# Leveraging adaptive modulation with multi-hop routing in elastic optical networks[1]

**Presenter: Yongcheng (Jeremy) Li**

**PhD student, School of Electronic and Information Engineering,**

**Soochow University, China**

**Email: liyongcheng621@163.com**

**Group Meeting, Friday, June 17, 2016**

[1] Costa, Lucas R., Guilherme N. Ramos, and André C. Drummond, "Leveraging Adaptive Modulation with Multi-Hop Routing in Elastic Optical Networks," Computer Networks (2016).

UCDAVIS

# Outline

1. Background
2. Related work
3. Maximizing the use of best modulation format
4. Performance evaluation
5. Conclusions

# Background

- Internet traffic has been growing exponentially and tends to continue doing so due to emerging applications such as high definition TV, cloud computing, multimedia applications, and real-time networks
- An Elastic Optical Network (EON) can dynamically adjust resources, such as optical bandwidth and modulation format, according to the requirements of each demand
- In EON, Routing and Spectrum Assignment (RSA) problem has evolved into the Routing, Modulation Level, and Spectrum Allocation (RMLSA) problem
- EON technology provides support for optical grooming, which enables transport from a single source to different destinations without having to establish more than one optical channel, using only one transponder at the source

# Background(Cont's)

- EON
  - Support to different levels of traffic demand (Gb/s to Tb/s)
  - Efficient use of spectrum through allocation of flexible optical paths on demand
  - Support to variable band rate with spectral expansion/contraction via number of subcarriers or modulation format
  - Efficient energy consumption by disconnecting OFDM subcarriers according to traffic demand
  - Adaptive restoration in case of network failures by adaptive spectrum allocation and modulation format optimizations

UCDAVIS
UNIVERSITY OF CALIFORNIA

# Background(Cont's)

- The differences between optical paths with fixed and flexible grids
  - In a fixed grid, a single frequency bandwidth of the spectrum is used, regardless of the client's demand
  - In a flexible grid, the bandwidth adapts to the demand

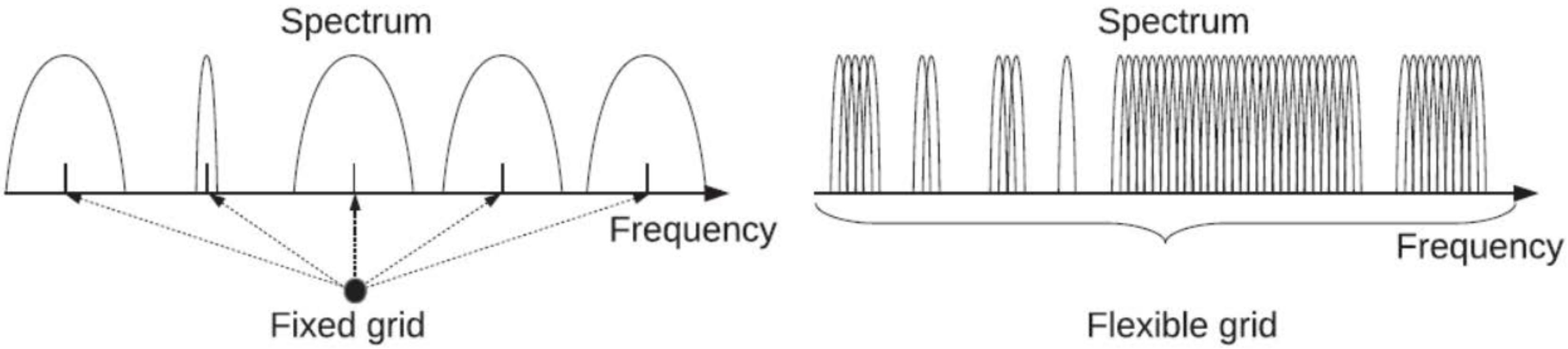
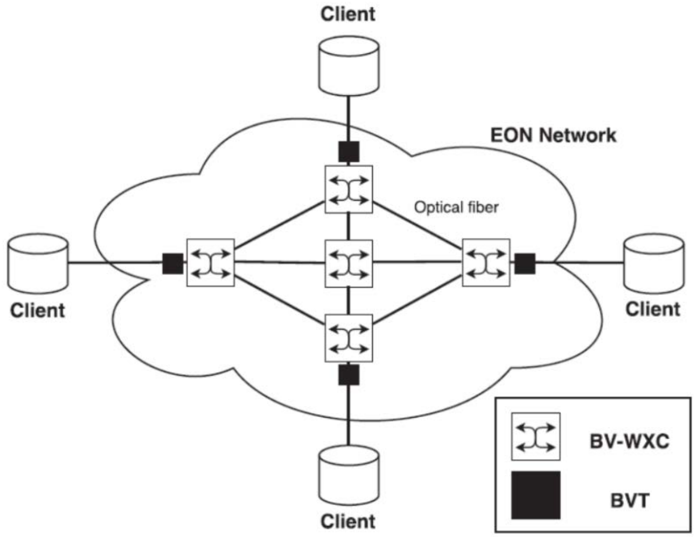



