2021 Japan-US Network Opportunity 2 (JUNO2)

Project Title: *Disaster-Resiliency Strategies for Next-Generation Metro Optical Networks*

ATN: 1818972

Speakers:
Dr. Yoshinari Awaji (NICT)
Dr. Massimo Tornatore (UCDavis)

August 18, 2021
Principal Investigator Meeting

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Project Team

- **PIs**
  - Massimo Tornatore; University of California, Davis; PI
  - Biswanath Mukherjee; University of California, Davis; Co-PI
  - Yoshinari Awaji; NICT (Japan); Team leader (PI Japan side)

- **@NICT**
  - Sugang Xu; NICT (Japan); Collaborator
  - Yusuke Hirota; NICT (Japan); Collaborator
  - Masaki Shiraiwa; NICT (Japan); Collaborator

- **@UCD**
  - Sifat Ferdousi; University of California, Davis; PDF
  - Giap Le; University of California, Davis; GSR
  - Subhadeep Sahoo, University of California, Davis; GSR
  - Ramanuja Kalkunte, University of California, Davis; GSR
  - Andrea Marotta; University of L'Aquila, Italy; Visiting Student

- **International Collaborators**
  - Prof. Francesco Musumeci; Politecnico di Milano, Italy
  - Prof. Gustavo Bittencourt; University of Bahia, Brasil
  - Virajit Garbhapu, M.Sc. Student, Politecnico di Milano, Italy
  - Giacomo Marchionni, M.Sc. Student, Politecnico di Milano, Italy

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2019: 3 in-person meetings

- Davis, Feb 27th to Mar. 1st 2019
  - Pre-OFC visit by Dr. Awaji and Dr. Hirota
- Sendai, July 4th and 5th, 2019
  - Pre-OECC visit by Dr. Tornatore
- Chicago, Oct 11°, 2019 (PI meeting)

2020: 1 in-person + 1 online general meeting

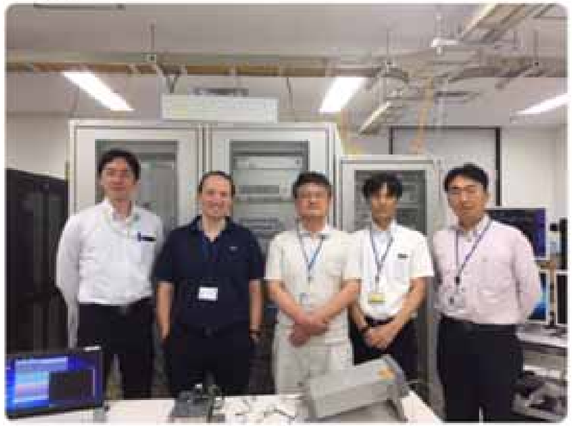
- San Diego, OFC, March 9, 2020
  - Dr. Hirota and Prof Tornatore
- Online, Sept 9, 2020

Massimo Tornatore
@MaxTornatore

Two intense days discussing disaster resiliency for next generation optical metro networks in our JUNO2 #NSF project . Thanks to Dr. Yoshinari Awaji and Dr. Yusuke Hirota from #NICT for visiting us in #UCDavis. @dmedhi

Massimo Tornatore
@MaxTornatore

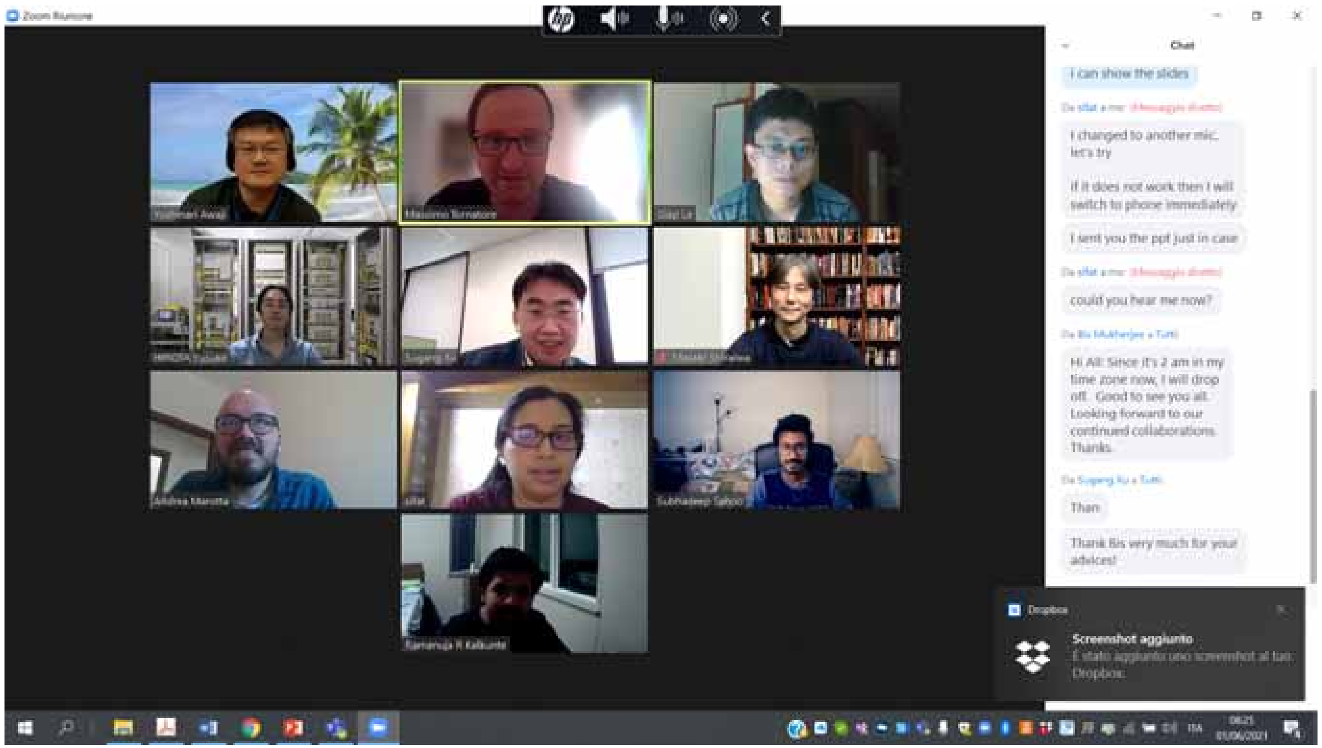
Visiting #NICT in Sendai, Japan, to discuss disaster resiliency in next generation optical networks for our #JUNO2 #NSF project. Inter-carrier recovery, #MachineLearning for failure management, and several other research directions can be explored over NICT's #OPCI testbed



1:14 AM - 5 Jul 2019

2021: 1 online meeting

- General online meeting, May 31/June 1
- Several other interactions via email and smaller telco



Motivation

A new generation of optical metro networks is needed to turn the vision of "Smart Cities" into reality

- From a **rigid ring-based aggregation infrastructure** to a **composite network-and-computing ecosystem** to support critical 5G services (e.g., autonomous driving)

- Several technical enablers:
  - Increased reconfigurability enabled by **SDN**
  - **Integration of optical and wireless** access networks
  - Metro nodes becoming edge data centers (**edge computing**)
  - **Network slicing** to logically partition network, computing, and storage resources
  - …

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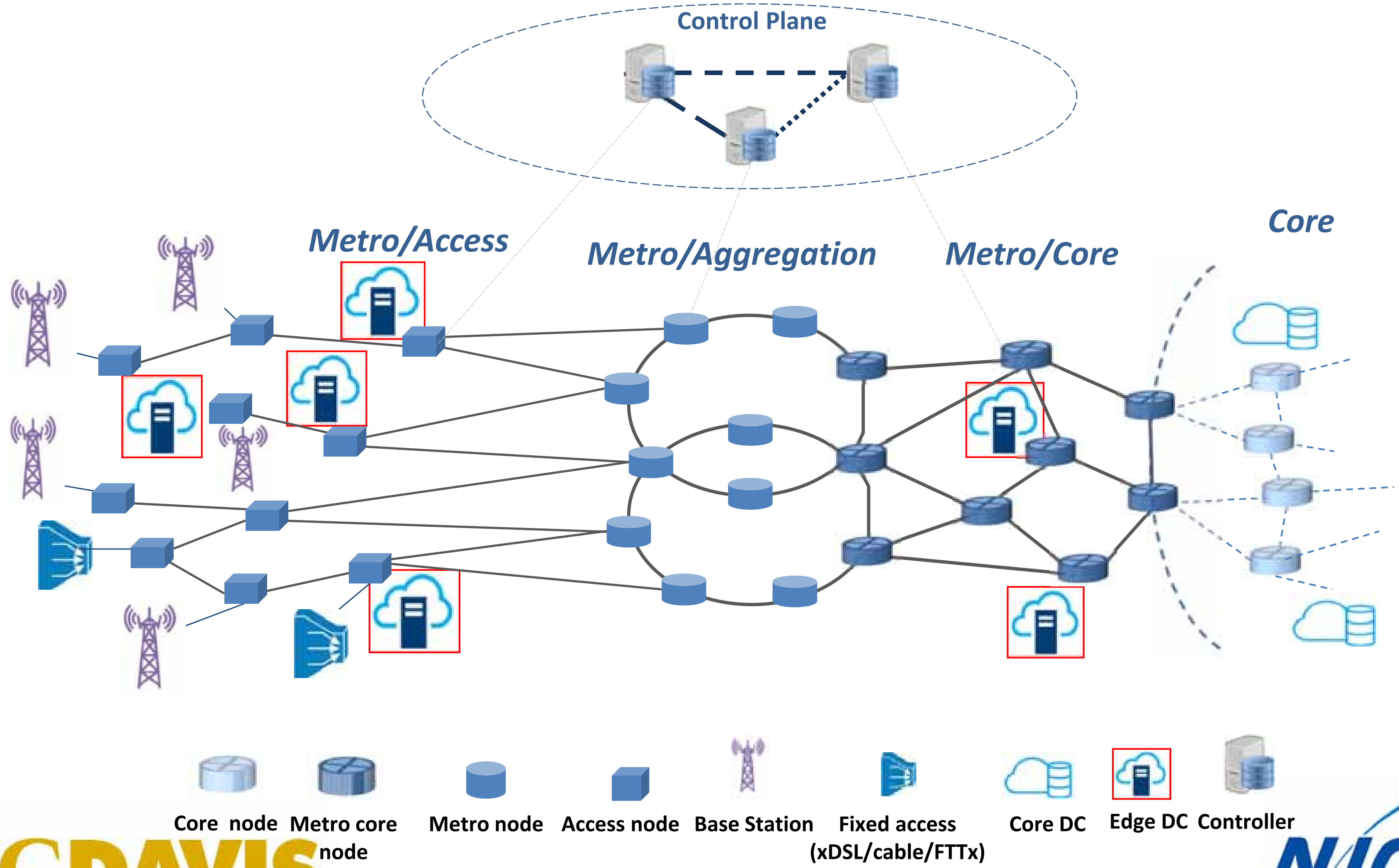
Evolution of Metro Access Networks (I)

Edge computing and SDN



Evolution of Metro Access Networks (II)

Network Slicing

This transformation calls for new solutions for resilient and sliceable next-generation metro-area networks (NG-MANs)

