Study of Multi-Entity Cooperation for Network-Cloud Recovery

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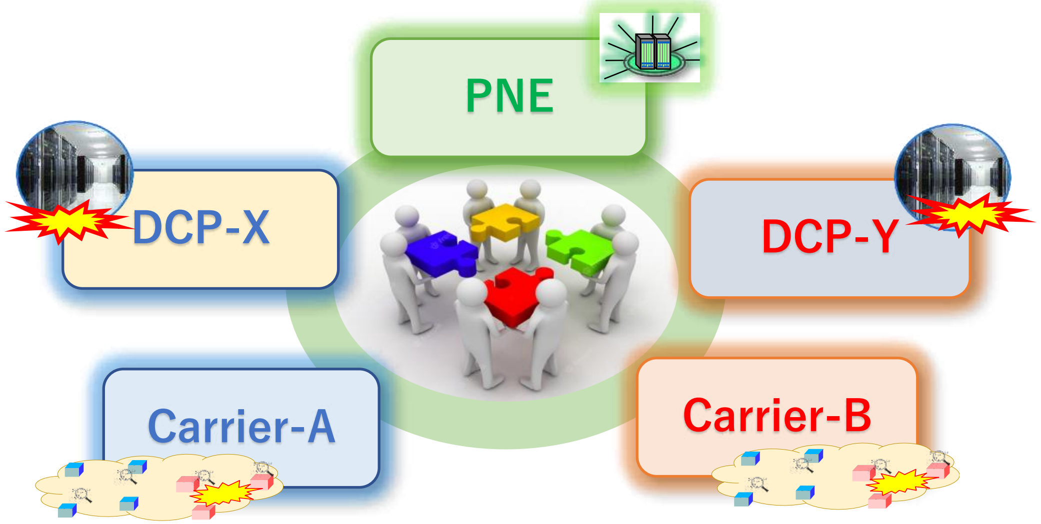
Outline

- **Background and motivations**
  - **In a Network-Cloud ecosystem (ecosystem) achieving resilience requires cooperation.**

Multi-entity ecosystem



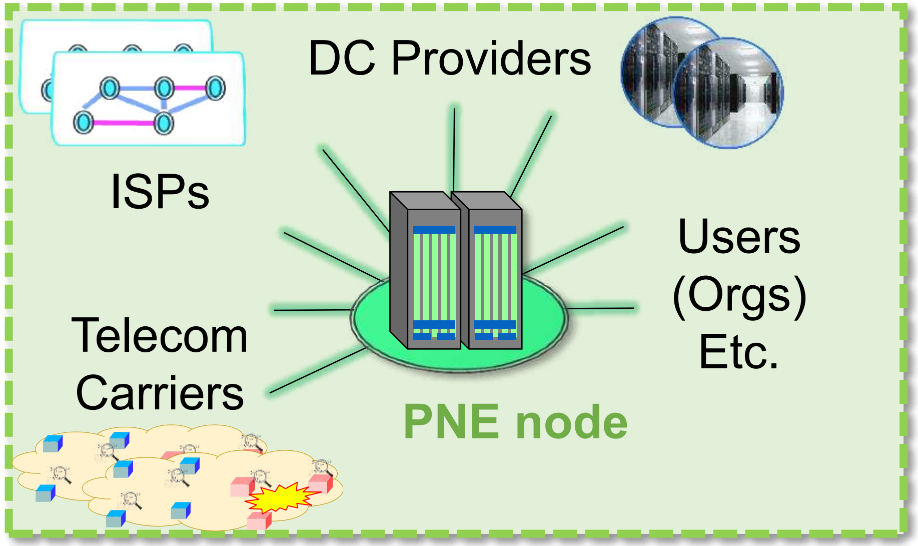
Multi-entity: network-cloud ecosystem is owned by different entities, e.g., Telecom **Carriers** and **Data Center Providers (DCPs)**

A new entity: ***Provider neutral exchange*** **(*PNE*),** a third-party entity facilitating multi-entity cooperation in ecosystem.

- **Modeling study of multi-entity cooperation for network-cloud recovery**
- **Platform study of multi-entity cooperation for network-cloud recovery**
- **Summary**

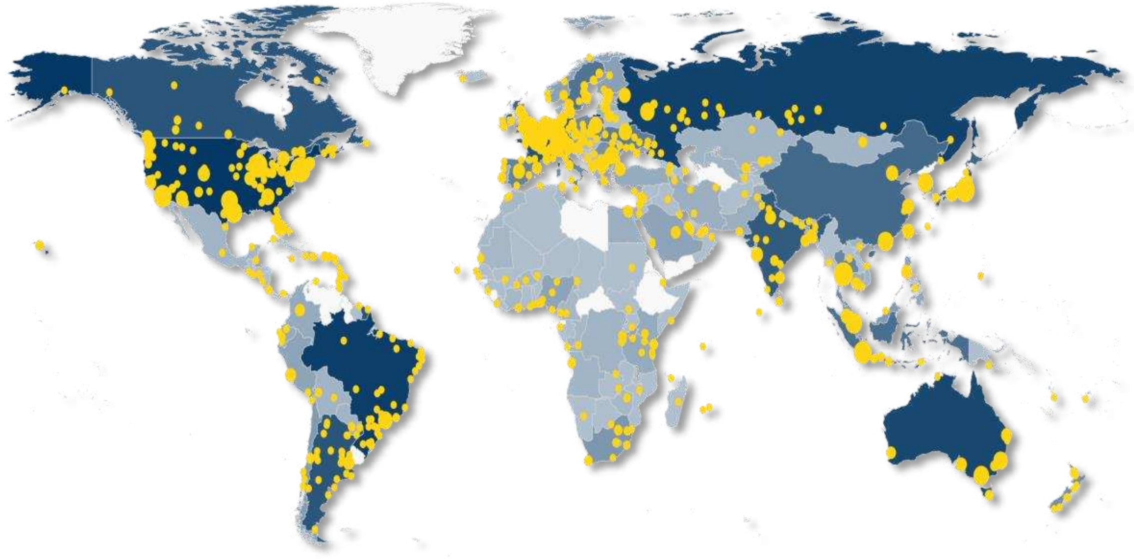
Introduction of Provider Neutral Exchange (PNE)

Provider neutral exchange (PNE)



PNE can be a consortium of distributed co-location centers or Internet exchange points.

***Candidate for PNE* (e.g., IXPs)**



Internet exchange points (IXPs) around the world[1]-[3]

[1] https://en.wikipedia.org/wiki/List_of_Internet_exchange_points
[2] https://www.pch.net/ixp/dir
[3] https://www.internetexchangemap.com/#/

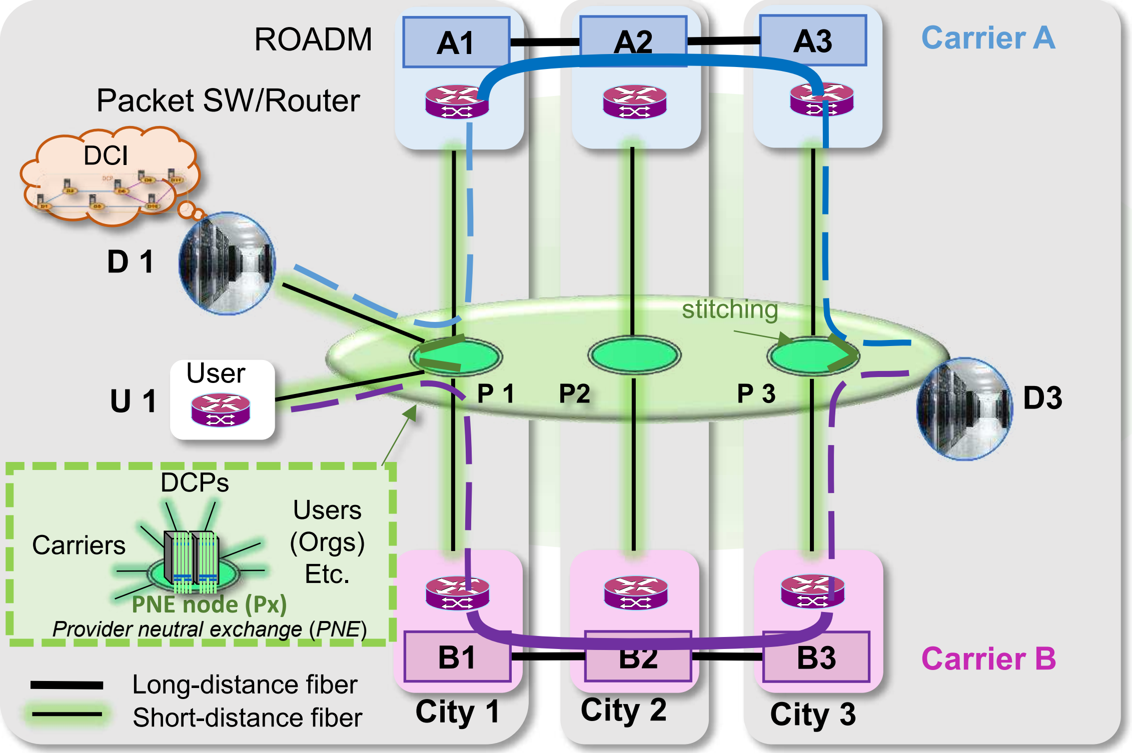
- Traffic exchange points in the network-cloud ecosystem
  - Interconnecting telecom carriers, ISPs, DC providers and users
- Candidates for PNE
  - IXP, colocation center, even DC provider and Telecom carrier

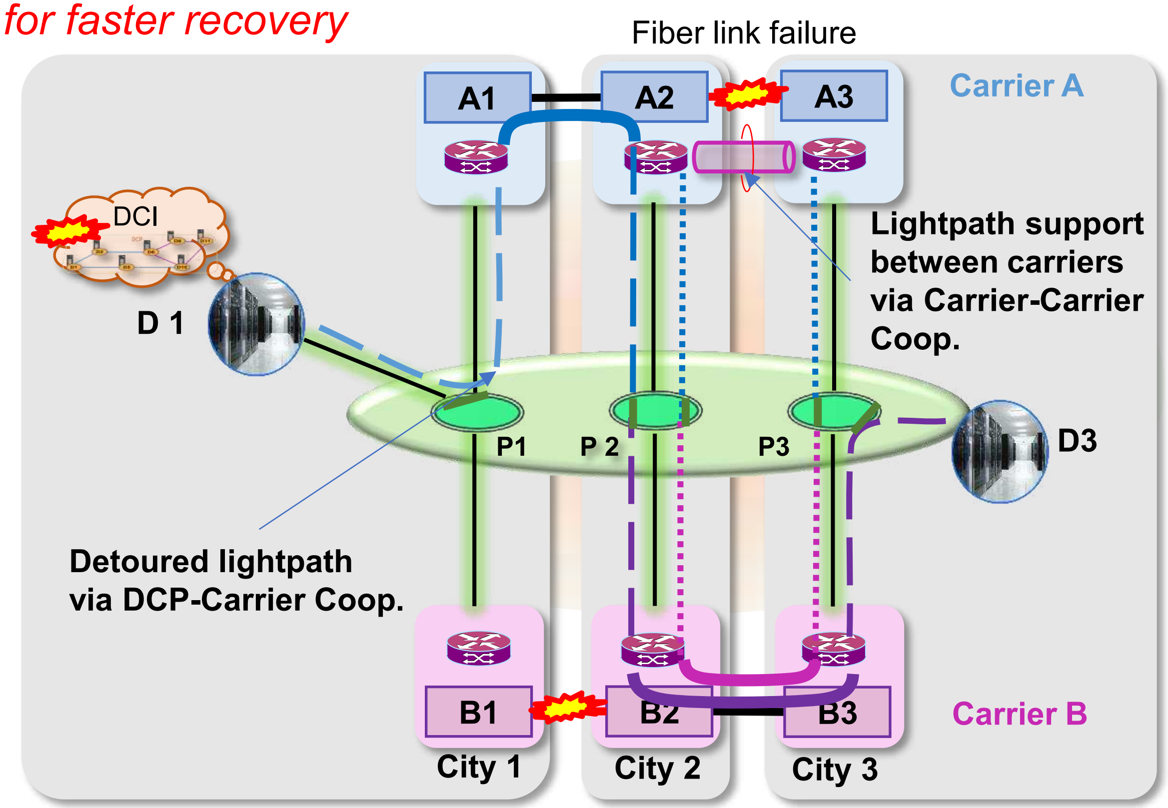
Target Use Cases: Cooperative Resource Allocation in Ecosystem

