A Network-State Management Service

Peng Sun

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Princeton & Microsoft

Complex Infrastructure

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Microsoft Azure

Number of	2010	
Data Center	A few	
Network Device	1,000s	
Network Capacity	10s of Tbps	

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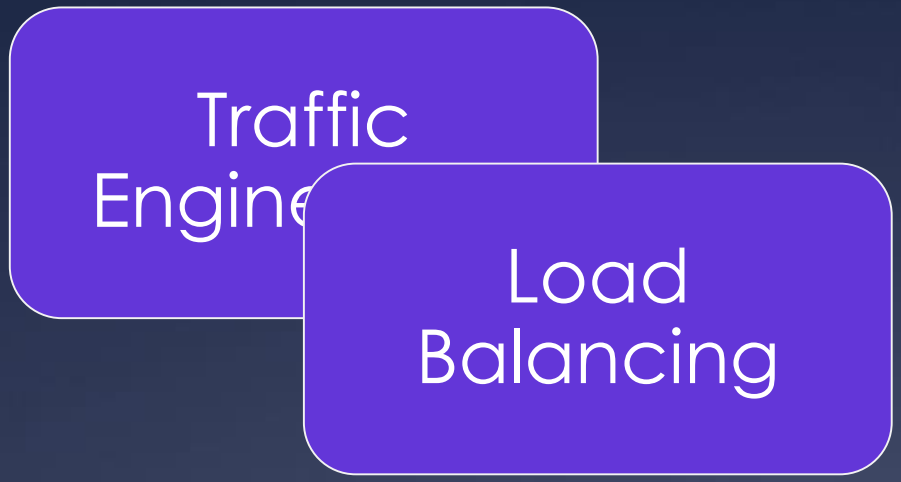
Variety of vendors/models/time

Management Applications

Management Applications

Traffic Engineering

Management Applications



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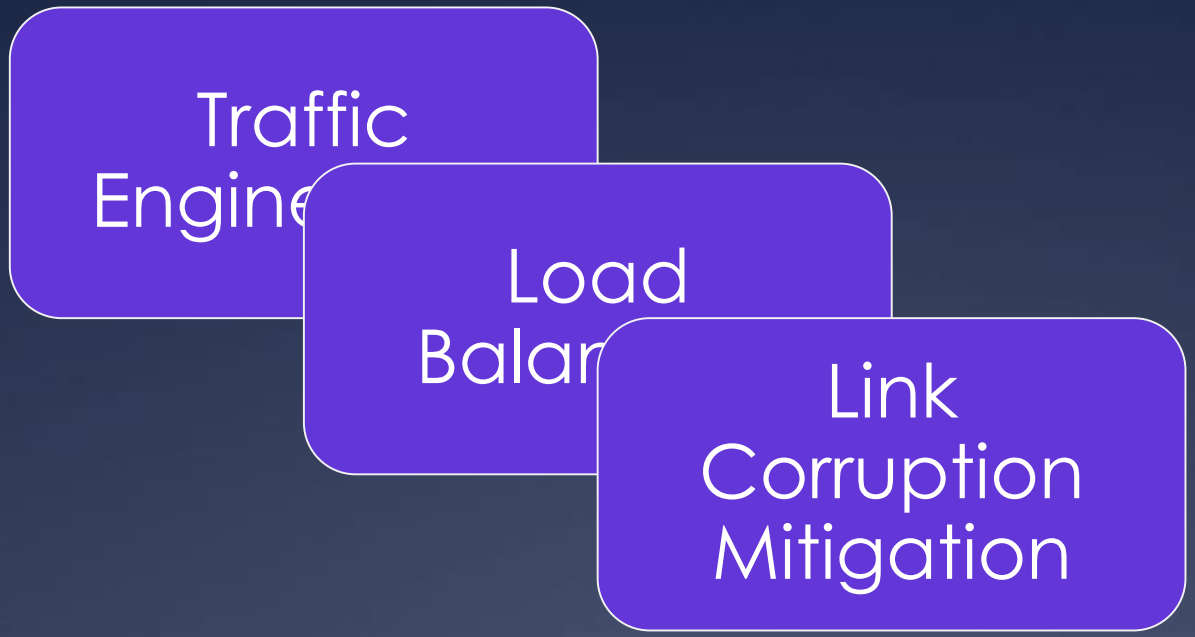
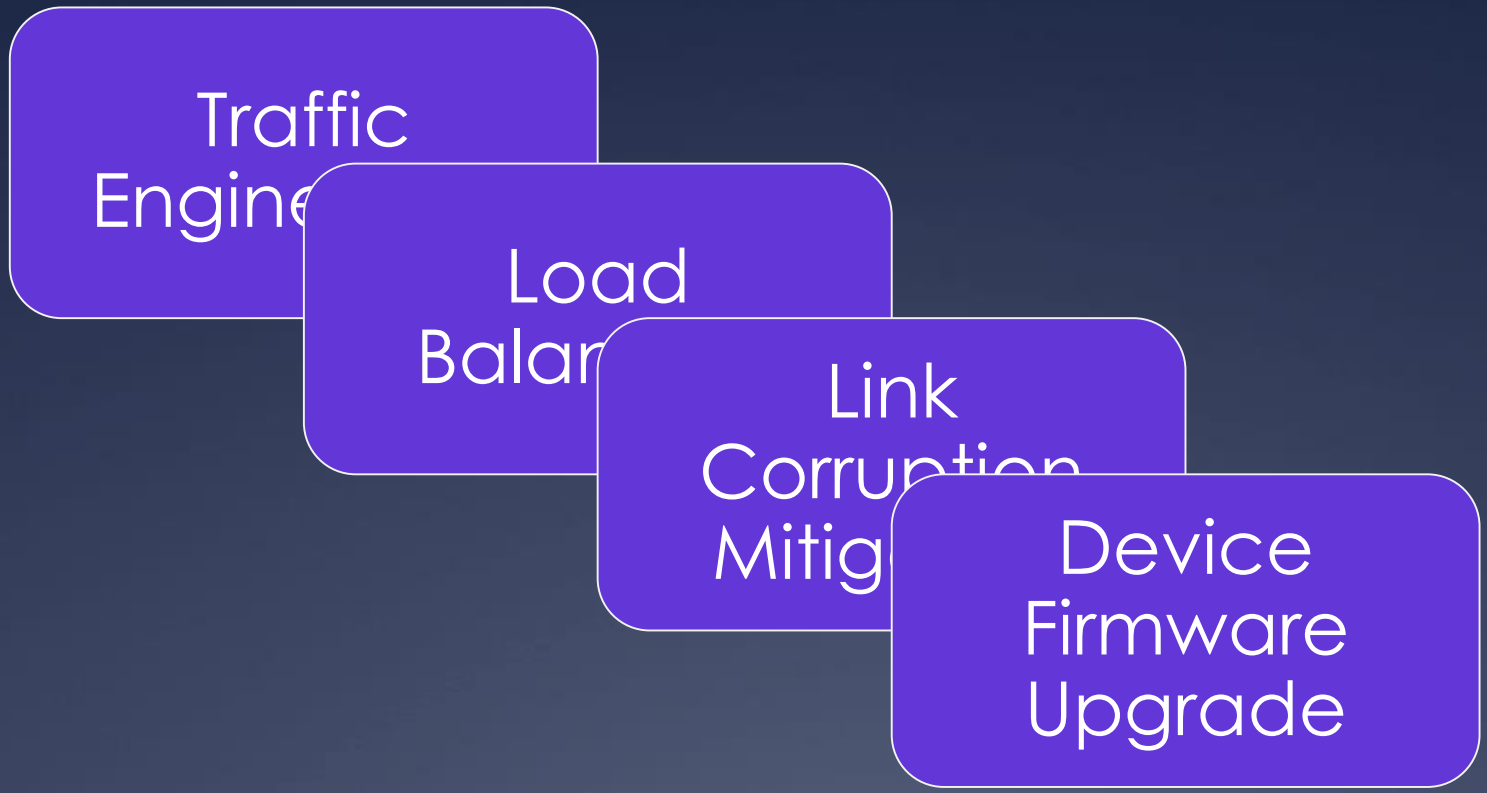


Management Applications

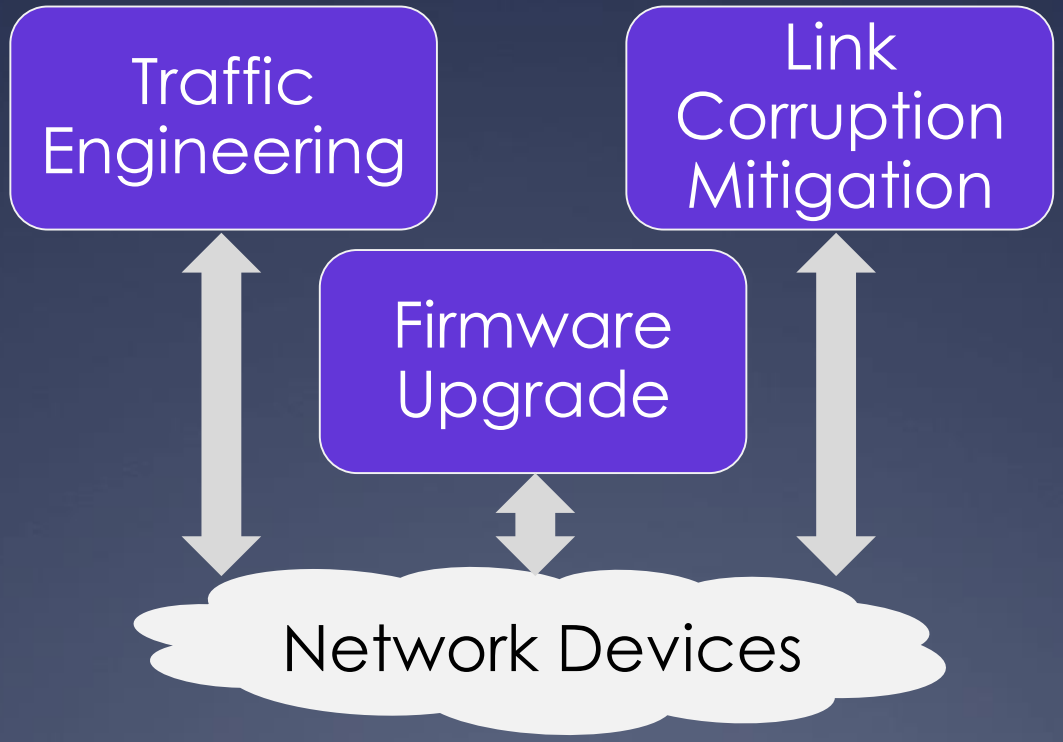


Our Question

How to safely run ***multiple*** management applications on ***shared*** infrastructure

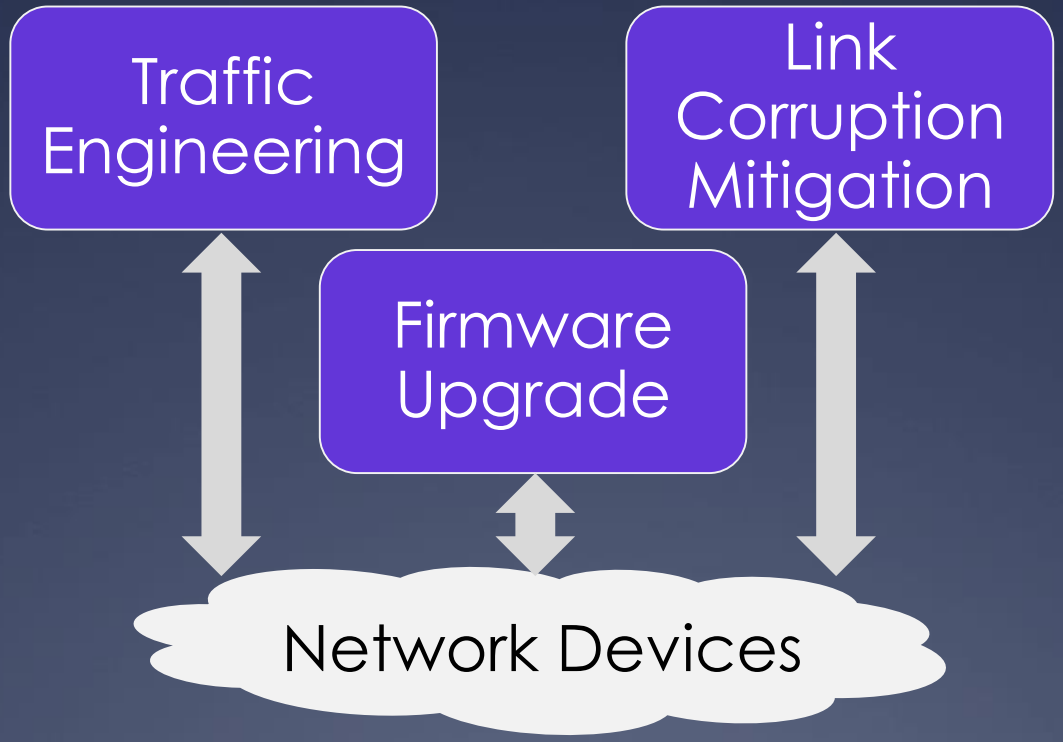
Naïve Solution

- Run independently

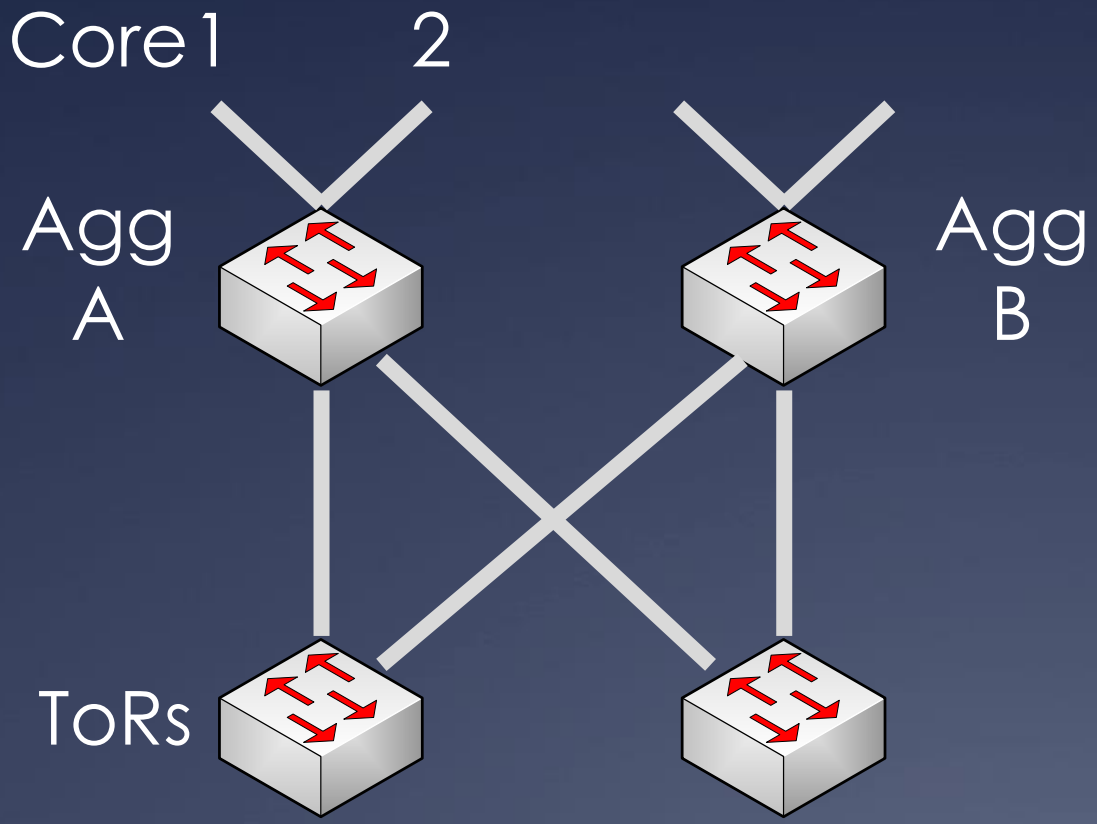


Naïve Solution

- It does not work due to 2 problems



Problem #1: Conflict



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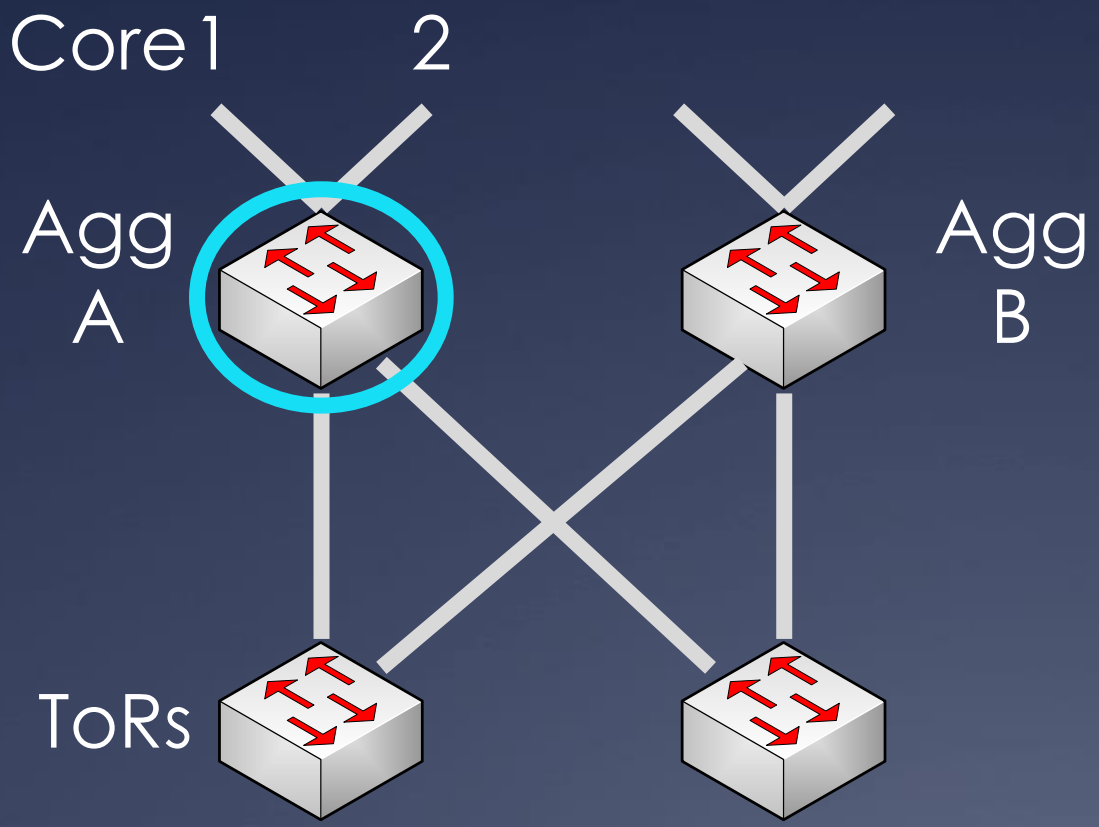

Link-corruption-mitigation adjusts traffic away from Core1

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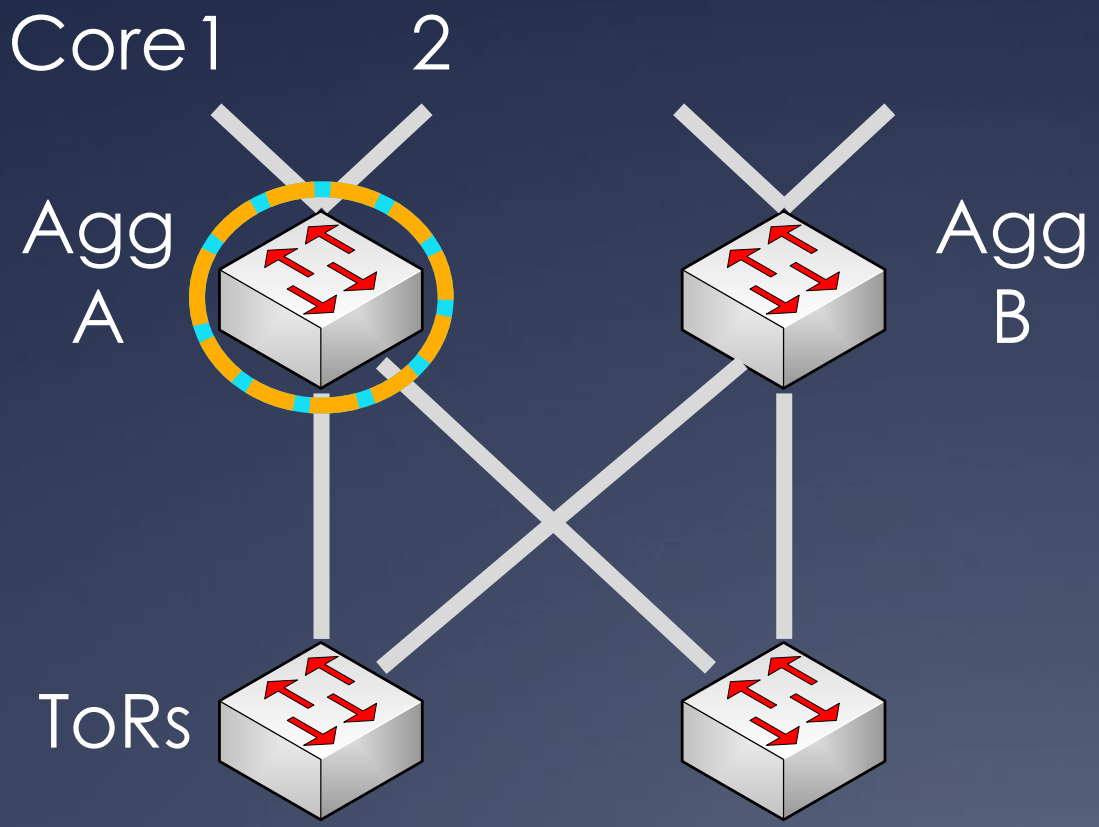
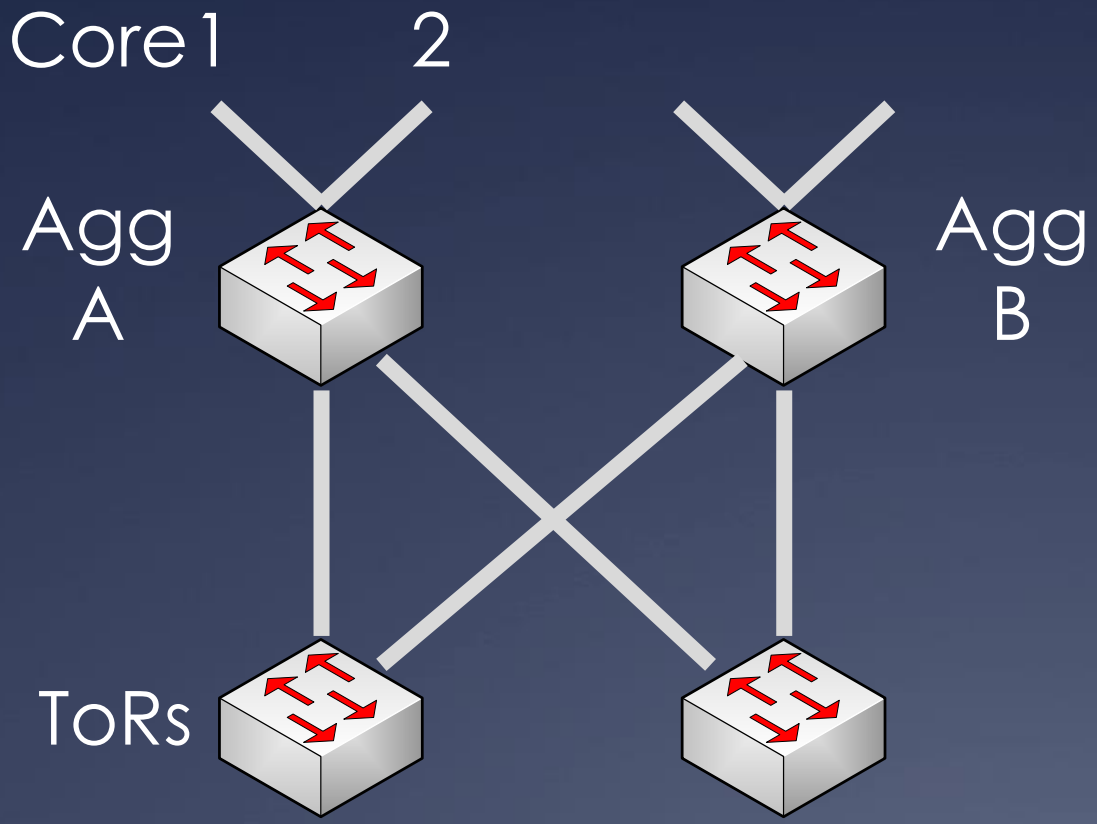


