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DISASTER PROTECTION IN EO-DCNS LEVERAGING COOPERATIVE STORAGE

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IMT Colloque
“Gestion de crise et numérique”

March 31, 2022

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CHAPITRE 1

INTRODUCTION: EO-DCN

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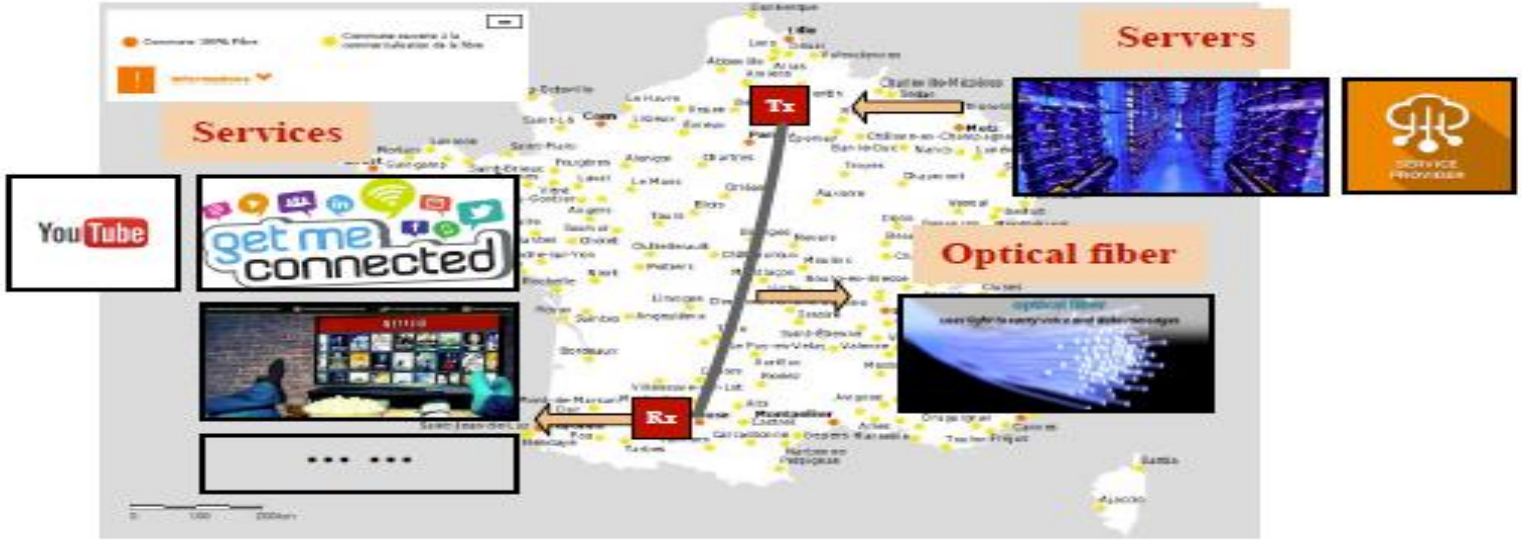
Dramatically Increased Data

- ►2,142 ZB Internet data in 2035
- ►700 hyperscale datacenters by the end of 2021



https://reseaux.orange.fr/cartes-de-couverture/fibre-optique

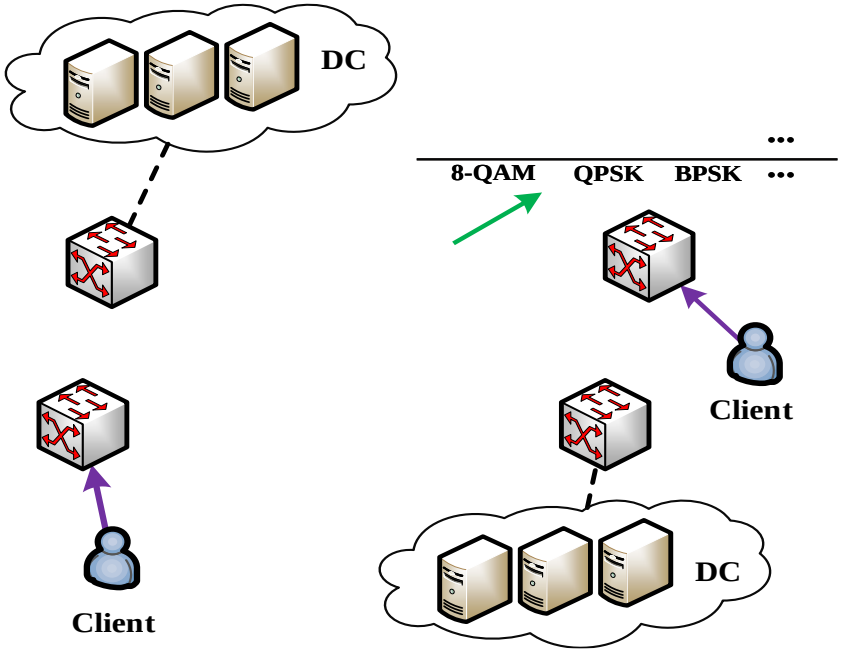


Figure 1: Architecture of EO-DCN [1].

