# Navigating Internet Research with P4: Solutions for Performance and Security

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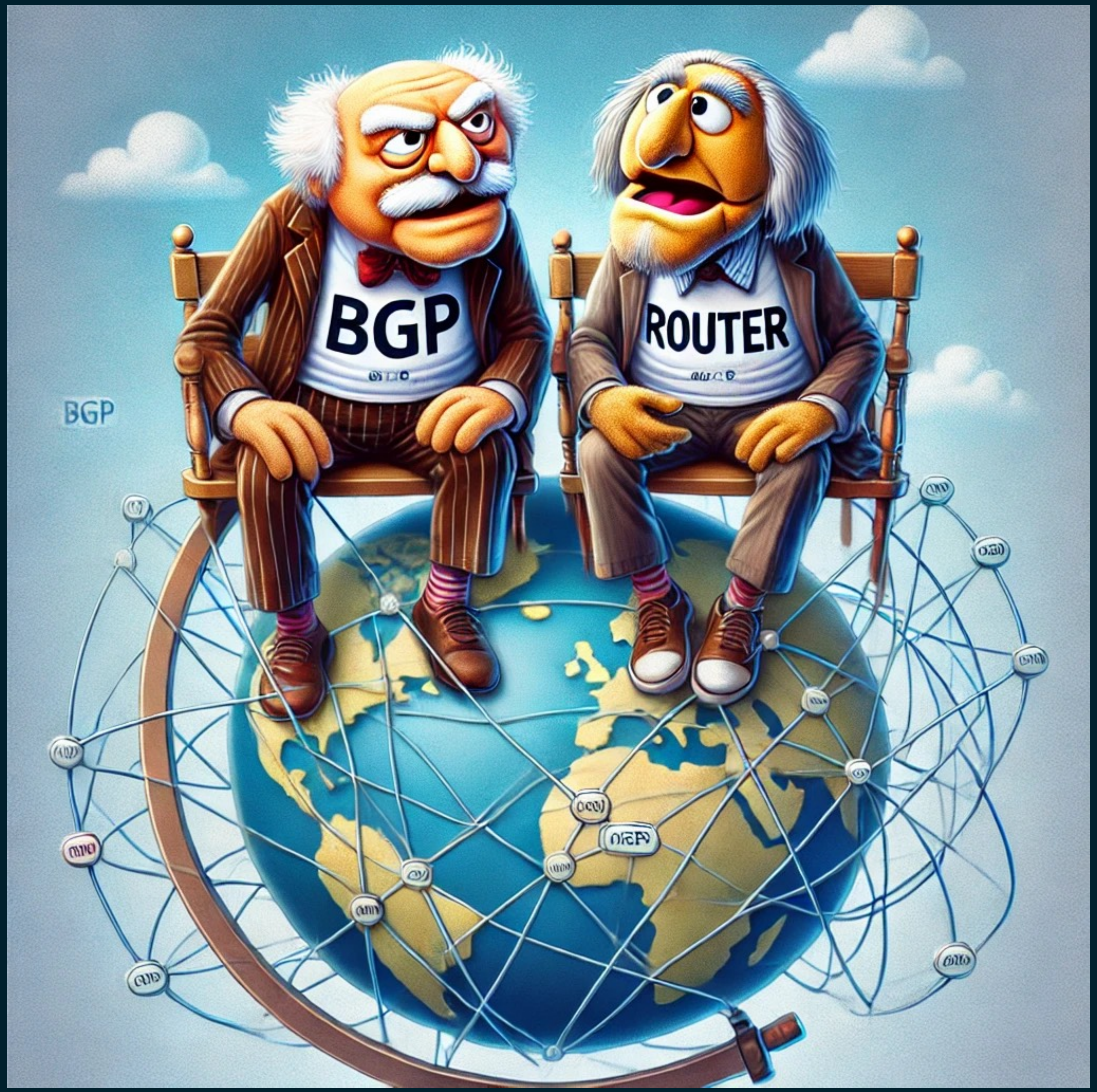
Maria Apostolaki
netsyn.princeton.edu



# What do we want from the Internet?

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Cyber-physical systems

Live streaming

Video conferencing

Online shopping

Online banking

Cryptocurrencies

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- Cyber-physical systems
- Live streaming
- Video conferencing
- Online shopping
- Online banking
- Cryptocurrencies

- Low latency
- Throughput
- Privacy
- Reliable connectivity

# What do we want from the Internet?

Cyber-physical systems

Today’s Internet provides best-effort service

Cryptocurrencies

…leading to performance, privacy, and security problems

BGP
ROUTER
BGP

# Internet research is hindered by both protocols and hardware

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BGP….

- lack of route control
- suboptimal routing
- insecure routing
- lack of path diversity

…

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- suboptimal routing
- insecure routing
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Internet Routers….

- fixed-headers support
- no cryptographic operation
- lack of performance visibility
- no DDoS support

….

What can you do with a couple of programmable points in the Internet?

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Tango: performance-driven routing system

NSDI’24

SABRE: secure overlay for BTC block propagation

NDSS’19

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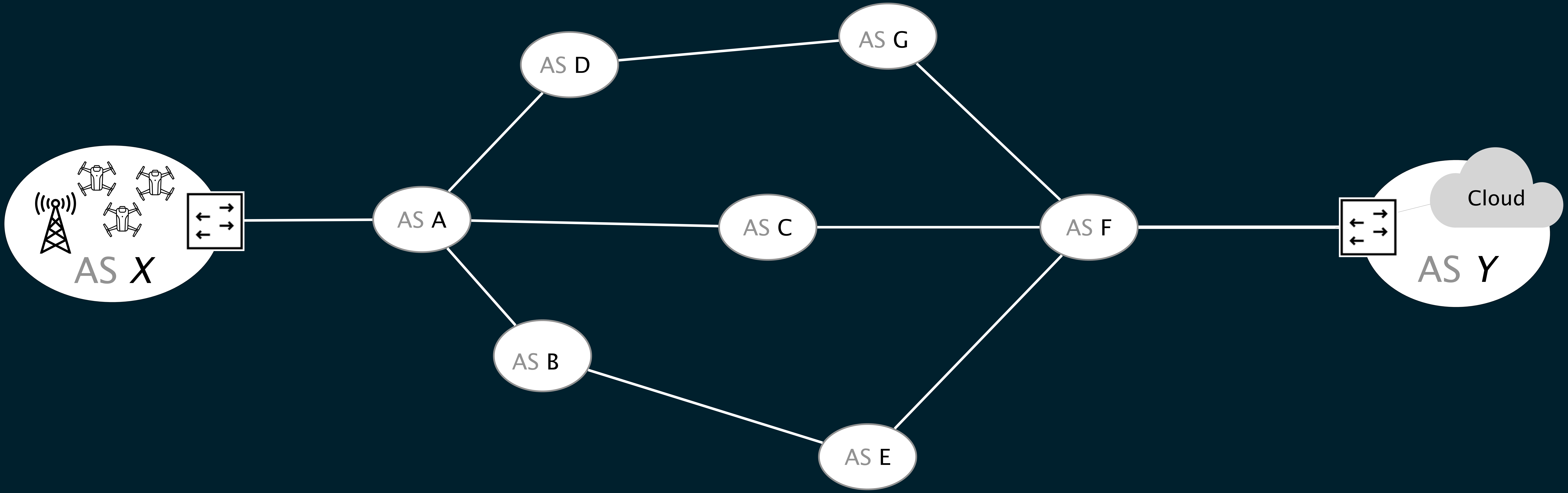
# To communicate with ASY, ASX



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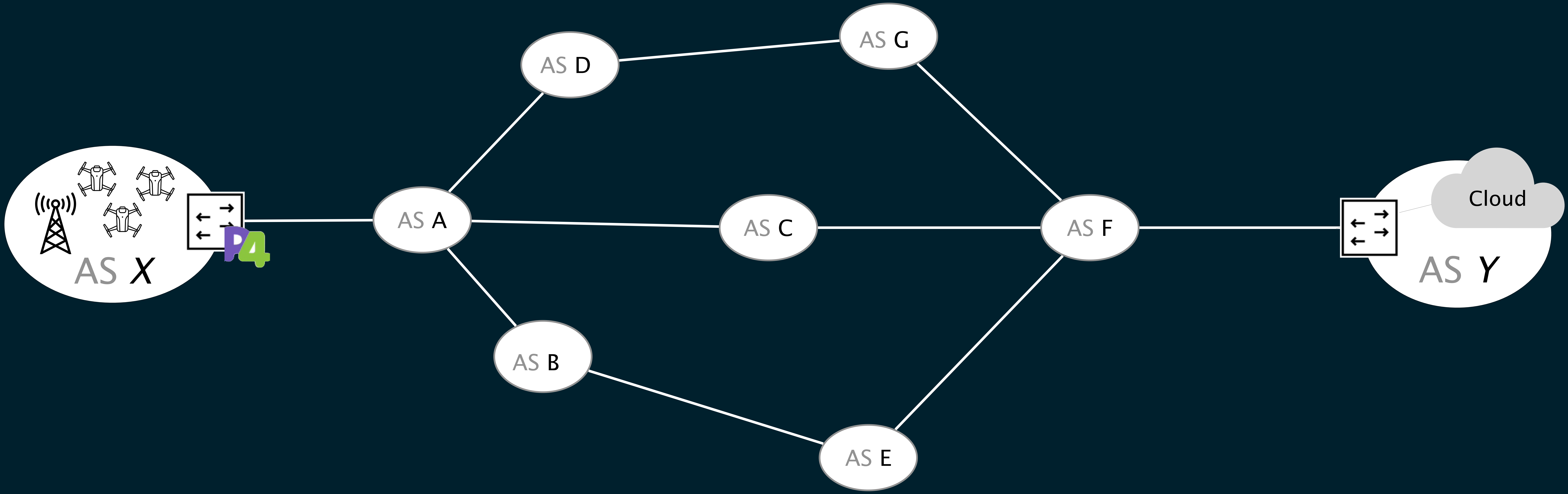
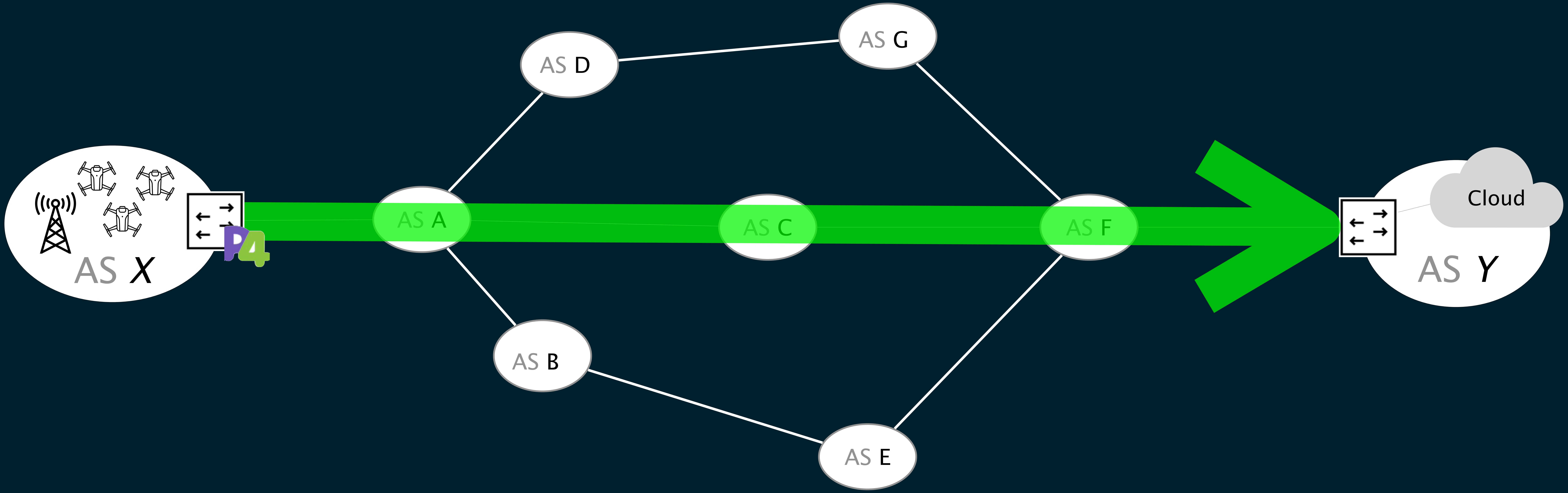
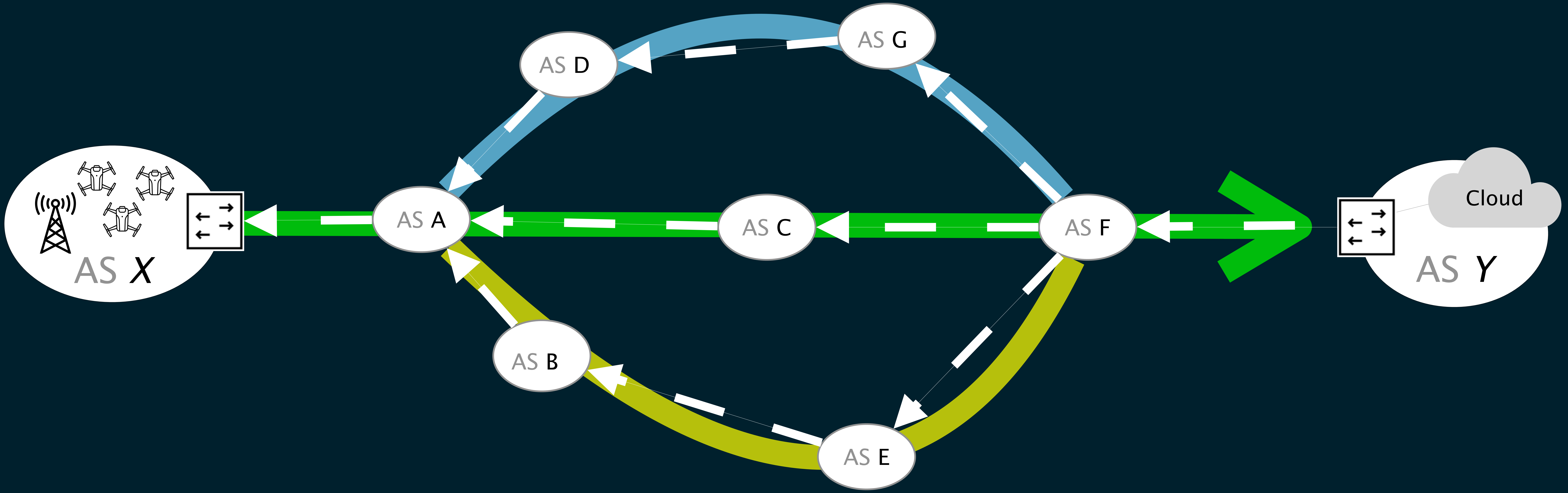


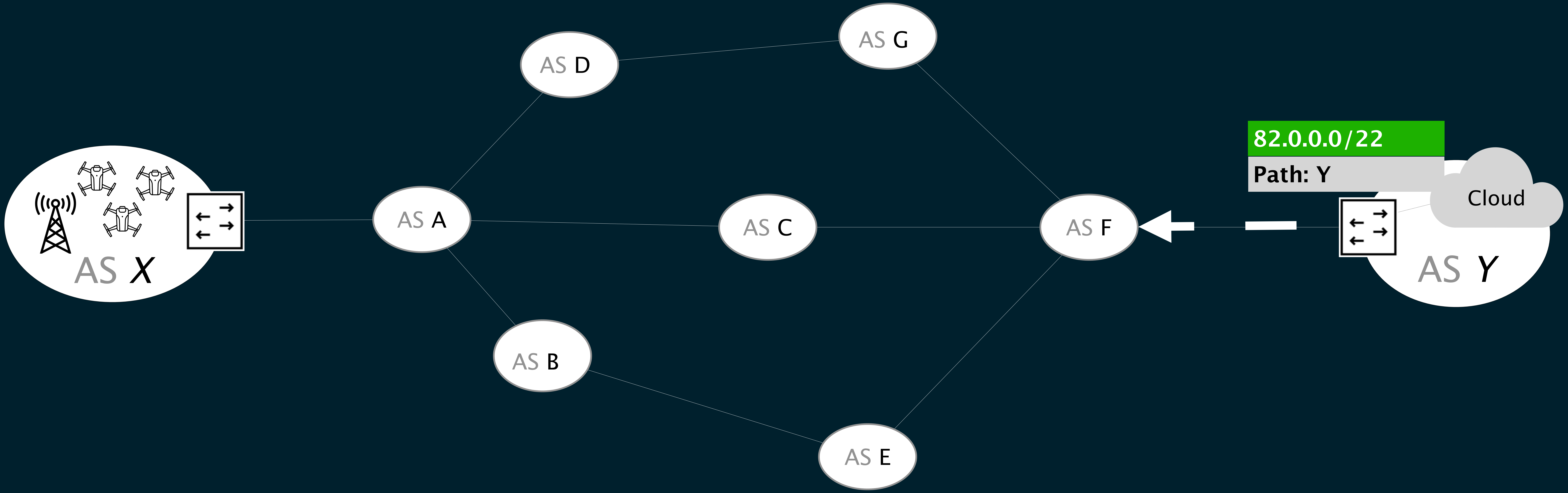
# To communicate with ASY, ASX can only use one path



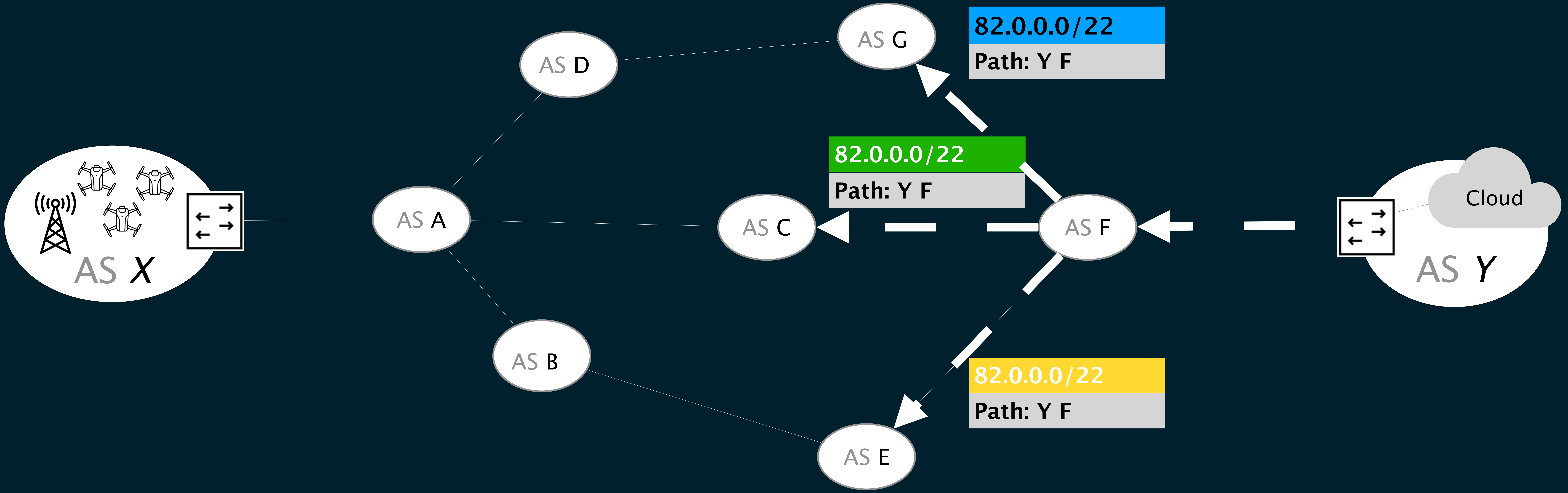
## To communicate with ASY, ASX can only use one path despite the path diversity, and independently of performance



BGP
BGP
ROUTER


AS G
AS D
82.0.0.0/22
Path: Y
Cloud
AS X
AS A
AS C
AS F
AS Y
AS B
AS E

# The BGP advertisement is propagated via multiple paths



82.0.0.0/22
Path: Y F

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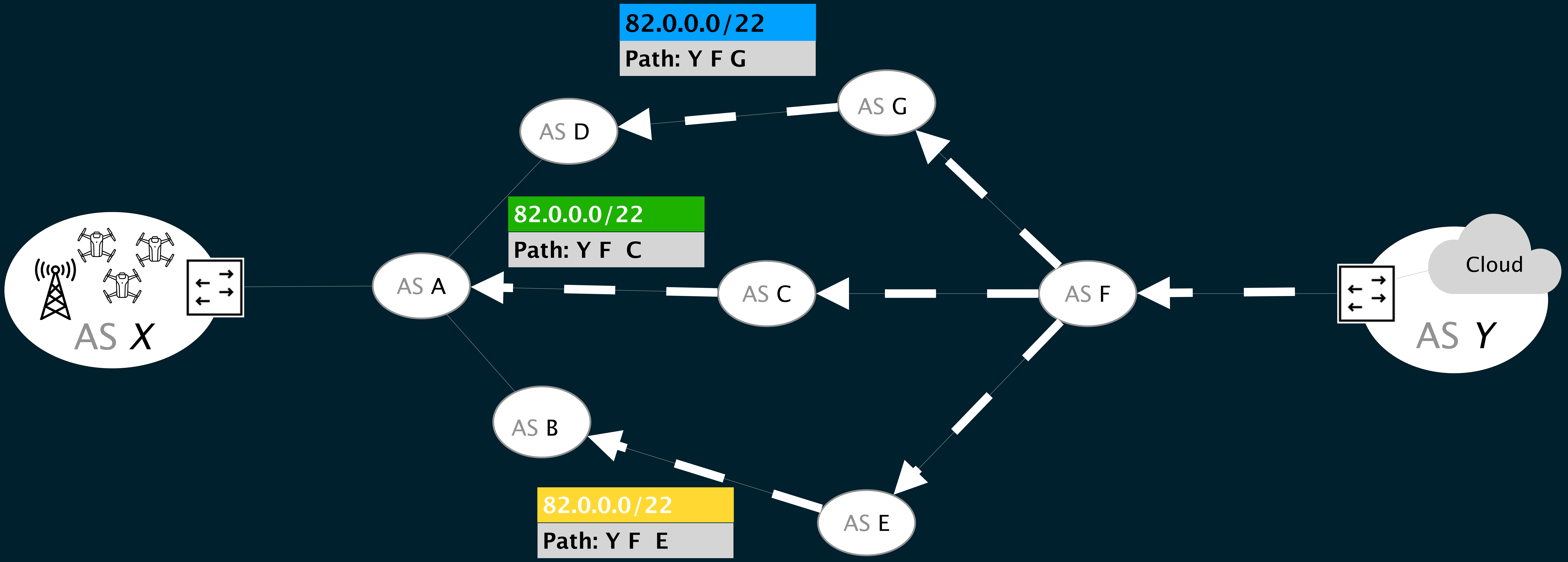


The BGP advertisement is propagated via multiple paths
But only a single advertisement  reaches the sender

AS G
AS D
AS A
AS C
AS F
AS B
AS E
Cloud
AS Y
AS X
82.0.0.0/22
Path: Y F C A

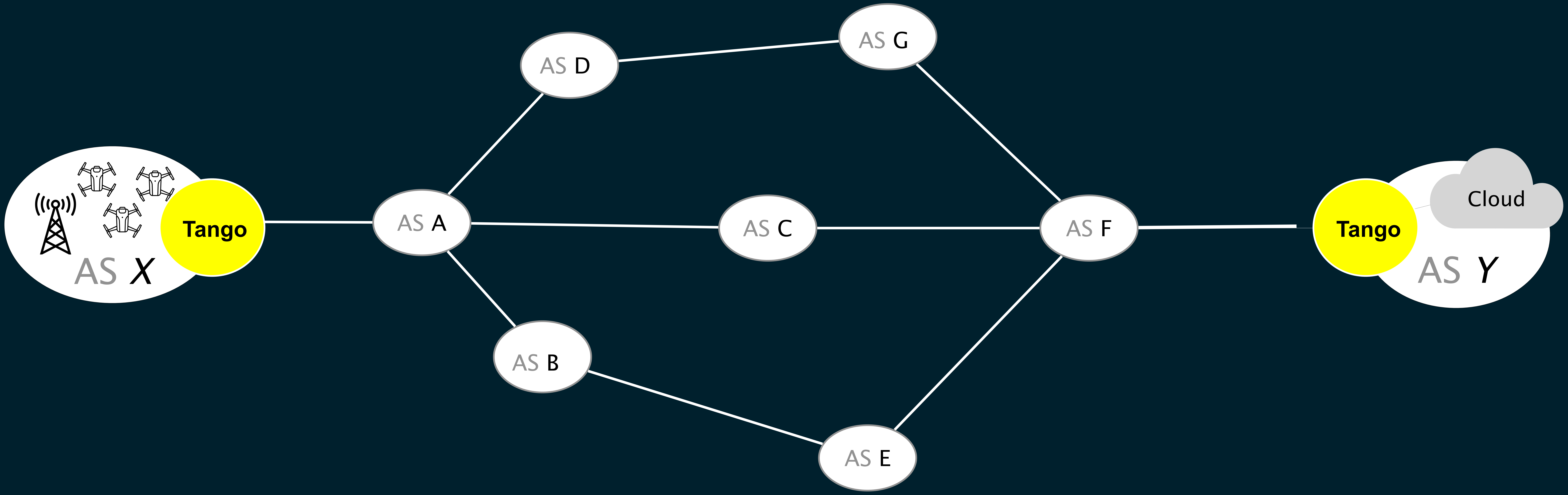
# What can you do with a couple of programmable points in the Internet?