Link-corruption-mitigation adjusts traffic away from Core1

TE tunes traffic among links to Core1, 2

Problem #2: Safety Violation



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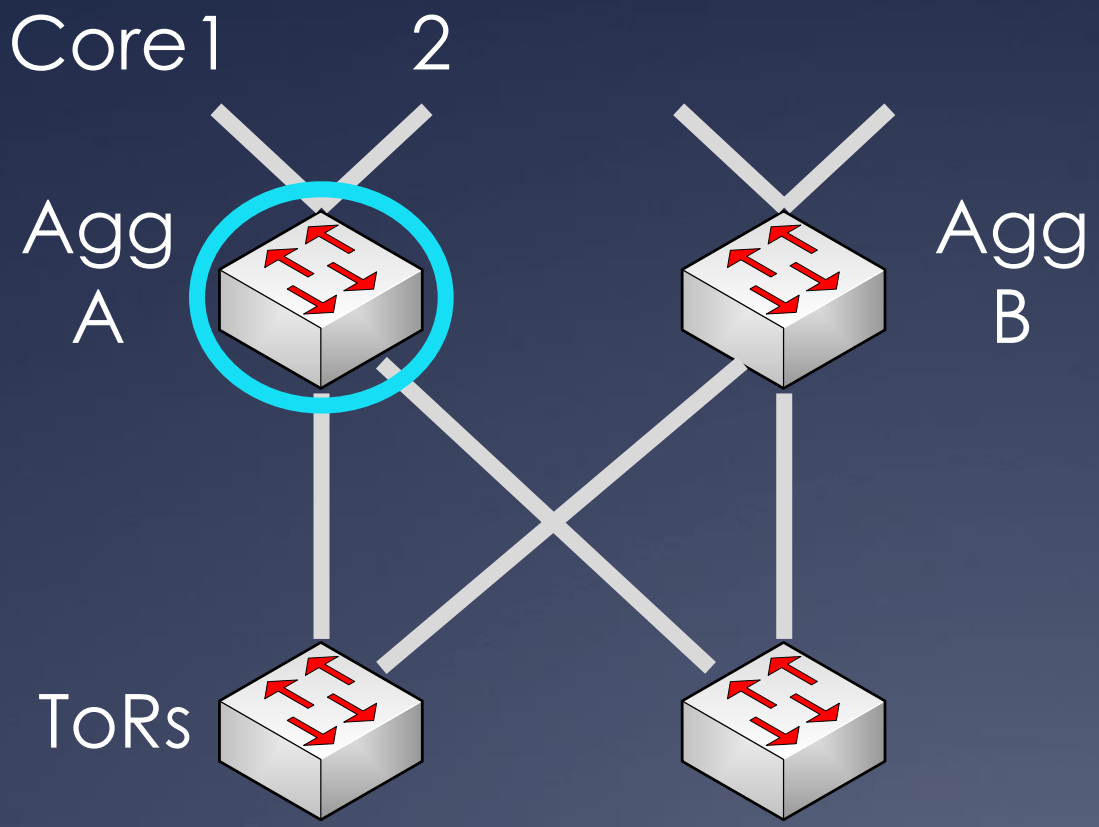

Link-corruption-mitigation shuts down faulty Agg A

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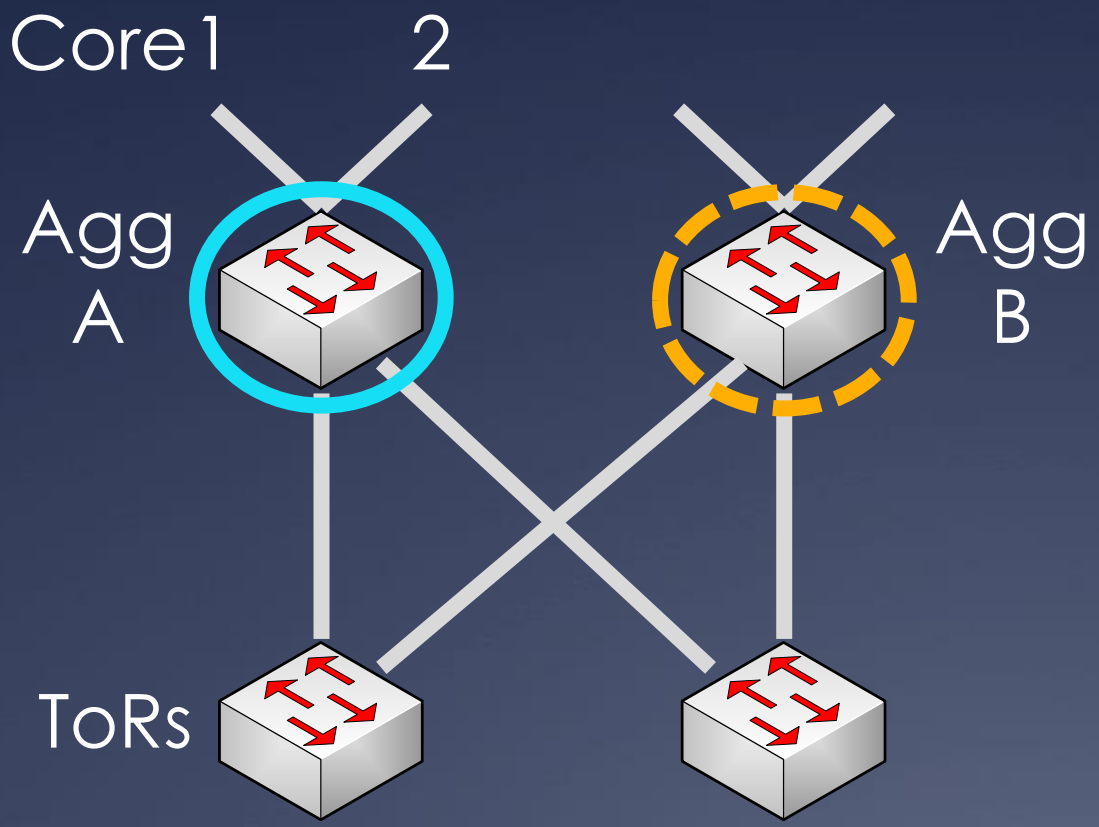

Link-corruption-mitigation shuts down faulty Agg A

Firmware-upgrade schedules Agg B to upgrade

Potential Solution #1

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- Central control of all actions

Too Complex to Build

- Difficult to develop
  - Combine all applications that are already individually complicated

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  - Combine all applications that are already individually complicated
- High maintenance cost
  - for such huge software in practice

Potential Solution #2

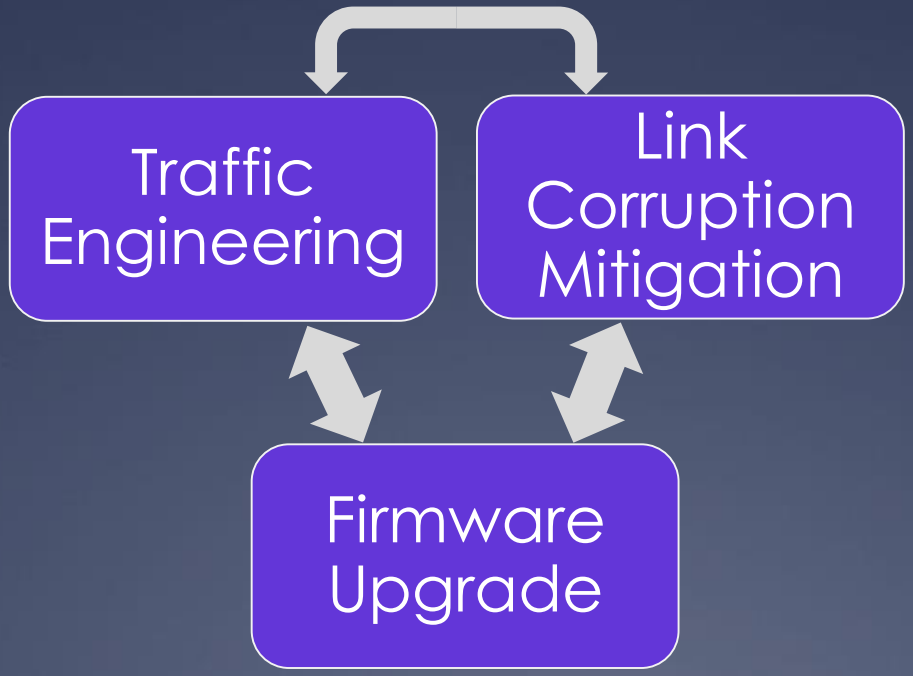
Traffic Engineering

Link Corruption Mitigation

Firmware Upgrade

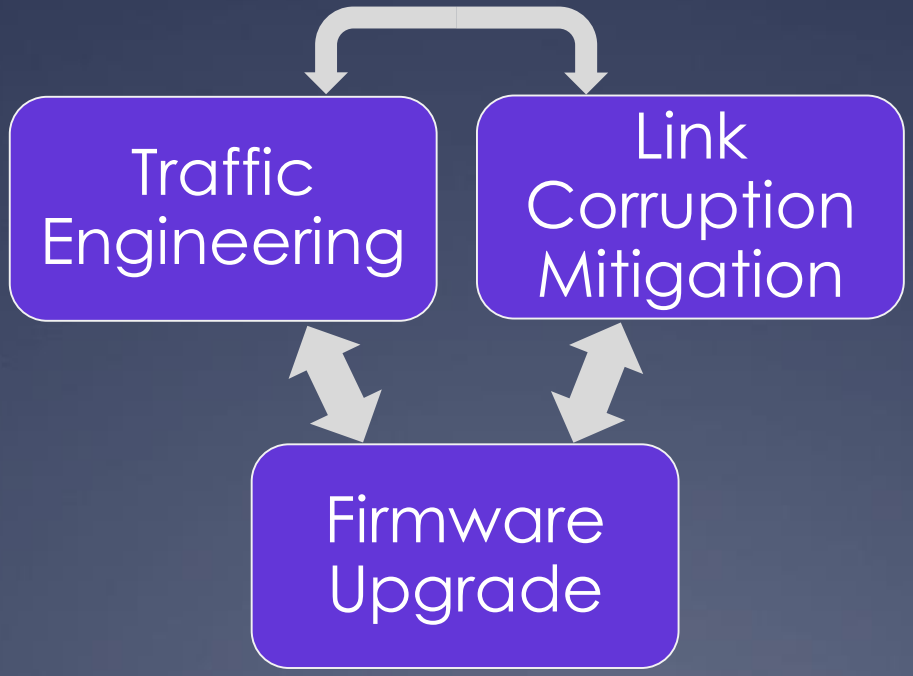
Potential Solution #2

- Explicit coordination among applications



Potential Solution #2

- Explicit coordination among applications
- Consensus over network changes



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  - Diverse network interactions

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Application	Routing	Device Config
Traffic Engineering		
Firmware upgrade		

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Application	Routing	Device Config
Traffic Engineering	✓	✗
Firmware upgrade	✗	✓

Main Enemy: Complexity

- Application development
- Application coordination

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What We Advocate

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- Loose coupling of applications
- Design principle:
  - Simplicity with safety guarantees
- Forgo joint optimization
  - Worthwhile tradeoff for simplicity
  - Applications could do it out-of-band

Overview of Statesman

- Network operating system for safe multi-application operation

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- Uses network state abstraction
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  - Dependency model of states

The "State" in Statesman

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  - Heterogeneity
  - Device-specific commands

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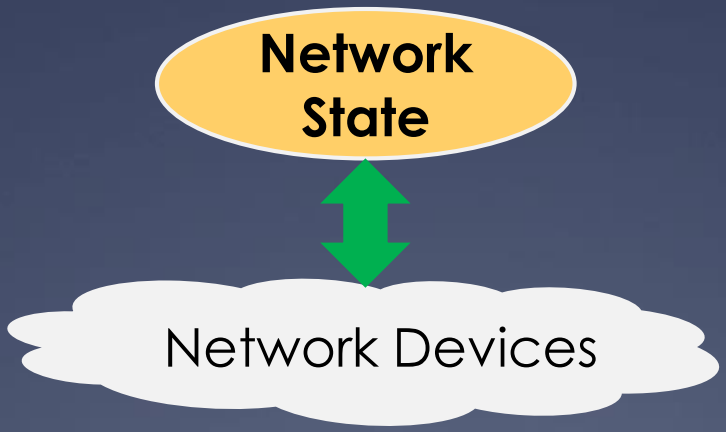
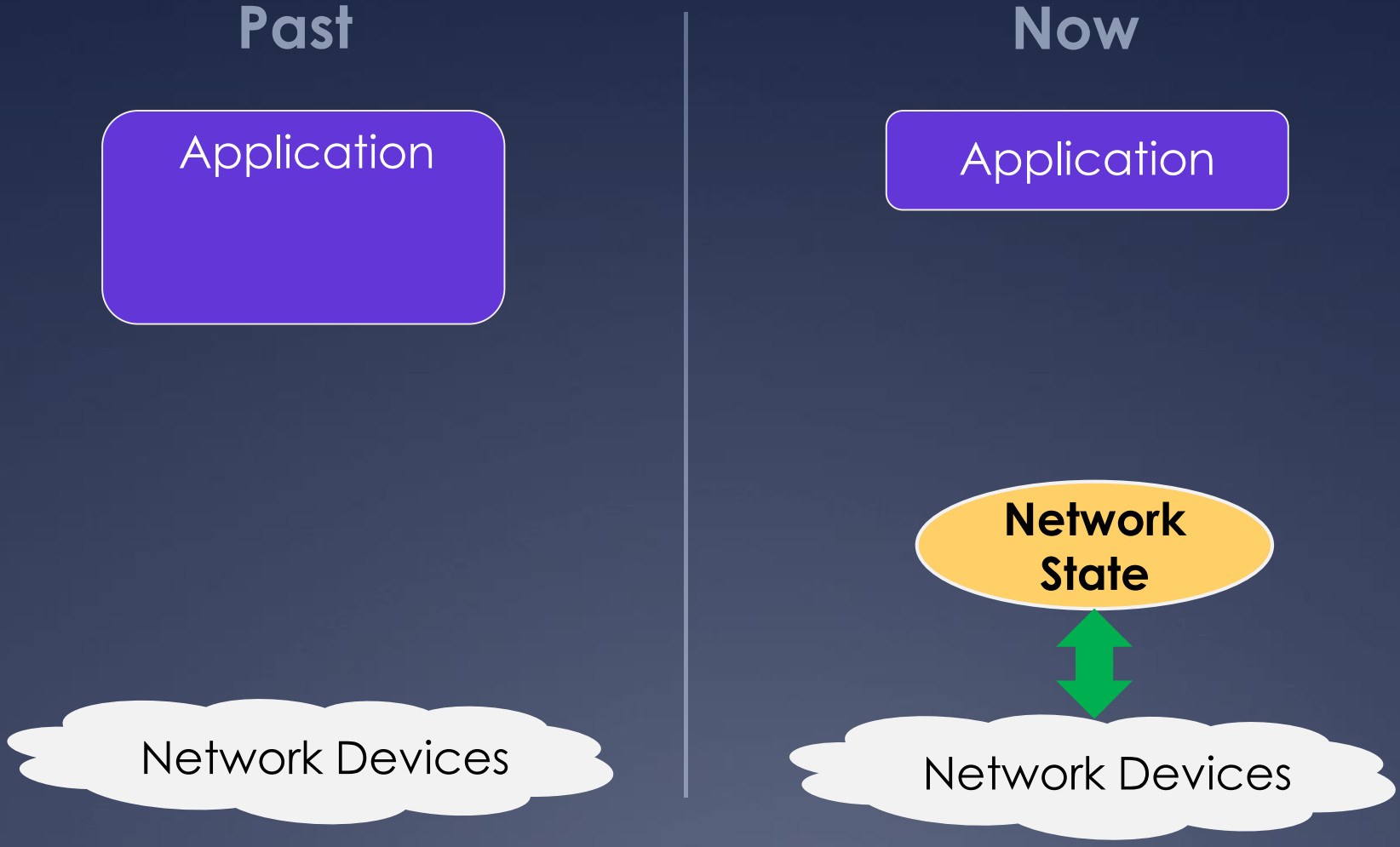


State Variable Examples

State Variable	Value
Device Power Status	Up, down
Device Firmware	Version number
Device SDN Agent Boot	Up, down
Device Routing State	Routing rules
Link Admin Status	Up, down
Link Control Plane	BGP, OpenFlow, …

Simplify Device Interaction



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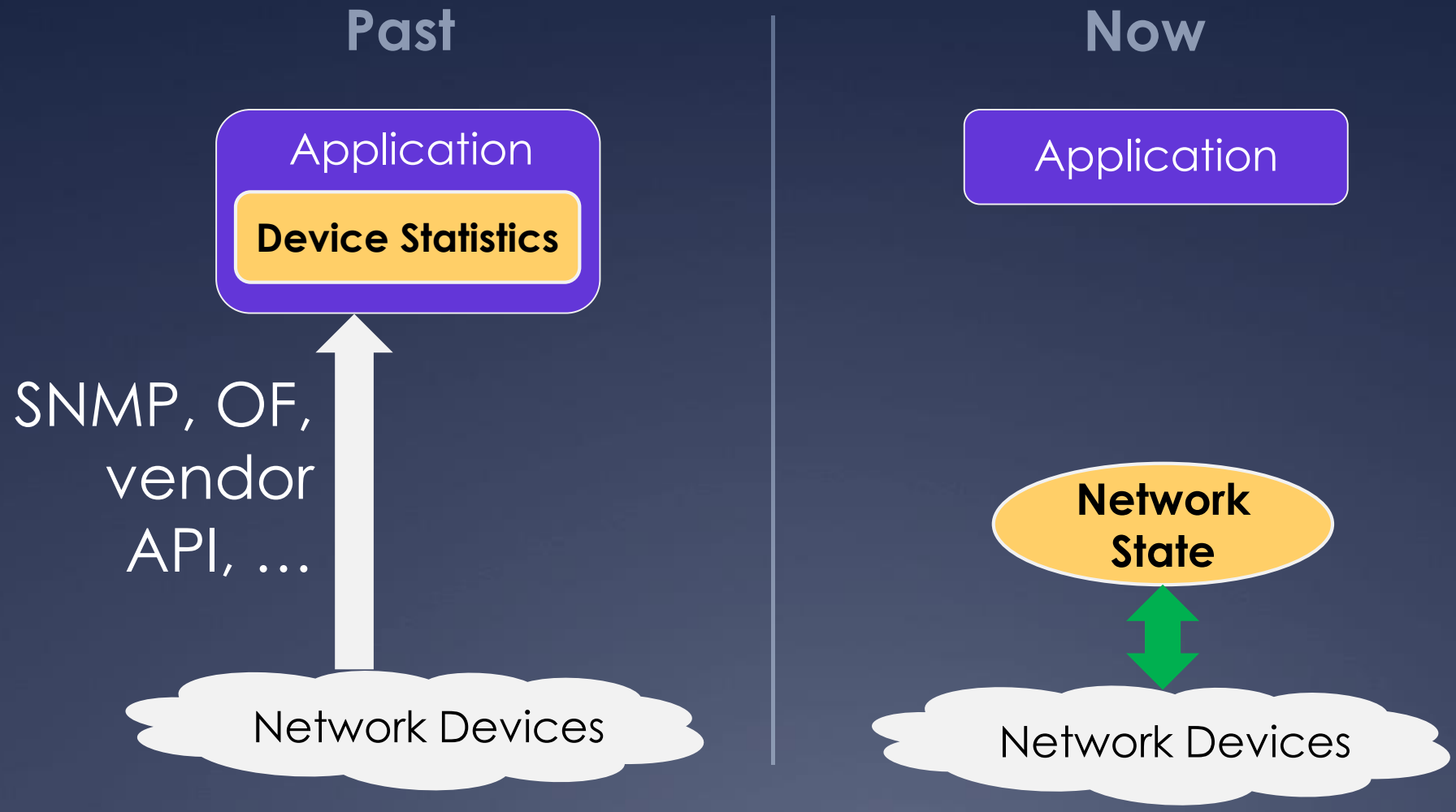

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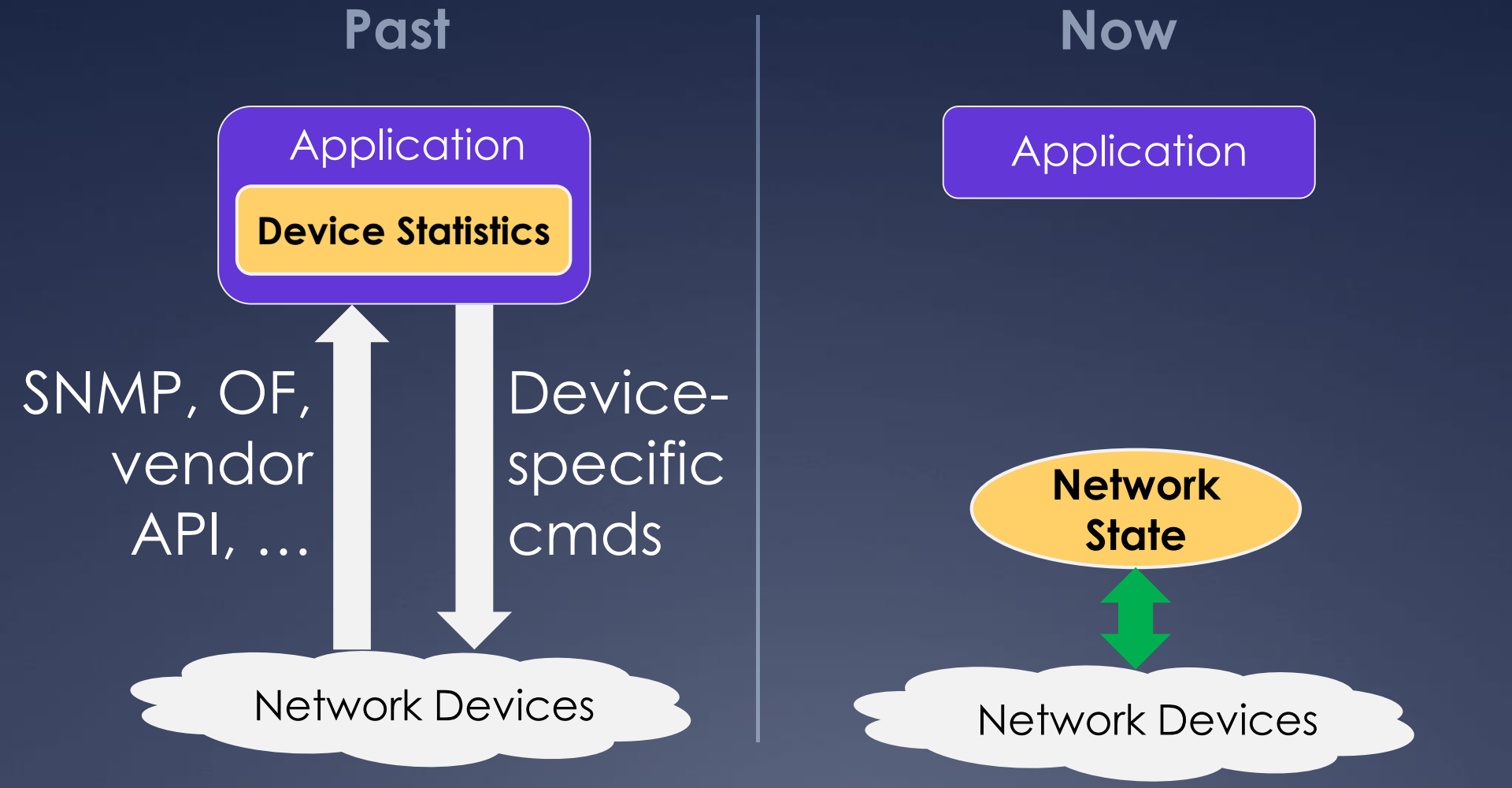

