs to…

- ☐ secure relay-to-relay connections
- ☐ remain reachable by Bitcoin clients

SABRE is an additional overlay network which allows communication, even if the Bitcoin network is partitioned

SABRE needs to…

- [ ] secure relay-to-relay connections
- [ ] remain reachable by Bitcoin clients
- [ ] relay blocks seamlessly

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- [ ] relay blocks seamlessly

Network Design

SABRE is an additional overlay network which allows communication, even if the Bitcoin network is partitioned

SABRE needs to…

- [ ] secure relay-to-relay connections
- [ ] remain reachable by Bitcoin clients
- [ ] relay blocks

Network Design (secure relay-to-relay connections; remain reachable by Bitcoin clients)

Node Design (relay blocks)

SABRE

Protecting Bitcoin against Routing Attacks

SABRE location

inherently safe locations

SABRE design

software/hardware

Deployability

deployment opportunities

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SABRE is an additional overlay network which allows communication, even if the Bitcoin network is partitioned

SABRE needs to…

- [ ] secure relay-to-relay connections
- [ ] remain reachable by Bitcoin clients
- [ ] relay blocks

Node Design

SABRE selects nodes that satisfy three properties

each node is hosted in /24 IP prefixes

nodes are connected via financially &
distance-wise optimal paths

relay graph is k-connected

SABRE selects nodes that satisfy three properties

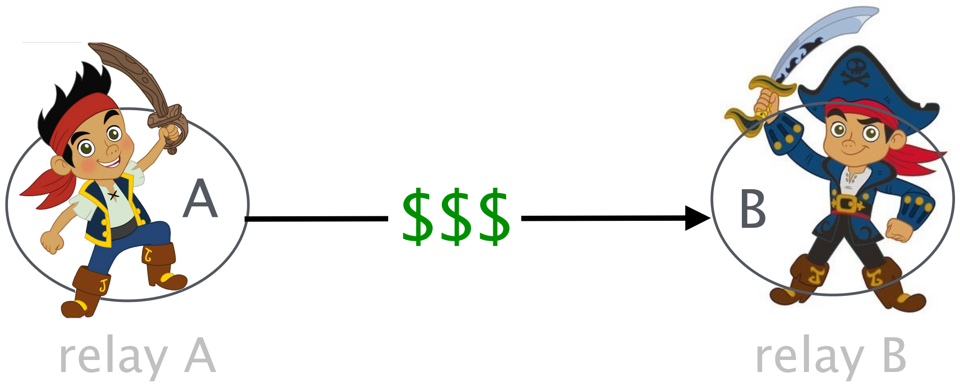
each node is hosted in /24 IP prefixes

longer prefix hijacks are not possible

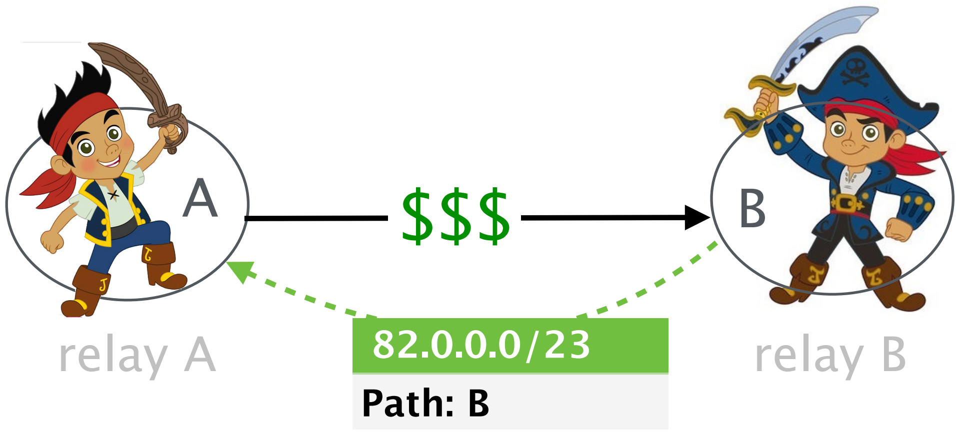
nodes are connected via financially & distance-wise optimal paths

relay graph is k-connected

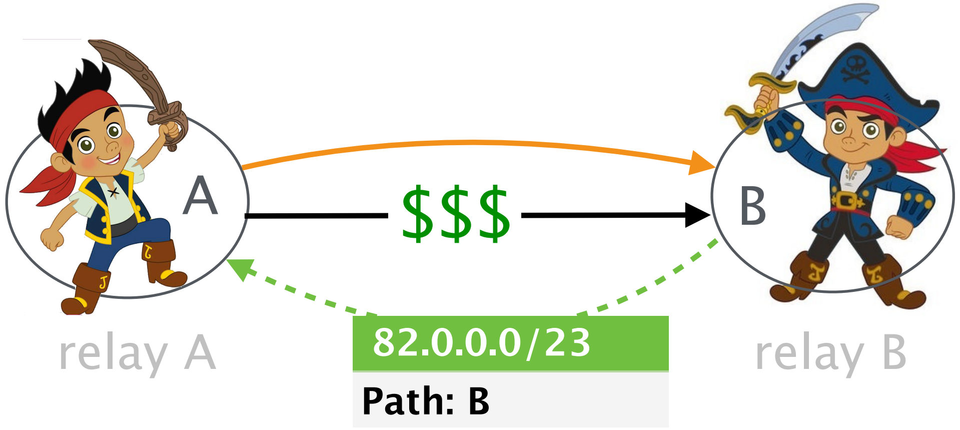
Relays A and relay B are hosted in ASes with customer-provider relationship