Fig. 1. Comparison of lightpaths with fixed and flexible grids.

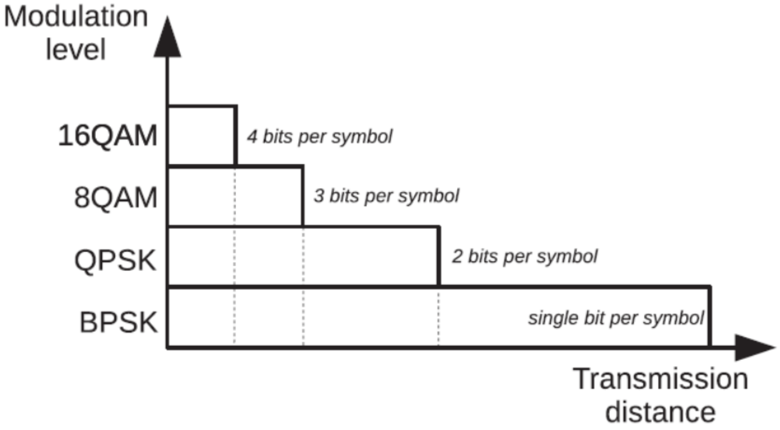
# Background(Cont's)

- This OFDM based EON architecture
  - Bandwidth-variable transponders (BVTs)
    - BVTs create the lightpaths with flexible bandwidth, allowing the resources to be adjusted to the current demand
  - Bandwidth-variable wavelength cross-connects (BV-WXC)
    - BV-WXCs are responsible for establishing an end-to-end path with enough bandwidth to accommodate the spectral resources defined by the BVTs



# Background(Cont's)

- Adaptive modulation format
  - Every lightpath is composed of an arbitrary number of OFDM subcarriers, each can be individually modulated (with a different BVT) for a transmission
  - Number of subcarriers and modulation format are adjusted to amount of traffic and optical reach requested
  - Choice of modulation level should consider *quality-of-transmission* (QoT) and, consequently, *optical signal-to-noise ratio* (OSNR)