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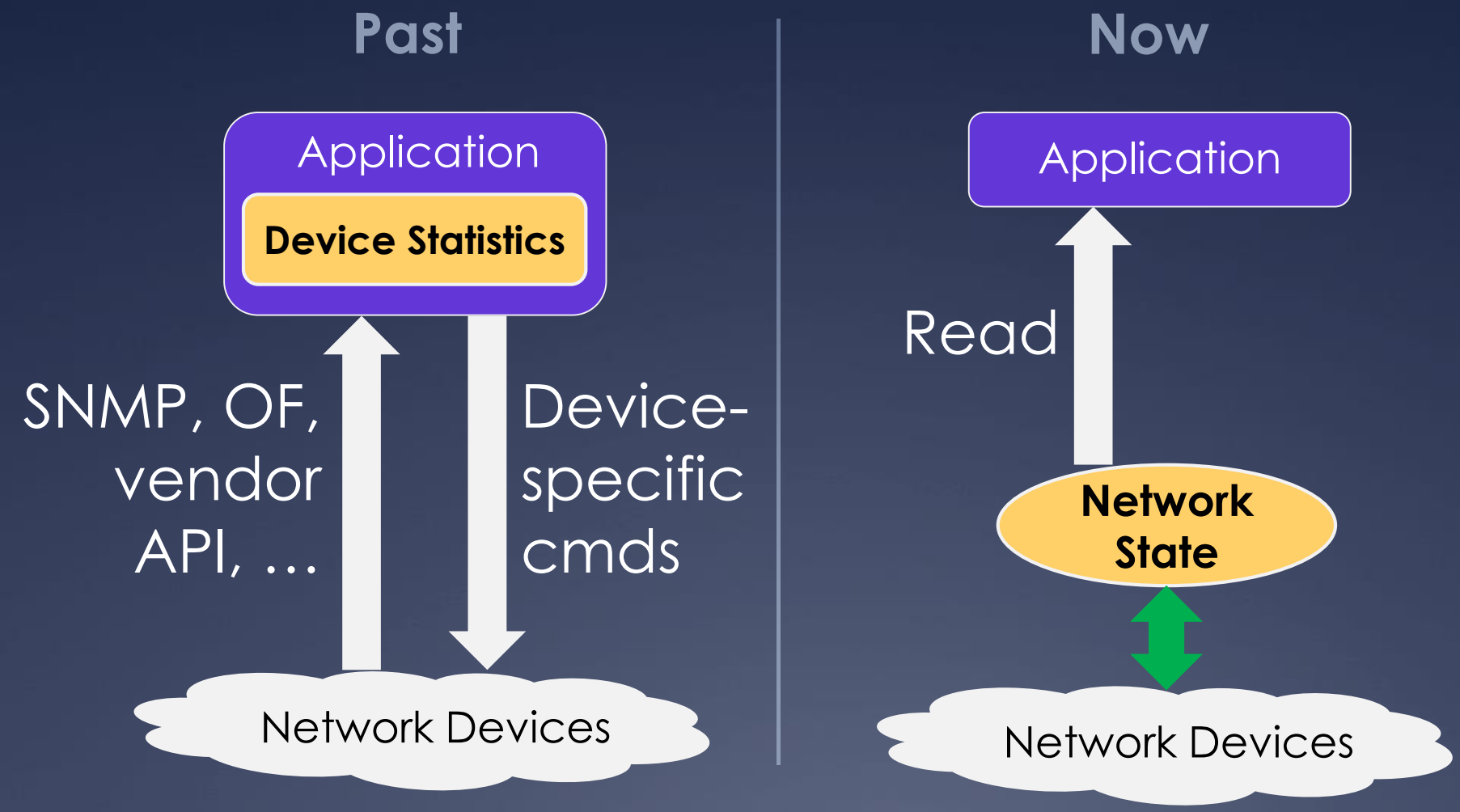

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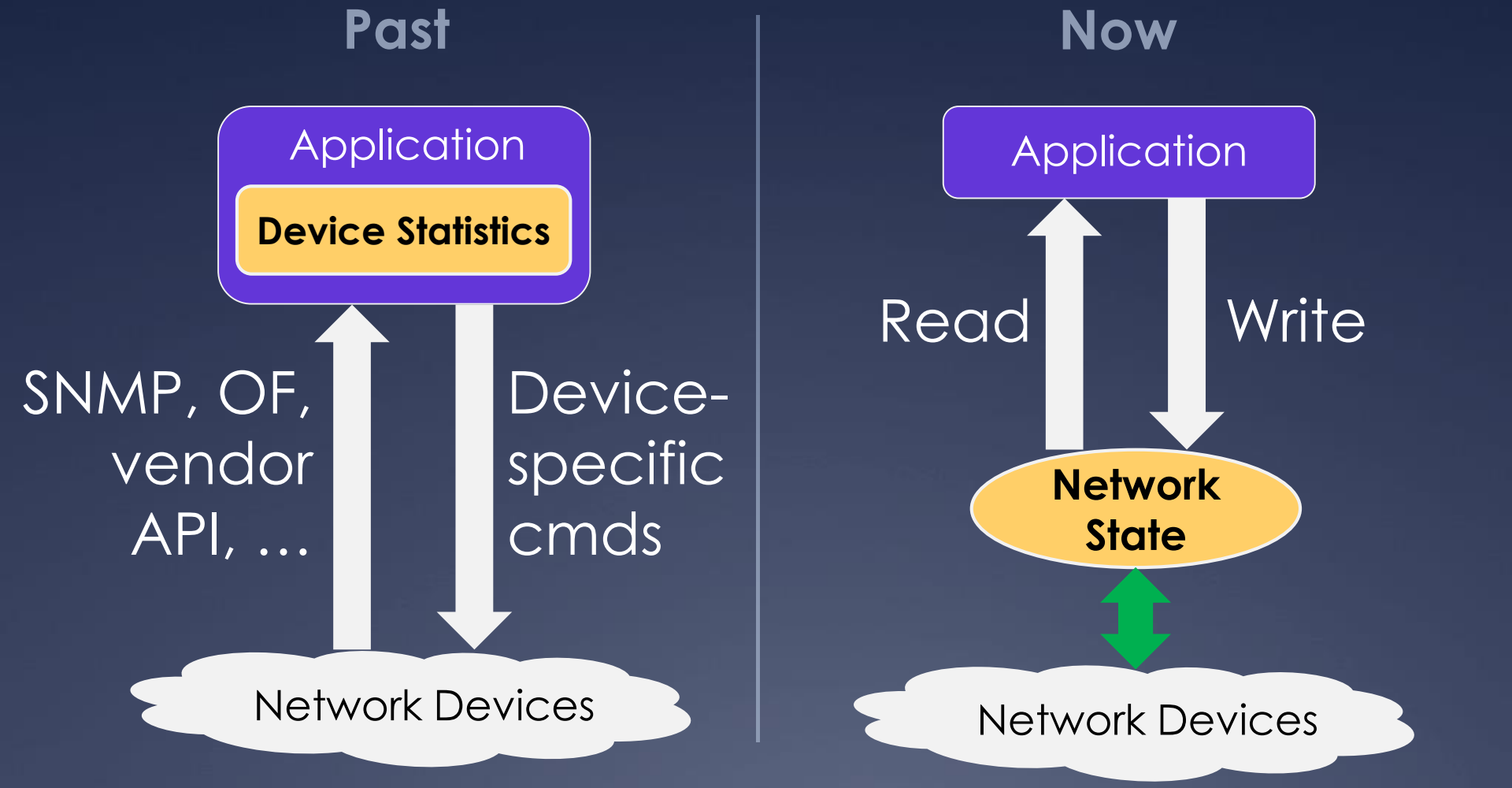
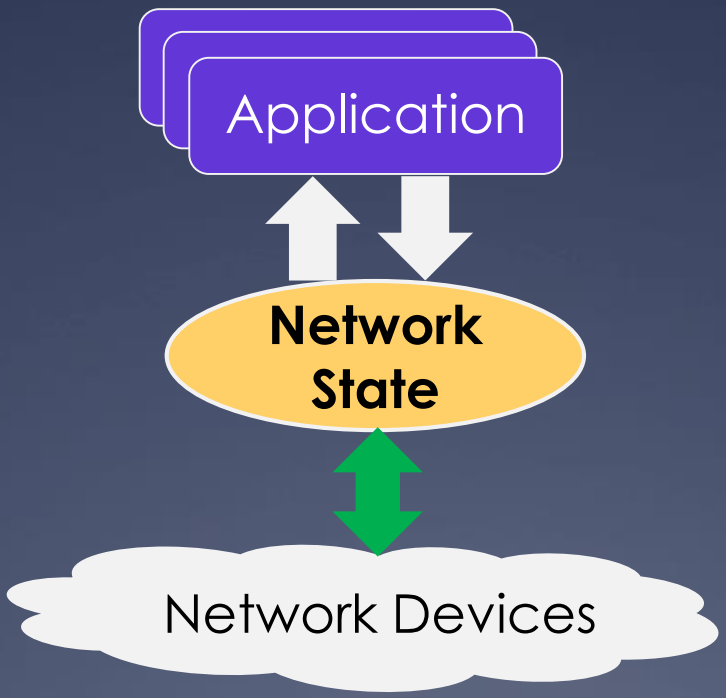
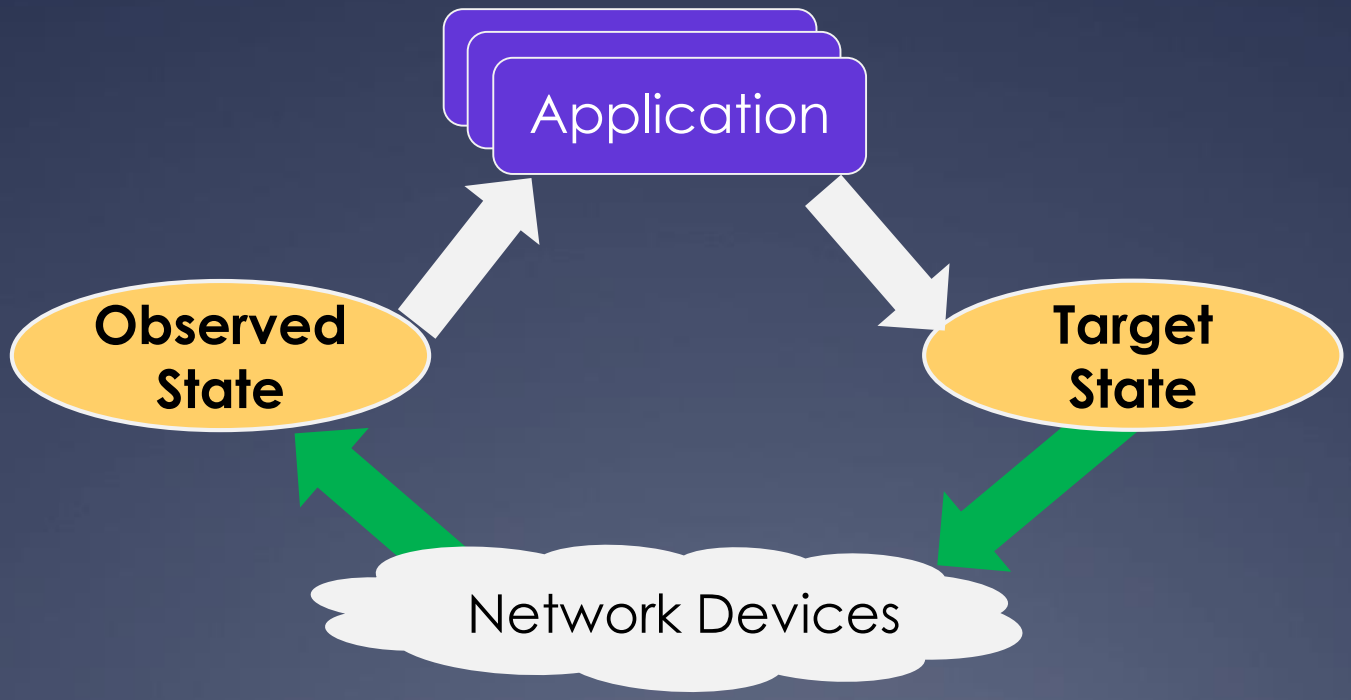


Views of Network State

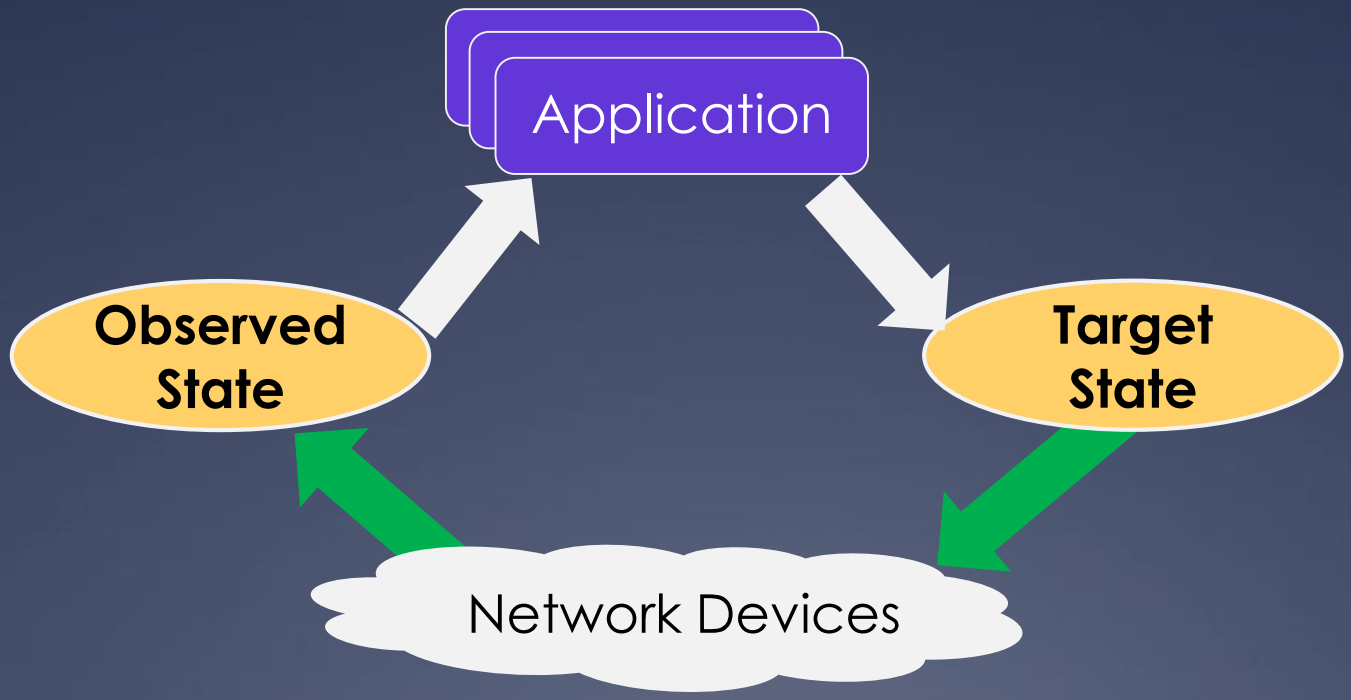


Views of Network State

Observed State	Actual state of the whole network
Target State	Desired state to be updated on the whole network



Two Views Are Not Enough



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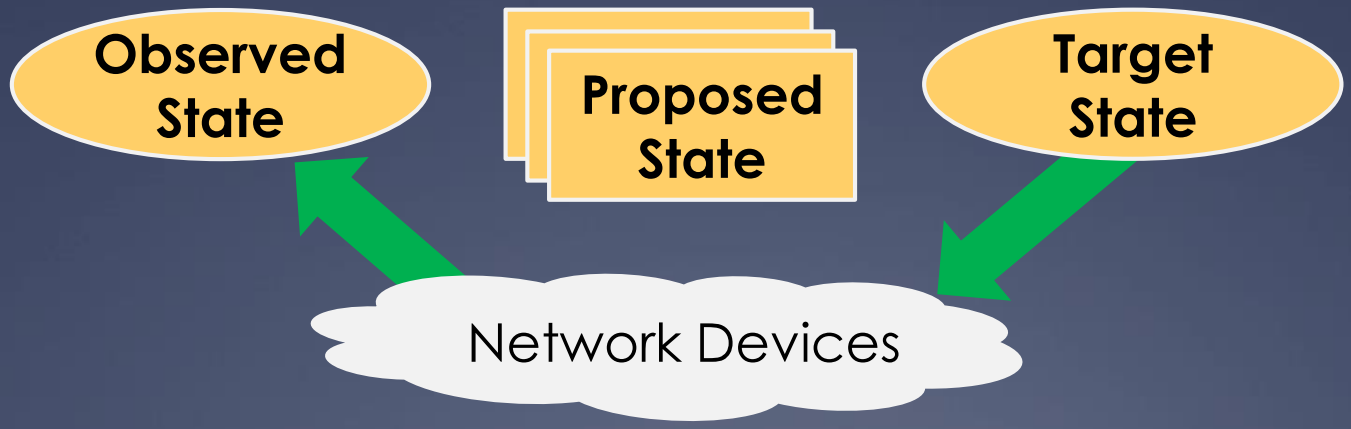
One More View	
Proposed State	A group of entity-variable-values desired by an application



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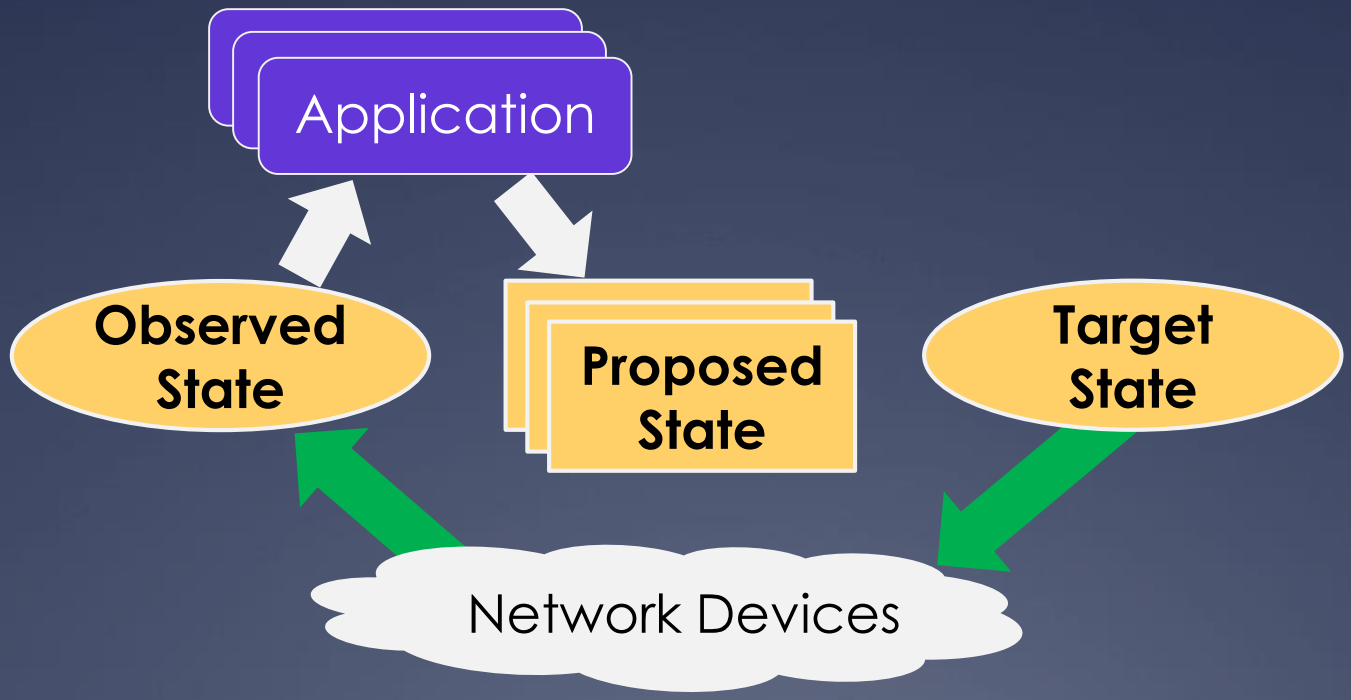