Elastic Optical Inter-DataCenter Networks (EO-DCNs):

- High spectrum efficiency
- Huge bandwidth
- Low latency and interference
- High availability
- Big data storage and cloud services

[1] M. Ju, Y. Liu, F. Zhou, S. Xiao. Disaster-Resilient and Distance-adaptive Services Provisioning in Elastic Optical Inter-Data Center Networks. IEEE JLT: 1-14, March 2022

CHAPITRE 2

NETWORK SURVIVABILITY AND LARGE-SCALE DISASTER FAILURES

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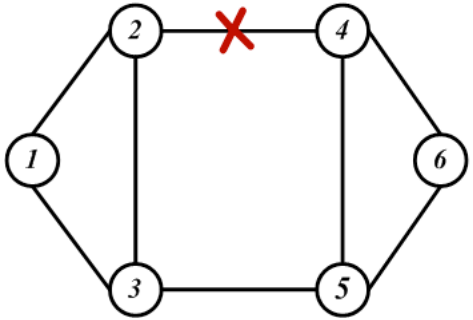
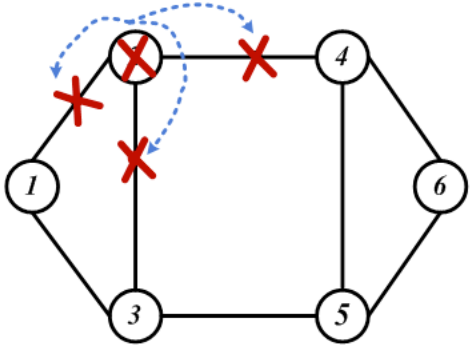
Link Failure

Construction, damaged Connectors, ……



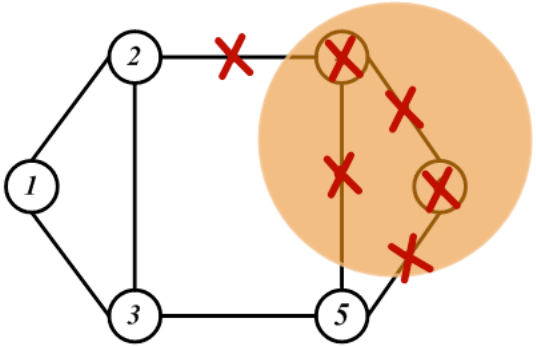
Node Failure

Node equipment failure (transponder,switching)……



Large Area Failure

Datacenter system damage, earthquake, wars, attacks ...



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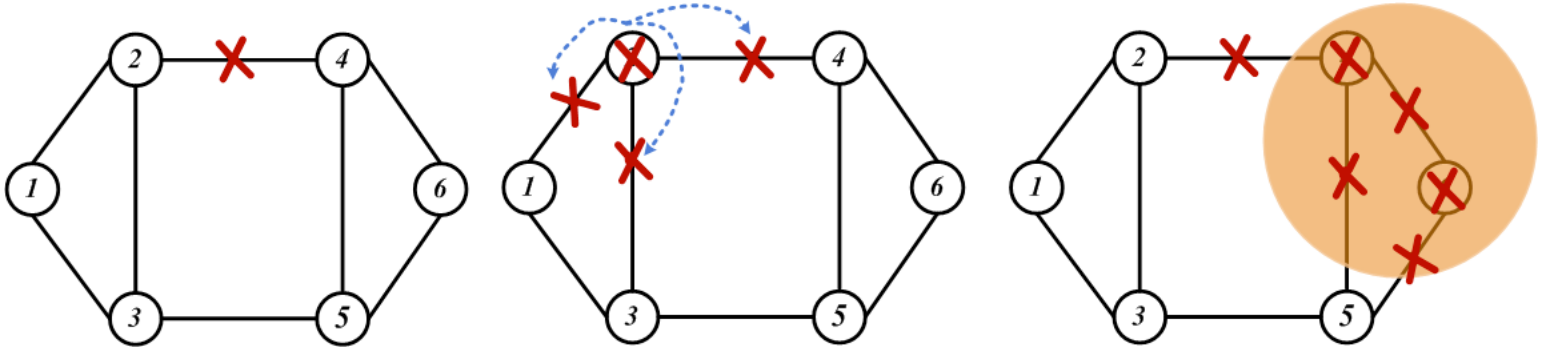

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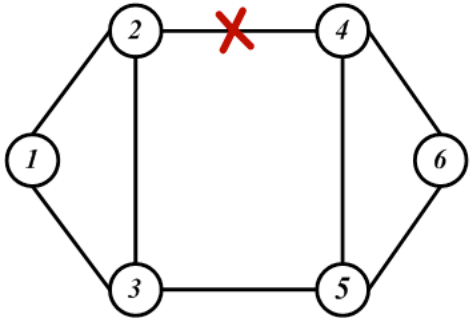
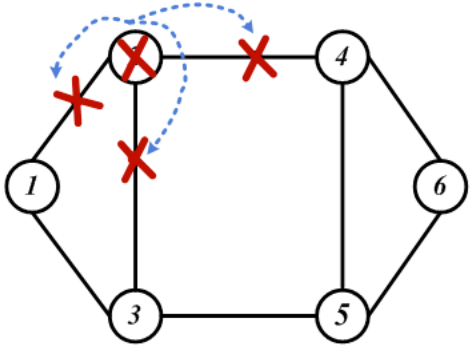


Most common !

Node Failure

Node equipment failure (transponder,switching)……



Large Area Failure

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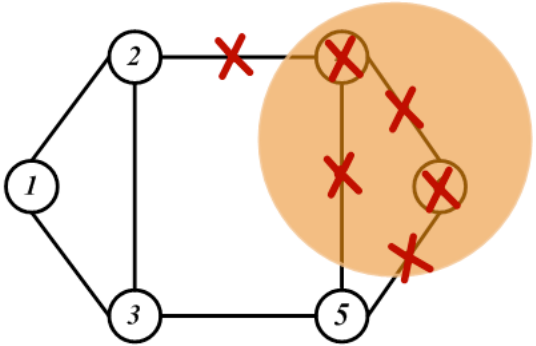
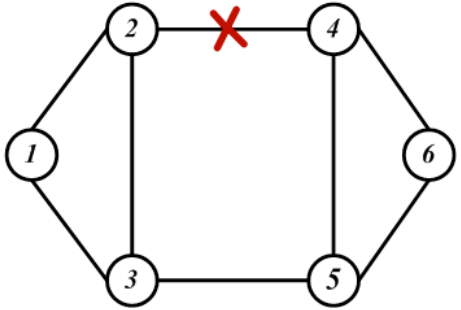


Threat on Datacenter networks!!