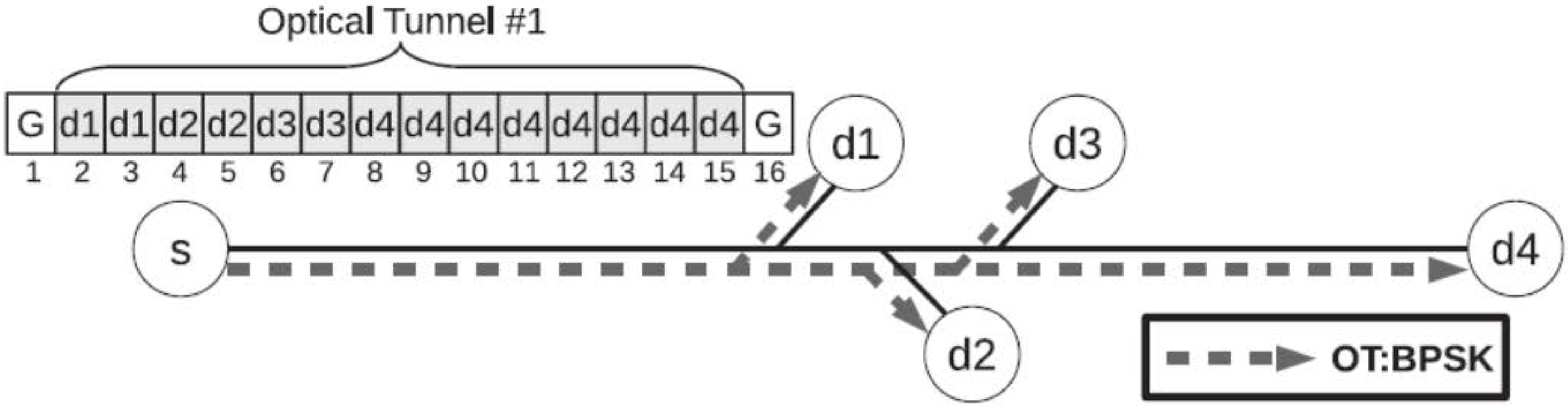

UCDAVIS
UNIVERSITY OF CALIFORNIA

# Background(Cont's)

- Traffic grooming
  - Aggregate multiple lightpaths in a single BVT and transmit them through the BV-WXCs
  - It achieves significantly better efficiency using the spectrum due to no guard bands are required between them
  - By using more of the spectrum in each BVT, less of such devices are needed to satisfy the same traffic demand, decreasing the network's operational costs
  - Despite enabling less transponders, this approach does not impact on the number of receivers because traffic from different source-destination pairs need to be received separately

# Related work

- FPA algorithm
  - It maximizes the use of the a BVT by aggregating multiple light-paths in one transponder
  - FPA improves spectrum usage by decreasing the number of guard bands between lightpaths that share a route
  - These resources can be readily used in additional connections through the network with fewer transponders per node

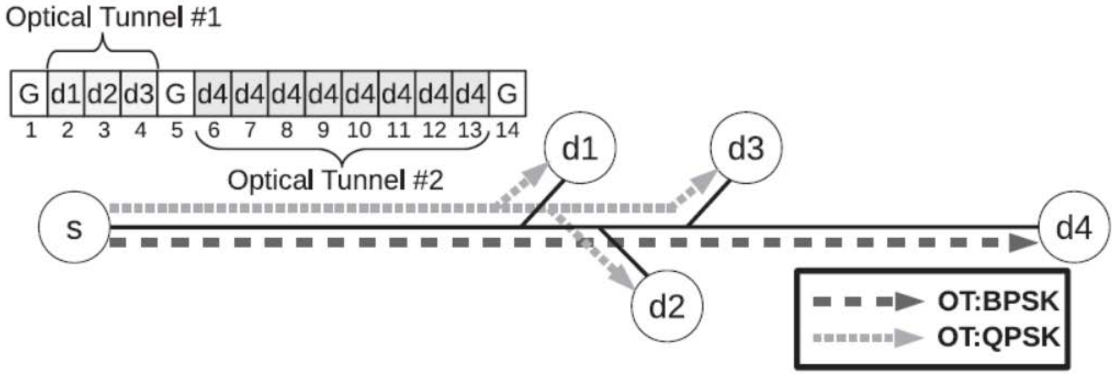



(a) Maximum possible spectrum aggregation, FPA algorithm.

UC DAVIS
UNIVERSITY OF CALIFORNIA

# Related work

- DFG algorithm
  - It optically groups traffic demands that share the link and have the same source, and commutes them through the link with no guard bands while considering the modulation in use in the optical tunnel
  - DFG algorithm does not consider dynamic traffic in the network nor investigate the use of multi-hop routing in the virtual topology, both issues that have shown interesting results




(b) Conscious spectrum aggregation, DFG algorithm.