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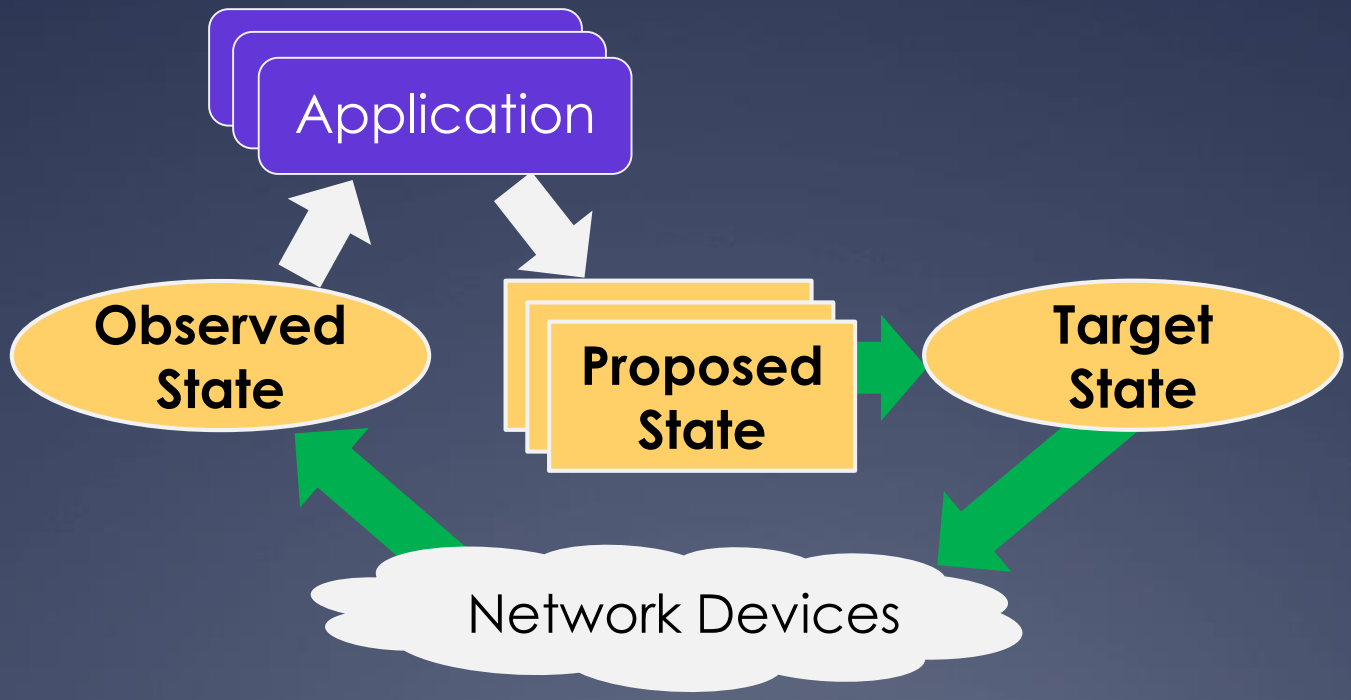

How Merging Works

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  - *Sufficient for current deployment*
- Safety invariant checking
  - Partial rejection & Skip update

Choose Safety Invariants

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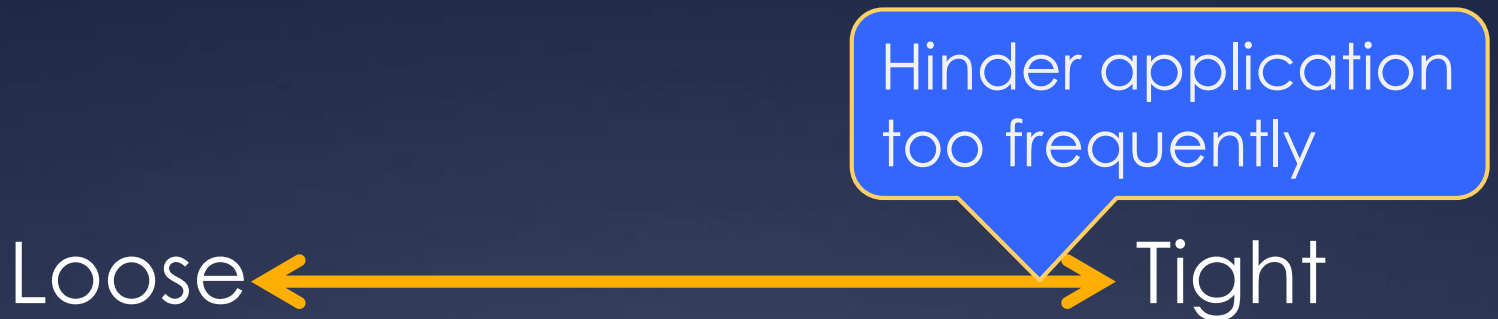

Choose Safety Invariants

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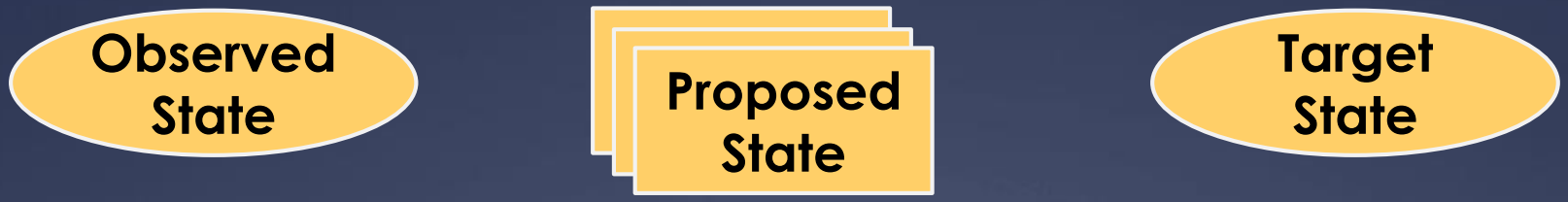
- Our current choice
  - Connectivity: Every pair of ToRs in one DC is connected
  - Capacity: 99% of ToR pairs have at least 50% capacity

Recap of Three-View Model

- Simplify network management



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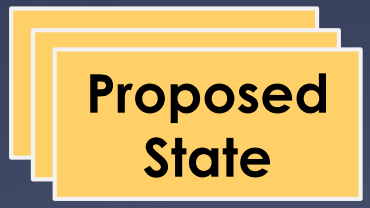

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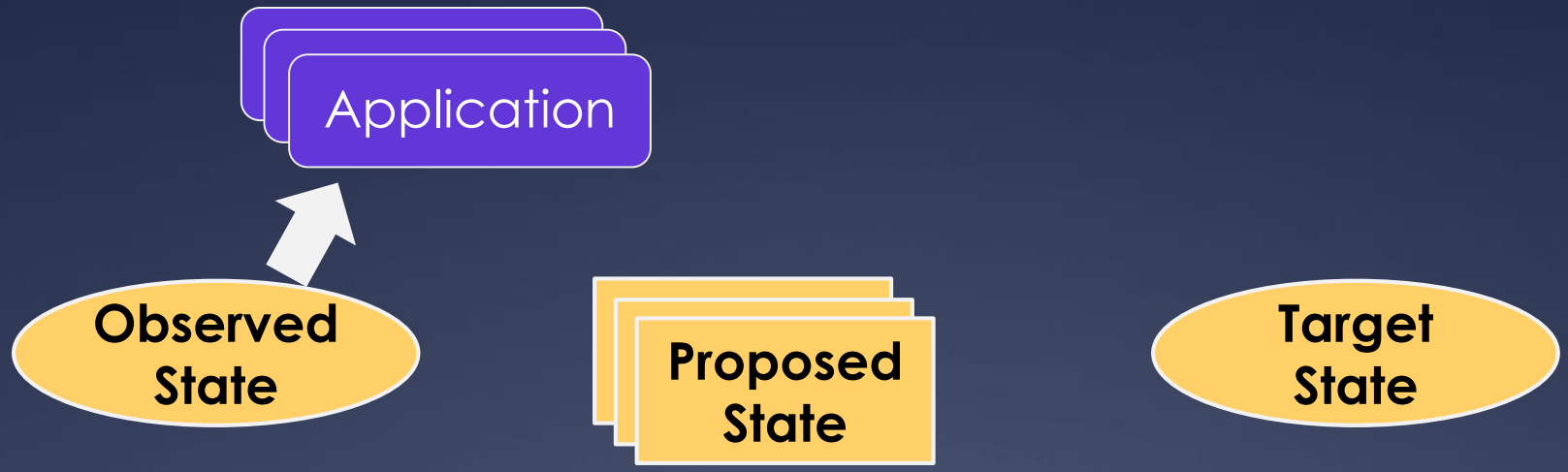

What we see from the network

Recap of Three-View Model

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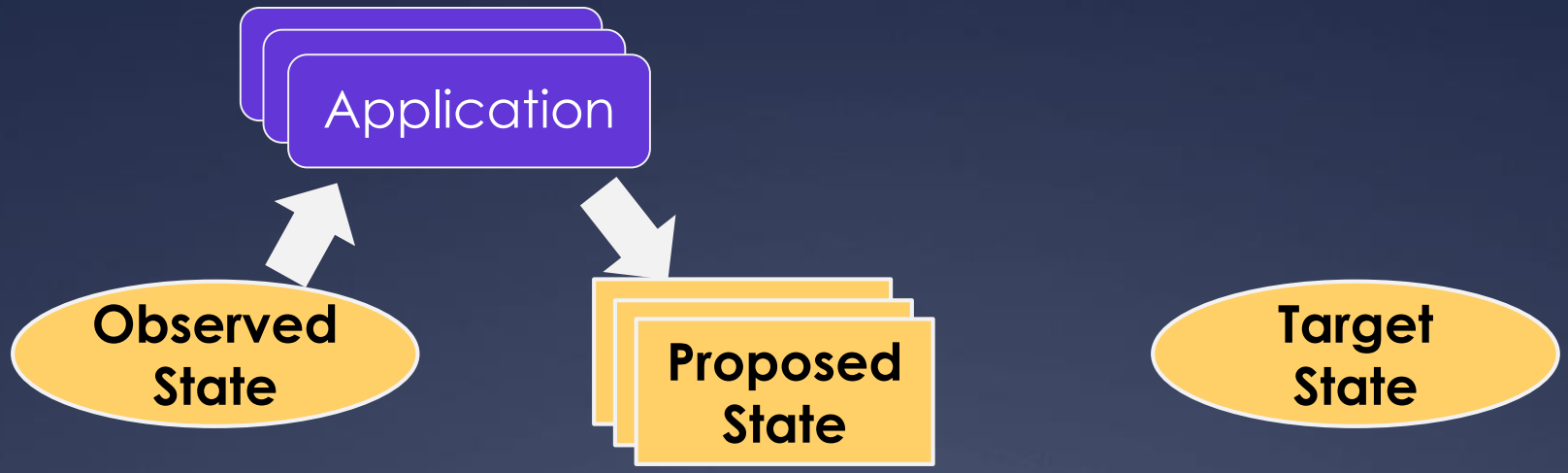

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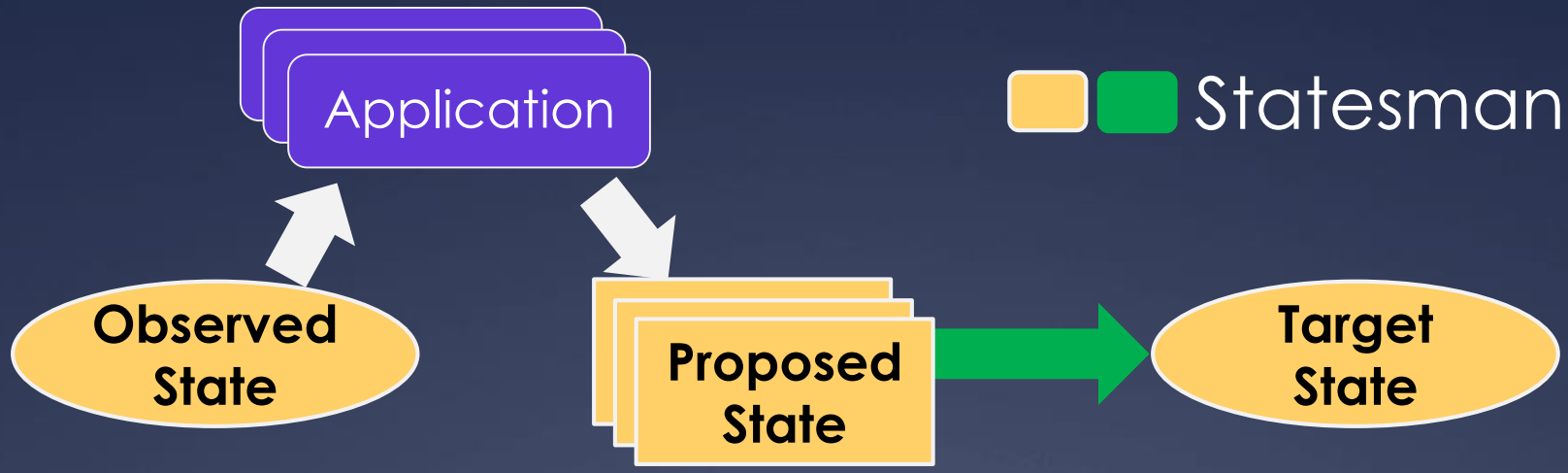

What we see from the network

What we want the network to be

What can be actually done on the network

Yet Another Problem

- What's in Proposed State
  - Small number of state variables that application cares

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- What's in Proposed State
  - Small number of state variables that application cares
- Implicit conflicts arises
  - Caused by state dependency

Implicit Conflict

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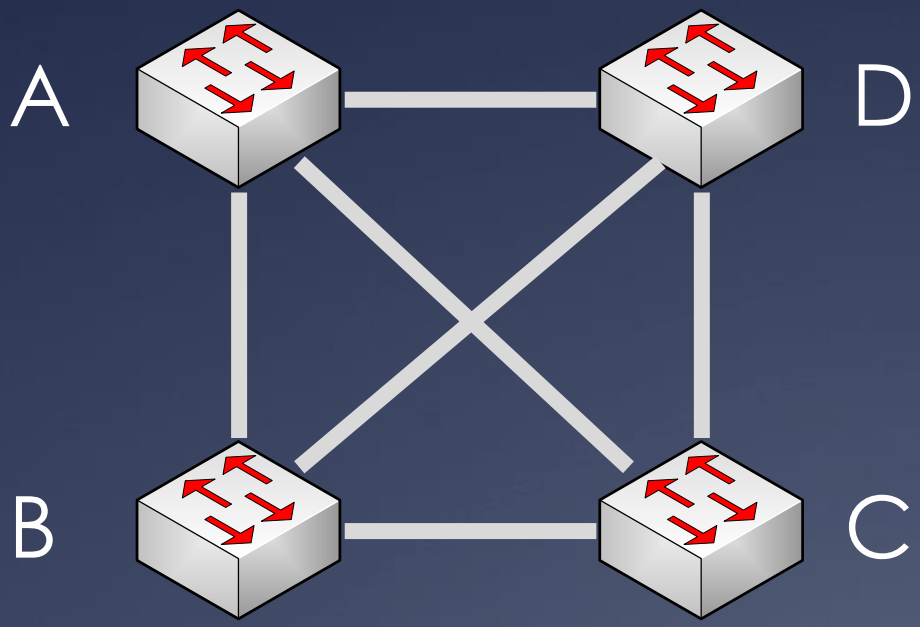

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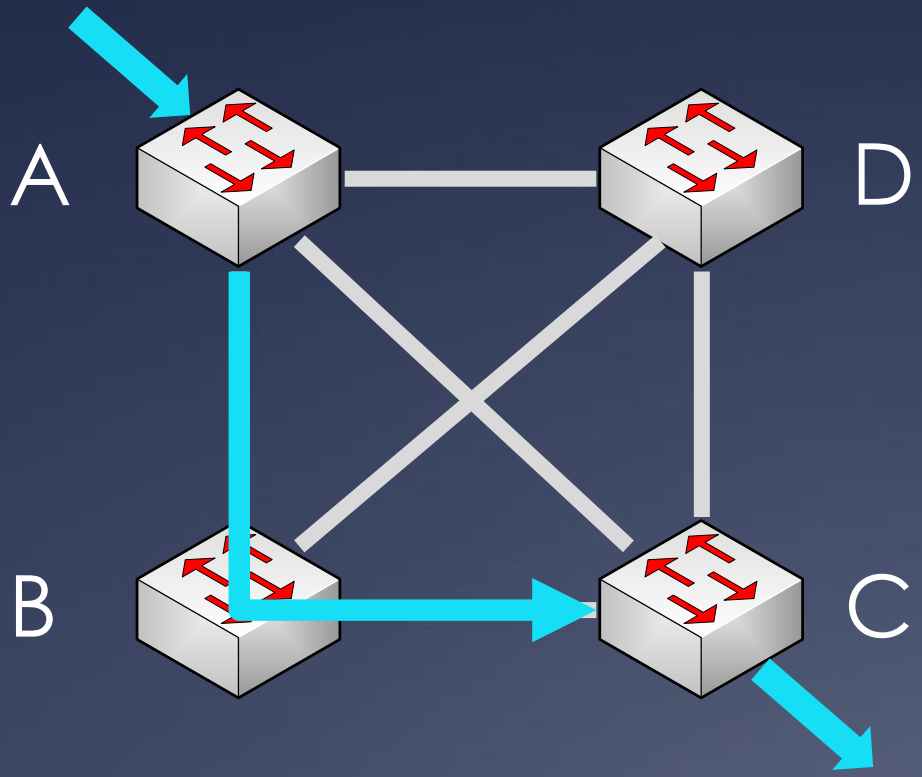

TE writes new value of routing state of B for tunneling traffic

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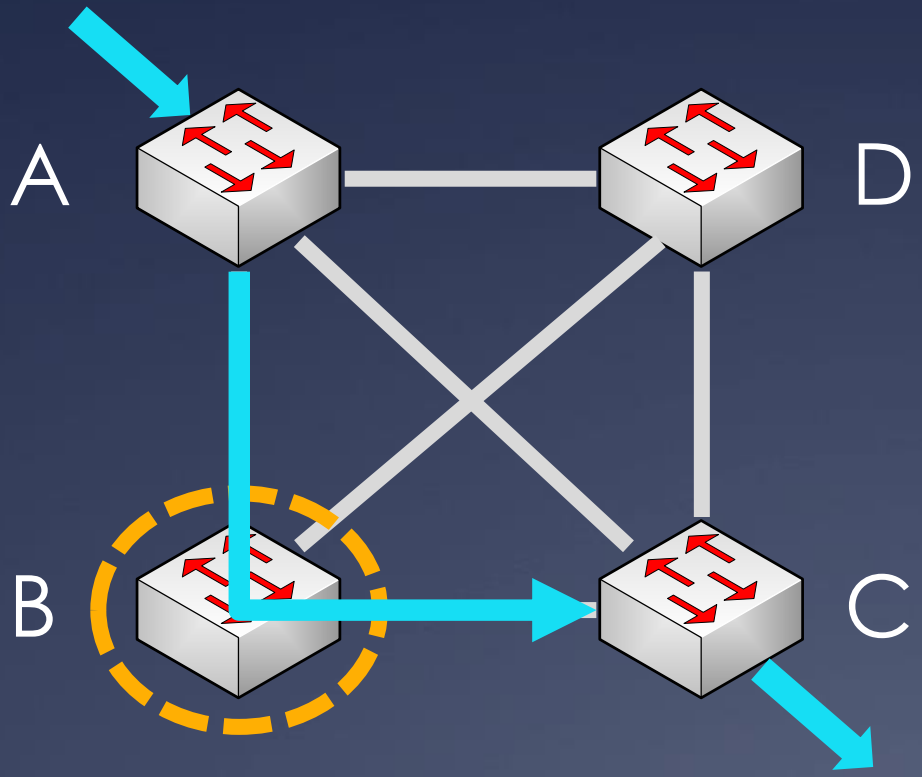

TE writes new value of routing state of B for tunneling traffic

Firmware-upgrade writes new value of firmware state of B

Dependency Relations

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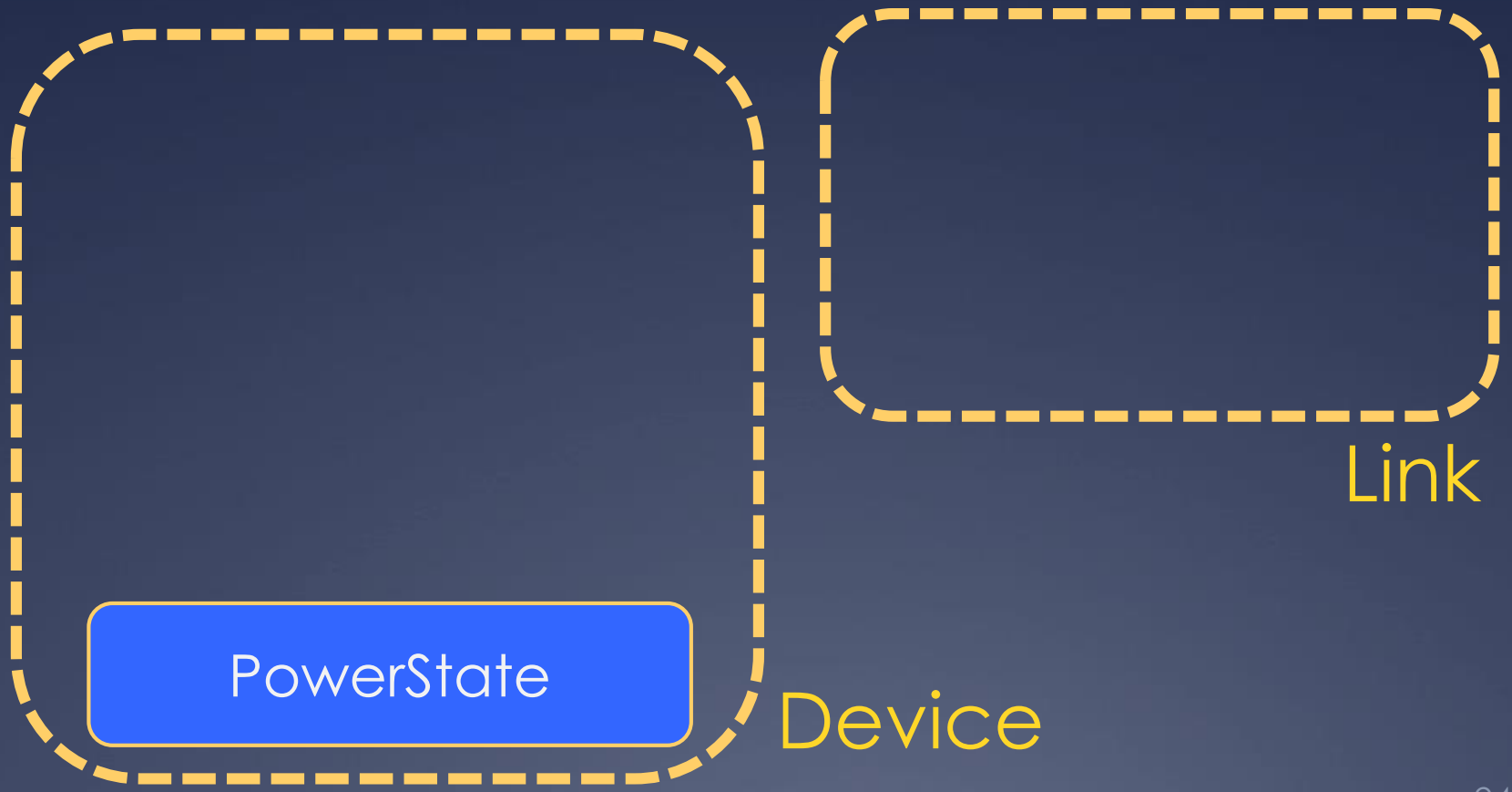