Link Failure

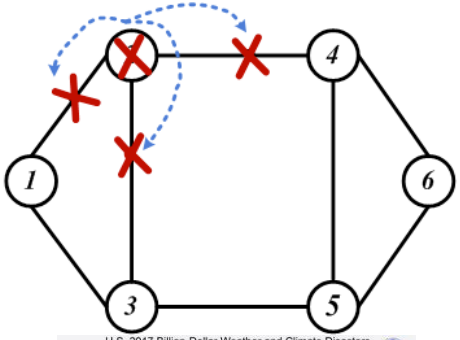
Construction, damaged Connectors, ……



Cables were cut by ship, 2017, Somalia. $10 million/day

Node Failure

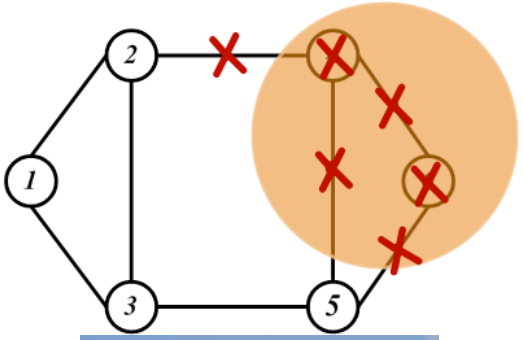
Node equipment failure (transponder,switching)……



Weather and climate disasters, 2017, USA. $306 billion

Large Area Failure

Datacenter system damage, earthquake, wars, attacks ...



A ”power surge” in one British Airways’ datacenter, 2017

Disasters

- Earthquake, hurricane, **volcano**, **flood**, fire, war ...
- Average loss of DC disconnection /minute : 402,542 $ in the USA and 212,254 $ in the UK in 2018

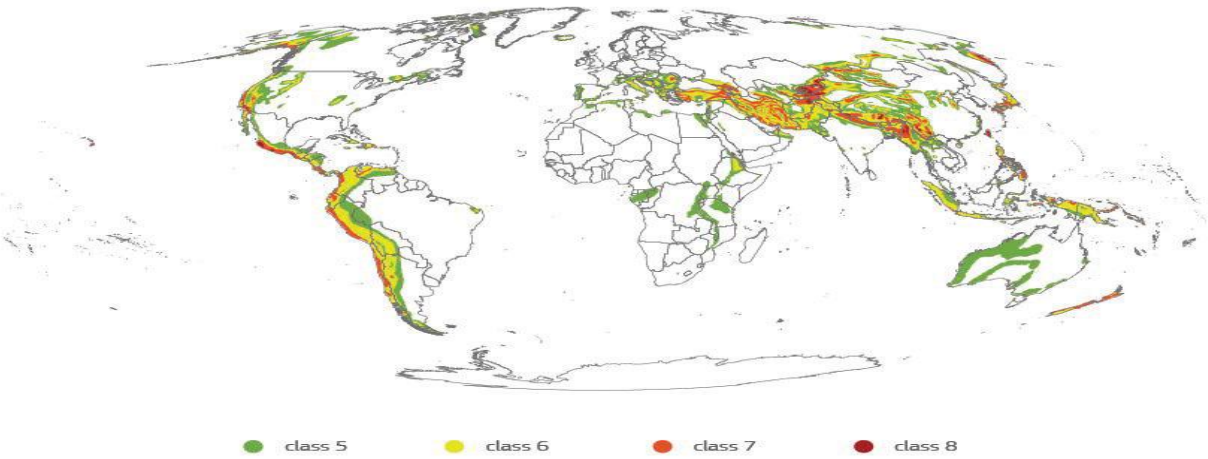


Figure 2: Earthquake Hazards Map [2].

[2] Pesaresi, M., et al. “Atlas of the human planet 2017. Global exposure to natural hazards,” 2017.

CHAPITRE 3

PROTECTION AGAINST LARGE-SCALE DISASTER FAILURES IN EO-DCNS

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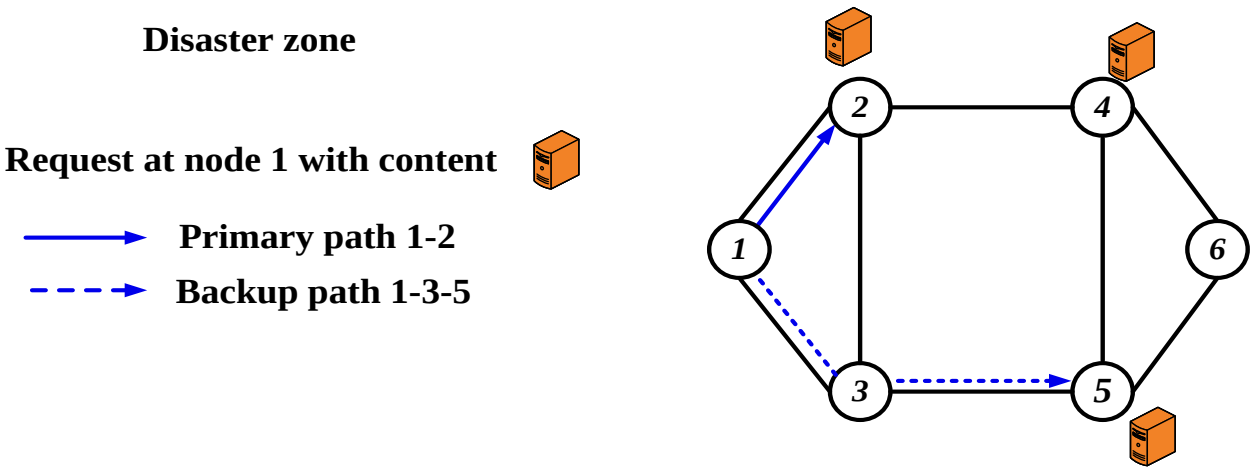
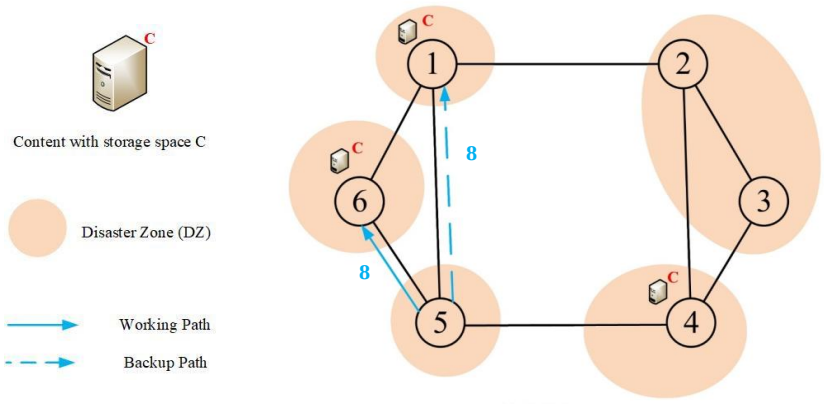
3.1 Large Area Disaster Failure in EO-DCNs