# Related work

- Approaches to the RSA/RMLSA problem

**Table 1**
Approaches to the RSA/RMLSA problem.

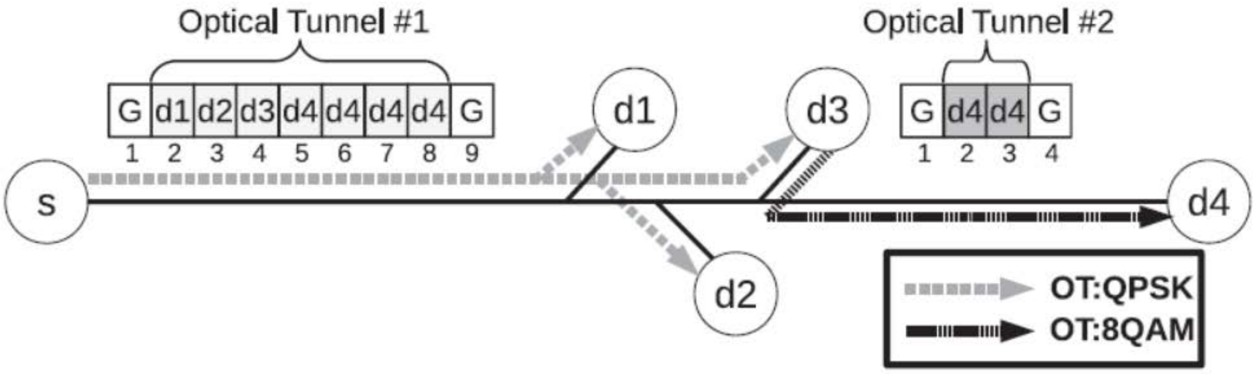
| Proposal | Network scenario | | | Grooming | |
|---|---|---|---|---|---|
| | Traffic | Routing | Modulation | Traffic | Optical |
| KSP, MSP, SPV [17] | Dynamic | Single-Hop | Static | No | No |
| RMLSA Approach [8] | Static | Single-Hop | Dynamic | No | No |
| TG-Approach [10] | Static | Single-Hop | Static | Yes | No |
| LB-SR [11] | Dynamic | Multi-Hop | Static | Yes | No |
| MTG [13] | Static | Single-Hop | Static | No | Yes |
| FPA [24] | Dynamic | Single-Hop | Static | No | Yes |
| MPH-SRNP [25] | Dynamic | Multi-Hop | Static | Yes | Yes |
| DFG [26] | Static | Single-Hop | Dynamic | Yes | Yes |
| MBM (our proposal) | Dynamic | Multi-Hop | Dynamic | Yes | Yes |

# Maximizing the use of best modulation format

- Important aspects
  - Traffic grooming for better usage of the channel's resources
  - Optical grooming for more efficient use of the resources;
  - Adaptive modulation for reducing the use of the network's spectral resources
- Objective
  - The greatest optical grooming possible through multi-hop routing, using higher modulation levels.
  - An optical transmission between two distant nodes must be composed of several shorter paths that satisfy the required QoT factor, allowing less spectral resources to be consumed by using more optical-electrical-optical (OEO) conversions
  - There is a trade-off between using less spectrum and using more transponders

# Maximizing the use of best modulation format

- MBM algorithm
  - Node d4 is too far from the source and only satisfies the QoT requirements through BPSK modulation
  - Nodes *d1, d2* , and *d3* , on the other hand, can be reached though more efficient modulations, such as QPSK
  - Multi-hopping is used for shorter lightpaths with higher modulation levels, effectively consuming less resources
  - An OEO occurs and a different transponder, the one with the highest modulation level possible
  - The advantage is that MBM uses less slots than DFG for satisfying the same demands



# Maximizing the use of best modulation format

- Algorithm process
  - Step 1: a single-hop for traffic and optical grooming
  - Step 2: a multi-hop step for the same goals through multiple hops in the virtual topology
  - Step 3: a final single-hop step (without grooming) based on the KSP algorithm

# Performance evaluation

- Simulation conditions
  - Compared to 5 other related algorithms: KSP, MSP, SPV, FPA, and MPH-SRNP
  - each simulation was run five times using the independent replications method, and results are presented with confidence intervals with 95% reliability
  - $10^5$ connection requests are generated with 15 levels of granularity varying from 12.5 Gb/s to 100 Gb/s
  - This process follows a Poisson distribution