Tango: performance-driven routing system

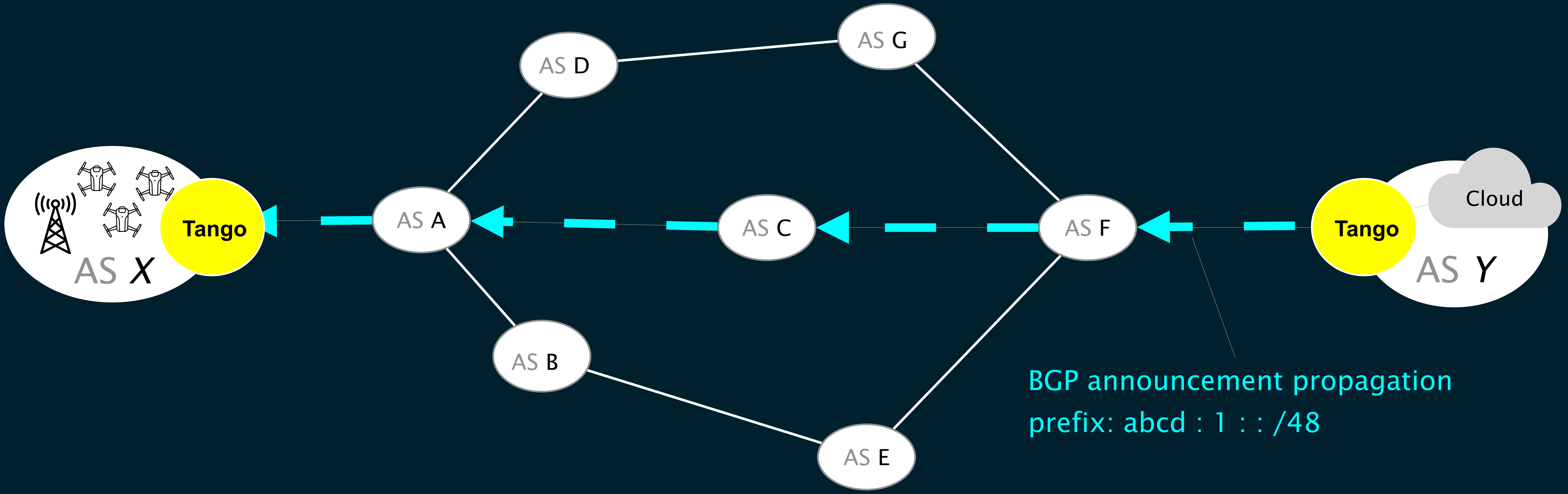
NSDI’24

SABRE: secure overlay for BTC block propagation

NDSS’19

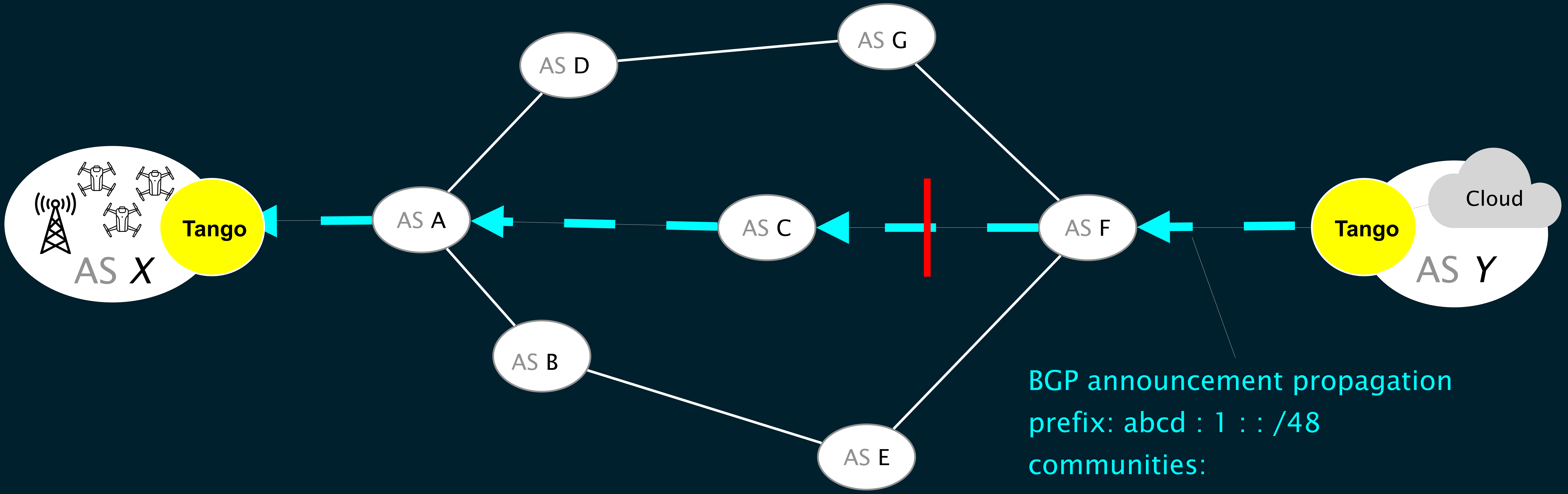

AS G
AS D
Tango
AS X
AS A
AS C
AS F
Tango
Cloud
AS Y
AS B
AS E

# ASX only sees a single path, exported by its upstream AS



BGP announcement propagation
prefix: abcd : 1 : : /48

## The Tango receiver advertises its IP prefix while suppressing the propagation of the default path



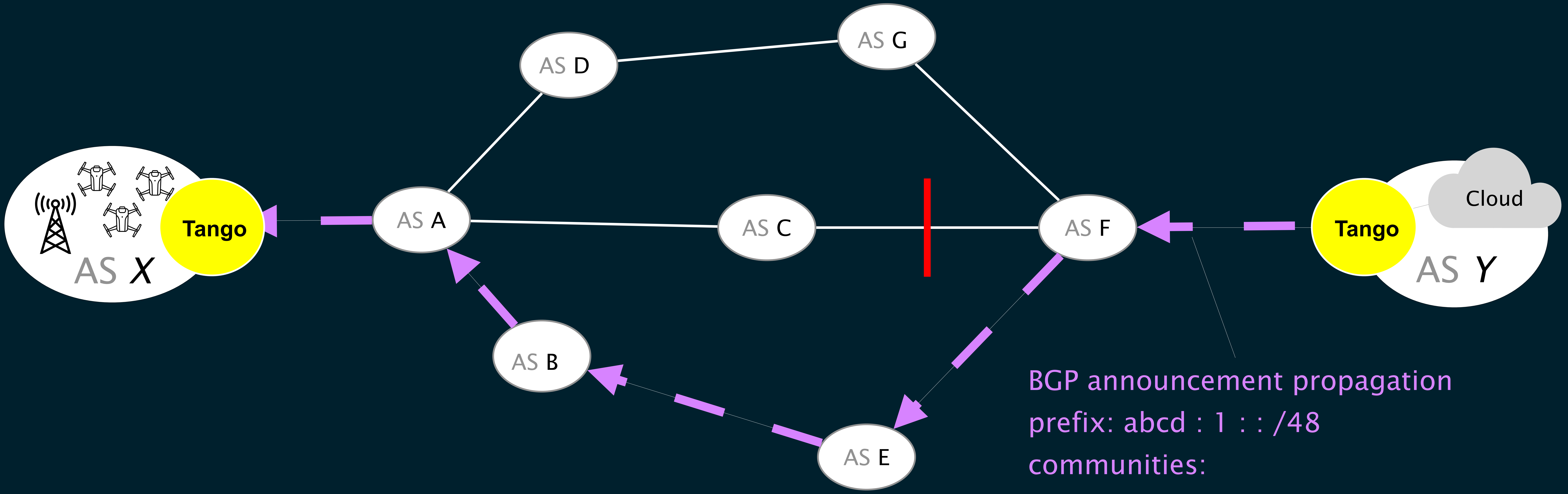
BGP announcement propagation

prefix: abcd : 1 : : /48

communities:

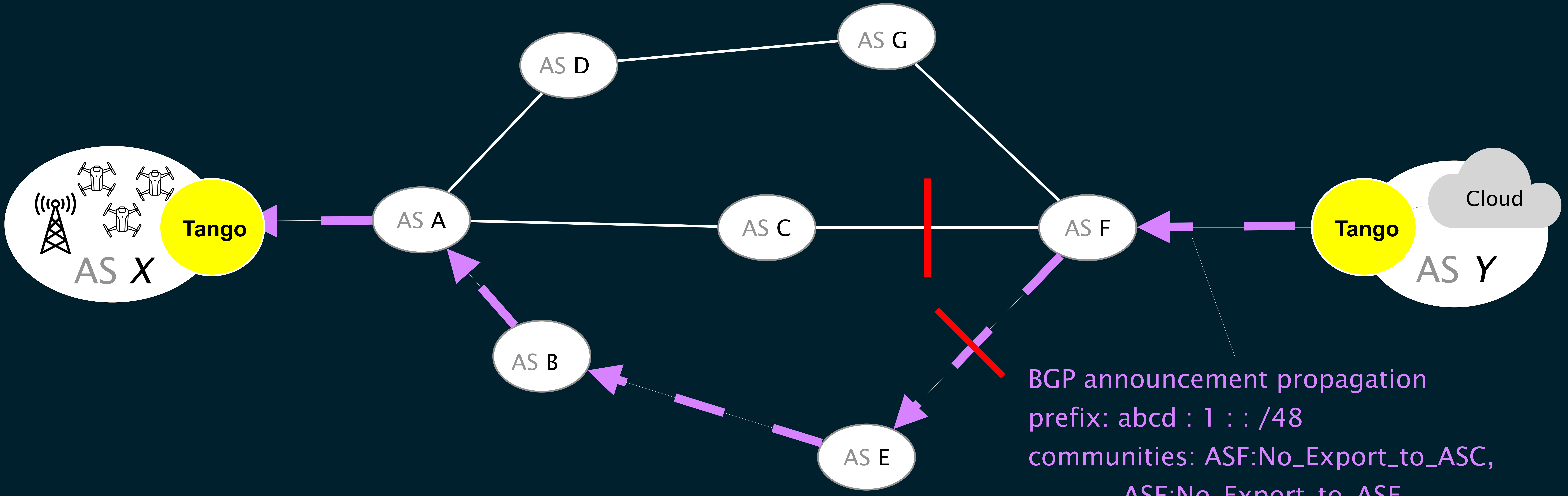
ASF:No_Export_to_ASC

# The Tango receiver finds a new path through AS E



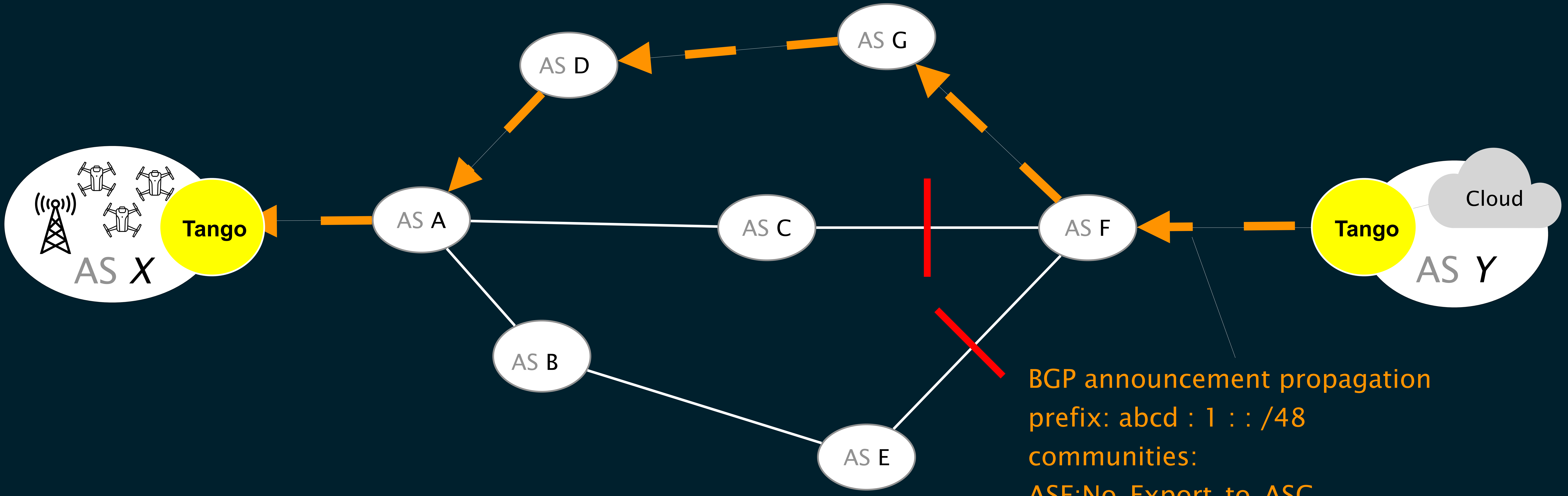
BGP announcement propagation
prefix: abcd : 1 : : /48
communities:
ASF:No_Export_to_ASC

# The Tango receiver finds a new path through AS E which it will again suppress



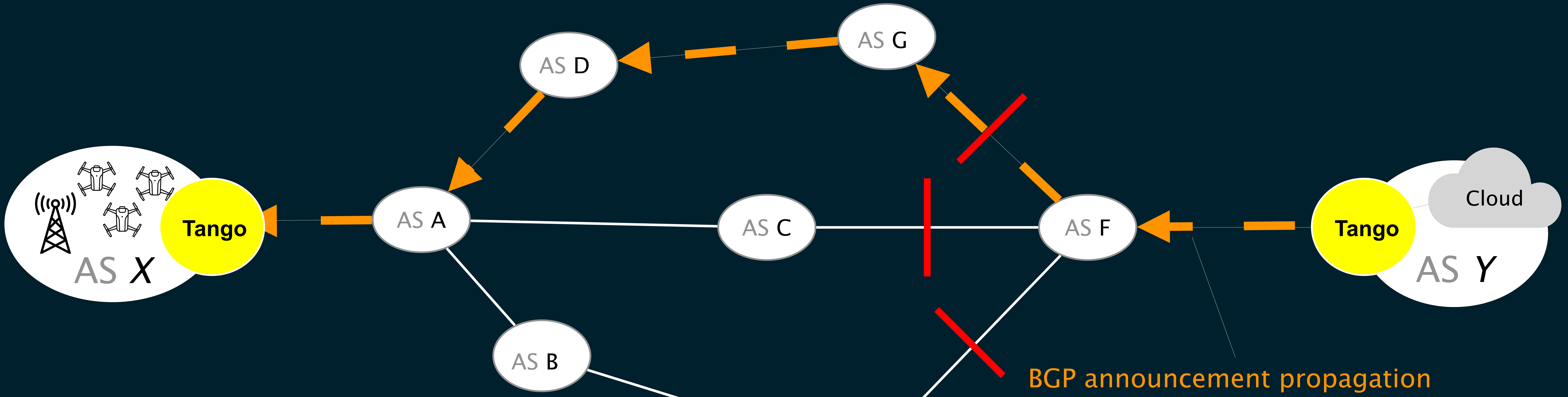
BGP announcement propagation
prefix: abcd : 1 : : /48
communities: ASF:No_Export_to_ASC,
ASF:No_Export_to_ASE

# The Tango receiver finds a new path through AS E which it will again suppress to find yet another path through AS G



BGP announcement propagation
prefix: abcd : 1 : : /48
communities:
ASF:No_Export_to_ASC,
ASF:No_Export_to_ASE

# The Tango receiver stops when there are no new paths



BGP announcement propagation
prefix: abcd : 1 : : /48
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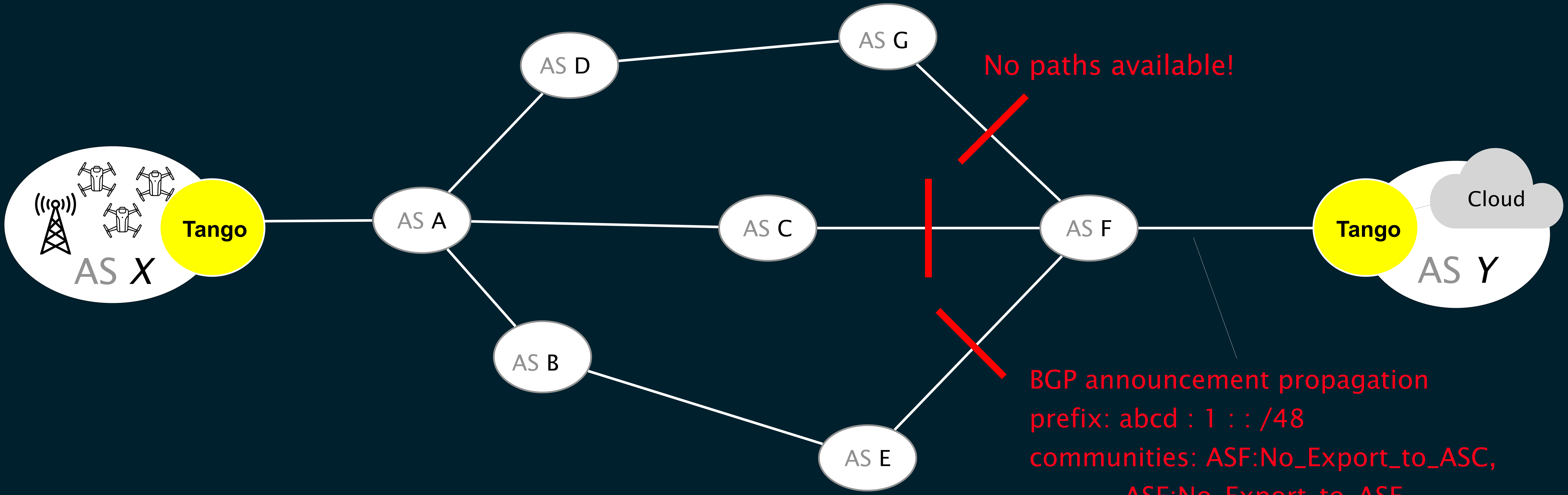
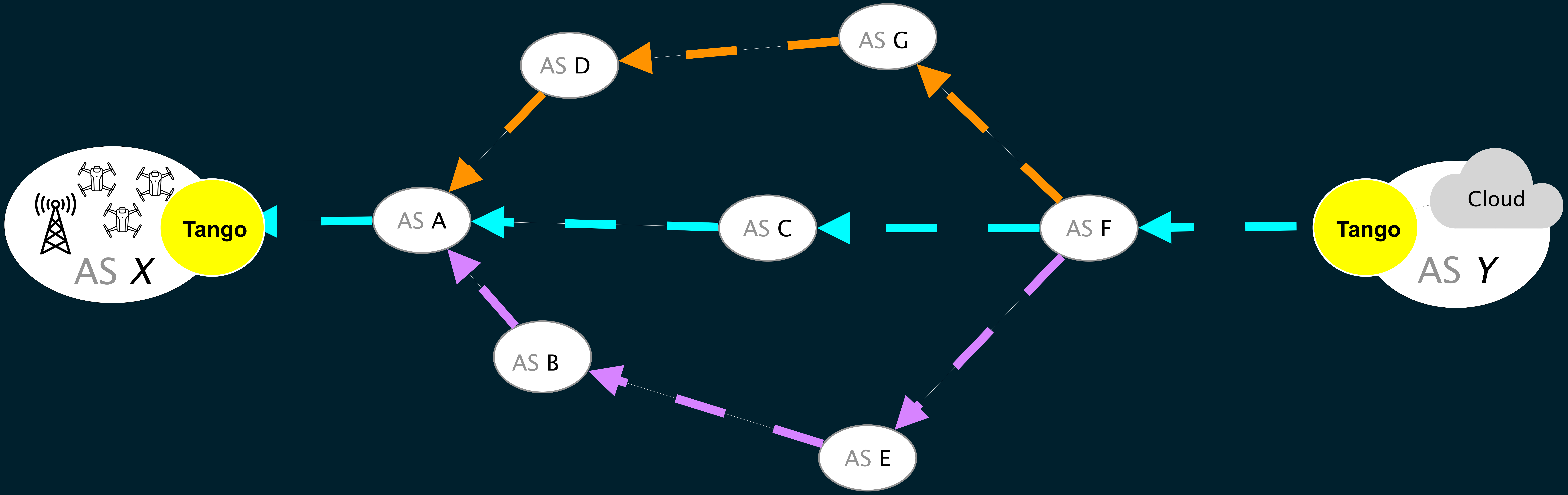


No paths available!