- Disasters: Volcano, Tsunamis, Hurricane, Flood, etc...
- Disaster zones: Set of OXC nodes (DCs) and fiber links
- DC content survivability
- Disaster-disjoint primary path and backup path



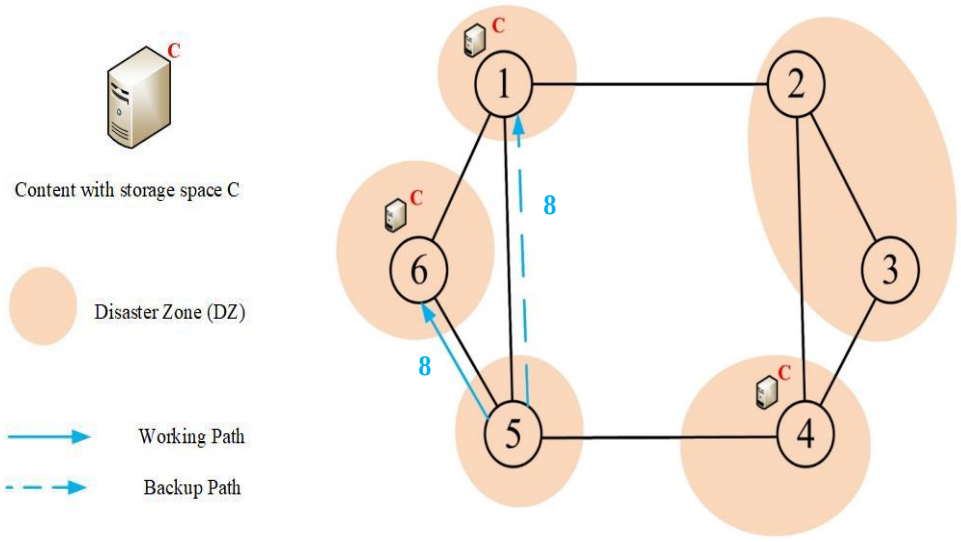
Dedicated End-to-content Backup Path Protection (DEBPP)

- ►Backup mirroed content on a redondant DC (Traditional storage system)
- ►1 working path + 1 end-to-content backup path
- ►Dedicated 1+1 protection



(a) DEBPP

Example: Node 5 requires content C with a bandwidth of 8 FS



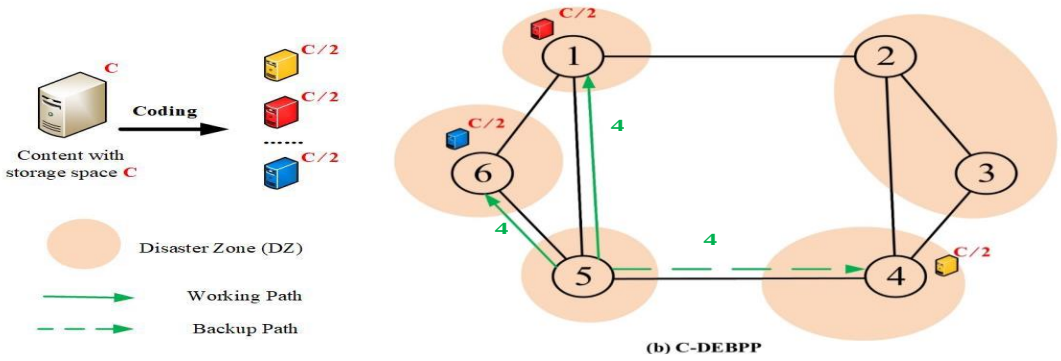
(a) DEBPP

DEBPP

- **Spectrum Usage**: 16 FS
- **Maximum FS Index**: 8 FS
- **Storage Space**: 2 C

Cooperative Storage System (CSS)+Mulitpath Routing

- Original content divided into k fragments
- Encoded into distinct numberless fragments with rate-less coding
- Recovery with k encoded fragments
- **Cooperative storage** : Content stored on k DCs each with one encoded fragement
- **Multiple working paths** + 1 end-to-content backup path