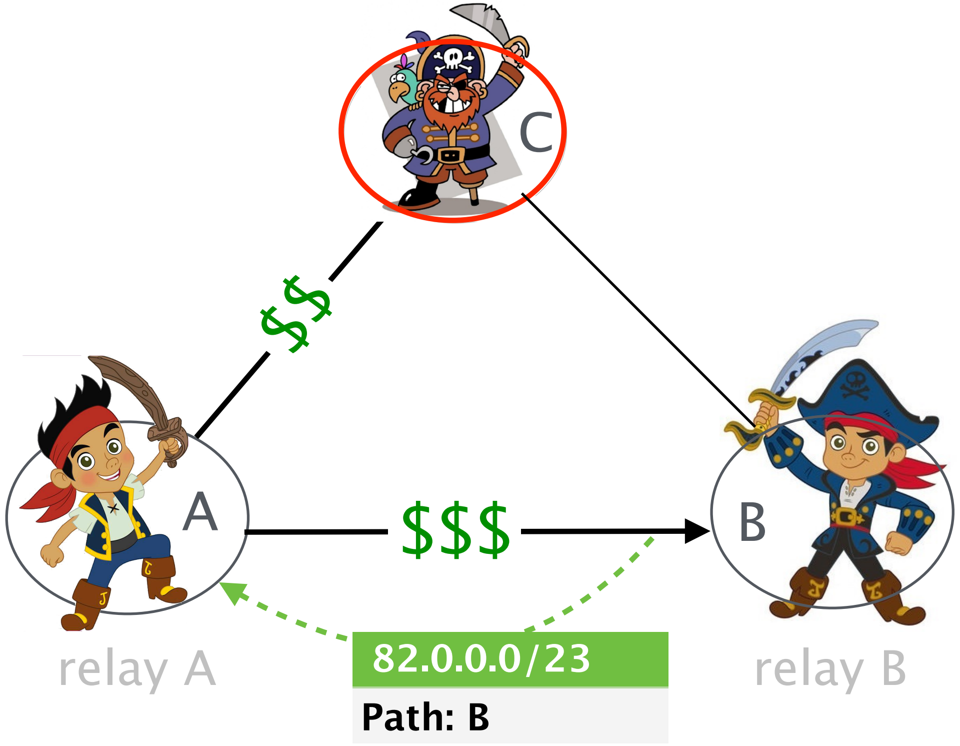
AS A receives a BGP advertisement from AS B for the prefix of relay B



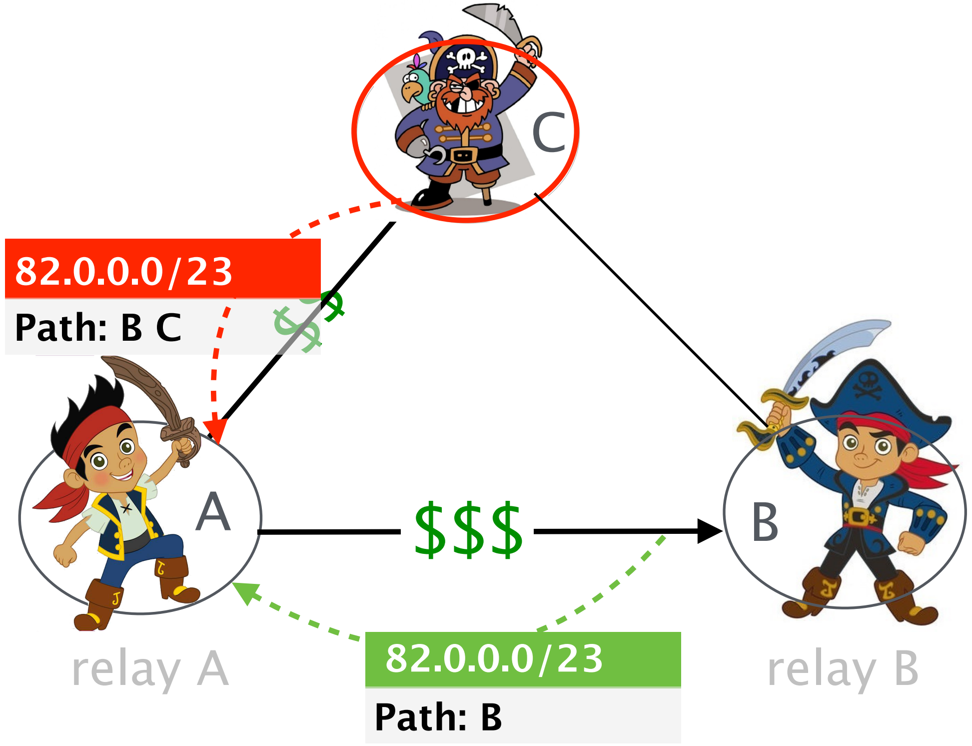
Relay A sends to relay B via a direct expensive link