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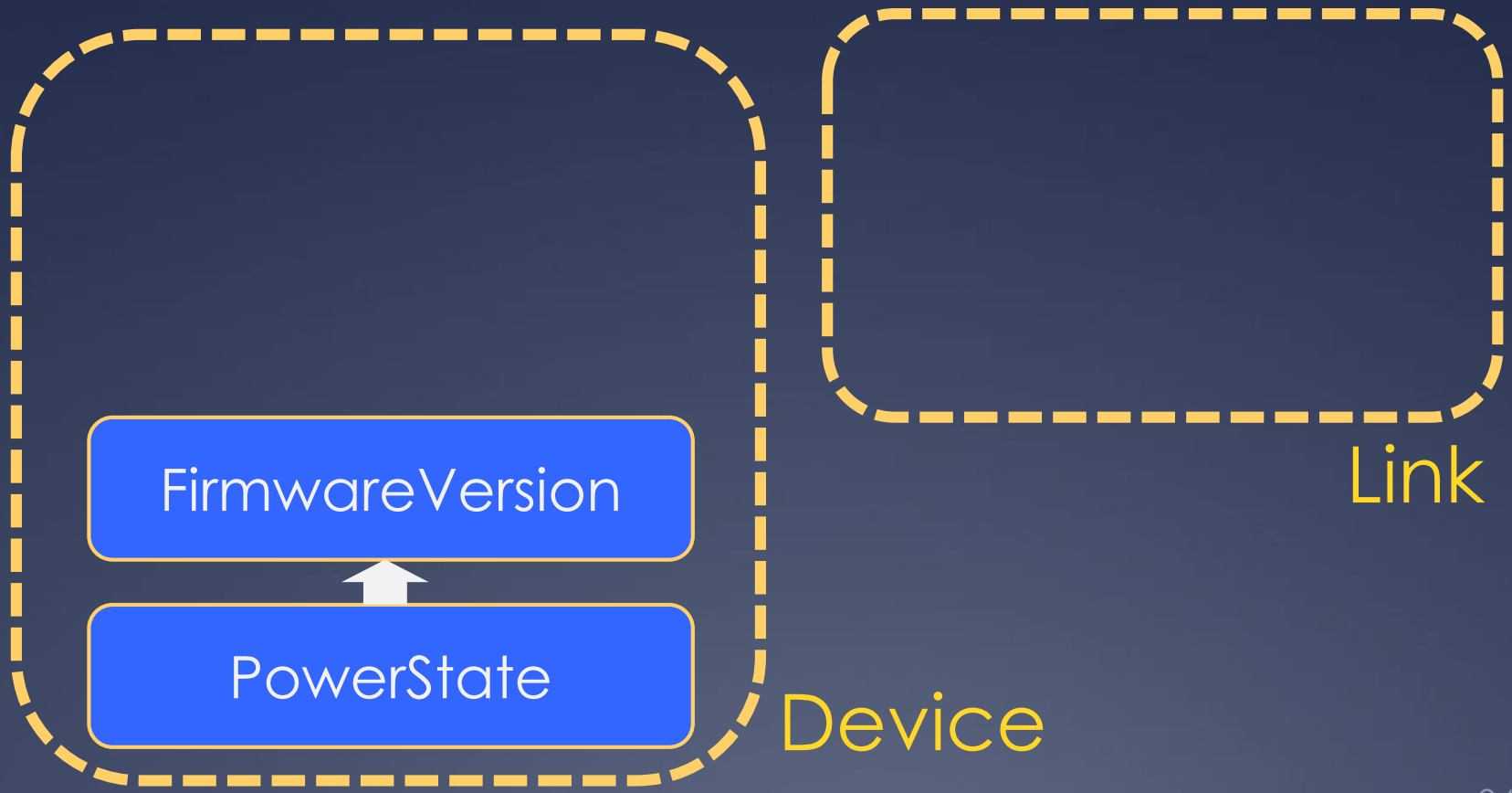

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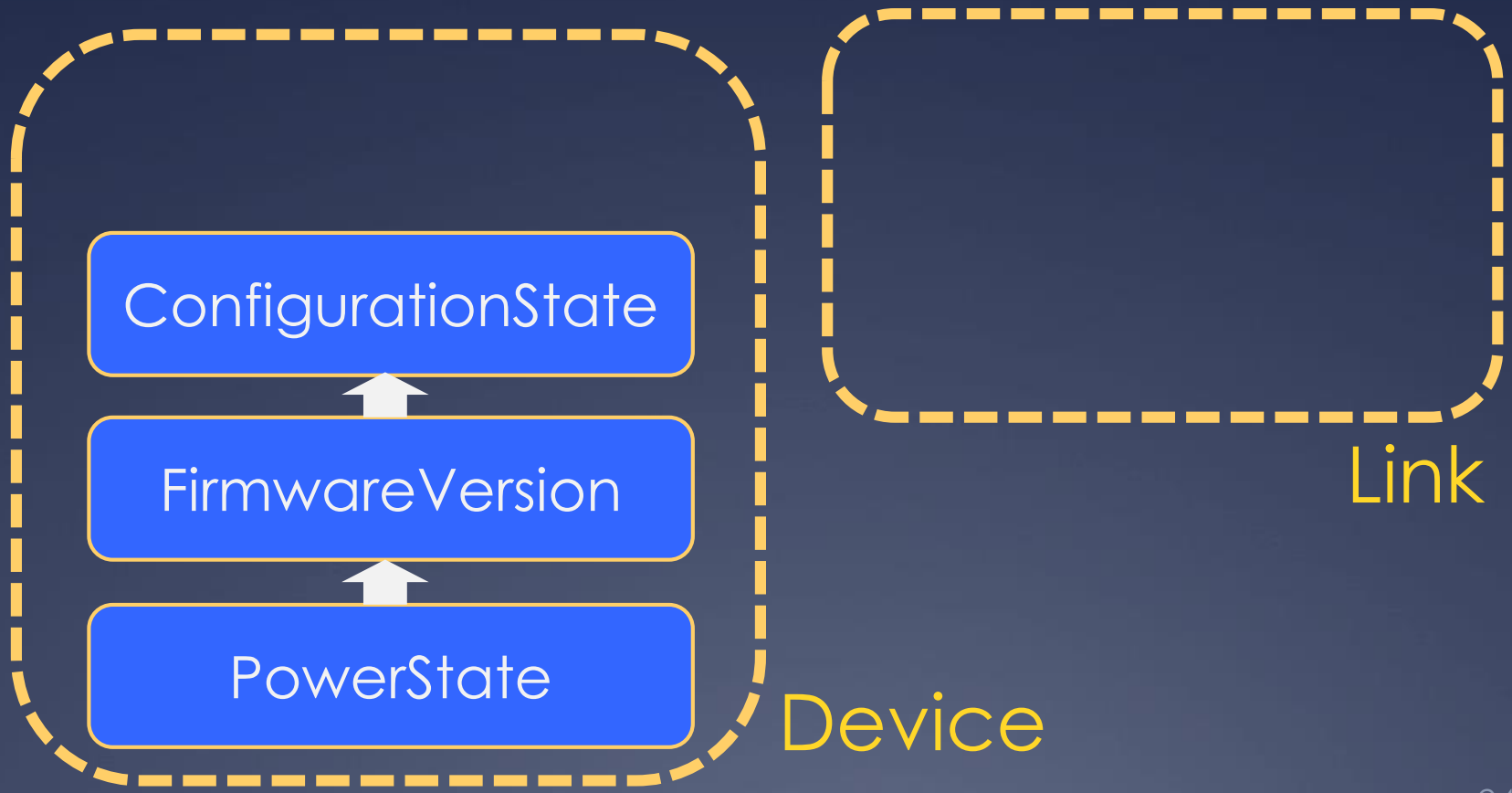

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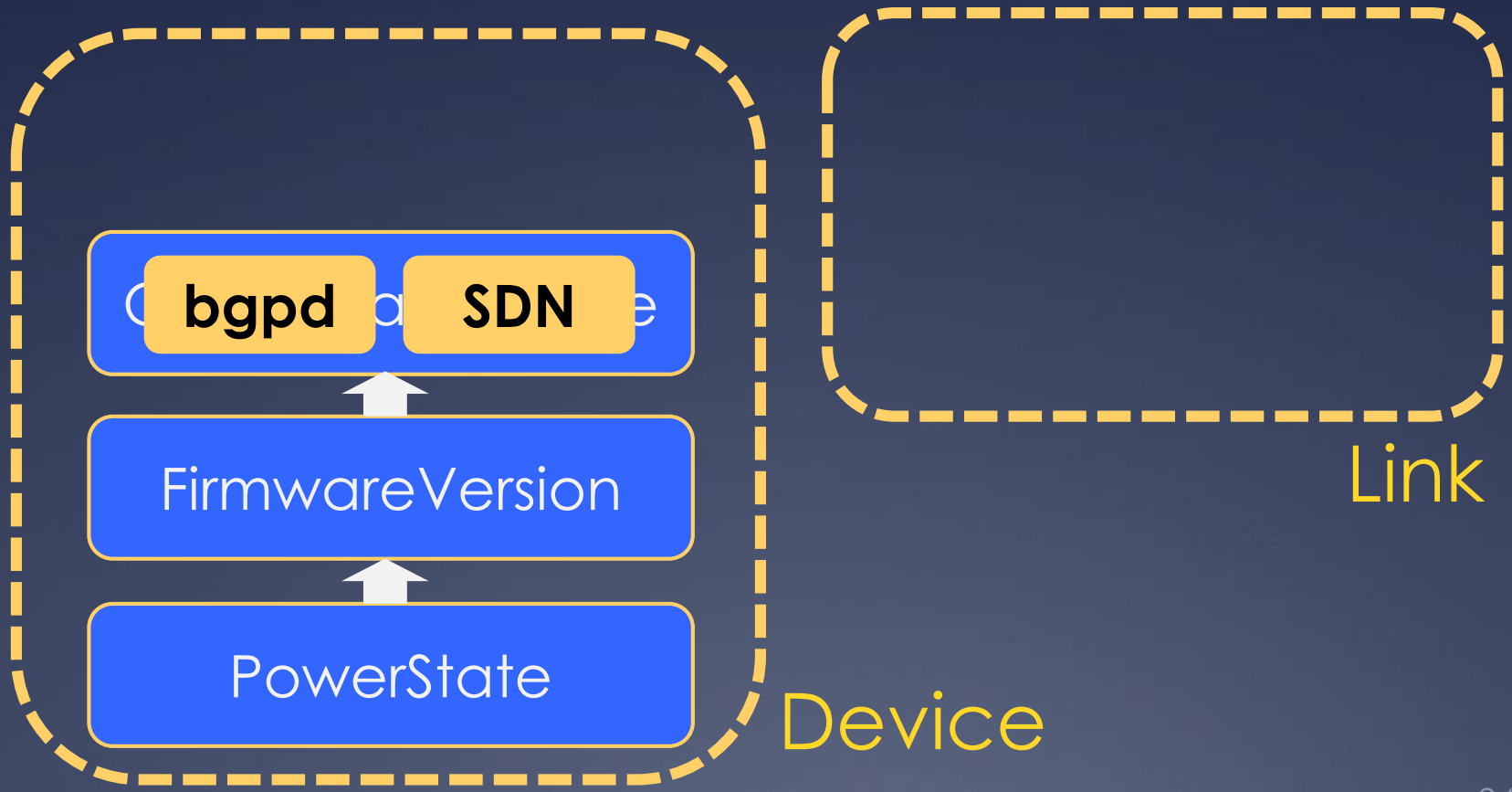

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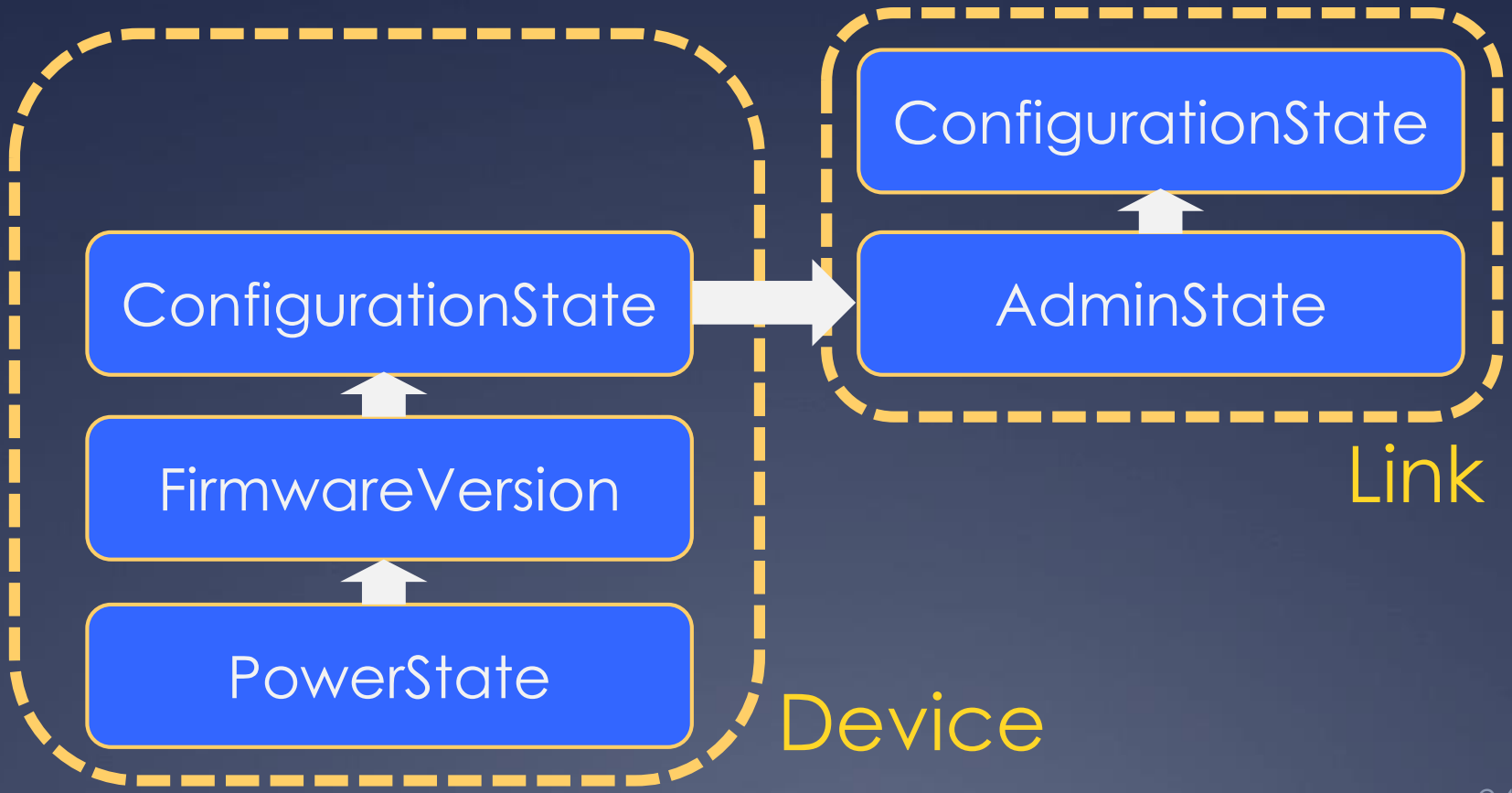

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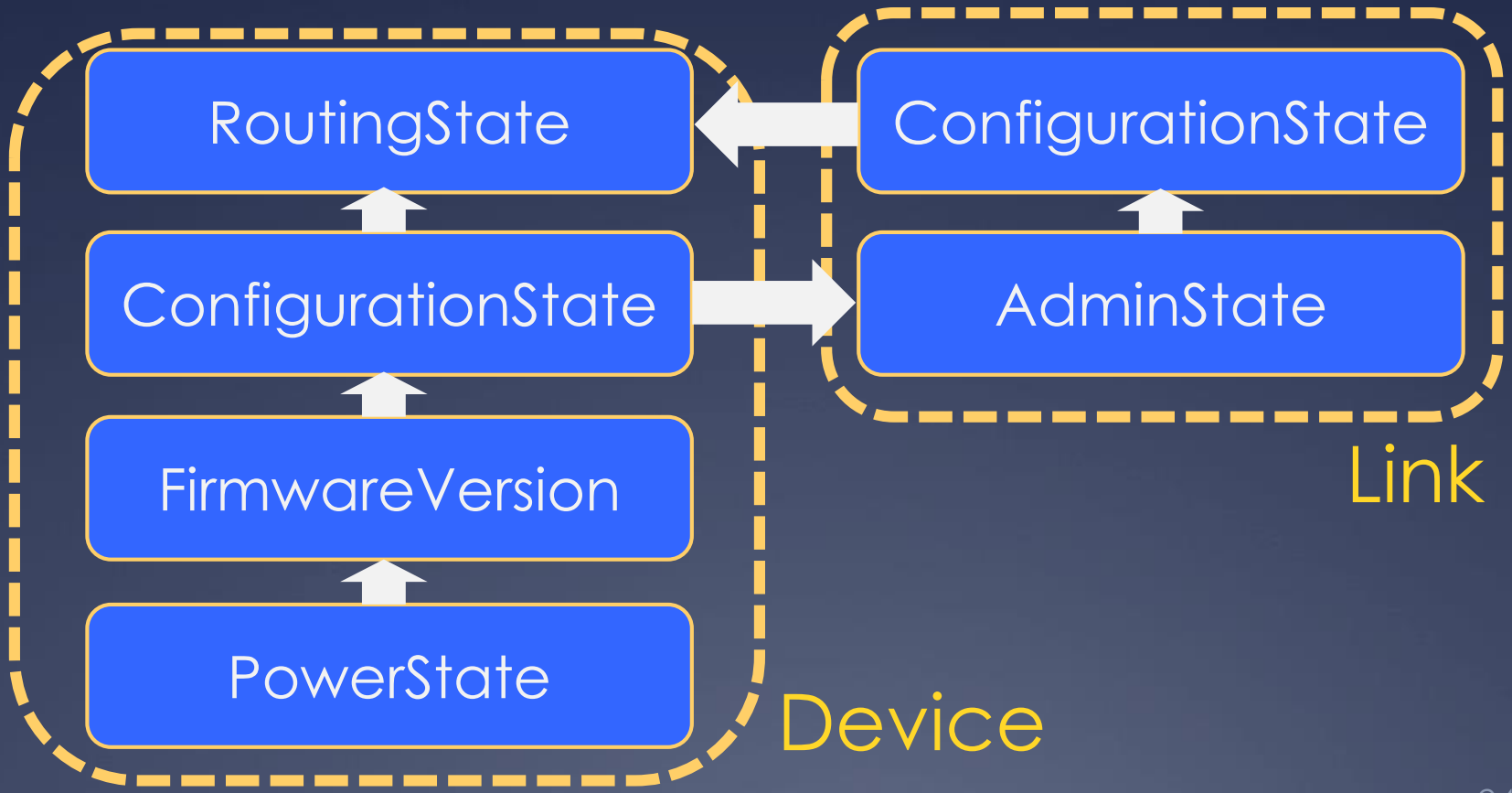

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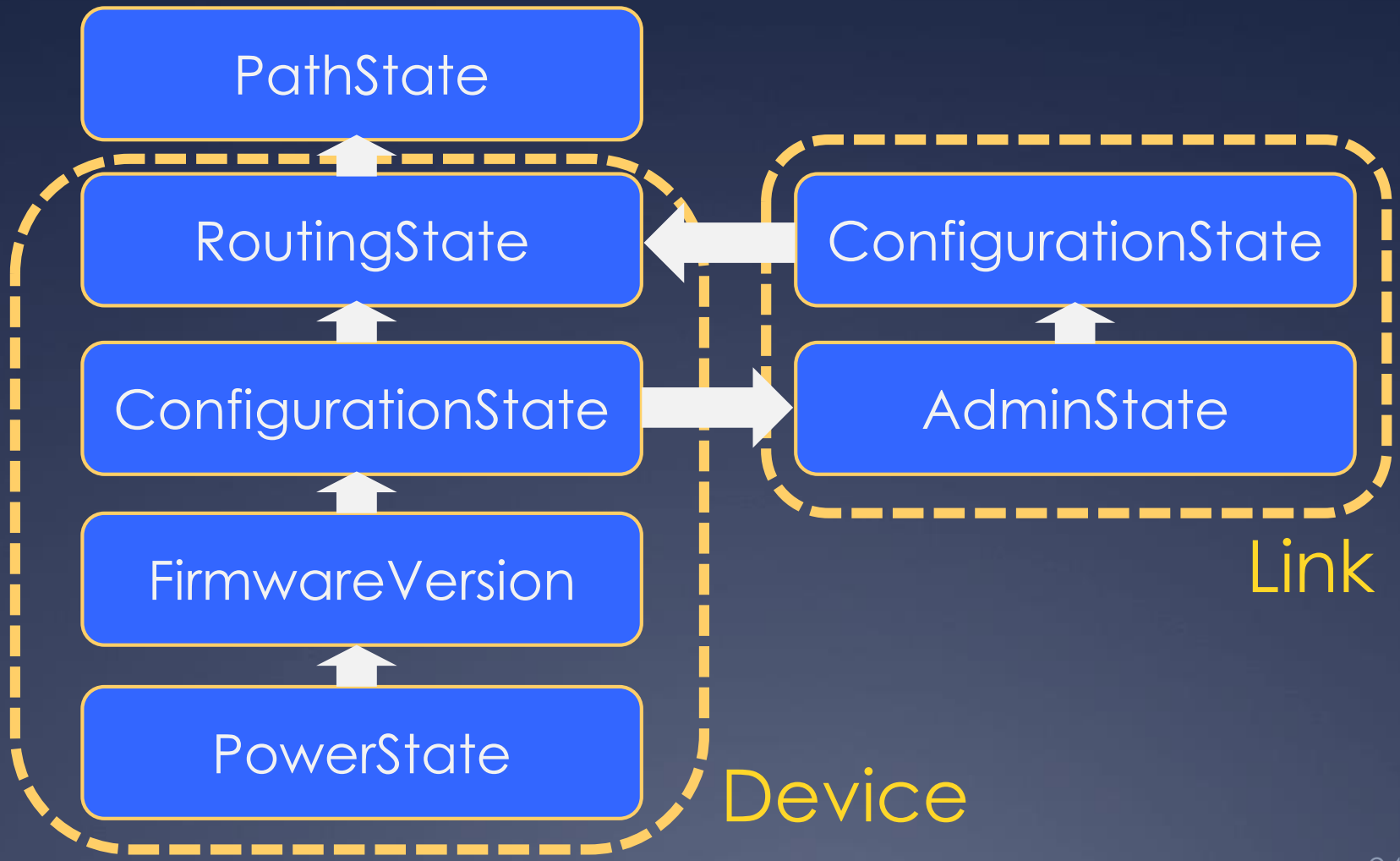


Build in Dependency Model

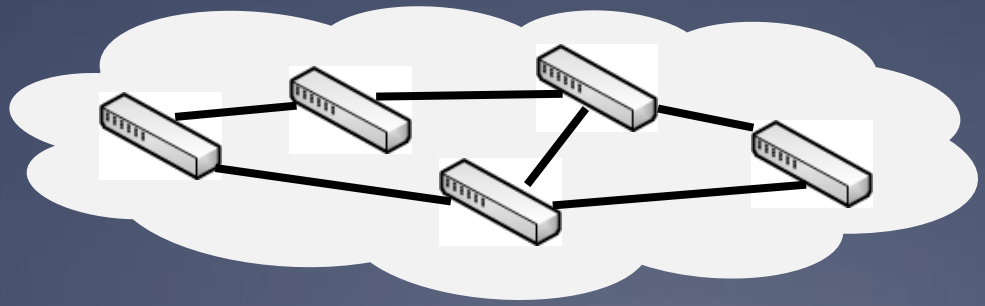
- Statesman calculates it internally
- Only exposes the result for each state variable
  - Whether the variable is controllable