Disaster affecting underlying NG-MAN

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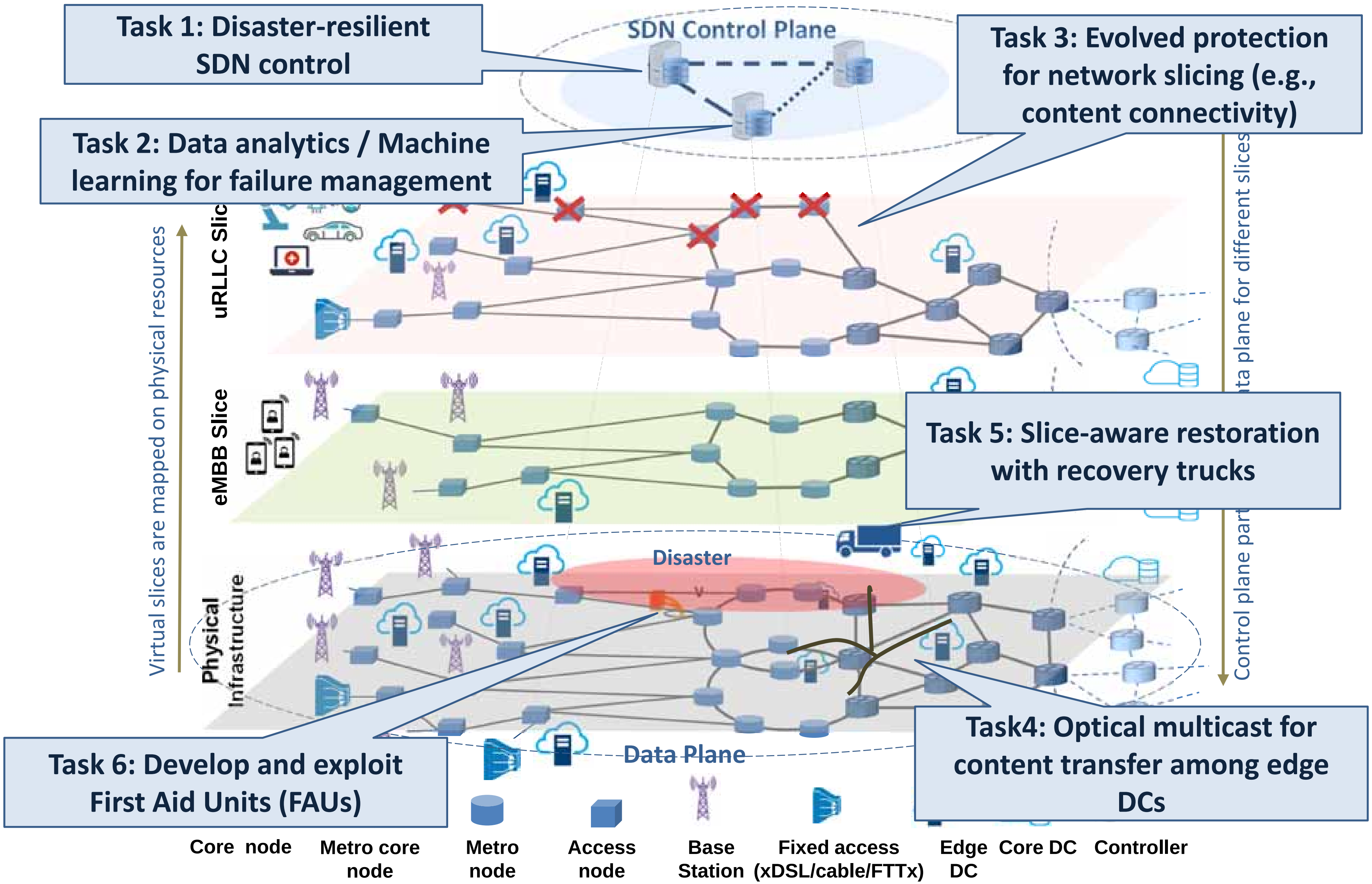
Project Overview



Overall Topics

	Disaster-resilient NG-MANs		
Phase	Pre-disaster phase		Post-disaster phase
Theme	Theme 1: Prevention Disaster-resilient design of the SDN control plane	Theme 2: Preparedness Protection strategies for sliceable NG-MANs	Theme 3: Fast recovery Recovery strategies with portable devices in NG-MANs
UC Davis	Task 1 Disaster-resilient SDN controller placement	Task 3 Disaster-resilient content-connected slice mapping	Task 5 Slice-aware restoration with recovery trucks for NG-MAN
NICT	Task 2 SDN modules for network slicing and data analytics	Task 4 Optical multicast for effective content transfer among edge DCs	Task 6 Develop and exploit First Aid Unit (FAU)
Key technologies	SDN/NFV, Machine learning	Edge computing, flexi grid & multicast	Novel portable/movable disaster recovery systems

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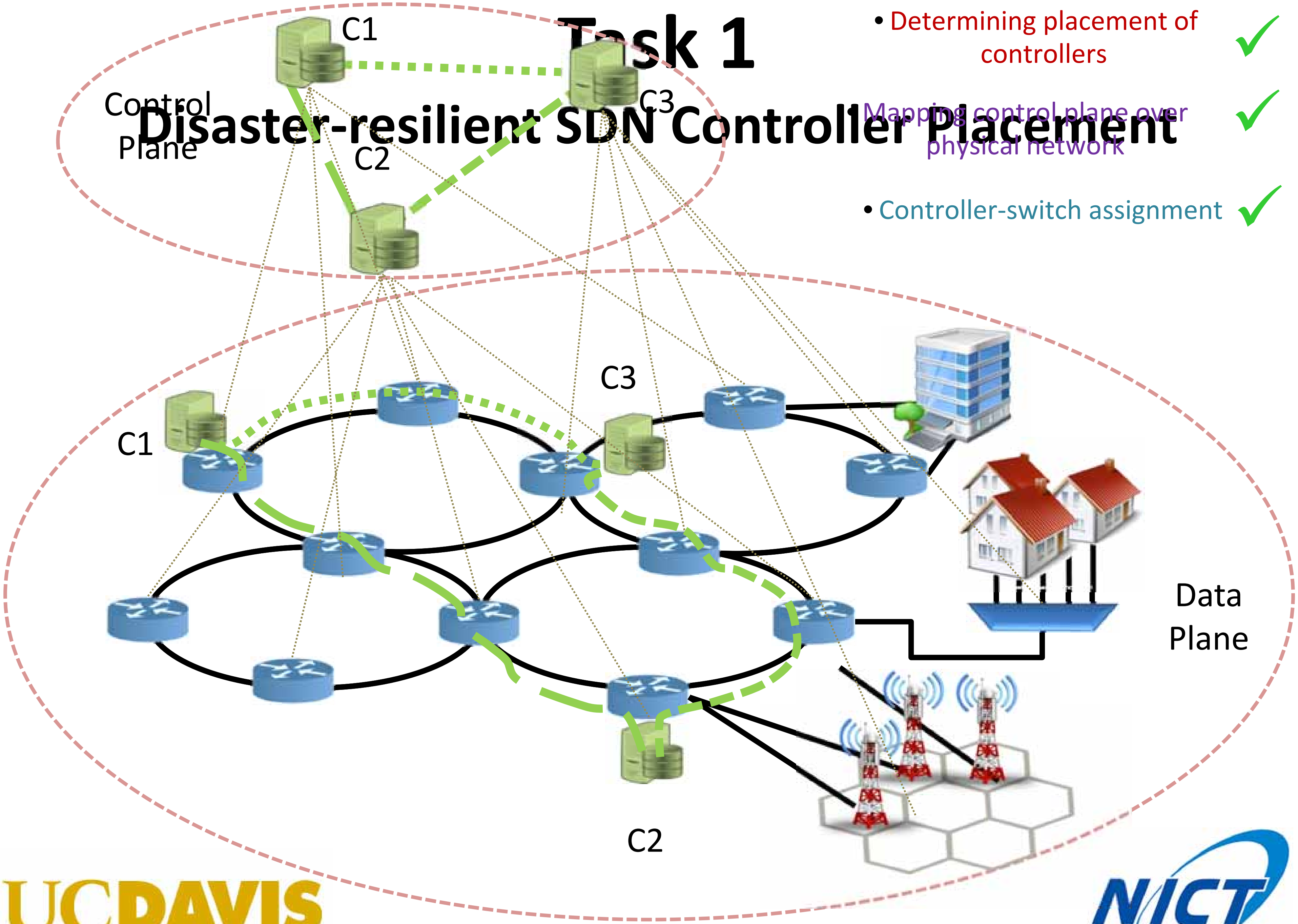
Task 1

Disaster-resilient SDN Controller Placement

- Determining placement of controllers ✓
- Mapping control plane over physical network ✓
- Controller-switch assignment ✓



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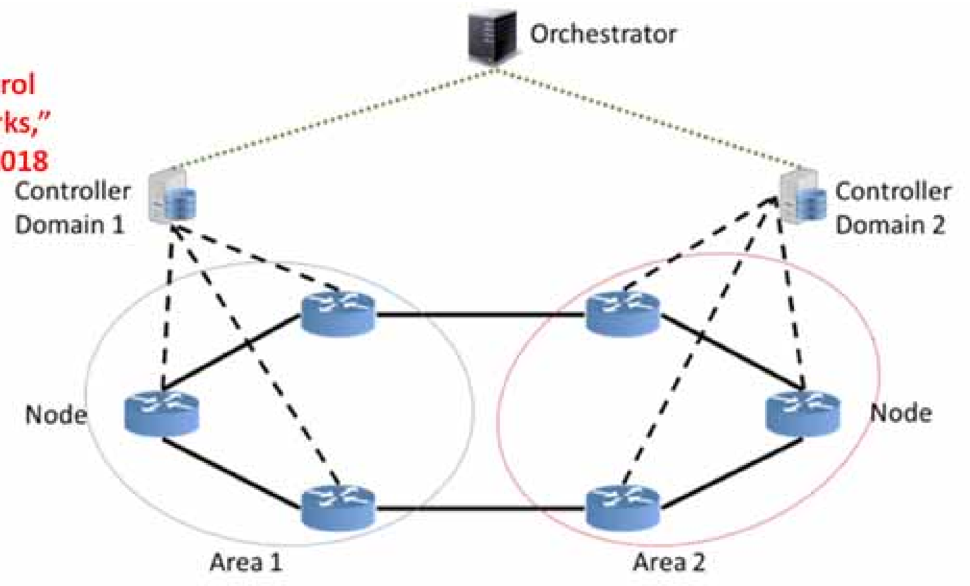
Task 1: Our Contribution on Fault-Tolerant Controller Placement (CP)

- **[Pre-planned controller replicas]** F.J. Ros, P.M. Ruiz, Five nines of southbound reliability in software-defined networks, in: Proc. of the ACM HotSDN, New York, NY, USA, 2014 & (B. Killi, et al., Capacitated next controller placement in software defined networks, IEEE Trans. Netw. Service Manage. 14 (3) (2017) 514–527)
- **[Path diversity]** F. Müller, et al., Survivor: an enhanced controller placement strategy for improving SDN survivability, in: Proc. of the IEEE GLOBECOM, 2014
- **[Disaster awareness]** S. Savas, et al., "Disaster-resilient control plane design and mapping in Software-Defined Networks," *In Proc. of HPSR,* Budapest, Hungary, July 2015
- **[Malicious Attacks]** D. Santos, A. de Sousa, C.M. Machuca, Robust SDN controller placement to malicious node attacks, in: Proc. of IEEE DRCN, 2018.
- **[Several types of failures]** D. Hock, et al., Pareto-optimal resilient controller placement in SDN-based core networks, in: Proc. of the 25th International Teletraffic Congress (ITC), 2013.
- **[T-SDN (Orchestrator+Controllers)]**
  - **R. Lourenço, et. al, "Robust hierarchical control plane for transport software-defined networks," Optical Switching and Networking, vol. 30, 2018**