# Performance evaluation

- Simulation conditions
  - The network topologies considered here are USANet (24 nodes and 43 bidirectional links) and PanEuro (27 nodes and 81 bidirectional links)
  - The bandwidth for each slot is 12.5 GHz and each link has 120 slots for capacity ( 1.5 THz)
  - One guard band has two slots (25 GHz)
  - Each node has 15 transponders and each of those has a maximum capacity of eight slots
  - The modulations are BPSK, QPSK, 8QAM, 16QAM with 1, 2, 3, and 4 bits per symbol
  - The maximal distances are 8000, 4000, 2000, and 1000 km

# Performance evaluation

- Bandwidth blocking ratio
  - The MBM algorithm has a lower BBR than the others, being about half of that of the KSP, MSP, and SPV algorithms

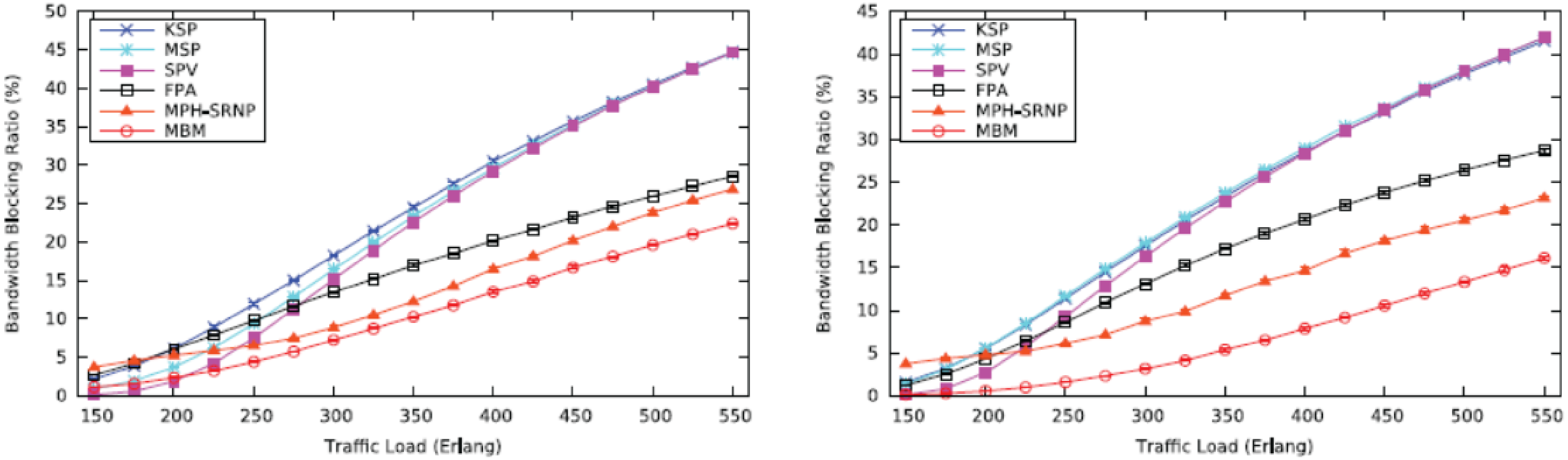



**Fig. 10.** BBR for USANet (left) and PanEuro (right).

# Performance evaluation

- Ratio of available transponders
  - MBM is slightly worse at this than FPA, around 6% in UsaNet and 12% in PanEuro, and significantly better than the others, up to 59%