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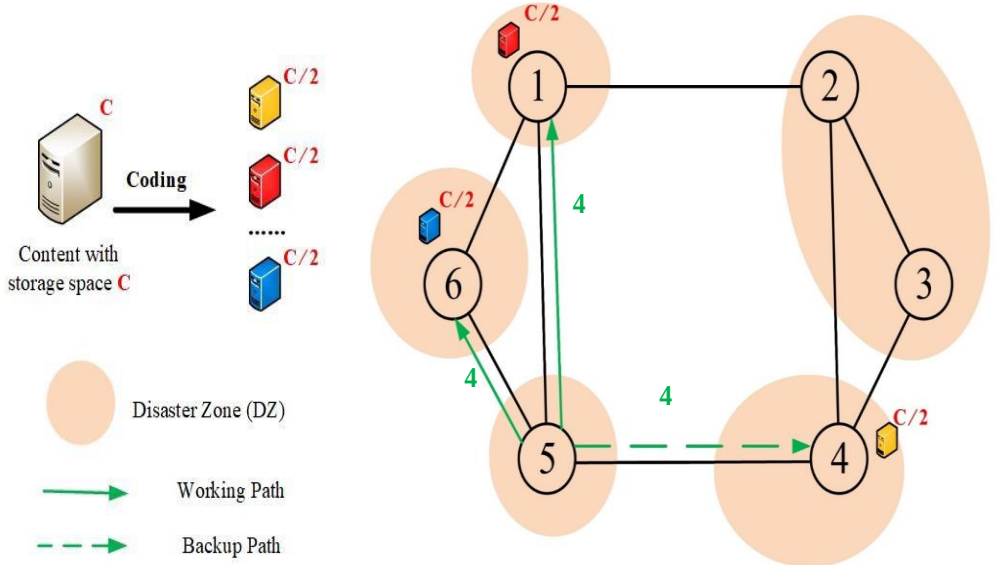

(b) C-DEBPP

C-DEBPP

- **Spectrum Usage**: 12 FS
- **Maximum FS Index**: 4 FS
- **Storage Space**: 1.5 C

DEBPP

- **Spectrum Usage**: 16 FS
- **Maximum FS Index**: 8 FS
- **Storage Space**: 2 C

Disaster-Resilient Service Provisioning Problem

Inputs:

- Set of disaster zones (DZs)
- Set of requests and their required
- Number of DCs and content replica (k)
- EON topology and set of FSs

Outputs:

- DC location
- Placement of content replica
- Disaster-disjoint primary and backup paths
- FS allocation

Objective: Minimize total spectrum utilization

- Spectrum utilization + Storage space
- DEBPP vs. C-DEBPP

Problem complexity and resolutions

- NP-hard problem !
- Optimal solution : Integer linear program (ILP) → not scalable
- Scalable and tractable approach: Heuristics or Column generation

CHAPITRE 4

OPTIMIZATION SOLUTIONS: ILP AND HEURISTIC

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Methodology 1: Joint ILP Formulation

Objective: minimize spectrum usage

Ojective:

Link-FSs Max-FSs

$$\textit{Minimize} \quad \theta_1 \cdot \left(\sum_{a \in A} \sum_{r \in R} p_{ra}^{W} \cdot \phi_r + \sum_{a \in A} T_a\right) + \theta_2 \cdot \Delta$$

Constraints:

- Datacenter and content assignment
- Disaster-disjoint path generation
- Spectrum allocation

Computational complexity:

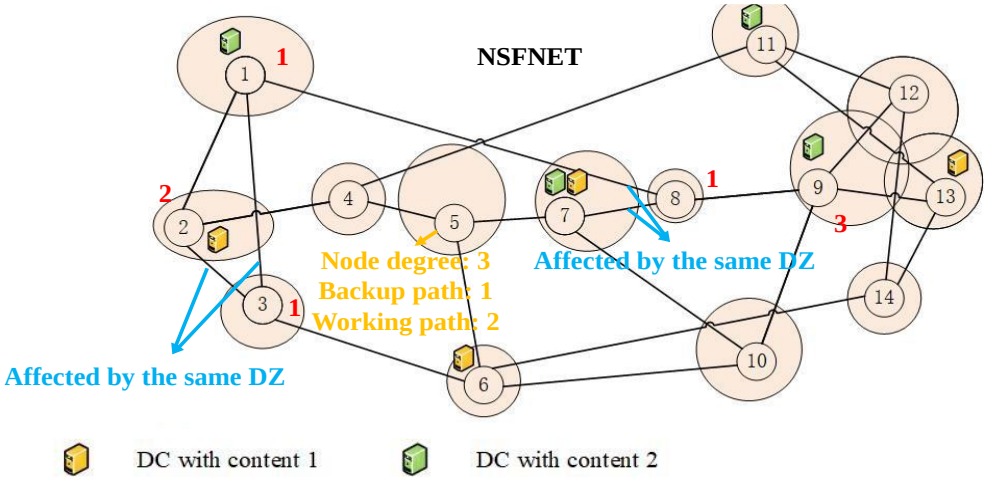
- DEBPP
  - No. of dominant variables $O(|R|^2, |R||A|, |R||Z|, |C||D|)$
  - No. of dominant constraints $O(|R|^2|A|, |R||Z||A|)$
- C-DEBPP
  - No. of dominant variables $O(|R|^2, |R||A|, |R||Z|, |C||D|)$
  - No. of dominant constraints $O(|R|^2|A|, |R|^2|Z|, |R||Z||A|)$

Main Idea of Heuristic: decomposition

- Step 1: Content and replica placement (ILP, facility location)
- Step 2: Working/backup path generation (K-shortest path routing)
- Step 3: Spectrum allocation (Coloring algorithm)

