



Multi-Domain Multi-Broker Elastic Optical Networks with Cognitive Functionalities

Roberto Proietti*, S.J. Ben Yoo

University of California, Davis

***rproietti@ucdavis.edu**

<http://sierra.ece.ucdavis.edu>

ICE-T PI Meeting

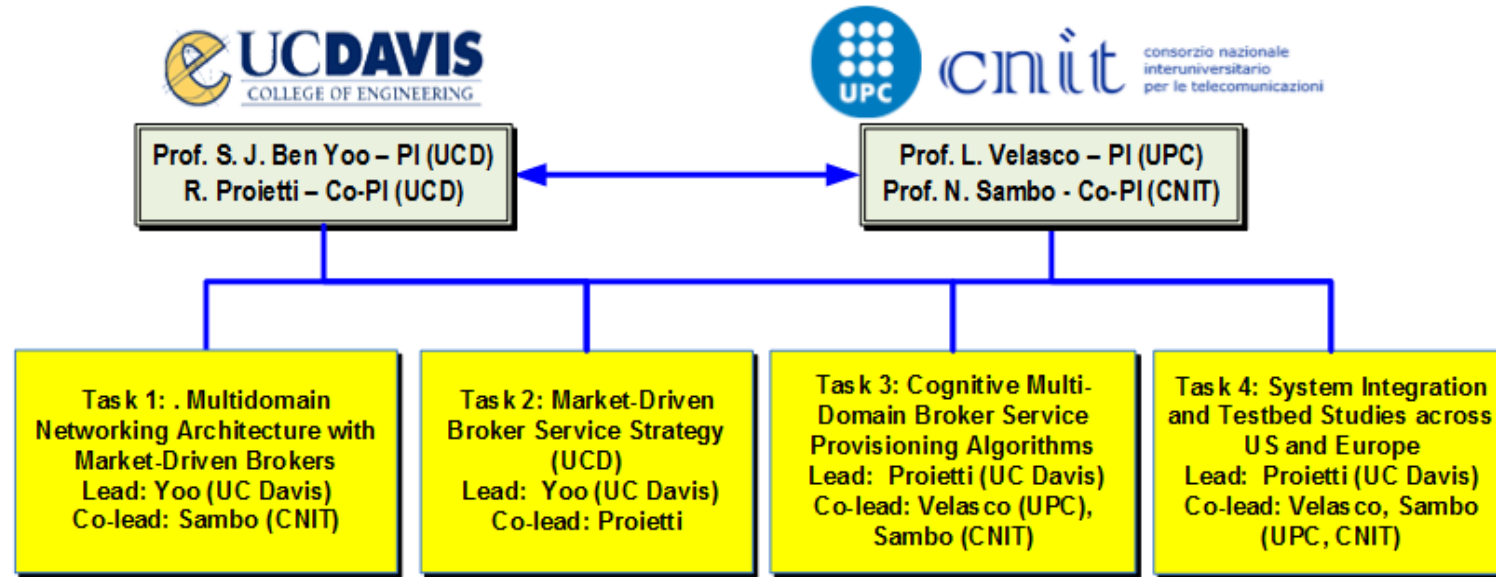
3:52 – 3:59 pm, Nov 7th 2019, Coimbra, Portugal



NSF ICE-T:RC 1836921



Research Team & Tasks

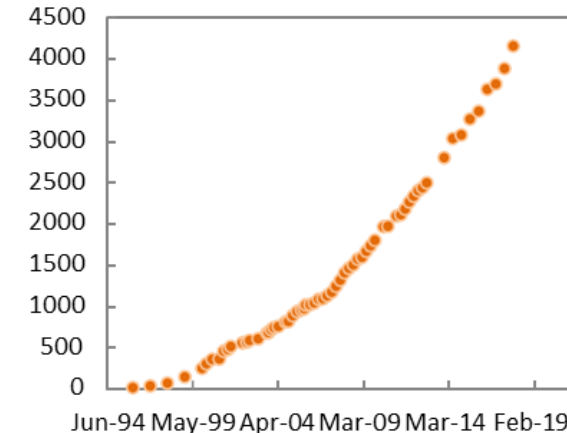


- 36-month project supporting one GSR student (60%) and one Postdoctoral researcher (20%)
- UPC and CNIT partners leverage “The *METRO High bandwidth, 5G Application-aware optical network, with edge storage, compUte and low Latency*” (Metro-Haul) project, a 36-month H2020-ICT-2016-2 Research and Innovative Action (RIA) (Grant Agreement Number: 761727), started in June 2017 and coordinated by British Telecom
- Metro-Haul is integrated by 20 EU partners including major network operators, vendors, SMEs, and research institutions and universities; the aim of *Metro-Haul* is to design and build a smart optical metro infrastructure able to support traffic originating from heterogeneous 5G access networks, addressing the anticipated capacity increase and its specific characteristics, e.g., mobility, low latency, low jitter etc.