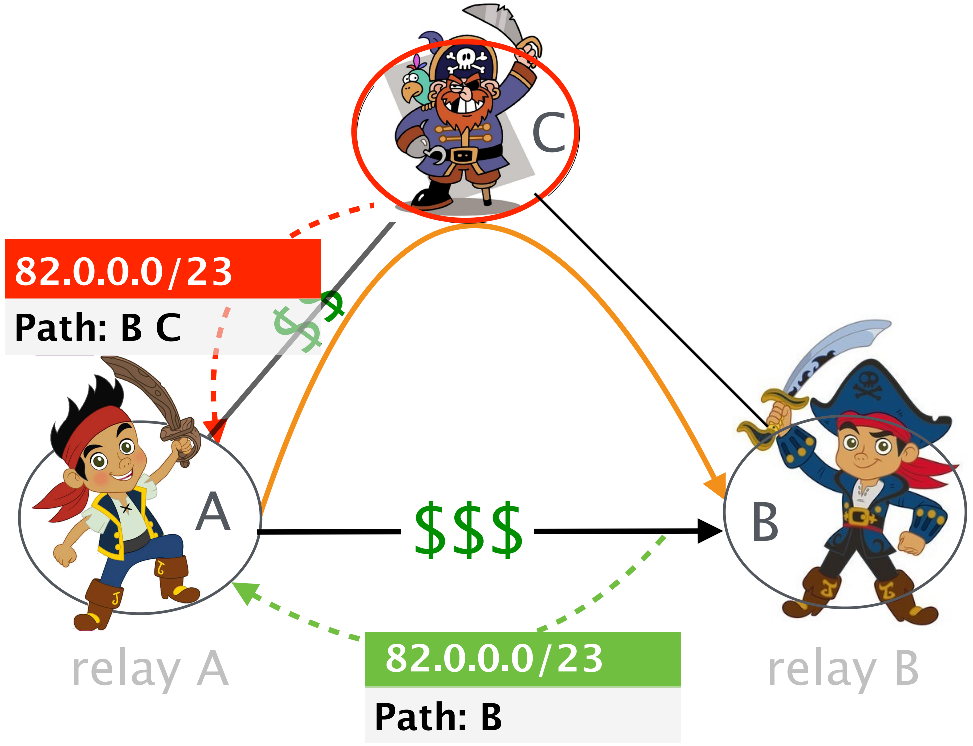
AS A has a malicious or compromised neighbor AS with a least expensive link



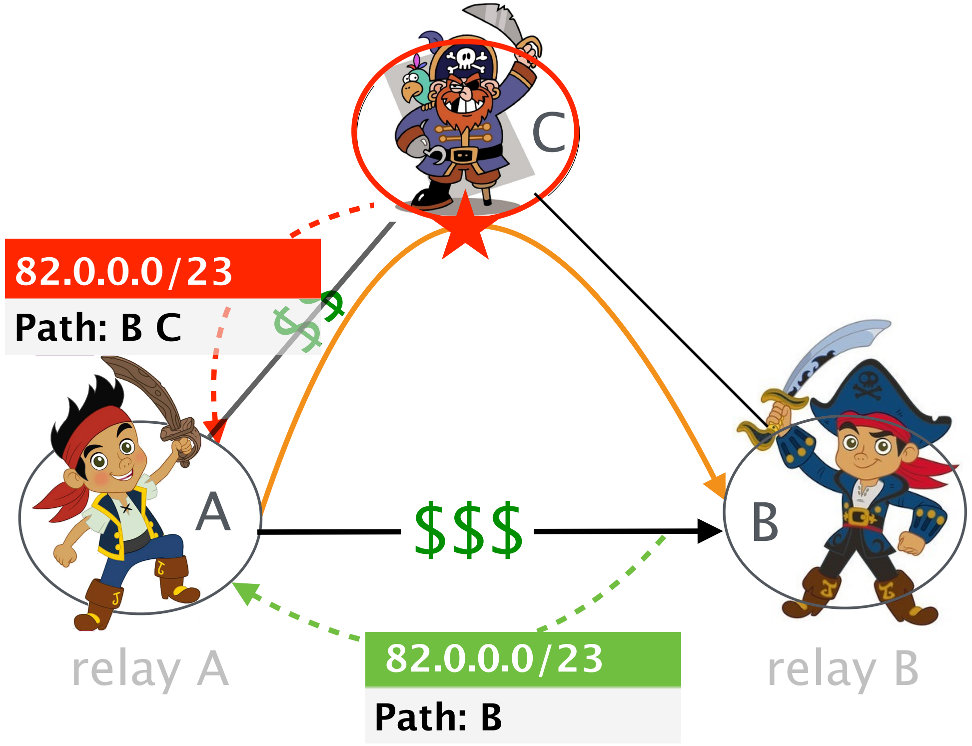
Attacker advertises AS B's prefix to AS A