Step 1: DC assignment and content placement

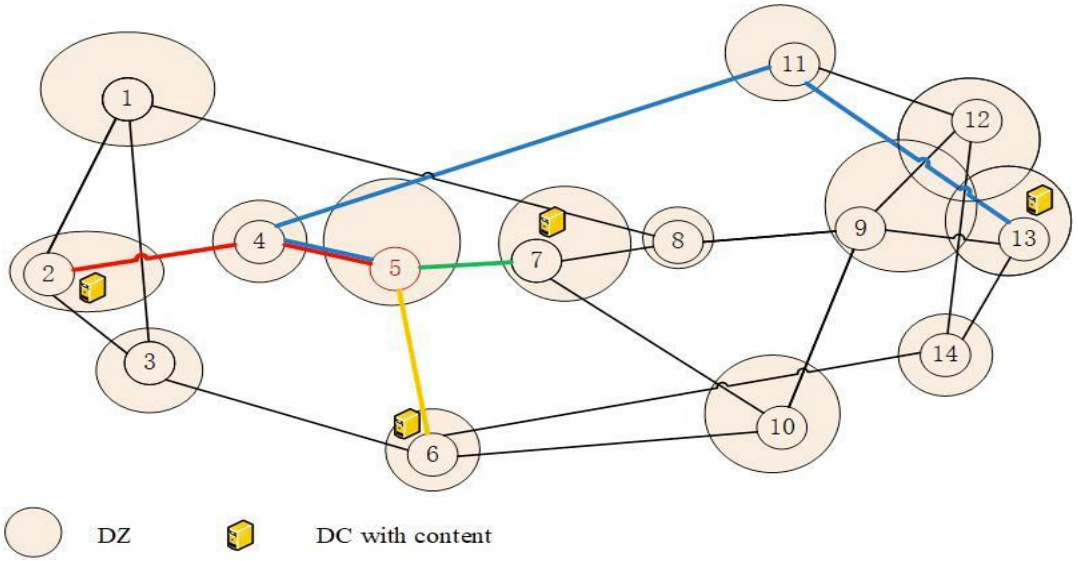
- K DC nodes: Average minimum distance ([3])
- Place content replica in DCs closer to its popular region



[3] Habib et al. Design of disaster-resilient optical DC networks. J. Lightw. Technol., 2012.

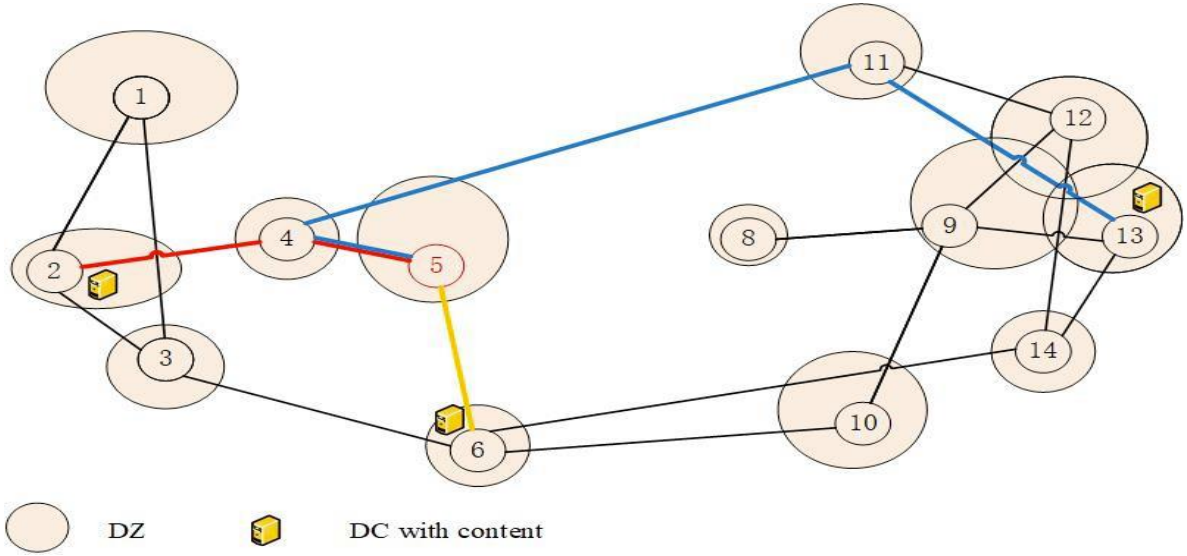
Step 2-1: Generate first path

- k-shortest paths routing to DCs
- Select the path with the minimum cost (spectrum utilization)



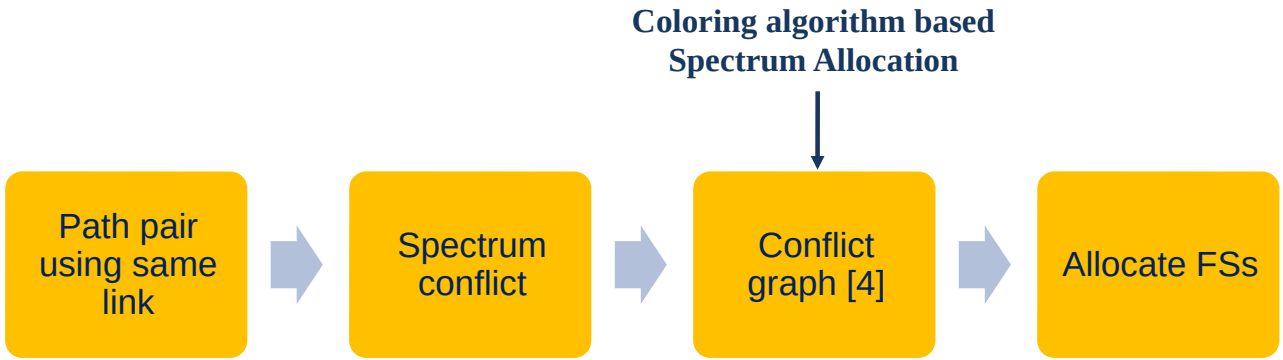
Step 2-2: Generate DZ-disjoint path

- Delete the DZ-affected links and nodes
- Apply again k-shortest routing to DCs until k paths are found



Step 3: Spectrum allocation (coloring based SA algorithm)

- Spectrum continuity constraint
- Spectrum contiguity constraint
- Spectrum distinction constraint



[4] H. Wu, F. Zhou, Z. Zhu, and Y. Chen, “On the distance spectrum assignment in elastic optical networks,” IEEE/ACM Trans. Netw., vol. 25, no. 4, pp. 2391–2404, Aug. 2017.