***Business-as-usual* Service:**
DCI lightpath/Slice service

***Failure/Disaster*:**
Enhanced resilience of ecosystems

We can employ the same
DCI lightpath/slice service for faster recovery





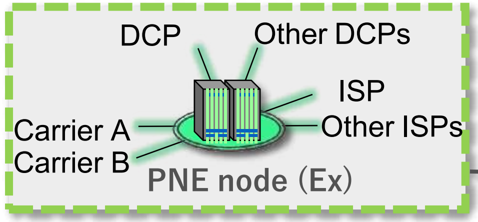
Questions:
- *How to facilitate cooperative resource allocation **without violating confidentiality**?*

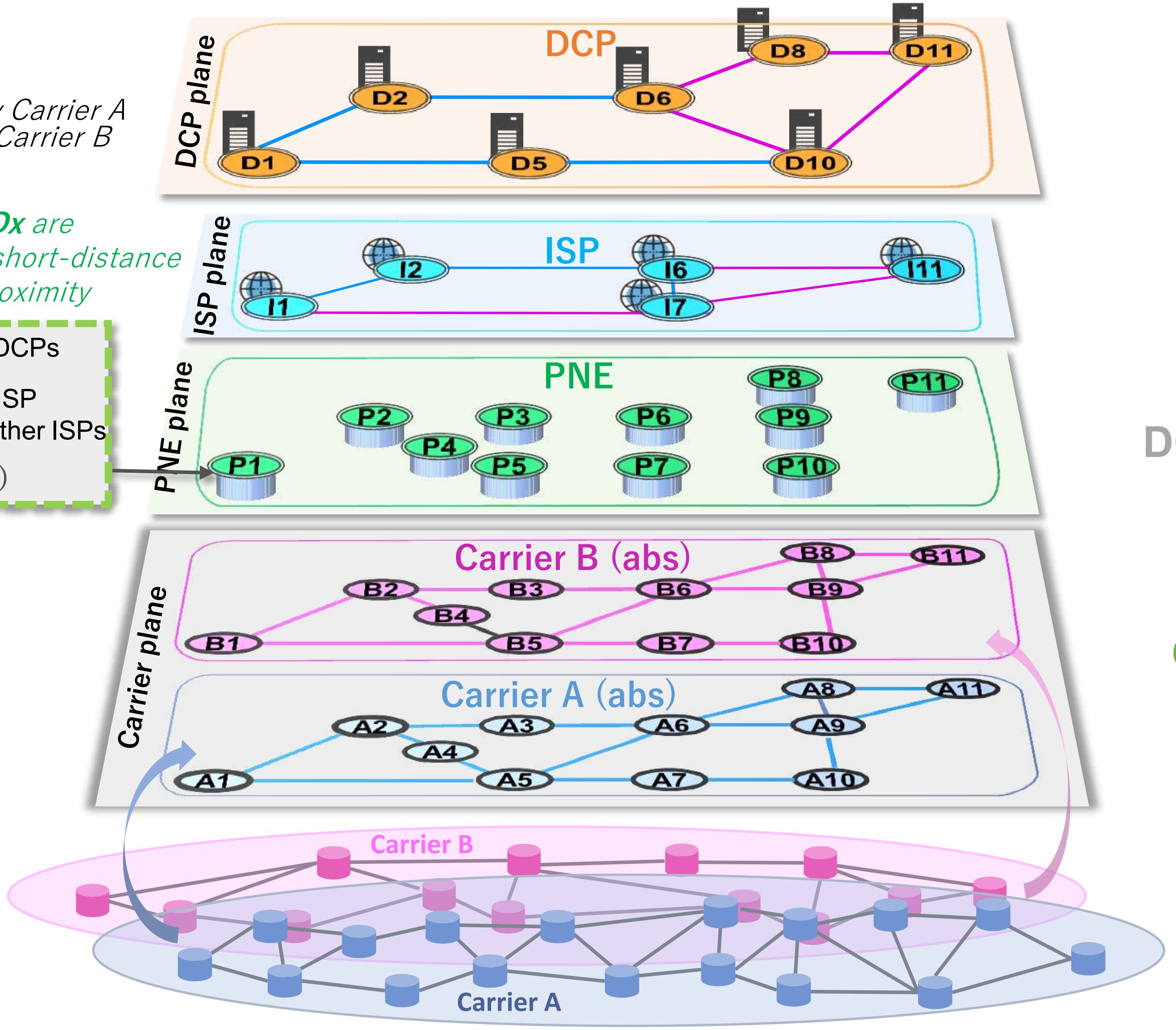
Modeling Study of Multi-Entity Cooperation for Network-Cloud Recovery

Modeling Study of Multi-Entity Cooperation for Network-Cloud Recovery

Connection supported by Carrier A
Connection supported by Carrier B

*Nodes **Ax, Bx, Ix, Dx** are connected through **Px** via short-distance links within close proximity*





Abstracted information with limited visibility

Confidential information

Overlapped physical network infrastructures of the carriers

DCP-Carrier-ISP Coop

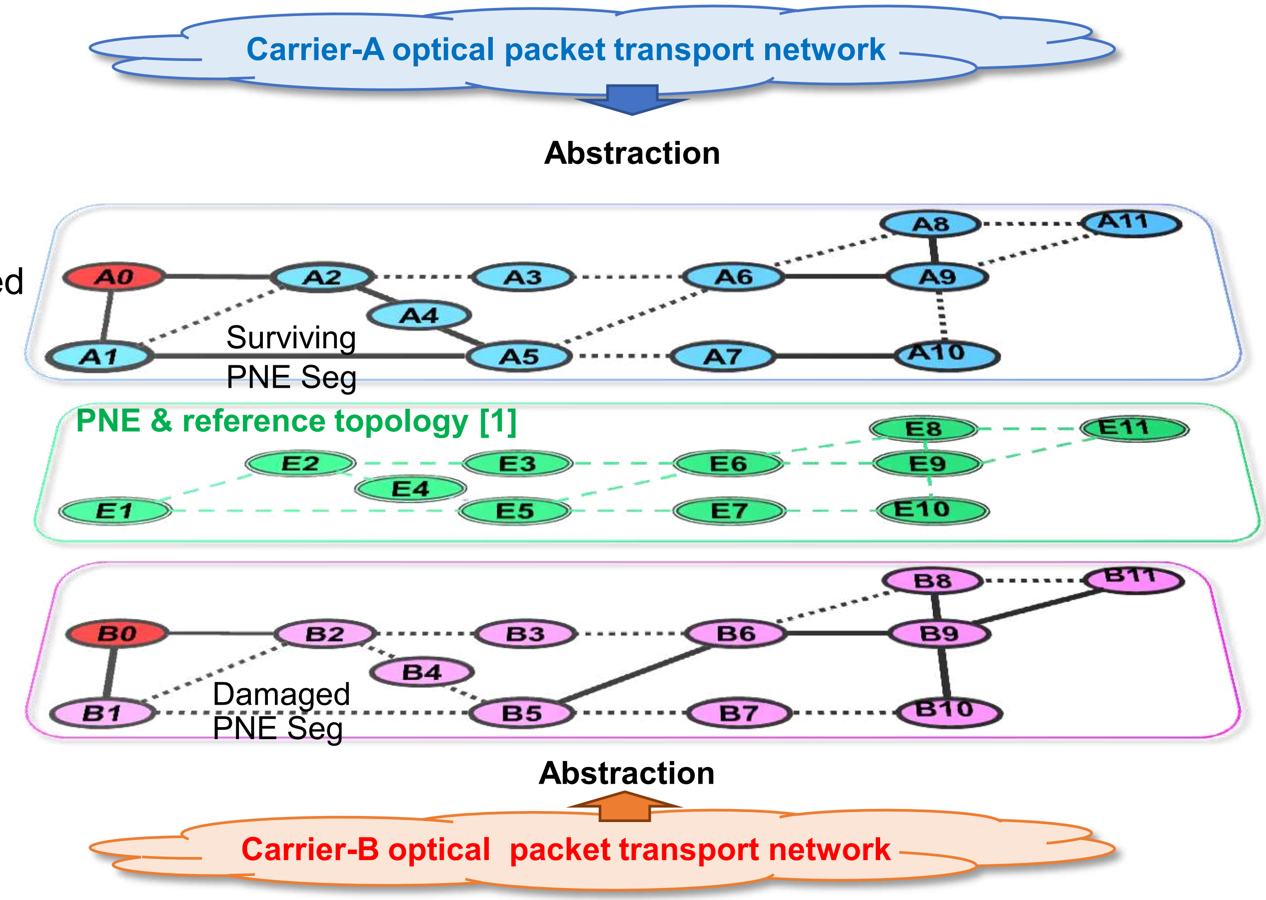
DCP-Carrier Coop

Carrier-Carrier Coop

Evaluations in Disaster Recovery Scenarios

To observe the potential benefits of carrier cooperation
Service restoration time and Carrier recovery cost

- **Topology:**
  - **Carrier networks**
    - For simplicity, both carrier networks are identical and abstracted to PNEN with 11 nodes and 15 links (a subset of Japan photonic network model **(JPNM) [1]**)
- **Damage scenario:**
  - **Damages in carrier networks**
    - *Heavy damage*: 5 survived links in Carriers A and B
    - *Light Damage*: 10 survived links in Carriers A and B
    - *Mixed damage*: 5 survived links in Carrier A and 10 survived links in Carrier B
  - **Recovery cost level of damaged fibre links**
    - *Low cost level*: [1, 4] units
    - *Medium cost level*: [1, 7] units
    - *High cost level*: [1, 10] units
  - **Strong correlated damage in carrier networks**
    - Carriers' co-located fibre links have a high probability, 0.8, to be failed simultaneously
- **Traffic demands:**
  - *Requests*: Avg. 12 highest priority IP-over-WDM connections
  - *Bandwidth*: Avg. 130 Gbps per connection Req
- **Etc.**
  - **Lightpath capacity** 100 Gbps
  - **Pseudo price of a carrier's lightpath support**
    - 2 units per survived link
    - Extra 50 units dummy price per damaged link in PNE topology