Data Traffic Evolution

- Number of users is increasing exponentially
- In the last few years, due to the introduction of new services → traffic requested by the users has significantly increased
 - **traffic is dynamic** also in the optical layer
 - optical connections may be dynamically established

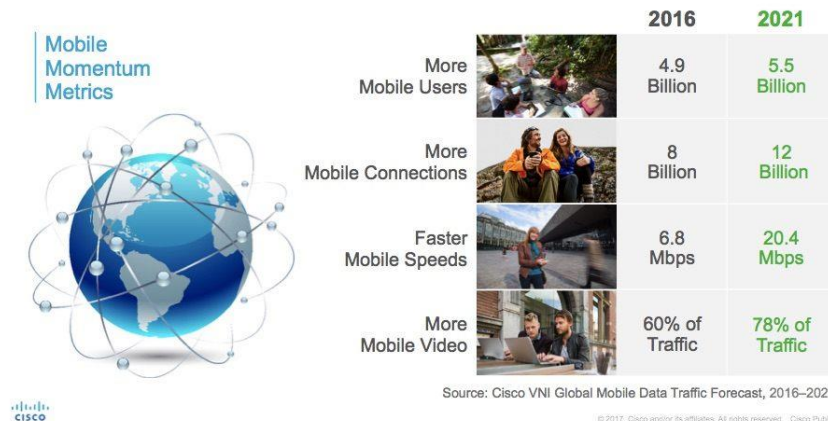
Millions of Internet users in the world



Jun-94 May-99 Apr-04 Mar-09 Mar-14 Feb-19

<https://www.internetworldstats.com/emarketing.htm>

Global Mobile Data Traffic Drivers



<https://www.weforum.org/agenda/2018/05/what-happens-in-an-internet-minute-in-2018>

New players Netflix and Amazon



<http://thoughtforyourpenny.com/technology/interwebz/streaming-video-statistics-know-2018>

