DISASTER PROTECTION IN EO-DCNS LEVERAGING COOPERATIVE STORAGE

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“Gestion de crise et numérique”

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1. INTRODUCTION: EO-DCN
2. NETWORK SURVIVABILITY AND LARGE-SCALE DISASTER FAILURES
3. PROTECTION AGAINST LARGE-SCALE DISASTER FAILURES IN EO-DCNS
4. OPTIMIZATION SOLUTIONS: ILP AND HEURISTIC
5. NUMERICAL RESULTS
6. CONCLUSIONS
CHAPITRE 1
INTRODUCTION: EO-DCN
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
1.1 Elastic Optical Inter-DataCenter Networks (EO-DCNs)

Elastic Optical Inter-DataCenter Networks (EO-DCNs):
- High spectrum efficiency
- Huge bandwidth
- Low latency and interference
- High availability
- Big data storage and cloud services

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

Chapitre 2: Network Survivability and Large-Scale Disaster Failures
2.1 Survivability in EO-DCNs

**Link Failure**
Construction, damaged Connectors, ……

**Node Failure**
Node equipment failure (transponder, switching) ……

**Large Area Failure**
Datacenter system damage, earthquake, wars, attacks …
2.1 Survivability in EO-DCNs

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### Link Failure
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### Node Failure
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### Large Area Failure
Datacenter system damage, earthquake, wars, attacks ……

**Most common!**

**Threat on Datacenter networks!!**
2.1 Survivability in EO-DCNs

**Link Failure**
Construction, damaged Connectors, ……

**Node Failure**
Node equipment failure (transponder, switching) ……

**Large Area Failure**
Datacenter system damage, earthquake, wars, attacks ……

- Cables were cut by ship, 2017, Somalia. $10 million/day
- Weather and climate disasters, 2017, USA. $306 billion
- 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].

CHAPITRE 3
PROTECTION AGAINST LARGE-SCALE DISASTER FAILURES 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

Disaster zone

Request at node 1 with content

Primary path 1-2

Backup path 1-3-5
Dedicated End-to-content Backup Path Protection (DEBPP)

- Backup mirrored content on a redundant DC (Traditional storage system)
- 1 working path + 1 end-to-content backup path
- Dedicated 1+1 protection
Example: Node 5 requires content C with a bandwidth of 8 FS

DEBPP
► Spectrum Usage: 16 FS
► Maximum FS Index: 8 FS
► Storage Space: 2 C
Cooperative Storage System (CSS)+Multilpath 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 fragment
- **Multiple working paths** + 1 end-to-content backup path
Example: Node 5 requires content C with a bandwidth of 8 FS

**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
Methodology 1: Joint ILP Formulation

Objective: minimize spectrum usage

Objective:
\[
\text{Minimize } \theta_1 \cdot (\sum_{a \in A} \sum_{r \in R} P^W_{ra} \cdot \phi_r + \sum_{a \in A} T_a) + \theta_2 \cdot \Delta
\]

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

**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
4.2 Methodology 2: Heuristic

**Step 3: Spectrum allocation (coloring based SA algorithm)**

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

Coloring algorithm based Spectrum Allocation

- Path pair using same link
- Spectrum conflict
- Conflict graph [4]
- Allocate FSs

CHAPITRE 5

NUMERICAL RESULTS
Simulations Settings

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

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

- 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)

Up to 17.8%
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**

**NSFNET**

**COST239**

Up to 50%
CHAPITRE 6
CONCLUSIONS
6.1 Summary

**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

6.2 Perspectives

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