Statesman System

Observed State

Proposed State

Target State



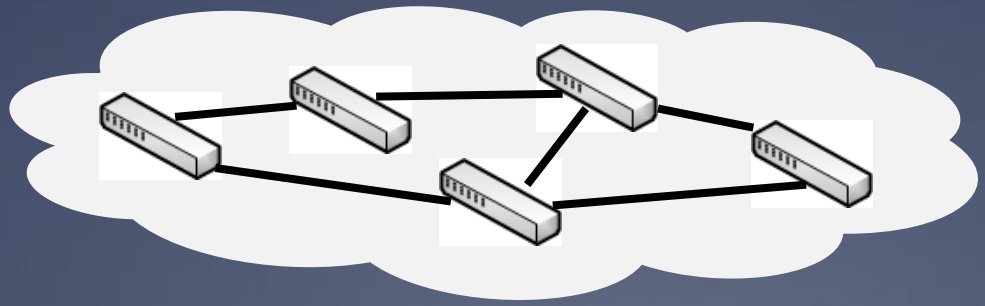
Statesman System

Storage Service

Observed State

Proposed State

Target State



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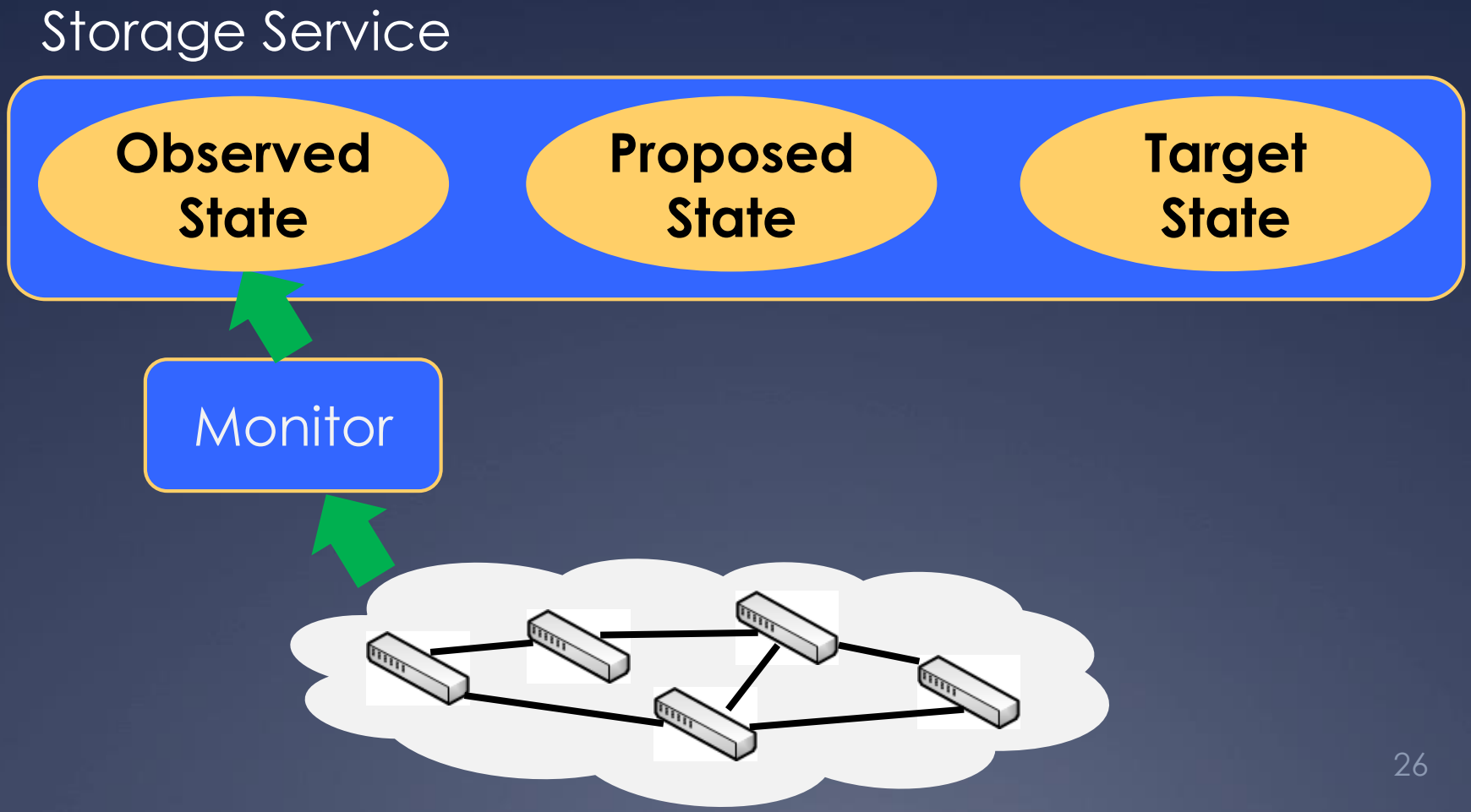

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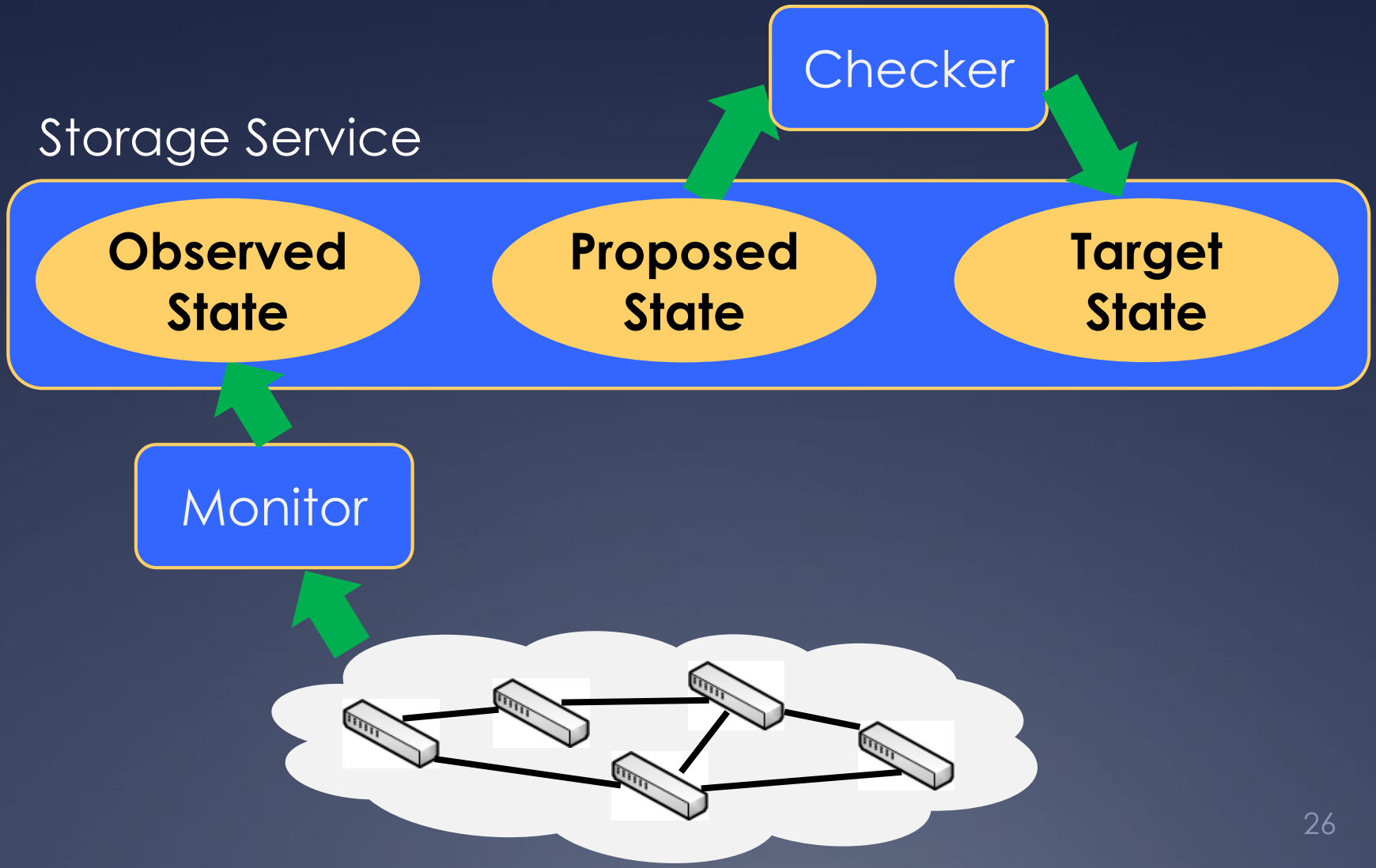

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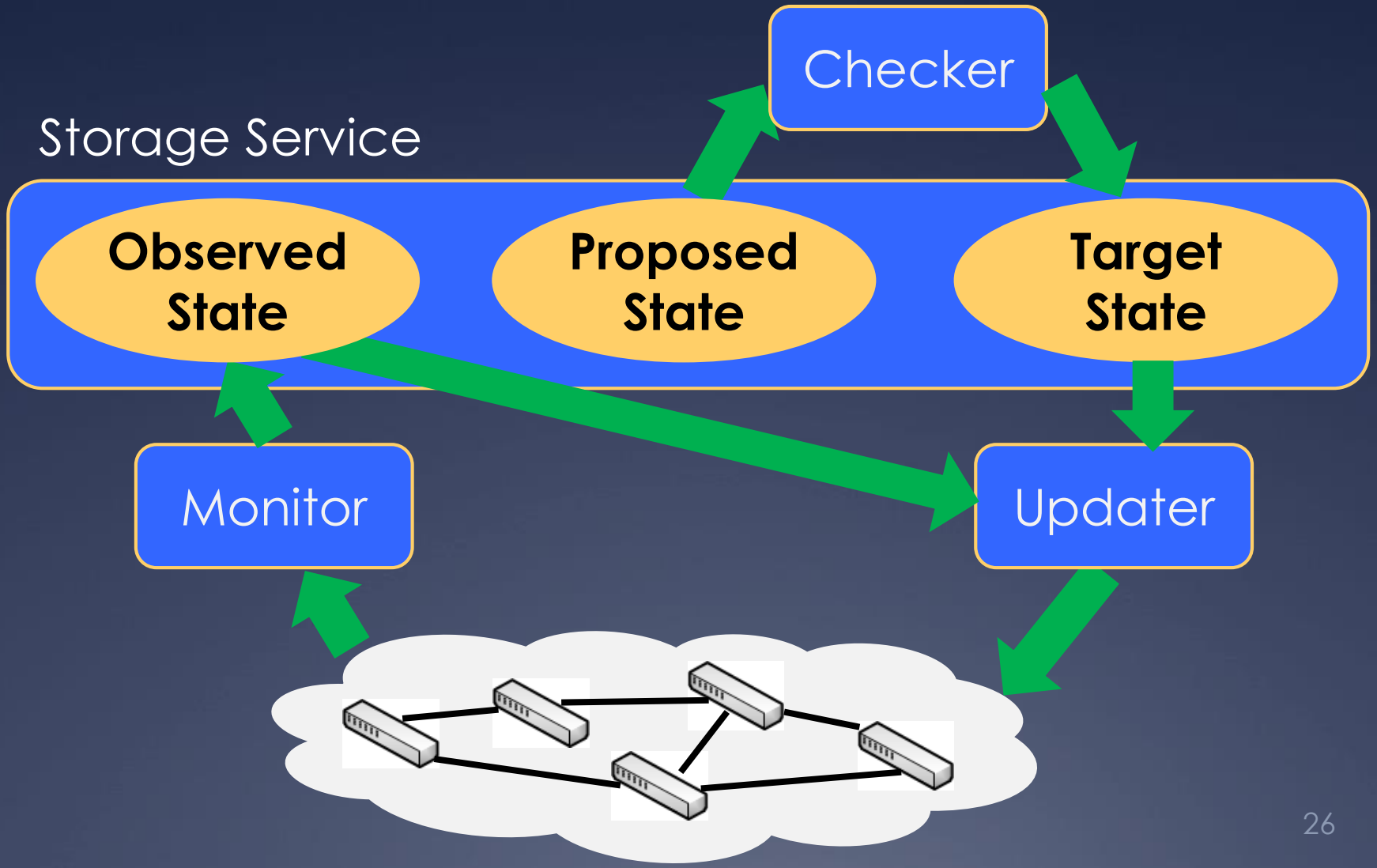

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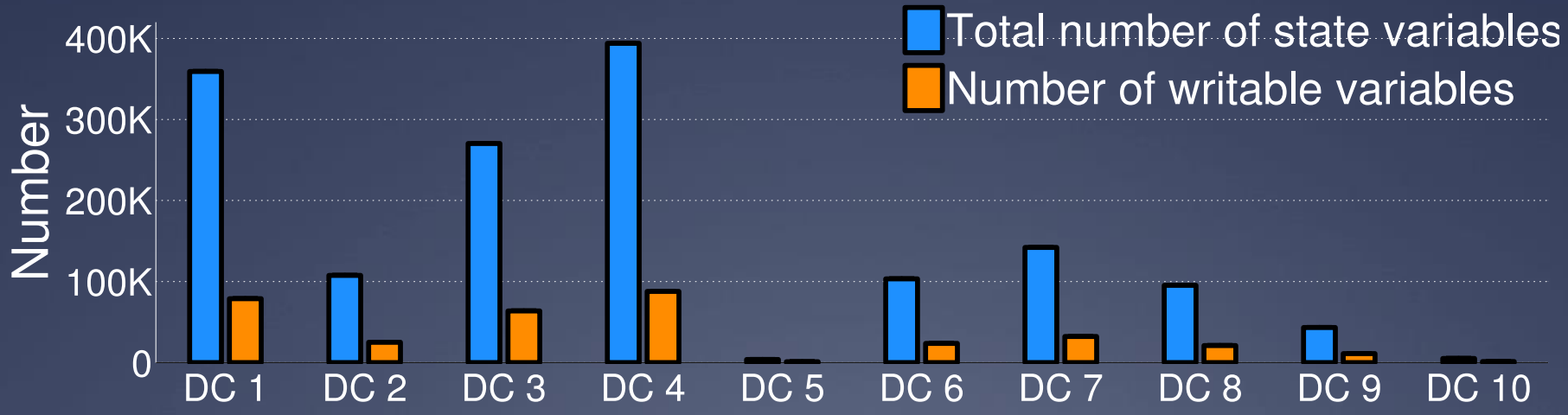

Production Applications

- 3 diverse applications built
  - Device firmware upgrade
  - Link corruption mitigation
  - Traffic engineering

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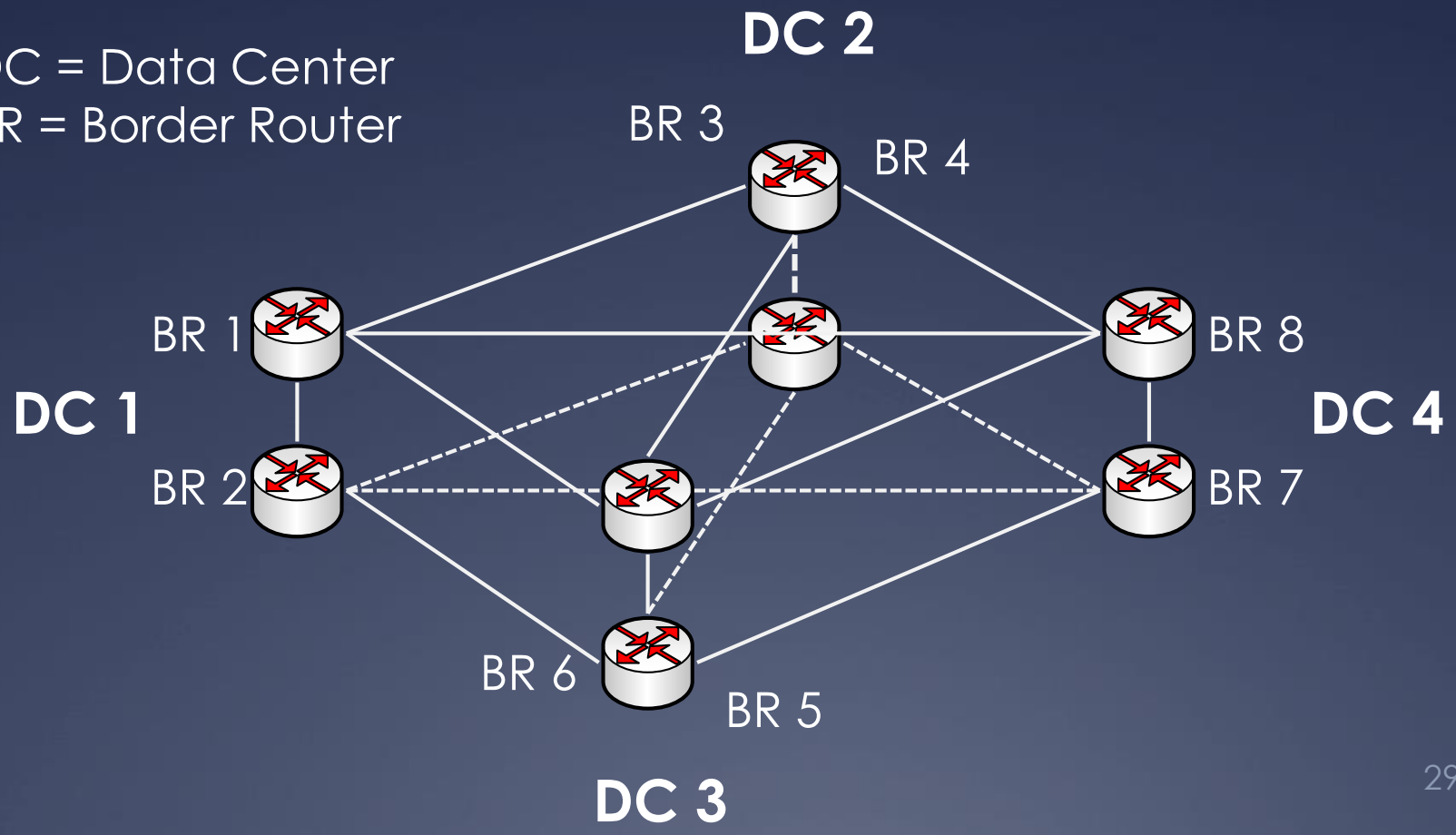
  - Link corruption mitigation
  - Traffic engineering
- Finish within months
- Only thousands of lines of code

