Disaster-Resiliency Strategies for Next-Generation Metro Optical Networks

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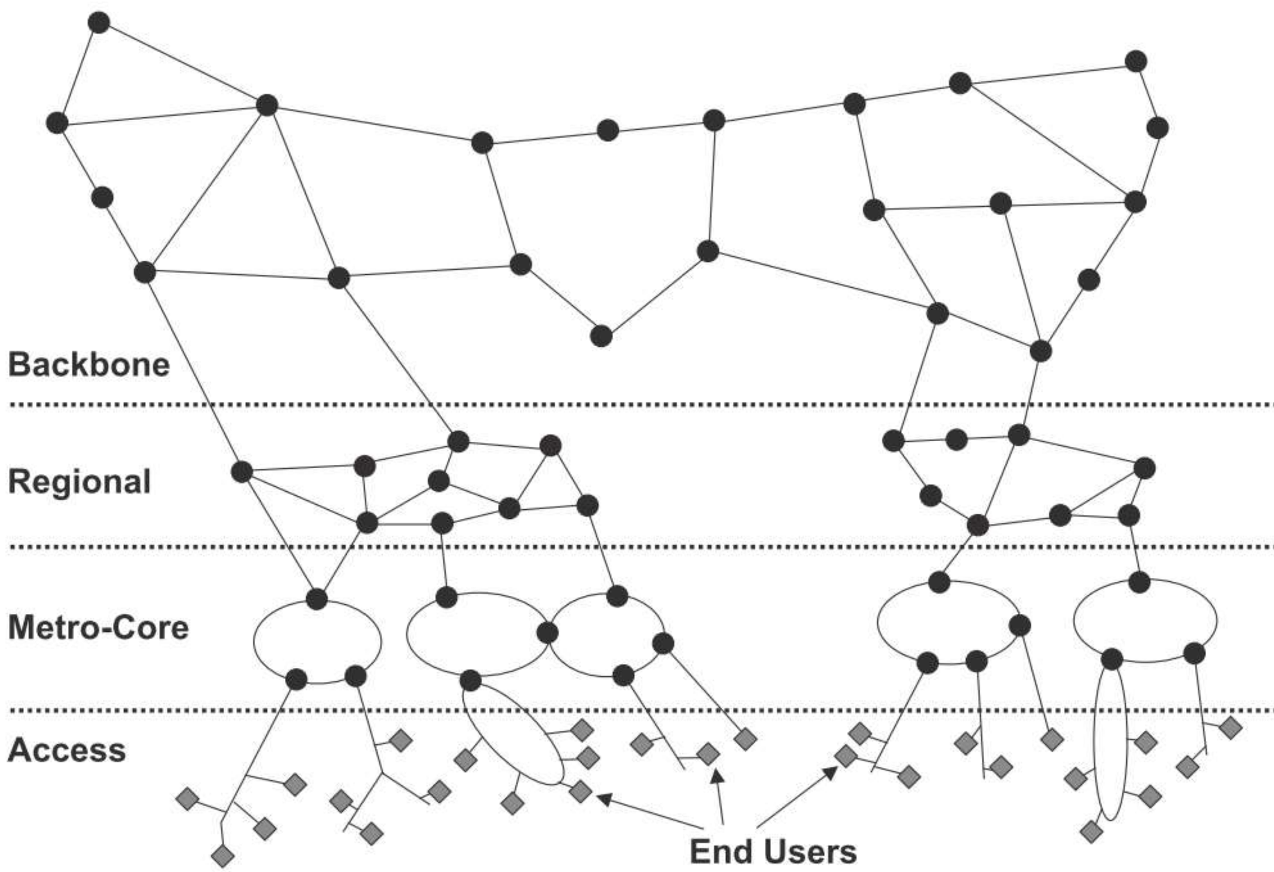
Nov. 16, 2018

Outline

1. Background of Metro Optical Networks, Network Planes, SDN, NFV, and Resilience Techniques
2. Disaster-Resiliency Strategies for Next-Generation Metro Optical Networks
   - ✓Control plane for NG-MAN
   - ✓Slice-protection for NG-MAN data plane
   - ✓Fast recovery techniques
3. Research Problem Formulation and Proposals

Hierarchy of Optical Networks



✓Differentiated based on:

- number of customers served
- required capacity
- and geographic extent

✓Metro-core:

- aggregates the traffic from access networks
- inter-connects telecom center offices
- serves thousands of customers
- spans an area of hundreds of kilometers
- be in ring topologies

[1] J. M. Simmons, "Optical Network Design and Planning," *Springer International Publishing*, 2014

Planes of Optical Networks: Conventional

- **Data plane**: responsible for forwarding of data
- **Management plane**: responsible for network operations
  - ✓historically used centralized network management system (NMS)
  - ✓performs fault, configuration, accounting, performance, and security (FCAPS)
- **Control plane:**
  - ✓performed by software **distributed** in network equipment
  - ✓discovers network topology, network resources, and network capabilities; disseminates of this information throughout the network; computes paths; and signals for connection establishment and teardown
  - ✓plays an important role in supporting dynamic traffic.

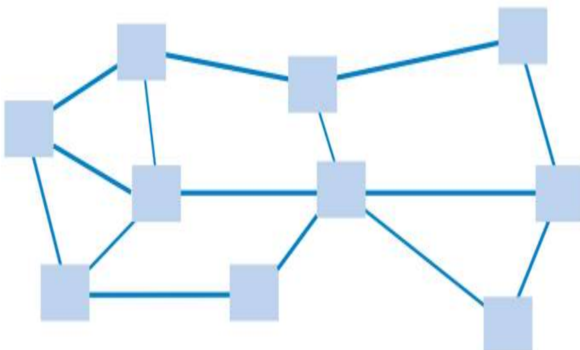
Basic Network Resilience Techniques

- Network survivability in two forms: **protection** and **restoration**
- Protection:
  - ✓ pre-provisioned failure recovery
  - ✓ fast recovery
  - ✓ single failure network survivability up to 100%
  - ✓ expensive due to duplicating network equipment
- Restoration:
  - ✓ compute alternative route around the failure
  - ✓ based on available resources
  - ✓ slower than protection
  - ✓ may not be viable due to no network resources

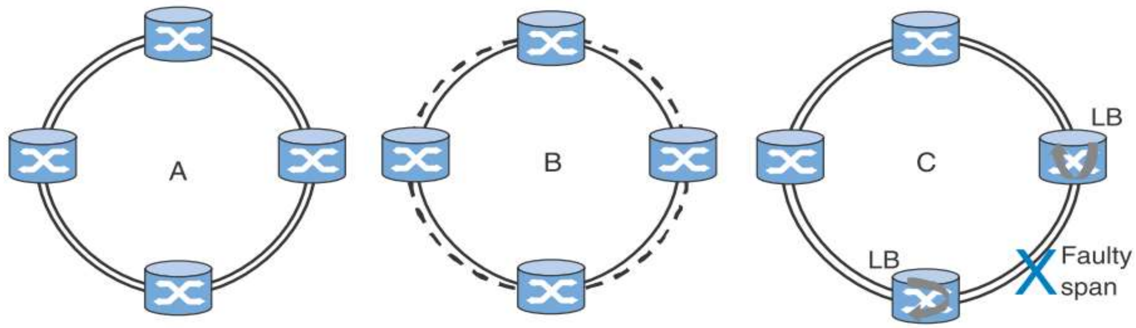
[2] L. Wosinska et al., "Network Resilience in Future Optical Networks," *Springer*, 2009

Network Topologies

Mesh Topology

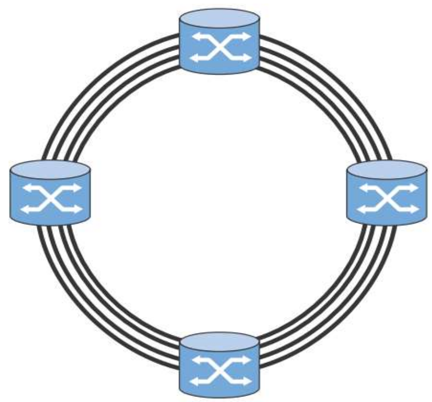


Ring Topology



- ✓ suitable for metro optical networks
- ✓ fast to switch to protection

- ✓ suitable for long-haul networks
- ✓ including cross-connecting nodes
- ✓ excellent protection strategies by rerouting the traffic away from failure condition