CHAPITRE 5
NUMERICAL RESULTS

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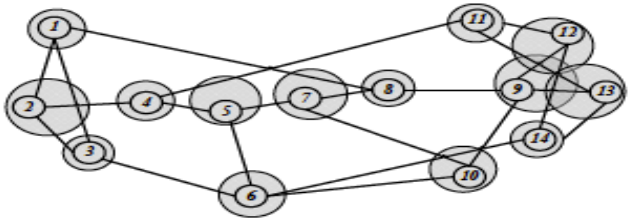
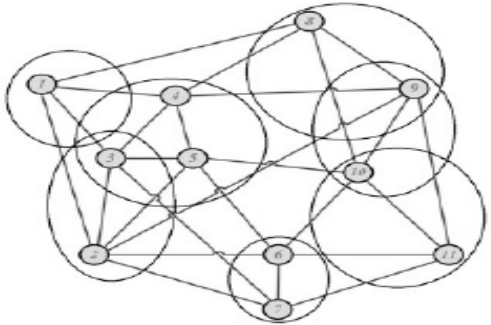
Simulations Settings

- NSFNET network
  14 nodes, 44 links
  3.1 nodal degree, 14 DZs



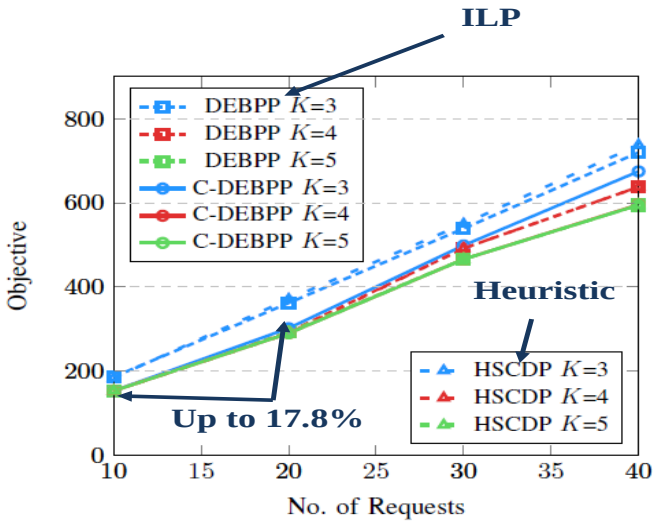
- Hardware: 3.5 GHz CPU, 8 GBytes RAM
- Software: CPLEX 12.06
- Traffic
  - FSs: randomly [1, 10]
  - No. of requests: 10, 20, 30, 40

- COST-239
  11 nodes, 52 links
  4.7 nodal degree, 7 DZs

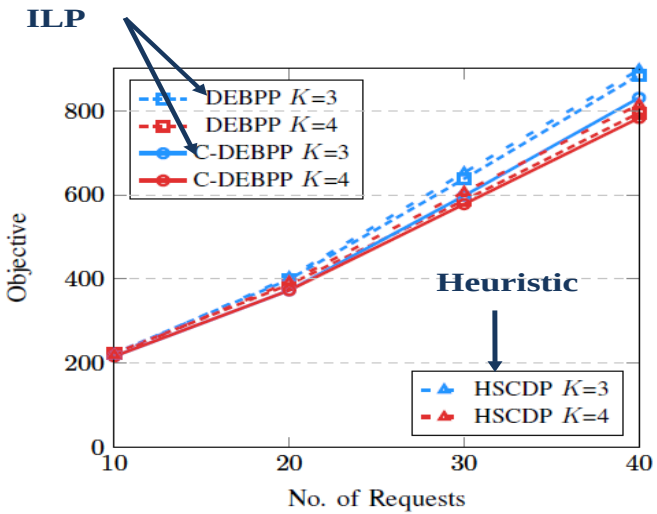


- Parameters:
  - Available DC locations: 4, 5
  - No. of contents: 10
  - No. of replicas per content (K): 3, 4, 5

Spectrum utilisation in NSFNET : C-DEBPP vs. DEBPP



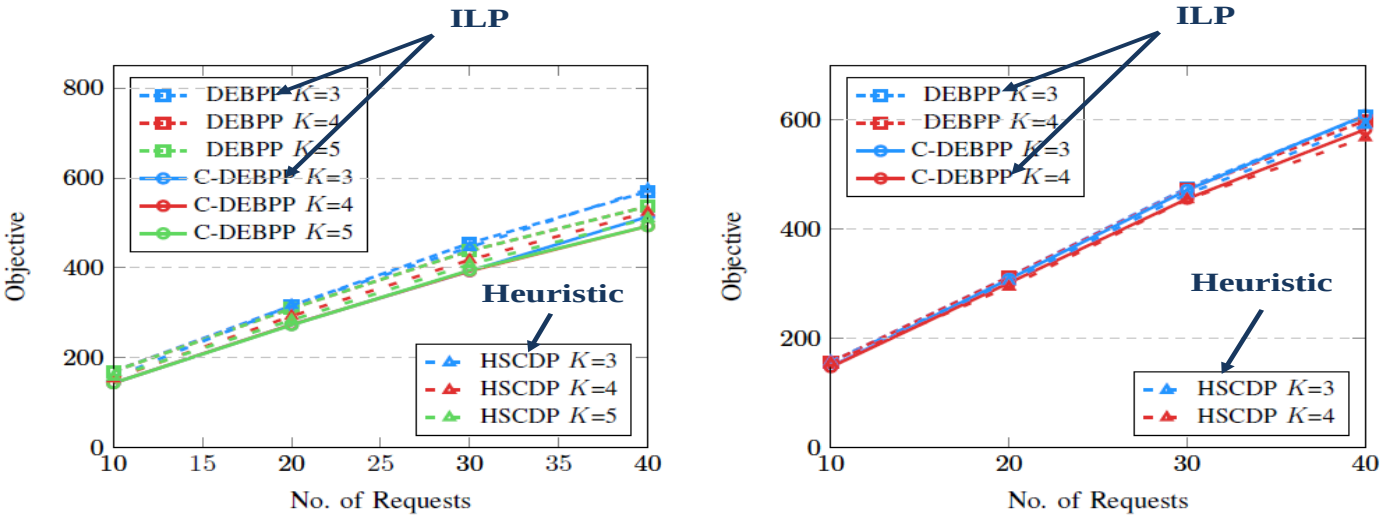
(a) Objective vs. K (5 probable DC locations)