BGP announcement propagation
prefix: abcd : 1 : : /48
communities: ASF:No_Export_to_ASC,
ASF:No_Export_to_ASE,
ASF:No_Export_to_ASG

# AS Y announces different IP prefixes along different paths



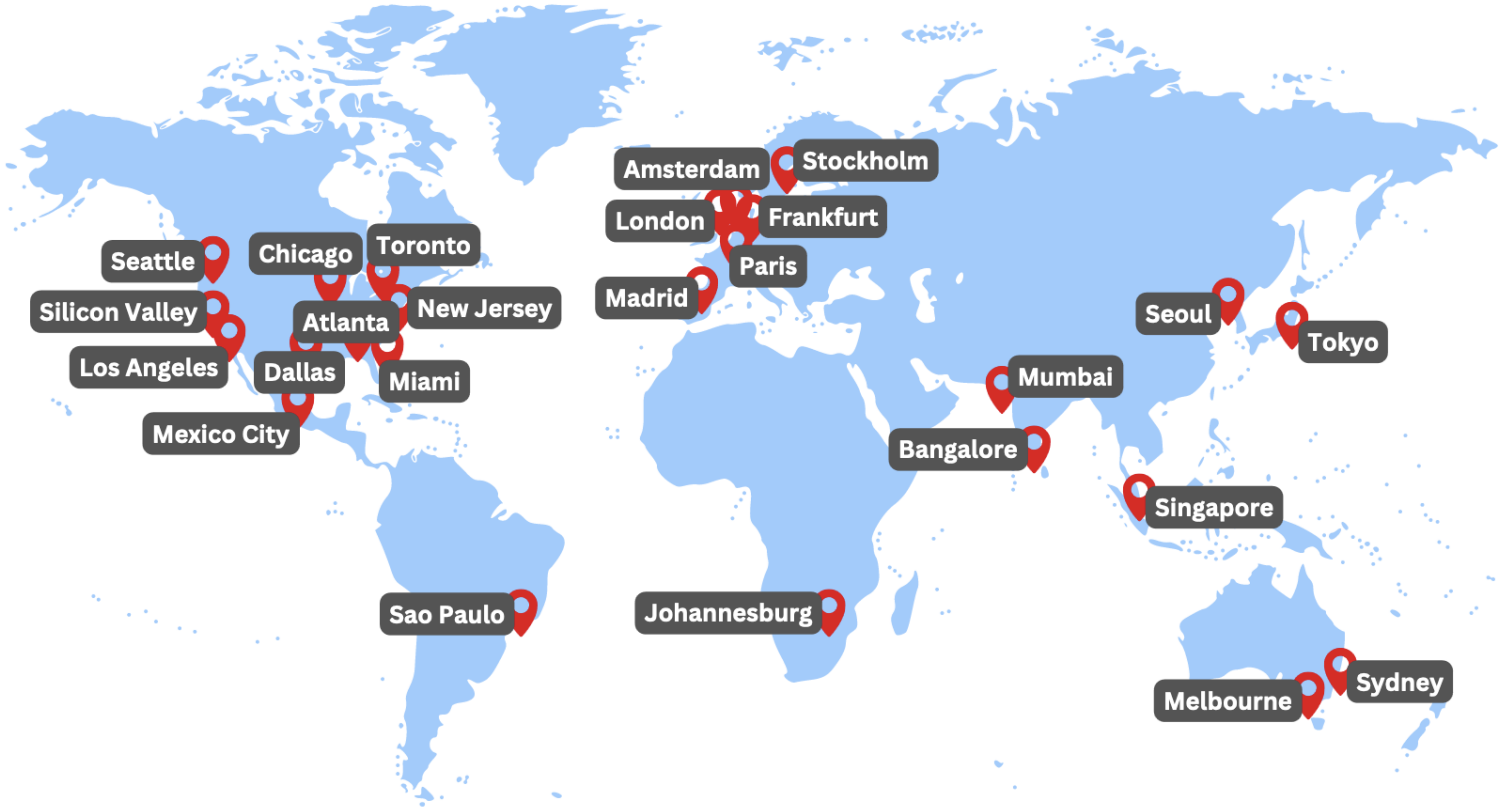
BGP
BGP
ROUTER

# Global testbed

Run Tango– Pathfinder from 23 nodes hosted by Vultr to exposes Internet paths

Routed traffic over the exposed and default paths to two destinations: LA and Stockholm

Collected latency and loss measurements every 10ms, over roughly 32 hours



# Tango-paths outperform the default path

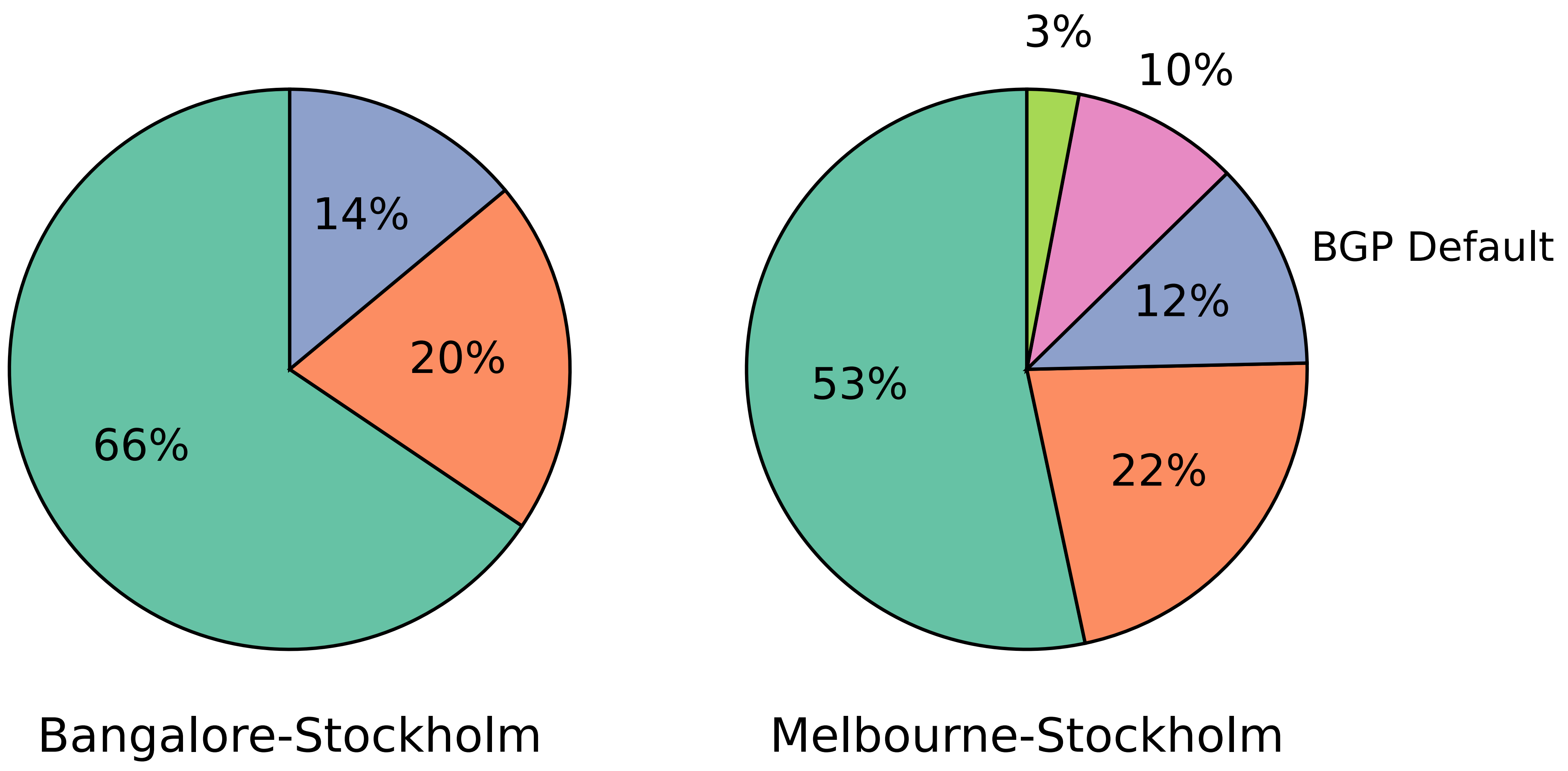
Across 23 measured pairs, 20 pairs had alternative paths that outperformed the default:

100% of the time for 15 pairs
75-88% of the time for 5 pairs

Bangalore-Stockholm: BGP default beaten by alternative paths 100% of the time

Melbourne-Stockholm: BGP default beaten by alternative paths 88% of the time

Breakdown of best paths for two pairs



BGP
BGP
ROUTER

# Tango's design requirements for performance-driven routing

## Route Control

Tango senders need to control which path traffic will use.

## Accurate Measurements

Measurements should not be affected by irrelevant conditions e.g., slow receivers, Wi-Fi.

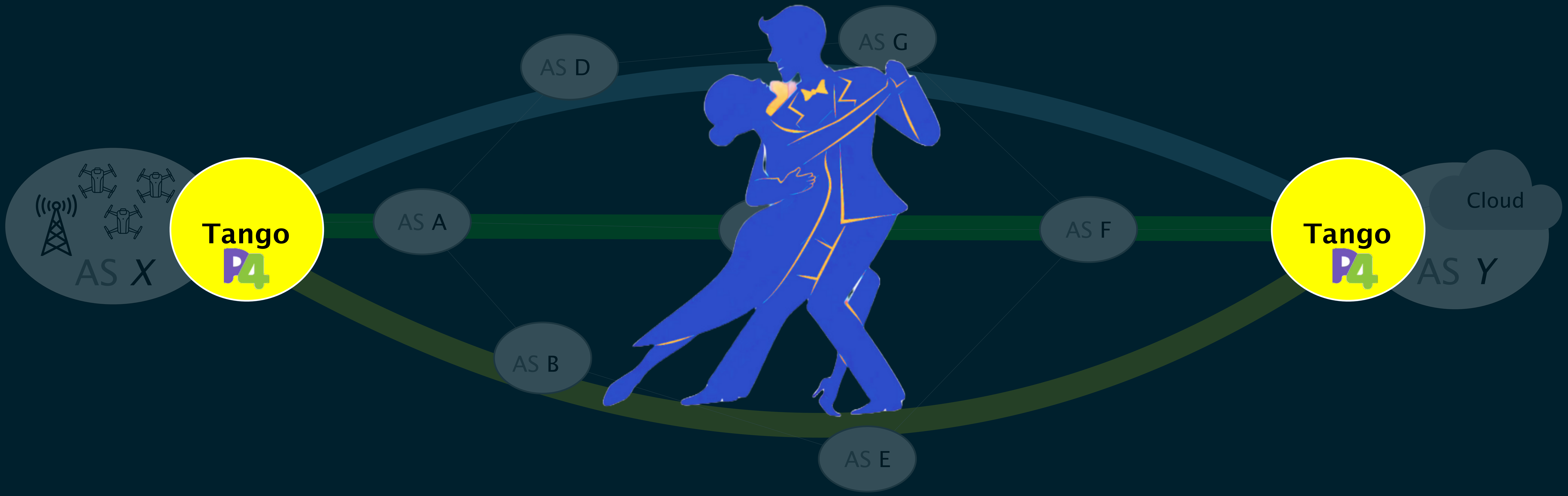
## Trustworthy Measurements

An on-path attacker should not be able to distort measurements to their advantage.

## Dynamic & Secure Rerouting

Tango should allow dynamic performance-driven and safe reroutes.

# Tango solves these challenges with P4 and co-operation



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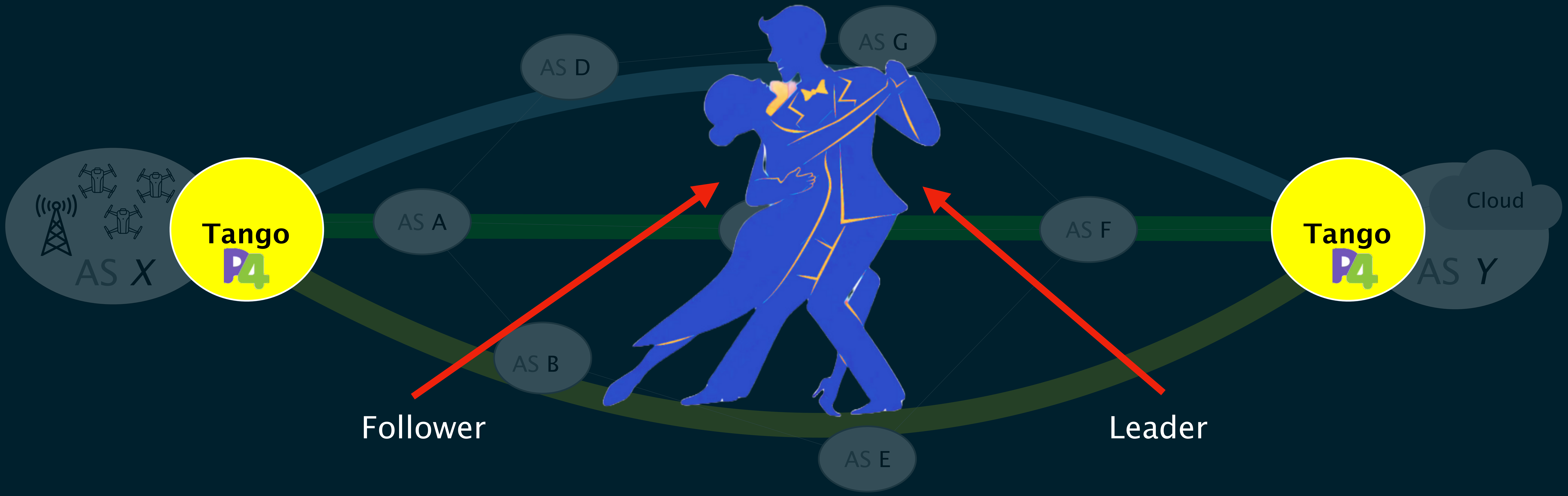

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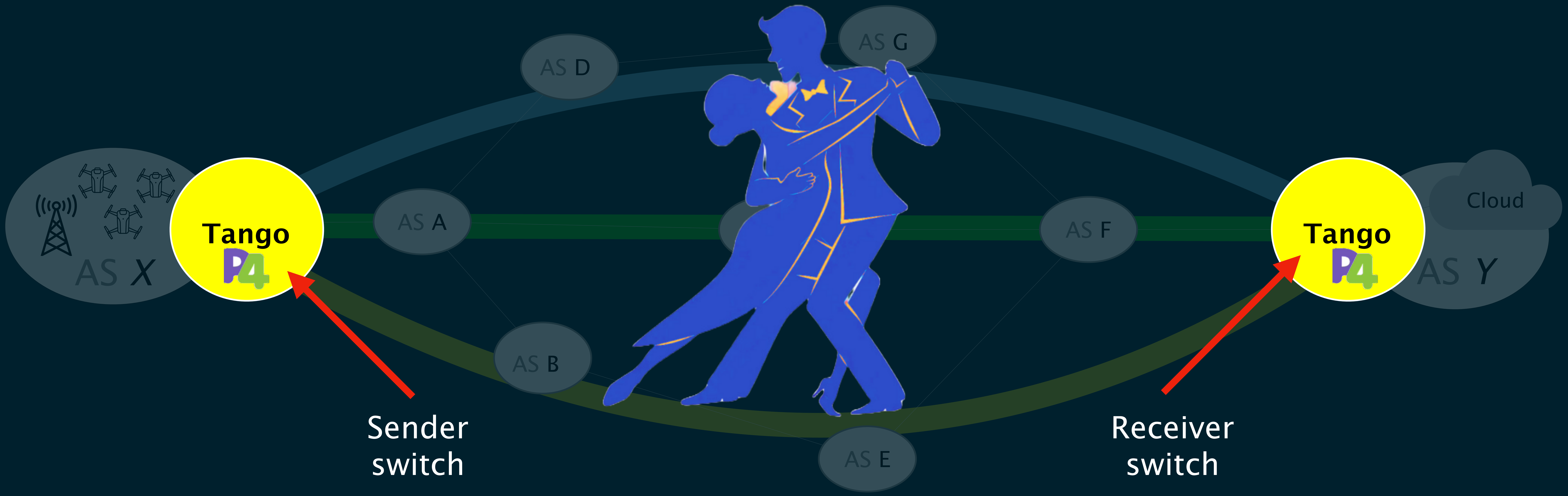

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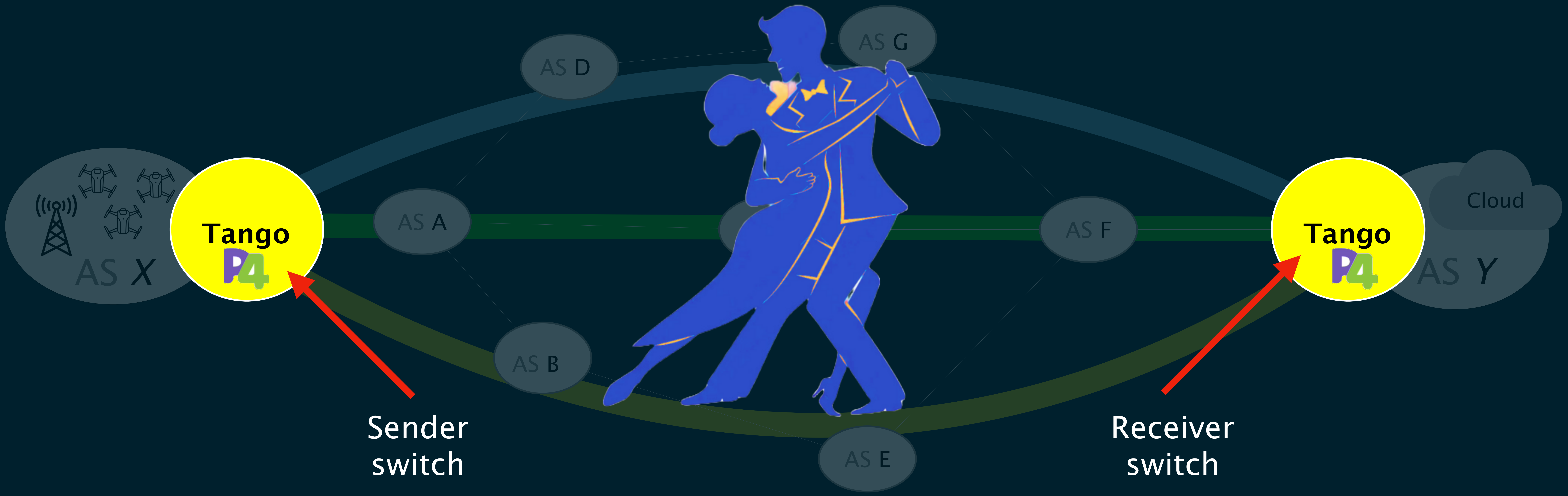

The sender switch performs the move that the receiver has signaled.

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abcd:1::/48
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Tango
AS A
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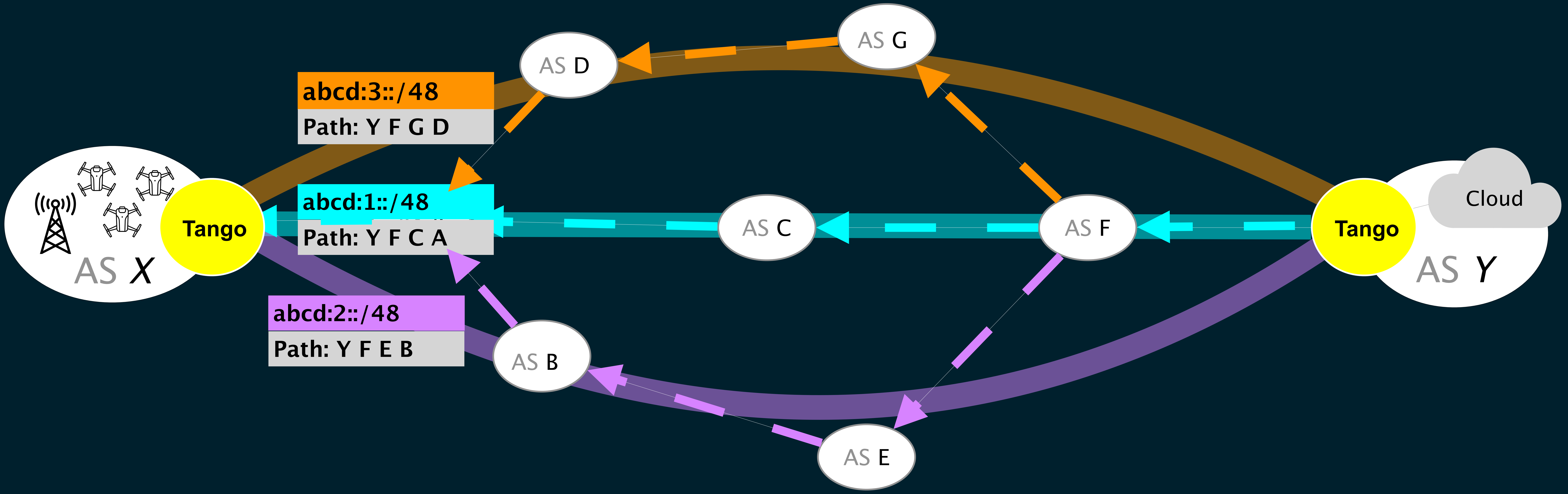
AS Y
AS B
AS E

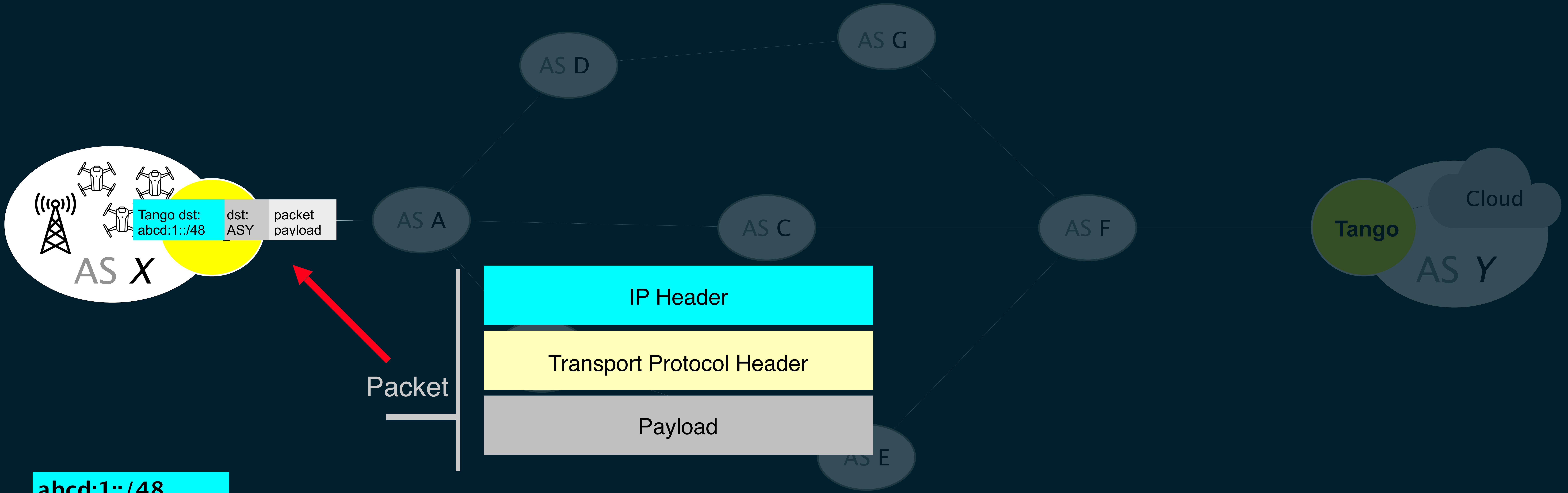
# AS Y announces different IP prefixes along different paths

AS D
AS G
abcd:3::/48
Path: Y
abcd:1::/48
Path: Y F C A
Tango
AS X
AS A
AS C
AS F
abcd:1::/48
Path: Y
Tango
Cloud
AS Y
AS B
AS E
abcd:2::/48
Path: Y