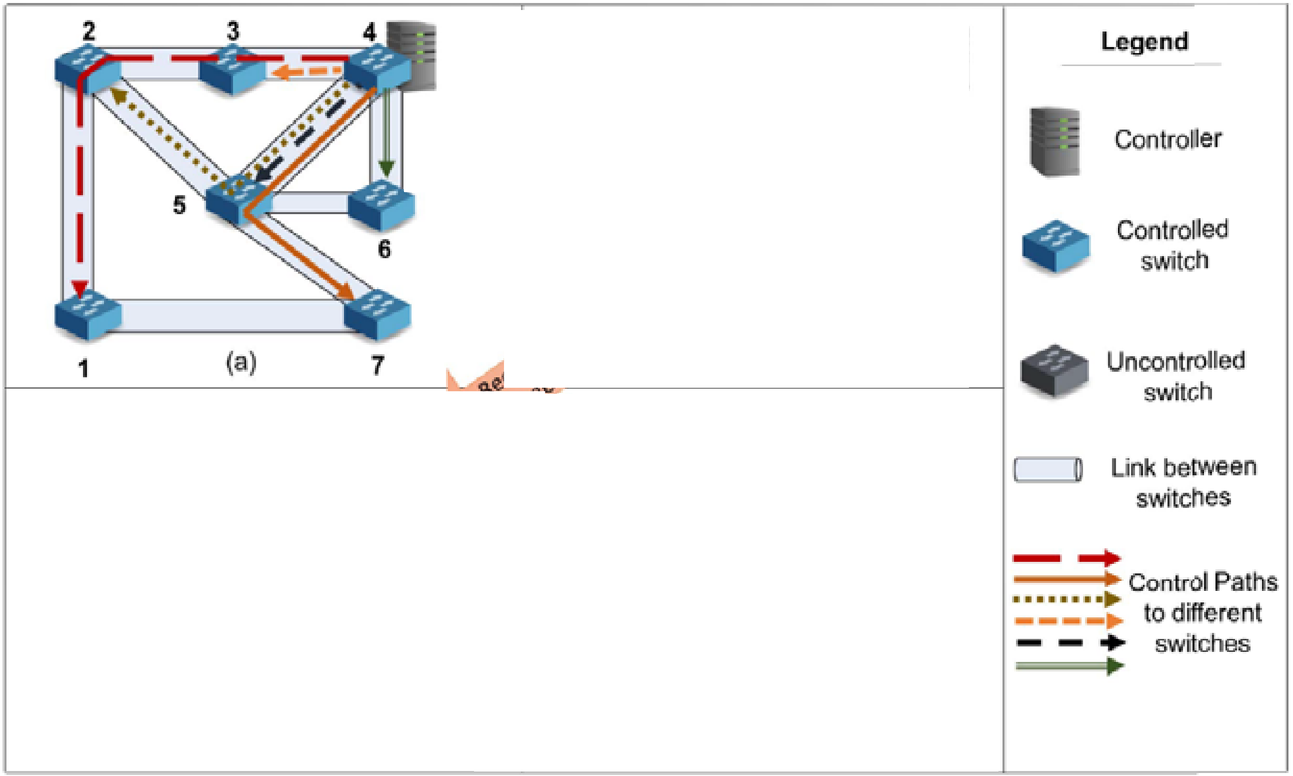
Ok controller has been properly placed…

.. still *how we interconnect controllers to switches* is crucial to minimize recovery time!

Task 1: Looking at "Controller to Switch" Paths!

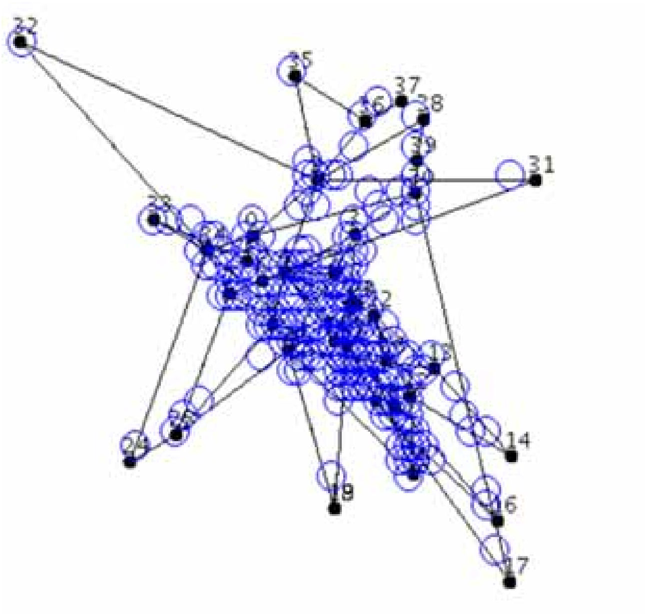
Multi-Stage Recovery

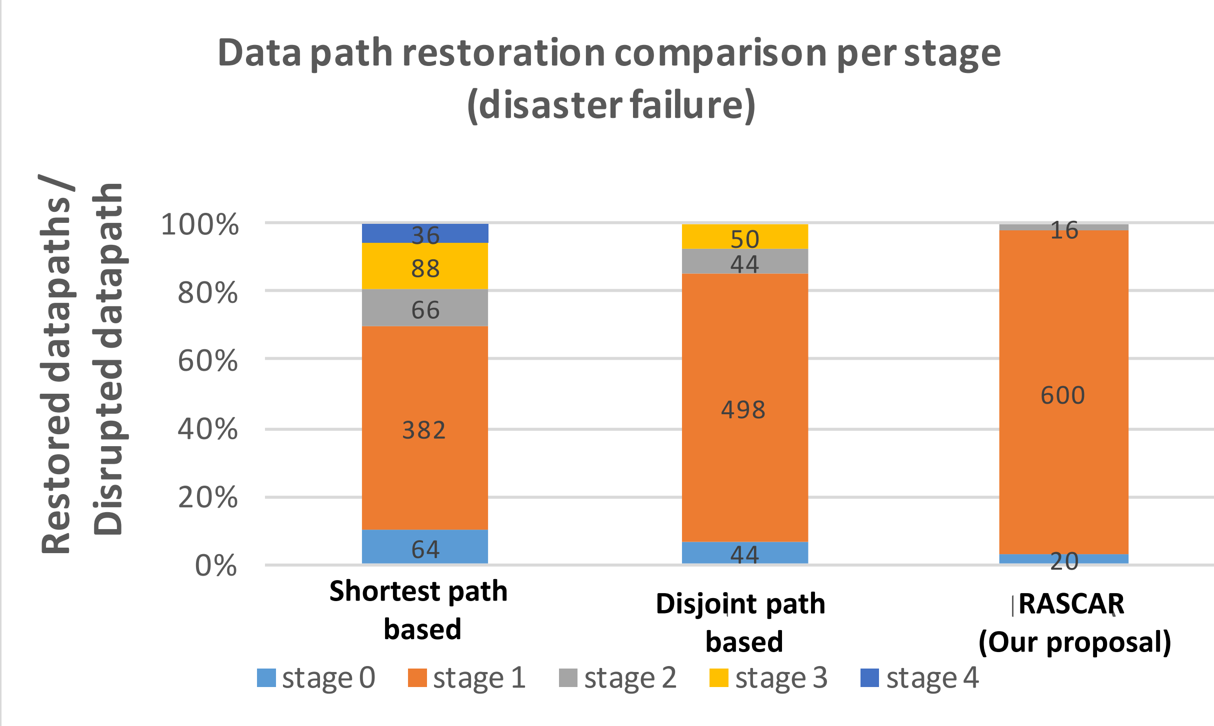
- Even a single failure affects multiple switch-to-controller **control paths**
- When switches lose control paths, they become "**uncontrolled**":
  - route traffic using old flow entries
  - cannot exchange control messages (e.g., flow setup request, flow installation)
  - cannot be used for data path restoration



Results: Recovery Speed vs. Cost

- **GEANT Network**
- **All possible disasters with radius = 100km**



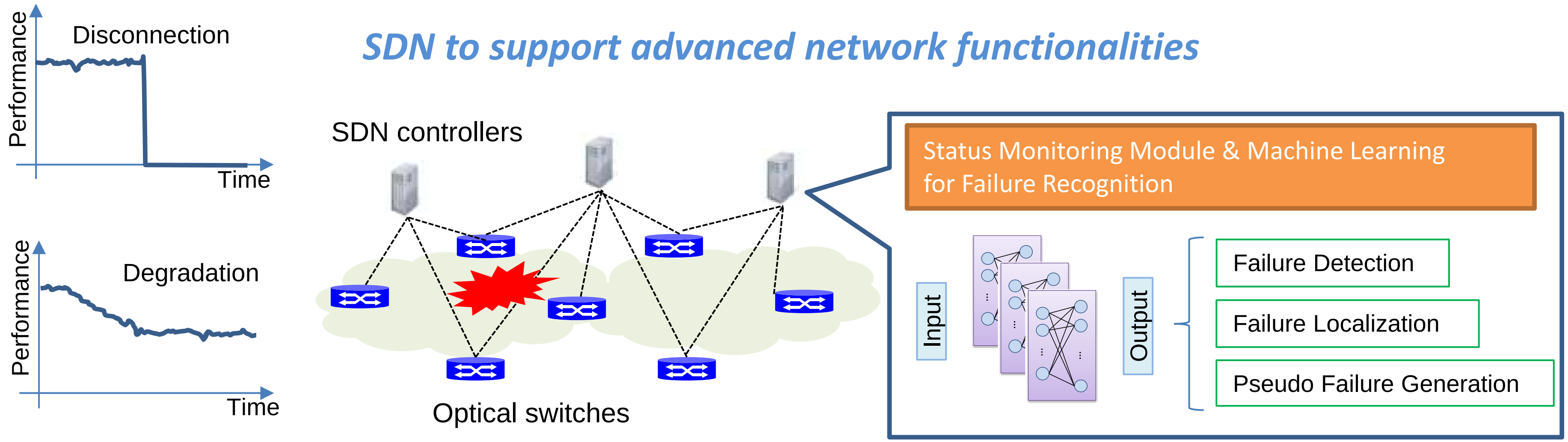


<u>Note: what about additional cost?</u>

Less than 1% additional resource consumption.
Only control paths become longer!

S. Savas, M. Tornatore, F. Dikbiyik, A. Yayimli, C. Martel, and Biswanath Mukherjee, "RASCAR: Recovery-Aware Switch-Controller Assignment and Routing in SDN," in IEEE Transactions on Systems and Network Management, vol. 15, no. 4, pp. 1222-1234, Dec. 2018.

Task 2: SDN Modules for Network Slicing and Data Analytics



- ***SDN-based monitoring for failure detection***: Failure detection mechanisms that make use of global network view provided by SDN to promptly correlate disaster failures.
  - Detection mechanism for disconnected links and failed nodes
  - Machine-Learning-based failure recognition for incomplete network connectivity
- Purpose:
  - With the distributed SDN controllers, perform the resilient slice management, failure detection and analytics ⟹ Support advanced network functionalities, quick response to failures