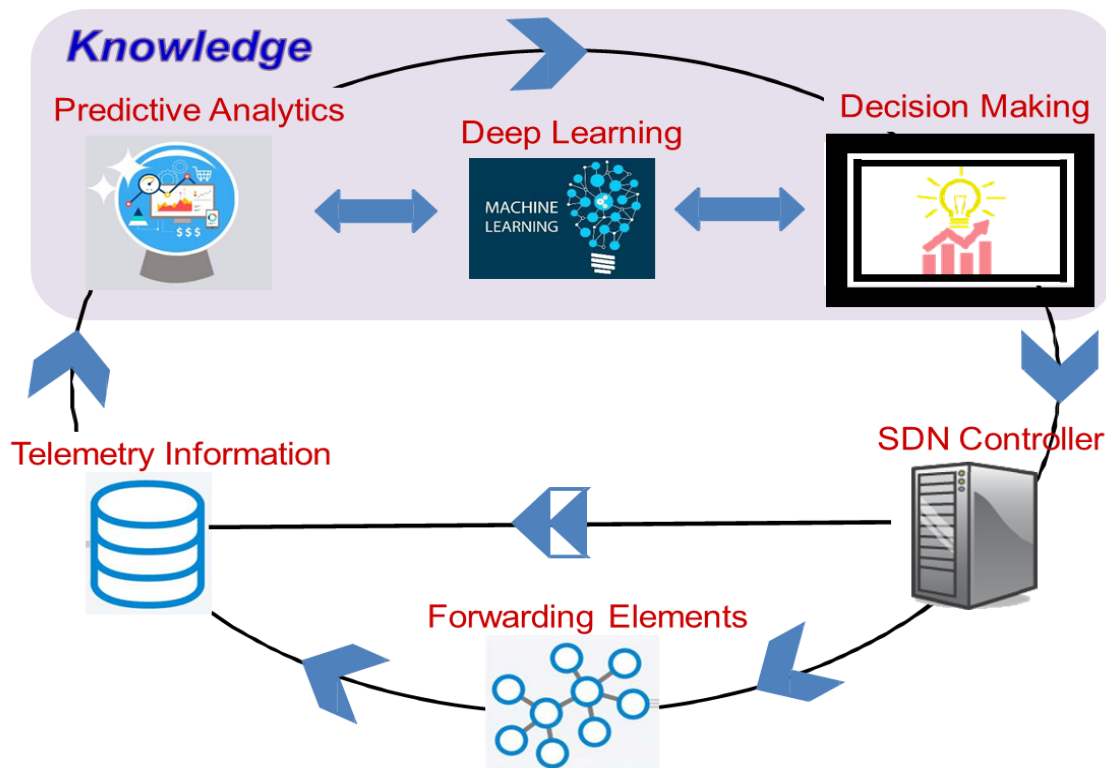
Knowledge-based Networking



Transport networks infrastructures and their operation are evolving and becoming **more complex**



Add **cognitive** capabilities to the network to facilitate self-configuration, self-adaptation... self-X (**autonomic networking**).



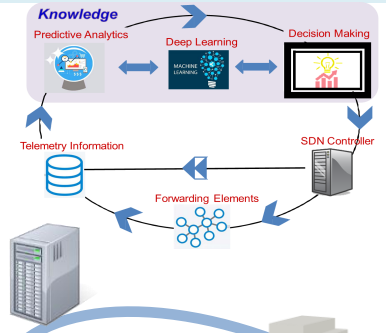
- Observe
 - Performance monitoring
 - Telemetry
- Analyze
 - Deep learning
- Act
 - Traffic engineering
 - QoT-aware provisioning
 - Fault recovery

Courtesy of Z. Zhu from OFC19 invited talk "Predictive Analytics in Hybrid Optical/Electrical DC Networks," paper # Th1H.5