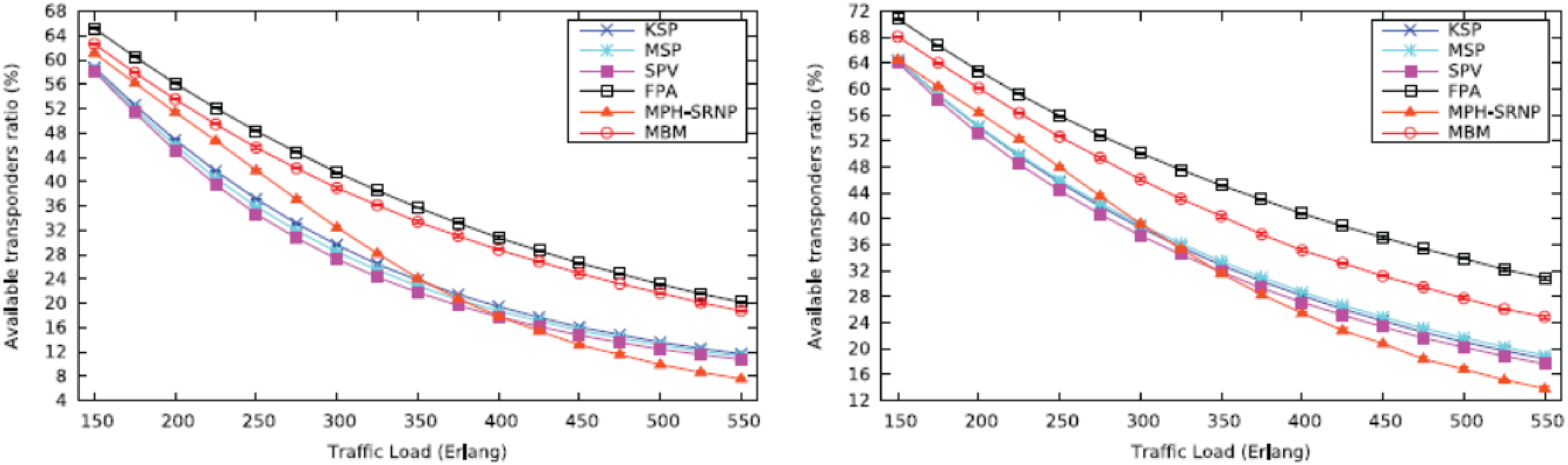



Fig. 12. Average ratio of available transponders for USANet (left) and PanEuro (right).

# Performance evaluation

- Average transponders per request
  - The ratio is less than 1.0 for FPA, MPH-SRNP, and MBM, an obvious effect of their traffic grooming aspect, where multiple connections share a single transponder
  - The multi-hop algorithms (MPH-SRNP and MBM) have the best results