Task 2: Two major topics using NICT testbed

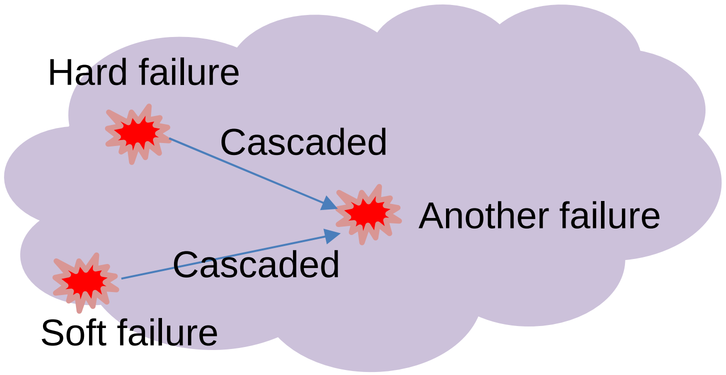
Development of Sendai Testbed

Remote testbed @Sendai NICT branch

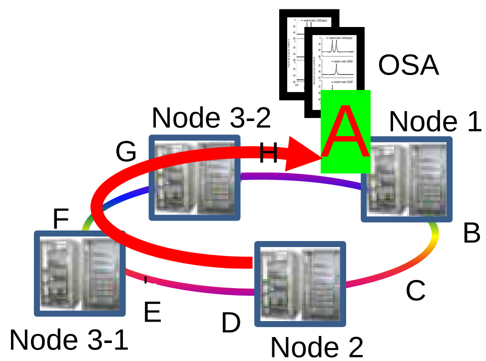
Collaborative Research

Cascade Failure in Optical Networks

ML-based Failure Recognition



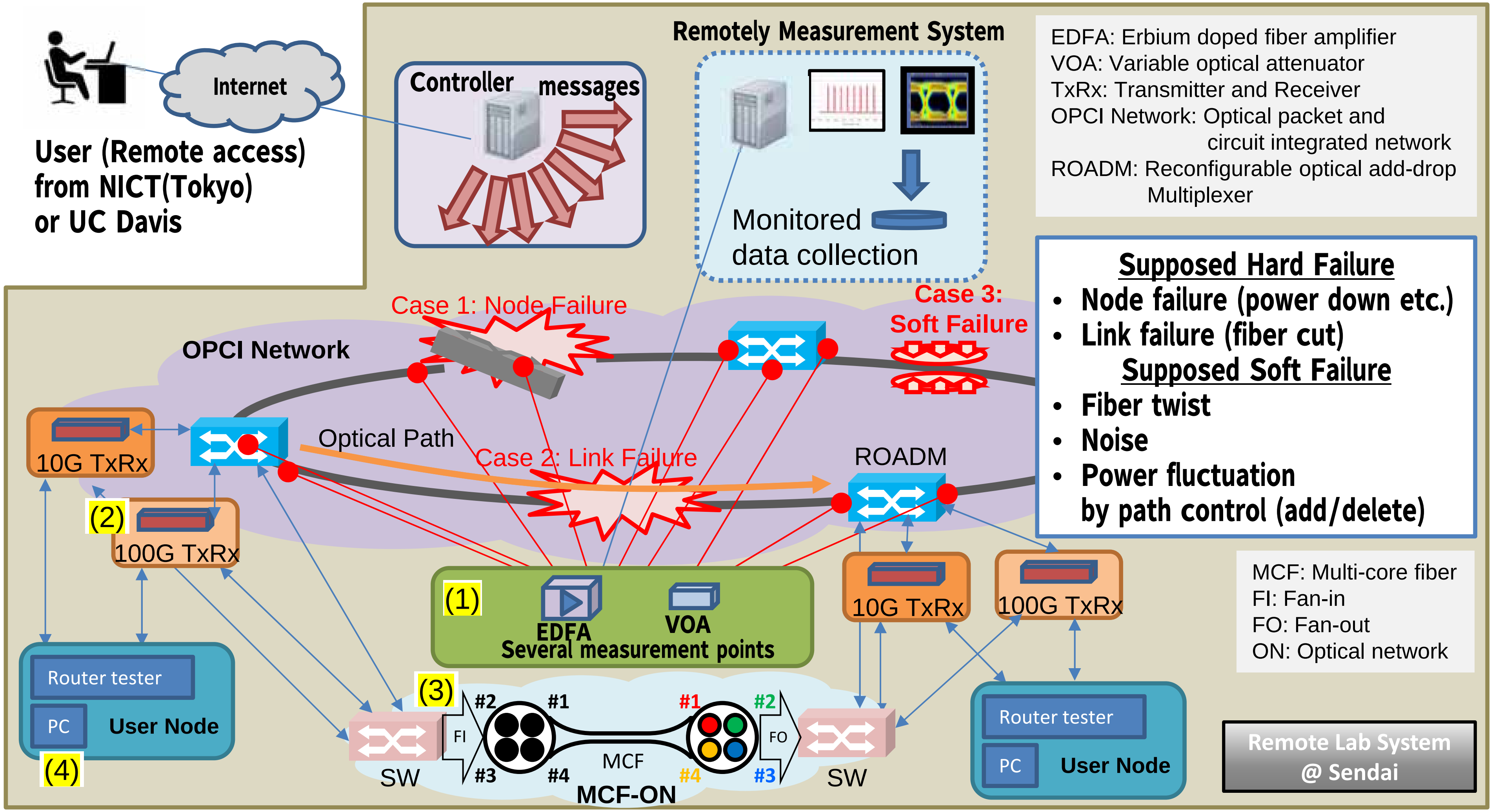
NICT (Sendai) + UC Davis



Data acquisition

Improvement of ML algorithms

Development of Sendai Testbed for Advanced Network Functionality



(1) Multipoint measurement system developed for remote data acquisition

(2) Coherent optical signals generated by 100G transponders

(3) Multi-core fiber optical network

(4) End-to-end network performance evaluation using application/IP traffic

Task 2: Cascade Failure

- Cascade failure: A failure causes another failure of different part of interconnected system. It may degrade quality of transmission (QoT) as soft failure/silent failure.
- Two possible approaches:
  - (1) Hardware implementation for mitigating the cascaded impact of hard failure which causes soft failures
  - (2) Early detection of failures and quick response to restore failures (ML based approach)

Details are undisclosed

Collaborative Research

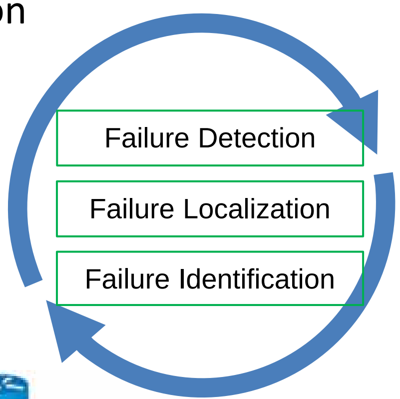
- Failures in optical networks
  - Hard Failure
  - Soft Failure

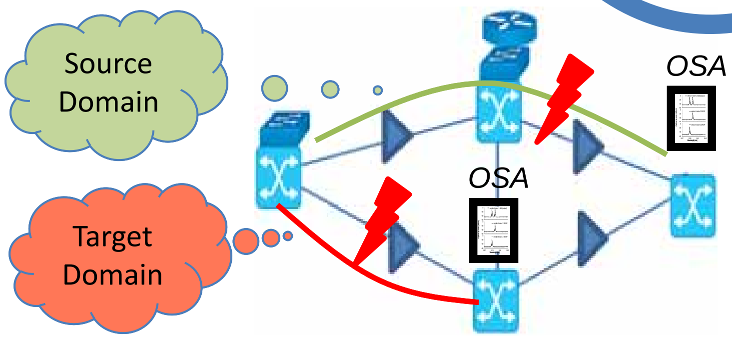
- Quick recognition of failures is important for failure management
  - Machine Learning (ML) technique is a promising solution

- Real data acquisition at Sendai testbed.
  - Experimental setup for several types of failure
  - Data acquisition by remote/local control of several equipment
  - Improvement of ML algorithm
  - Evaluation and discussion

UC Davis

Improvement of ML algorithms
- Neural Network
- Transfer Learning etc.

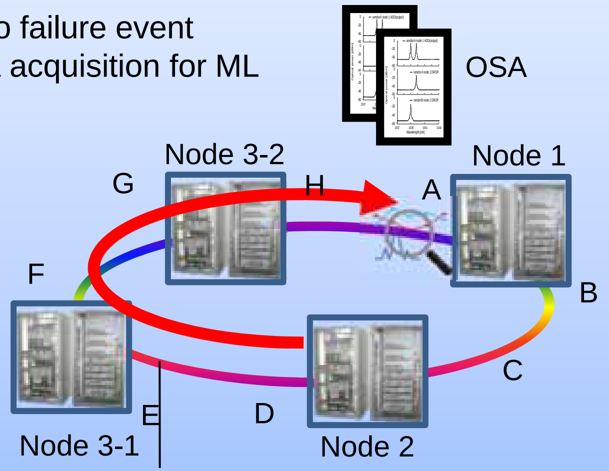




Transfer Learning: Re-use data form source domain in a target domain

NICT (Sendai)

Pseudo failure event
& Data acquisition for ML



Develop failure recognition algorithm in both side and discuss in detail for better algorithm.

F. Musumeci, V. G. Venkata, Y. Hirota, Y. Awaji, S. Xu, M. Shiraiwa, B. Mukherjee, M. Tornatore, "Transfer Learning across Different Lightpaths for Failure-Cause Identification in Optical Networks," ECOC, Mo2K-1, 2020.

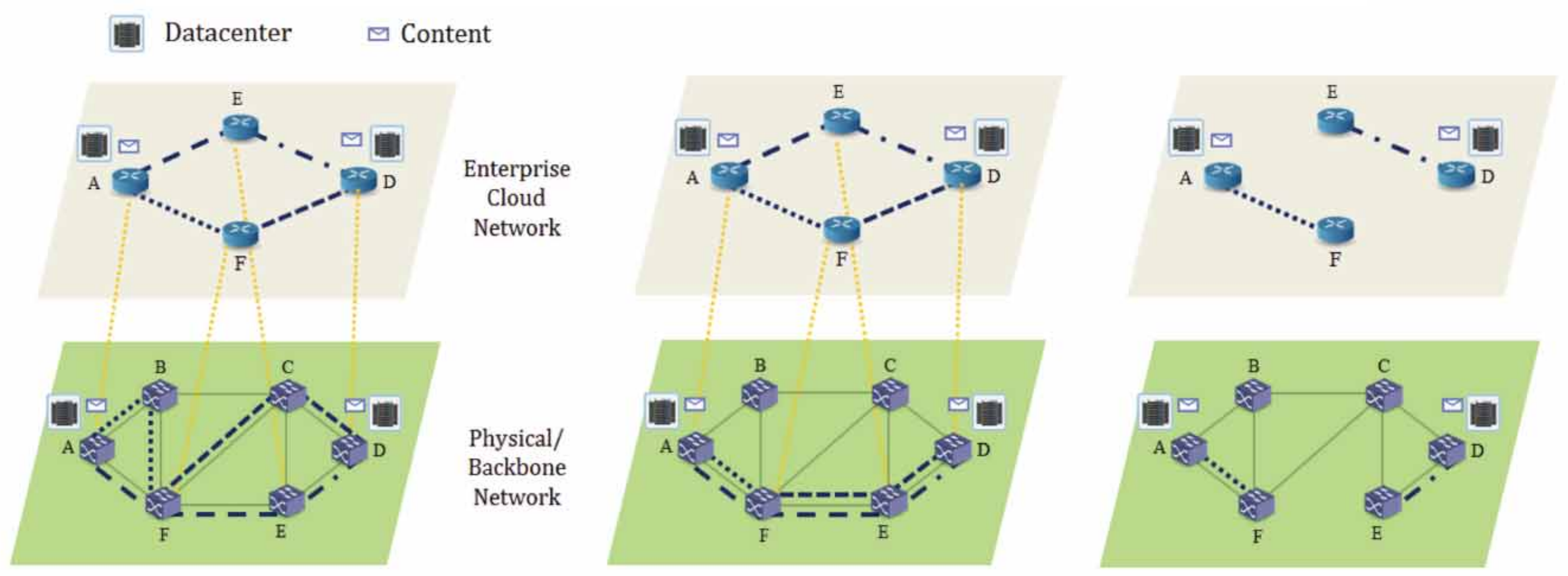
Task 3: "Content Connectivity" for Disaster Resiliency

Network Connectivity - ensure reachability of any pair of nodes in the network (end-to-end) in case of failure

Content Connectivity - ensure reachability of content from any point of a network (end-to-content) in case of failure

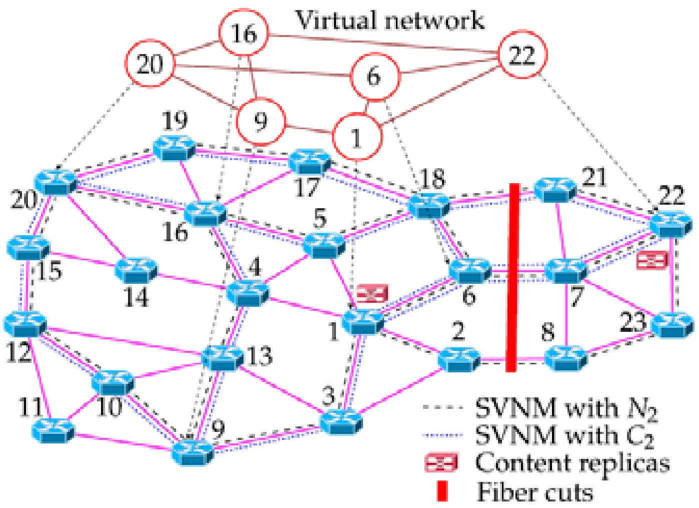
***Costs less** than network connectivity*