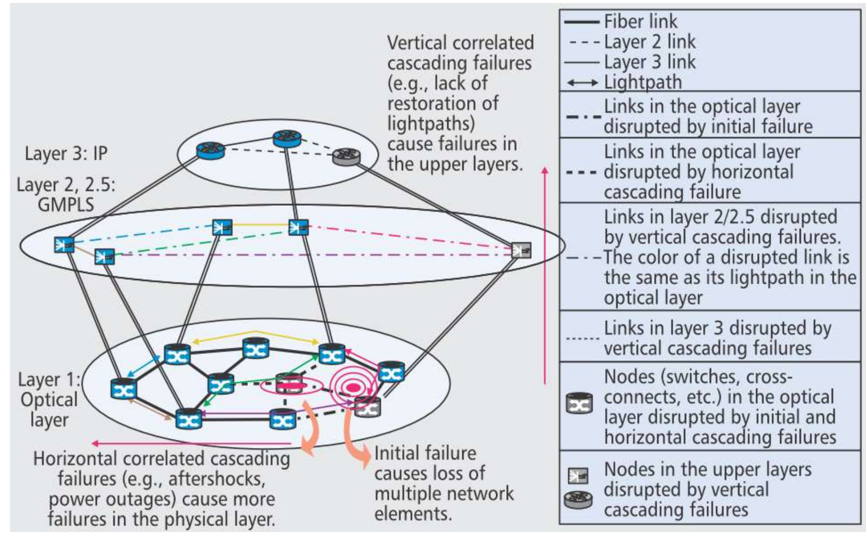
- ✓ bidirectional
- ✓ many wavelengths and optical links
- ✓ ring nodes performs both OADM and de/aggregation

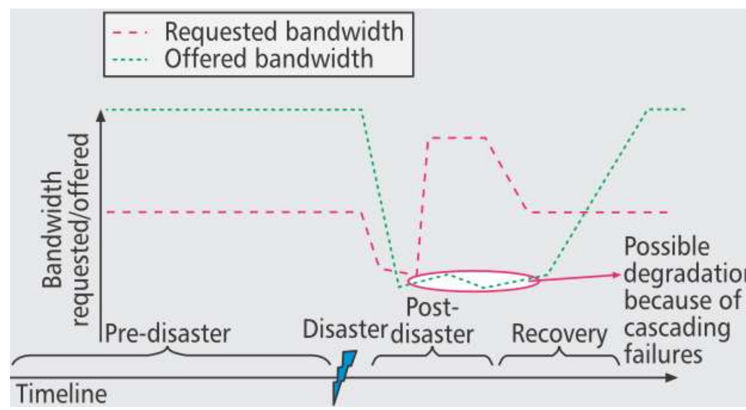
Next-Generation Optical Ring

[2] L. Wosinska et al., "Network Resilience in Future Optical Networks," *Springer*, 2009

Network Adaptivity from Disaster/Cascading Failures

- Protection/restoration techniques (for single single-event failure) do not work for disaster disruptions.
- A disaster may cause correlated cascading failures:
  - ✓ **horizontal** failures at optical layer
  - ✓ **vertical** failures at the upper layers
- Post-disaster traffic **flood** may cause severe **congestion**.
- **Content connectivity**: reachability of content from a network





[3] B. Mukherjee, M. F. Habib and F. Dikbiyik, "Network adaptability from disaster disruptions and cascading failures," in *IEEE Communications Magazine*, vol. 52, no. 5, pp. 230-238, May 2014.

Network Adaptivity from Disaster/Cascading Failures

- **Network Adaptivity**: ability to re-range itself (self-organization networks), and to re-disseminate network content
- **Network preparedness**:
  - ✓normal preparedness
  - ✓enhanced preparedness
  - ✓post-disaster preparedness

[3] B. Mukherjee, M. F. Habib and F. Dikbiyik, "Network adaptability from disaster disruptions and cascading failures," in *IEEE Communications Magazine*, vol. 52, no. 5, pp. 230-238, May 2014.

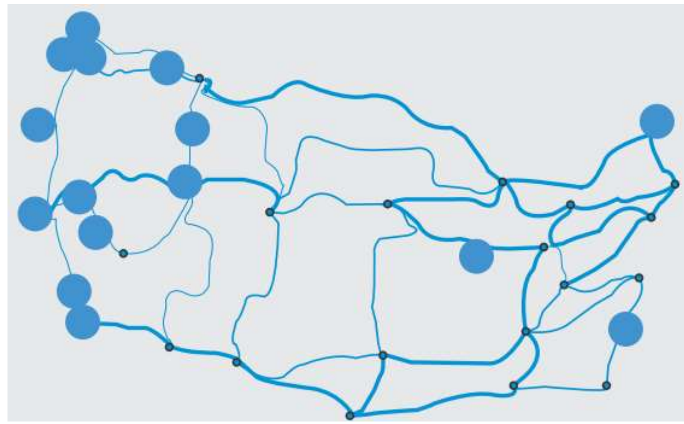
Adaptivity to Disruptions by Degraded-Service Tolerance

Normal Preparedness:

- ✓ **Probabilistic** approach
- ✓ Optical layer only
- ✓ Risk-aware routing
- ✓ Protection of links and nodes

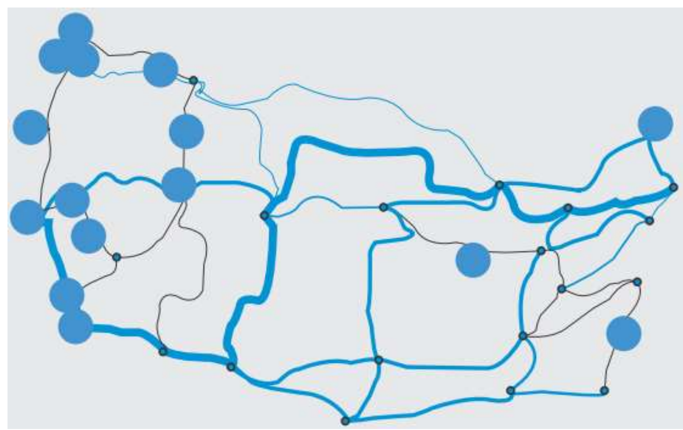
Notes:

- ✓ line thickness = bandwidth utilization
- ✓ circles = risky regions



Risk-unaware routing

Line thickness: capacity utilization



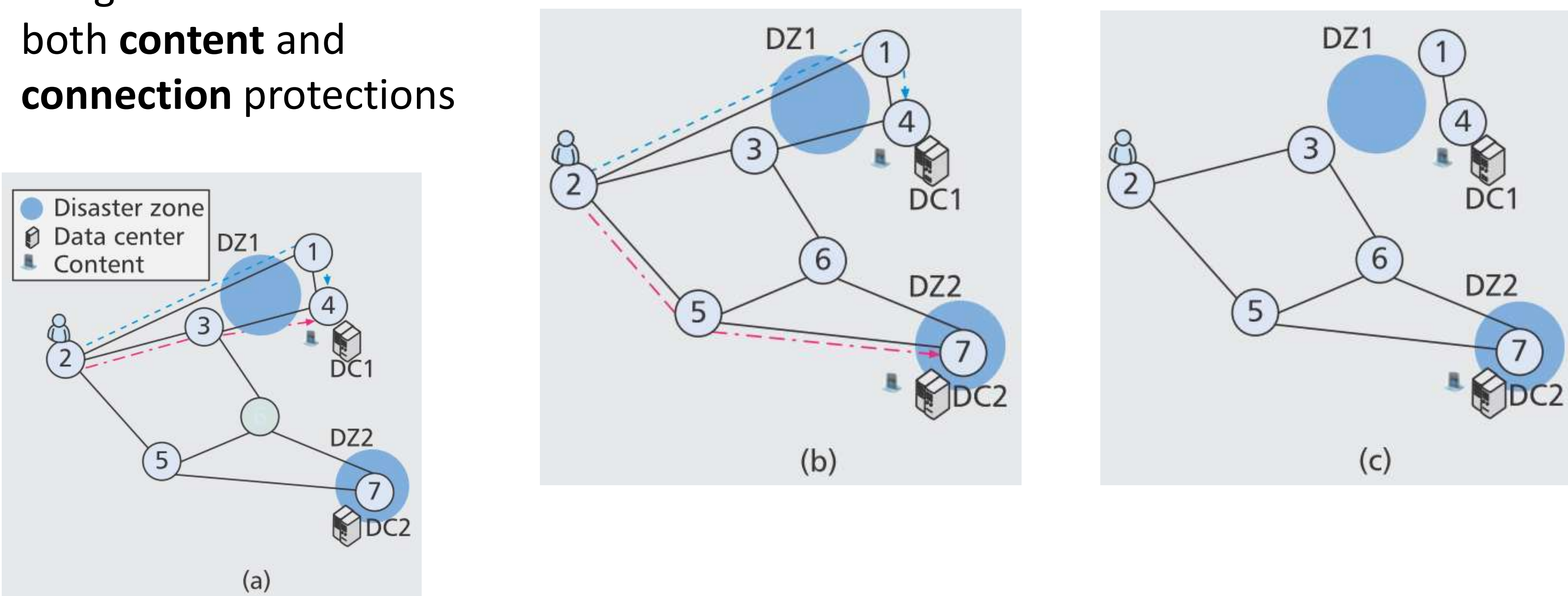
Risk-aware routing

[3] B. Mukherjee, M. F. Habib and F. Dikbiyik, "Network adaptability from disaster disruptions and cascading failures," in *IEEE Communications Magazine*, vol. 52, no. 5, pp. 230-238, May 2014.

Adaptivity to Disruptions by Degraded-Service Tolerance

Normal Preparedness:

- ✓ Integrated solution for both **content** and **connection** protections

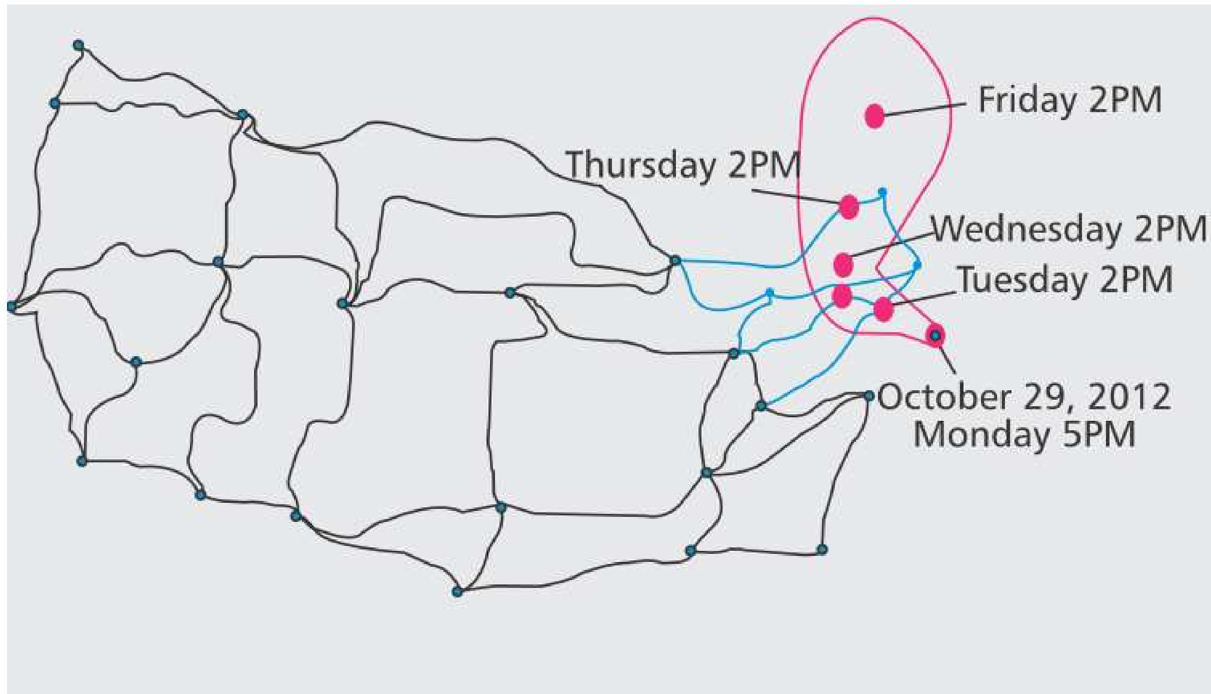


[3] B. Mukherjee, M. F. Habib and F. Dikbiyik, "Network adaptability from disaster disruptions and cascading failures," in *IEEE Communications Magazine*, vol. 52, no. 5, pp. 230-238, May 2014.

Adaptivity to Disruptions by Degraded-Service Tolerance

Enhanced Preparedness:

- ✓ disasters may be well known in advance
- ✓ **re-allocate** networks resources
- ✓ **replicate** data

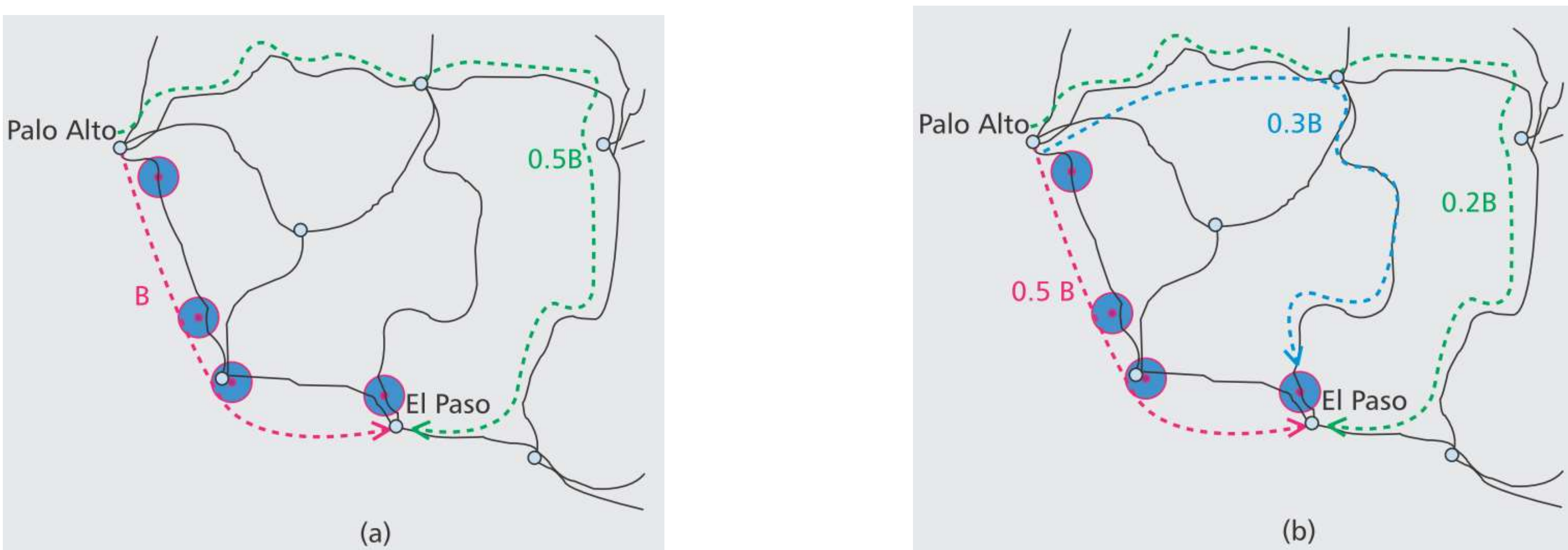


[3] B. Mukherjee, M. F. Habib and F. Dikbiyik, "Network adaptability from disaster disruptions and cascading failures," in *IEEE Communications Magazine*, vol. 52, no. 5, pp. 230-238, May 2014.