# AS Y announces different IP prefixes along different paths

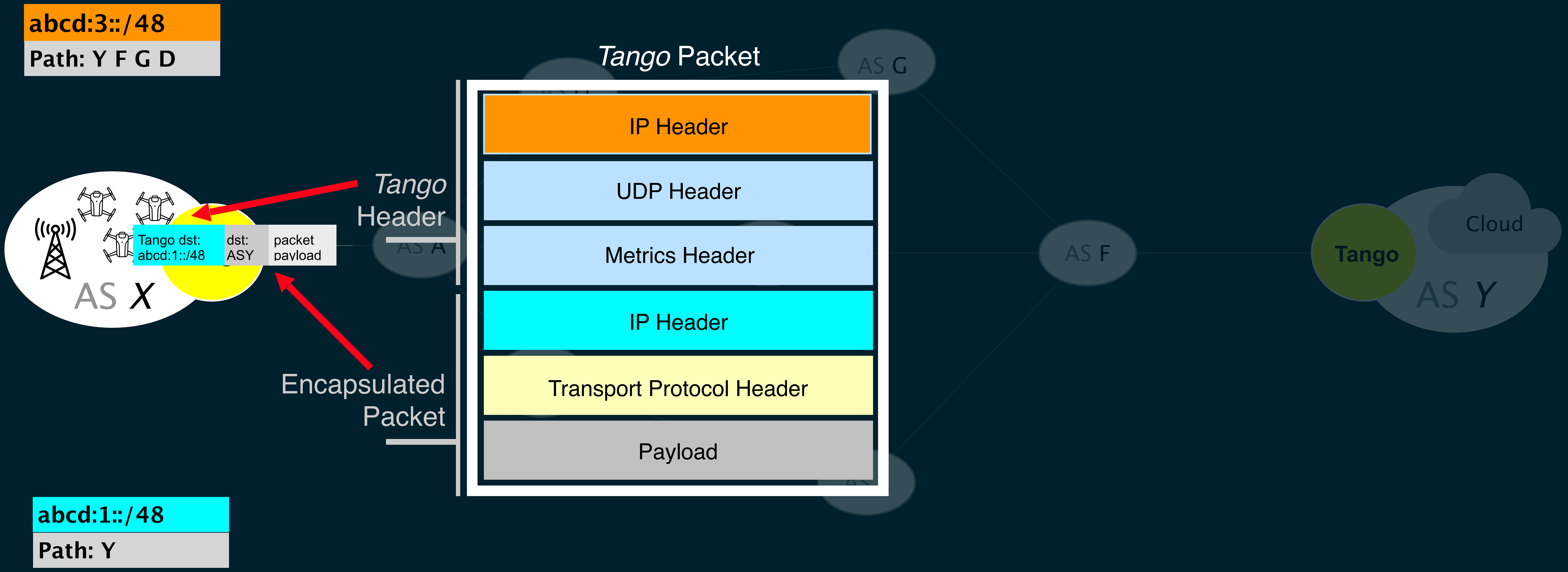


# Upon reception of a packet,



| abcd:1::/48 |
|---|
| Path: Y |

# Upon reception of a packet, the sender encapsulates it with a destination within the prefix that correspond to the path of choice



abcd:3::/48

Path: Y F G D

*Tango* Packet

- IP Header
- UDP Header
- Metrics Header
- IP Header
- Transport Protocol Header
- Payload

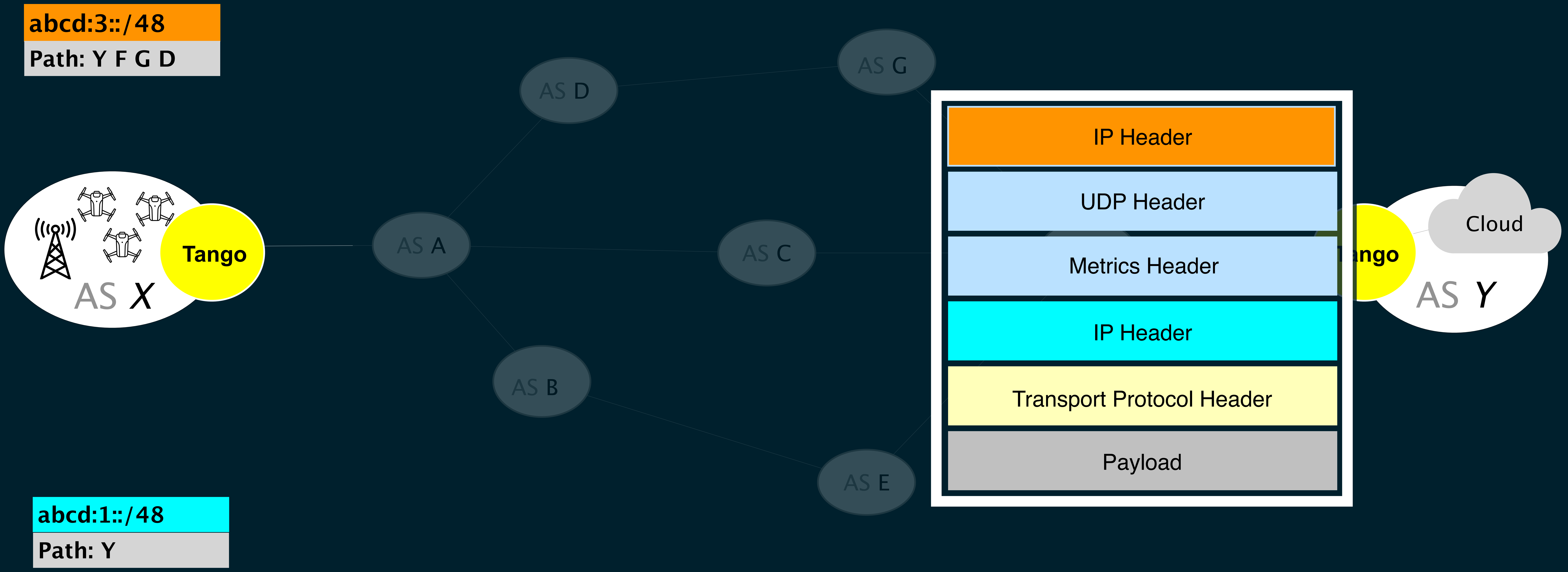
*Tango* Header

Encapsulated Packet

abcd:1::/48

Path: Y

# The receiver decapsulates packets before letting them reach their destination



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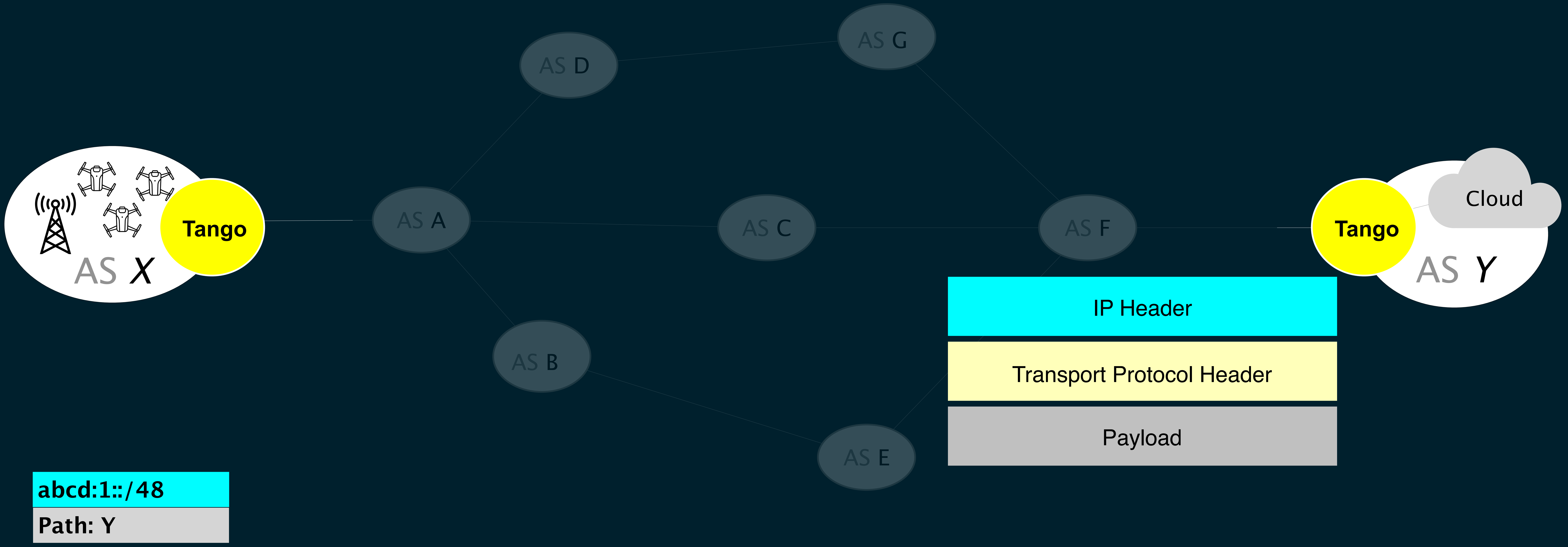

IP Header

Transport Protocol Header

Payload

abcd:1::/48

Path: Y

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## Trustworthy Measurements

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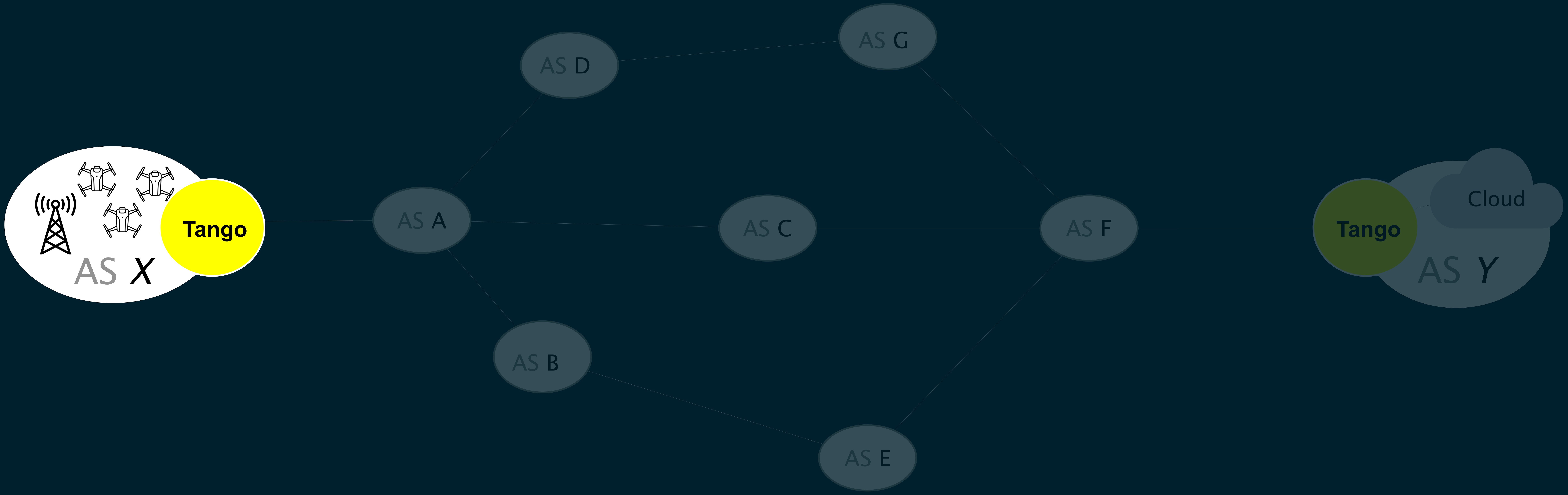
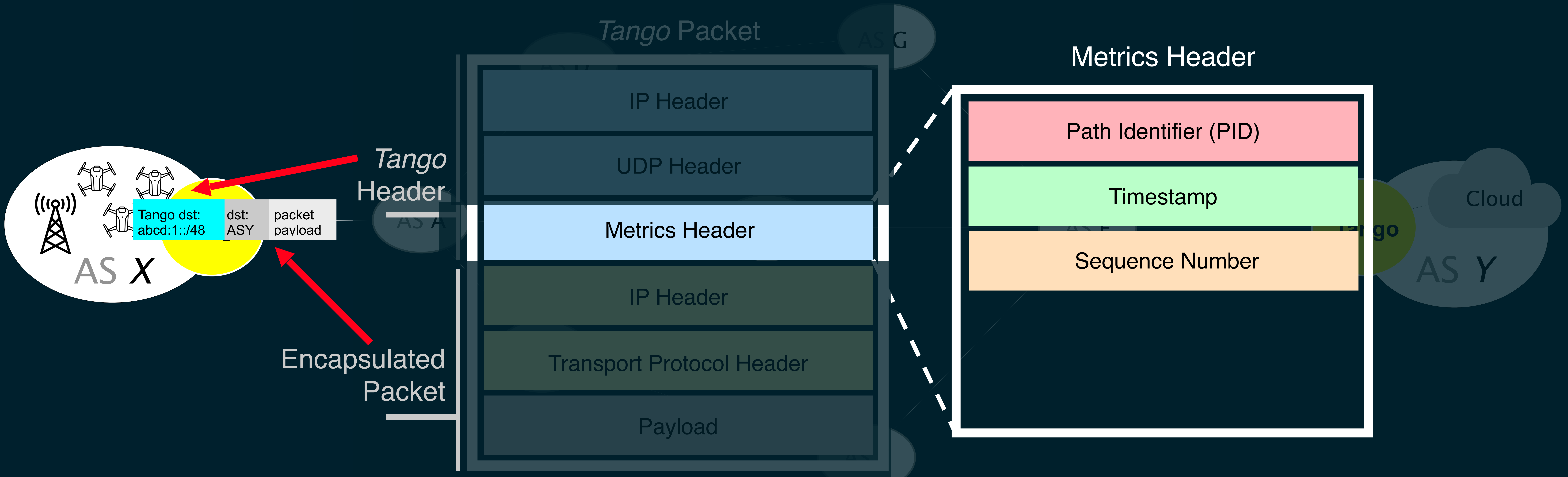
## Dynamic & Secure Rerouting

Tango should allow dynamic performance-driven and safe reroutes.

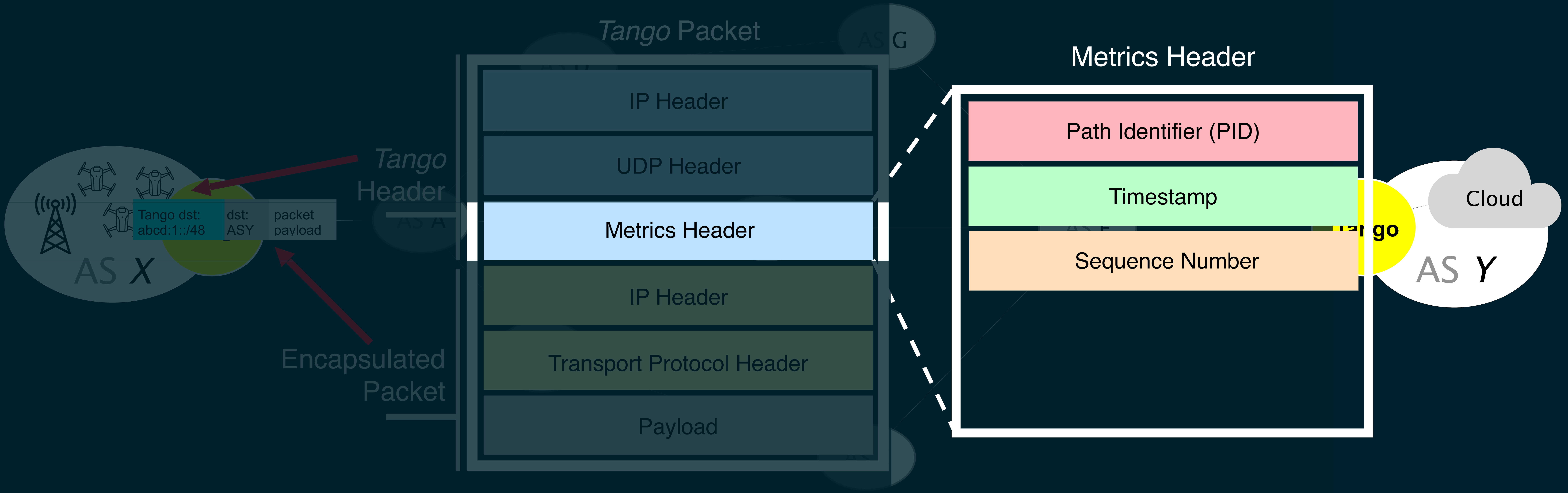
# Conventional active round-trip measurements are inaccurate and can be easily manipulated



# The sender includes the timestamp of each packet's departure, and a per-path sequence number in the Tango header.



# The receiver calculates one-way latency and loss for each path avoiding the noise of the access networks



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## Dynamic & Secure Rerouting

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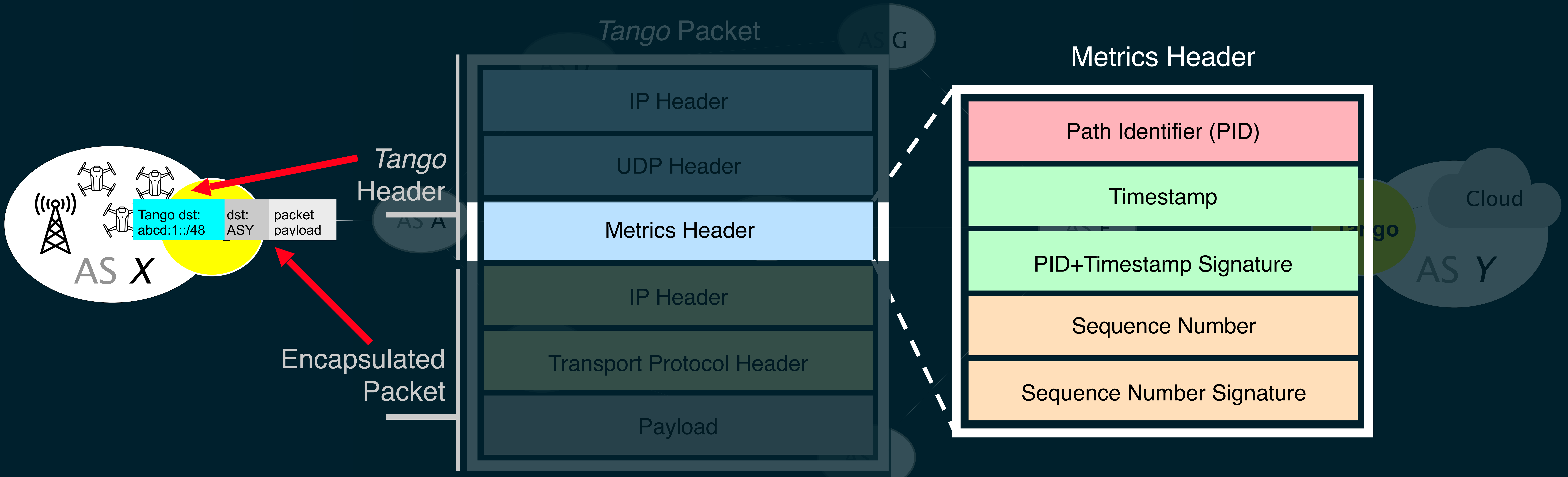
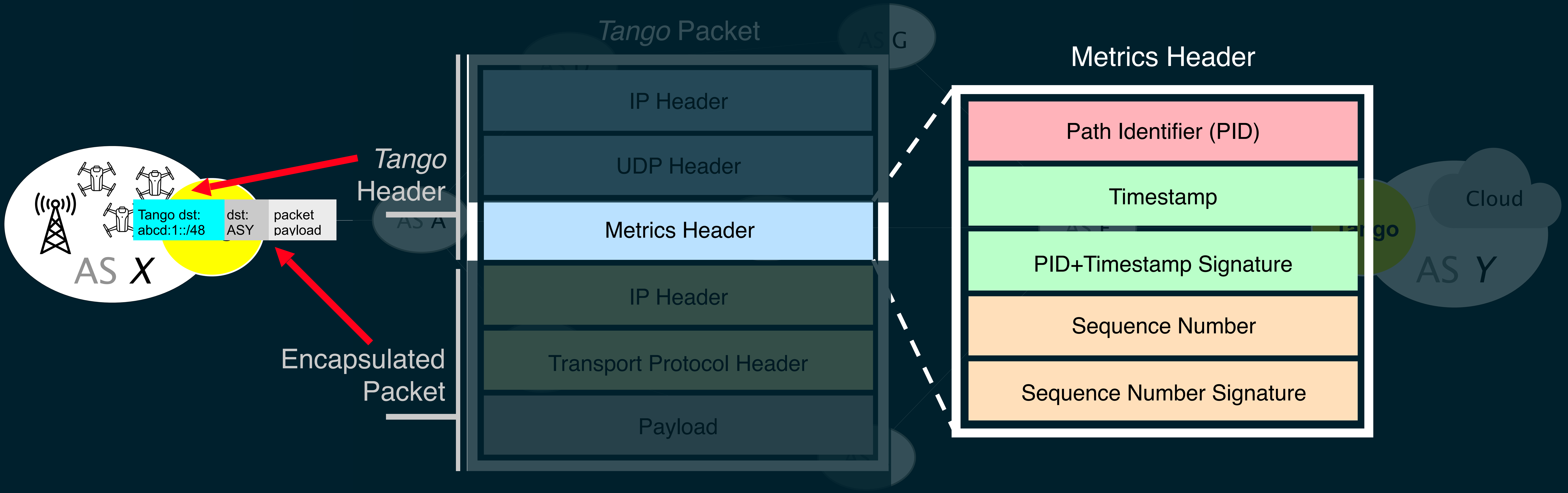
## Tango sender adds a path-specific signature to each ms timestamp, an attacker cannot manipulate or replay it to affect latency measurements



# Tango sender adds one bit signature to each sequence number, an on-path attacker would need to guess multiple to affect loss rate



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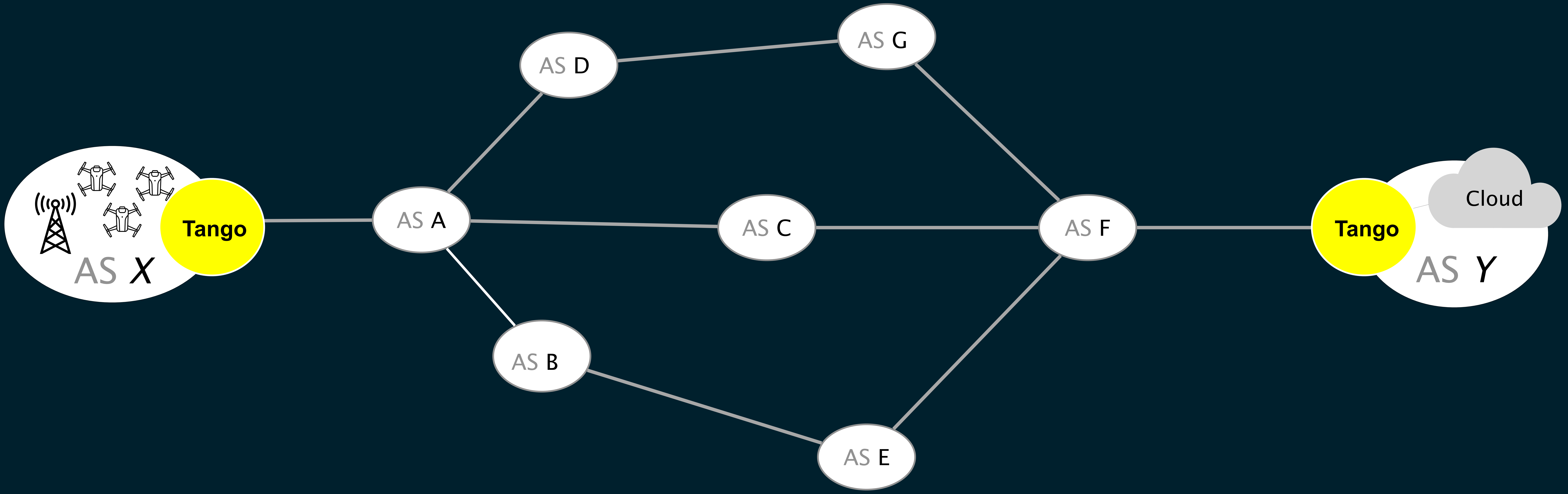
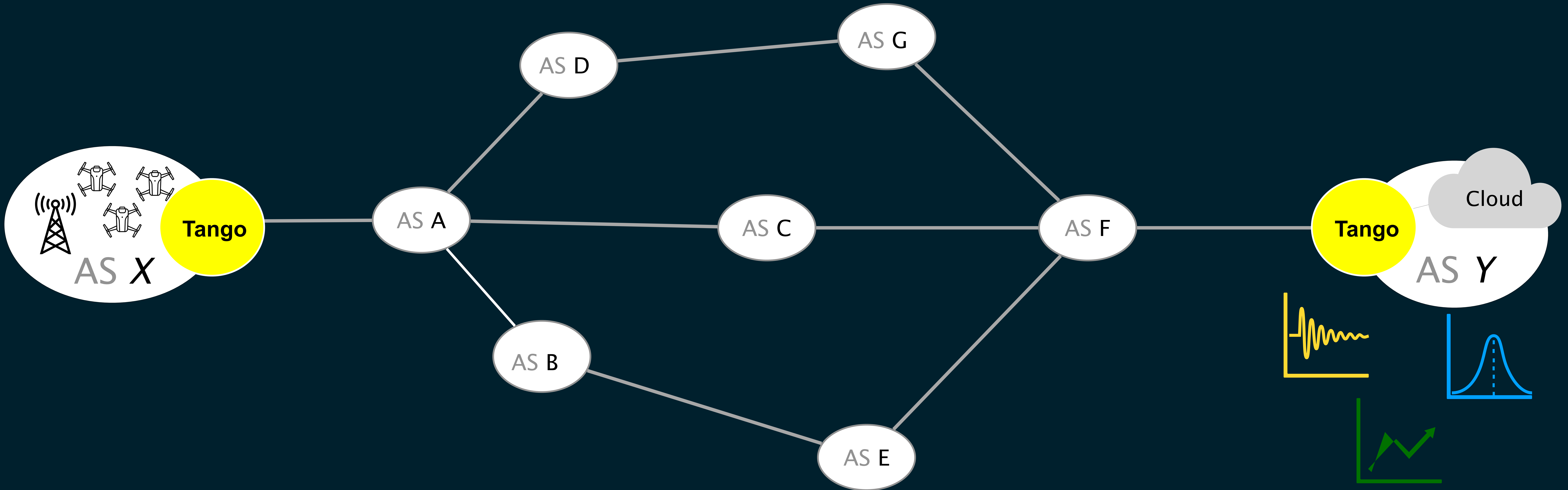
## **Dynamic & Secure Rerouting**