*Might be **feasible** when network connectivity is not*

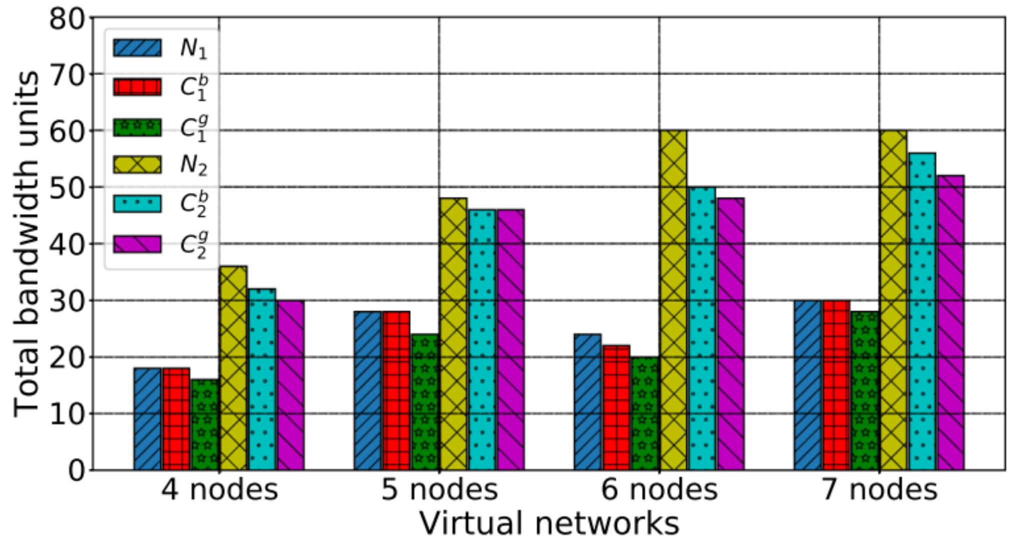


Task 3: ① Generalization of content connectivity modeling against k-link failures (C_k)

Survivable virtual network mapping (SVNM) with content connectivity against multiple link failures



Tokyo23 network provided by NICT

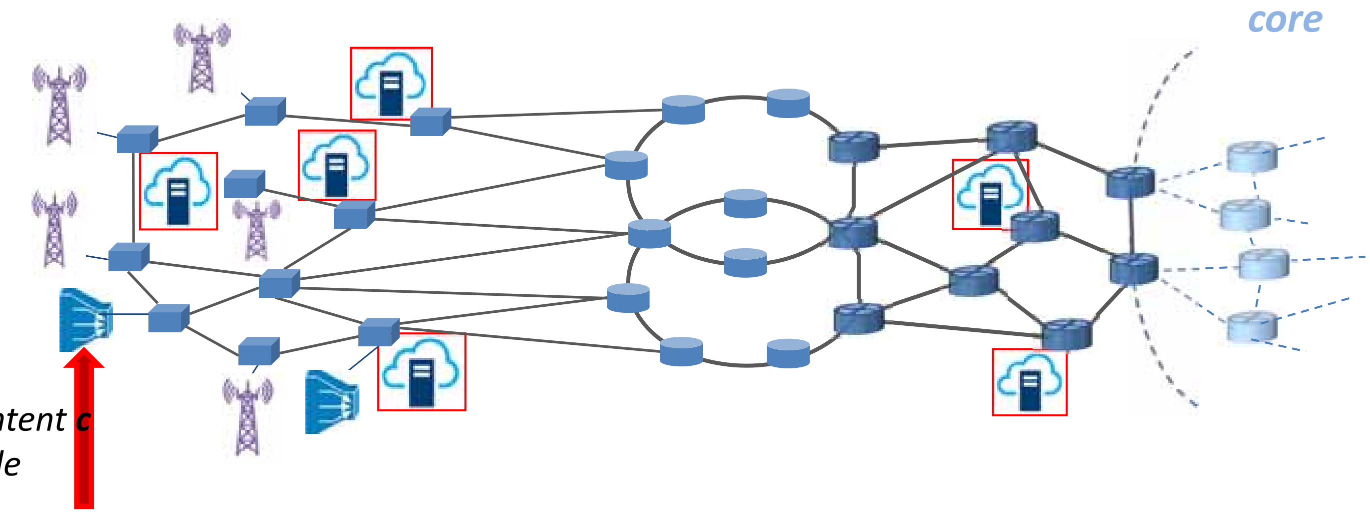


- **N_1 / N_2** - cost of **Network Connectivity** against single-link and double-link failures
- **C_1 / C_2** - cost of **Content Connectivity** against single-link and double-link failures

Main conclusion: Content Connectivity **decreases cost** and **increases availability** wrt Network Connectivity

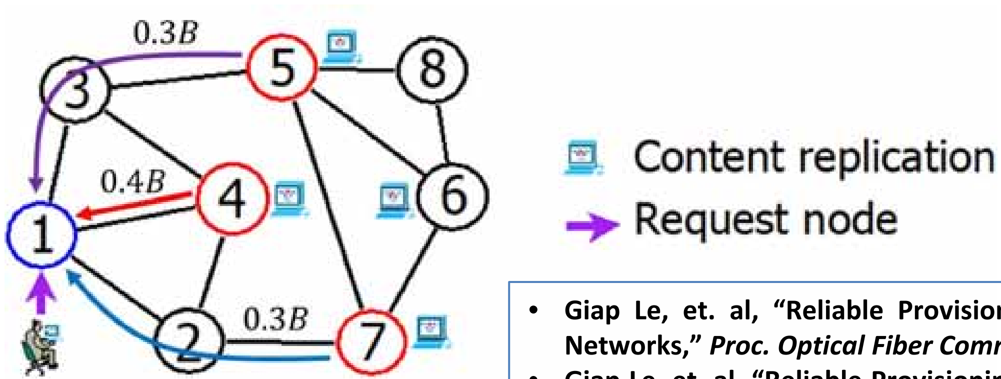
G. Le, et. al, "Survivable Virtual Network Mapping with Content Connectivity Against Multiple Link Failures in Optical Metro Networks," IEEE/OSA Journal of Optical Communication and Networking, 2020

Task 3: ② Reliable Provisioning Using Multipath Routing from Multiple DCs (MPMD)



Content *c* is widely replicated at multiple DCs --> opportunity for MPMD

Example of MPMD

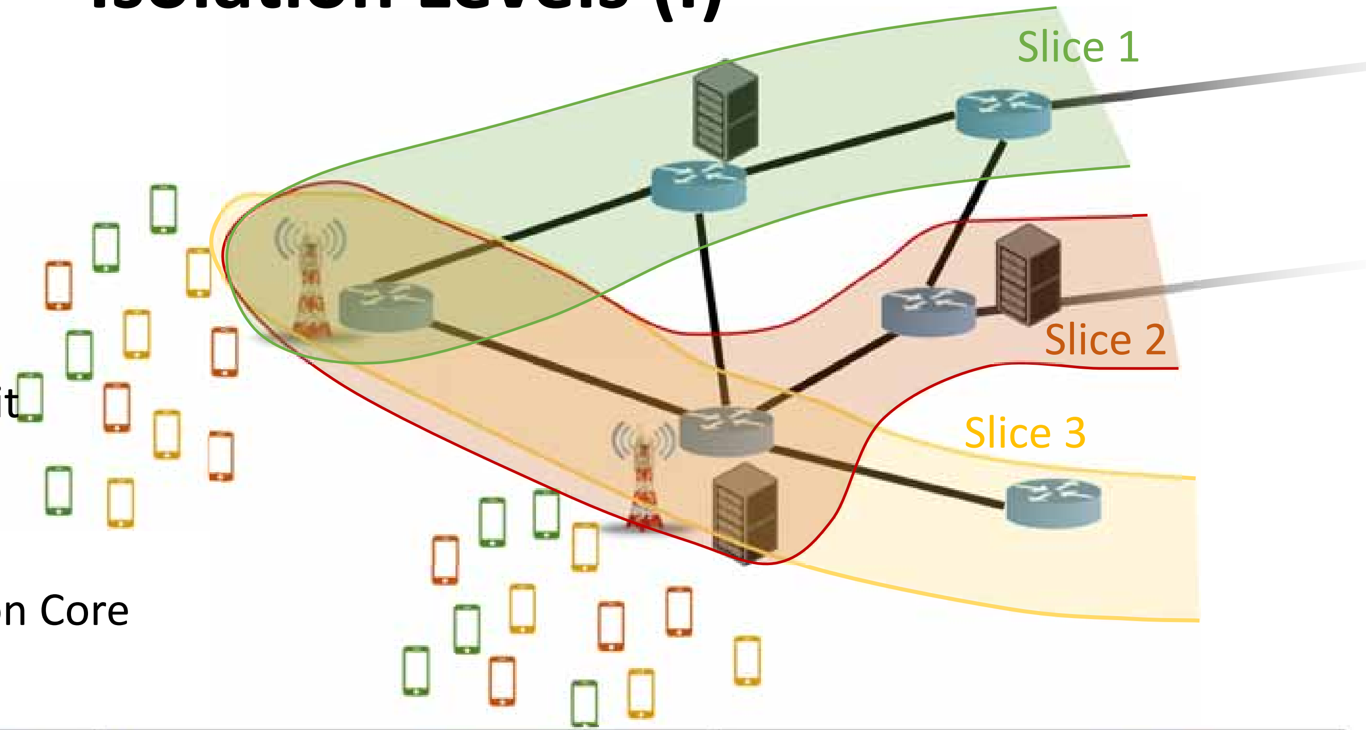


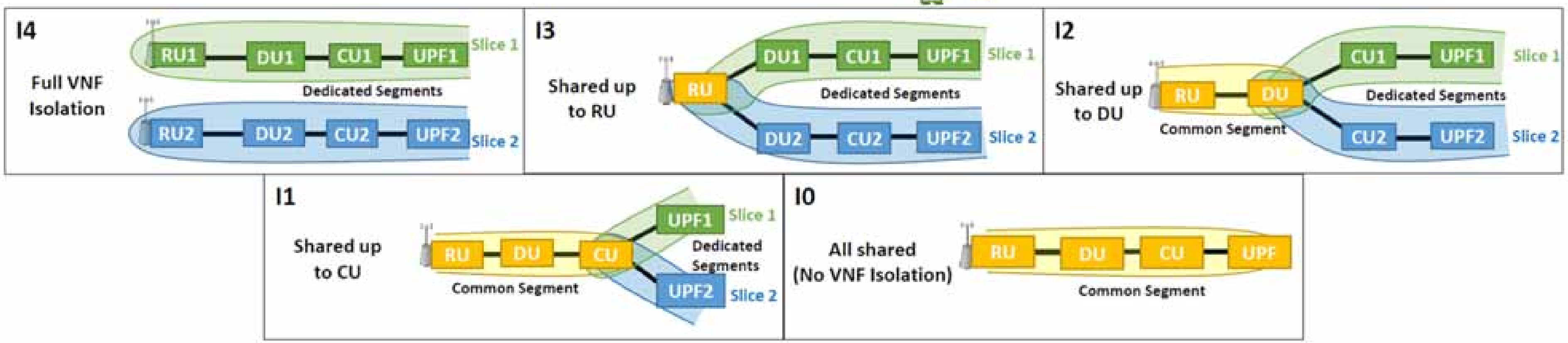
- *We formulated the MPMD problem as an ILP and developed heuristics*
- *Compared with MPSD (Multipath Routing from a Single DC) and DPP (Dedicated-Path Protection)*

- **Giap Le, et. al, "Reliable Provisioning for Dynamic Content Requests in Optical Metro Networks," *Proc. Optical Fiber Communications Conference (OFC)*, June 2021.**
- **Giap Le, et. al, "Reliable Provisioning with Degraded Service using Multipath Routing from Multiple Datacenters for Dynamic Content Requests in Optical Metro Networks," *IEEE/OSA Journal of Optical Communications and Networking* (to submit)**

Task 3: ③ Reliable Slicing with Different Isolation Levels (I)

RU	Radio Unit
DU	Distributed Unit
CU	Central Unit
NGC	New Generation Core





- A. Marotta, D. Cassioli, M. Tornatore, Y. Hirota, Y. Awaji, and B. Mukherjee, "Reliable Slicing with Isolation in Optical Metro-Aggregation Networks," Proc., Optical Fiber Communications Conference OFC, 2020.