Adaptivity to Disruptions by Degraded-Service Tolerance

Post-Disaster Actions:

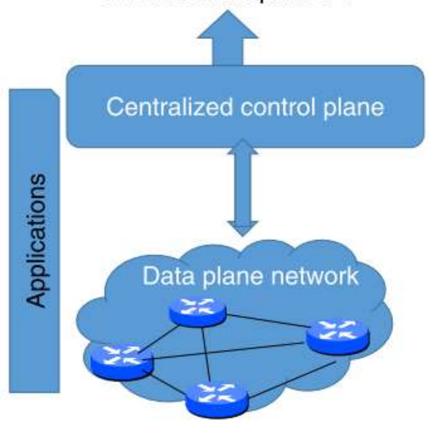
- ✓ re-provisioning using excess capacity (EC)
- ✓ **multipath** provisioning approaches
- ✓ different tolerances of services [5]



[3] B. Mukherjee, M. F. Habib and F. Dikbiyik, "Network adaptability from disaster disruptions and cascading failures," in *IEEE Communications Magazine*, vol. 52, no. 5, pp. 230-238, May 2014.

[4] S. S. Savas, M. F. Habib, M. Tornatore, F. Dikbiyik and B. Mukherjee, "Network adaptability to disaster disruptions by exploiting degraded-service tolerance," in *IEEE Communications Magazine*, vol. 52, no. 12, pp. 58-65, December 2014.

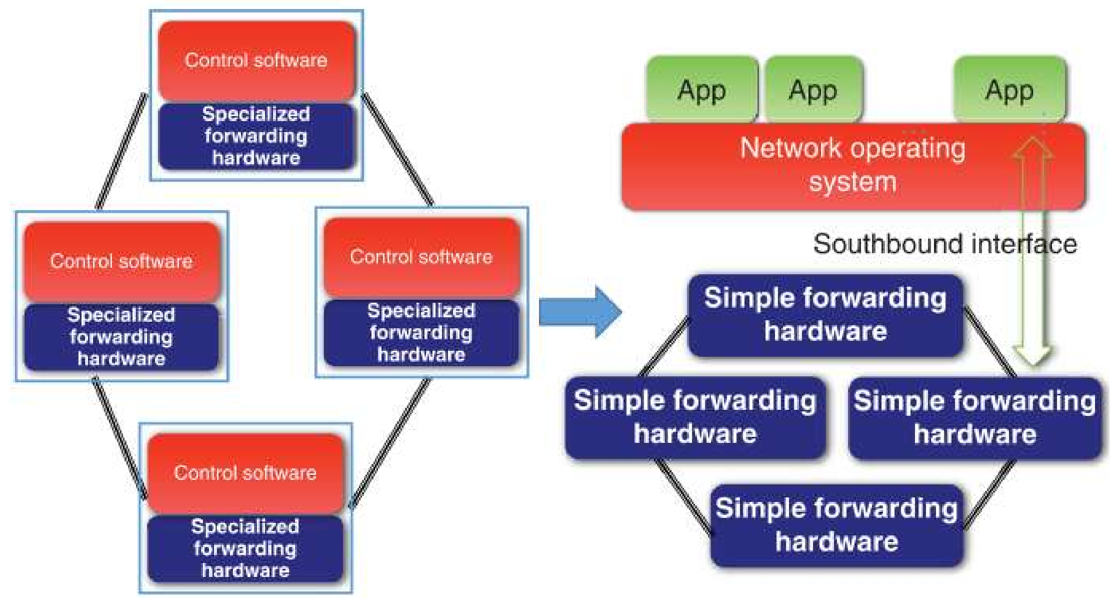
Software-Defined Networking (SDN)



Principle: **decoupling** control plane and data plane

Motivations from a technical perspective:

1. to independently scale the control plane and data plane to meet NG-traffic growth and demands
2. to improve service velocity and innovation
3. to enable flexible and efficient network virtualization



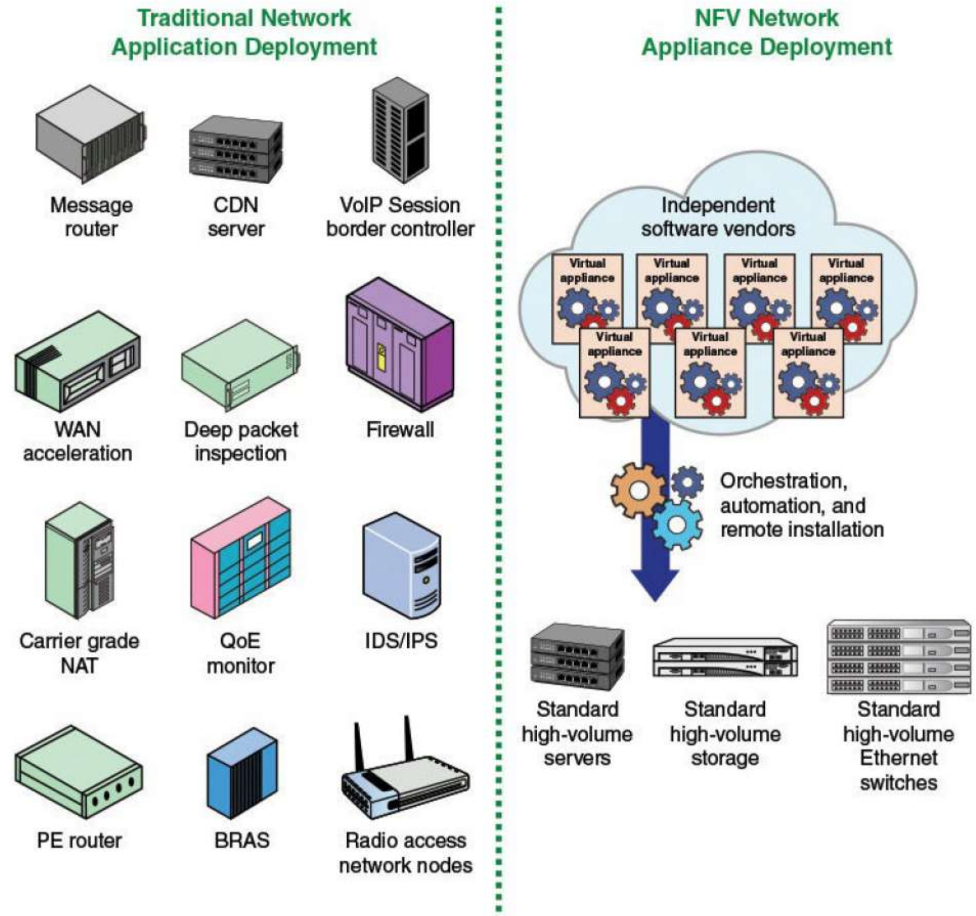
Conventional and Software-defined Networking Comparison

[5] Ying Zhang, "Network Function Virtualization: Concepts and Applicability in 5G Networks," ***IEEE** PRESS*, 2018

Network Function Virtualization (NFV)

Principles:

- ✓ ***decouples*** network ***functions*** *from proprietary* ***hardware*** platforms and implements these functions in ***software*** (on VMs)
- ✓ moves network functionality to software
- ✓ uses commodity hardware
- ✓ uses standardized and open Application Program Interfaces (APIs)
- ✓ support more efficient evolution, development, and repositioning of network functions
- ✓ overlay (logical, virtual) networks on top of a physical network



[5] Ying Zhang, "Network Function Virtualization: Concepts and Applicability in 5G Networks," ***IEEE*** *PRESS*, 2018
[6] William Stallings, " Foundation of Modern Networking: SDN, NFV, QoE, IoT, and Cloud," *Pearson Education, Inc, 2016*

Project Overview

Key terms:

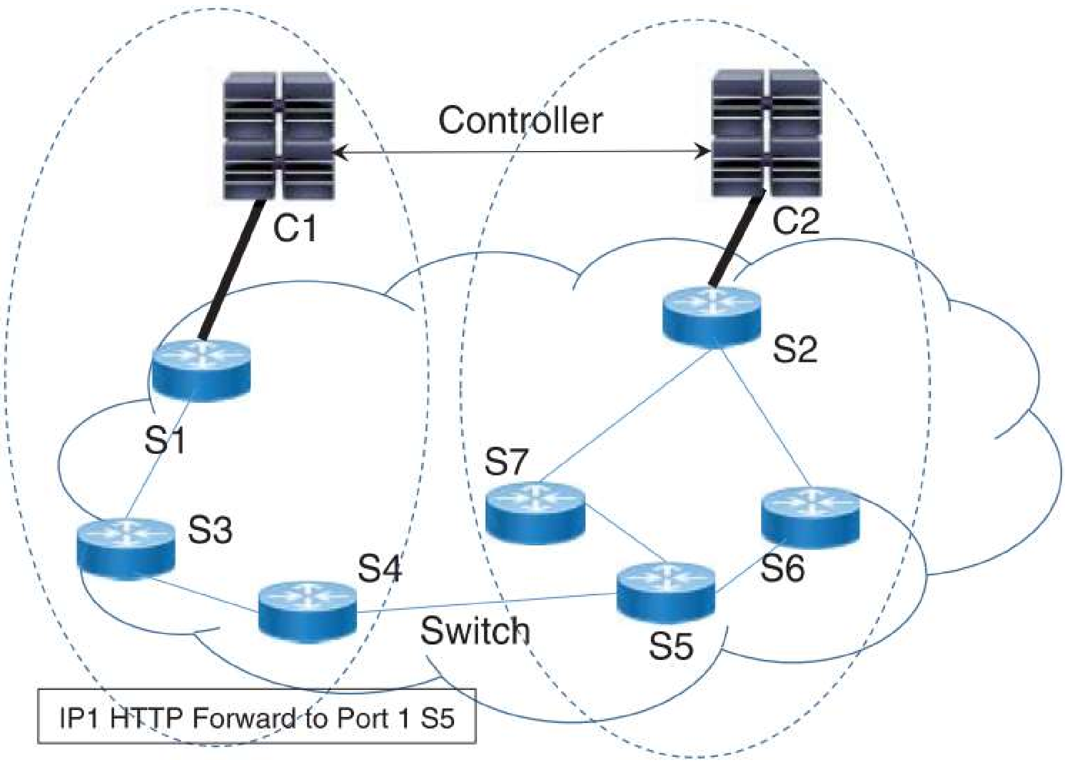
- ✓**ultra-reliable**, **low-latency** services (autonomous driving, augmented reality, telemedicine), **resilient** against largely-disruptive events
- ✓enable technologies: network-and-computing ecosystem, SDN, Edge Computing, and Slice Networking (NFV)

Research directions:

- ✓disaster-resilient control plane in NG-MAN: cognitive and hierarchical control plane that remains operational even main controllers fails
- ✓slicing protection for disaster-resilient NG-MAN data plane
- ✓rapid recovery during post-disaster phase

Resilient Control Plane Considerations

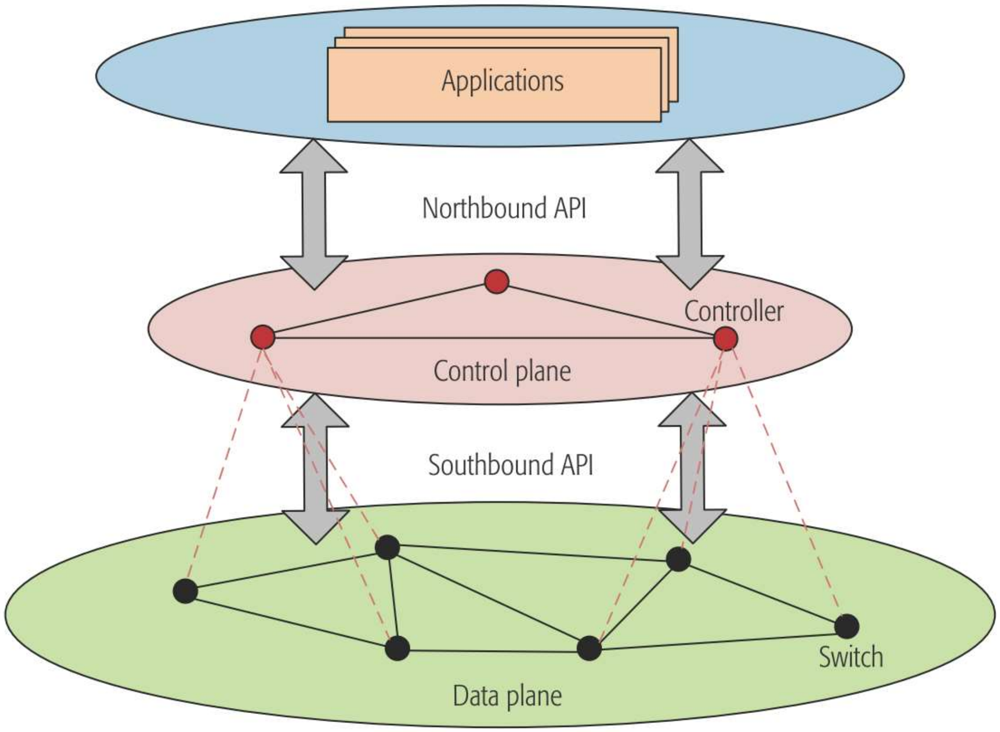
- Switches go **offline** without controller connection
- Control packets should be transmitted on different paths (or even on a different network)
- **Flexible, dynamic, resilient** binding between controllers and switches
- Migration of functions and backup if one controller fails



Example of controller and switch connection

[5] Ying Zhang, "Network Function Virtualization: Concepts and Applicability in 5G Networks," ***IEEE*** *PRESS*, 2018

Controller Placement in SD MON



Simplified Architecture for SDN

- *Research problem*: How many and how to place controllers and allocate switches to them
- Constraints:
  - ✓minimum latency (processing + propagation)
  - ✓enhanced reliability and resilience
  - ✓minimum development cost
  - ✓minimum energy consumption

[7] G. Wang, Y. Zhao, J. Huang and W. Wang, "The Controller Placement Problem in Software Defined Networking: A Survey," in *IEEE Network*, vol. 31, no. 5, pp. 21-27, 2017.

Reliability and Resilience of Control Plane

- **Reliability**: inversely proportional to expected percentage of control path loss
- **Resilience**: capability to sustain loss of connectivity upon controller and link abruptions

Objectives	Solutions	Details	Methods
Minimize net-work latency	Heller's Solution [2]	Examine the impacts of placements on average and the worse-case propagation latency	K-center
	CCPP [3]	Reduce both the number and load of controllers	Integer programming

[7] G. Wang, Y. Zhao, J. Huang and W. Wang, "The Controller Placement Problem in Software Defined Networking: A Survey," in *IEEE Network*, vol. 31, no. 5, pp. 21-27, 2017.

Reliability and Resilience of Control Plane

Maximize reliability and resilience	Hu's solution [4]	Maximize the reliability of networks	Simulated annealing
	K-critical [5]	Create robust control topology and balance load among controllers	Robust tree
	Guo's Solution [6]	Design a new resilience metric and improve the resilience of SDN	Interdependence graph and cascading failure
	Survivor [7]	Explore path diversity and improve survivability of SDN	Generic, proximi-ty-based and residual capacity-based heu-ristics
	POCO [8]	Evaluate trade-off between failure free and controller failure values	Pareto-based optimal placement

[7] G. Wang, Y. Zhao, J. Huang and W. Wang, "The Controller Placement Problem in Software Defined Networking: A Survey," in *IEEE Network*, vol. 31, no. 5, pp. 21-27, 2017.

Reliability and Resilience of Control Plane

Minimize de-ployment cost and energy consumption	Sallahi' solution [9]	Minimize the cost of installing controllers, linking controllers to switches and linking controllers together	Linear programming
	Rath's solution [10]	Minimize packet drops, delay and cost of deployment	Non-zero-sum based game theoretic
	GreCo [11]	Reduce the cost of energy consumption	Heuristic approach
	LiDy [12]	Propose a dynamic flow management algorithm to reduce energy consumption and maintenance costs	Heuristic location search and placement algorithm

