POLITECNICO DI MILANO

BONSAI Lab





Survivable Virtual Topology Mapping To Provide Content Connectivity Against Double-Link Failures

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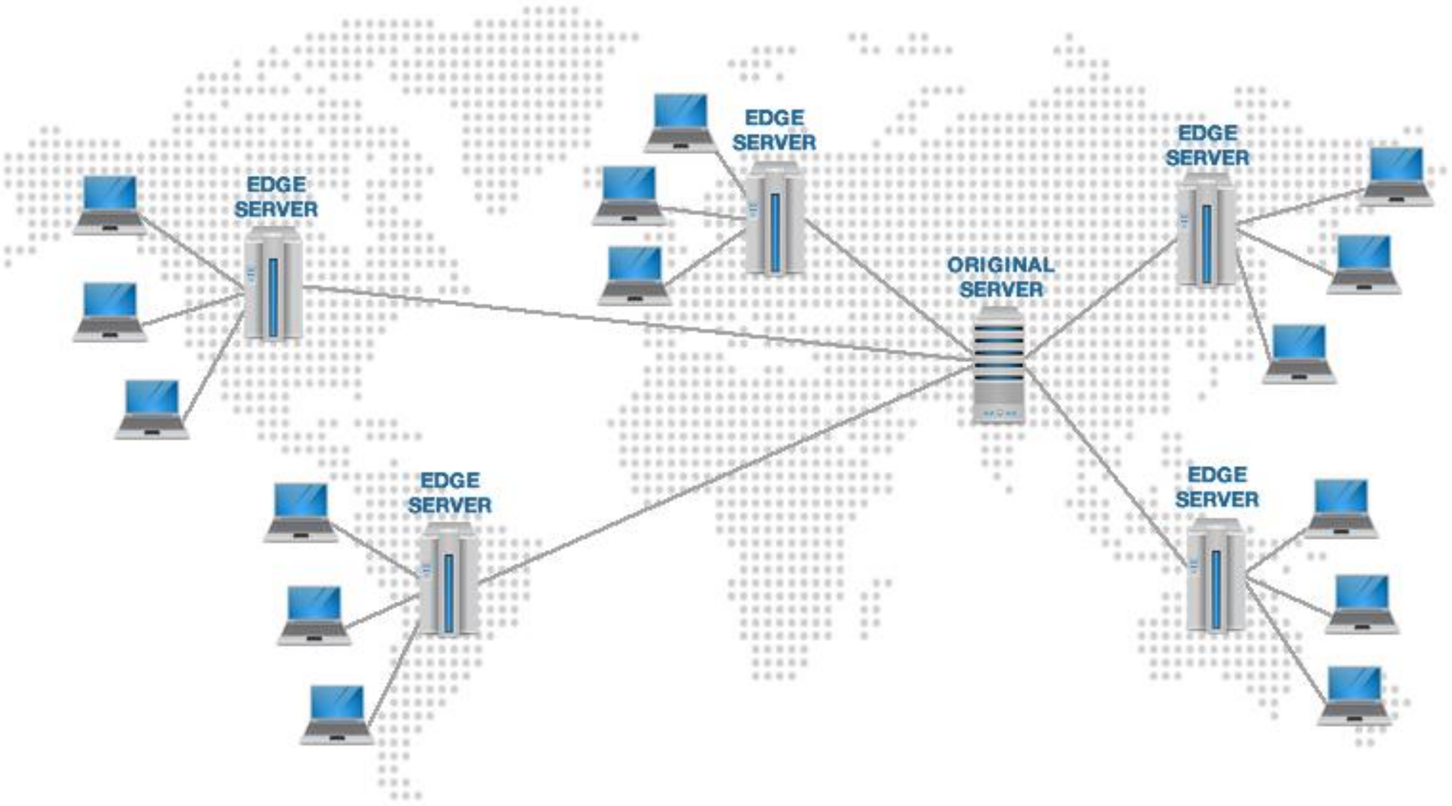
OUTLINE

- Motivations
- Survivable virtual topology mapping problem
- Network connectivity Vs content connectivity
- Problem statement
- Case-study & results
- Conclusions & future works

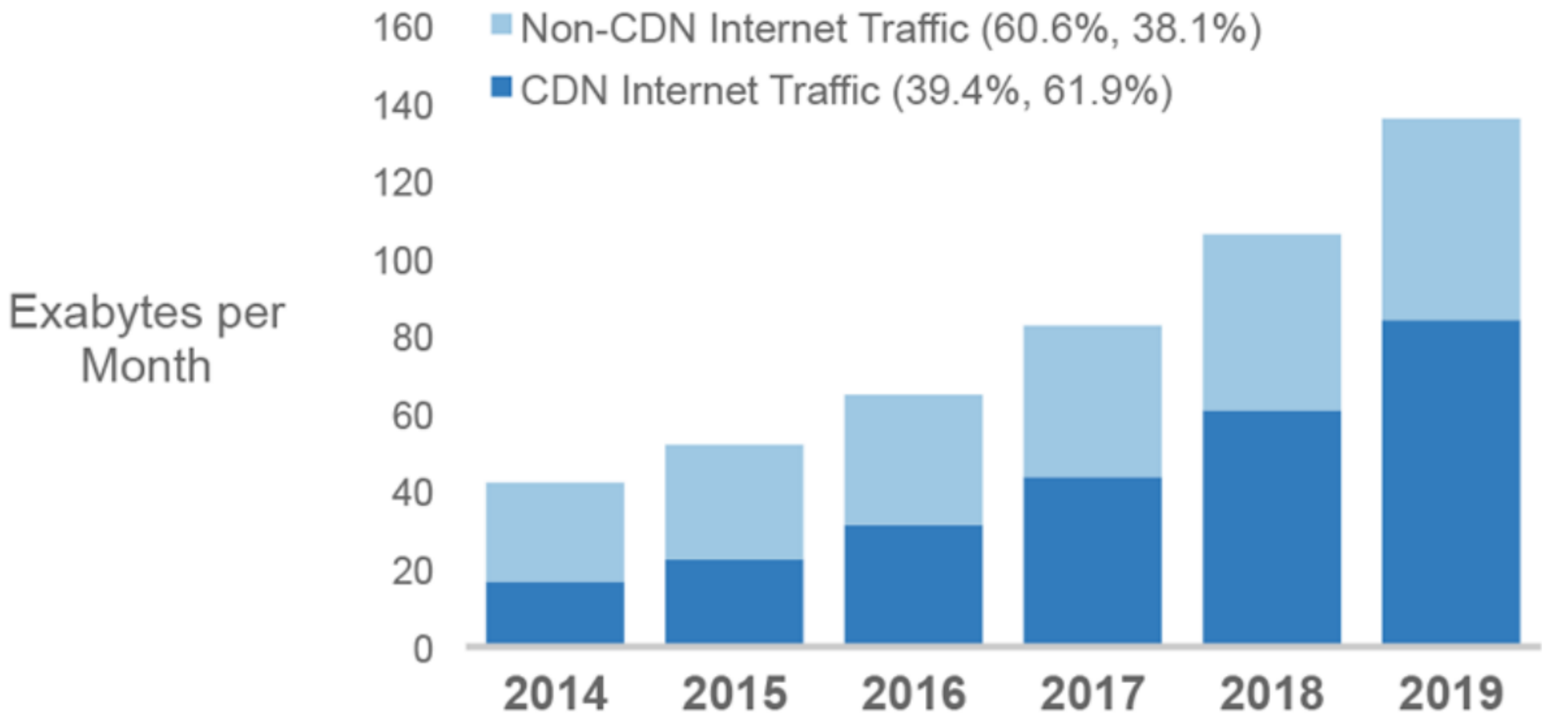
CONTENT DELIVERY NETWORKS (CDNs)

- ❑ Improved user experience
- ❑ Bandwidth
  - Reduce probability of link congestion
  - Reduce energy consumption
- ❑ Reduce delay
- ❑ Availability
  - A single server is easily overloaded
- ❑ Load balancing