Knowledge-based Multi-domain Optical Networking

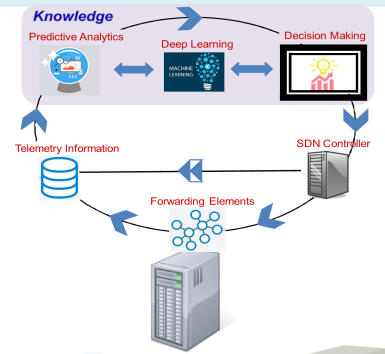


Domain Manager 1

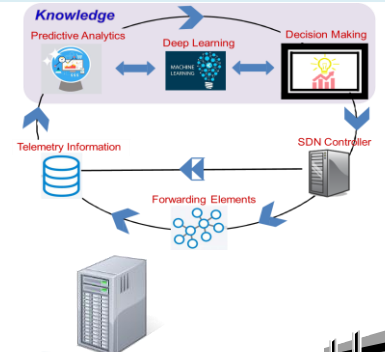


User 1

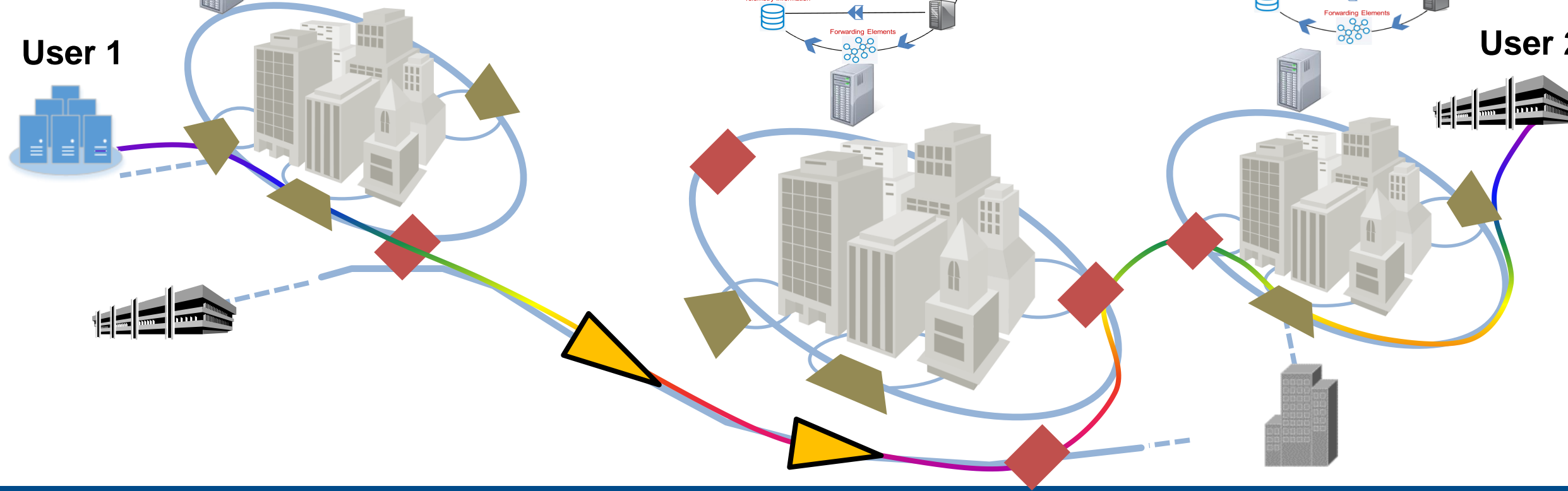
Domain Manager 2



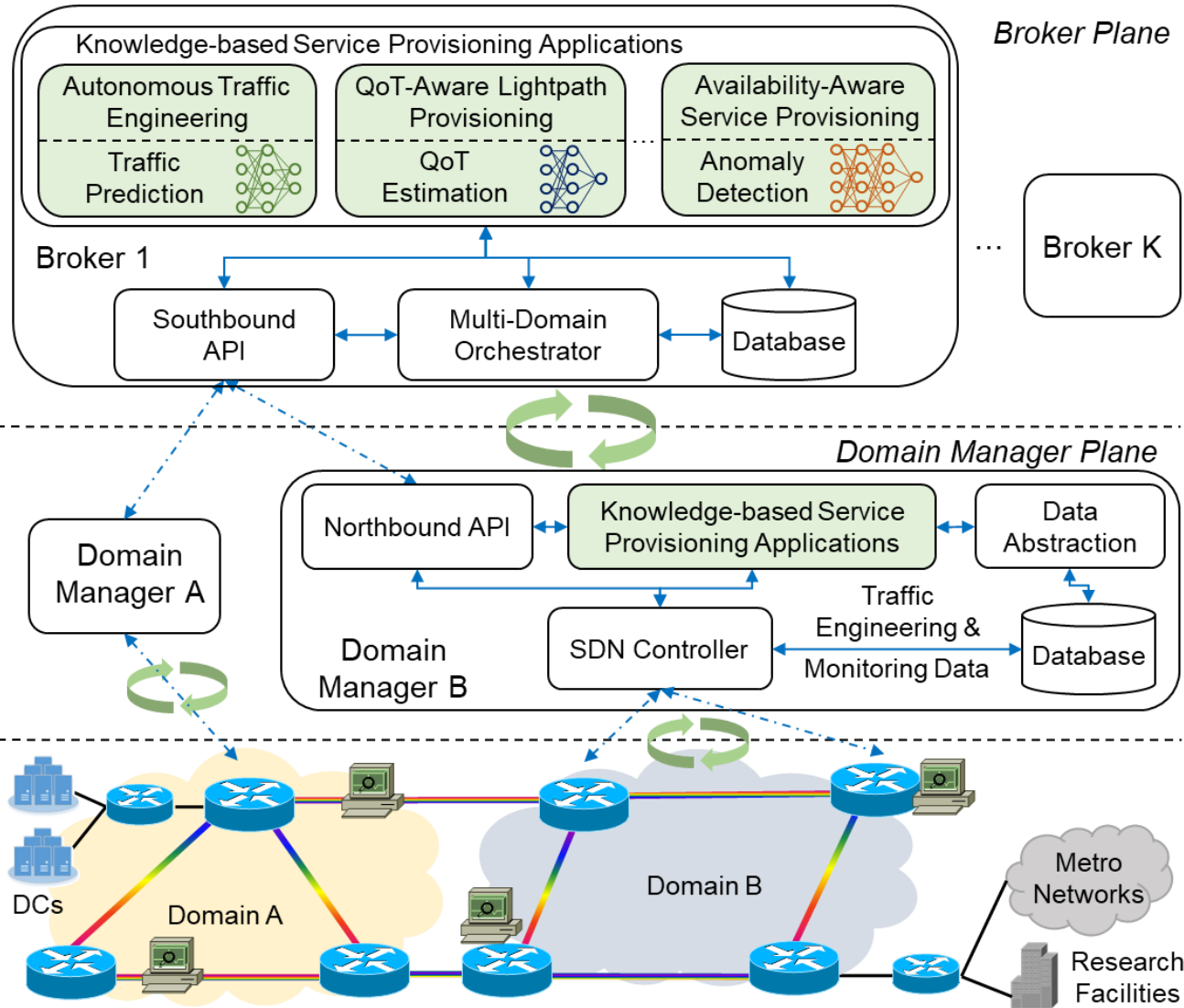
Domain Manager 3



User 2



Broker-based Knowledge-based Networking



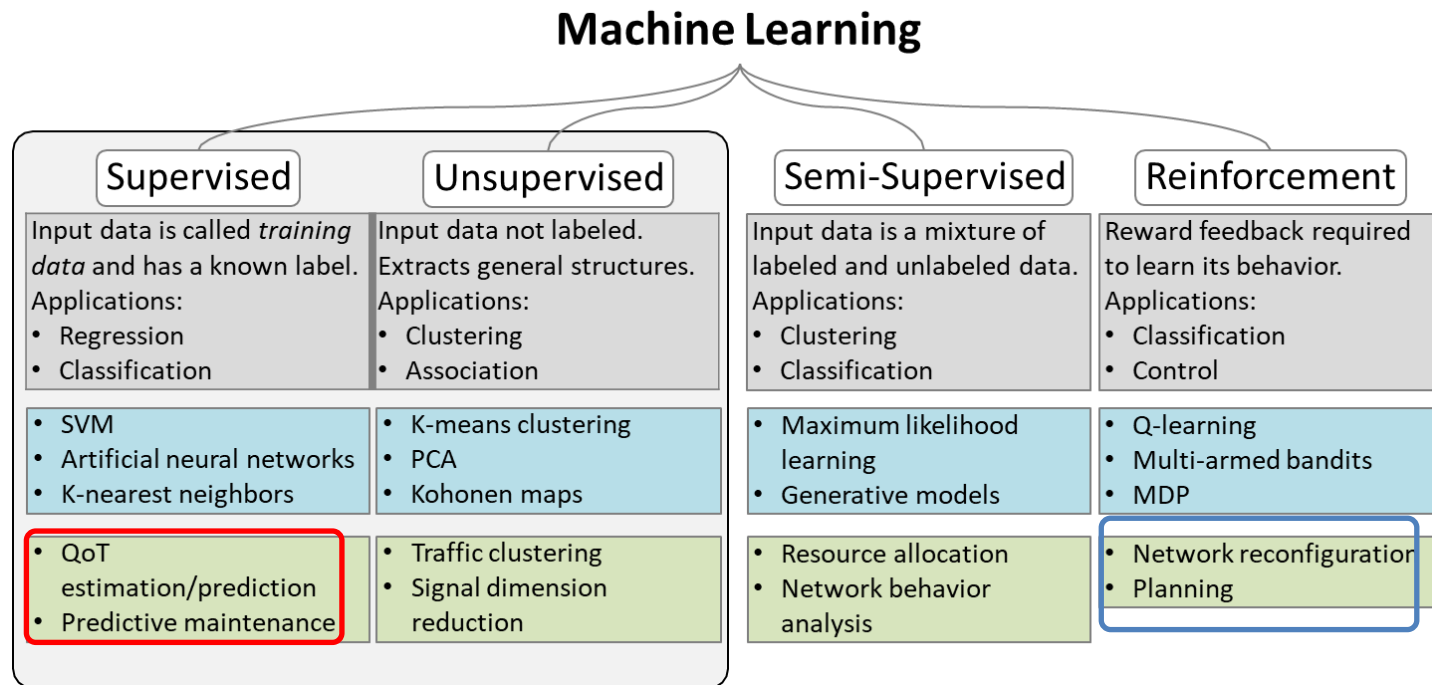
- The Broker plane consists of multiple *incentive-driven* (revenue, reputation, etc.) brokers providing multi-domain services
 - Brokers may compete or cooperate
- Domain managers work with brokers according to mutual *service level agreements*
 - Intra-domain abstraction
 - Domain-level knowledge (data analytics)
 - Monitoring data at edge nodes
- Brokers combine the information from domain managers and perform hierarchical data analytics and perform *knowledge-based networking*
 - QoT assurance
 - Routing and spectrum assignment
 - Cognitive fault management