**Tango should allow dynamic performance-driven and safe reroutes.**

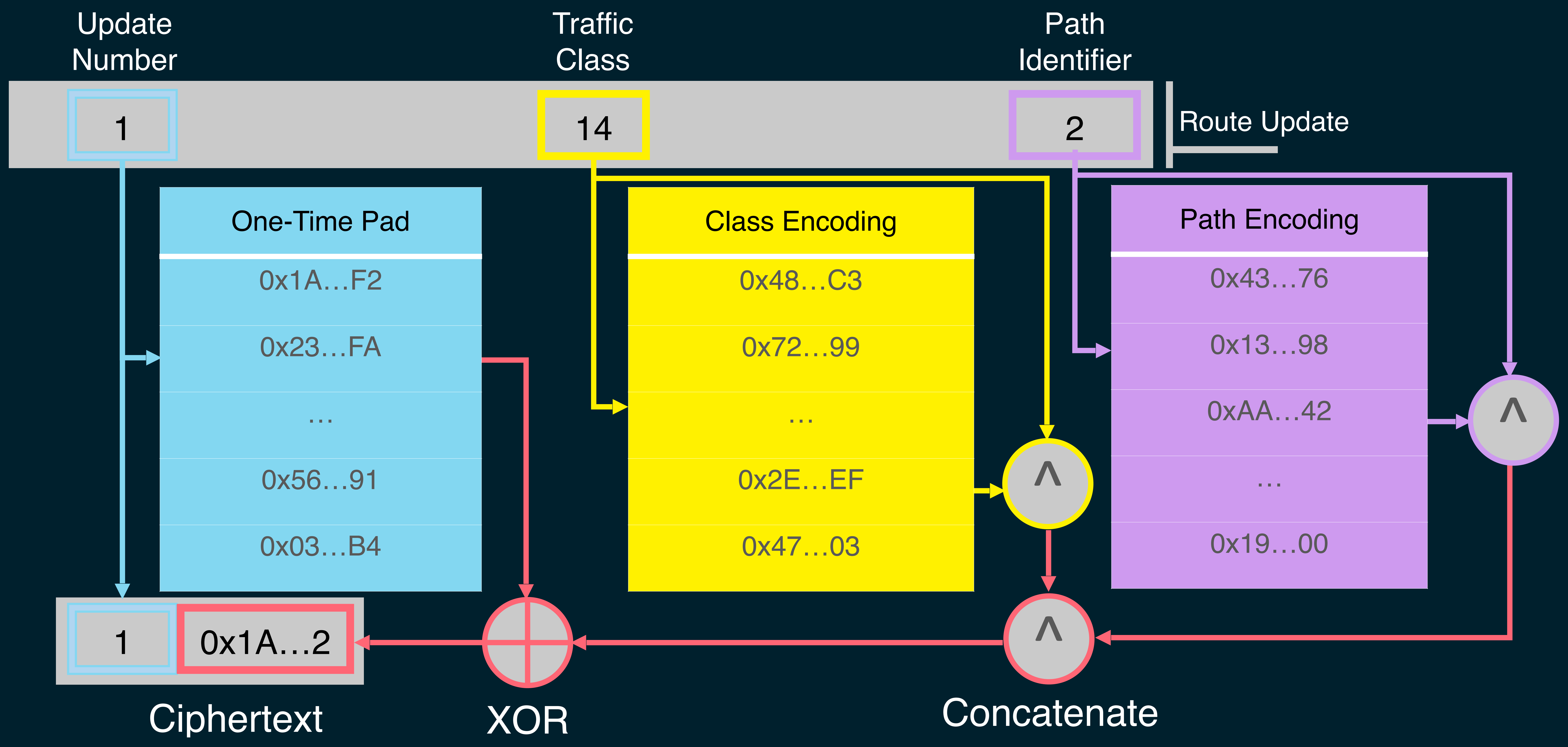
# The Tango sender selects paths,



# The Tango sender selects paths, but the Tango receiver collected the measurements



# Tango protects reroute commands with one-time-pad



Internet

Princeton

Vultr -Stockholm

Cloud

Tango Sender

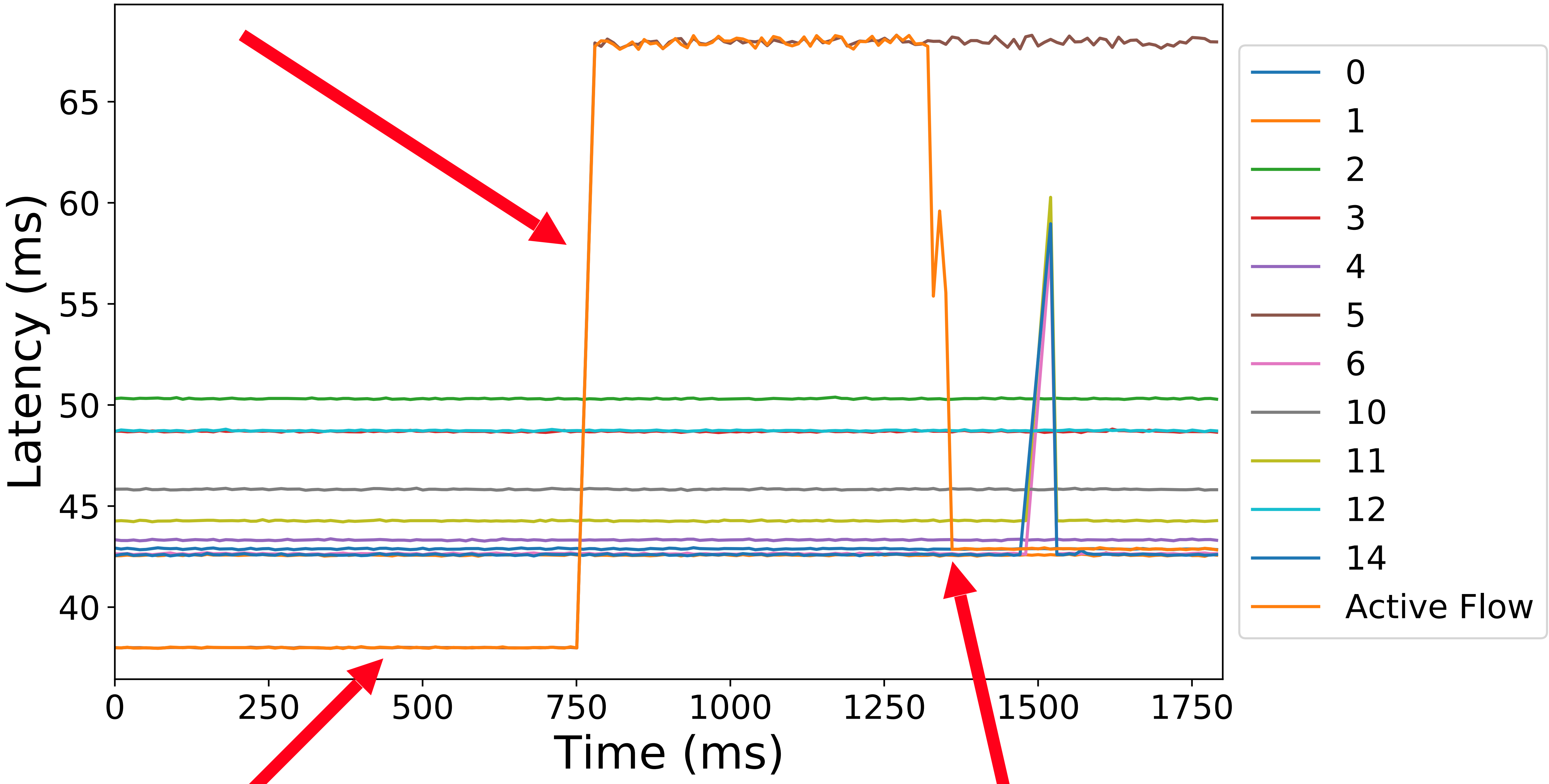
Tango Receiver

# Real–world Testbed

We run Tango between Princeton and Stockholm!

Route update complete in <1s

delay spike



initial best path

dynamically move to new best path

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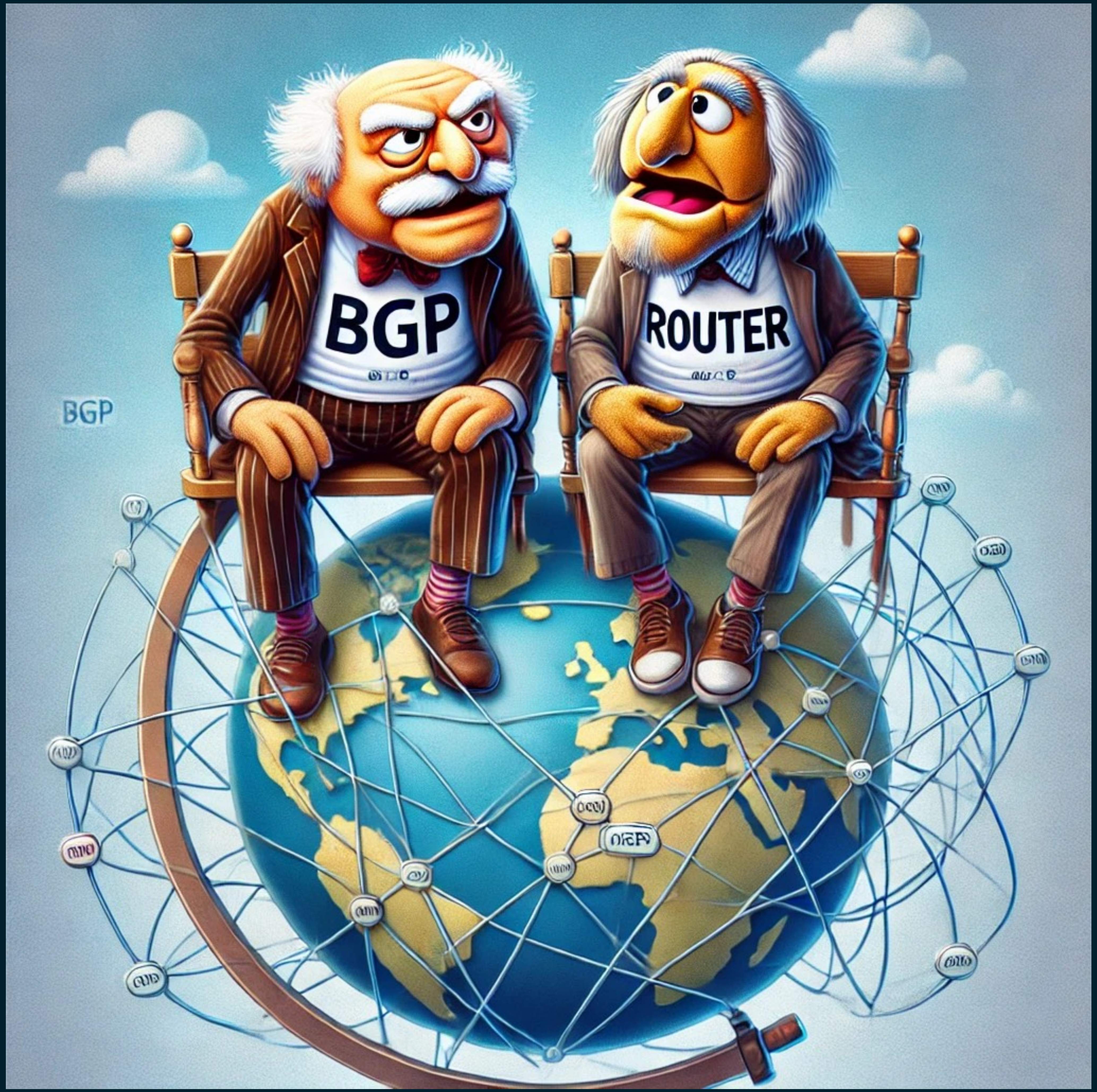
SABRE: secure overlay for BTC block propagation