THE EVOLUTION OF CONTENT DELIVERY NETWORKS

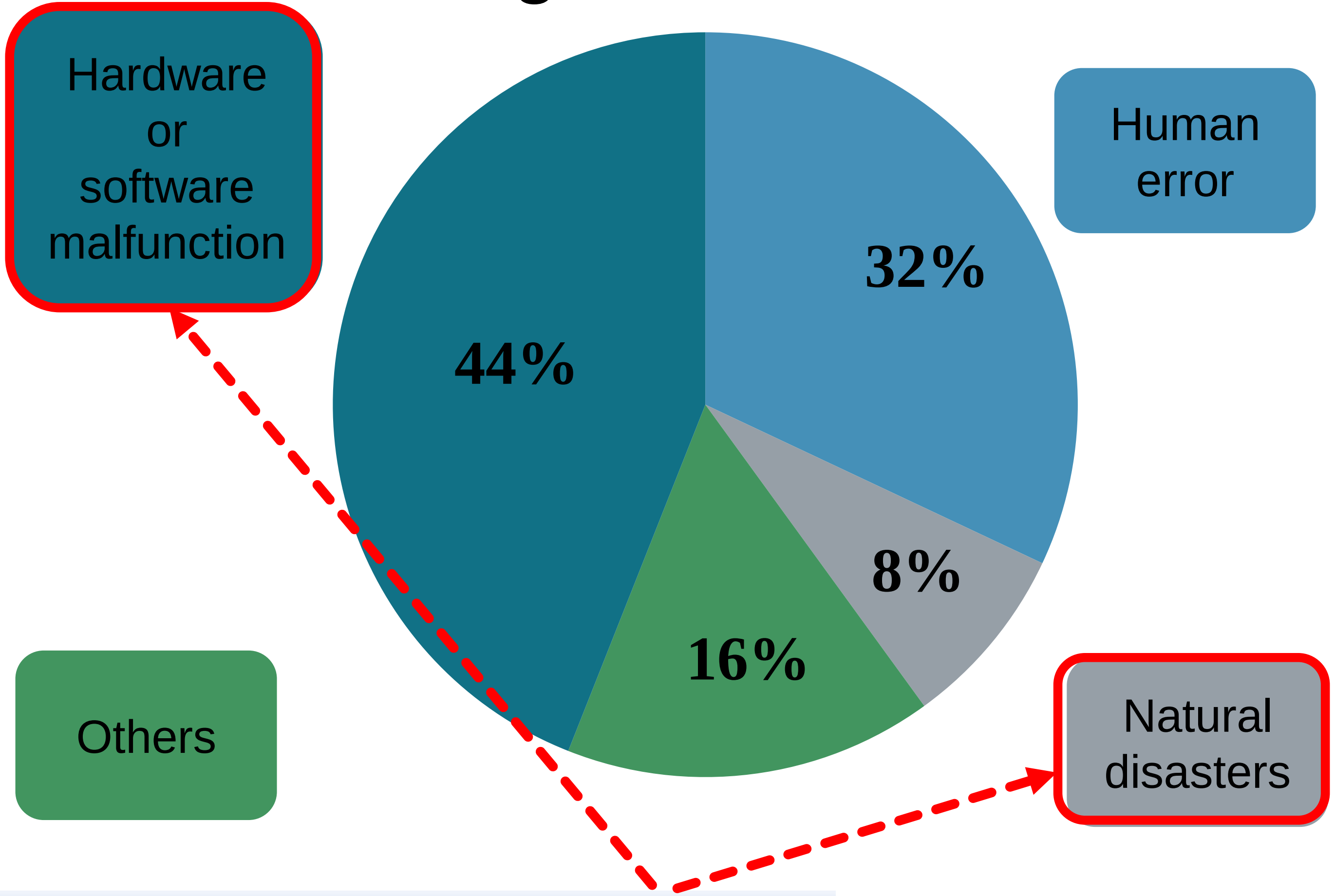
- Social media
- Online gaming
- Electronic payment transactions
- Multimedia streaming
- ...etc



End-to-end → End-to-content

Source: Index, Cisco Visual Networking. "Forecast and Methodology, 2014–2019 White Paper, Cisco, 2015."

Leading causes of Data loss



Source: http://www.cloudwards.net/world-backup-day-2015
http://www.paragon-software.com/survey_results.html

CHARACTERISTICS OF DISTRUPTIONS FOR CDN PROVIDERS (I)

- Total loss of connectivity
- More than 6 hours to recover from failure
- Failure due to hardware malfunction

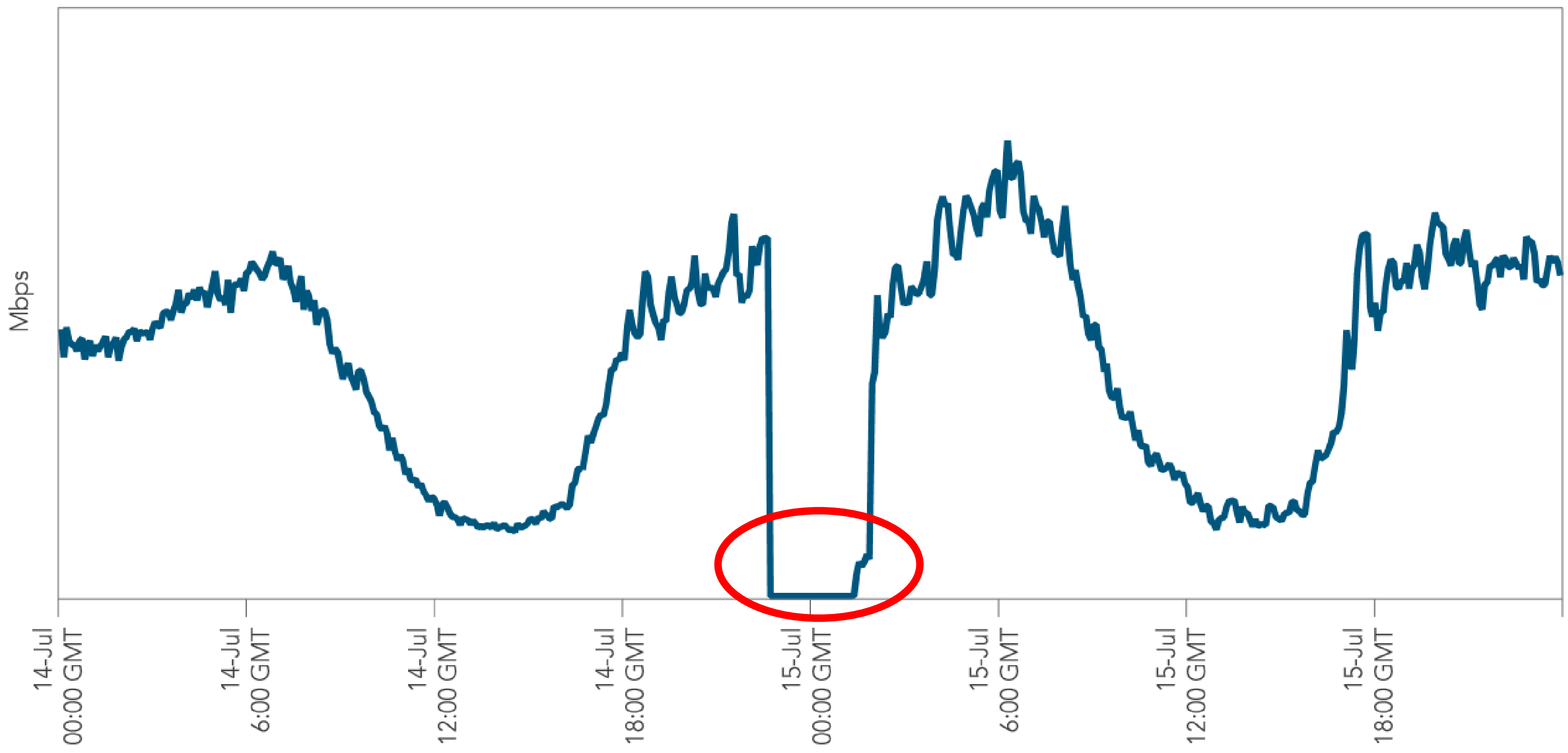


Figure 37: Akamai Traffic Served to French Polynesia, July 14–15, 2015

Source: Q3 2015 State of the Internet Report - AKAMAI

CHARACTERISTICS OF DISTRUPTIONS FOR CDN PROVIDERS (II)