Task 4: Optical Multicast for Effective Content Transfer among Edge DCs

"Content connectivity" can be realized only if relevant data is replicated in several edge DCs

- *Constant and intensive synchronization and backup procedures among edge DCs via optical multicasting (Verification on OPCI network testbed)*

- ***Selection of multicast tree leaves for disaster resiliency*** - How do we determine which nodes receive the synchronization data of the multicast tree?
- ***Slicing and multicasting*** - How to slice network resources for multicast transmissions?
- ***Verification of optical multicasting with SDN control in Sendai testbed*** - SDN controllers need to monitor transmitted data and to construct multicasting slices considering the locations of edge DCs.

OPCI network testbed @Sendai NICT branch

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Task 4: Multicast/multipath in SDN-controlled ON

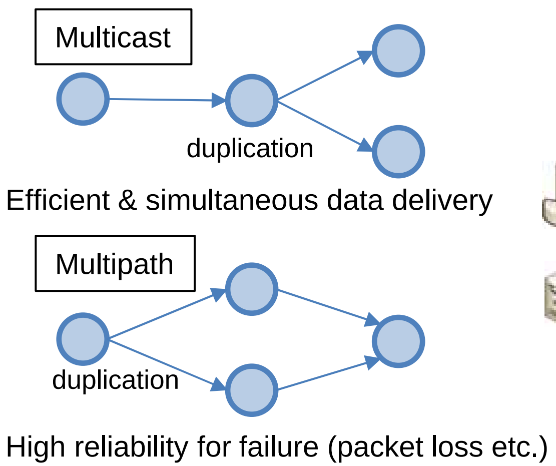
- We study how to deliver large size data for enhancing content connectivity
- 3 types of transmissions for data transfer to multiple receivers

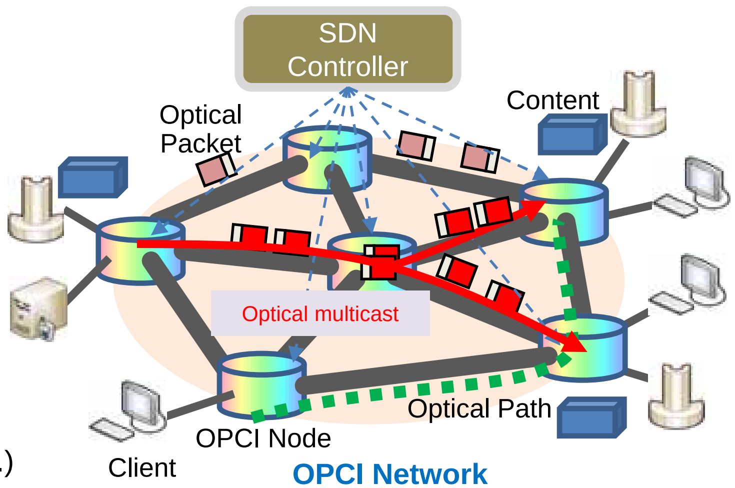
	Required bandwidth	Elapsed time	Switching load
Serial unicast	Low	Very long	Not heavy
Parallel unicast	Very large	Short	Moderate
Optical multicast	Low	Short	Not heavy

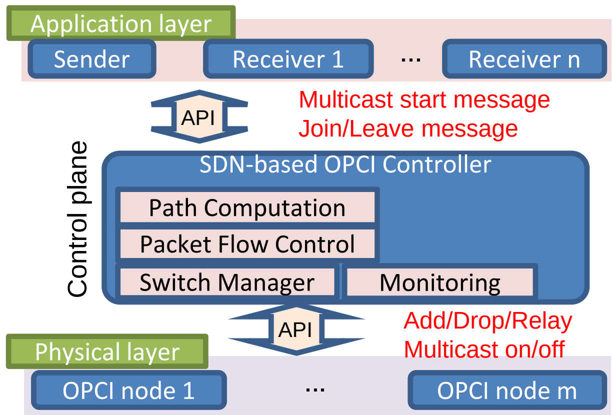
* To duplicate packets electrically is not suitable for large data transfer.

- Optical path multicast is difficult because …
  - Wavelength continuity constraint is difficult in case of multicast against unicast
  - One 10G transceiver cannot execute handshake to multiple 10G receivers simultaneously

- Proposal: Optical level multicast/multipath packet transmission
  - We developed OPCI node and demonstrate its functionality with end-to-end transmissions.
    - Optical multicast transmissions
    - Optical multipath transmissions





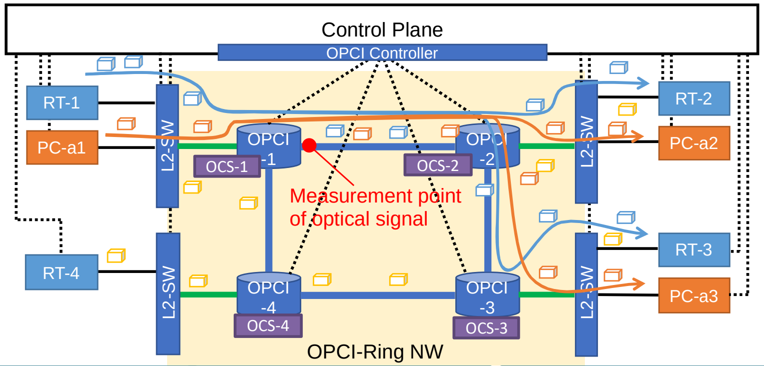


Overview of Optical Multicast Control in OPCI Network

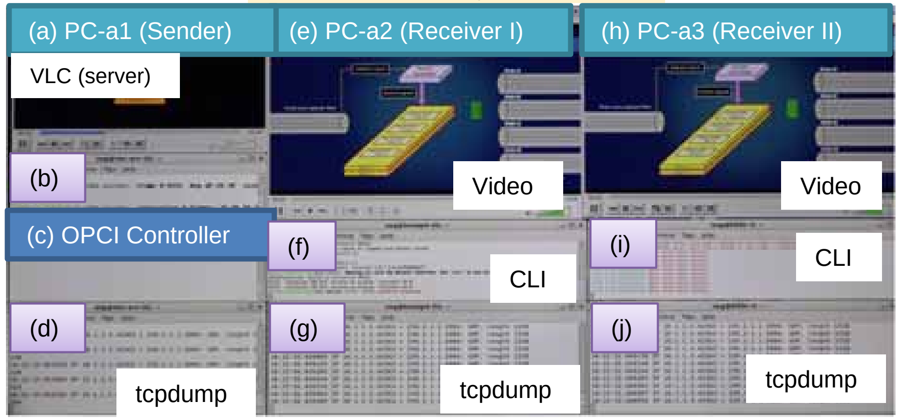
Task 4: Multiple transmissions for CC in ON

Optical Multicast for High Content Connectivity

We develop an SDN-based control for optical-multicast packet transmission and experimentally demonstrate multicast functionality by validating it using an application-layer network service for efficient content duplication in Optical Packet/Circuit Integrated (OPCI) network.



PoC



Video streaming using optical multicast

Efficient Content Delivery to multiple DCs simultaneously

Y. Hirota, S. Xu, M. Shiraiwa, Y. Awaji, M. Tornatore, B. Mukherjee, H. Furukawa, N. Wada, "Experimental Demonstration of Optical Multicast Packet Transmissions in Optical Packet/Circuit Integrated Networks," OFC, Th2A.27, Mar. 2020.

Optical Multipath for High Reliability

We develop a highly reliable optical packet transmissions using multipath and continuous repetition transmission (CRT) techniques, and experimentally demonstrate their functionalities in an Optical Packet/Circuit Integrated (OPCI) network testbed. The combination of both techniques reduces the packet loss rate as one hundredth.

Details are undisclosed

Task 5: Slice-Aware Service Restoration with Recovery Trucks for NG-MANs

Some examples of deployable recovery units (e.g., recovery trucks, FAUs)?

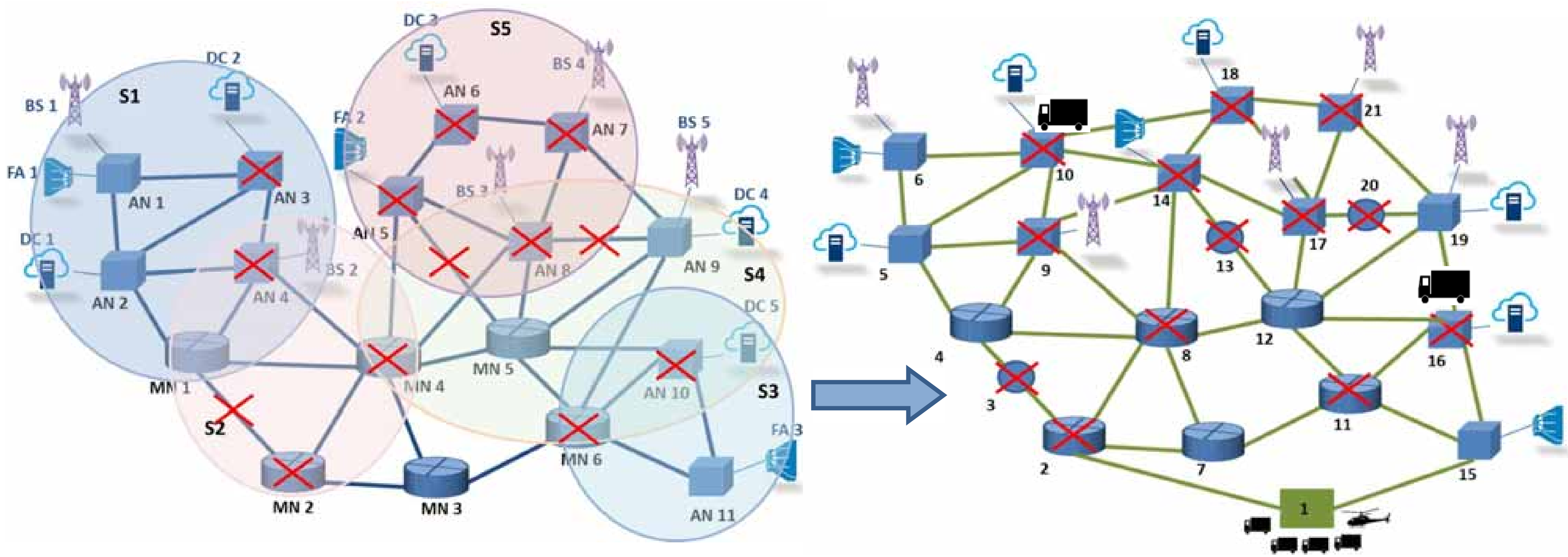
- Rec… e *both* repa… *porary relie…* s going on … *twork reco…*

  … repair unit… , i.e., … t

  –
  –
  –

"Slice-aware" routing and deployment strategy to minimize downtime penalty and ensure fast restoration of important slices

Task 5: Slice-Aware Service Restoration with Recovery Trucks



Slice-aware routing and deployment strategy considerations:

	Slice-aware	Slice-unaware	Slice-aware w/o temp. relief
Cumulative penalty	29.04	41.09	47.88