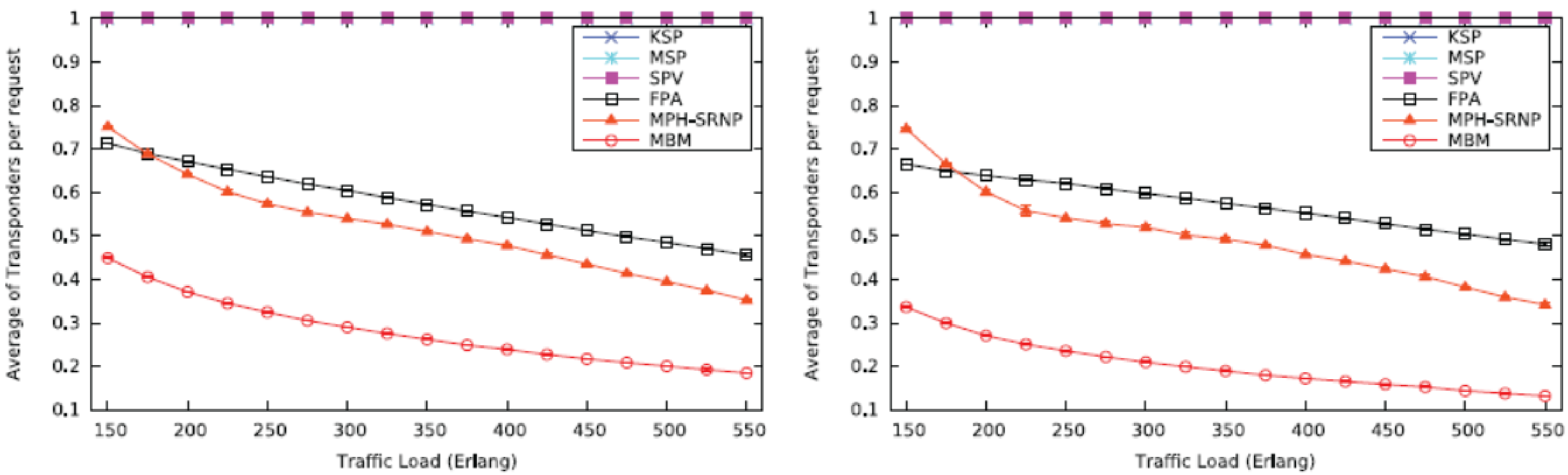


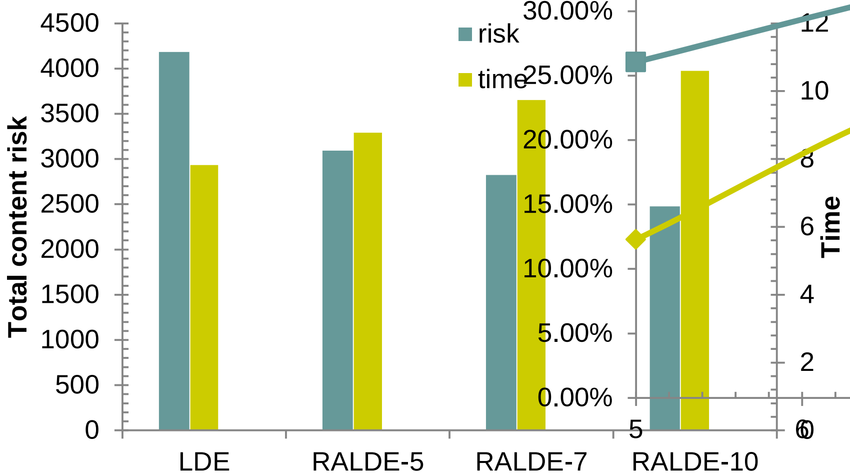

Fig. 13. Average ratio of transponders used per request for USANet (left) and PanEuro (right).