- Partial loss of connectivity
- More than 1 week to recover from failure
- Failure due fiber cut undersea

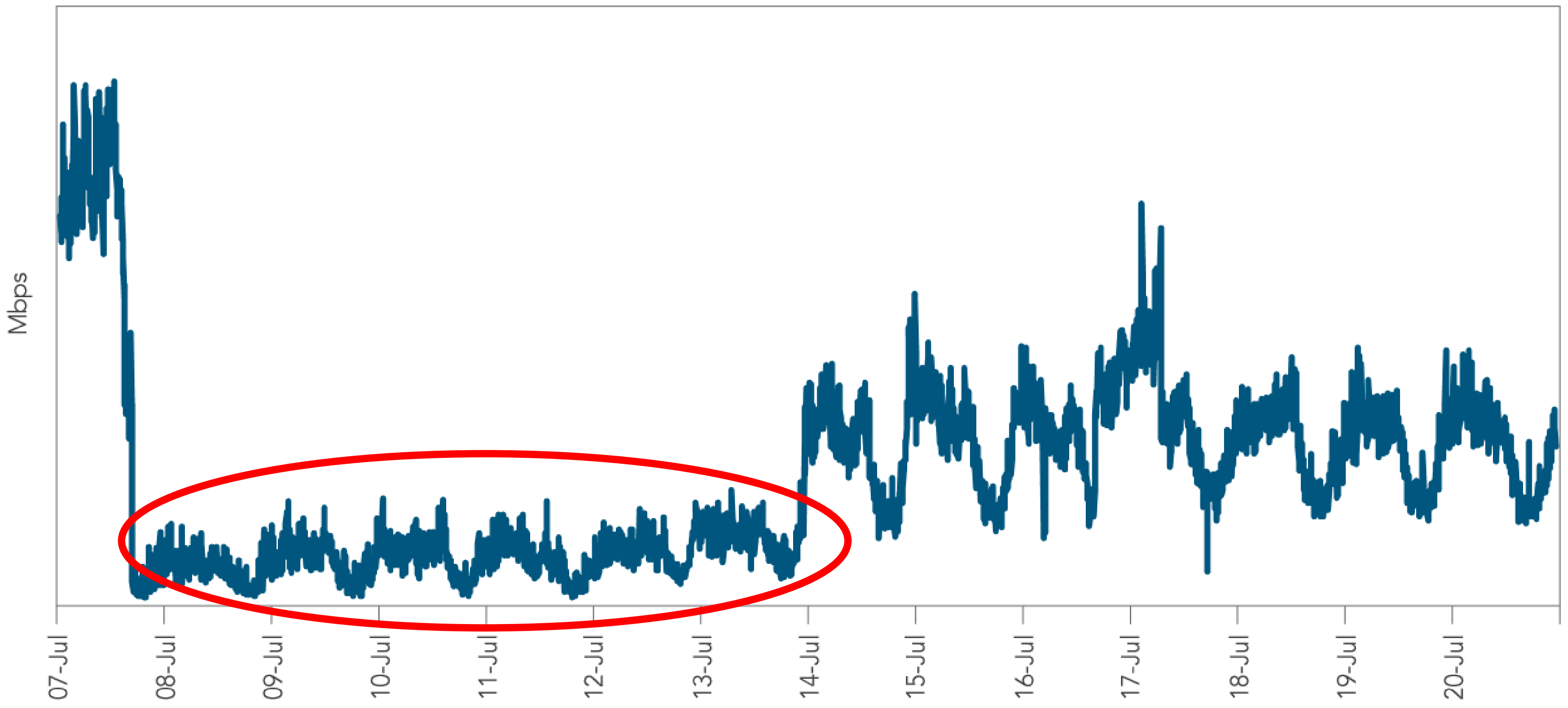


Figure 36: Akamai Traffic Served to the Northern Mariana Islands, July 7 – 18, 2015

Source: Q3 2015 State of the Internet Report - AKAMAI

CHARACTERISTICS OF DISTRUPTIONS FOR CDN PROVIDERS (III)

- Total loss of connectivity
- More than 3h to restore connectivity
- Government shutting down internet during national exams days