Objective: Minimize service downtime penalty

➢ ***Vehicle type***

S. Ferdousi, M. Tornatore, S. Xu, Y. Awaji, and B. Mukherjee,, "Slice-Aware Service Restoration with Recovery Trucks for Optical Metro-Access Networks," IEEE GlobeCom 2019 (Best Paper Award)

Task 5: Dynamic Slice-Aware Service Restoration – work in progress

Focus shifting from red area to blue area

Increase in user demands - require more service units (e.g., radio resources)

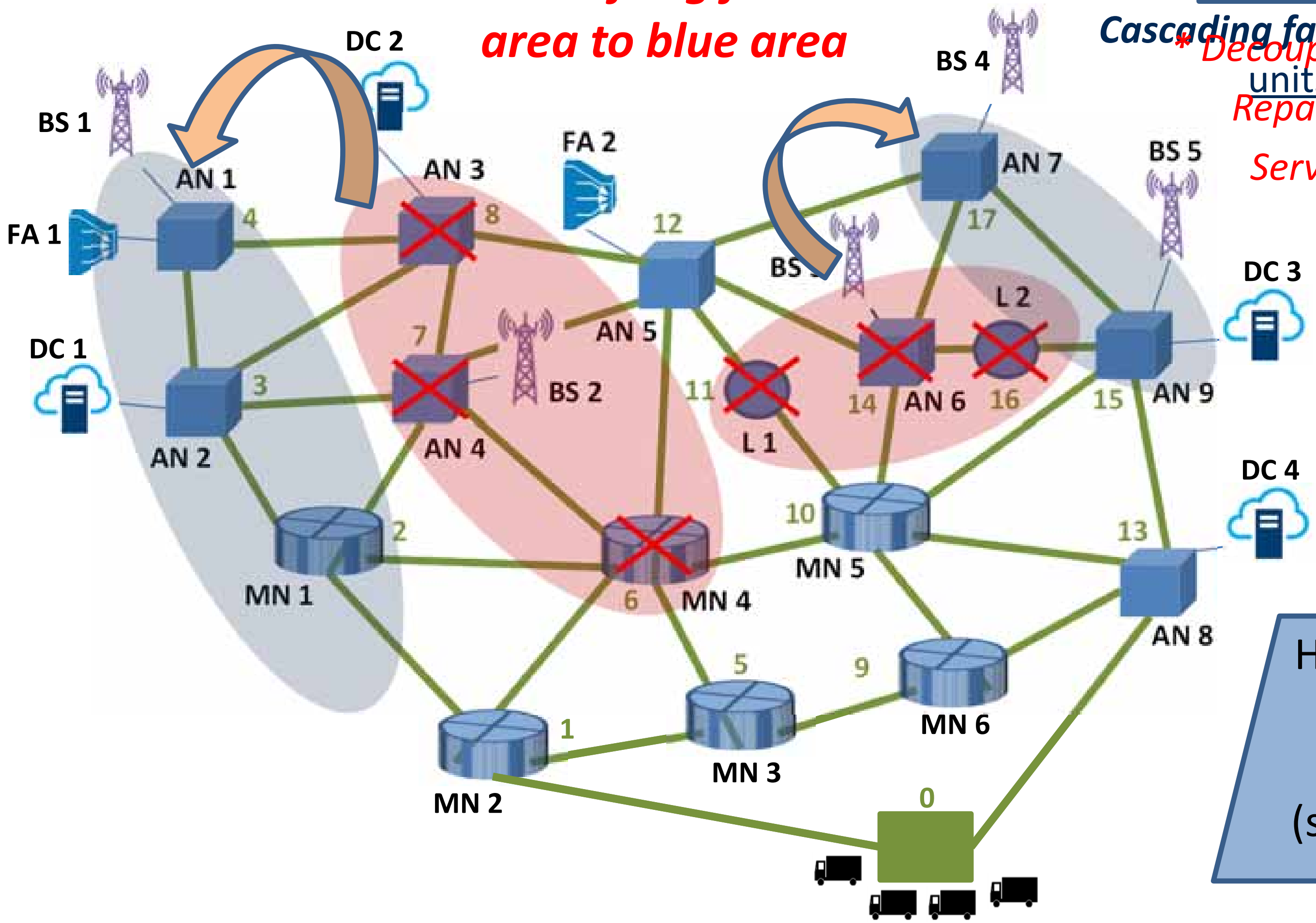
Disjoint Resource Allocation

Cascading failures - require more repair units and service units

** Decouple repair and service units **

Repair units remain deployed

Service units can be mobile

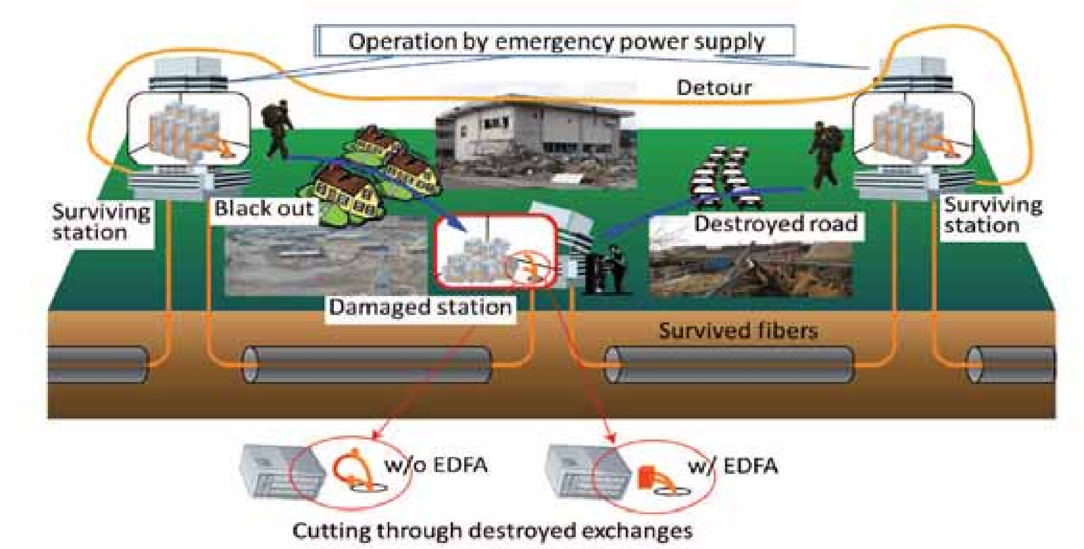


Highly applicable for disaggregated subsystems – FAU (synergy with Task 6)

S. Ferdousi, M. Tornatore, S. Xu, Y. Awaji, and B. Mukherjee, paper in preparation for TNSM

Task 6: Develop and exploit First Aid Unit (FAU)

Interconnection of surviving facilities and FAU to restore network connectivity



- *Impairment information collection utilizing monitoring systems*
- *Impairment-aware emergency optical network planning*
- *Development of supportive hardware and control system*

- *Impairment information collection*
  - Employ emergency optical performance monitoring (OPM) subsystem in FAU
  - Create emergency telemetry platform using outside surviving network resources (e.g., wireless/Internet)
- *Impairment-aware emergency optical network planning*
- *FAU upgrade*

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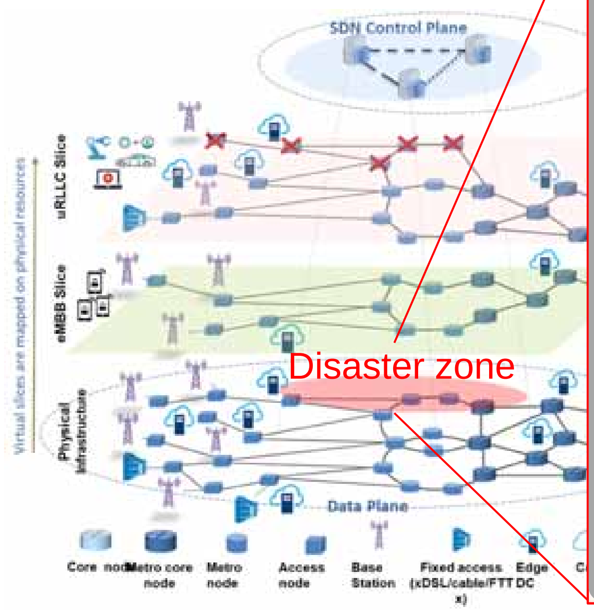
Task 6 Goal: Offer Robust OPM/Telemetry in Post-disaster Recovery

- A. Emergence integration of multi-vendor OPM resource (FAU)
  - Integration of multi-vendor monitor devices FAU via open API and OpenConfig YANG model
- B. Robust OPM/Telemetry
  - Swift creation of robust OPM/Telemetry which is functionable in the degraded and unstable C/M-Plane, or an emergency C/M-plane with limited BW