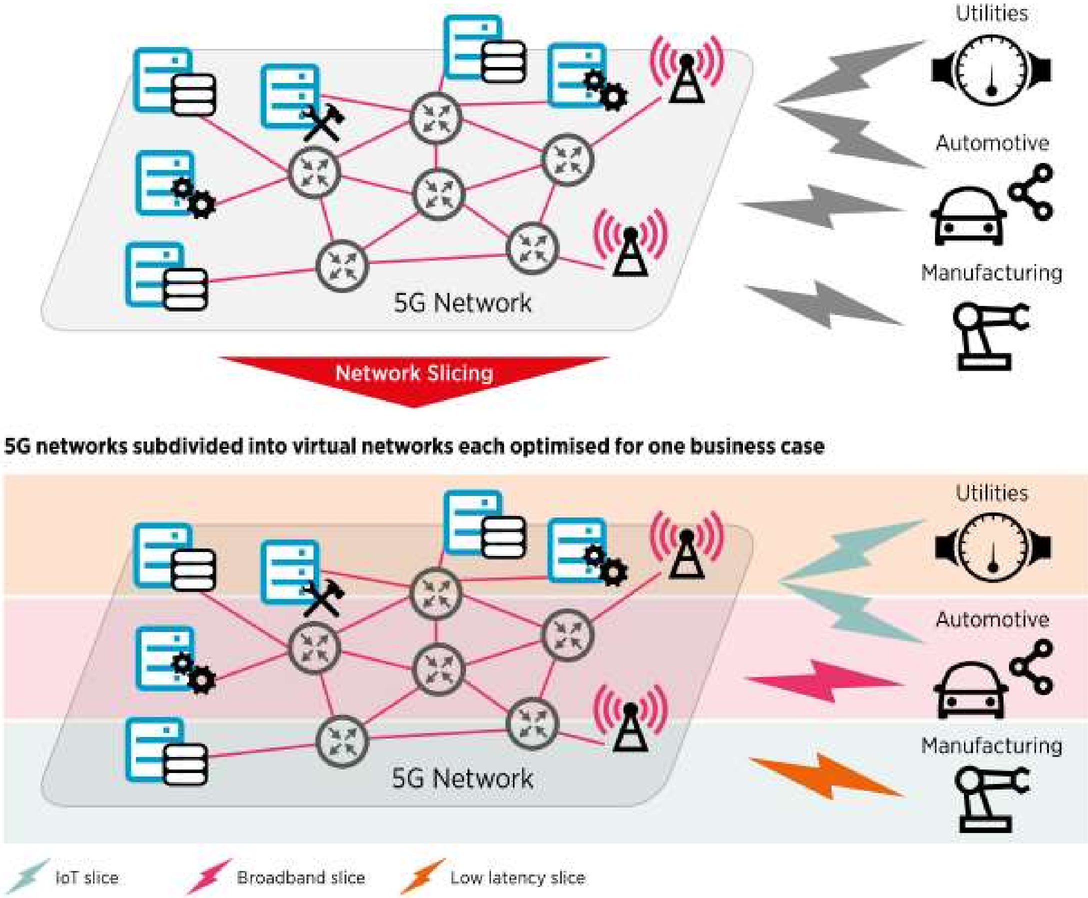
[7] G. Wang, Y. Zhao, J. Huang and W. Wang, "The Controller Placement Problem in Software Defined Networking: A Survey," in *IEEE Network*, vol. 31, no. 5, pp. 21-27, 2017.

Reliability and Resilience of Control Plane

- ✓ **Conclusion:** to shorten latency between controllers and switches, maximize reliability and resilience, and minimize deployment cost and energy consumption
- ✓ **Requirements:**
  - efficient algorithm (real time)
  - multi-objective optimization problems
  - multiple-controller cooperation
  - cost awareness
  - resilient awareness

[7] G. Wang, Y. Zhao, J. Huang and W. Wang, "The Controller Placement Problem in Software Defined Networking: A Survey," in *IEEE Network*, vol. 31, no. 5, pp. 21-27, 2017.

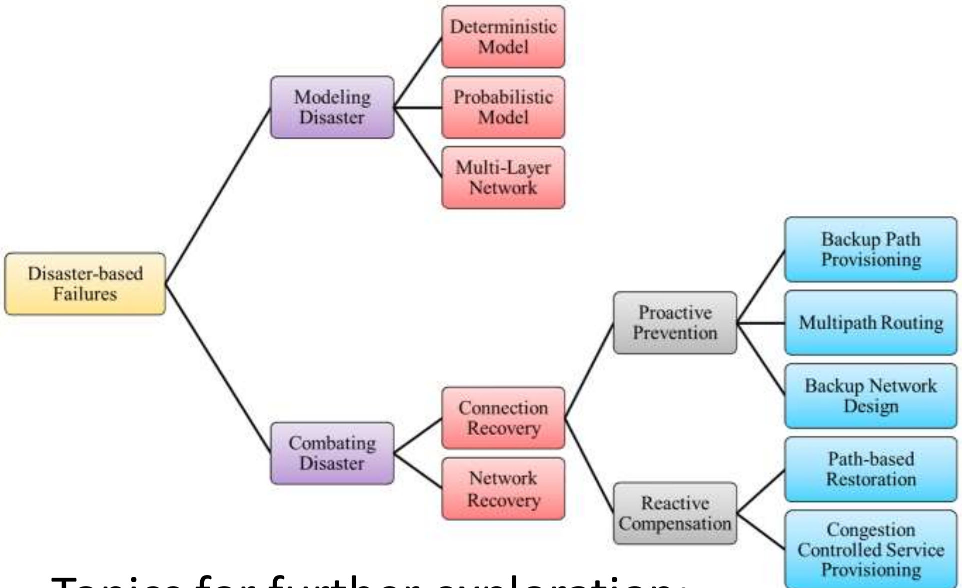
Network Slicing Protection

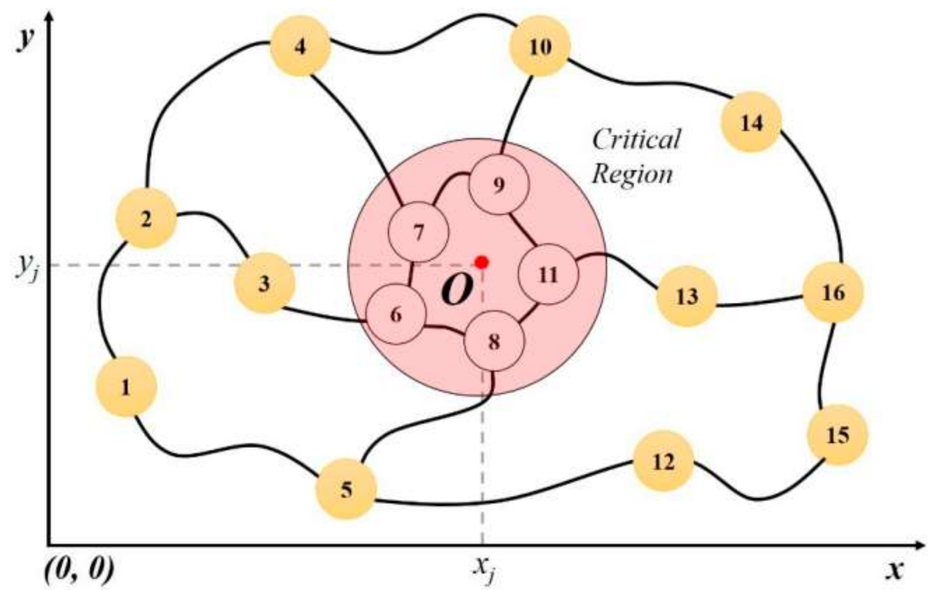


- ✓ Key technology to enable network flexibility
- ✓ Multiple logical networks on a common shared physical infrastructure
- ✓ To meet various targeting specific needs (latency, reliability, data rates)
- ✓ All components in a slice must be protected (BW, computing and storage resources)

[8] Global mobile Suppliers Association (GSA), "5G Network Slicing for Vertical Industries, White Paper, " Sept. 2017