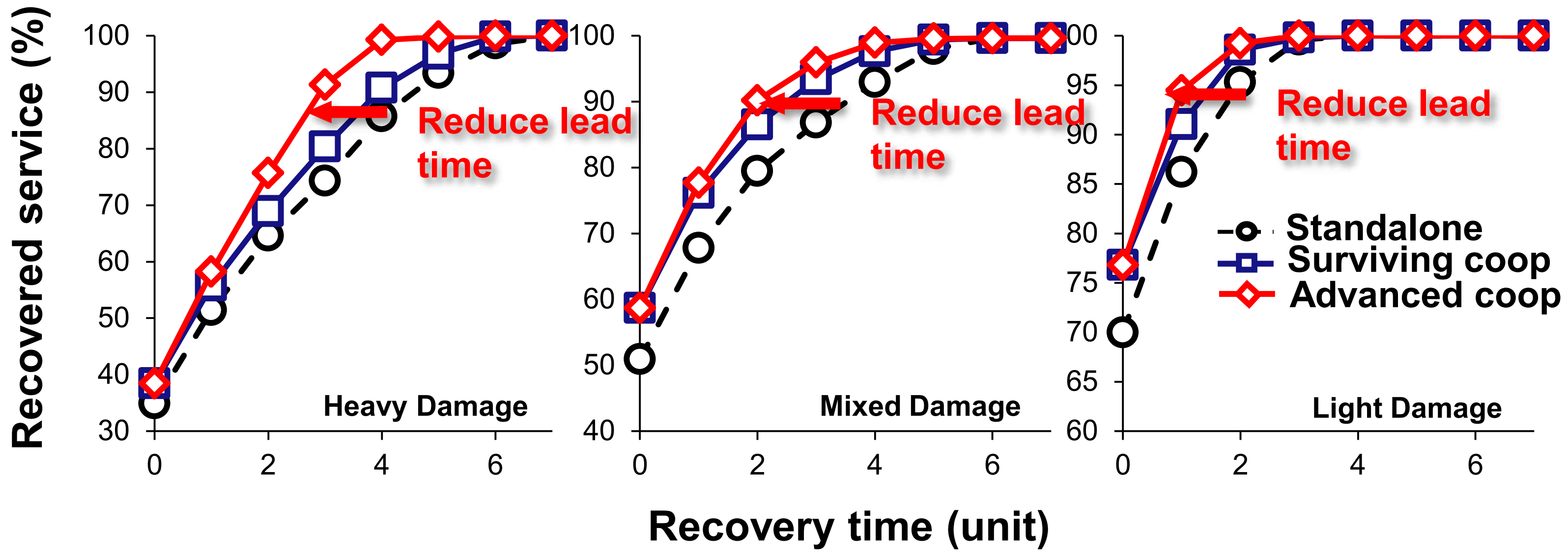


Overlapped carrier networks in disaster area

[1] T. Sakano et al., IEICE Tech. Rpt. PN2013-01, 2013.

Case Study 1: Carrier- Carrier Cooperative Recovery

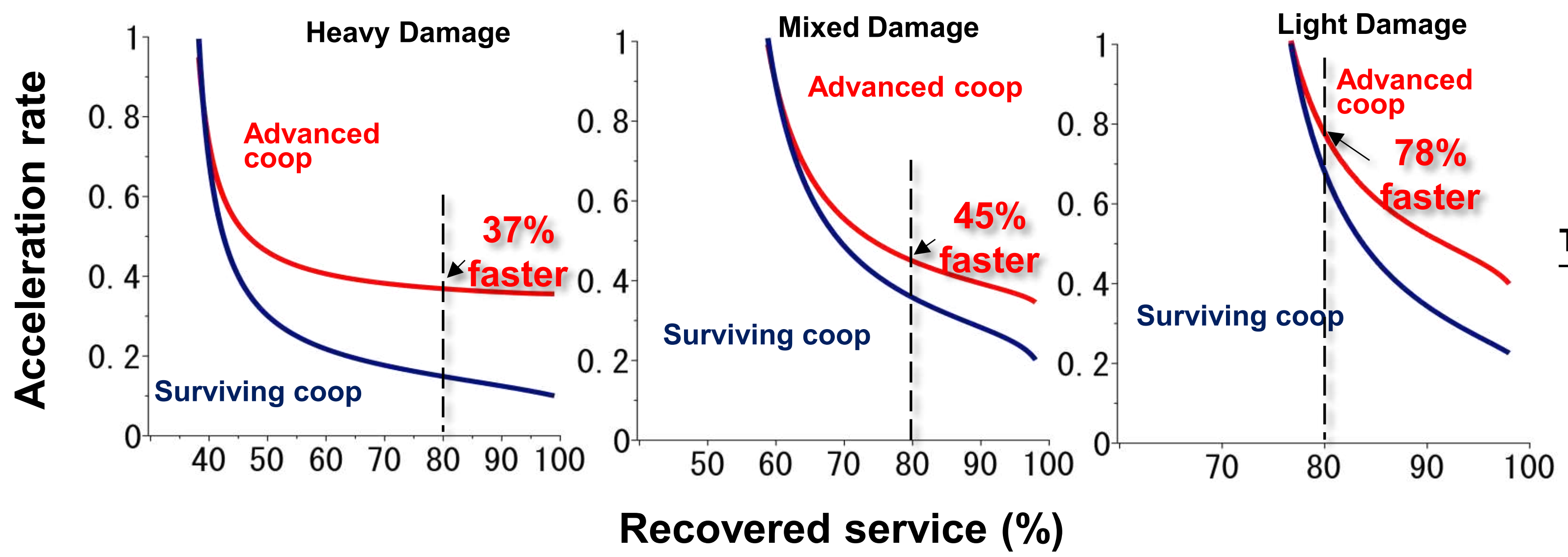
Lead Time Reduction



Original data
(lead time reduction)

Examples @ *Recovery Cost Level*: [1, 10]

Similar results with *recovery cost levels*: [1, 4], [1, 7]



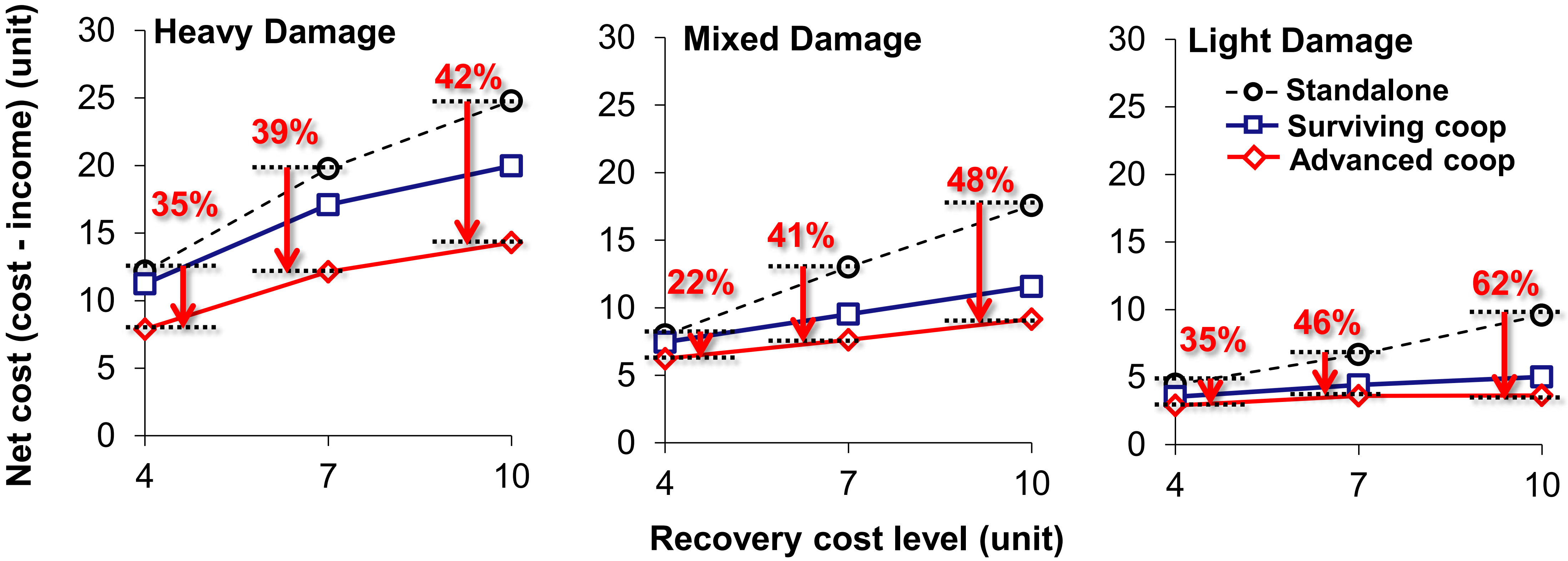
Trends observation
(lead time reduction)

Acceleration rate =

$$\frac{\text{Time in standalone recovery} - \text{Time in cooperative recovery}}{\text{Time in standalone recovery}}$$

S. Xu, et al, *ONDM2023* (**Best Paper Award**)
S. Xu, et al, *JOCN,* May 2024.

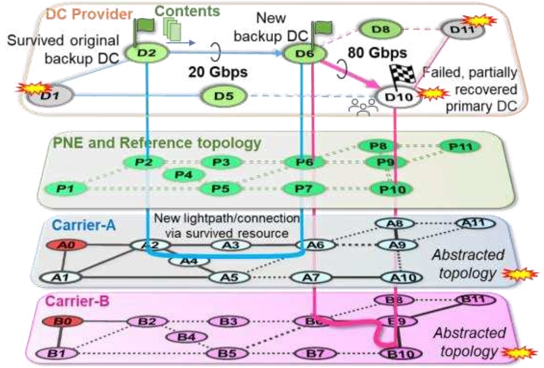
Case Study 1: Carrier- Carrier Cooperative Recovery
Cost Reduction

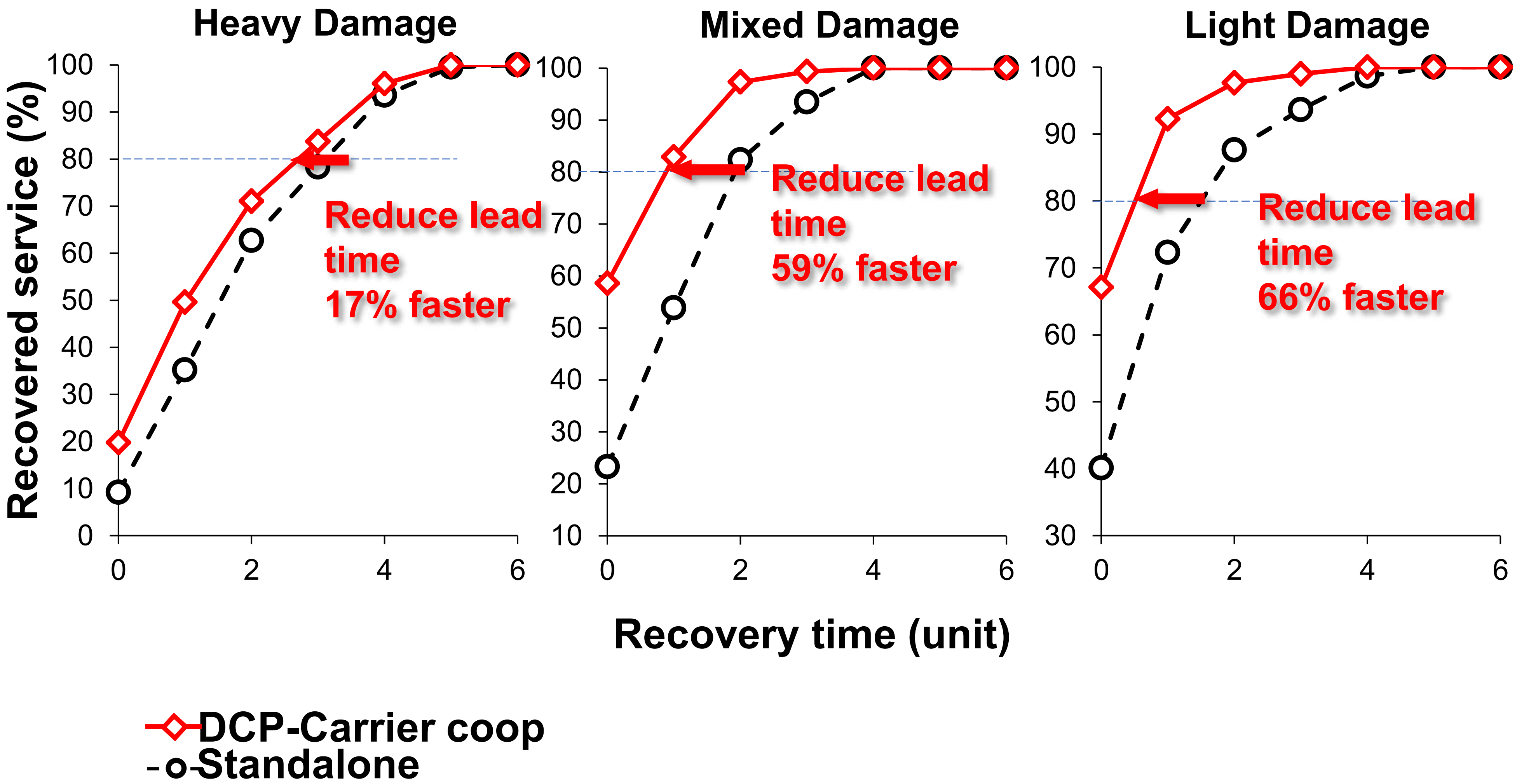


For each carrier, **Net cost** = Σ(**Recovery cost** + **Payment** for buying *lightpath supports*)