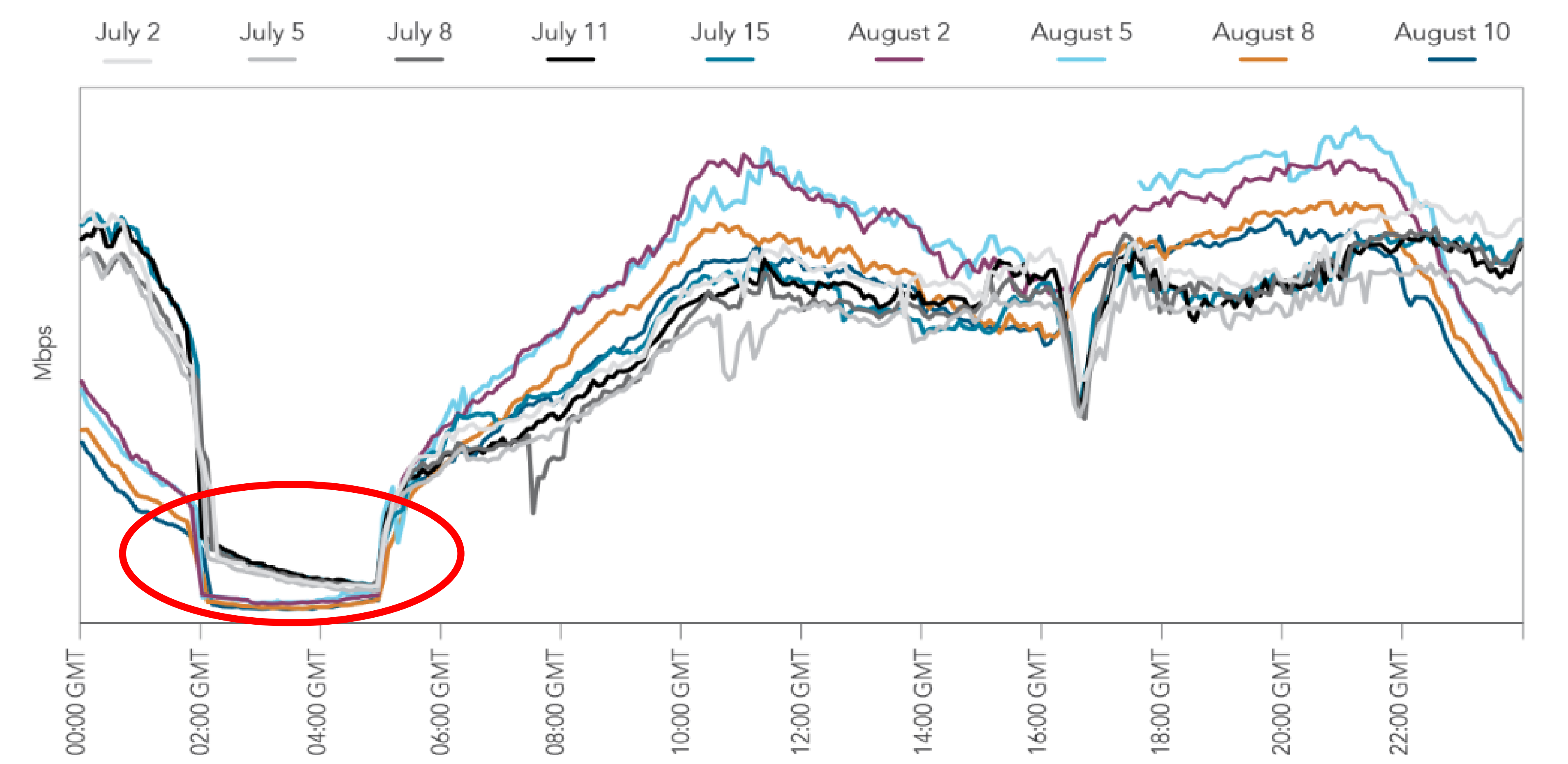


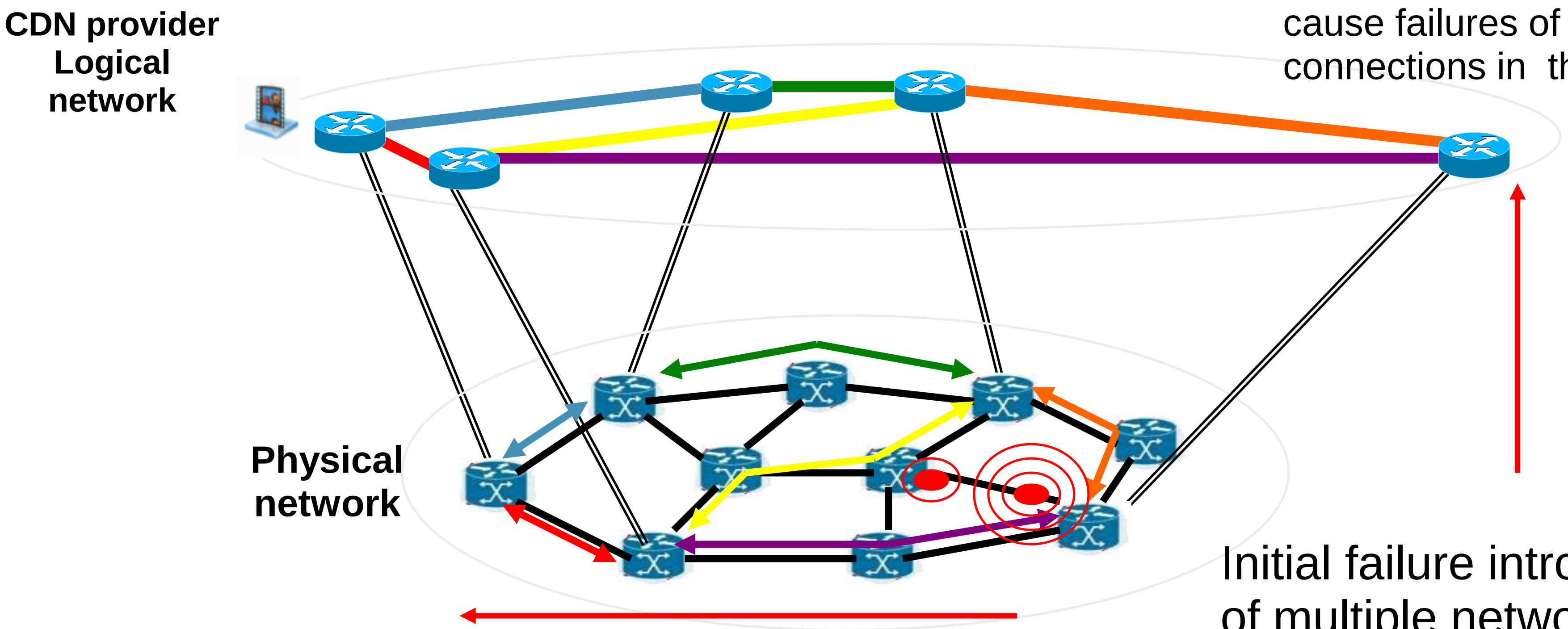
Figure 39: Akamai Traffic Served to Iraq, Multiple Days in July & August 2015

Source: Q3 2015 State of the Internet Report - AKAMAI

HOW CAN A CDN PROVIDER OVERCOME TOTAL LOSS OF CONNECTIVITY DURING FAILURE EVENTS?

The idea is to perform a **survivable** design combined with an **optimal content placement** to allow the CDN provider to continue the content distribution until the failure recovery from **single/multiple failures** is done.

IMPACT OF PHYSICAL LAYER FAILURES



Vertical correlated cascading failures cause failures of multiple logical connections in the upper layers.

Initial failure introduces loss of multiple network elements.

Horizontal correlated cascading failures cause more failures on the physical layers.

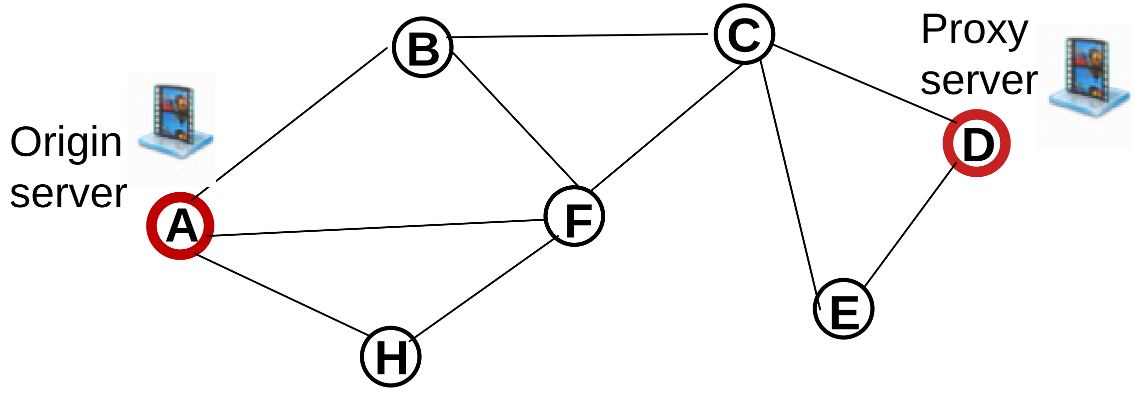
NETWORK CONNECTIVITY Vs CONTENT CONNECTIVITY

Traditional metric: **Network connectivity**

- Reachability of all nodes from any point in the network.