Network Slicing Protection





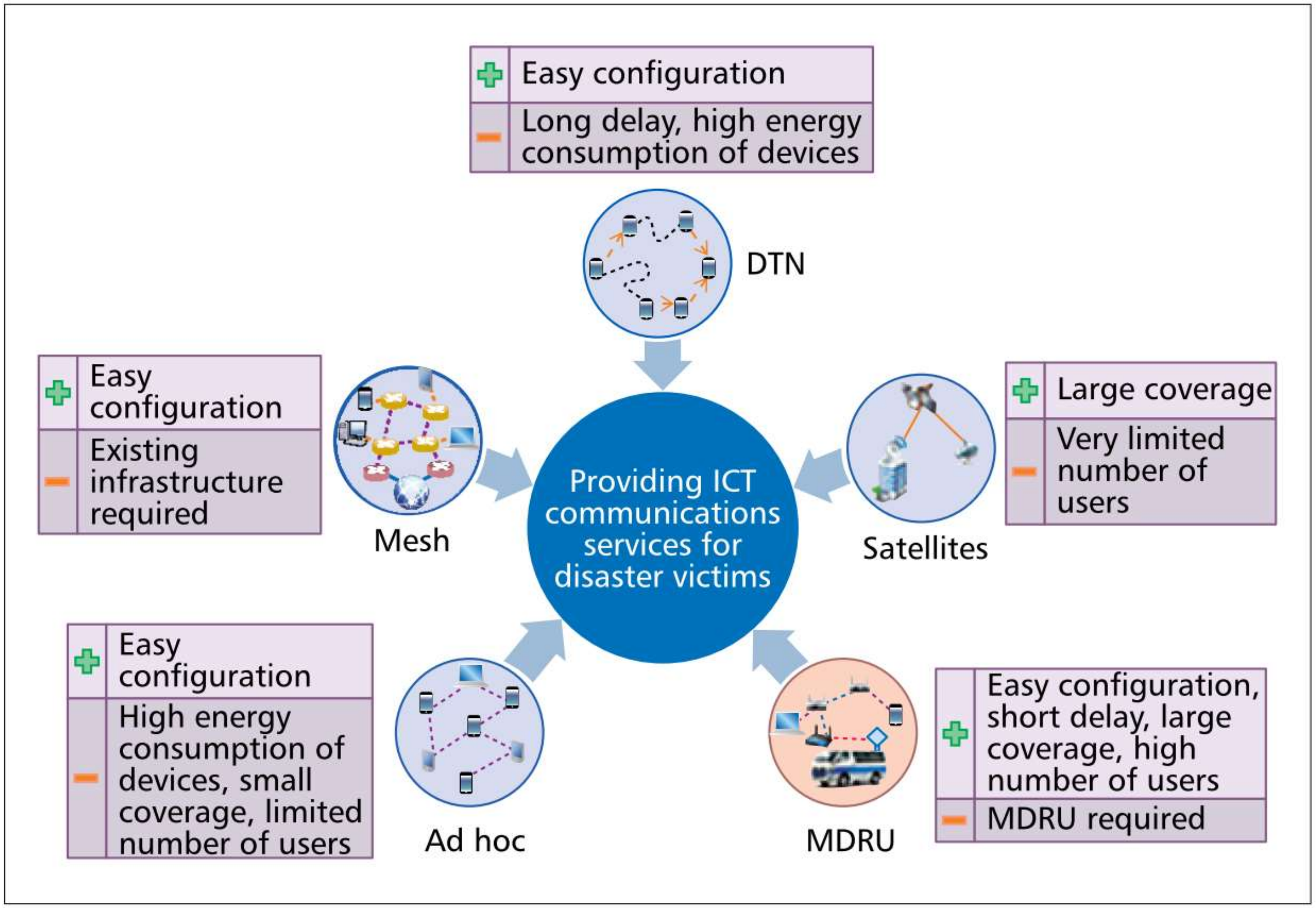
Topics for further exploration:

- ✓ content connectivity by distributed or backup data
- ✓ congestion-aware, disaster-failure-aware routing and wavelength assignment

[9] Habib, M.F.; Tornatore, M.; Dikbiyik, F.; Mukherjee, B. Disaster survivability in optical communication networks. Comput. Commun. 2013, 36, 630–644.

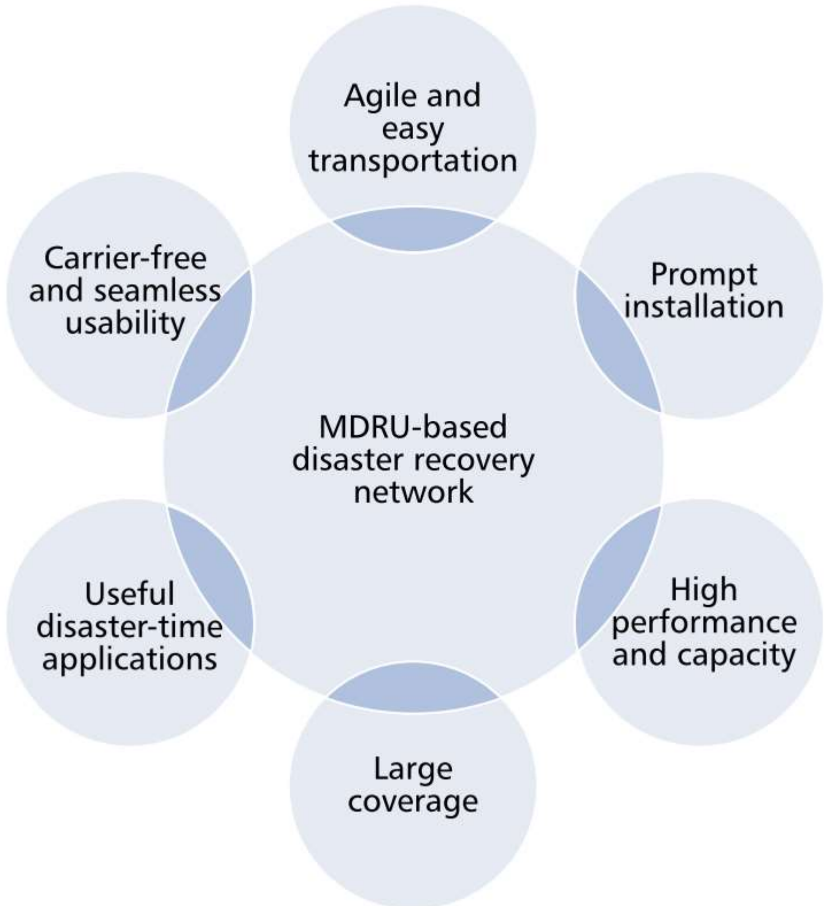
[10] Ashraf, M. W.; Idrus, S. M.; Iqbal, F.; Butt, R. A. & Faheem, M., “Disaster-Resilient Optical Network Survivability: A Comprehensive Survey, “” *Photonics*, 2018.

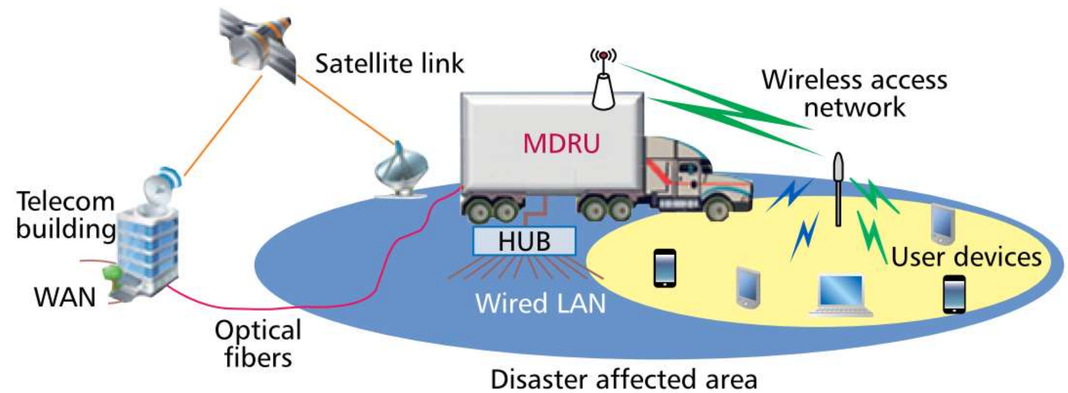
Network Post-disaster Recovery

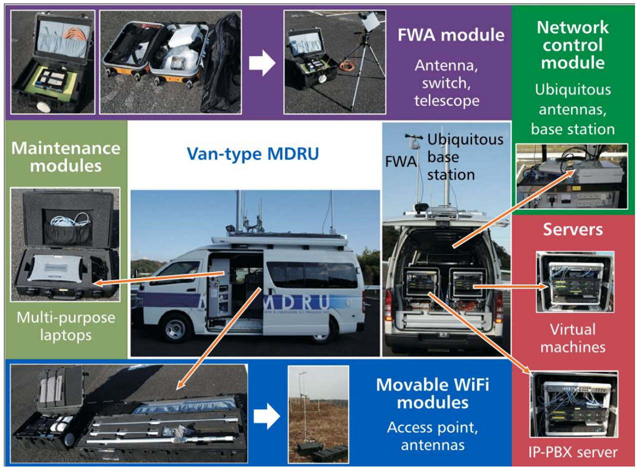


[11] T. Sakano *et al.*, "Bringing movable and deployable networks to disaster areas: development and field test of MDRU," in *IEEE Network*, vol. 30, no. 1, pp. 86-91, January-February 2016.