– Σ(**Income** of offering *lightpath supports*)

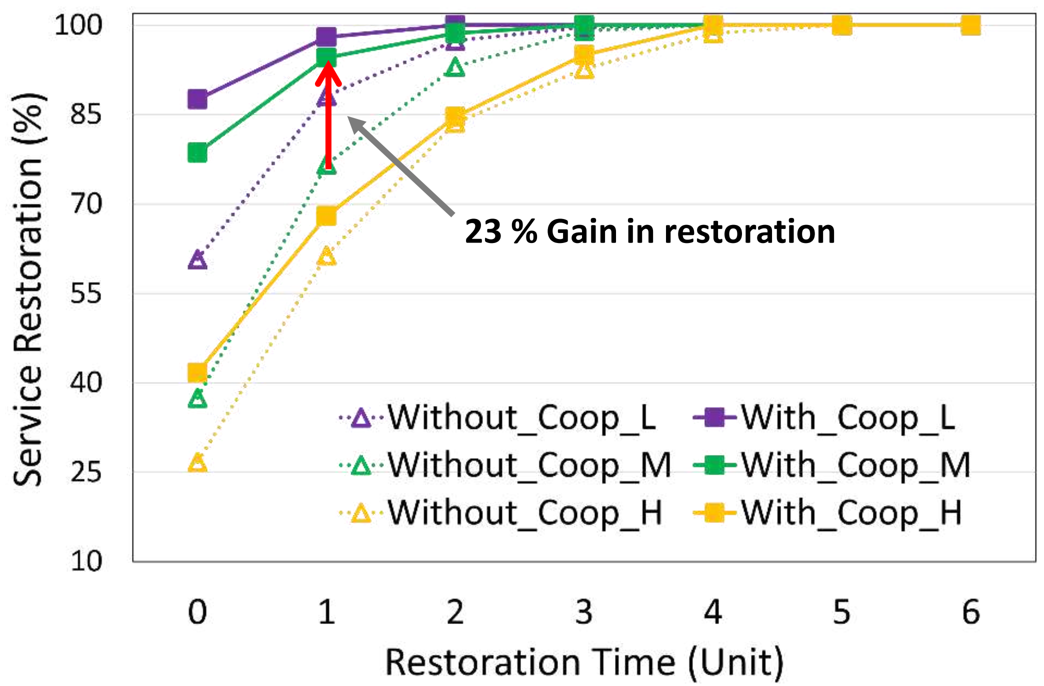
Case Study 2: DC provider - Carrier Cooperative Recovery
Lead Time Reduction in Cloud Service Restoration

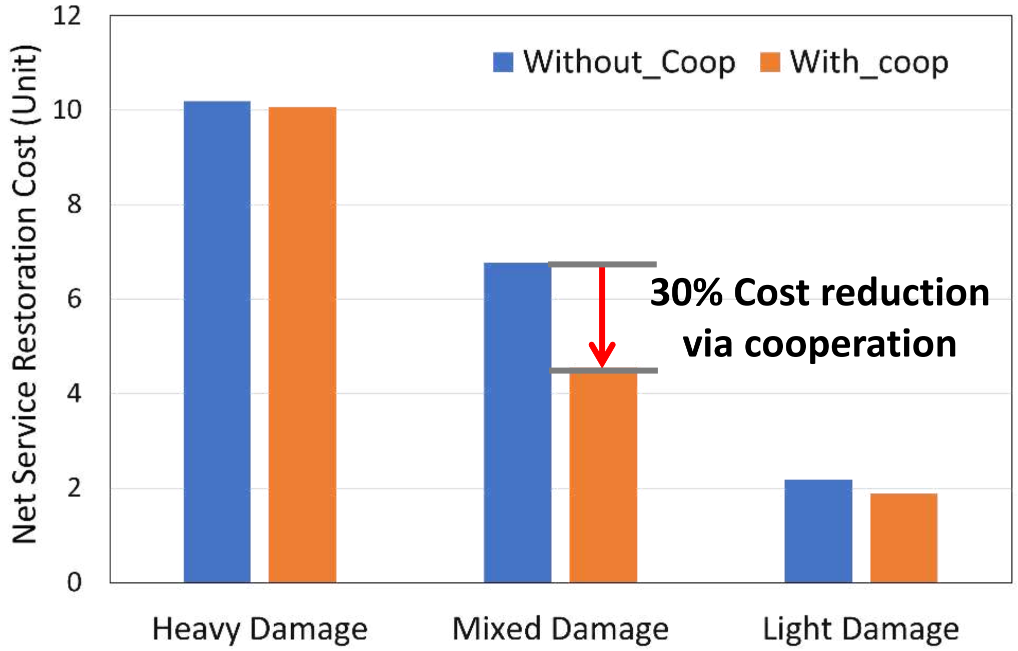




S. Sahoo et al., OFC2022, W2A.23, Mar. 2022.

Case Study 2: DC provider - Carrier Cooperative Recovery
Efficiency and Cost Reduction in Cloud Service Restoration





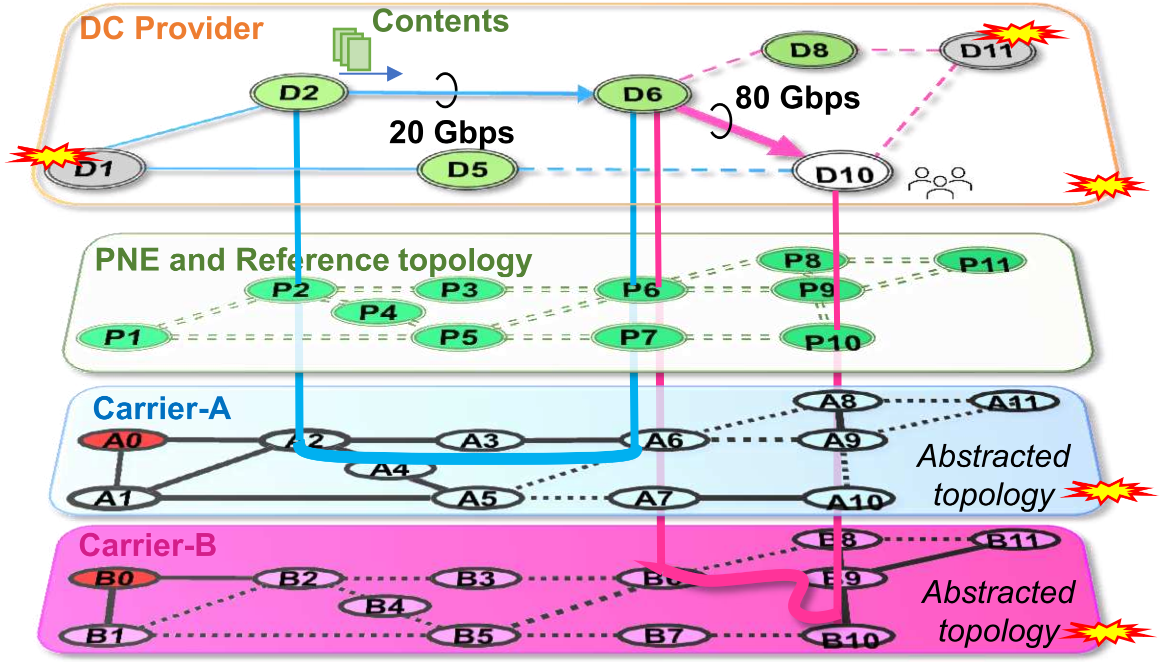
S. Sahoo, S. Xu, S. Ferdousi, Y. Hirota, M. Tornatore, Y. Awaji, and B. Mukherjee, "Datacenter-Carrier Cooperation over Optical Networks during Disaster Recovery," *Optical Fiber Communication Conference (OFC)*, San Diego, California, USA, Mar. 2022

Platform Study of Multi-Entity Cooperation for Network-Cloud Recovery

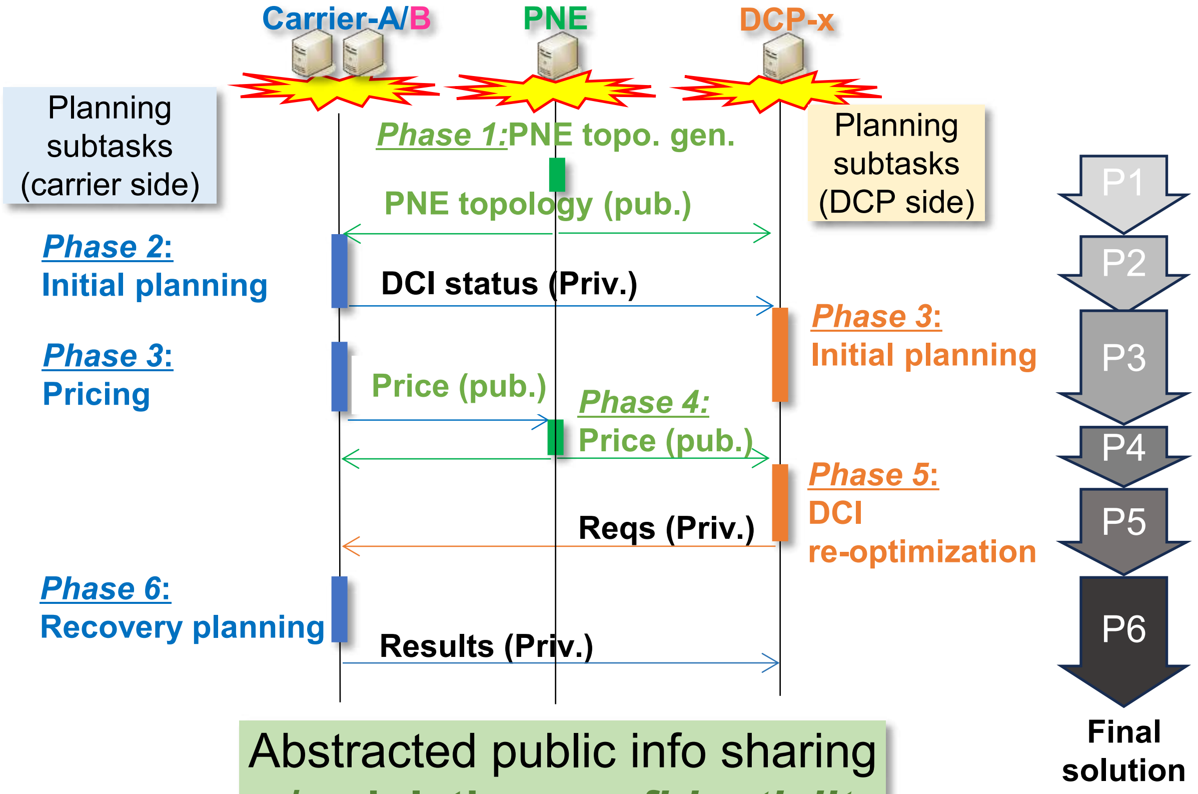
Cooperative Planning: DCP-Carrier Cooperative Recovery [1][2]