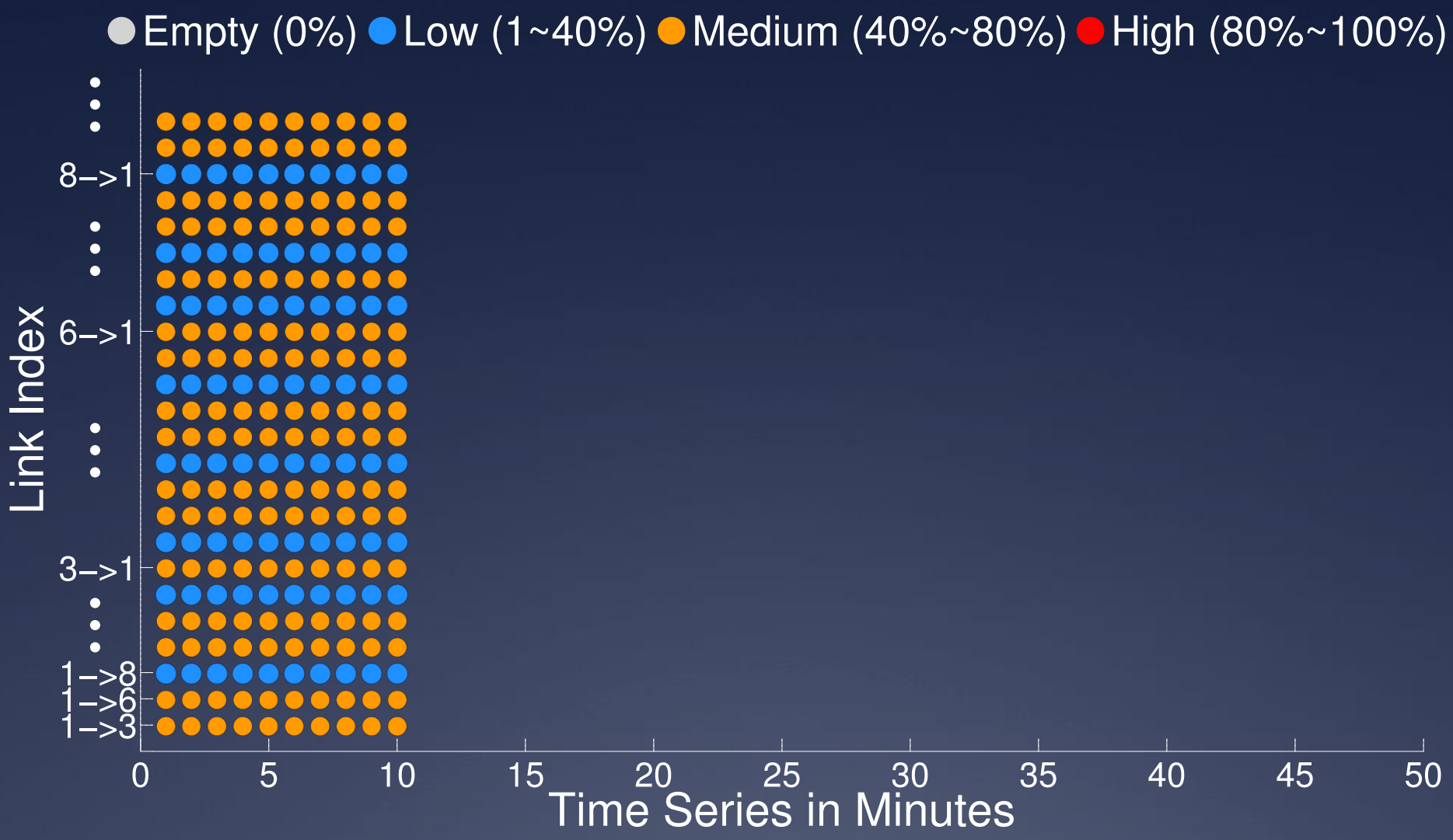
Case #1: Resolve Conflict

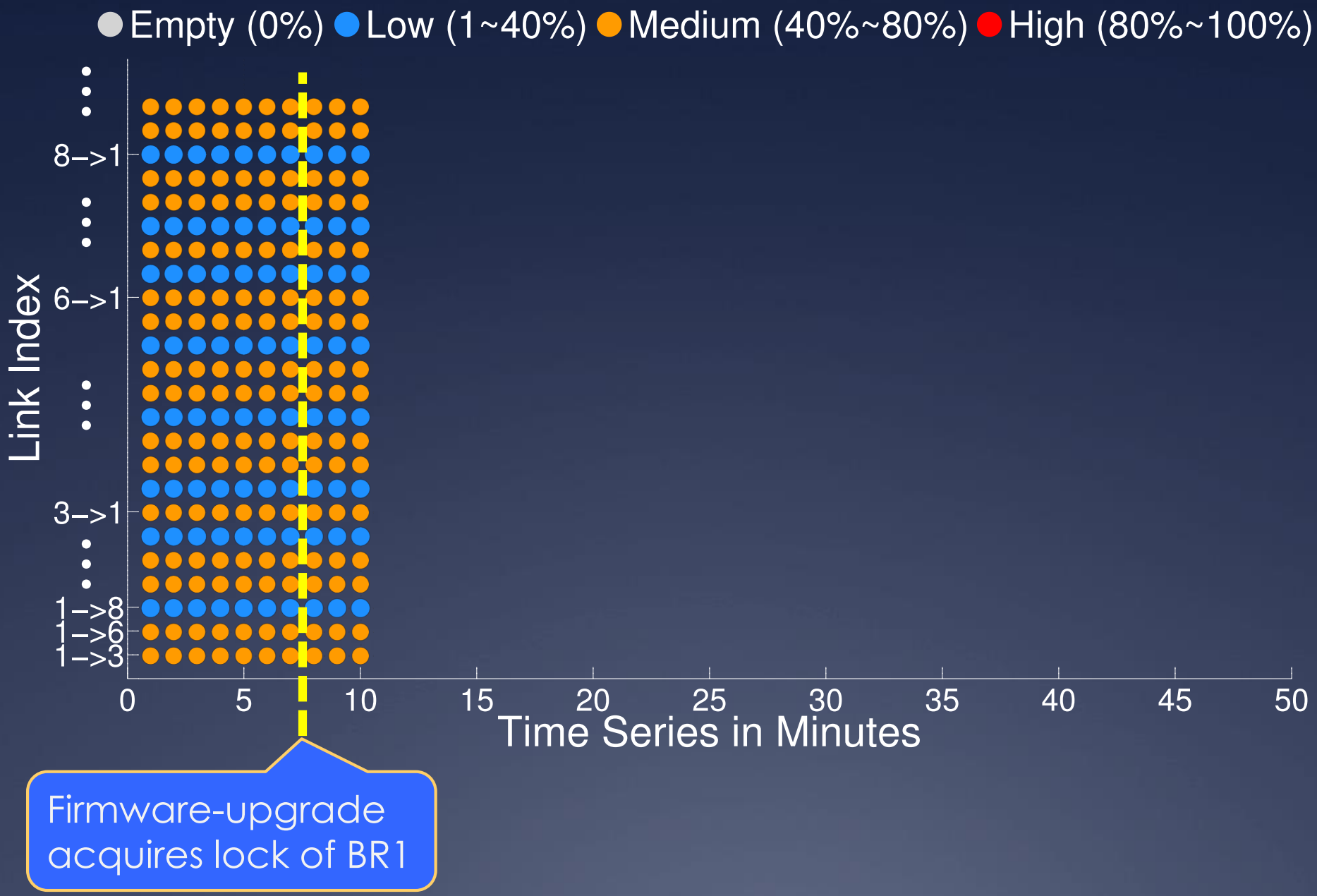
Inter-DC TE & Firmware-upgrade

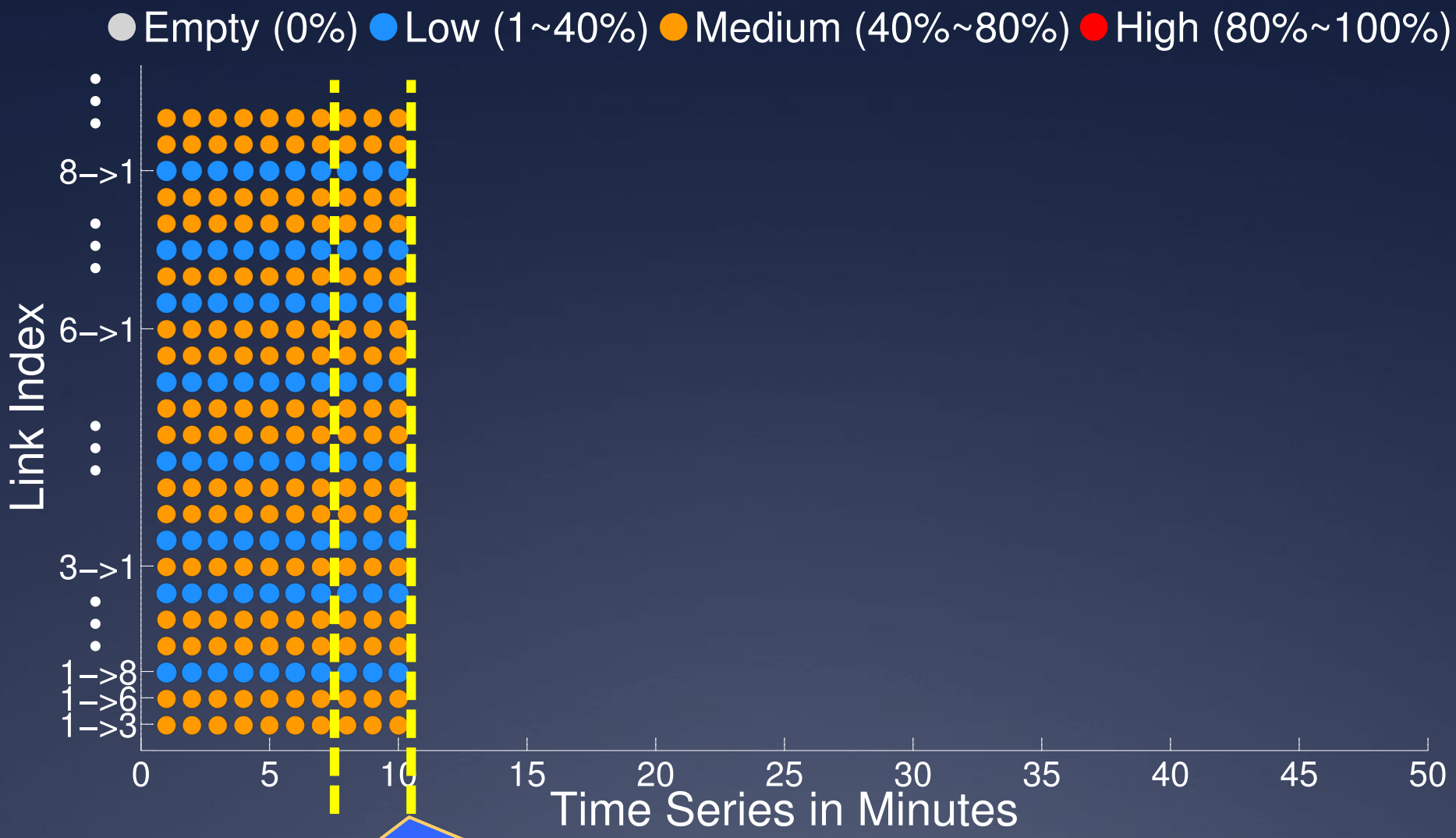
DC = Data Center
BR = Border Router




Empty (0%)
Low (1~40%)
Medium (40%~80%)
High (80%~100%)
Link Index
8–>1
6–>1
3–>1
1–>8
1–>6
1–>3
0
5
10
15
20
25
30
35
40
45
50
Time Series in Minutes

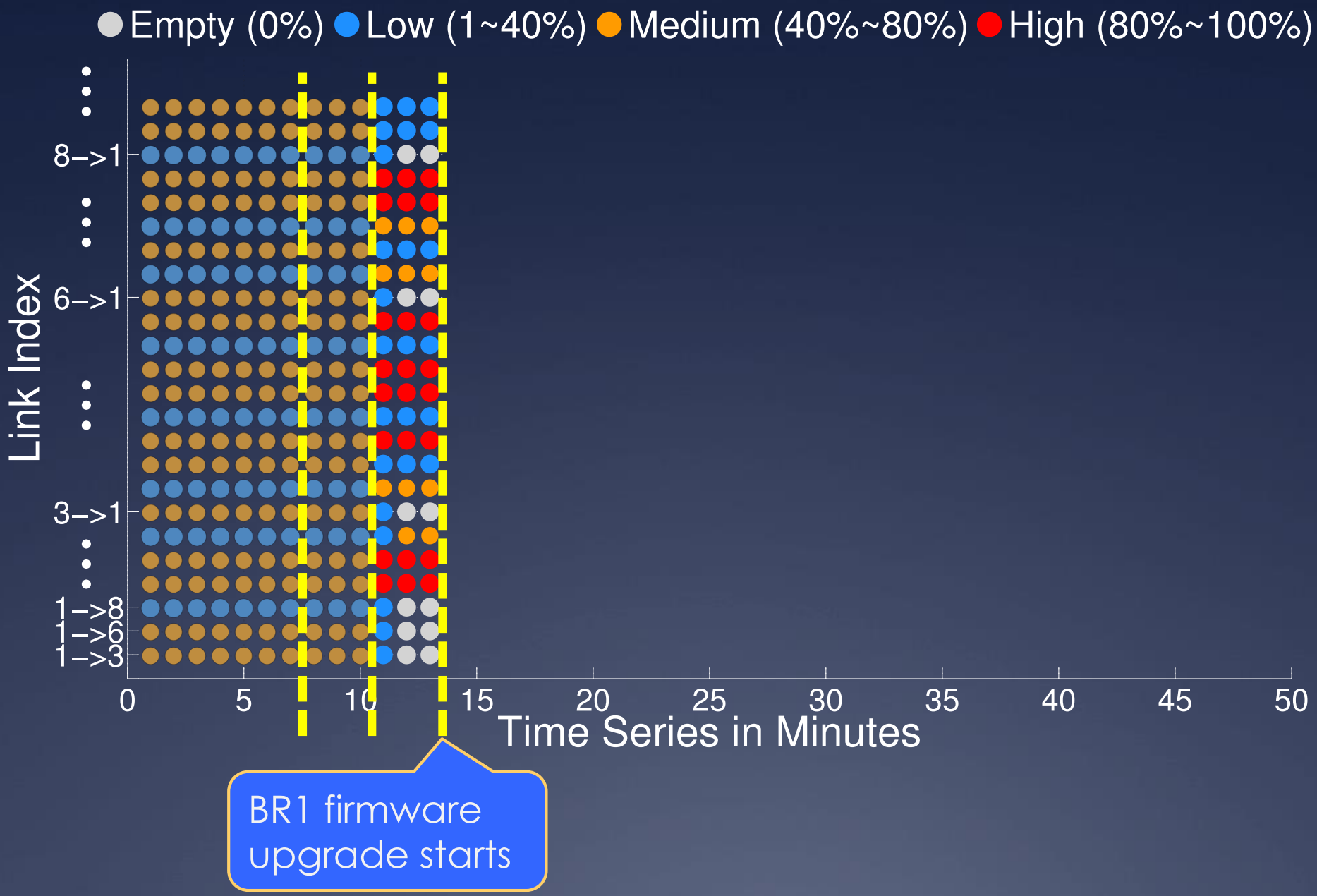

Empty (0%)
Low (1~40%)
Medium (40%~80%)
High (80%~100%)
Link Index
8–>1
6–>1
3–>1
1–>8
1–>6
1–>3
0
5
10
15
20
25
30
35
40
45
50
Time Series in Minutes

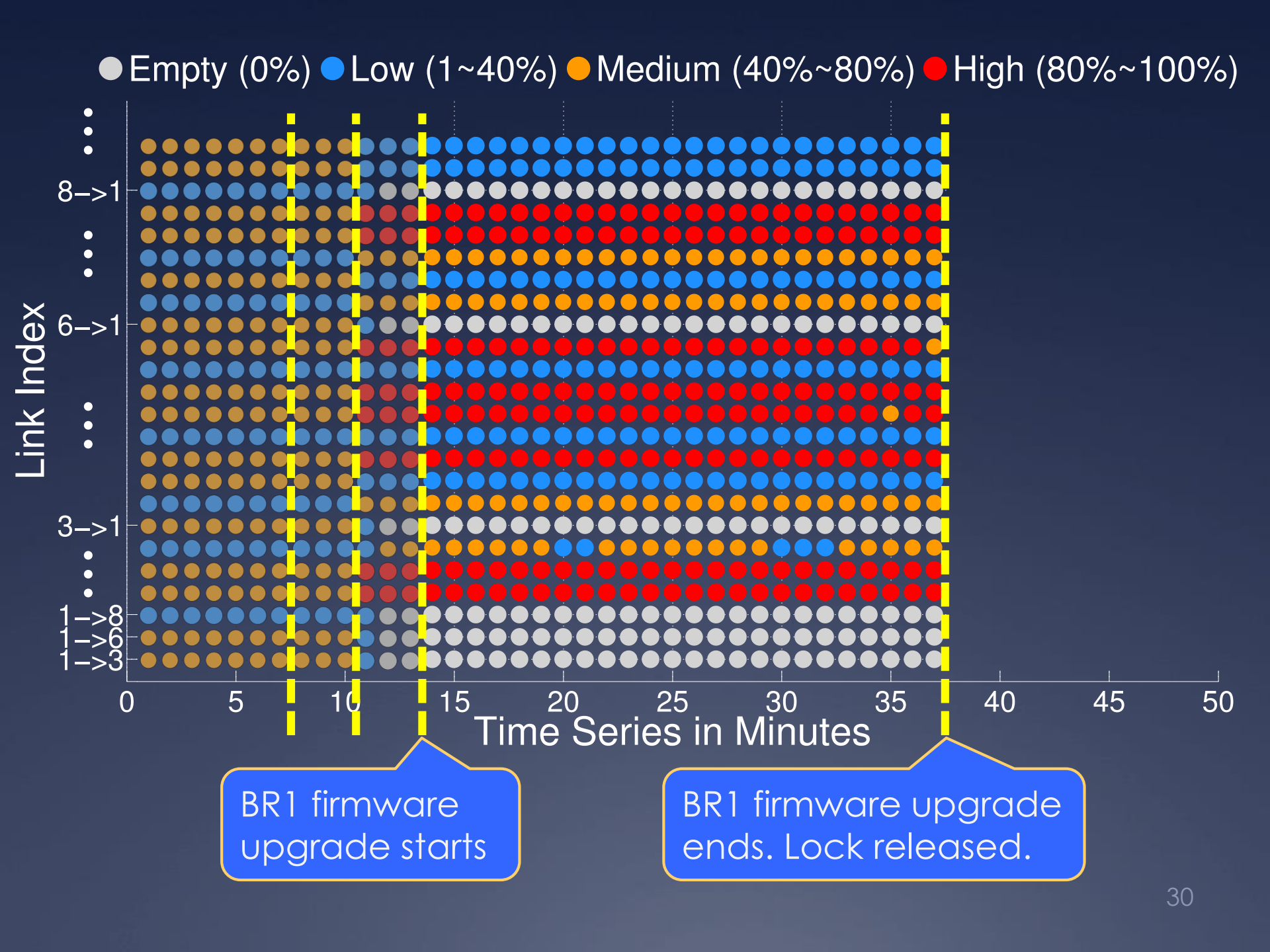

Empty (0%)
Low (1~40%)
Medium (40%~80%)
High (80%~100%)
Link Index
8–>1
6–>1
3–>1
1–>8
1–>6
1–>3
0
5
10
15
20
25
30
35
40
45
50
Time Series in Minutes
Firmware-upgrade acquires lock of BR1

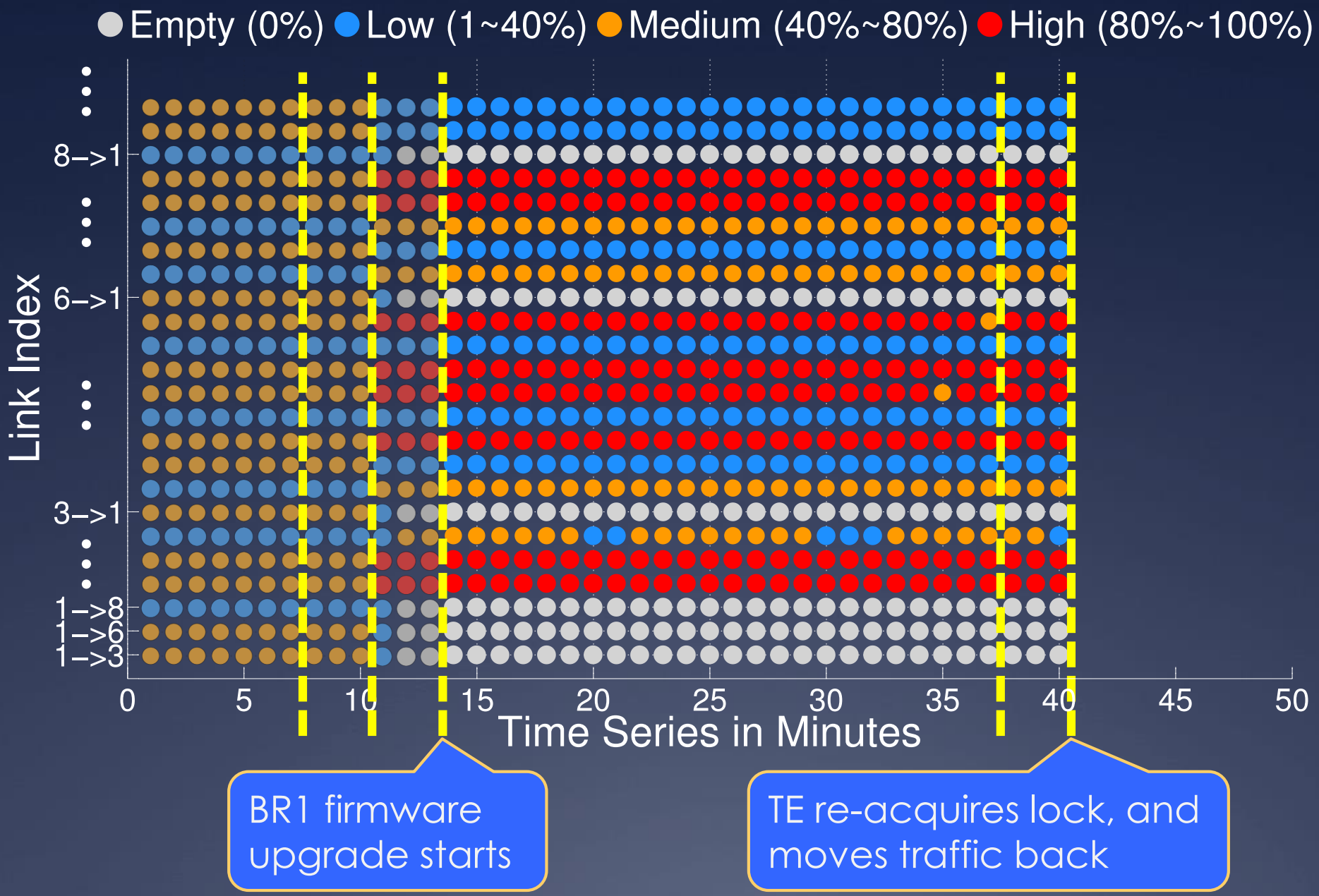


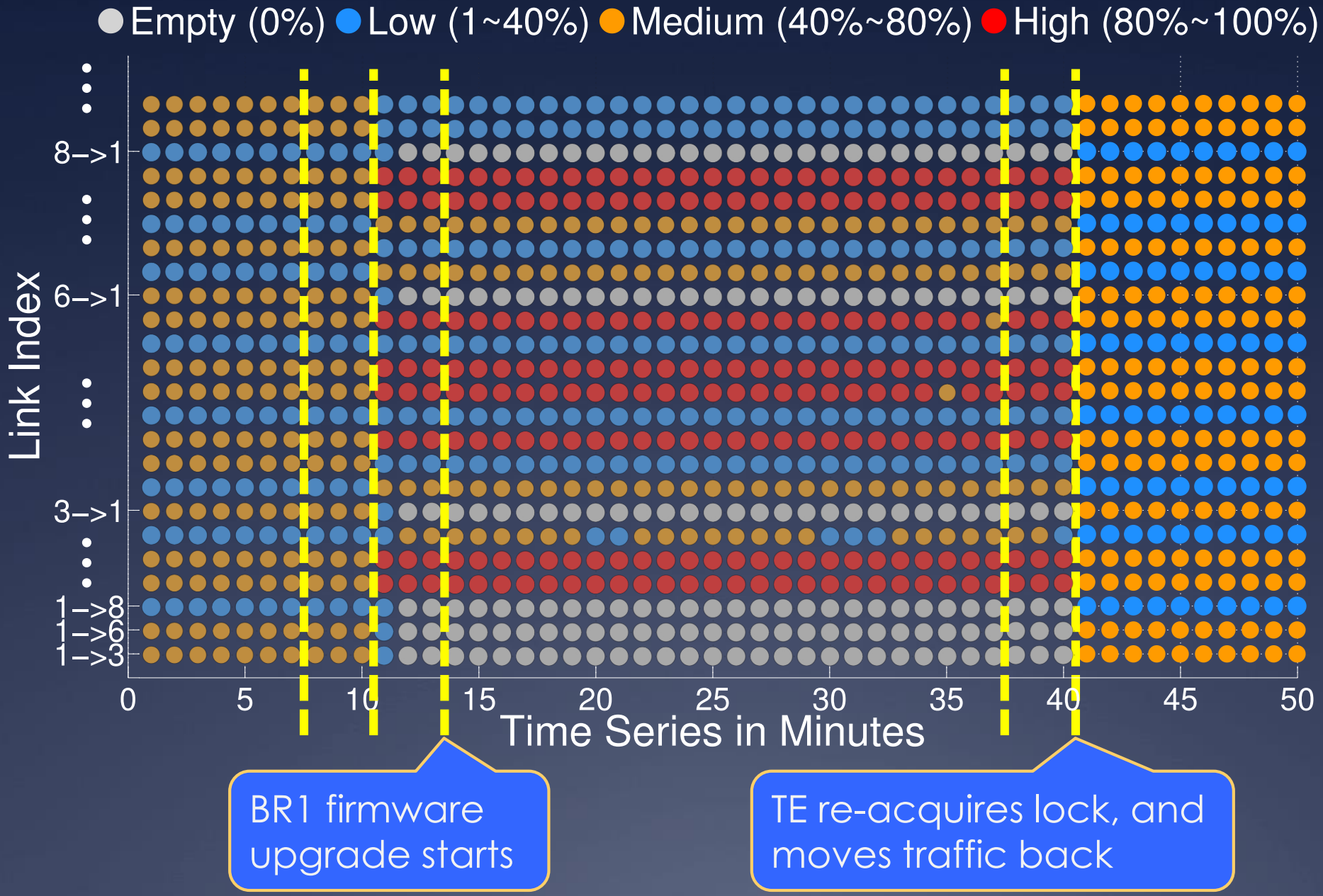
TE fails to acquire lock, and moves traffic away

TE fails to acquire lock, and moves traffic away


Empty (0%)
Low (1~40%)
Medium (40%~80%)
High (80%~100%)
Link Index
8–>1
6–>1
3–>1
1–>8
1–>6
1–>3
0
5
10
15
20
25
30
35
40
45
50
Time Series in Minutes
BR1 firmware upgrade starts


Empty (0%)
Low (1~40%)
Medium (40%~80%)
High (80%~100%)
Link Index
8–>1
6–>1
3–>1
1–>8
1–>6
1–>3
0
5
10
15
20
25
30
35
40
45
50
Time Series in Minutes
BR1 firmware upgrade starts
BR1 firmware upgrade ends. Lock released.