AS A prefers the path via the attacker, because it is less expensive



The attacker can disconnect the relays



SABRE selects nodes that satisfy three properties

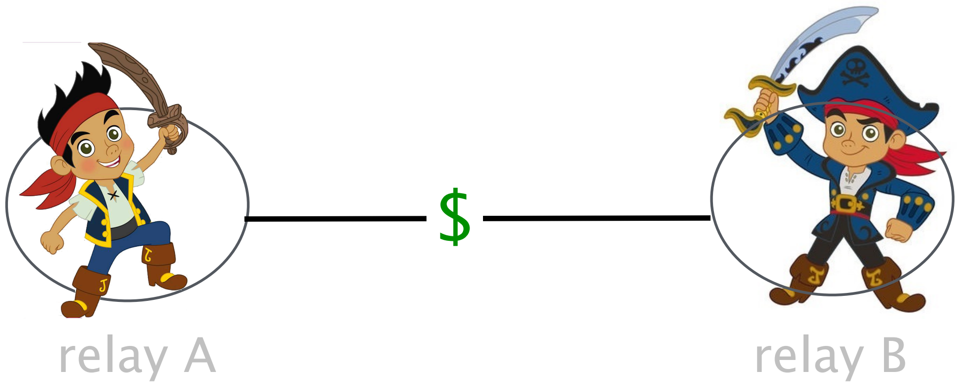
each node is hosted in /24 IP prefixes

nodes are connected via financially & distance-wise optimal paths

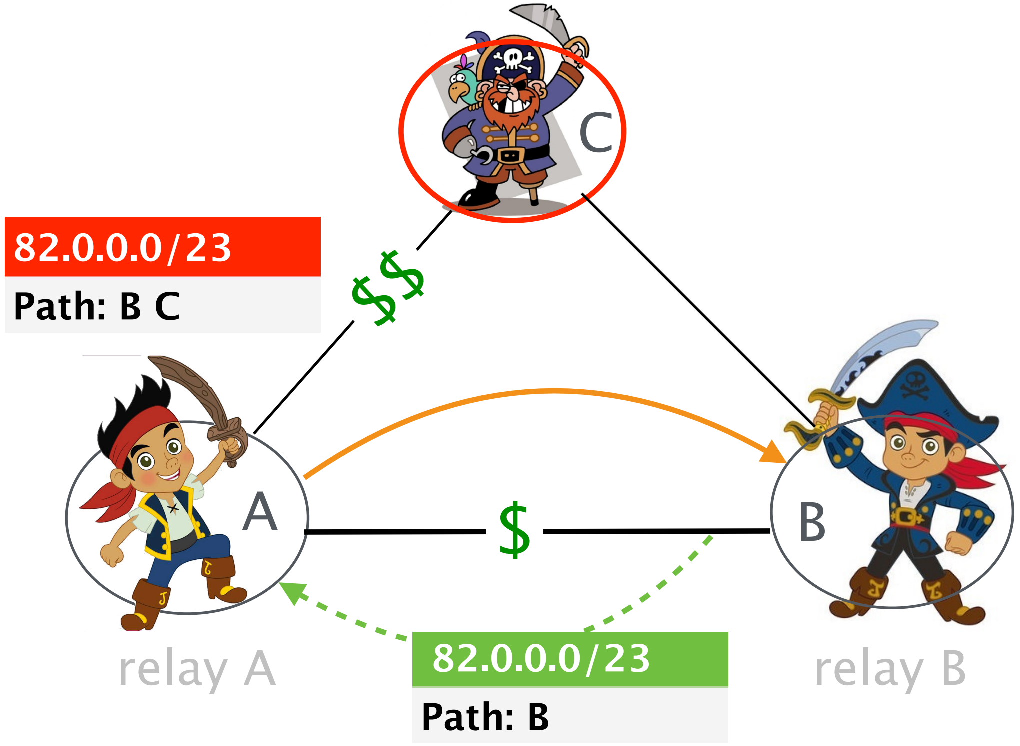
no strictly more preferred path exists

relay graph is k-connected

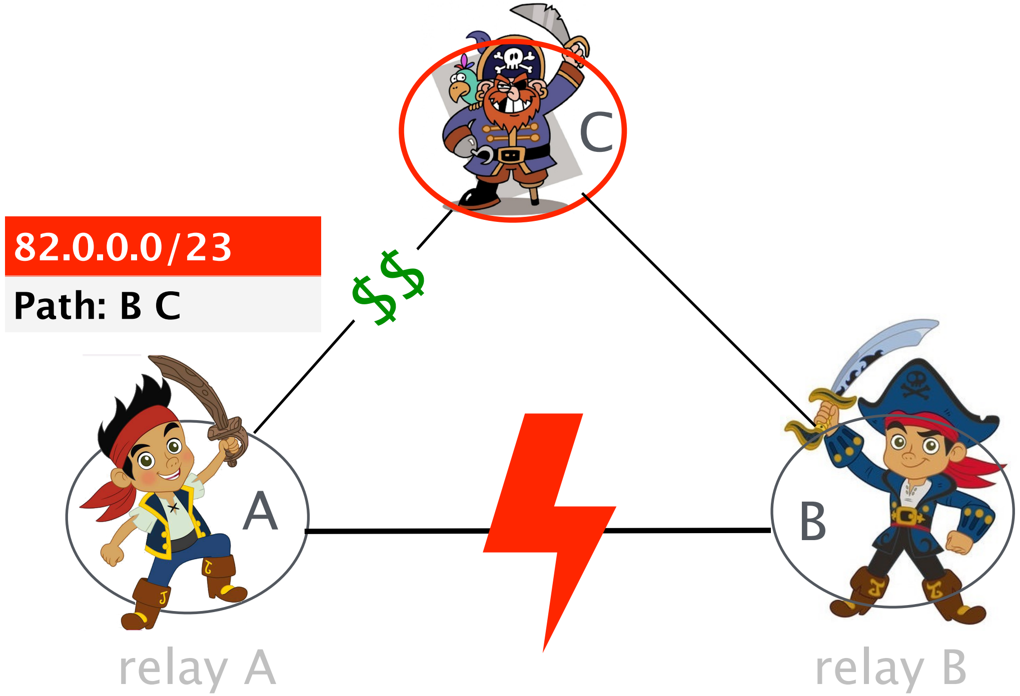
Relays A, B are hosted in ASes
with a more cost effective agreement