DCP-Carrier cooperative recovery

Cooperative planning



Framework: Progressive cooperative planning (distributed and multilateral optimization)



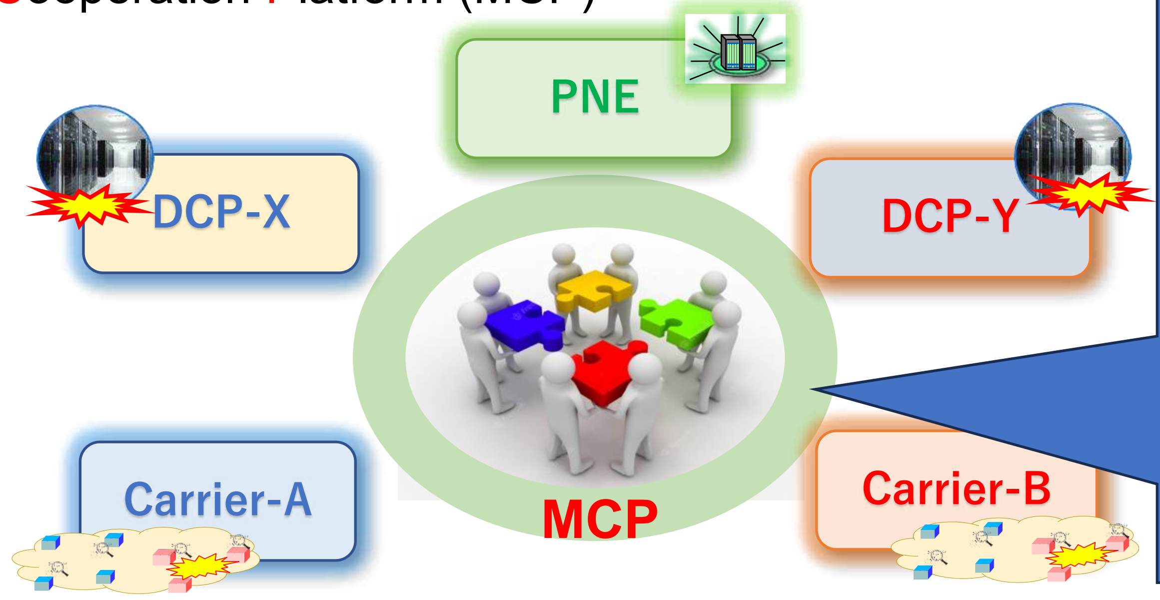
Abstracted public info sharing
w/o violating *confidentiality*

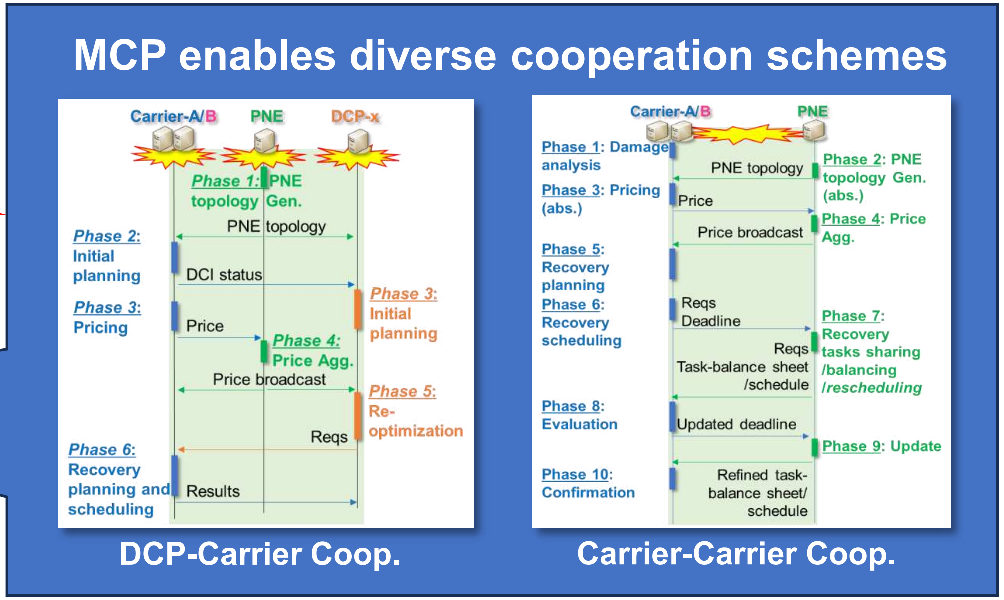
[1] S. Sahoo et al., "Datacenter-carrier cooperation over optical networks during disaster recovery," in Proc. OFC2022, Mar. 2022.

[2] S. Sahoo et al., "Strategic Cooperation among Datacenter Providers and Optical Network Carriers for Disaster Recovery," in Proc. Globecom2022, Dec. 2022.

Motivation: Create a MCP (Tool) to Facilitate Cooperation in Ecosystem

Multi-Entity Cooperation Platform (MCP)

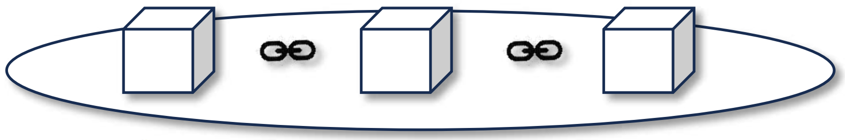




Key requirement: Open/Fair public info sharing in cooperation

Fit

Blockchain (DLT-based)



Ethereum

Hyperledger FABRIC

Hyperledger Foundation

Features of DLT-based Info sharing

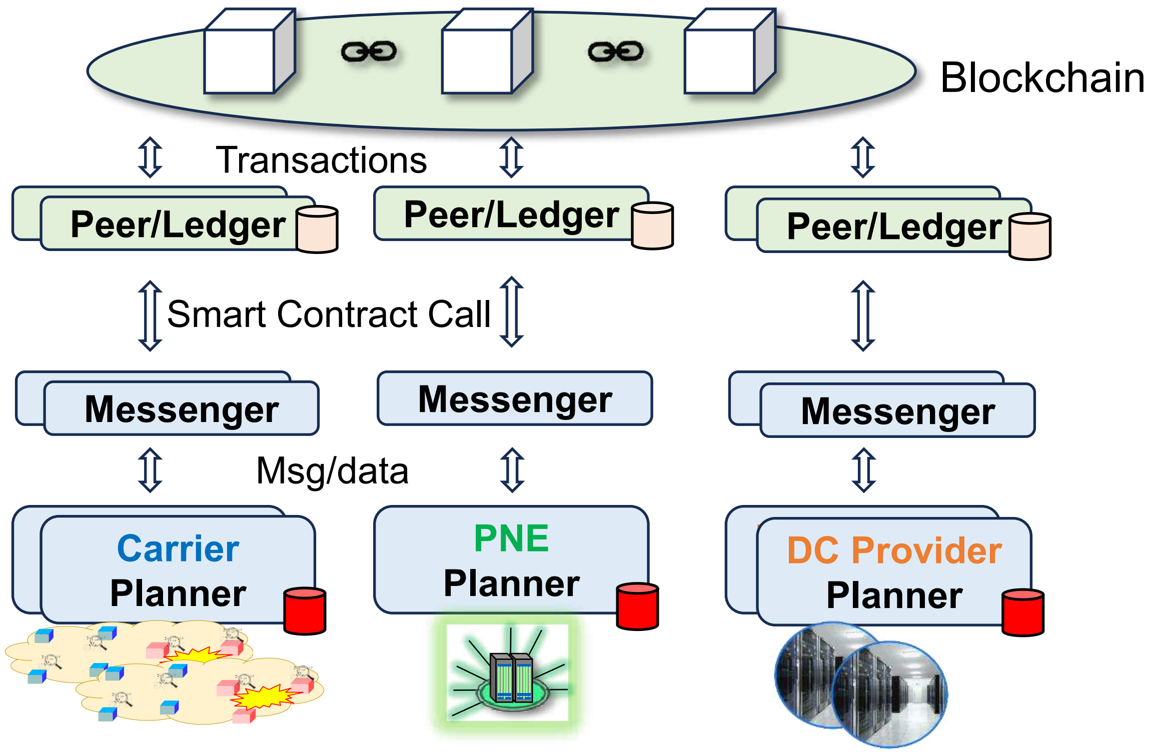
- Decentralization
- Tamper-proof
- Privacy protection
- Reliable data sharing
- Etc.

Example of mainstream implementation of **Distributed Ledger Technology (DLT)** supporting non-financial applications

S. Xu, S. Sahoo, N. Yoshikane, S. Ferdousi, M. Shiraiwa, Y. Hirota, T. Tsuritani, M. Tornatore, Y. Awaji, and B. Mukherjee, ONDM2024

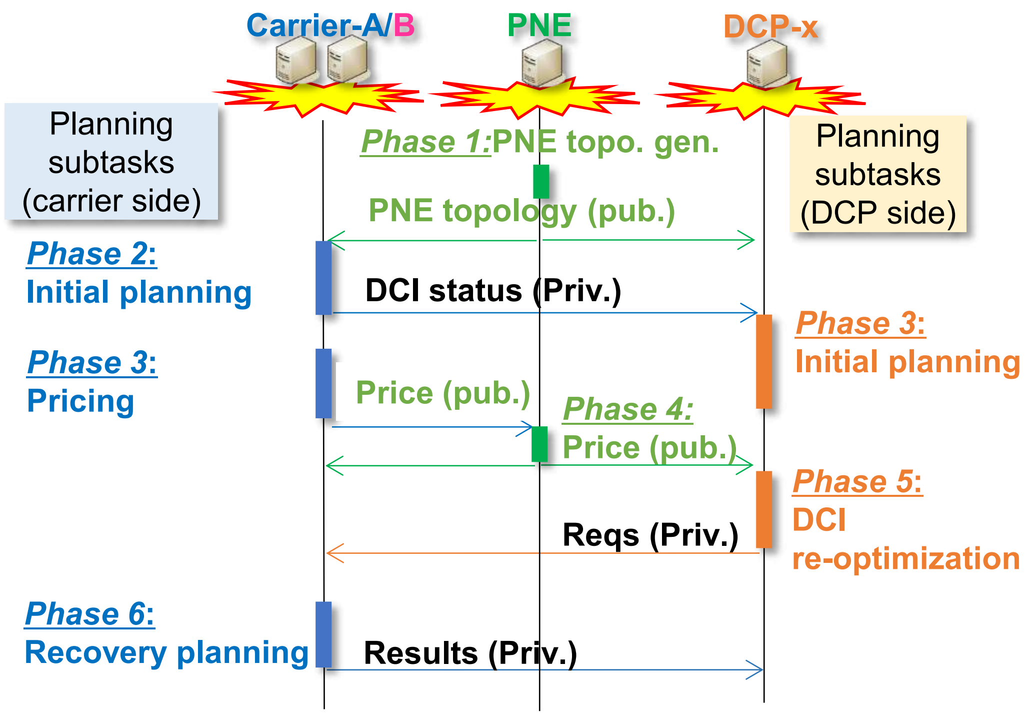
System Structure of MCP for Cooperative Recovery Planning