Network Post-disaster Recovery







Joint Research by Tohoku Univ., NTT and Fujitsu Corps

[11] T. Sakano *et al*., "Bringing movable and deployable networks to disaster areas: development and field test of MDRU," in *IEEE Network*, vol. 30, no. 1, pp. 86-91, January-February 2016.

Bio-inspired Self-organization Capabilities for NG-MON

Weaver ant *(Oecophylla)*

Termite

Wasp (*Polybia occidentalis)*

Swarm Intelligence Properties:
- ✓ Autonomy
- ✓ Adaptability
- ✓ Scalability
- ✓ Flexibility
- ✓ Robustness
- ✓ Massively parallel
- ✓ **Self Organization and Healing**

Bio-inspired Self-organization Capabilities for NG-MON

Selfnet

Link to project website: SELFNET

Contact: SELFNET-Contact@5G-PPP.eu

Horizon 2020 – Call:	H2020-ICT-2014-2
Topic:	ICT-14-2014
Type of action:	RIA
Duration:	36 Months
Start date:	1/7/2015
Project Title:	SELFNET: A FRAMEWORK FOR SELF-ORGANIZED NETWORK MANAGEMENT IN VIRTUALIZED AND SOFTWARE DEFINED NETWORKS

Research Article

The SELFNET Approach for Autonomic Management in an NFV/SDN Networking Paradigm

Pedro Neves,[1] Rui Calé,[1] Mário Rui Costa,[1] Carlos Parada,[1] Bruno Parreira,[1] Jose Alcaraz-Calero,[2] Qi Wang,[2] James Nightingale,[2] Enrique Chirivella-Perez,[2] Wei Jiang,[3] Hans Dieter Schotten,[3] Konstantinos Koutsopoulos,[4] Anastasius Gavras,[5] and Maria João Barros[5]

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[4]*Creative Systems Engineering (CSE), Agiou Meletiou 45, 11257 Athens, Greece*
[5]*Eurescom, Wieblinger Weg 19, 69123 Heidelberg, Germany*

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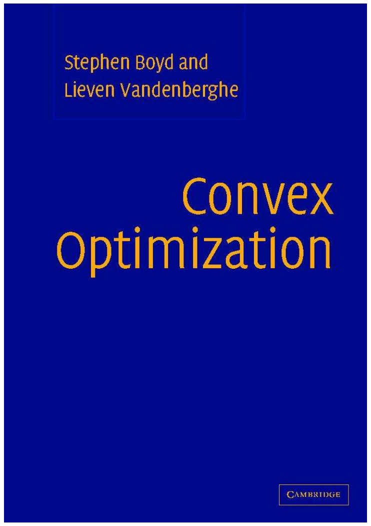
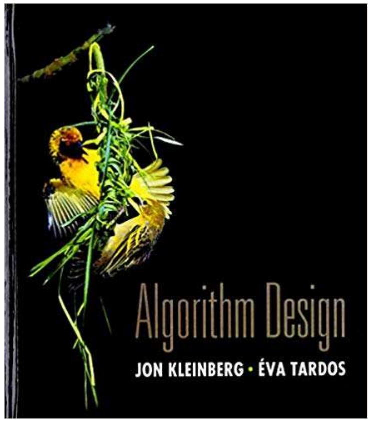
Received 4 December 2015; Accepted 24 December 2015

Topic: Self-organized, Self-healing Mechanisms in NFV/SDN Next-Generation Metro Optical Networks:

- ✓ auto disaster failure detection and mitigation
- ✓ fast and robust recovery

Tools and What need to be learned
(in a short time)





Convex optimization

A convex optimization problem is one of the form

$$\begin{array}{ll} \text{minimize} & f_0(x) \\ \text{subject to} & f_i(x) \leq b_i, \quad i = 1, \ldots, m, \end{array} \tag{1.8}$$

where the functions $f_0, \ldots, f_m : \mathbf{R}^n \rightarrow \mathbf{R}$ are convex, *i.e.*, satisfy

$$f_i(\alpha x + \beta y) \leq \alpha f_i(x) + \beta f_i(y)$$

for all $x,\ y \in \mathbf{R}^n$ and all $\alpha,\ \beta \in \mathbf{R}$ with $\alpha + \beta = 1$, $\alpha \geq 0$, $\beta \geq 0$. The least-squares problem (1.4) and linear programming problem (1.5) are both special cases of the general convex optimization problem (1.8).

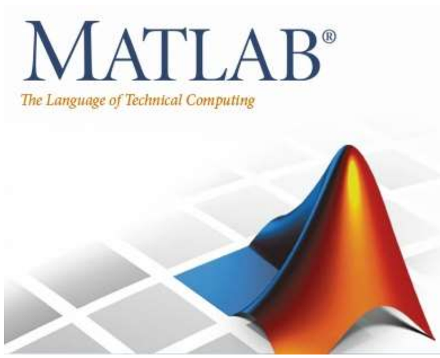
Linear programming

Another important class of optimization problems is *linear programming*, in which the objective and all constraint functions are linear:

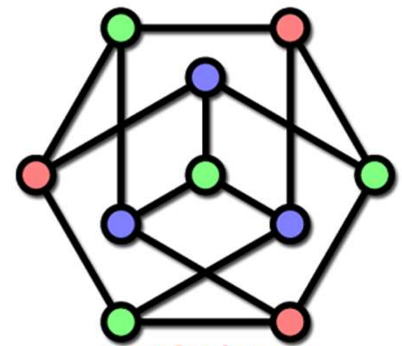
$$\begin{array}{ll} \text{minimize} & c^T x \\ \text{subject to} & a_i^T x \leq b_i, \quad i = 1, \ldots, m. \end{array} \tag{1.5}$$

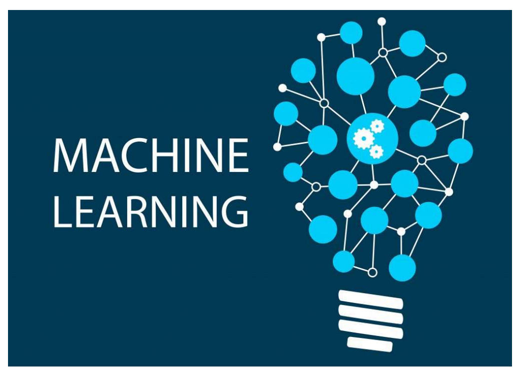
Here the vectors $c, a_1, \ldots, a_m \in \mathbf{R}^n$ and scalars $b_1, \ldots, b_m \in \mathbf{R}$ are problem parameters that specify the objective and constraint functions.

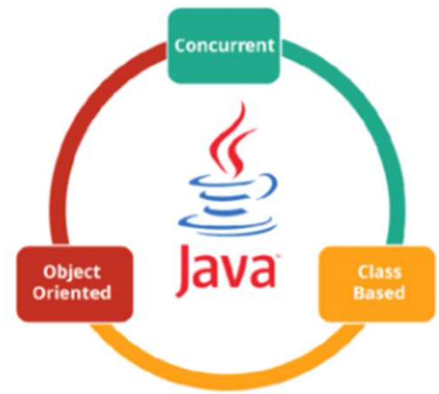
Tools and What need to be learned



C
Programming







In Summary

Object goals: **Disaster-resilient Metro Optical Networks**

- ✓ ultra-reliable, low-latency
- ✓ **resilient** against largely-disruptive events
- ✓ including novel concepts: SDN, NFV, Edge Computing, Slicing Protection

Research Problem Proposals:

- ✓ controller placement (physical place, number, topology)
- ✓ allocate switches to controllers
- ✓ content connectivity by distributed or backup data
- ✓ congestion-aware, disaster-failure-aware routing and wavelength assignment
- ✓ recovery using movable and deployable units
- ✓ self-organized and self-healing for SDN/NFV Metro Optical Networks

Thank you for your attention!

Comments and Suggestions