Empty (0%)
Low (1~40%)
Medium (40%~80%)
High (80%~100%)
Link Index
8–>1
6–>1
3–>1
1–>8
1–>6
1–>3
0
5
10
15
20
25
30
35
40
45
50
Time Series in Minutes
BR1 firmware upgrade starts
TE re-acquires lock, and moves traffic back

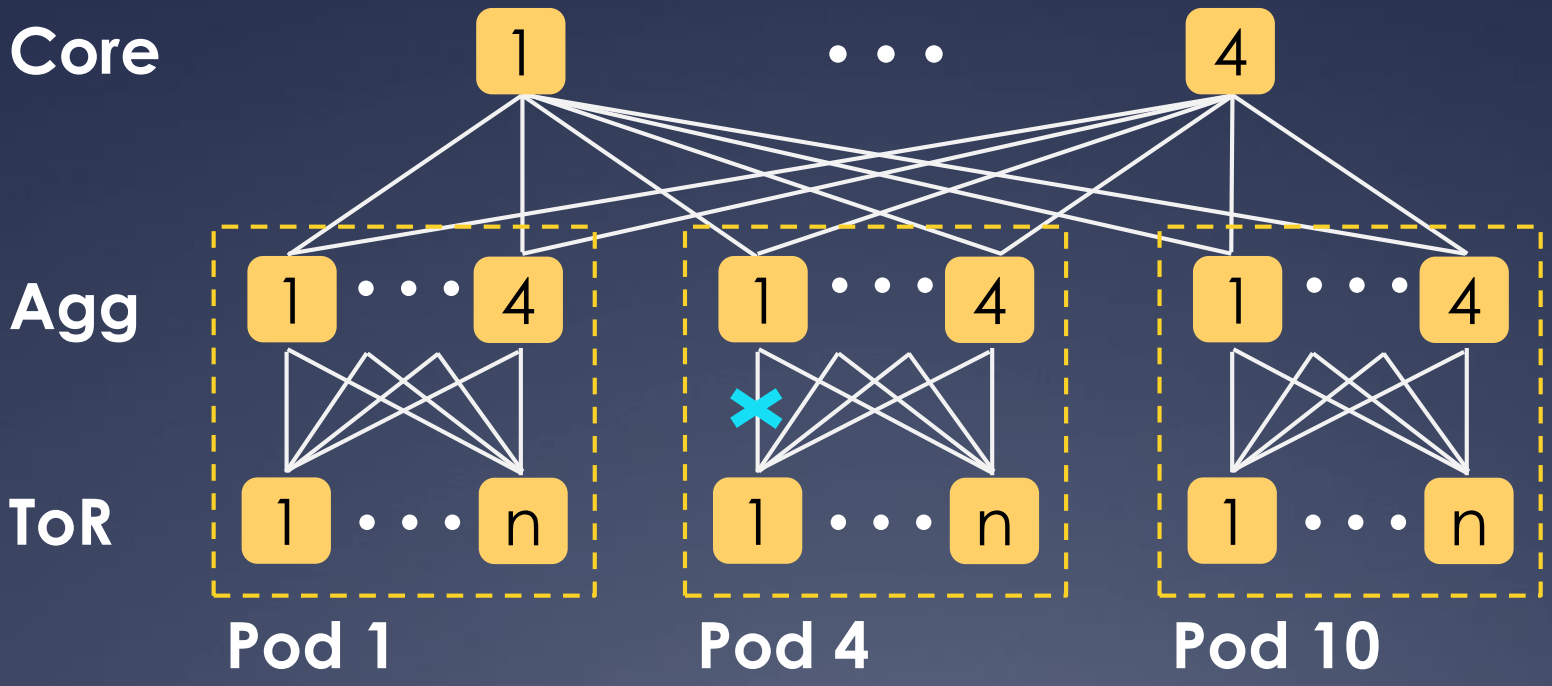

Empty (0%)
Low (1~40%)
Medium (40%~80%)
High (80%~100%)
Link Index
8–>1
6–>1
3–>1
1–>8
1–>6
1–>3
0
5
10
15
20
25
30
35
40
45
50
Time Series in Minutes
BR1 firmware upgrade starts
TE re-acquires lock, and moves traffic back

Case #1 Summary

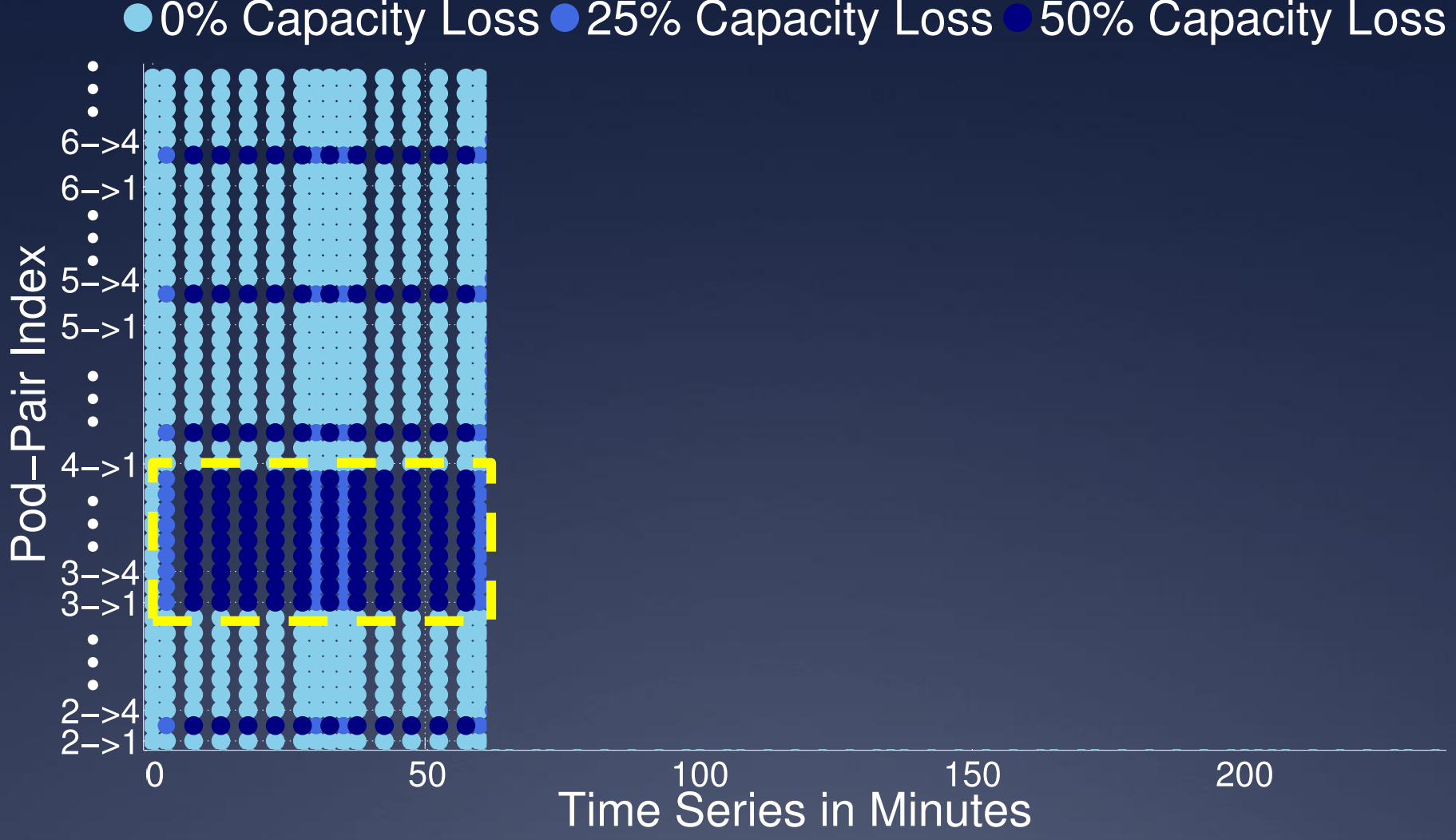
- Each application:
  - Simple logic
  - Unaware of the other
- Statesman enables:
  - Conflict resolution
  - Necessary coordination

Case #2: Maintain Capacity Invariant

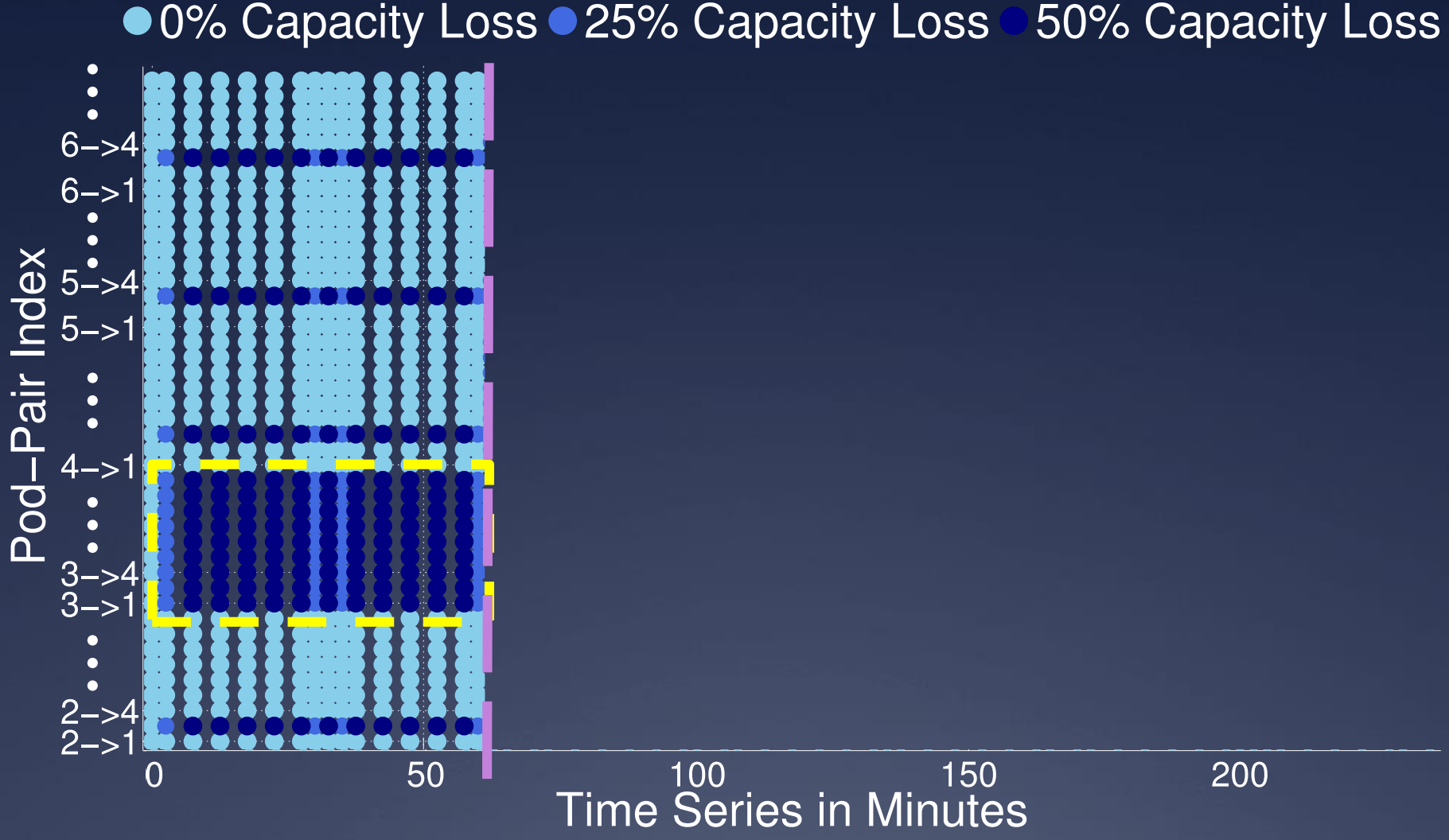
Firmware-upgrade & Link-corruption-mitigation



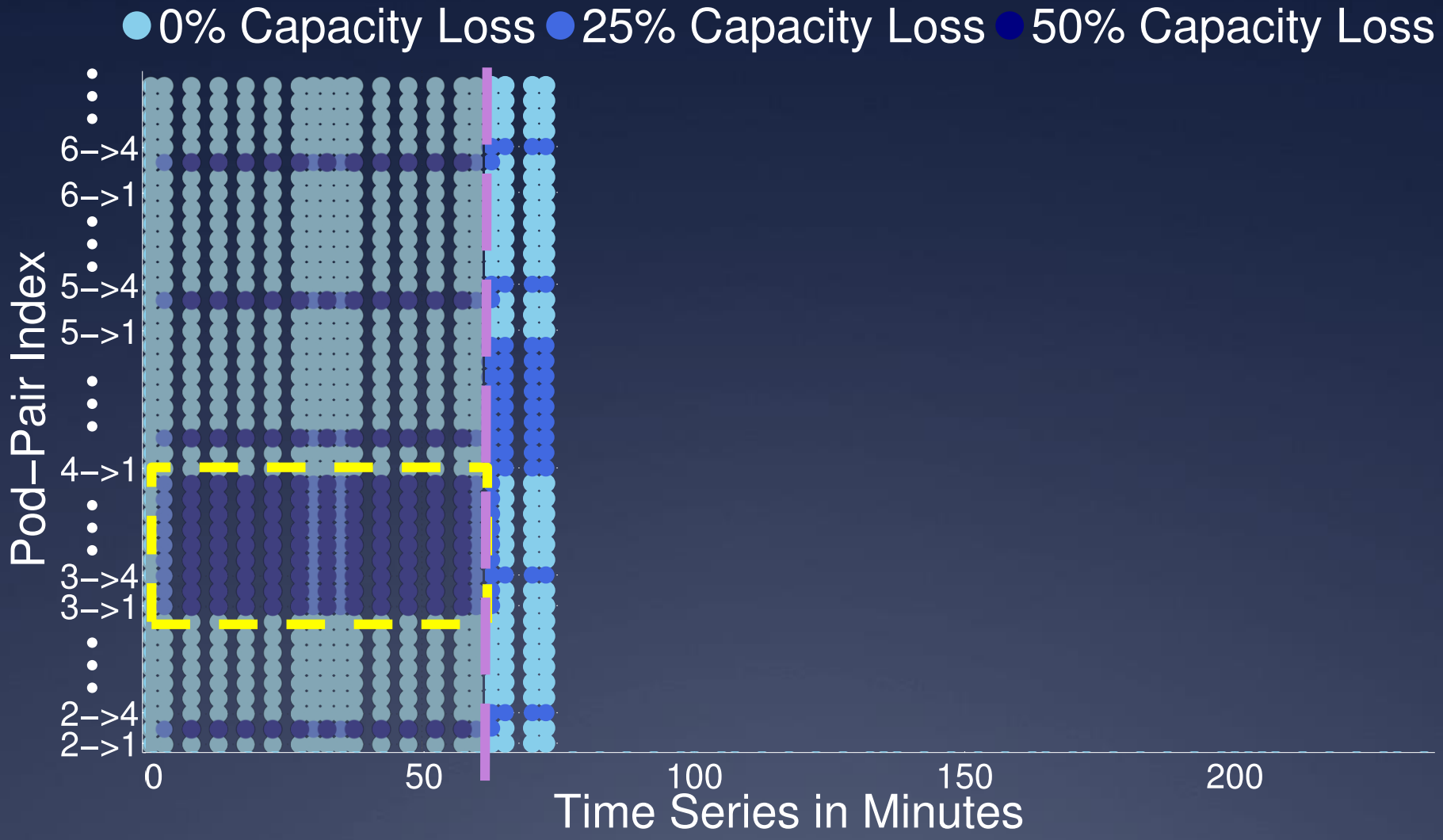

0% Capacity Loss
25% Capacity Loss
50% Capacity Loss
Pod–Pair Index
6–>4
6–>1
5–>4
5–>1
4–>1
3–>4
3–>1
2–>4
2–>1
0
50
100
150
200
Time Series in Minutes



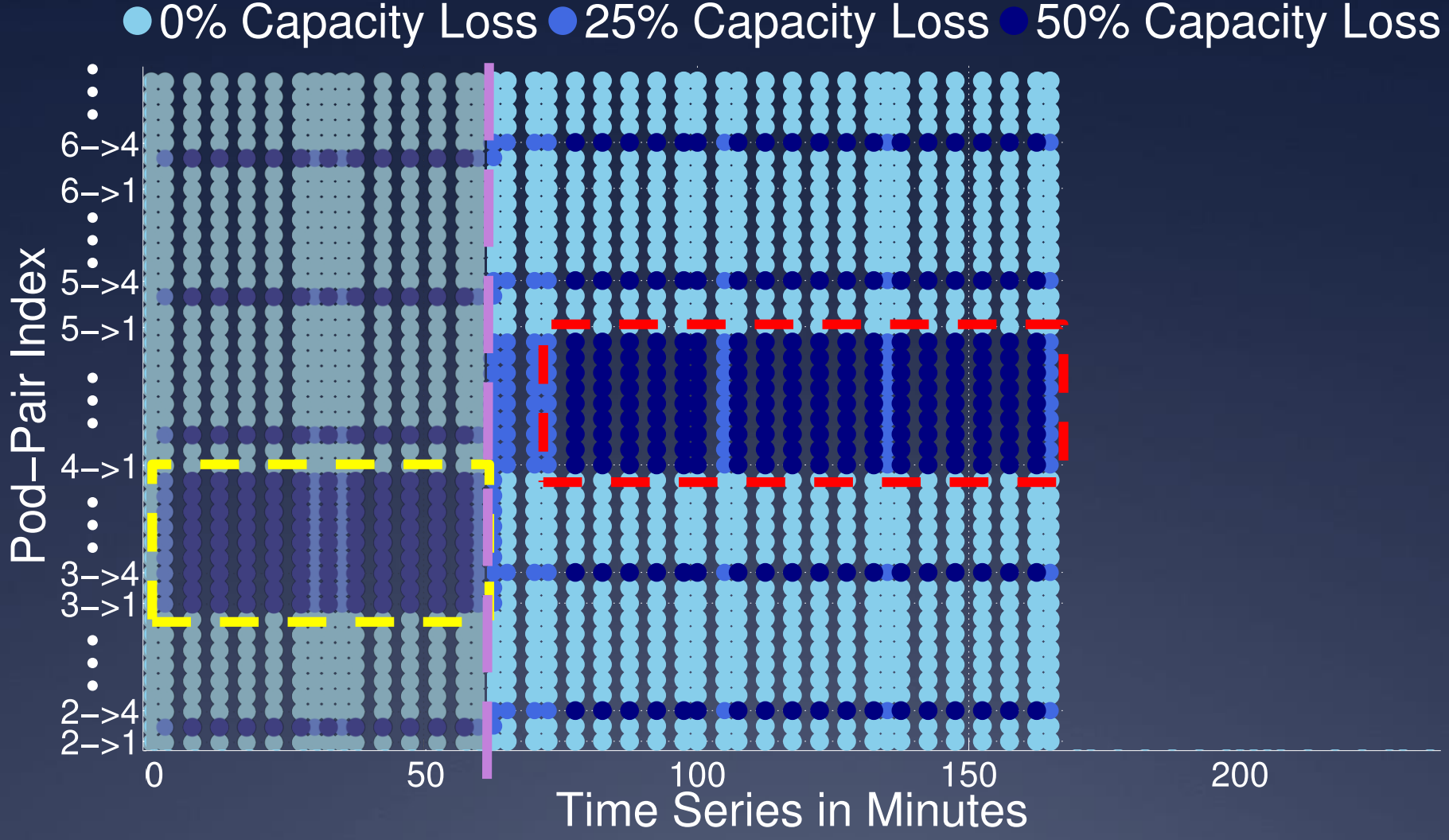
Upgrade proceeds in normal speed in Pod 3 and 5



Upgrade proceeds in normal speed in Pod 3 and 5

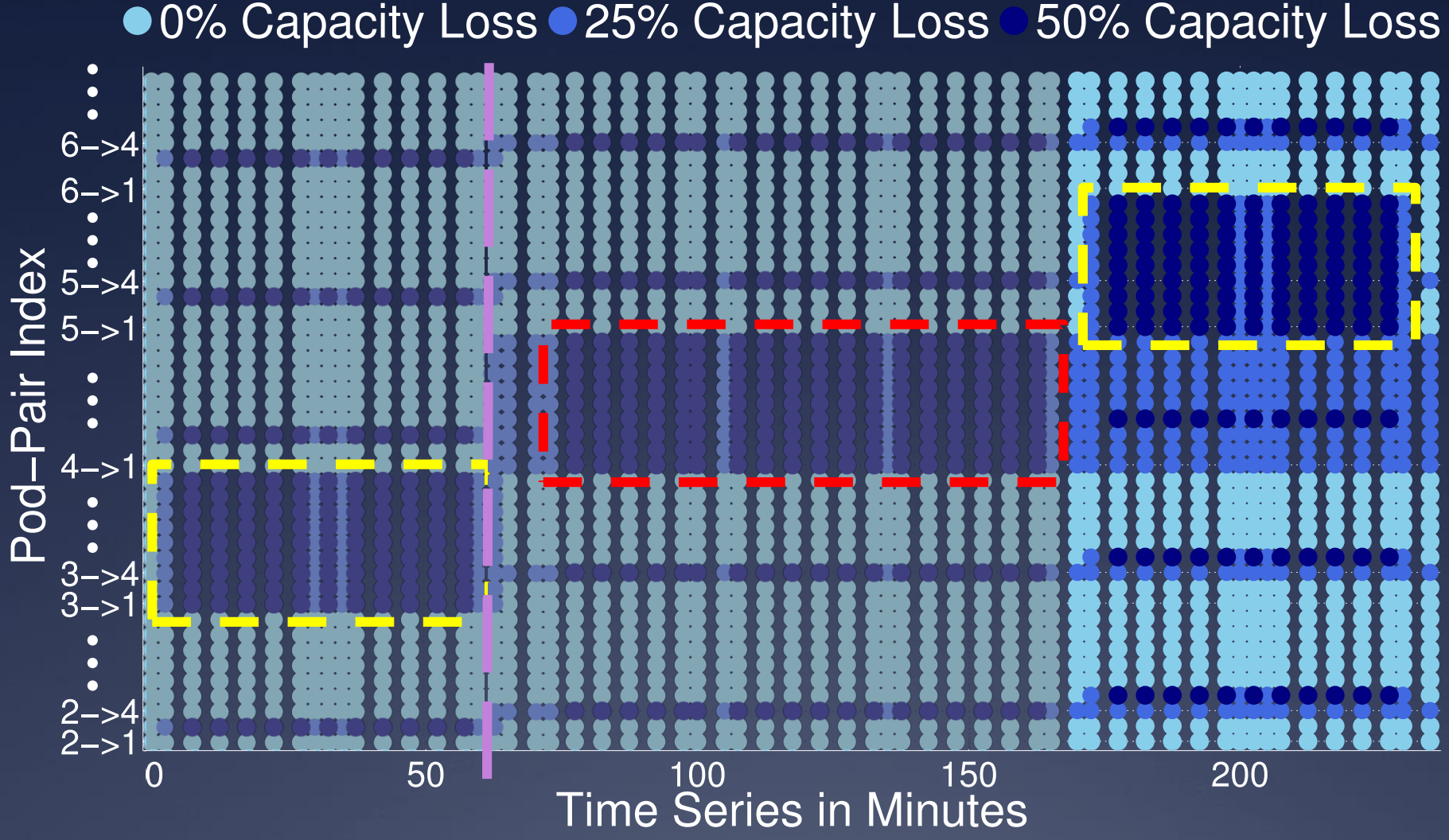


Upgrade proceeds in normal speed in Pod 3 and 5



Upgrade proceeds in normal speed in Pod 3 and 5

Upgrade in Pod 4 is slowed down by checker due to lost capacity



Upgrade proceeds in normal speed in Pod 3 and 5

Upgrade in Pod 4 is slowed down by checker due to lost capacity

Case #2 Summary

- Statesman:
  - Automatically adjusts application progresses
  - Keeps the network within safety requirements

Conclusion

- Need network operating system for multiple management applications

Conclusion

- Need network operating system for multiple management applications
- Statesman
  - Loose coupling of applications
  - Network state abstraction

Conclusion

- Need network operating system for multiple management applications
- Statesman
  - Loose coupling of applications
  - Network state abstraction
- Deployed and operational in Azure

Thanks!

Questions?

Check paper for related works