- Optical Performance Monitoring
- Observe-Analyze-Act Cycle

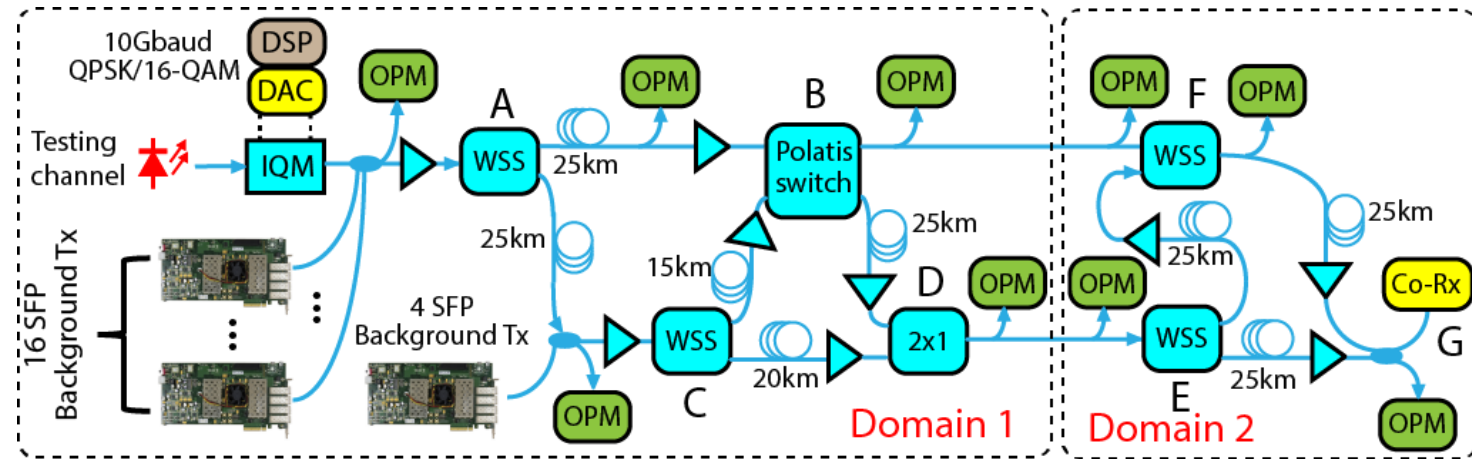
Some of the Research Outcomes in Year 1



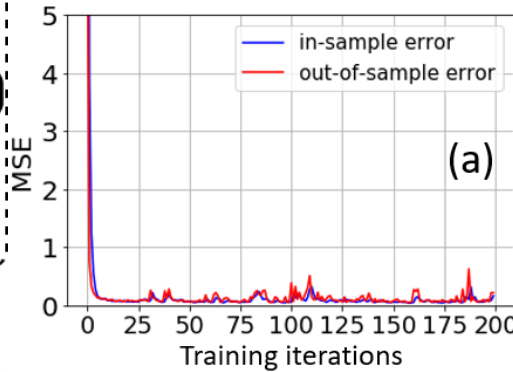
- Hierarchical Approach for end-to-end QoT estimation in multi-domain networks
- Autonomic routing, modulation and spectrum assignment algorithm with multi-agent deep reinforcement learning



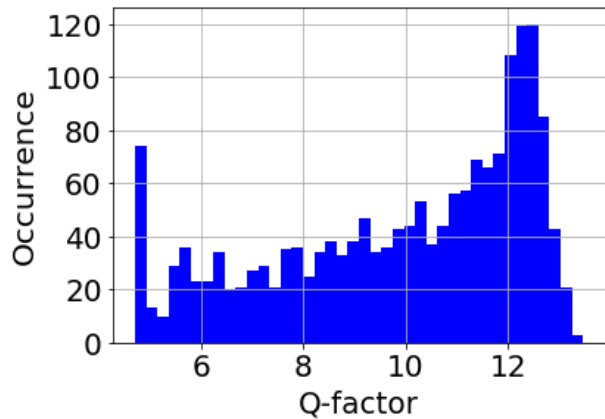
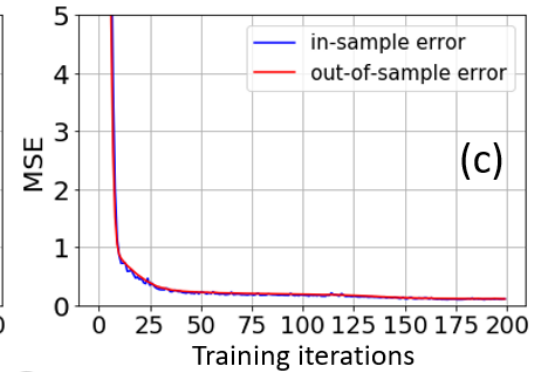
Experimental Dataset Collection & Training Results