MCP



Supports

Cooperative recovery planning



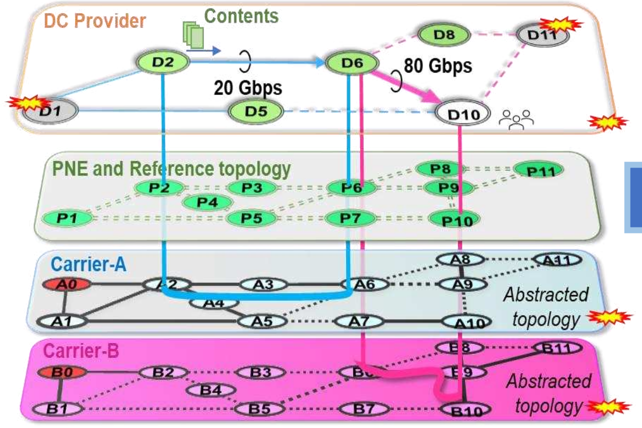
Abstracted public info sharing
w/o violating *confidentiality*

Three Features of MCP

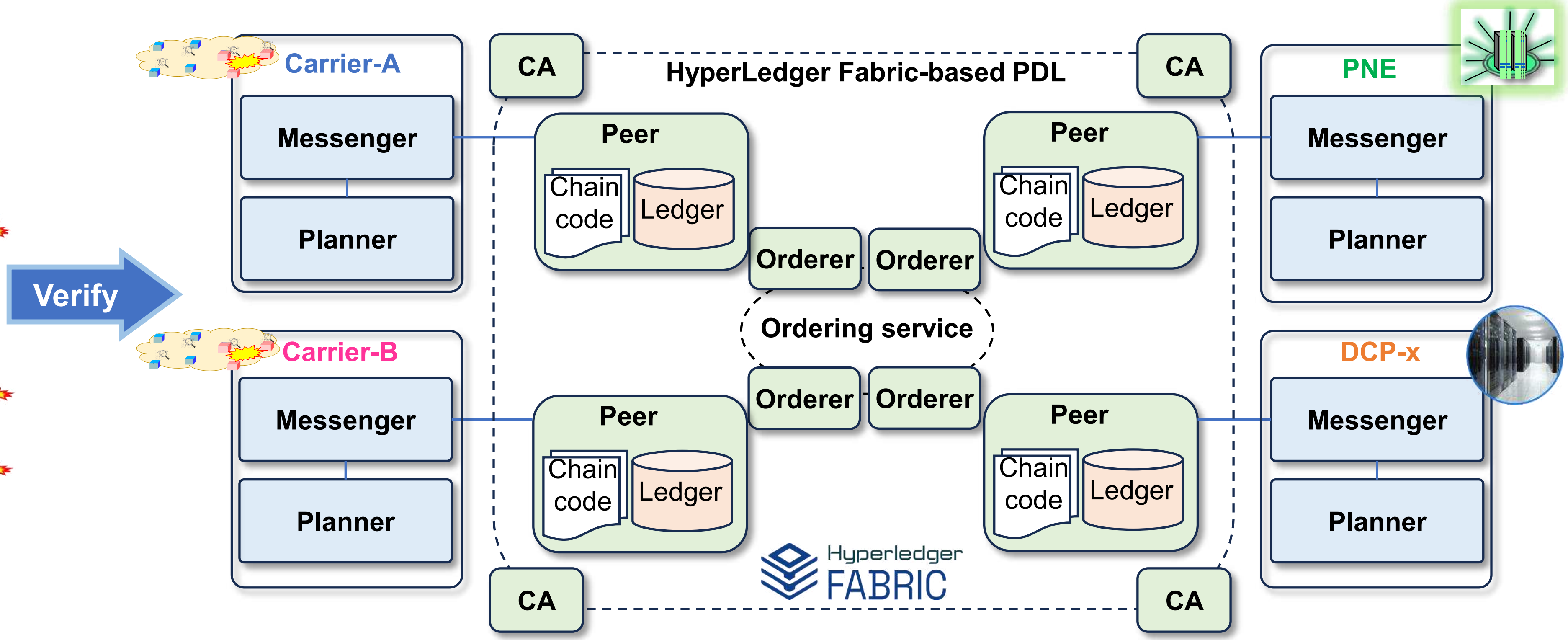
Support for diverse cooperation → Multi/Bilateral info sharing → Simple coordination among stakeholders

Demonstration with a MCP Prototype

Experimental Setup of MCP with HyperLedger Fabric (OSS)



DCP-Carrier Cooperation [1]



Implementation of MCP prototype:

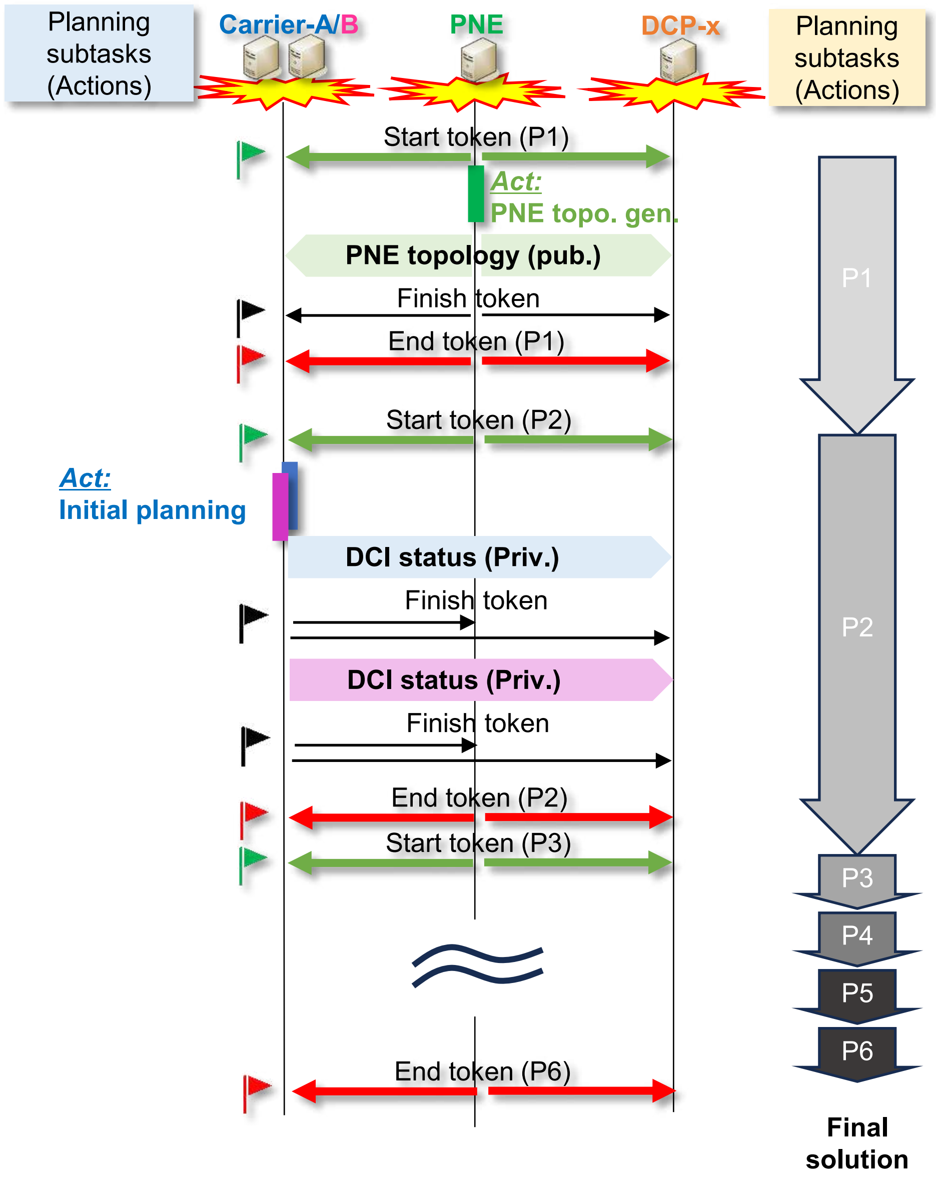
Stakeholders: Carrier-A/B, DCP-x, PNE

State Machine: Pytransitions, a lightweight, object-oriented finite-state machine (OSS)

Block Chain: HyperLedger Fabric (OSS)

[1] S. Sahoo et al., "Datacenter-carrier cooperation over optical networks during disaster recovery," in Proc. OFC2022, Mar. 2022.

Observation on Running Time



A) MCP running time via block chain < 3 min

- Signaling
  - Start token
  - Finish token
  - End token
- Data sharing
  - Public
  - Private

B) Recovery planning time < 15 min

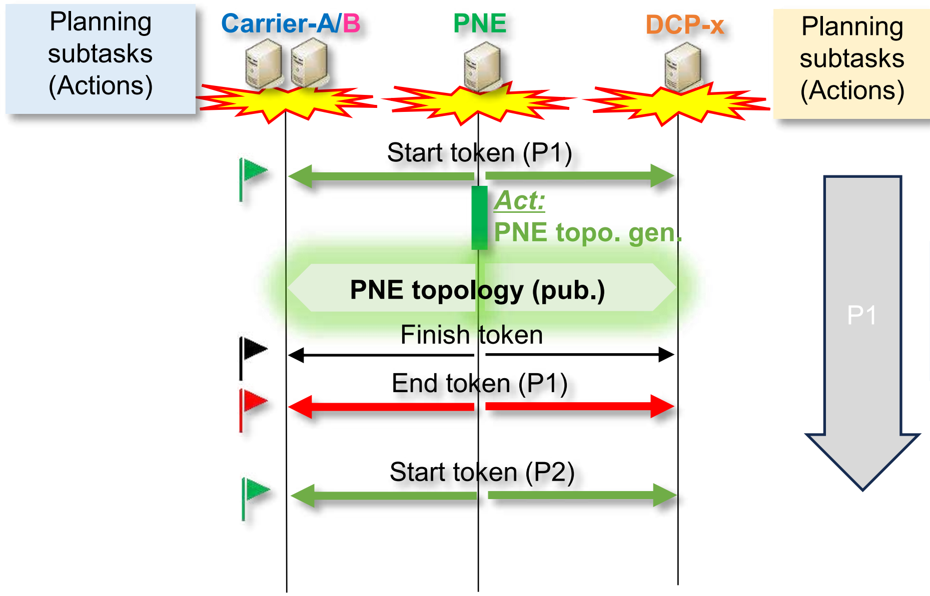
- Carrier-A/B
- DCP-x
- PNE

Time for cooperative planning with MCP: In the order of minutes

Comparison

Time for manually performed recovery tasks in carrier networks:
In the order of hours, days, even months

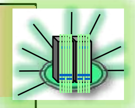
Behavior of MCP via Block Chain for Open/Fair Public Info Sharing



Zoom in Block Chain

TransactioId: ff8d1431a38d2e
blockNo: 979
- arg:topology_broadcast_data
- arg:{"type":"topology","number":1,"from":"pne","to":"all"}
- arg:
{
"Phase": 1,
"topology": {
"uuid": "00000000-0000-0000-0000-000000000000",
"node": [
{
"uuid": "00000001-0000-0000-0000-000000000000",
"name": [
{
"value-name": "node-id",
"value": "node1"
}
],
"node-edge-point": [

PNE broadcasted reference topology (public info sharing) via DLT system



PNE reference topology shared by PNE in Phase 1

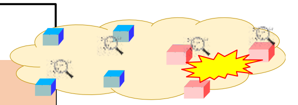
Example: PNE topology sharing in Phase 1 with public <chaincode> from PNE to all stakeholders