(b) Objective vs. K (4 probable DC locations)

NSFNET

Spectrum utilization in COST239 : C-DEBPP vs. DEBPP

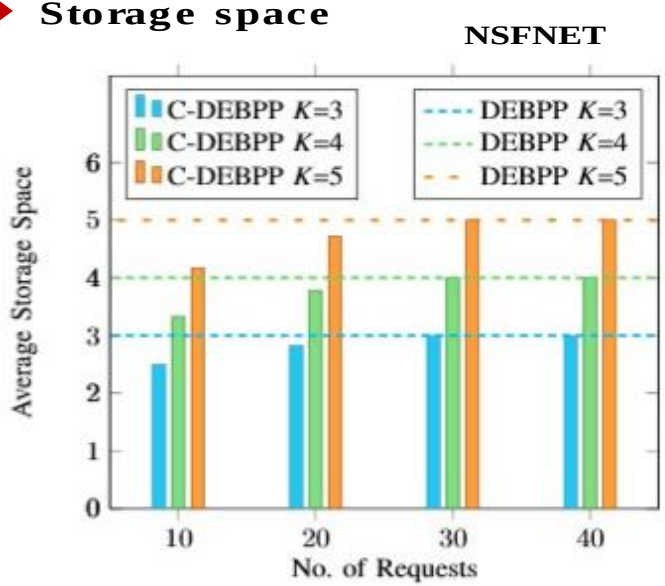


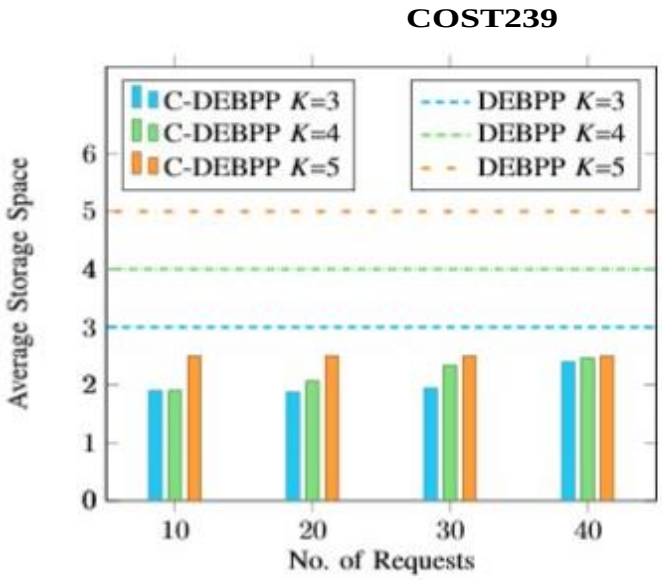
(a) Objective vs. K (5 probable DC locations) (b) Objective vs. K (4 probable DC locations)

COST239

Storage Space: C-DEBPP vs. DEBPP

- **Storage space**





Up to 50%

CHAPITRE 6
CONCLUSIONS

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Protection Schemes

- DEBPP
- C-DEBPP (Cooperative Storage, Multipath routing)

Advantage of C-DEBPP

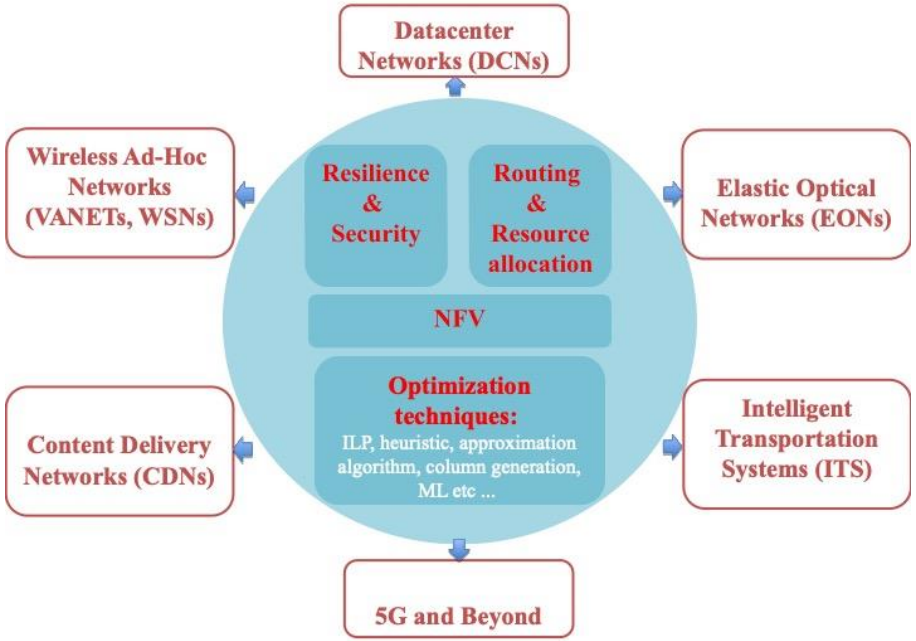
- Spectrum utilization savings: up to 17.8%
- Storage space savings: up to 50%

Optimization Methods

- ILP
- Heuristic

M. Ju, Y. Liu, F. Zhou, S. Xiao. Disaster-Resilient and Distance-adaptive Services Provisioning in Elastic Optical Inter-Data Center Networks. IEEE JLT: 1-14, March 2022

Y. Liu, F. Zhou, C. Chen, Z. Zhu, T. Shang, J. Torres-Moreno. Disaster Protection in Inter-DataCenter Networks leveraging Cooperative Storage. IEEE TNSM, pp1-14, June 2021.



Perspectives

- Security-aware multilayer planning
- Disaster-resilient service provisioning
- Optimization techniques are helpful: ILP, heuristic, CG

THANK YOU

QUESTIONS

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