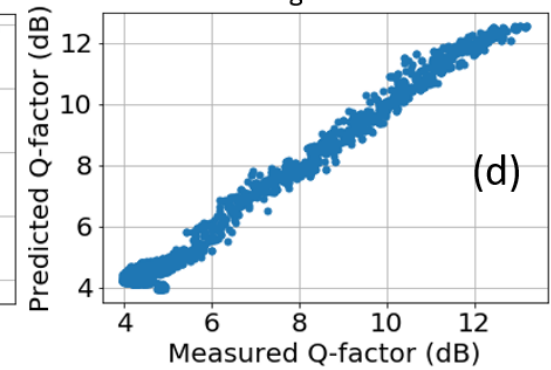
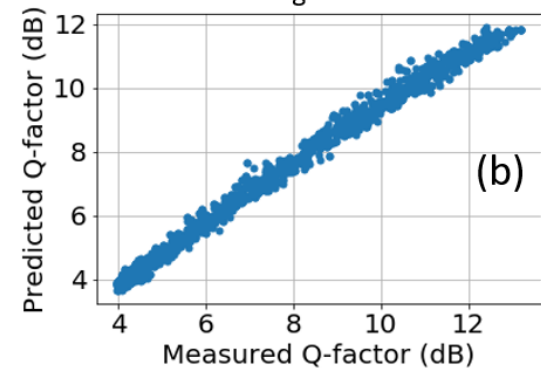
Omniscient-case



Hierarchical-case



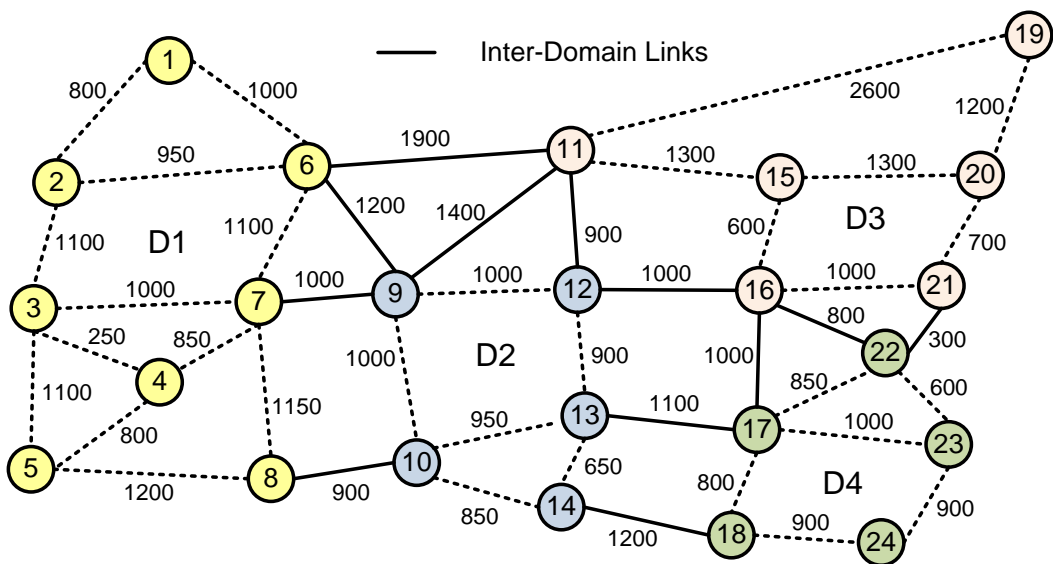
24,000 (3,000 per path times 8 paths) datasets have been collected for the intra-domain measurement
 18,000 (3,000 per path times 6 paths) datasets have been collected for the intra-domain measurement