Maximum block size: 10MB

Total generated blocks: tens of blocks

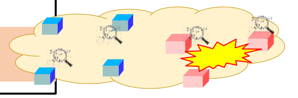
TransactioId: ff8d1431a38d2e32353652e034142ccb92447c91
blockNo: 979

Trimmed Carrier-A log



34142ccb92447c91

Trimmed Carrier-B log

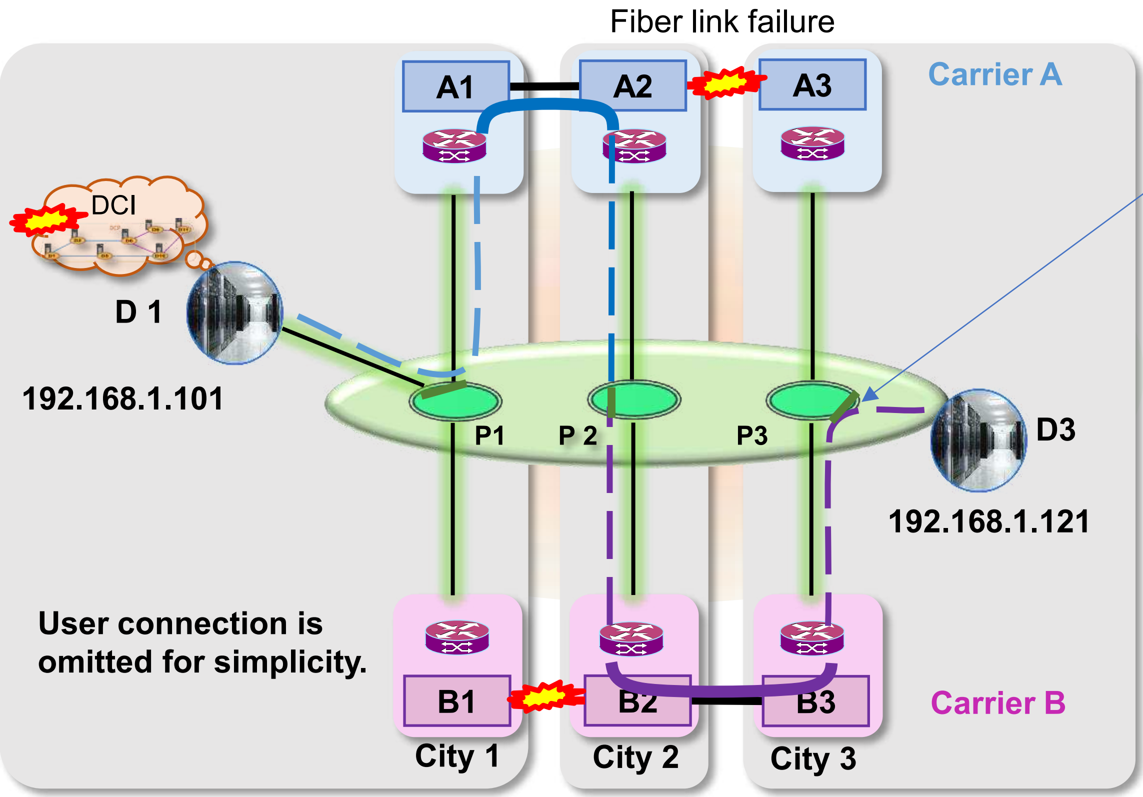


34142ccb92447c91
- arg:topology_broadcast_data

Trimmed DCP-x log

Data-Plane: Detoured DCI Connection via Surviving Resource of Carriers

***Failure/Disaster*:**
Enhanced resilience of ecosystems



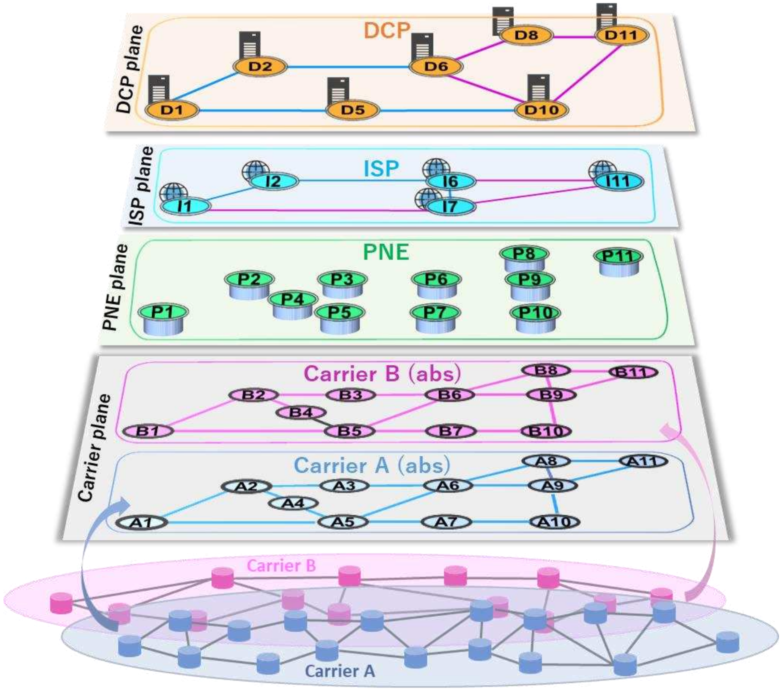
Detoured DCI connection via Carrier-A/B surviving resource by DCP-Carrier Coop.

```
64 bytes from 192.168.1.121: icmp_seq=22237 ttl=64 time=8.51 ms
64 bytes from 192.168.1.121: icmp_seq=22238 ttl=64 time=9.00 ms
64 bytes from 192.168.1.121: icmp_seq=22239 ttl=64 time=8.34 ms
64 bytes from 192.168.1.121: icmp_seq=22240 ttl=64 time=8.16 ms
64 bytes from 192.168.1.121: icmp_seq=22241 ttl=64 time=8.50 ms
64 bytes from 192.168.1.121: icmp_seq=22242 ttl=64 time=7.90 ms
64 bytes from 192.168.1.121: icmp_seq=22243 ttl=64 time=8.24 ms
64 bytes from 192.168.1.121: icmp_seq=22244 ttl=64 time=8.41 ms
64 bytes from 192.168.1.121: icmp_seq=22245 ttl=64 time=8.01 ms
64 bytes from 192.168.1.121: icmp_seq=22246 ttl=64 time=15.1 ms
```


Summary

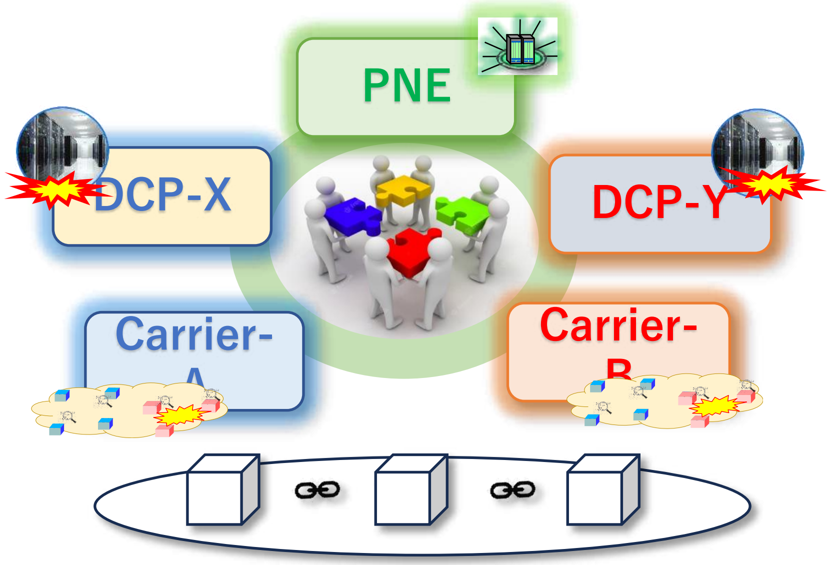
- Problem of multi-entity cooperation for efficient network-cloud recovery

Modeling study



Overlapped physical network infrastructures of the carriers

Platform study



Blockchain-based Platform

- Modeling study:
  - Revealed the potential of cooperation among different entities to achieve efficient recovery even with limited visibility!
- Platform study:
  - Verified a blockchain-based platform (MCP) for supporting the Open and Fair cooperation among different entities!

Thank you very much!