Attacker's advertisement is less preferred, thus attacker cannot discontent the relays

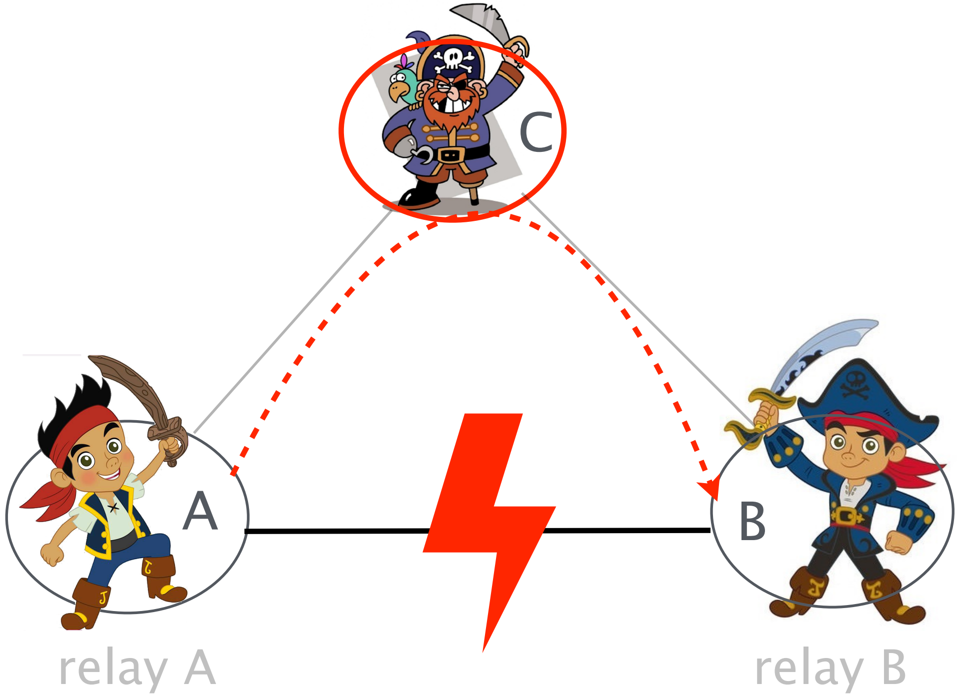


Aggreements can be revoked, link can be cut …



Peering agreement can be revoked, link can be cut …

Relay A will inevitably send traffic via ASC



SABRE selects nodes that satisfy three properties

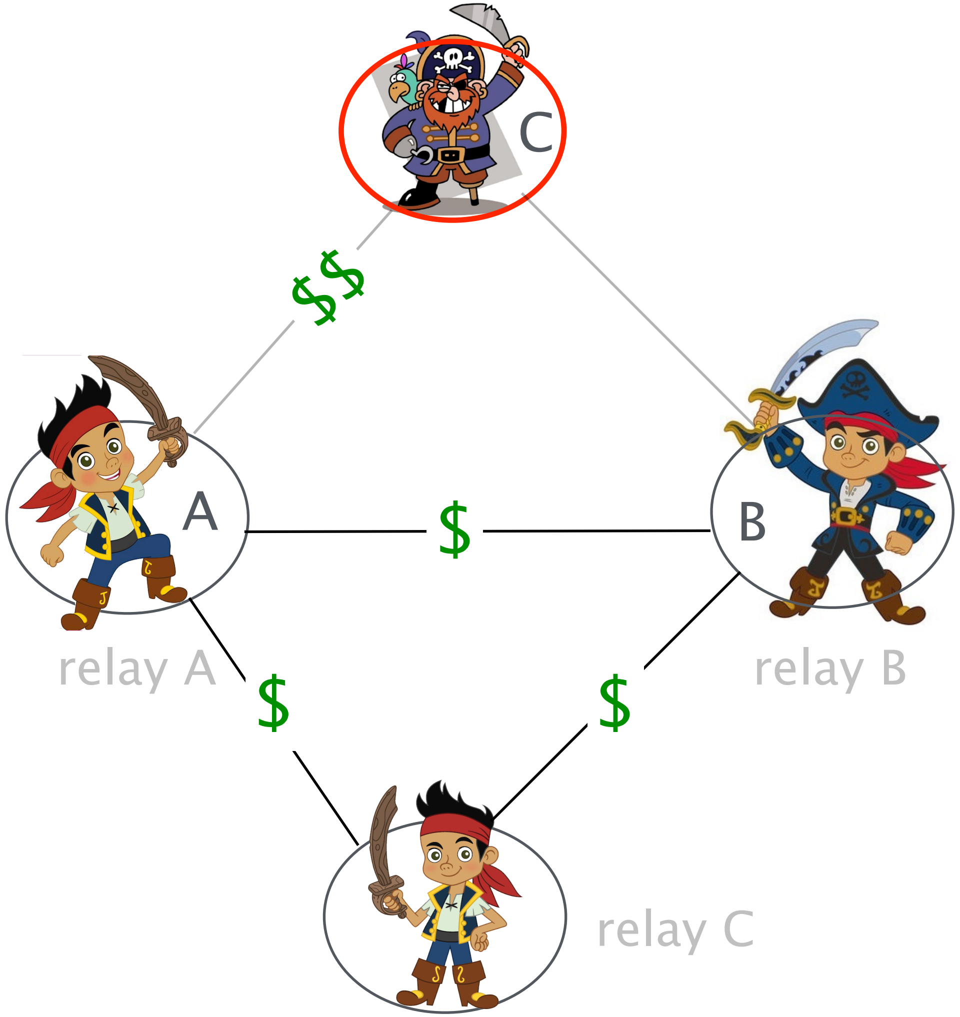
each node is hosted in /24 IP prefixes

nodes are connected via financially & distance-wise optimal paths

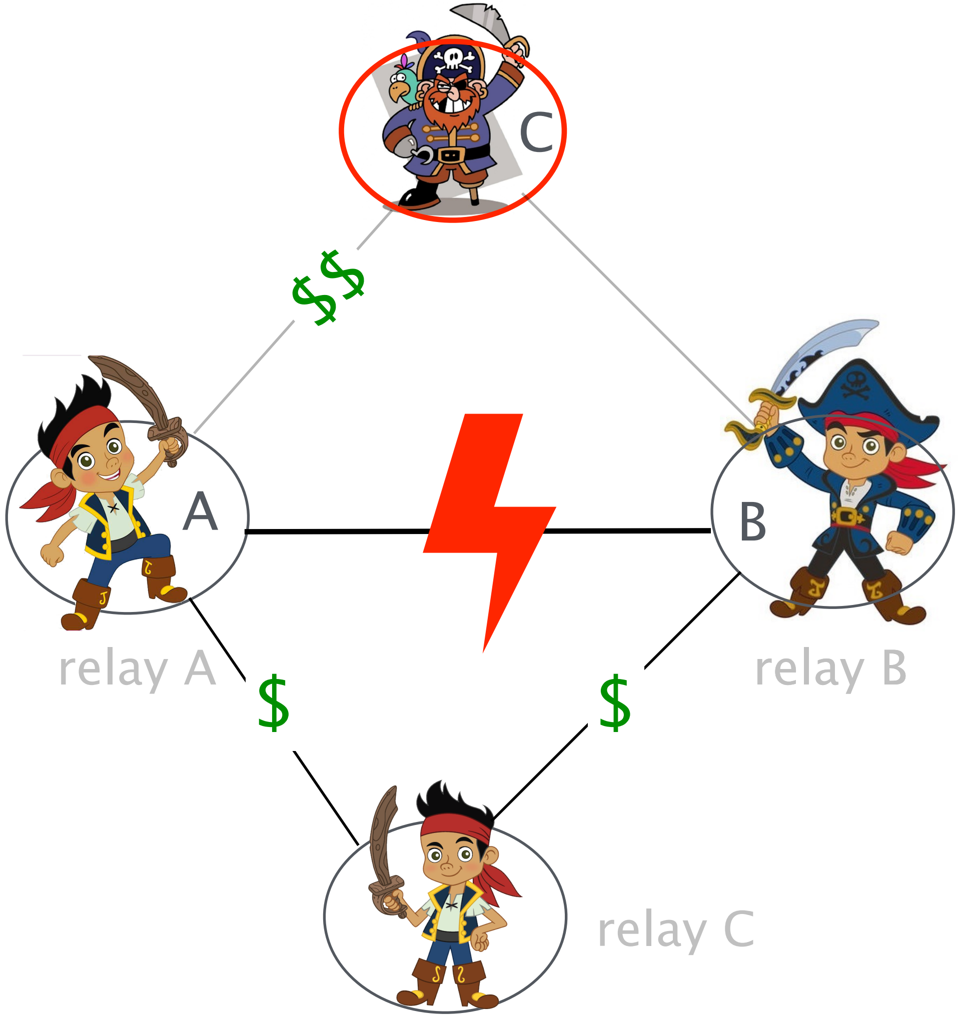
relay graph is k-connected

relay connectivity is not disrupted by any k-1 cuts

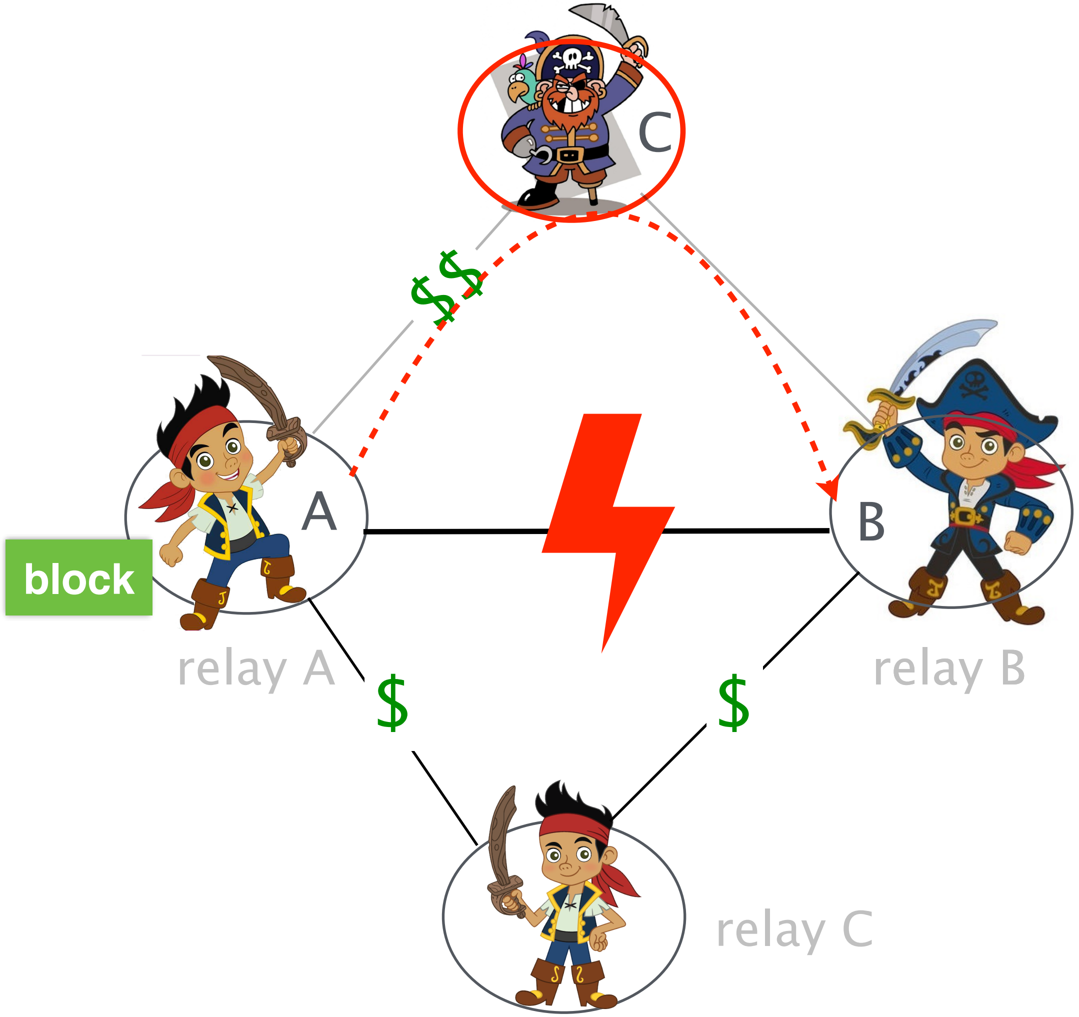
2-k connected graph retains connectivity even if one peering link is cut



If the link between relays A and B is cut



If the link between relays A and B is cut
Relays A, B can still exchange blocks via the relay C



SABRE is an additional overlay network which allows communication, even if the Bitcoin network is partitioned

SABRE needs to…

- ☑ secure relay-to-relay connections
- ☐ remain reachable by Bitcoin clients
- ☐ relay blocks

Node Design

SABRE positions nodes s.t. most clients
are protected from each potential attacker
by at least one relay node

see paper for more

SABRE is an additional overlay network which allows communication, even if the Bitcoin network is partitioned

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Node Design

We evaluate SABRE's network design by its effectiveness against two attack types

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Network-wide attacks