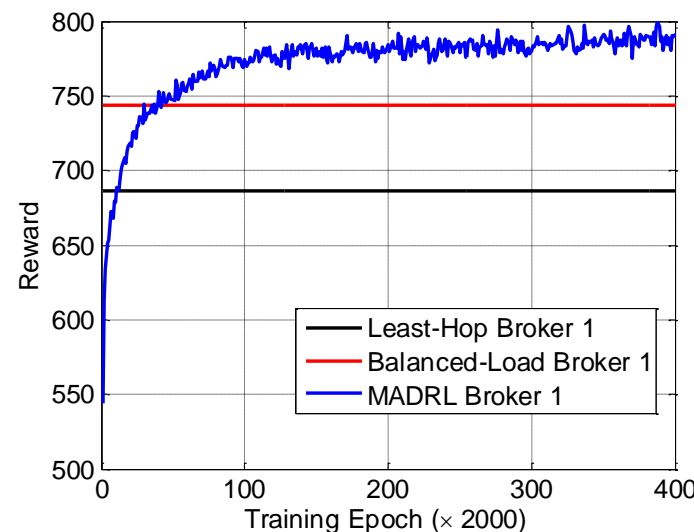
Autonomic routing, modulation and spectrum assignment algorithm with multi-agent deep reinforcement learning



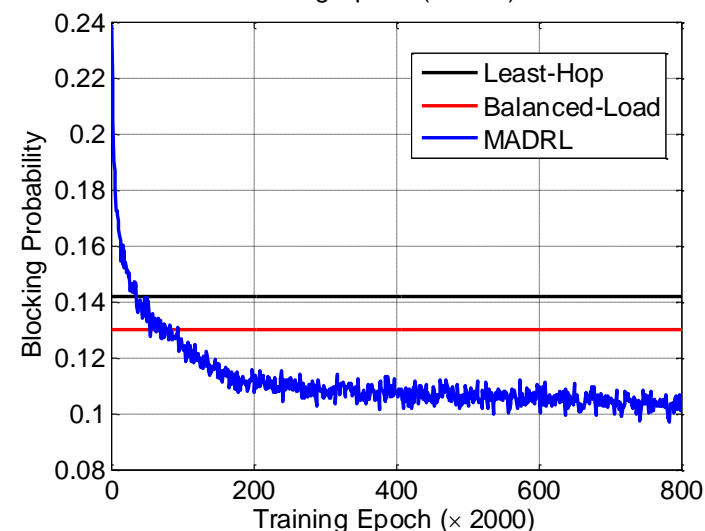
Simulation Setup



- Topology: four-domain topology
- Number of brokers: 2, each handles a fixed partition of requests
- Link capacity: 100 channels
- Request Model: Poisson, Bandwidth demand of [2, 15] channels
- Number of candidate paths: 5
- Baselines: balanced-load routing & least-hop routing



Evolution of Rewards Broker 1



Evolution of Overall Inter-Domain Request Blocking Probability

List of Publications and **Future Work**



1. "On Incentive-Driven VNF Service Chaining in Inter-Datacenter Elastic Optical Networks: A Hierarchical Game-Theoretic Mechanism", Xiaoliang Chen, Zuqing Zhu, Roberto Proietti and S. J. Ben Yoo, *IEEE Trans. Netw. Service Manag.*, 2019
2. "Self-taught Anomaly Detection with Hybrid Unsupervised/Supervised Machine Learning in Optical Networks", Xiaoliang Chen, Baojia Li, Roberto Proietti, Zuqing Zhu, S. J. Ben Yoo, *J. Lightw. Techn.*, 2019
3. "Hierarchical Learning for Cognitive End-to-End Service Provisioning in Multi-Domain Autonomous Optical Networks", Gengchen Liu, Kaiqi Zhang, Xiaoliang Chen, Hongbo Lu, Jiannan Guo, Jie Yin, Roberto Proietti, Zuqing Zhu, and S. J. Ben Yoo, *J. Lightw. Techn.*, 2019
4. "DeepRMSA: A Deep Reinforcement Learning Framework for Routing, Modulation and Spectrum Assignment in Elastic Optical Networks", Xiaoliang Chen, Baojia Li, Roberto Proietti, Hongbo Lu, Zuqing Zhu, S. J. Ben Yoo, *J. Lightw. Techn.*, 2019
5. "Cooperative Learning for End-to-end Delay Modeling in Broker-assisted Multi-domain Networks", M.Ruiz, C.-Y.Liu, F. Tabatabaeimehr, X.Chen, R.Proietti, S. J. B.Yoo, and L. Velasco, submitted to OFC20

• Plans for Year 2:

- Extend current work with UPC and CNIT for traffic prediction and anomaly detection in multi-domain scenario
- Investigate transfer learning techniques for QoT estimation and provisioning
- Start collaborative testbed work with CNIT and UPC
 - exchange student visit from UPC planned for Spring 2020 after OFC20 conference