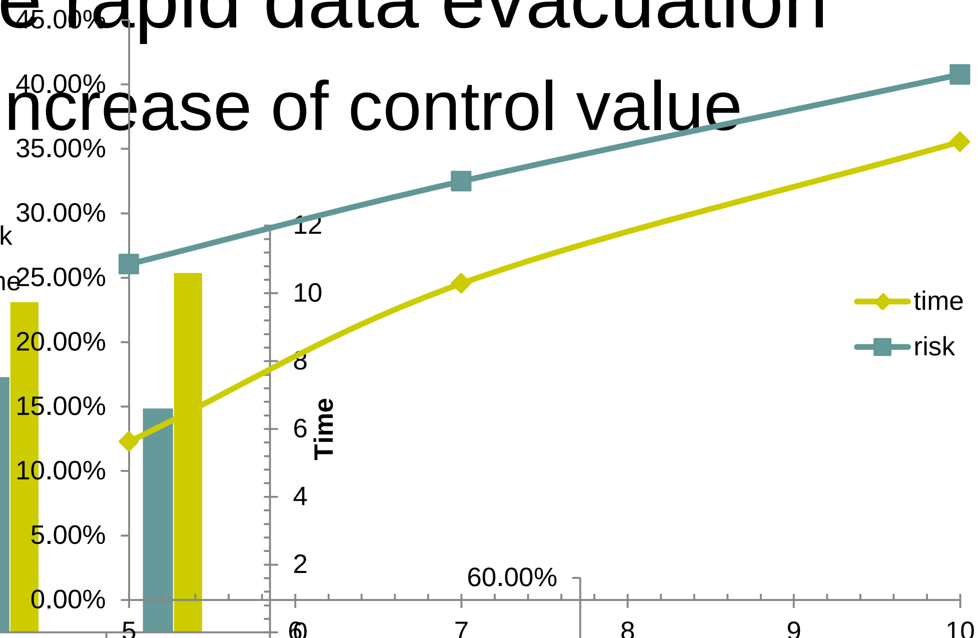
# Conclusion

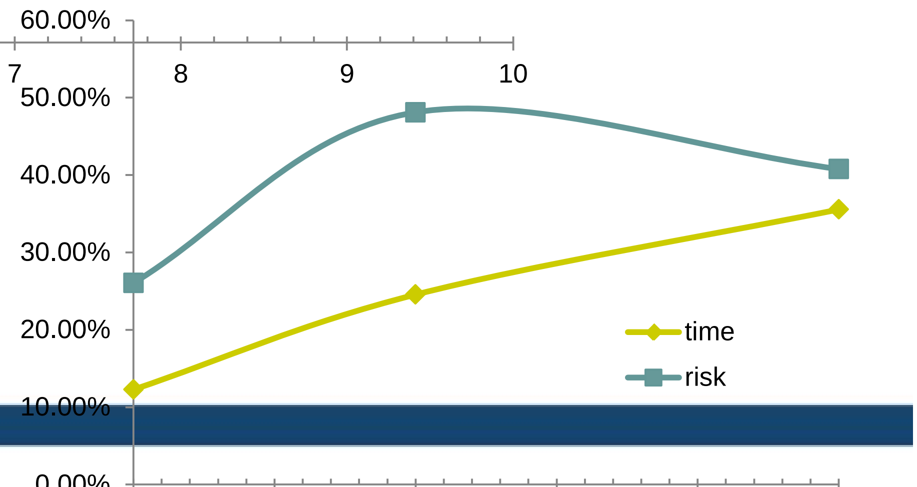
- This works focuses on solving the routing, modulation level, and spectrum allocation problem in a dynamic context through spectral modulation control, traffic and optical grooming
- The proposed *Maximizing the Use of Best Modulation Format* approach associates these techniques to make better use of the networks' spectral resources and to satisfy larger data rate demands by using higher modulation levels through multiple hops in the virtual topology
- It was compared to five other well known algorithms on two network topologies, and results showed that MBM's bandwidth blocking ratio was lower than all others, and significantly so in most cases

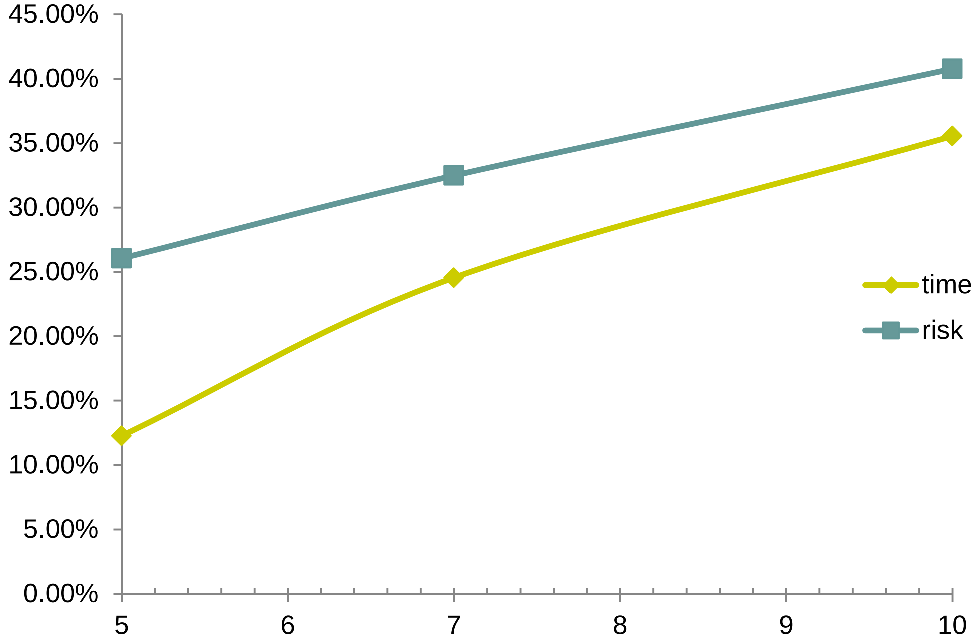
# Current work

- Risk-aware rapid data evacuation
  - With the increase of control value




45.00%
40.00%
35.00%
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
5
6
7
8
9
10
time
risk

# Thank you for your attention!


**Presenter: Yongcheng(jeremy) Li**

**PhD student, School of Electronic and Information Engineering,**

**Soochow University, China**

**Email: liyongcheng621@163.com**


**Group Meeting, May. 20 2016**

UCDAVIS
UNIVERSITY OF CALIFORNIA