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Network-wide attacks

Node-level attacks

We evaluate SABRE's network design by its effectiveness against two attack types

Network-wide attacks

What is the largest partition each single AS can create?

Node-level attacks

How many clients are protected against isolation?

What is the largest partition each single AS can create?

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- current network

any single AS in the world can create partitions of >90% of the clients

What is the largest partition each single AS can create?

- current network — any single AS in the world can create partitions of >90% of the clients
- 6 SABRE nodes 3-connected — only 3% of ASes in the world can create a partition of 15%-30%

see paper for more results

We evaluate SABRE's network design by its effectiveness against two attack types

Network-wide attacks

What is the largest partition each single AS can create?

Node-level attacks

How many clients are protected against isolation?

How many clients are protected against isolation?

How many clients are protected against isolation?

- current network

at most 10% of Bitcoin clients
are protected from 50% of ASes

How many clients are protected against isolation?

- current network — at most 10% of Bitcoin clients are protected from 50% of ASes
- 6 SABRE nodes 5-k connected — 89.5% of Bitcoin clients are protected from 92.5% of ASes

see paper for more results

SABRE

Protecting Bitcoin against Routing Attacks

SABRE location

inherently safe locations

SABRE design

software/hardware

Deployability

deployment opportunities

SABRE is an additional overlay network which allows communication, even if the Bitcoin network is partitioned

SABRE needs to…

- [x] secure relay-to-relay connections
- [x] remain reachable by Bitcoin clients
- [ ] relay blocks

A SABRE node performs four operations

- maintains connections with Bitcoin clients
- receives blocks
- verifies blocks
- transmits blocks to Bitcoin clients

Two ways to deploy a SABRE node

Two ways to deploy a SABRE node

Private deployment

Serving few predefined clients

Two ways to deploy a SABRE node

Private deployment

Serving few predefined clients

Public deployment

Serving all Bitcoin clients

Two ways to deploy a SABRE node

Private deployment

Public deployment

Serving few predefined clients

Private SABRE nodes need not scale

SABRE nodes need to

- establish connection to a predefined set of IPs
- be unreachable for unknown clients
- receive and relay blocks

Private SABRE nodes need not scale

SABRE nodes need to

- establish connection to a predefined set of IPs
- be unreachable for unknown clients
- receive and relay blocks

regular Bitcoin client with few whitelisted IPs is sufficient

Two ways to deploy a SABRE node

Private deployment

Serving few predefined clients

Public deployment

Serving all Bitcoin clients

Public SABRE nodes need to scale

SABRE nodes need to

- maintain thousands of connections
- distinguish spoofing and malicious request
- receive, verify and relay blocks fast