New metric : **Content connectivity**

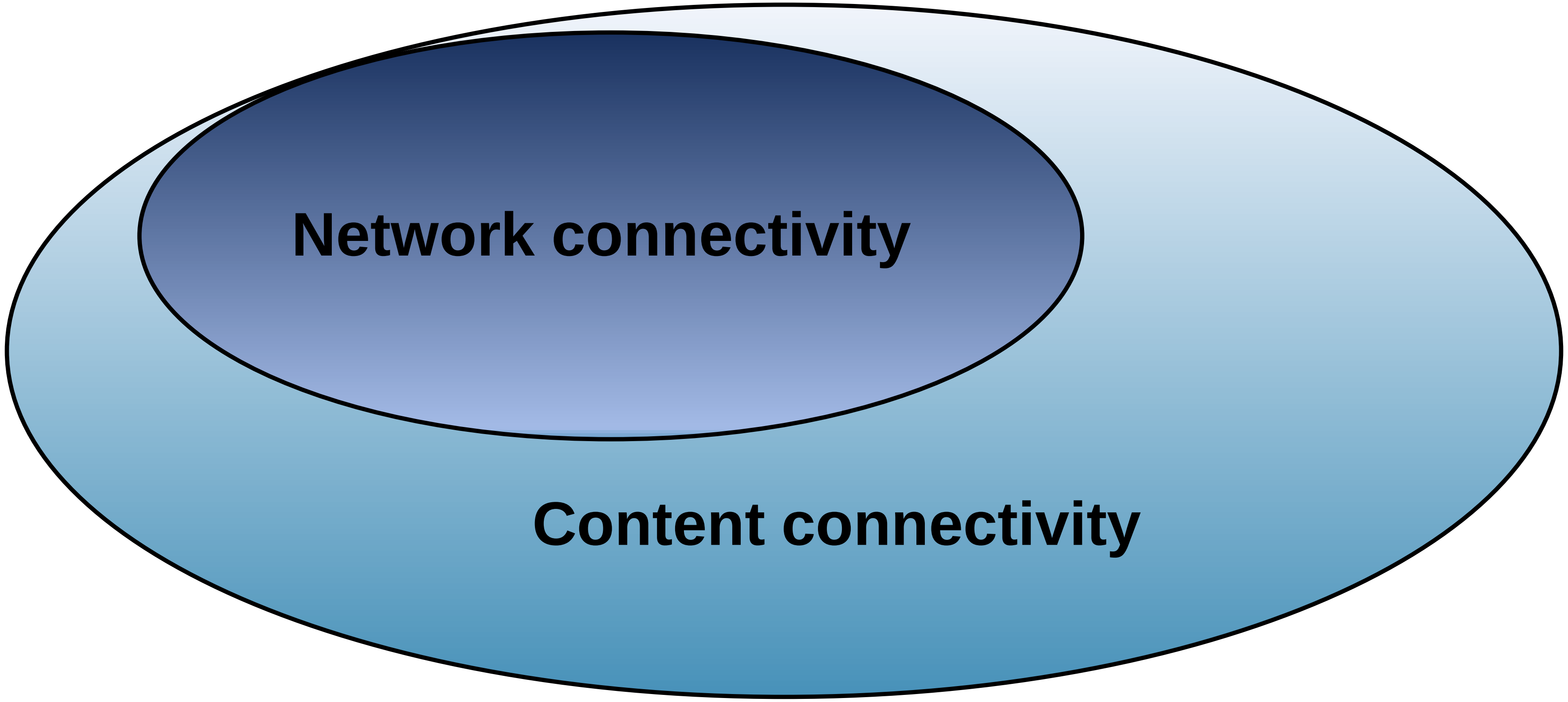
- Reachability of the content from any point in the network.



CDN provider virtual network

**"Fault-Tolerant Virtual Network Mapping to Provide Content Connectivity in Optical Networks," M. F. Habib et al.

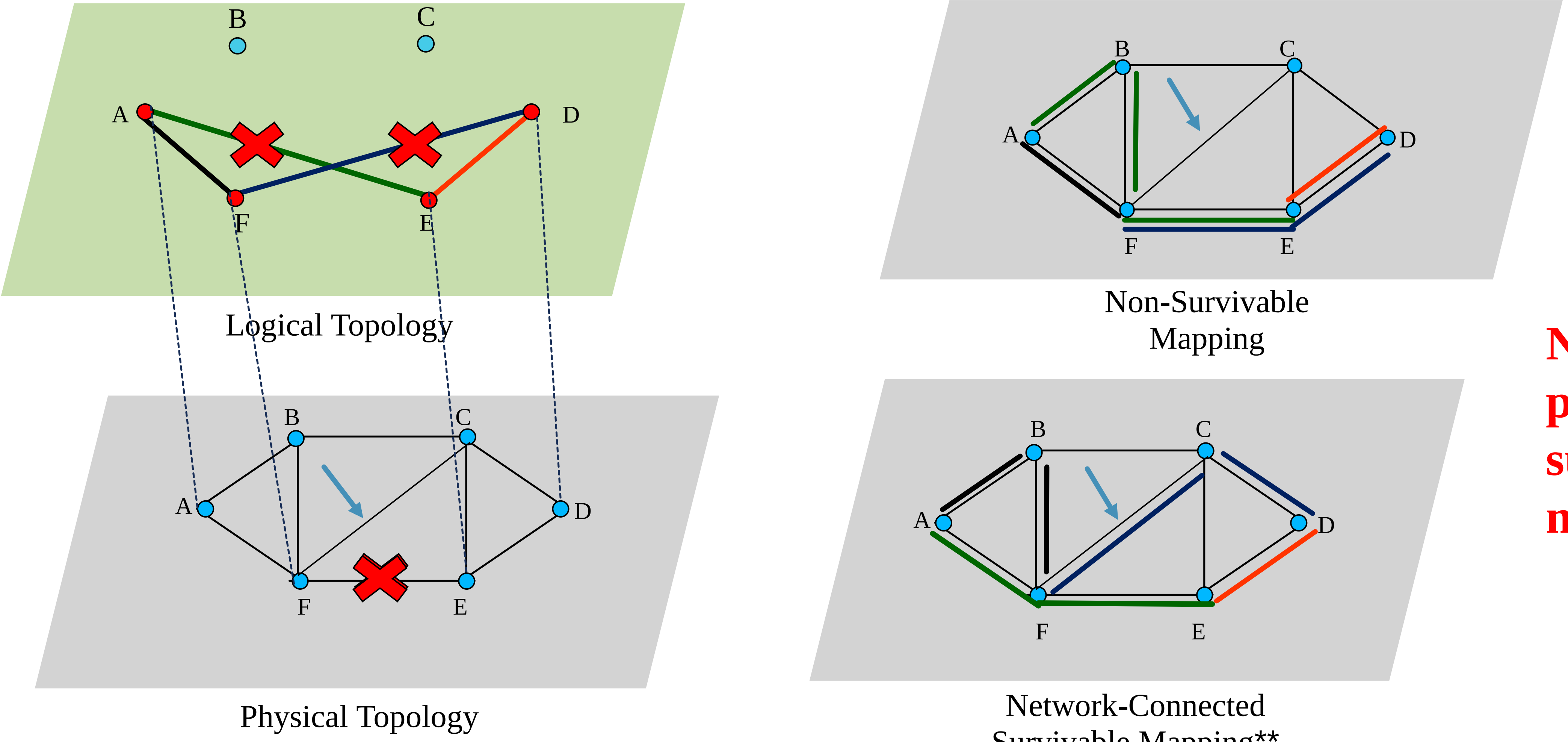
NETWORK CONNECTIVITY Vs CONTENT CONNECTIVITY (II)



Two factors:

- **Survivable virtual topology mapping**
- **Optimal content placement**

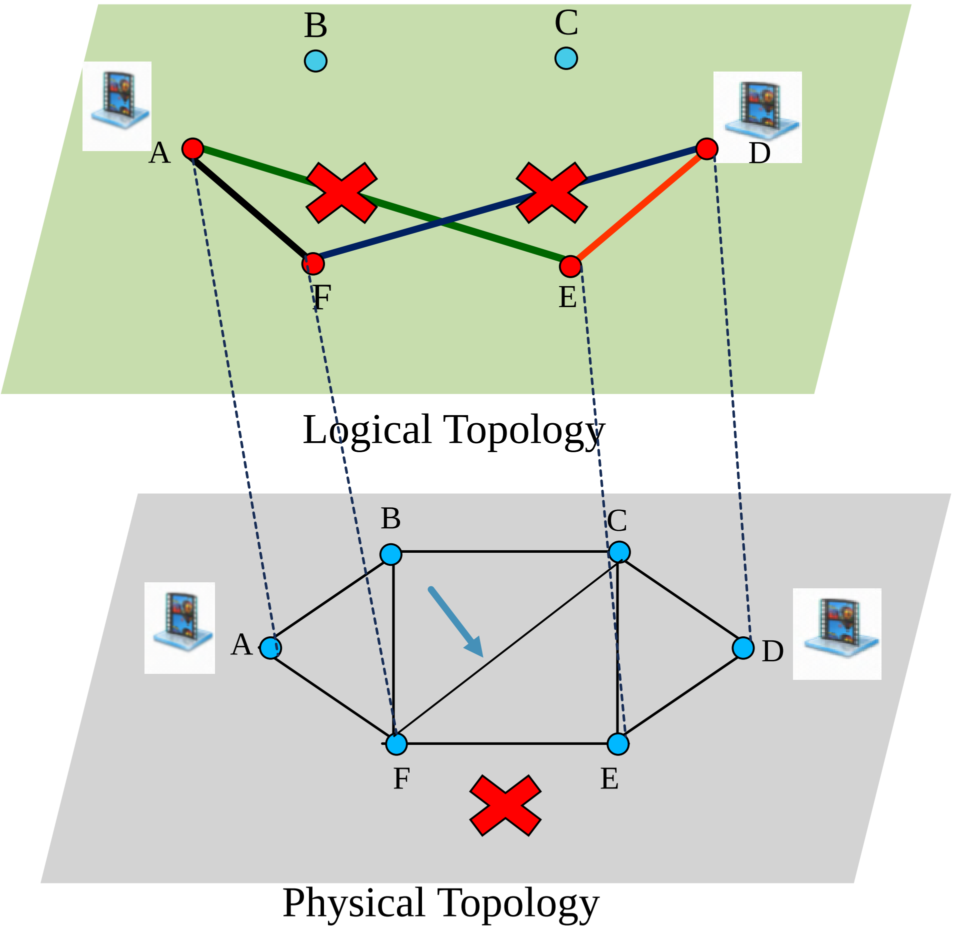
NETWORK CONNECTED SURVIVABLE MAPPING

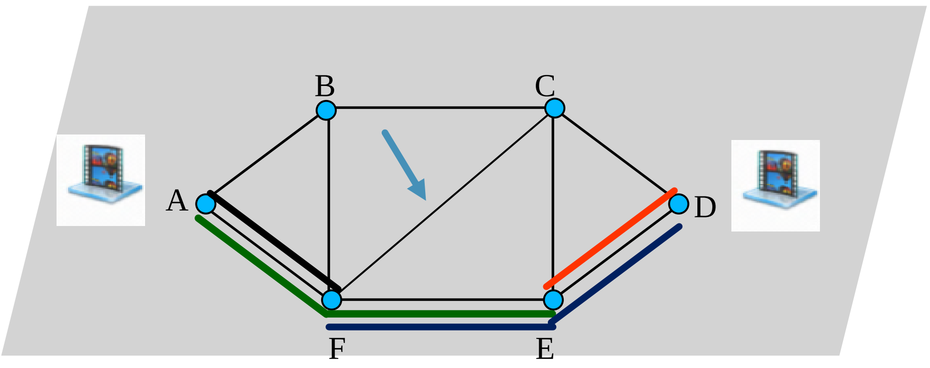


No possible survivable mapping

**Menger's theorem

CONTENT CONNECTED SURVIVABLE MAPPING





Content-Connected Survivable Mapping

Content Connectivity is still guaranteed

PROPOSED DESIGN SCENARIOS

Design scenario	Failure type	Survivable mapping	Optimal content placement
Content connectivity ** (CC1)	Single-link	-	✓
Network connectivity (NC1)	Single-link	✓	-
Network connectivity + Content connectivity (NC1+NC2)	Double-link	✓	✓
Content connectivity (CC2)	Double-link	-	✓
Network connectivity (NC2)	Double-link	✓	-

**“Fault-Tolerant Virtual Network Mapping to Provide Content Connectivity in Optical Networks,” M. F. Habib et al.

PROBLEM STATEMENT

- Given
  - Physical topology
  - Logical topology
  - Potential data center locations
- Objective
  - **Minimize the resource usage** (i.e., wavelength channels)
- While
  - Flow constraints
  - Data center placement constraints
  - Capacity constaints
- Outputs
  - Optimal routing
  - Optimal placement of data centers

Integer Linear programming

VARIABLES

- $P_{ij}^{st} \in \{0,1\}$: $(s,t) \in E_L$ mapped over physical link $(i,j) \in E$

Mapping virtual links to physical links

- $A_d^{sc} \in \{0,1\}$: Virtual node $\mathrm{s} \in V_L$ can get content $\mathrm{c} \in C$ in data center $\mathrm{d} \in D$
- $R_d^c \in \{0,1\}$: Content $\mathrm{c} \in C$ is replicated at data center $\mathrm{d} \in D$

Content placement

- $\alpha_z^{st} \in \{0,1\}$: Failure of physical link $\mathrm{z} \in E$ disrupts the logical link $(s,t) \in E_L$

Select disturbed Virtual links

- $F_{st\,z}^{u\,c} \in \{0,1\}$: Virtual node $\mathrm{u} \in V_L$ can get content $\mathrm{c} \in C$ using logical link $(s,t) \in E_L$ after a failure occurs in $\mathrm{z} \in Z$

Reachability to data center after single-link failures

- $T_{st\,z_1\,z_2}^{u\,c} \in \{0,1\}$: Virtual node $\mathrm{u} \in V_L$ can get content $c \in C$ using logical link $(s,t) \in E_L$ after a first failure occurs in $z_1 \in \mathrm{E}$ and a second failure occurs in $z_2 \in E$ such that $z_1 \neq z_2$

Reachability to data center after double-link failures

INTEGER LINEAR PROGRAMMING FORMULATION **(NC1+CC2)**

$$\sum_{j:(i,j)\in E} P_{ij}^{st} - \sum_{j:(j,i)\in E} P_{ji}^{st} = \begin{cases} 1 & i = s \\ -1 & i = t \\ 0 & otherwise \end{cases}$$

$$\forall (s,t) \in E_L, c \in C, (i,j) \in E$$

Mapping virtual links to physical links

$$R^{cd} \geq A_d^{sc} \qquad \forall d \in D, c \in C, s \in V_L$$

$$\sum_{d\in D} R^{cd} \leq K \qquad \forall c \in C$$

$$\sum_{(i,j)\in z} P_{ij}^{st} / M \leq \alpha_z^{st} \leq \sum_{(i,j)\in z} P_{ij}^{st} \quad \forall (s,t) \in E_L, z \in Z$$

$$\sum_{(s,t)\in CS(S,V_L - S)} P_{ij}^{st} + P_{ji}^{st} < |CS(S, V_L - S)|$$

$$\forall S \subset V_L, (i,j) \in E$$

$$\sum_{(s,t)} P_{ij}^{st} \leq W \qquad \forall (i,j) \in E$$

$$F_{st\ z}^{u\ c} \leq \alpha_z^{st} \qquad \forall u \in V_L, c \in C, (s,t) \in E_L, z \in E$$

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Content placement

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Select disrupted virtual links

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Survivable mapping constraint

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Capacity constaint

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Reachability constraints

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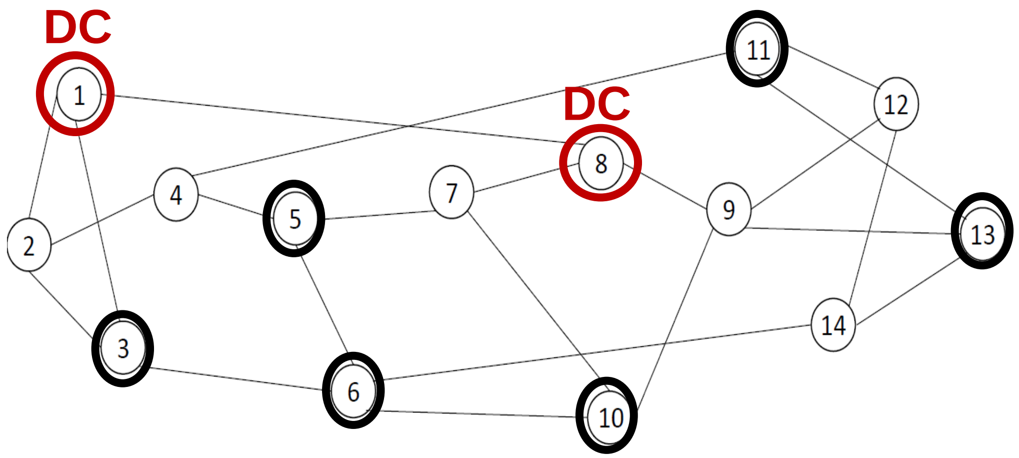
Objective function:

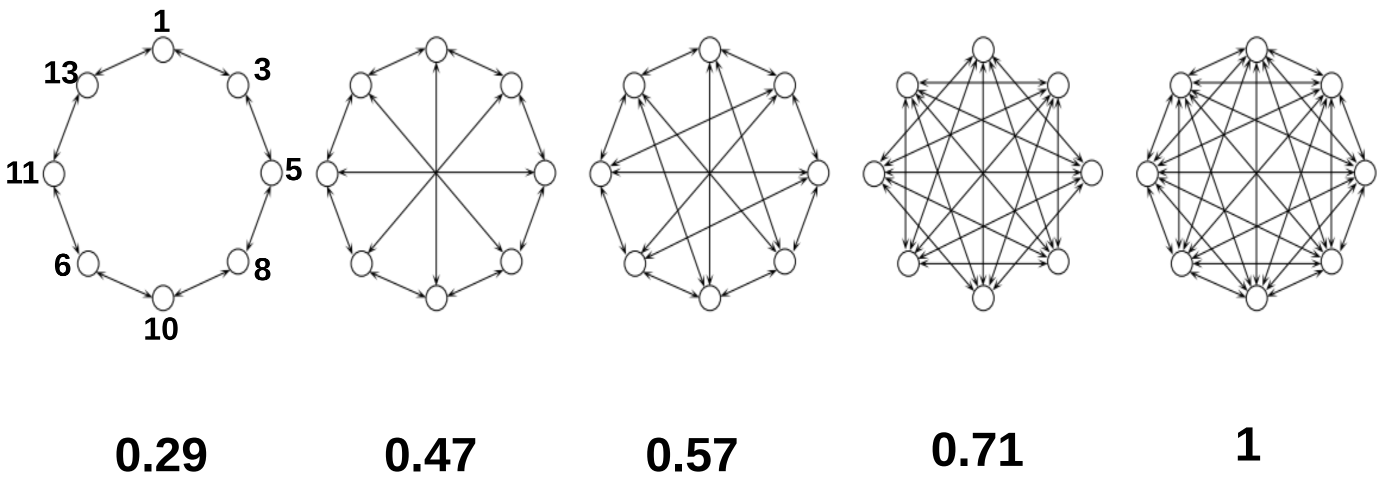
$$Minimize \sum_{(s,t)\in E_L} \sum_{(i,j)\in E} P_{ij}^{st}$$

Physical topology



NSFNET (14 Nodes, 22 bidirectional links)

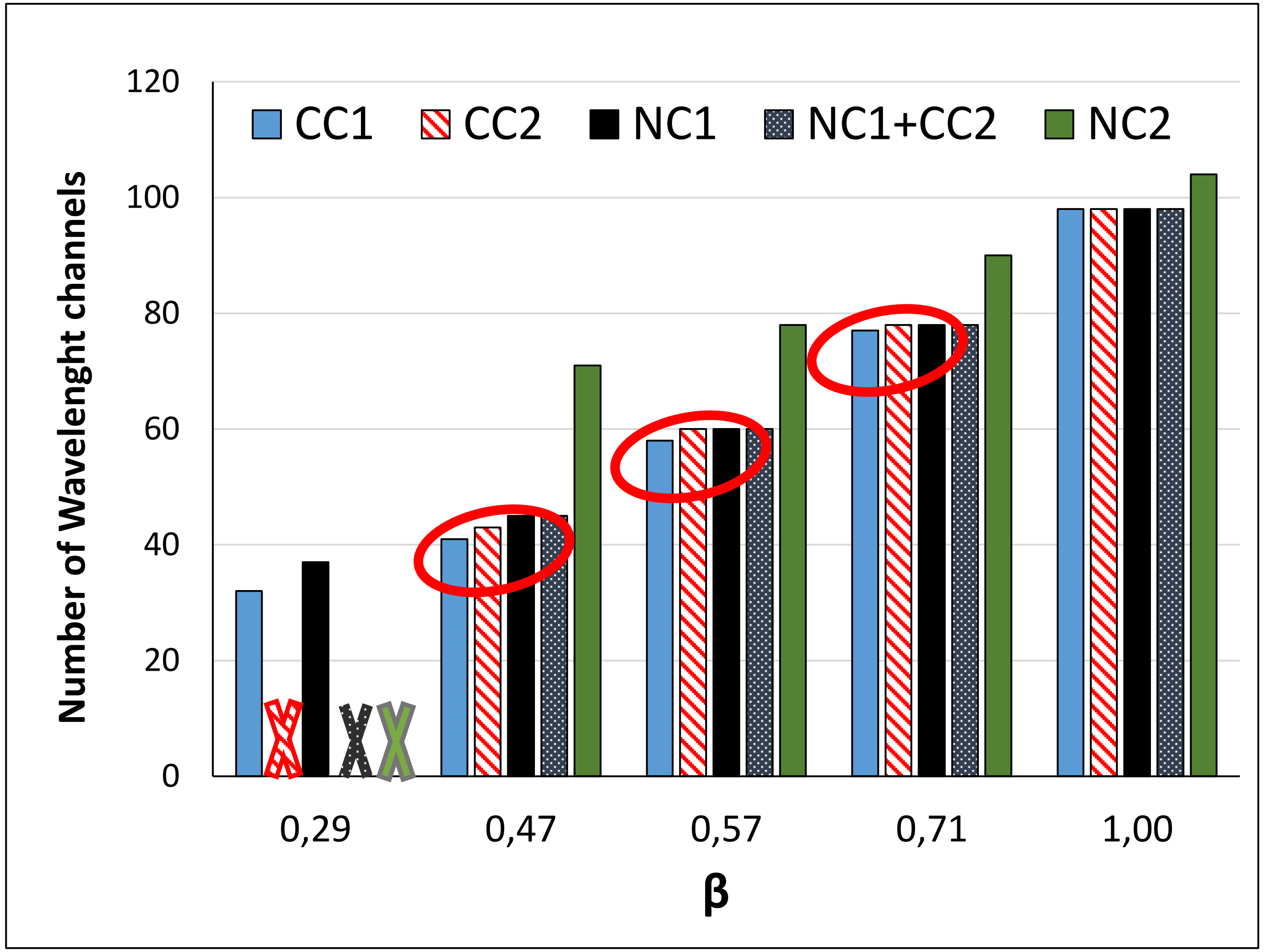
Logical topologies



Connectivity degree (β)