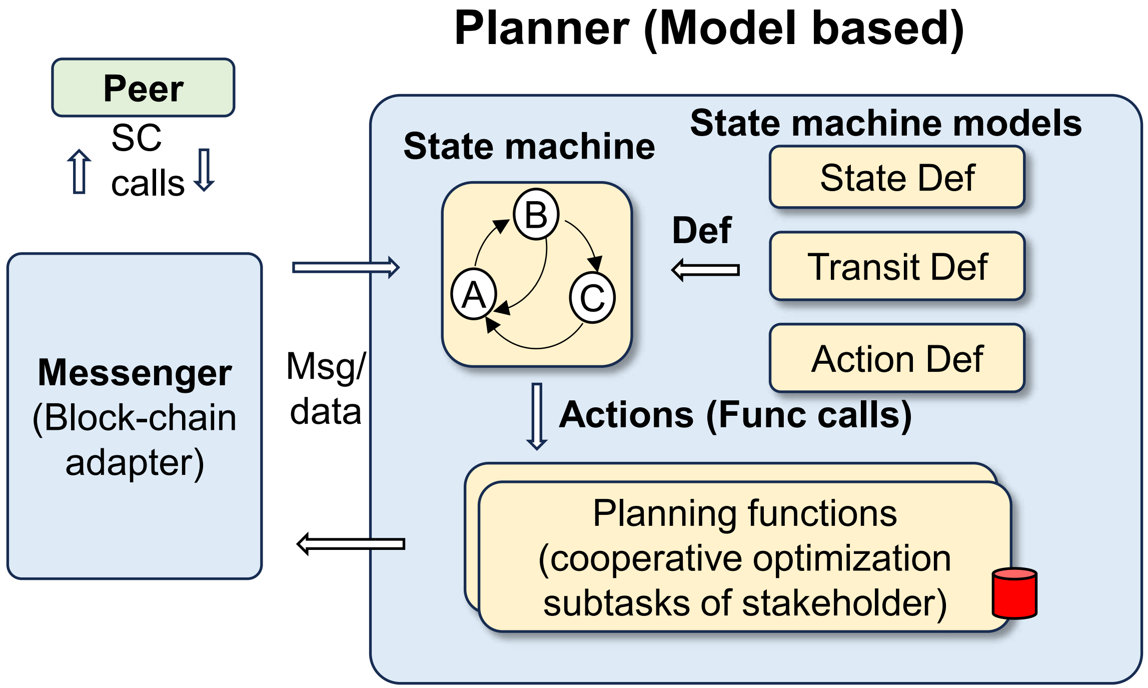
Acknowledgements

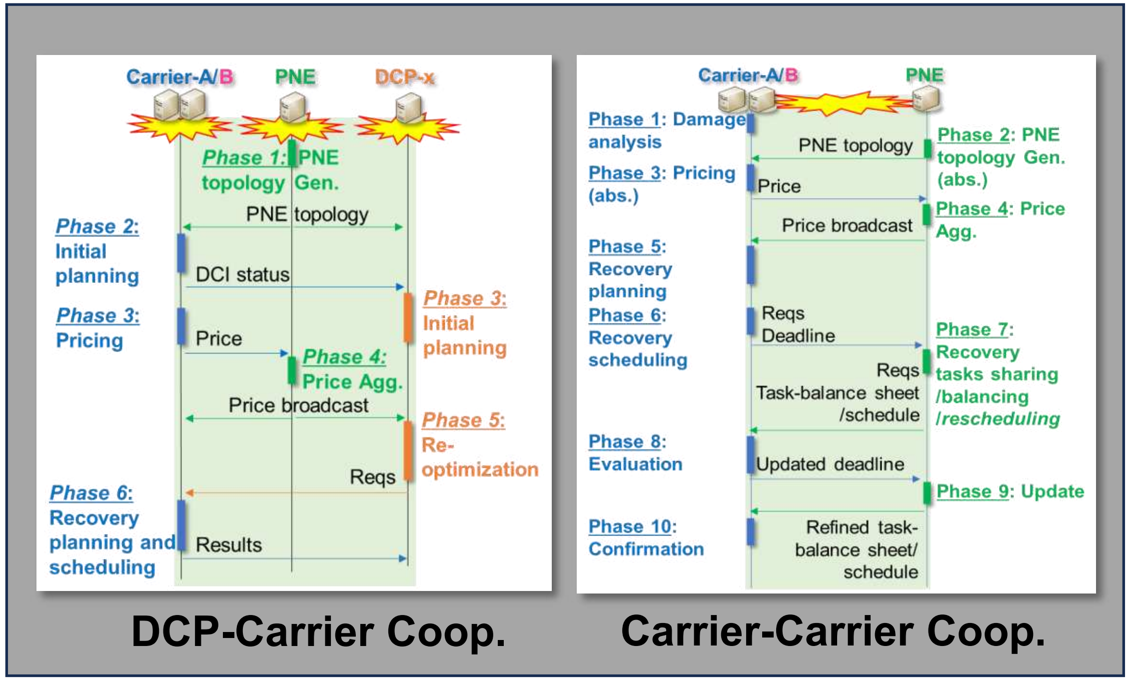
This work is supported in part by US-Japan JUNO3 project: NSF Grant no. 2210384.

Special thanks to our community for giving us such a great opportunity for sharing our cooperation works!

State-Machine-based Planner and Model-Driven Cooperation

MCP — **Supports** → **Diverse cooperative planning models**



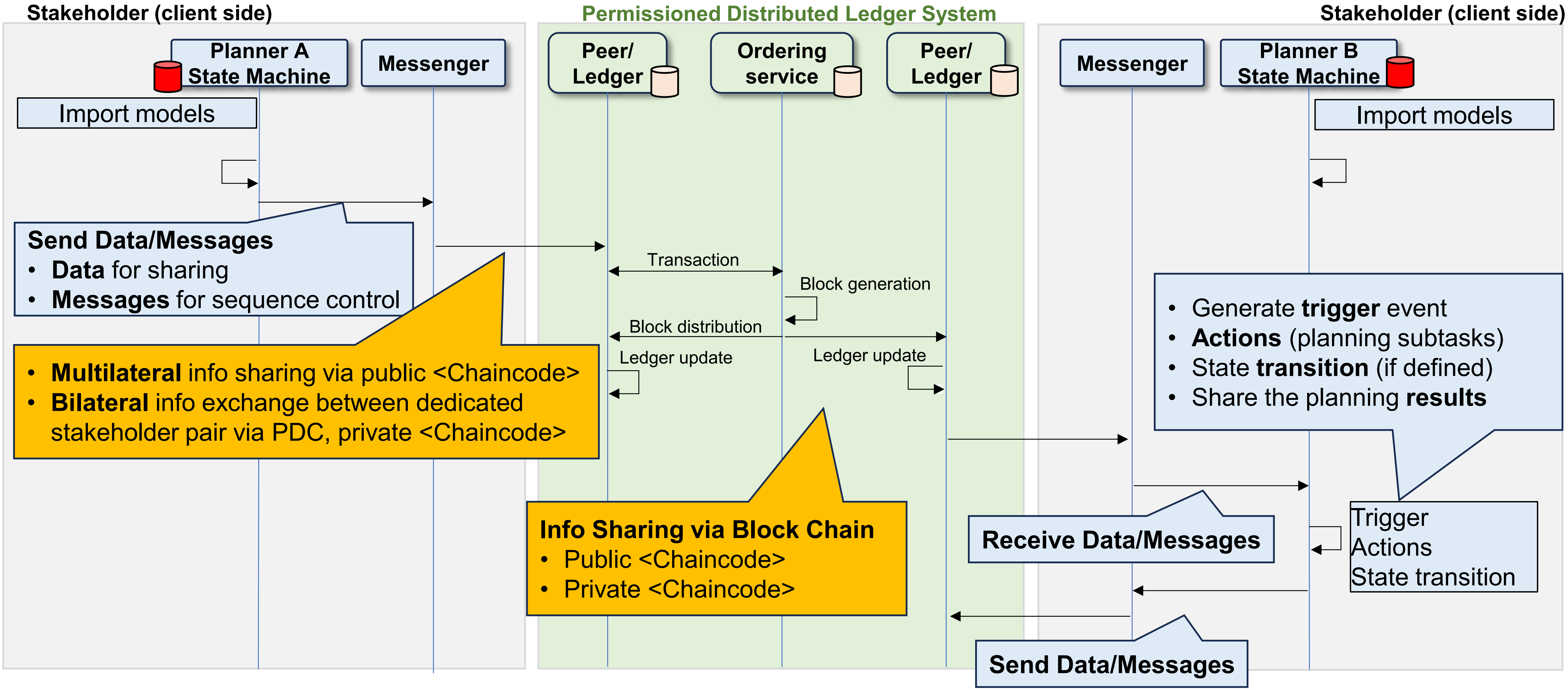


State machine model Def for individual roles

{'trigger':'Event', 'source':'Current_State', 'dest':'Next_State',
'Actions' : 'Planning Tasks'
}

Support for diverse cooperation → Multi/Bilateral info sharing → Simple coordination among stakeholders

Multilateral (Public) and Bilateral (Private) Info Sharing/Exchanging via Block Chain

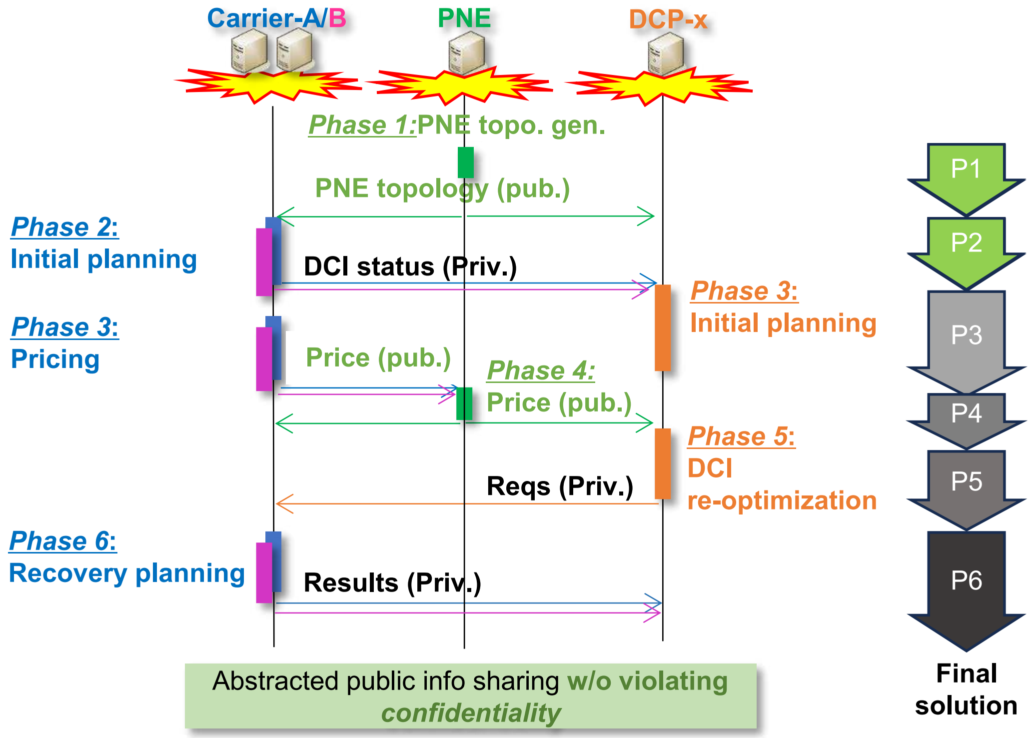


Support for diverse cooperation → **Multi/Bilateral info sharing** → Simple coordination among stakeholders

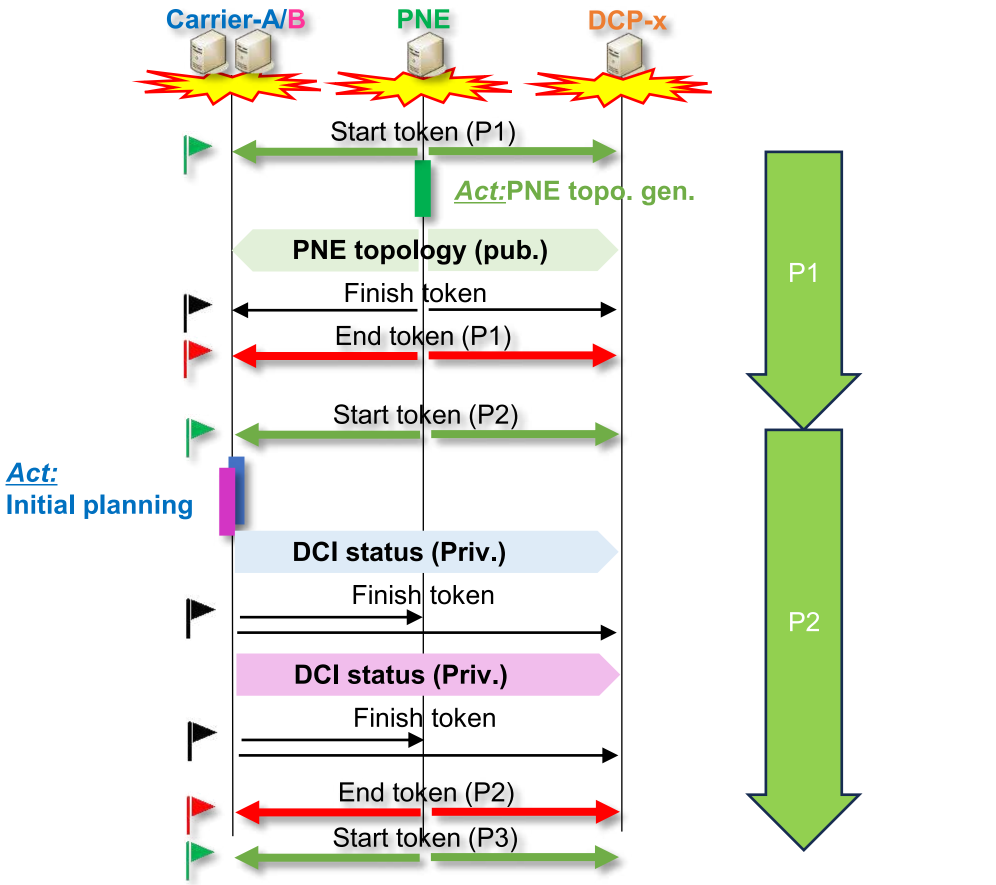
Simple Coordination among Stakeholders for Large-Scale Cooperation

Phase Shift during Cooperative Planning

Need coordination



Token-based Signals Drive State Transition/Action/Info Sharing



Support for diverse cooperation → Multi/Bilateral info sharing → **Simple coordination among stakeholders**