Public SABRE nodes need to scale

SABRE nodes need to

- maintain thousands of connections
- distinguish spoofing and malicious request
- receive, verify and relay blocks fast

Simple software implementation would not suffice

SABRE can leverage programmable data planes

SABRE DP

SABRE DP allows relay nodes to deal with high malicious or benign load

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is faster than any server optimization

can serve few Billions of packets per second

SABRE DP allows relay nodes to deal with high malicious or benign load

is faster than any server optimization

protects against malicious requests

- Dynamic Black/White lists
- Protection from spoofing &
- Repetitive request

SABRE DP allows relay nodes to deal with high malicious or benign load

is faster than any server optimization

protects against malicious requests

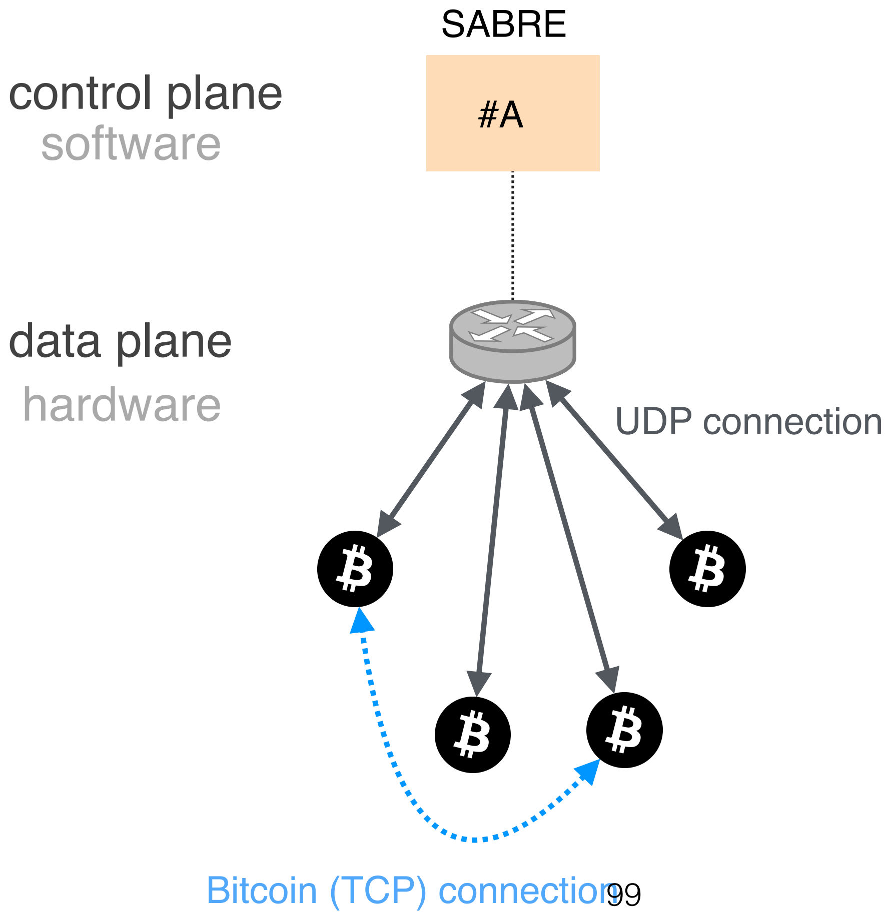
minimum software interaction

almost all clients are seven directly from hardware

Not all operations can be done in hardware

Not all operations can be done in hardware

SABRE node has both software and hardware parts



SABRE is an additional overlay network which allows communication, even if the Bitcoin network is partitioned

SABRE needs to…

- ☑ secure relay-to-relay connections
- ☑ remain reachable by Bitcoin clients
- ☑ relay blocks

SABRE

Protecting Bitcoin against Routing Attacks

SABRE location

inherently safe locations

SABRE design

software/hardware

Deployability

deployment opportunities

Multiple deployment scenarios

SABRE’s deployment is practical

bootstrap with a software-only SABRE

- decreased cost
- allows private deployments

SABRE's deployment is practical

bootstrap with a software-only SABRE

multiple SABRE relays can co-exist

each party (e.g. pool) can deploy their own SABRE

SABRE's deployment is practical

bootstrap with a software-only SABRE

multiple SABRE relays can co-exist

community's consensus is not required

clients can connect to both relays and regular clients

SABRE's deployment is practical

bootstrap with a software-only SABRE

multiple SABRE relays can co-exist

community's consensus is not required

network design applies to other relays

e.g., FIBRE, FALCON can relocate their nodes according to SABRE properties

SABRE

Protecting Bitcoin against Routing Attacks

SABRE location

inherently safe locations

SABRE design

software/hardware

Deployability

deployment opportunities

SABRE

Protecting Bitcoin against Routing Attacks

Few SABRE relays can protect Bitcoin from partitions
by placing relay nodes in selected locations

SABRE can operate seamlessly under high load
by serving clients directly in hardware

SABRE can be partially deployed and benefit early adopters
e.g., each pool can deploy SABRE in software

SABRE vs FALCON & FIBRE

	SABRE	FALCON	FIBRE
longer prefix hijack	protected all nodes in / 24	vulnerable no node in / 24	vulnerable no node in / 24
same prefix hijack	protected	# possible attackers	# possible attackers