Details are undisclosed



Details are undisclosed

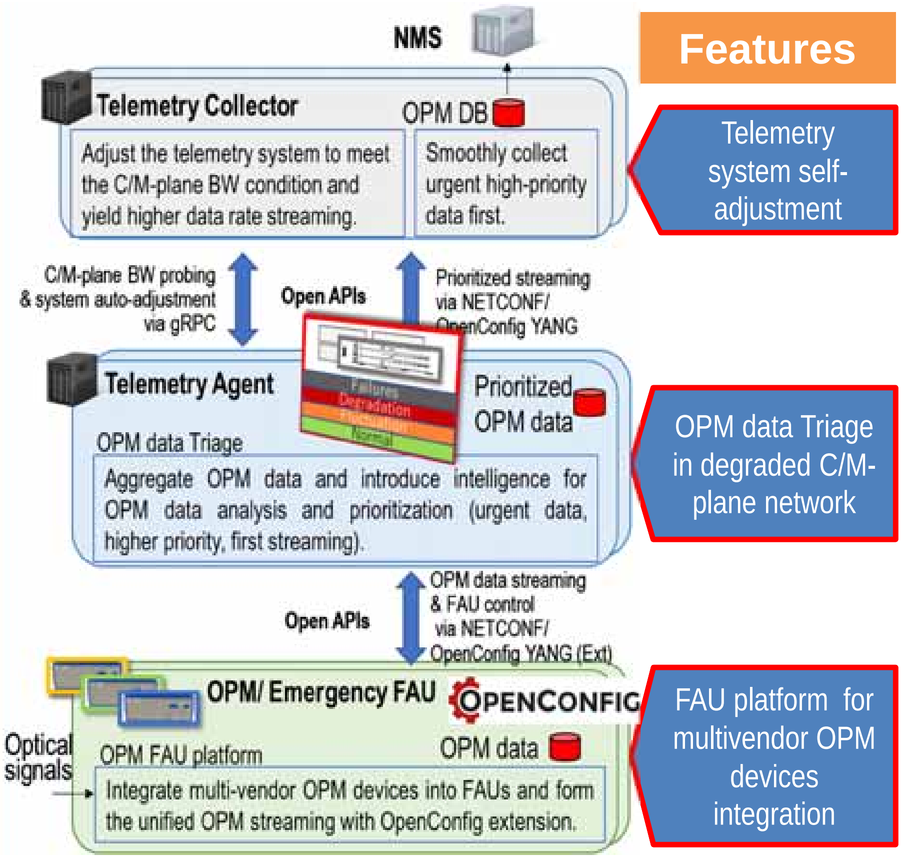
A

Various first aid units (FAUs) OPM monitors

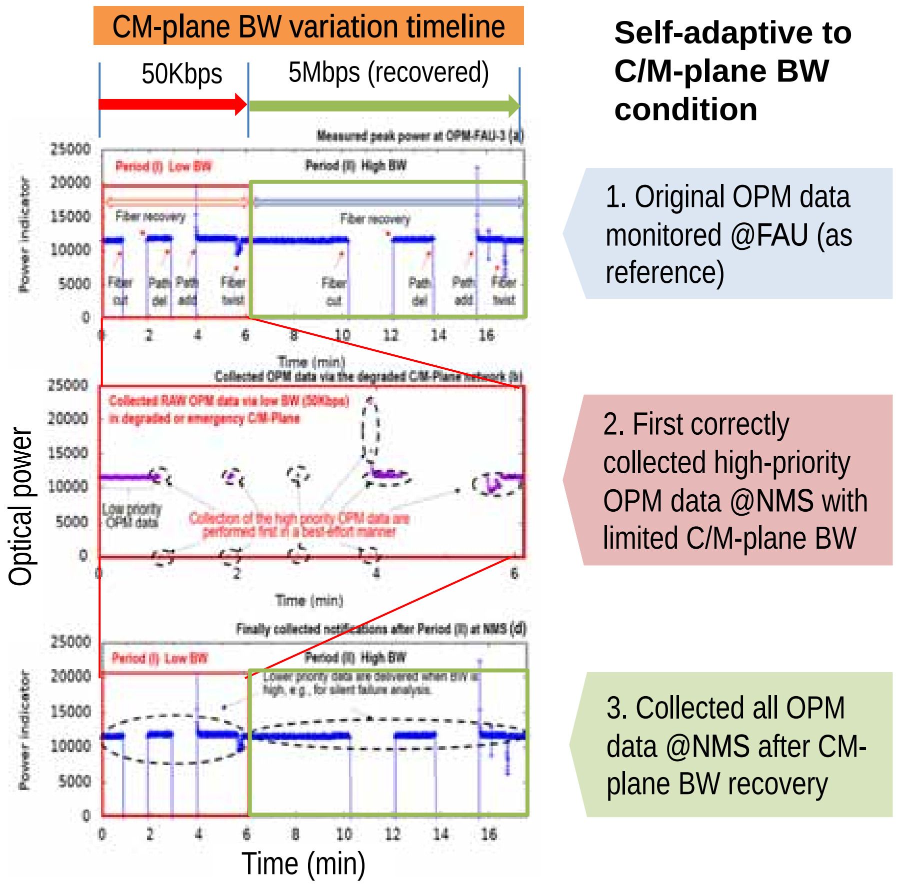
Integration of multi-vendor monitor devices FAU via open API and OpenConfig YANG model

Task 6 (A, B): Achieve Emergency FAU integration and Robust OPM/Telemetry under C/M-plane Constraint

Hierarchical Open and Robust OPM/Telemetry functionable under C/M-plane BW constraint



POC experiments: validation of Robust OPM/Telemetry in degraded C/M-plane network



S. Xu, Y. Hirota, M. Shiraiwa, M. Tornatore, Y. Awaji, N. Wada, and B. Mukherjee, "Quick OPM recreation and robust telemetry in emergency optical networks for early disaster recovery," European Conference on Optical Communication (ECOC) 2019.

S. Xu, Y. Hirota, M. Shiraiwa, M. Tornatore, S. Ferdousi, Y. Awaji, N. Wada, and B. Mukherjee, "Emergency OPM recreation and telemetry for disaster recovery in optical networks," IEEE/OSA Journal of Lightwave Technology, vol. 38, no. 9, pp. 2656-2668, Jan. 2020.

Task 6 (C): Achieve Tight Interaction between Decentralized Telemetry and SDN Control

Details are undisclosed

Publications (Year 1)

TASK 1

- S. Savas, M. Tornatore, F. Dikbiyik, A. Yayimli, C. Martel, and Biswanath Mukherjee, "RASCAR: Recovery-Aware Switch-Controller Assignment and Routing in SDN," in **IEEE Transactions on Systems and Network Management,** vol. 15, no. 4, pp. 1222-1234, Dec. **2018**.
- R. Lourenco, S. Savas, M. Tornatore, B. Mukherjee, "Robust Hierarchical Control Plane for Transport Software-Defined Networks", in **Optical Switching and Networking**, Vol. 30, pp. 10-22, Nov. **2018** .

TASK 2

- F. Musumeci, C. Rottondi, G. Corani, S. Shahkarami, F. Cugini, and M. Tornatore, "A Tutorial on Machine Learning for Failure Management in Optical Networks," in **IEEE/OSA Journal of Lighwave Technology,** vol. 37, no. 16, pp. 4125-4139, 15 Aug.15, **2019** (Task 2).

TASK 5

- S. Ferdousi, M. Tornatore, S. Xu, Y. Awaji, and B. Mukherjee, "Slice-Aware Service Restoration with Recovery Trucks for Optical Metro-Access Networks," **IEEE GlobeCom 2019** (BPA).

TASK 6

- S. Xu, Y. Hirota, M. Shiraiwa, M. Tornatore, Y. Awaji, N. Wada, ans B. Mukherjee, "Quick OPM Recreation And Robust Telemetry In Emergency Optical Networks For Early Disaster Recovery", European Conference on Optical Communication **(ECOC) 2019.**

Publications (Year 2)

TASK 2

- F. Musumeci, V. Venkata, Y. Hirota, Y. Awaji, S. Xu, M. Shiraiwa, B. Mukherjee, and M. Tornatore, "Transfer Learning across Different Lightpaths for Failure-Cause Identification," submitted to **ECOC, 2020**.

TASK 3

- G. Le, A. Marotta, S. Ferdousi, S. Xu, Y. Hirota, Y. Awaji, M. Tornatore, and B. Mukherjee, "Survivable Virtual Network Mapping with Content Connectivity Against Multiple Link Failures in Optical Metro Networks," **IEEE/OSA Journal of Optical Communication and Networking 2020**.
- O. Ayoub, A. Bovio, F. Musumeci, and M. Tornatore, "Survivable Virtual Network Mapping in Filterless Optical Networks," Proc., 24th International Conference on Optical Network Design and Modeling (**ONDM**), May. **2020**.
- A. Marotta, D. Cassioli, M. Tornatore, Y. Hirota, Y. Awaji, and B. Mukherjee, "Reliable Slicing with Isolation in Optical Metro-Aggregation Networks," Proc., Optical Fiber Communications Conference **OFC, 2020**.

TASK 4

- Y. Hirota, S. Xu, M. Shiraiwa, Y. Awaji, M. Tornatore, B. Mukherjee, H. Furukawa, and N. Wada, "Experimental Demonstration of Optical Multicast Packet Transmissions in Optical Packet/Circuit Integrated Networks," Proc,. Optical Fiber Communication Conference, **OFC 2020.**

TASK 5

- S. Ferdousi, M. Tornatore, F. Dikbiyik, C. U. Martel, S. Xu, Y. Hirota, Y. Awaji, and B. Mukherjee, "Joint progressive network and datacenter recovery after large-scale disasters**," IEEE Transactions on Network and Service Management, 2020.**

TASK 6

- S. Xu, N. Yoshikane, M. Shiraiwa, Y. Hirota, T. Tsuritani, S. Ferdousi, Y. Awaji, N. Wada, and B. Mukherjee, "Toward Disaster-Resilient Optical Networks with Open and Disaggregated Subsystems, " 16th International Conference on the Design of Reliable Communication Networks **(DRCN), 2020**.
- S. Xu, Y. Hirota, M. Shiraiwa, M. Tornatore, S. Ferdousi, Y. Awaji, N. Wada, and B. Mukherjee, "Emergency OPM recreation and telemetry for disaster recovery in optical networks," **IEEE/OSA Journal of Lightwave Technology,** vol. 38, no. 9, pp. 2656-2668, Jan. **2020**.

Publications (Year 3)

TASK 2

- Y. Hirota, M. Shiraiwa, S. Xu, M. Tornatore, B. Mukherjee, and Y. Awaji, "Experimental Demonstration of Potential Performance Degradation by Gain Changes in Multi-core Fiber Networks and Suppression of Soft Failure using Burst-mode EDFA," **Photonics in Switching and Computing (PSC) 2021** (under review).

TASK 3

- G. Le, S. Ferdousi, A. Marotta, S. Xu, Y. Hirota, Y. Awaji, M. Tornatore, B. Mukherjee, "Reliable Provisioning for Dynamic Content Requests in Optical Metro Networks", in Proc. **OFC 2021**.
- O. Ayoub, A. de Sousa, S. Mendieta, F. Musumeci and M. Tornatore, "Online Virtual Machine Evacuation for Disaster Resilience in Inter-Data Center Networks," in **IEEE Transactions on Network and Service Management** (accepted, early access).
- L. Askari, M. Tamizi, O. Ayoub, M. Tornatore, "Protection Strategies for Dynamic VNF Placement and Service Chaining ," Proc. of **ICCCN 2021** [Invited].
- A. Marotta, D. Cassioli, M. Tornatore, Y. Hirota, Y. Awaji, and B. Mukherjee, "Reliable Slicing with Isolation in Optical Metro-Aggregation Networks", submitted to **JOCN**.
- O. Ayoub, A. Bovio, F. Musumeci and M. Tornatore, "New Technique for Survivable Virtual Network Mapping Based on Capacity Sharing against Double-Link Failures", In Proc. **CNSM 2021.**

TASK 5

- J. Rak, R. Girão-Silva, T. Gomes, G. Ellinas, B. Kantarci, M. Tornatore, "Disaster Resilience of Optical Networks: State of the Art, Challenges, and Opportunities," **Optical Switching and Networking**, **2021**.
- O. Ayoub, A. Bovio, F. Musumeci and M. Tornatore, "Survivable Virtual Network Mapping with Fiber Tree Establishment in Filterless Optical Networks," in **IEEE Transactions on Network and Service Management** (submitted, second round of review).

TASK 6

- S. Xu, K. Ishii, N. Yoshikane, S. Ferdousi, M. Shiraiwa, Y. Hirota, T. Tsuritani, M. Tornatore, Y. Awaji, N. Wada, S. Namiki, and B. Mukherjee, "An Approach to Large-scale Disaster-Resilient Optical Networks with Openness and Disaggregation," in Proc. **IEICE Communication System Tech. Rpt.**, Sept. **2021**.
- S. Xu, K. Ishii, N. Yoshikane, S. Ferdousi, M. Shiraiwa, Y. Hirota, T. Tsuritani, Y. Awaji, N. Wada, S. Namiki, and B. Mukherjee, "Towards large-scale disaster-resilient open and integrated disaggregate/legacy optical networks," in Proc. Asia Communications and Photonics Conference (**ACP2021**) , Shanghai, China, Oct. 2021. [Invited].

Submitted or planned (Year 4)

- S. Ferdousi, M. Tornatore, S. Xu, Y. Awaji, and B. Mukherjee, “Dynamic Slice-Aware Service Restoration with Recovery Trucks for Optical Metro-Access Networks," to be submitted to **IEEE Transactions on Network and Service Management**.
- G. Le, S. Ferdousi, A. Marotta, S. Xu, Y. Hirota, Y. Awaji, S. S. Savas, M. Tornatore, B. Mukherjee, “Reliable Provisioning with Degraded Service using Multipath Routing from Multiple Datacenters for Dynamic Content Requests in Optical Metro Networks,” to be submitted to **IEEE/OSA Journal of Optical Communications and Networking**.
- S. Xu, Y. Hirota, M. Shiraiwa, M. Tornatore, Y. Awaji, and B. Mukherjee, “Achieve instinctive local reaction and chained network-wide SDN control to failures in multi-vendor multi-domain post-disaster recovery,” to be submitted to **OFC 2022**.
- Q. Zhang, O. Ayoub, J. Wu, F. Musumeci, G. Li and M. Tornatore, "Progressive Slice Recovery with Guaranteed Slice Connectivity after Massive Failures," submitted to **IEEE/ACM Transaction on Networking**, first round of review, minor revision.

Summary of dissemination

- 23 publications to date [11 journals, 12 in conference]
  - 14 publications [5 journals, 9 conferences] (*joint*)
  - 9 [6 journals, 3 conferences] (*single partner*)

  +4 in preparation (3 *joint collaboration*)
- Invited talks:
  - DRCN 2020, ECOC 2020, OECC 2019, OFC 2019, OMTA 2021, ACP 2021, ECOC 2021 (tutorial) …
- *Other activities*: PI Tornatore is lead Guest Editor of a new yearly special issue of IEEE Transaction on Network and Service Management on "Design of Reliable Communication Networks"

END

Thanks for your attention!!