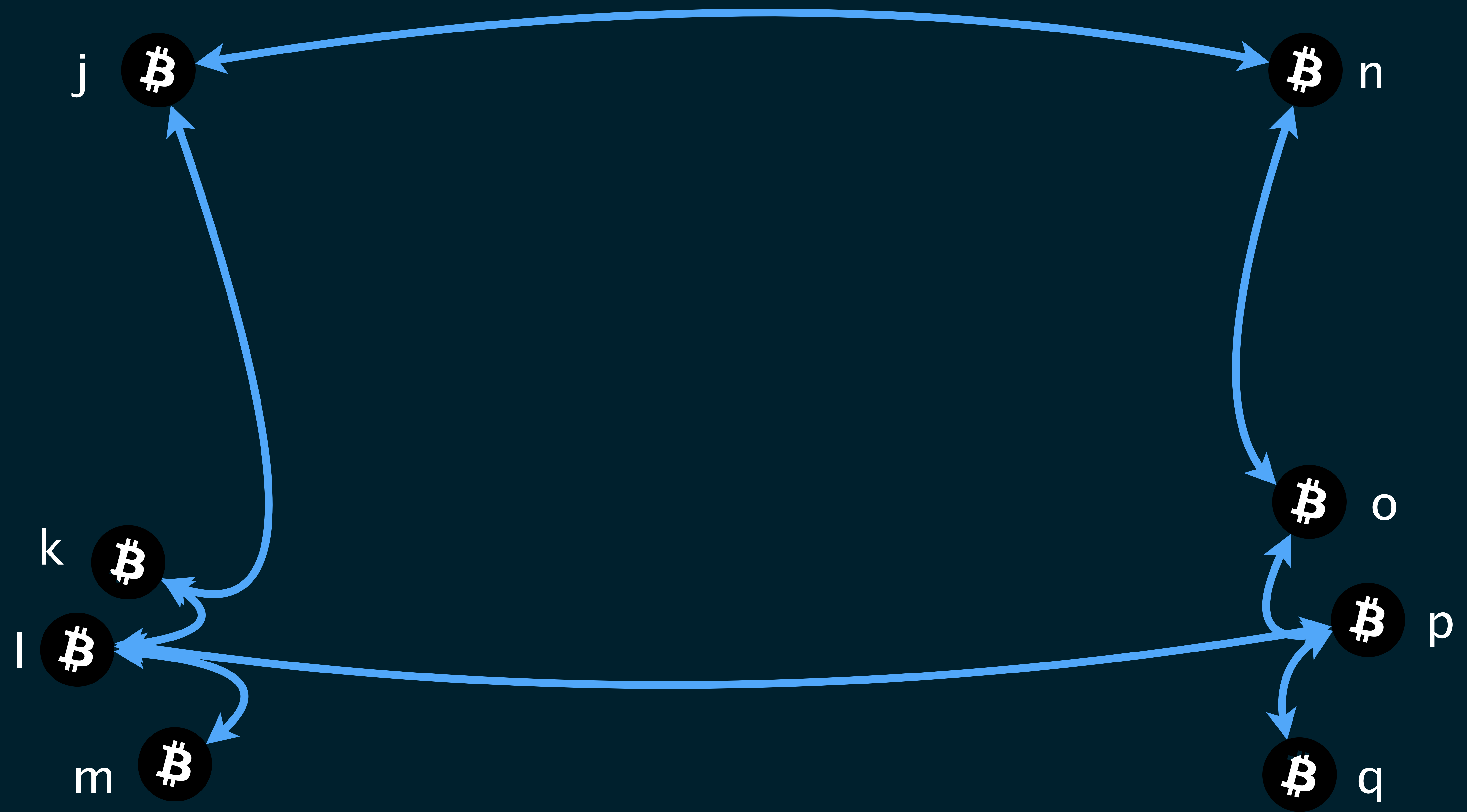
NDSS'19



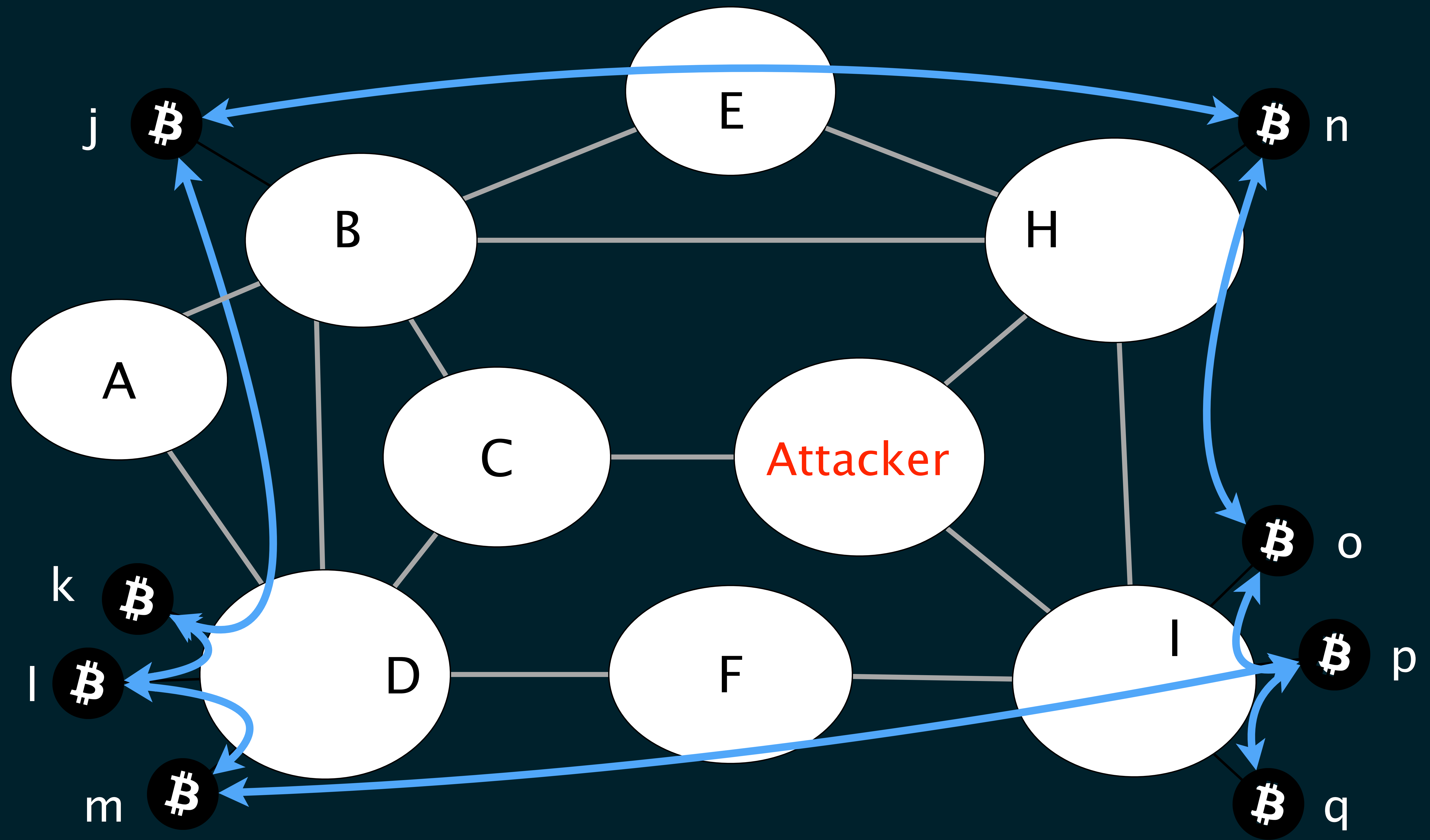
BGP
BGP
ROUTER

Bitcoin clients exchange Blocks

which contain the most recent transactions



# A malicious or compromised AS aims at isolating the grey zone



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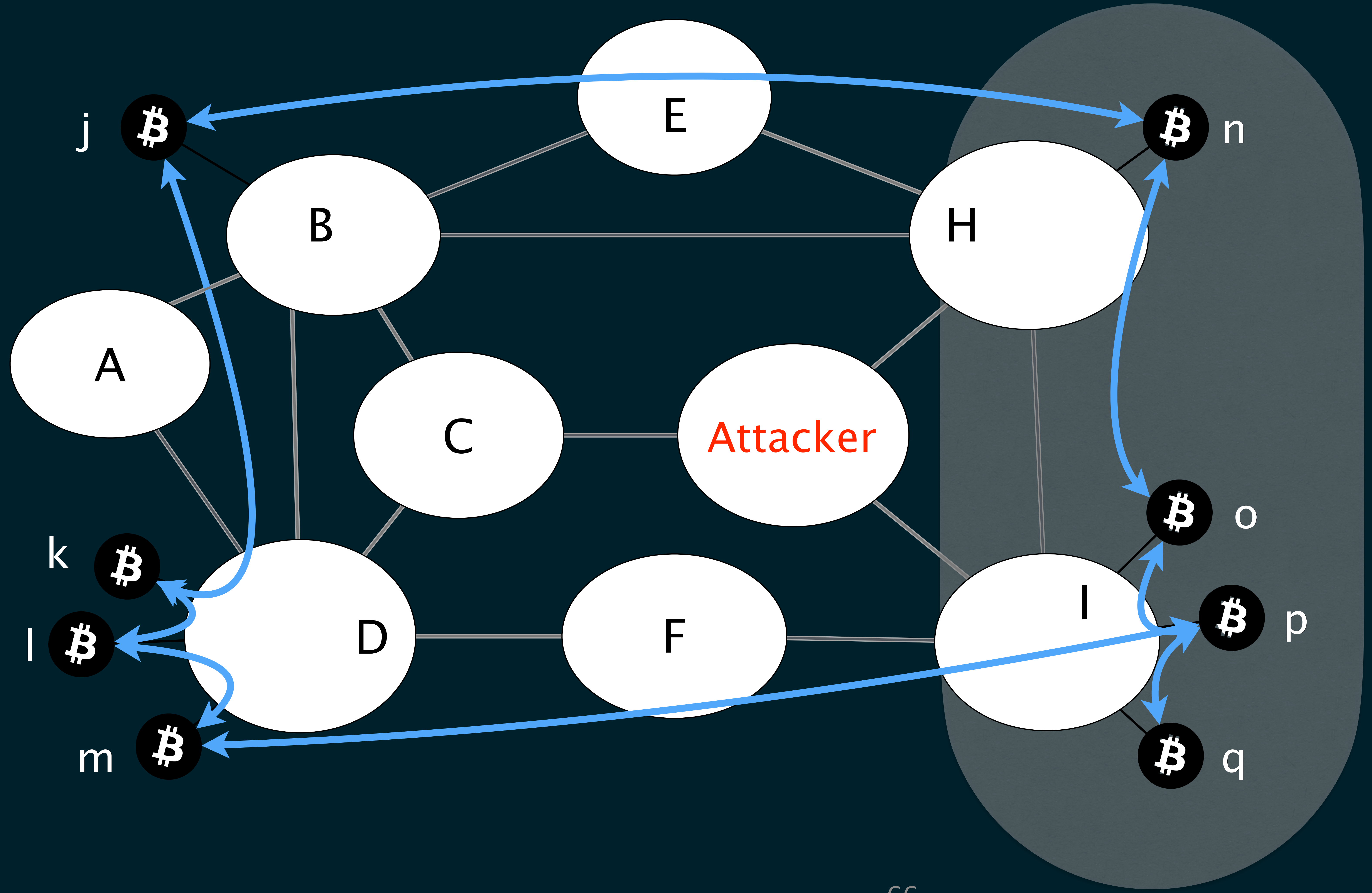
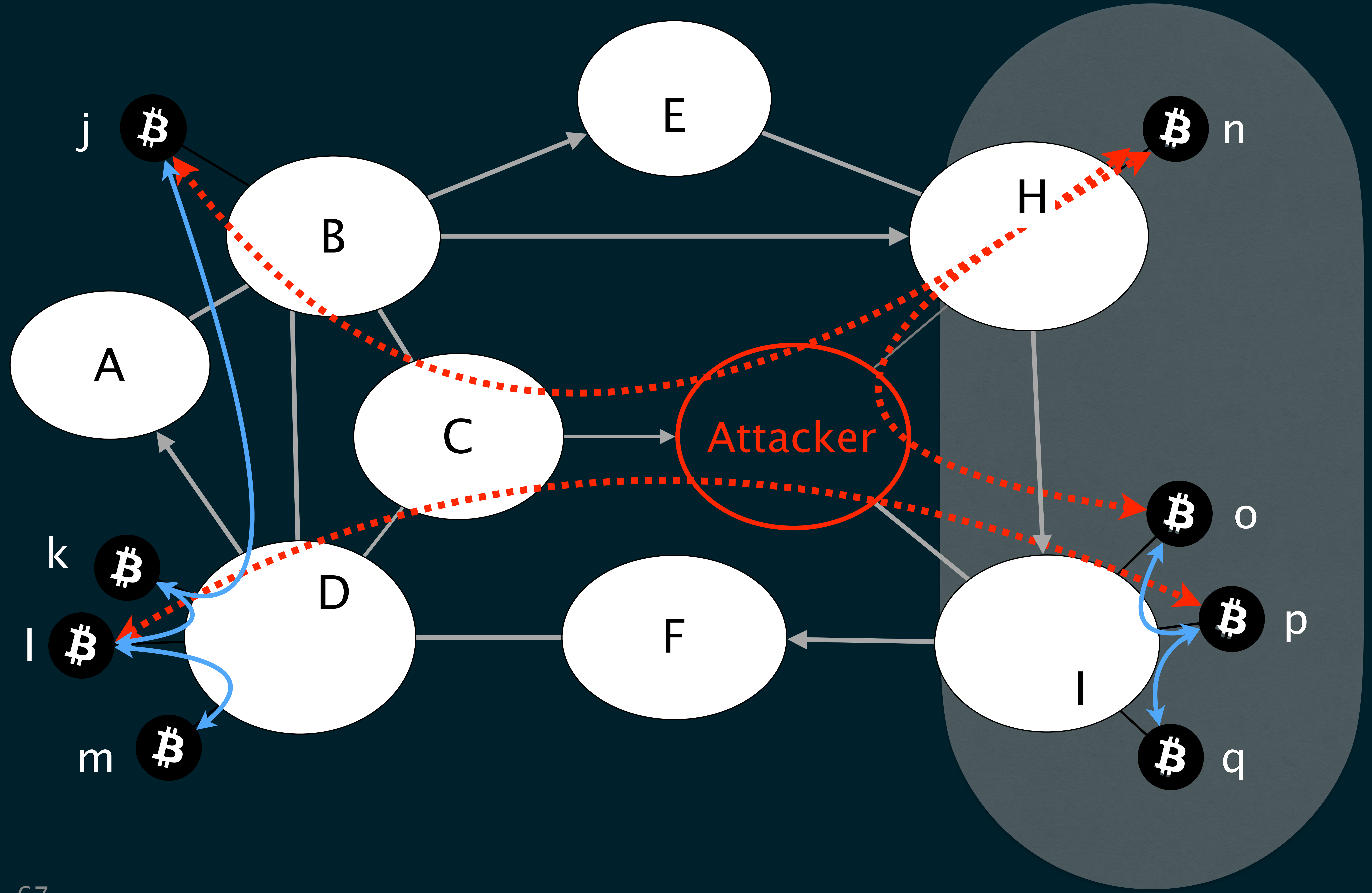
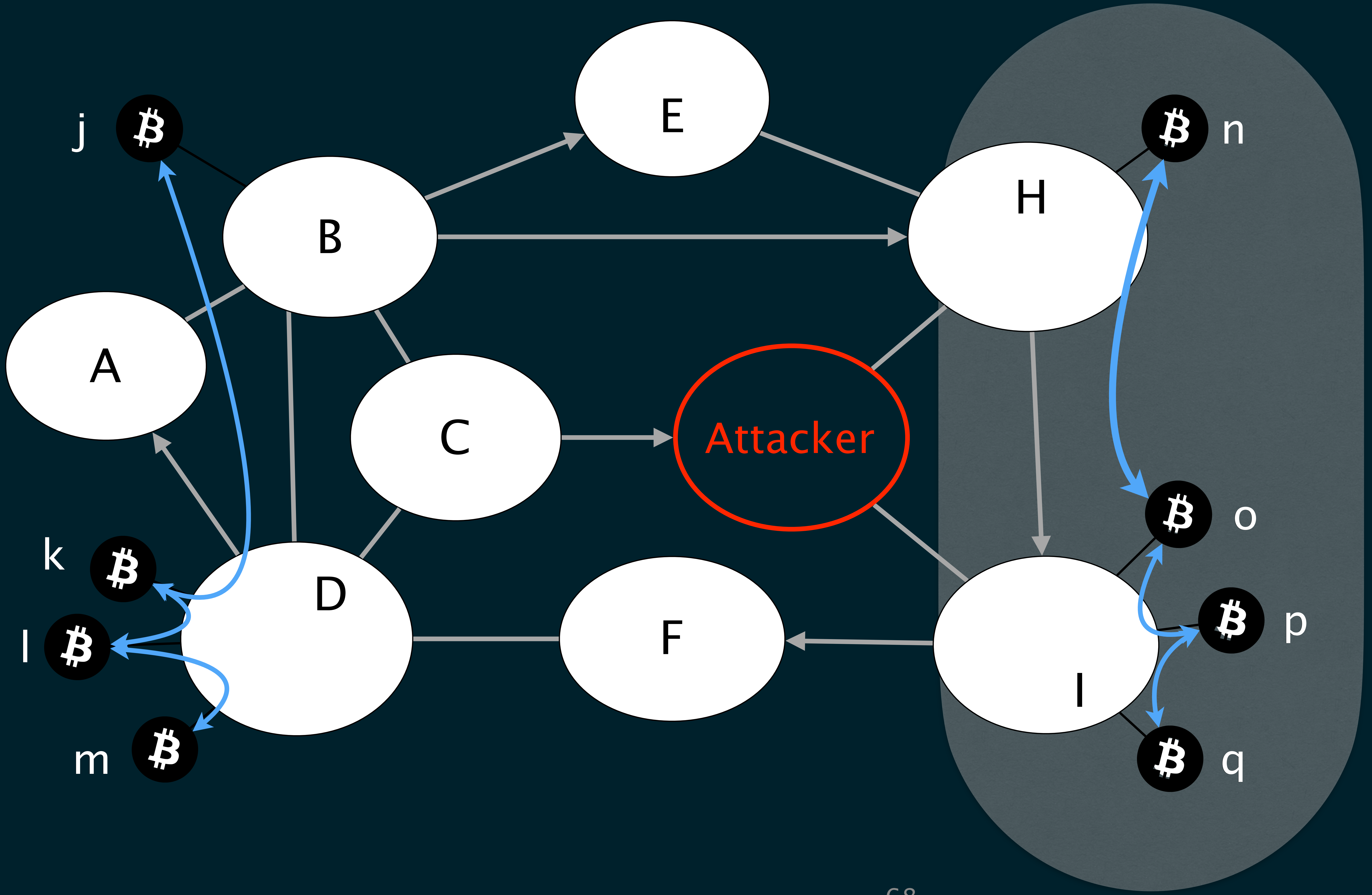


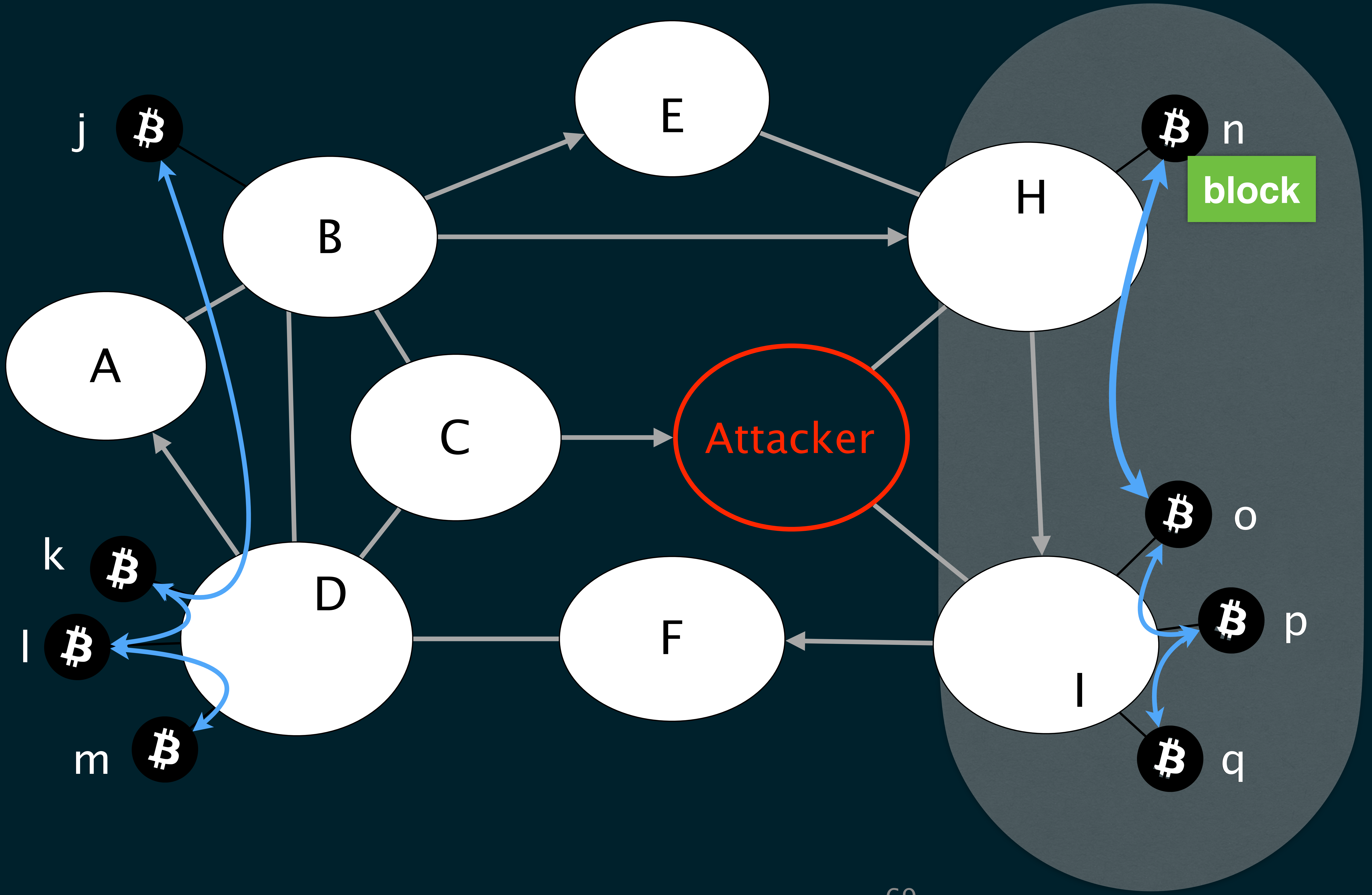
# Attacker attracts connections with BGP hijacking



# Attacker drops connections crossing the partition



# A new block in the grey zone cannot be propagated further



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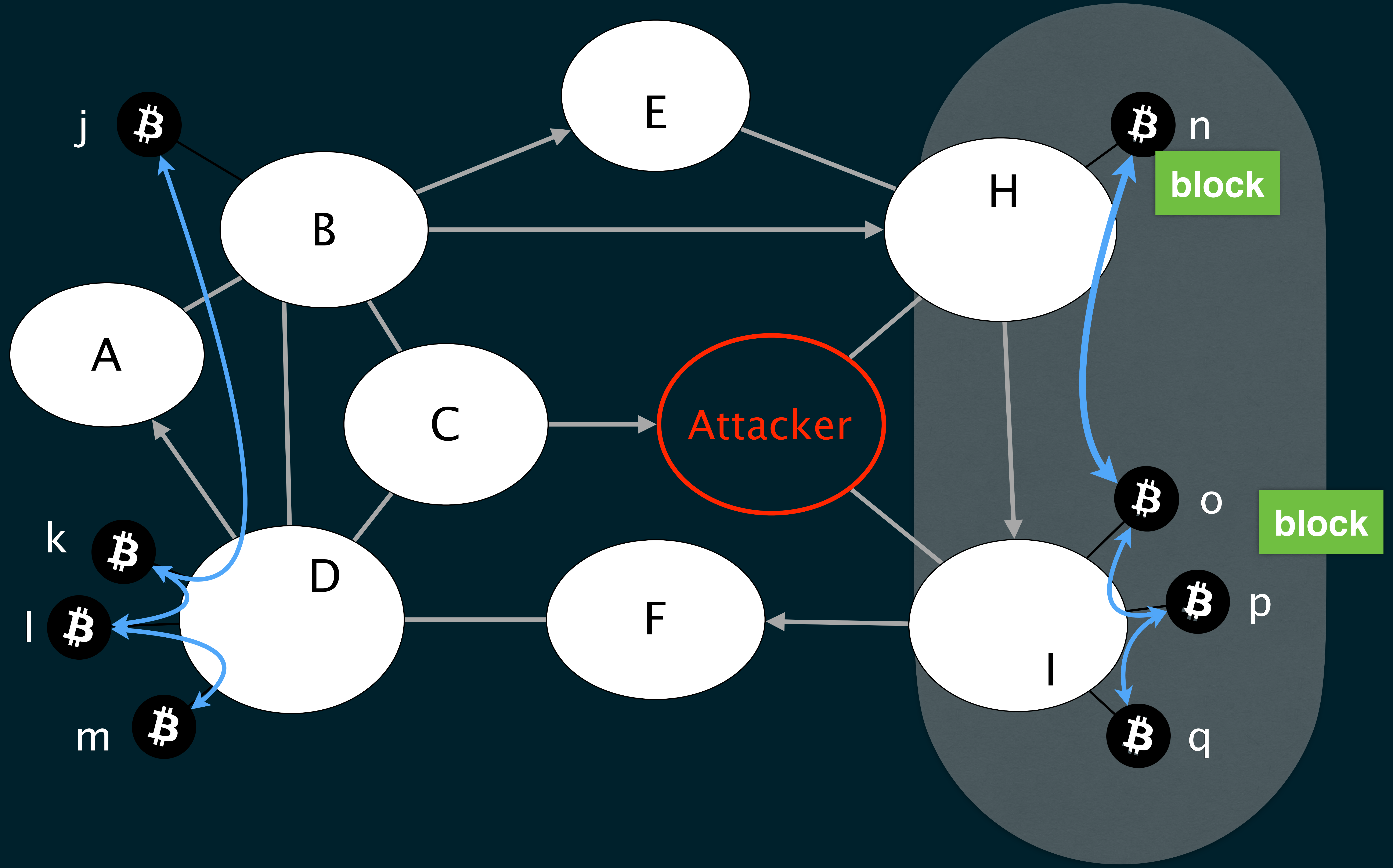

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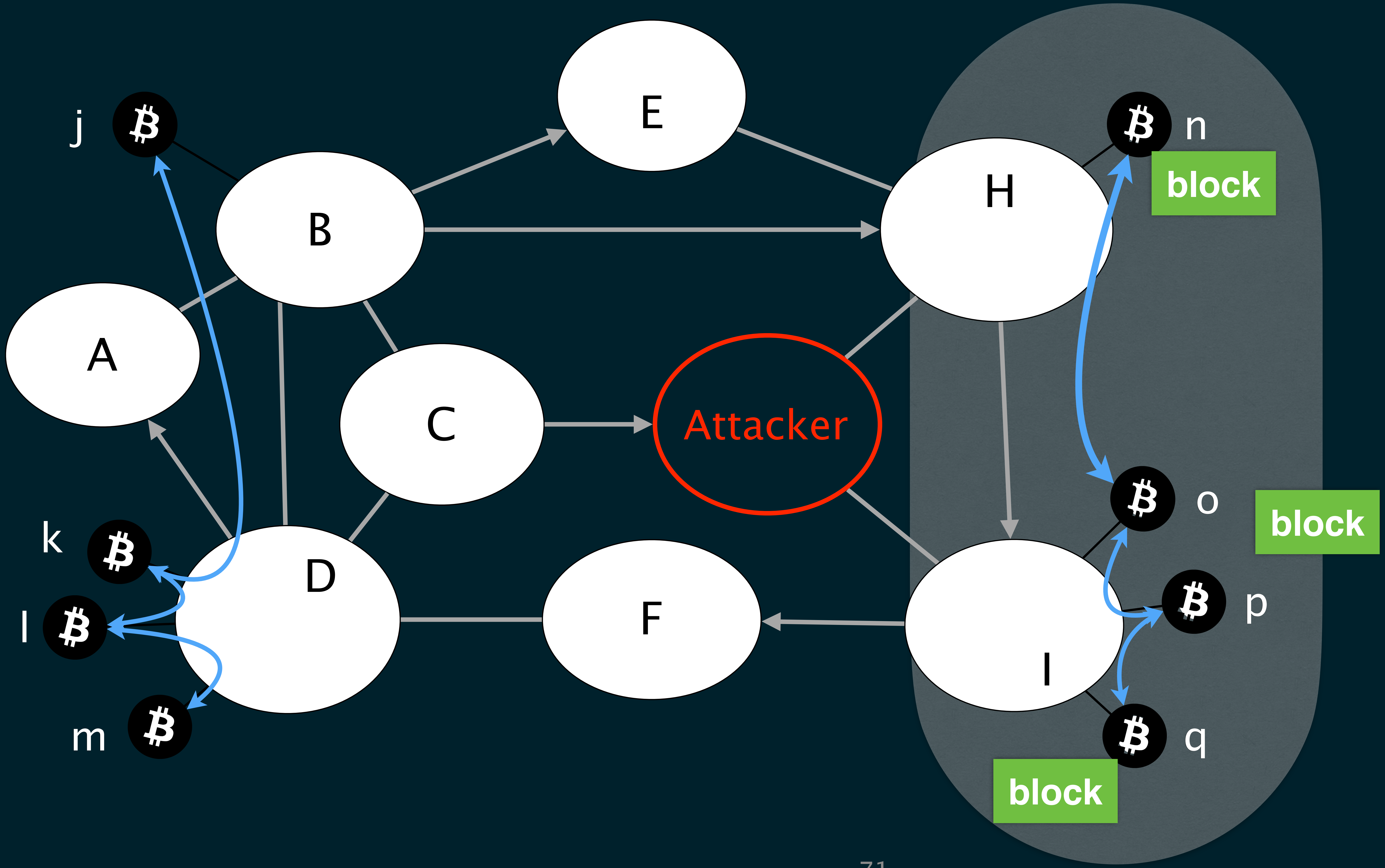