RESOURCE USAGE COMPARISON

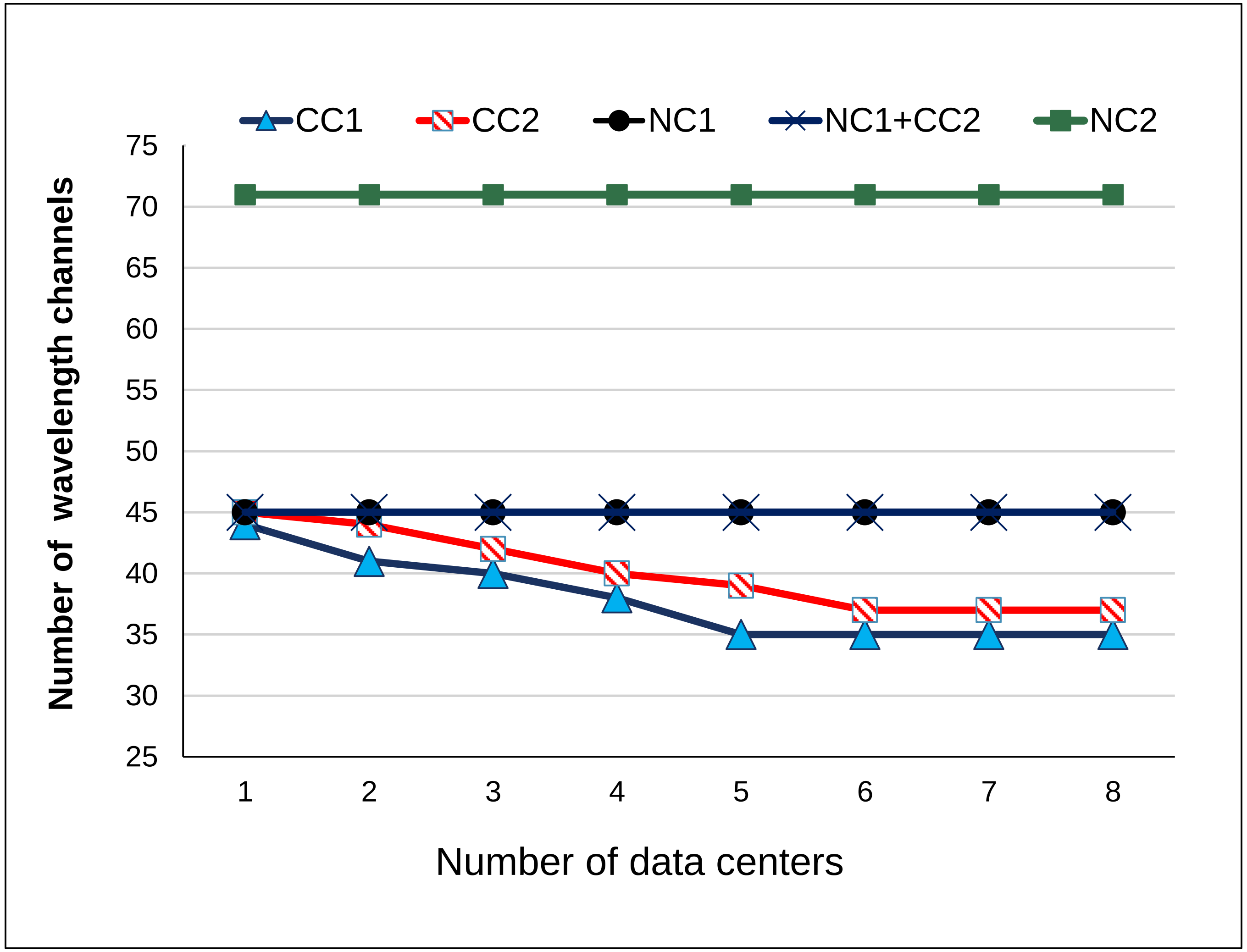
- Disaster locations: **All Physical links**
- Limited set of potential data center locations
- Number of data centers: **2**
- Limited number of wavelength per link



EFFECT OF REPLICAS

Assumptions:

- Logical topology $\boldsymbol{\beta = 0.47}$
- All nodes are assumed to hold a data center



CONCLUSIONS

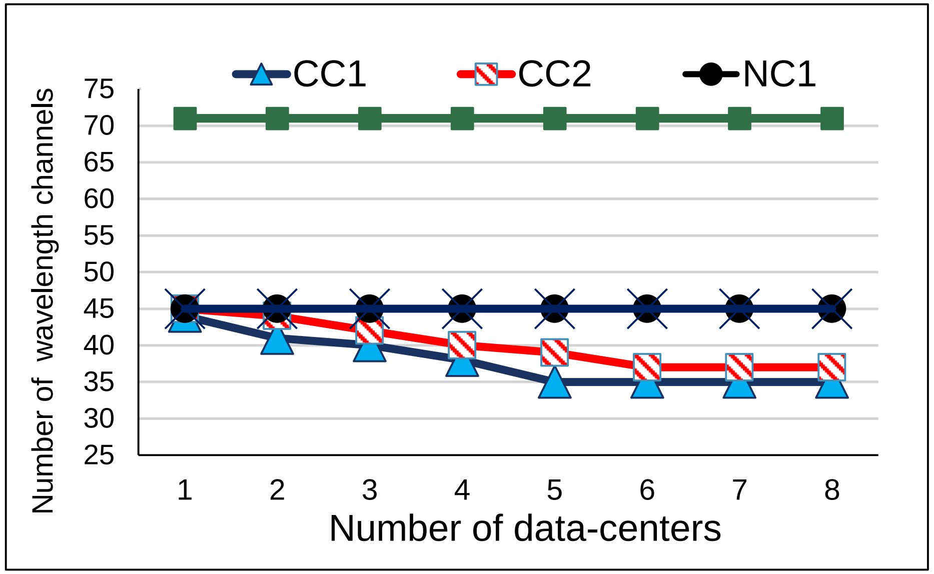
- For the proposed logical topologies, we show that it is possible to guarantee content connectivity with minimum resources and with a limited number of data centers.

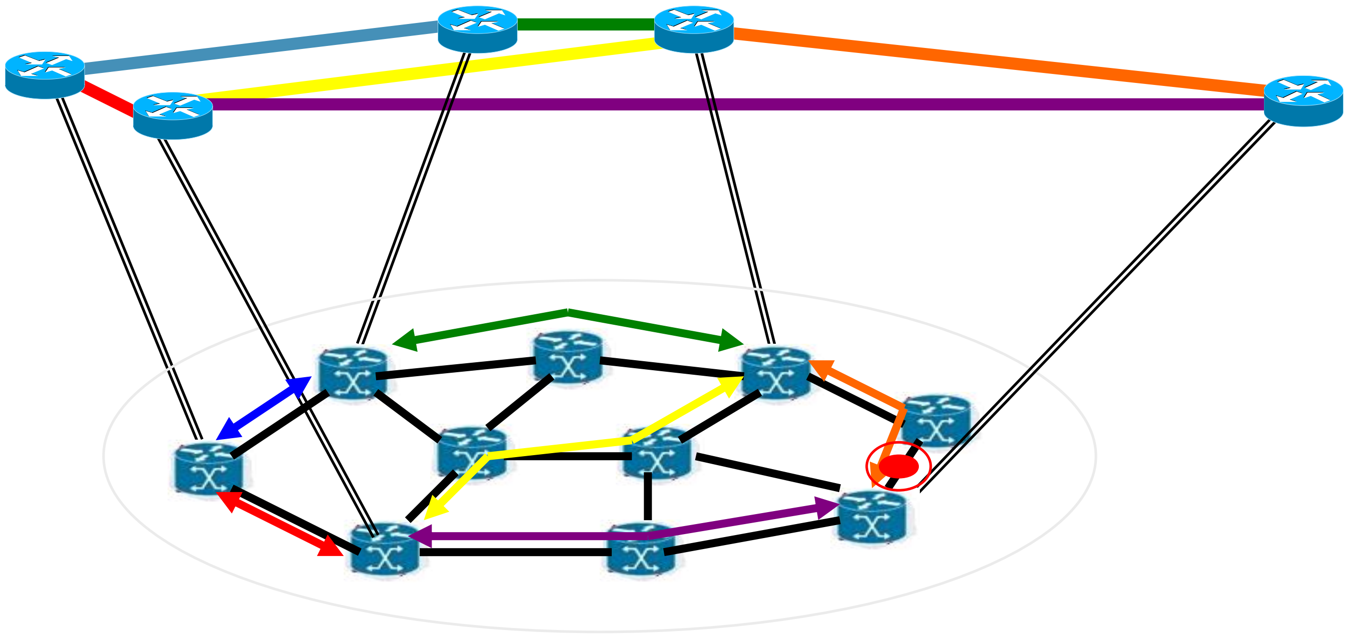
- CC1 requires almost the same amount of resources as NC1 for all design scenarios
  - No impact of the logical topology

- It is possible to guarantee continuity of the service after double-link failures with less resources
  - NC1 + CC2 requires 53% less resources with respect to NC2 on 8 node mesh virtual network with average node degree equal to 3
  - Especially when NC2 is not applicable

FUTURE WORKS

- Investigate theoritical bounds of content connectivity
- Design an heuristic to solve the problem for large instances
- Solve the problem under new constraints such as latency, storage capacity and content categorization





Thank you