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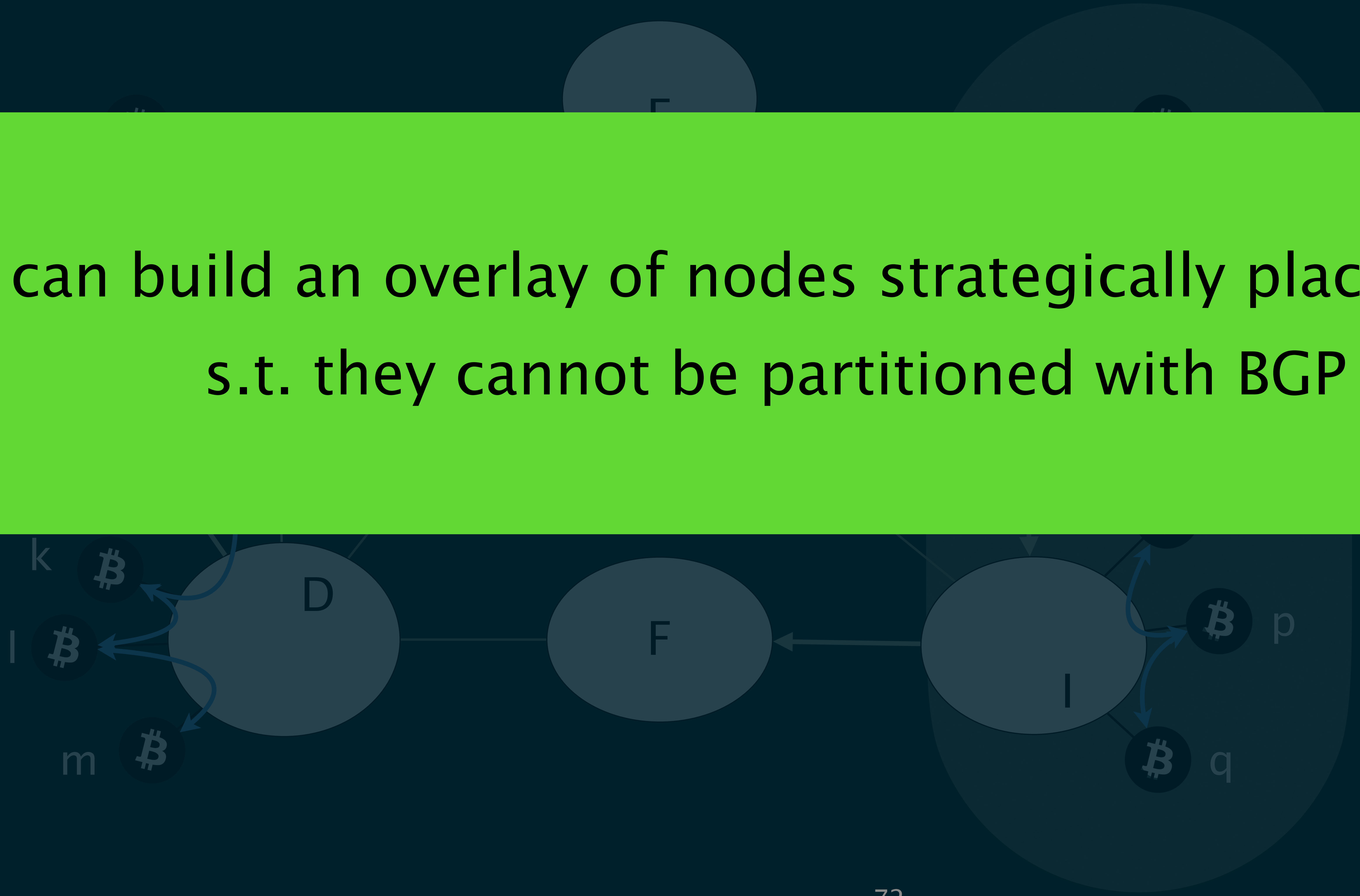
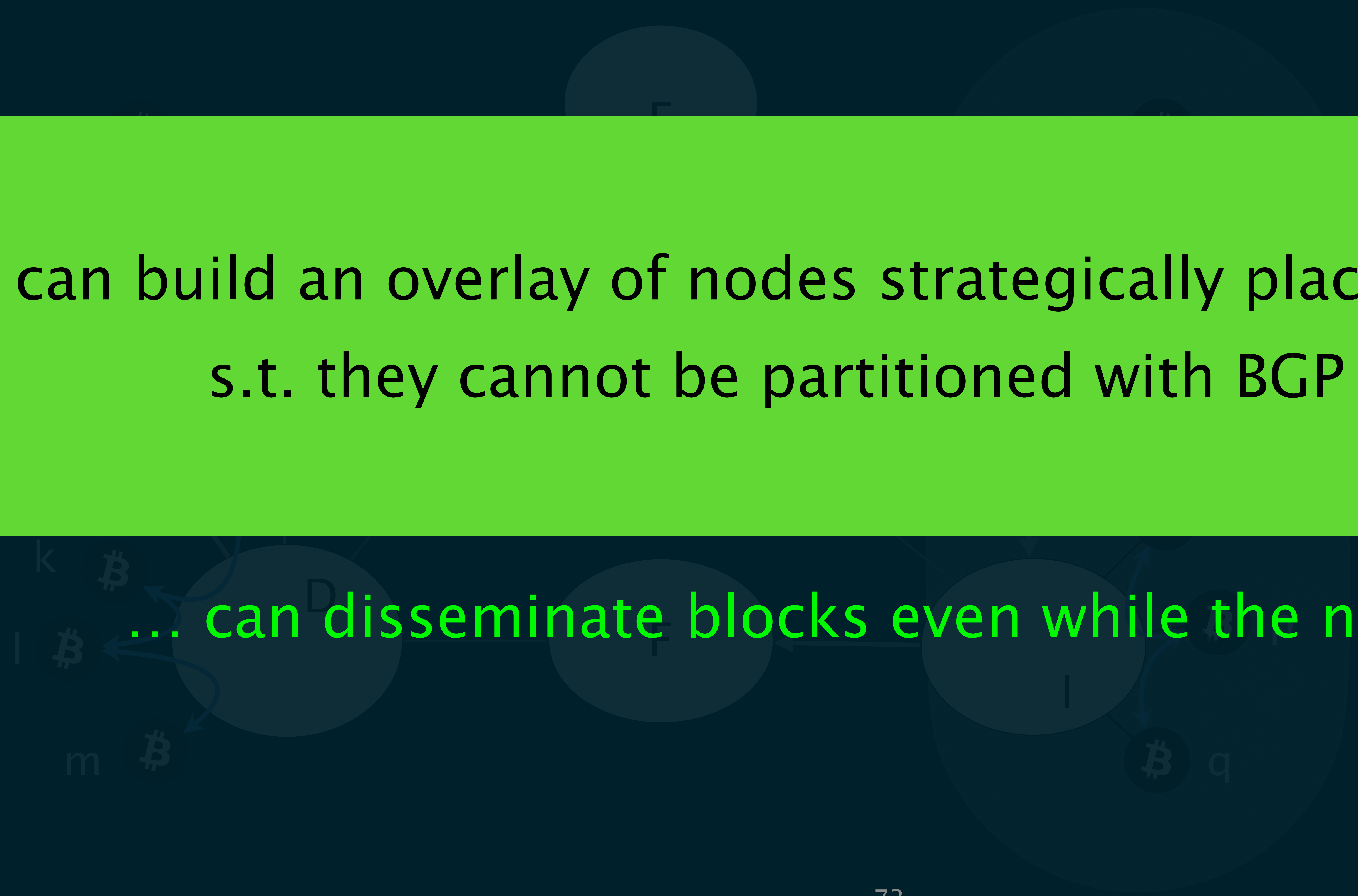


We can build an overlay of nodes strategically placed in the Internet s.t. they cannot be partitioned with BGP hijacks

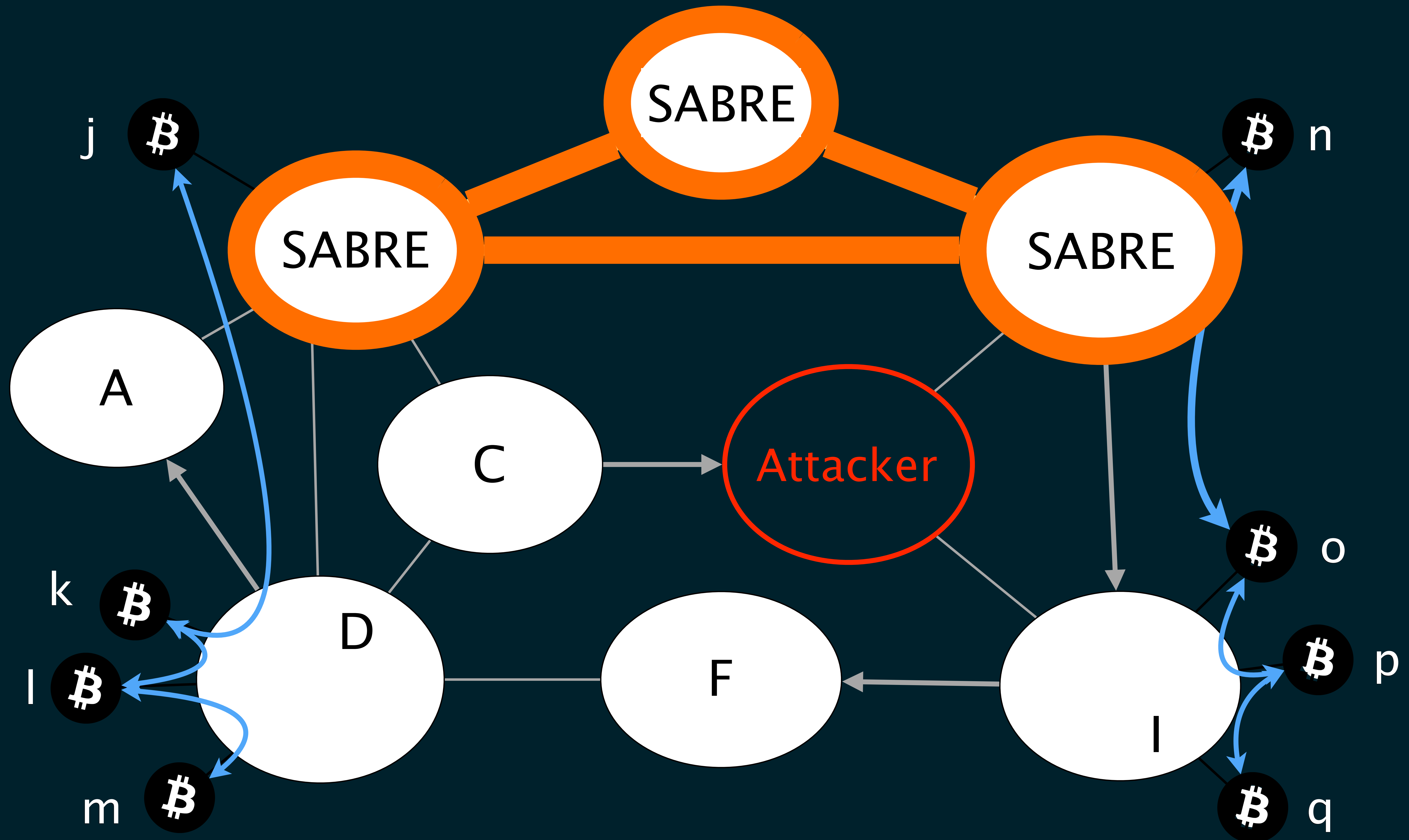
## A new block in the grey zone cannot be propagated further



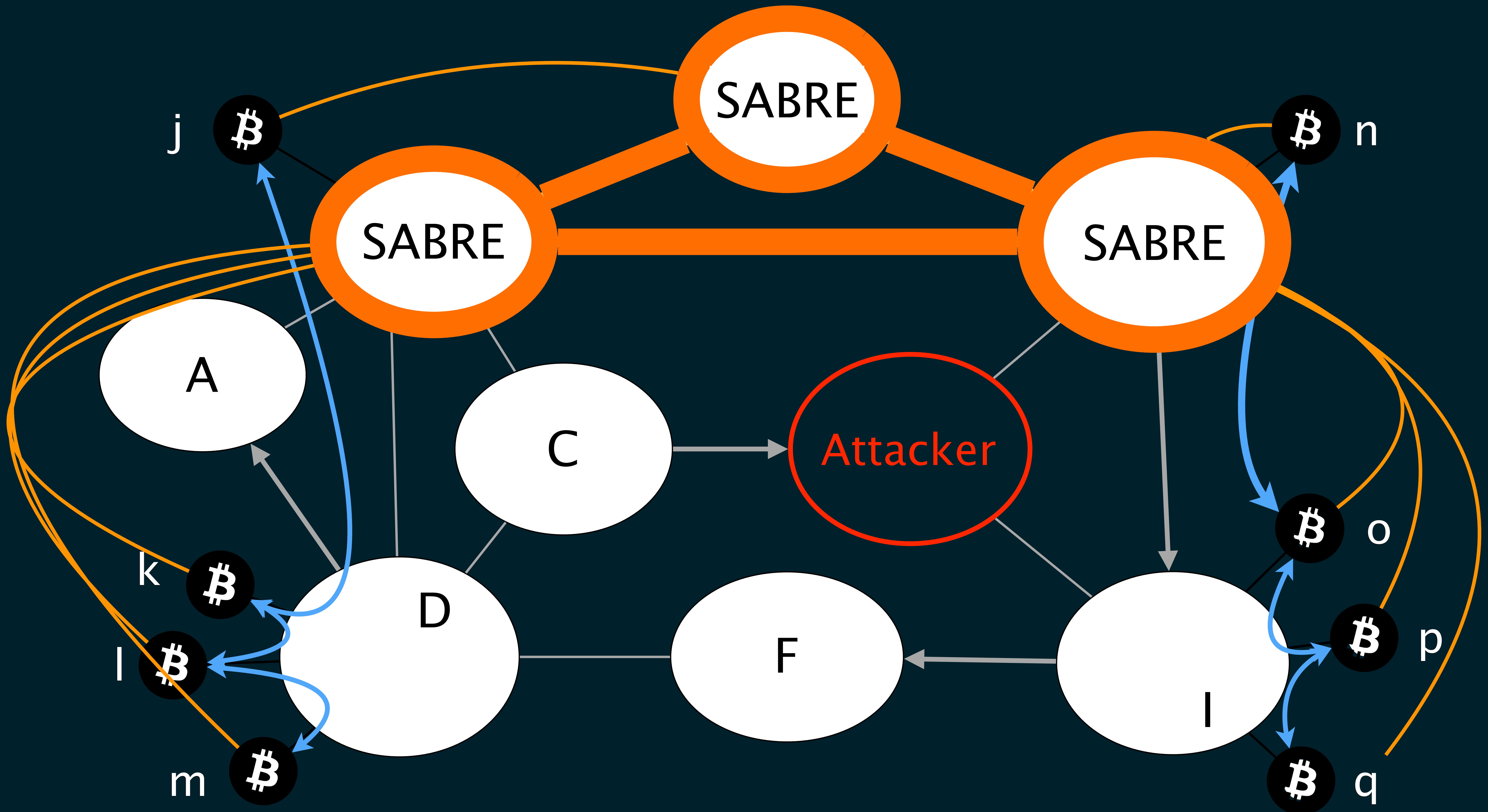
We can build an overlay of nodes strategically placed in the Internet s.t. they cannot be partitioned with BGP hijacks

… can disseminate blocks even while the network is partitioned

# A strongly-connected overlay can disseminate blocks even while the network is partitioned



# A strongly-connected overlay can disseminate blocks even while the network is partitioned



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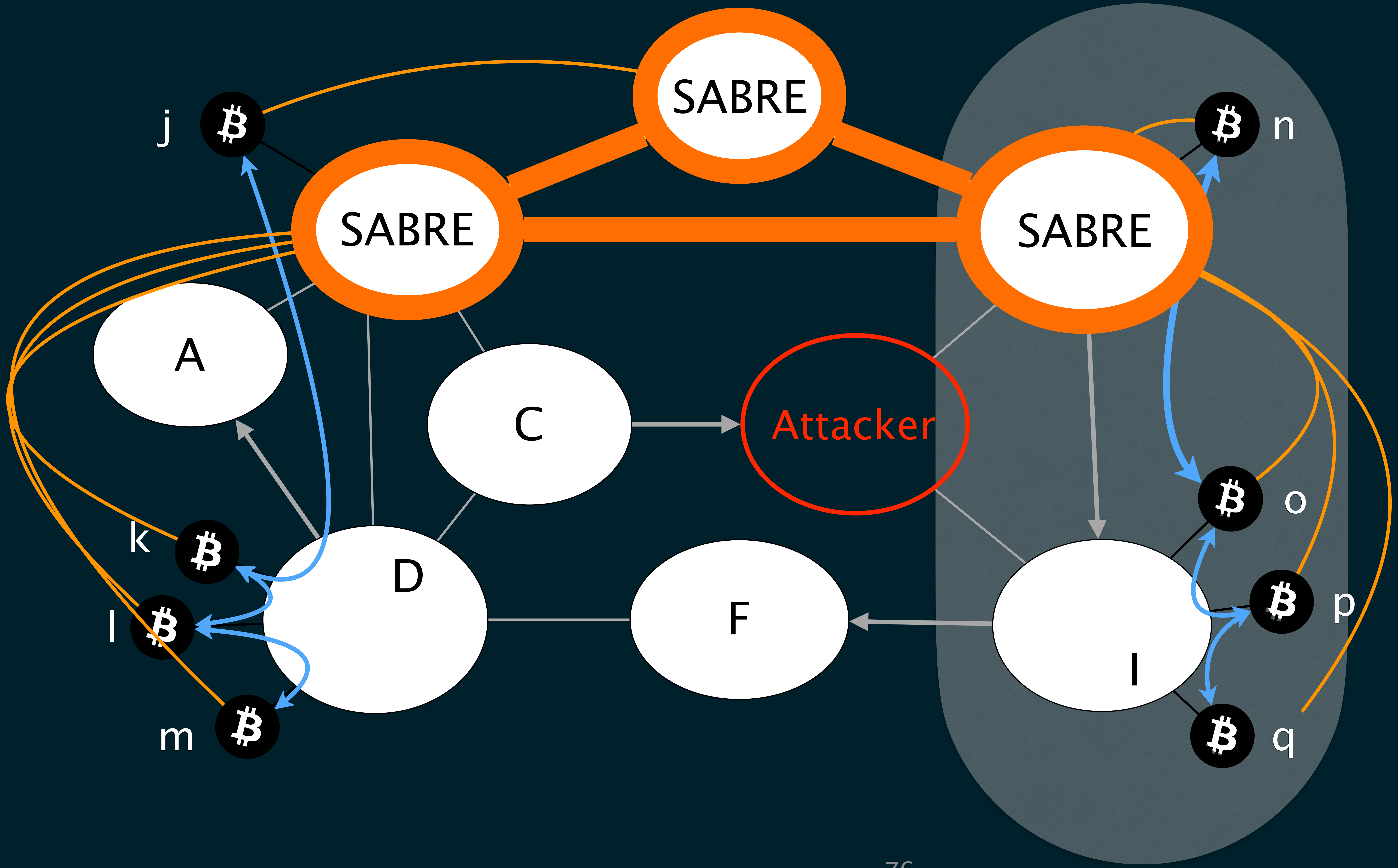

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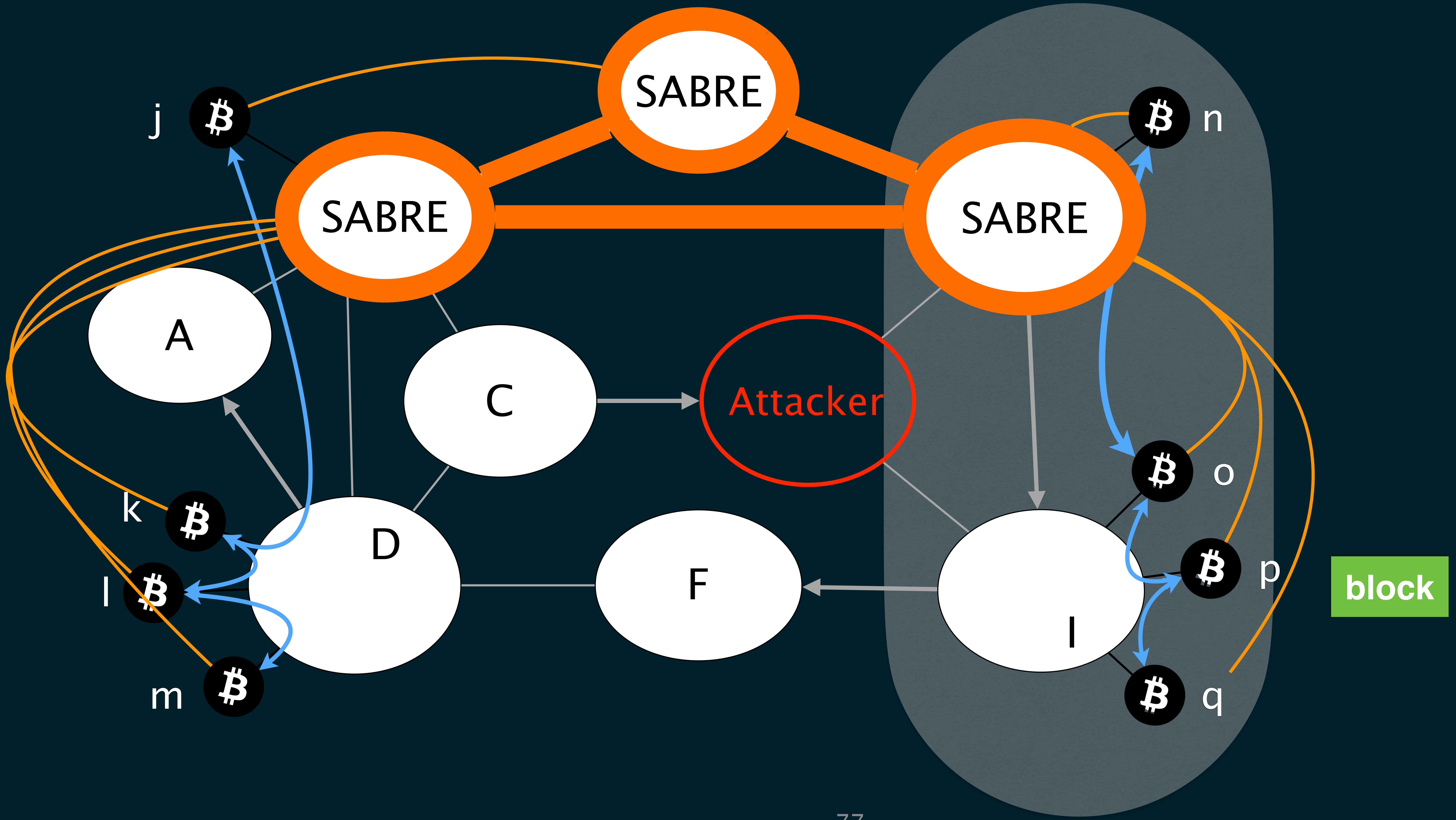

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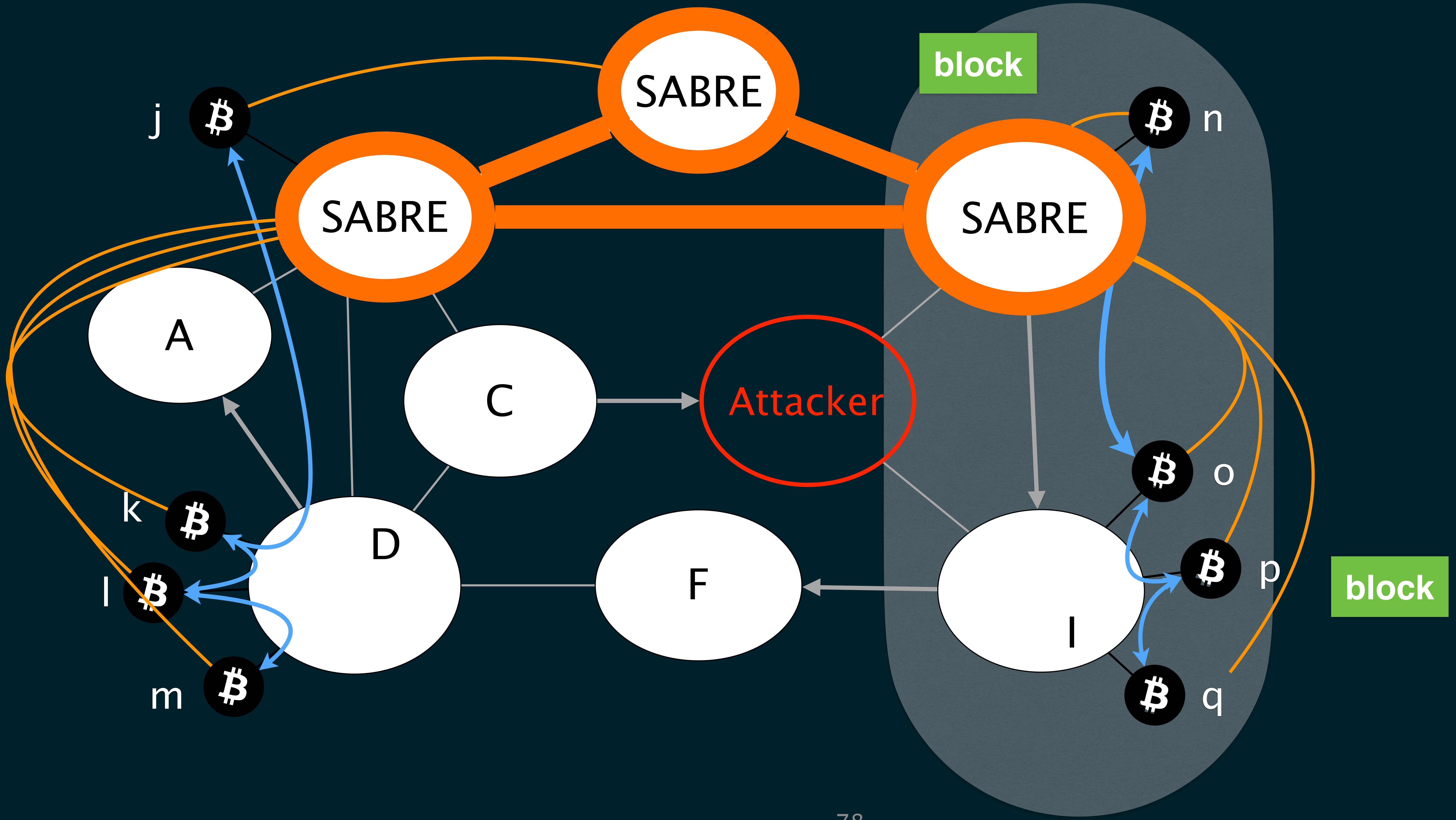

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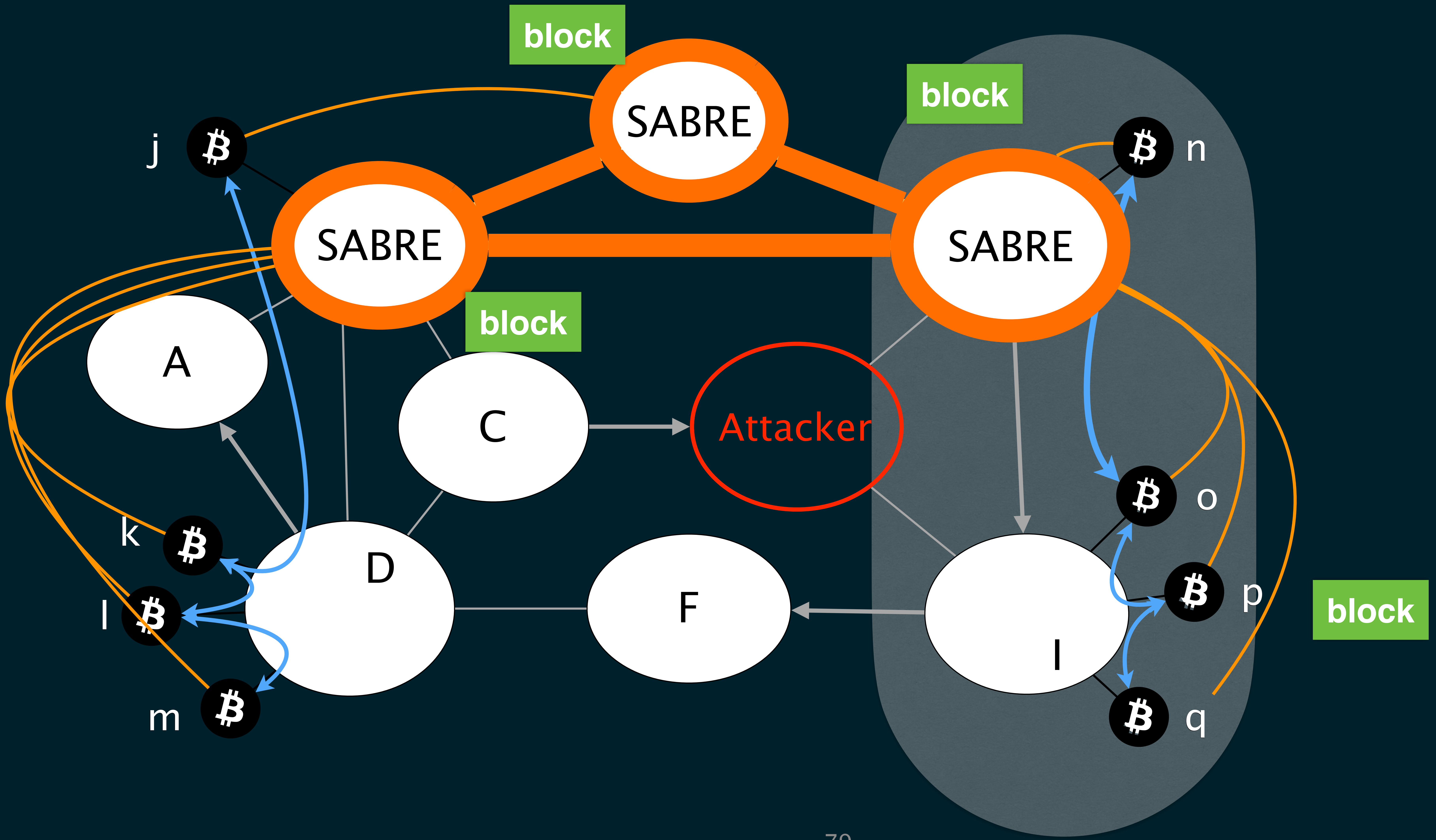

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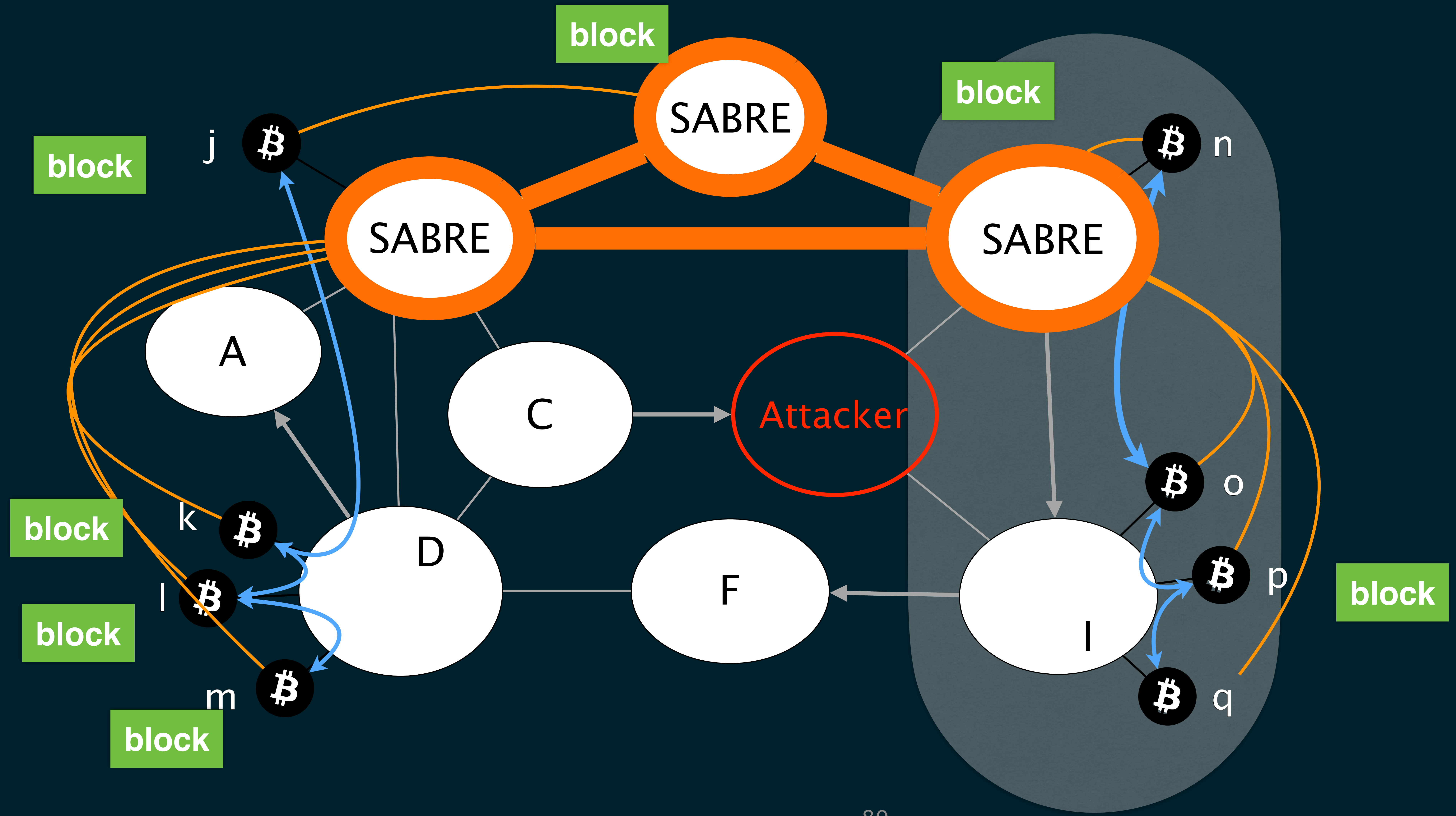

BGP
BGP
ROUTER

## How should the SABRE nodes be implemented?

# Public SABRE nodes need to scale

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SABRE nodes need to…

- maintain thousands of (malicious) connections
- distinguish spoofing and malicious requests
- receive, verify and relay blocks fast

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*Simple software implementation would not suffice!*

# SABRE can leverage programmable network devices

SABRE DP

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

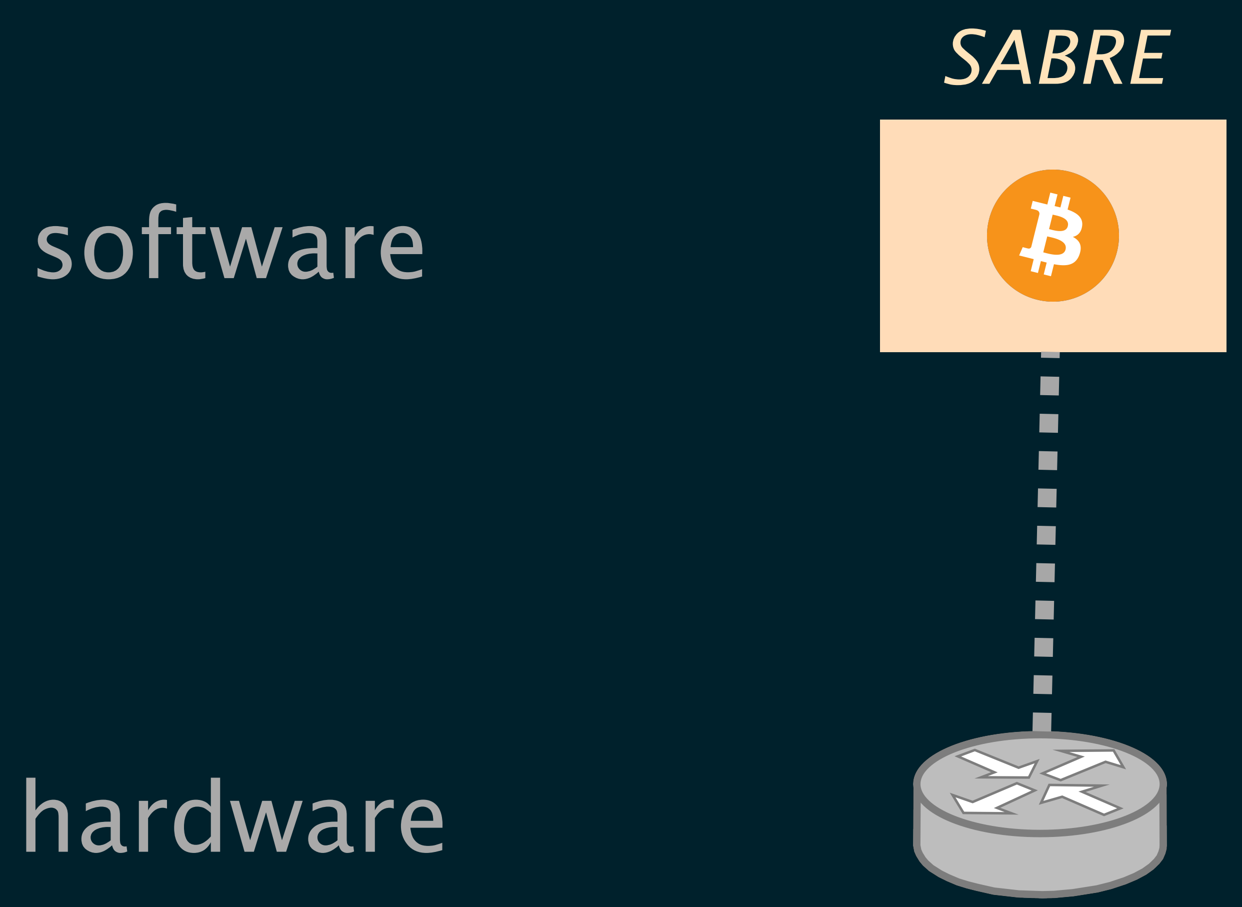
*SABRE*

software

Validates new blocks

Updates hardware with new blocks

# Not all operations can be done in hardware, a SABRE node combines a software and a hardware part



Validates new blocks

Updates hardware with new blocks

Maintains connections to 1000s of clients

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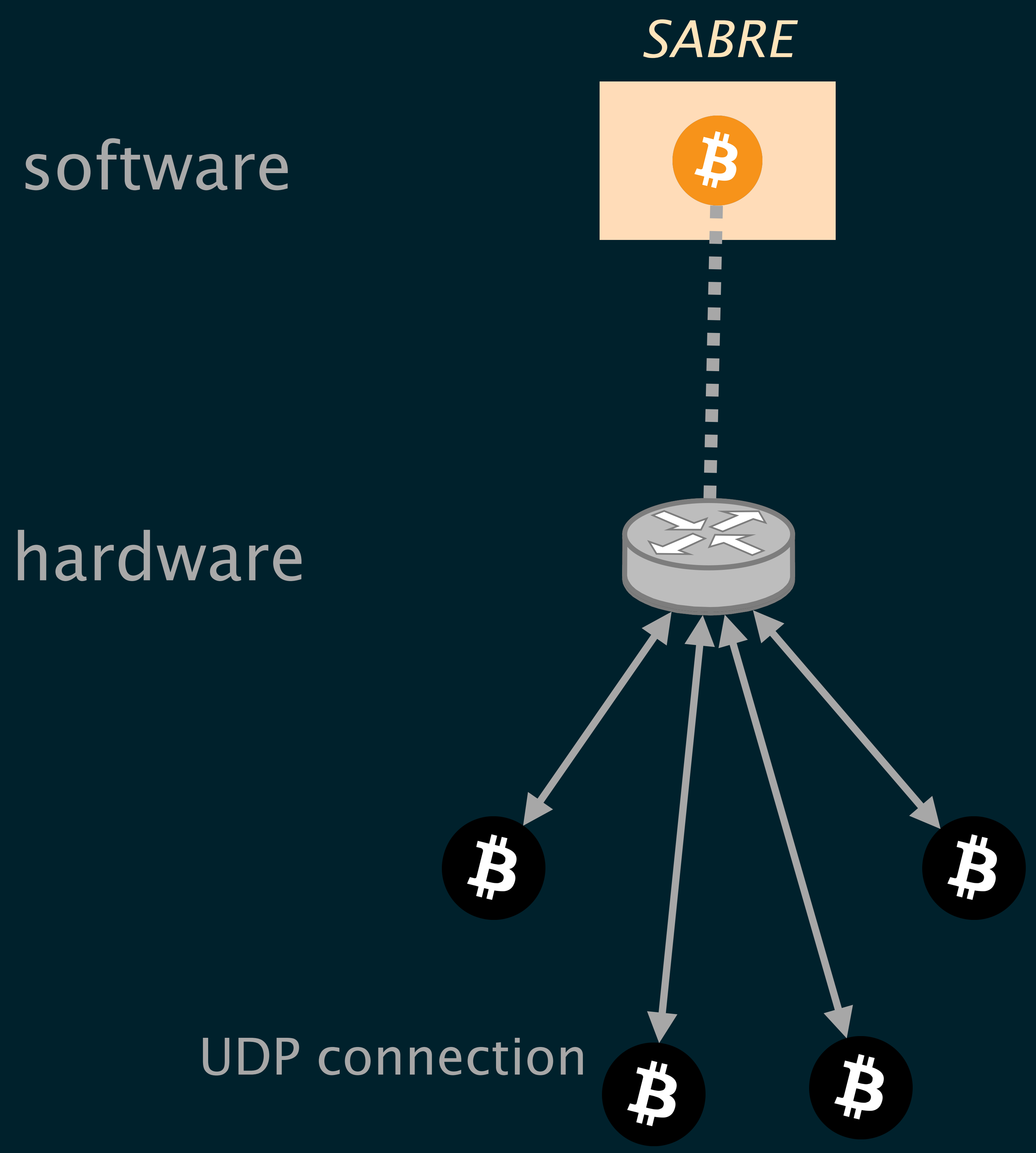

Validates new blocks

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Maintains connections to 1000s of clients

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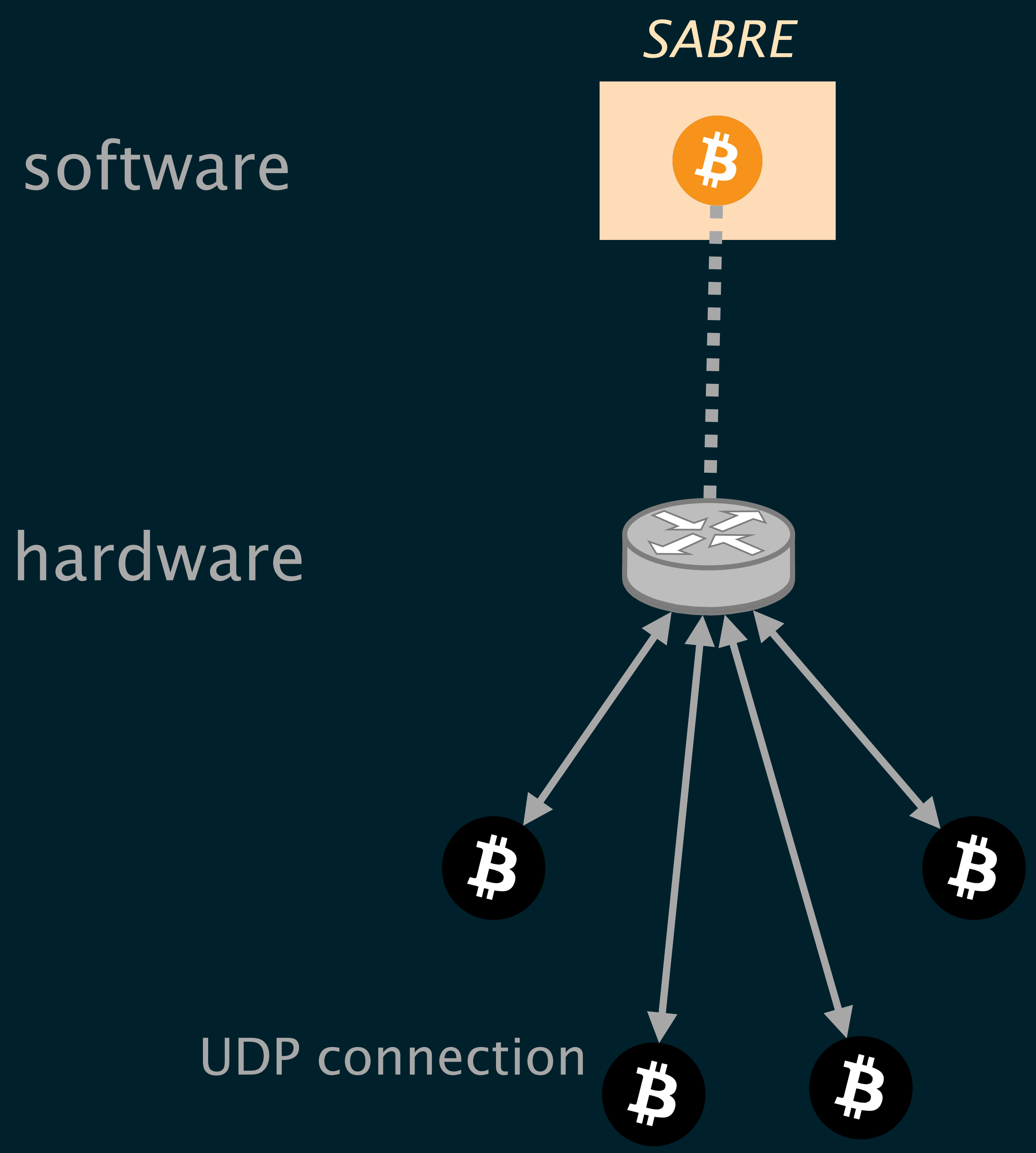

Validates new blocks

Updates hardware with new blocks

Maintains connections to 1000s of clients

Propagates new blocks to connected clients

Protects the software from malicious clients

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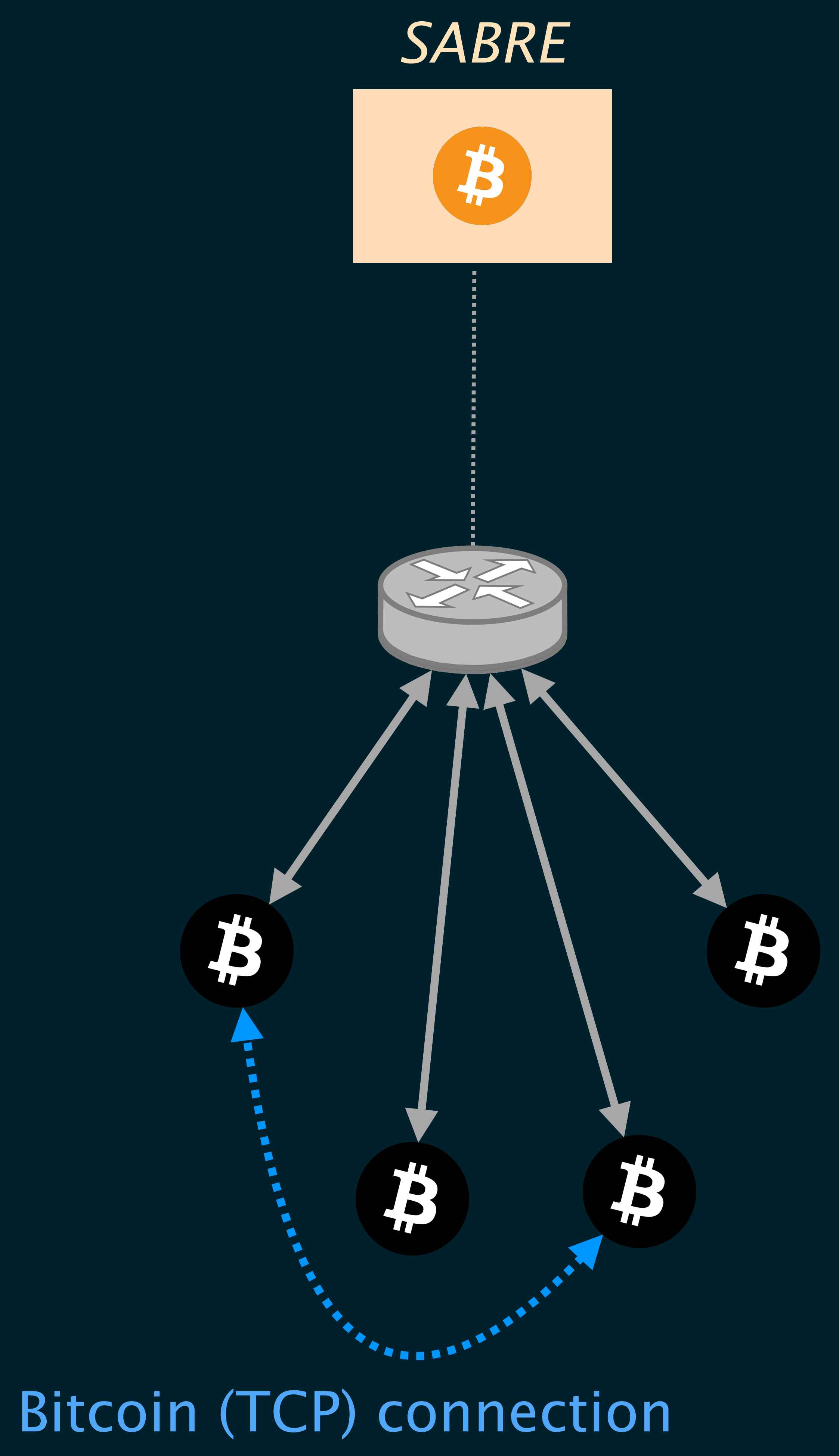

Validates new blocks

Updates hardware with new blocks

Maintains connections to 1000s of clients

Propagates new blocks to connected clients

Protects the software from malicious clients

## What can you do with a couple of programmable points in the Internet?

Tango: performance-driven routing system

NSDI’24

SABRE: secure overlay for BTC block propagation

NDSS’19

## What can you do with a couple of programmable points in the Internet?

<your answer here>

Maria Apostolaki

netsyn.princeton.edu