Dynamic Crosstalk-Aware Lightpath Provisioning in Spectrally–Spatially Flexible Optical Networks

M. Klinkowski and G. Zalewski, “Dynamic Crosstalk-Aware Lightpath Provisioning in Spectrally–Spatially Flexible Optical Networks,” Journal of Optical Communications and Networking, vol. 11, no. 5, pp. 213–225, May 2019.

Paper review

Andrea Marotta

Group Meeting

Friday, June 7, 2019

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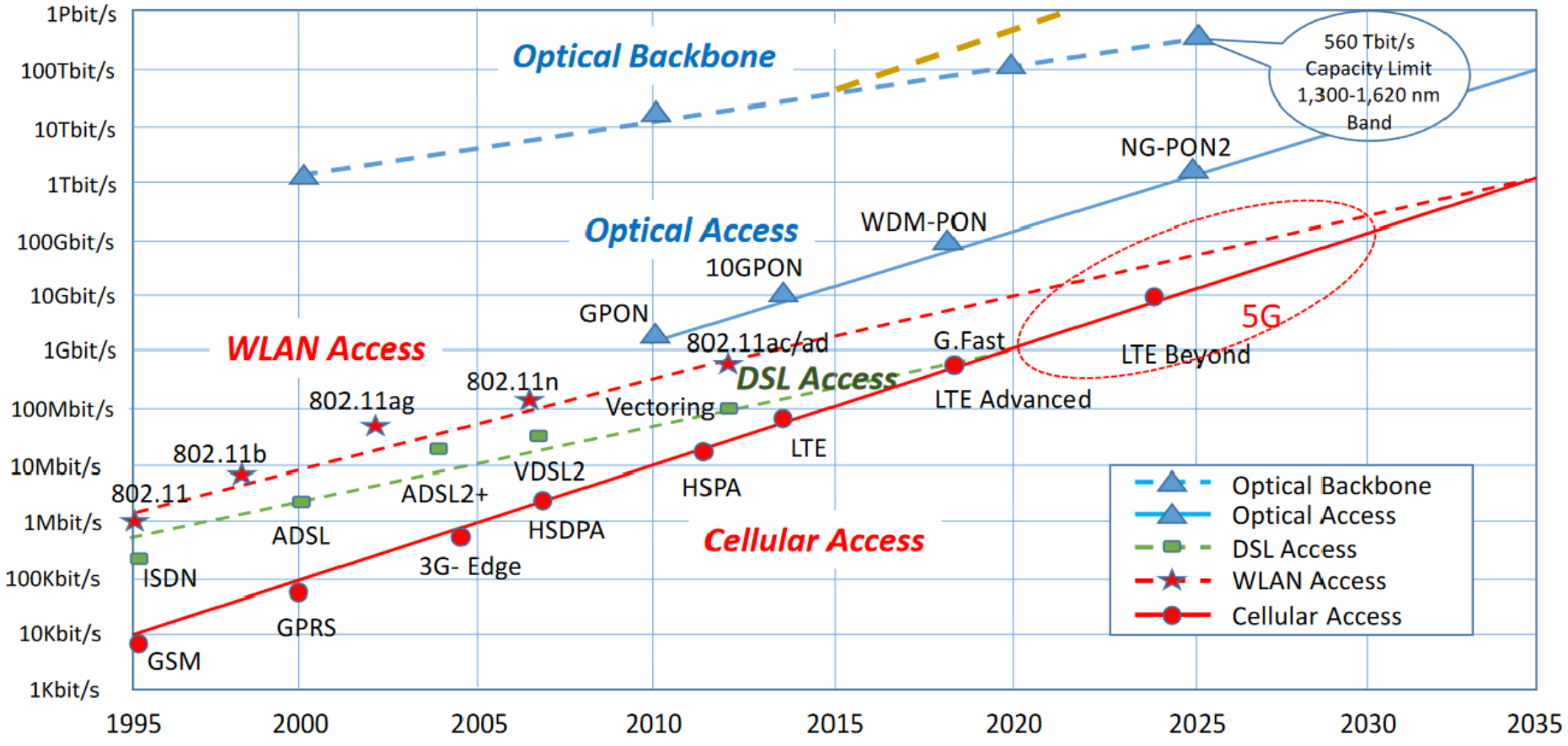
Outline

- Introduction
- Motivation
- Problem definition
- Cross-Talk estimation approaches
- Cross-Talk-Aware Lightpath-Provisioning Algorithm
- Scenario
- Analysis of results
- Conclusion

Introduction (1)

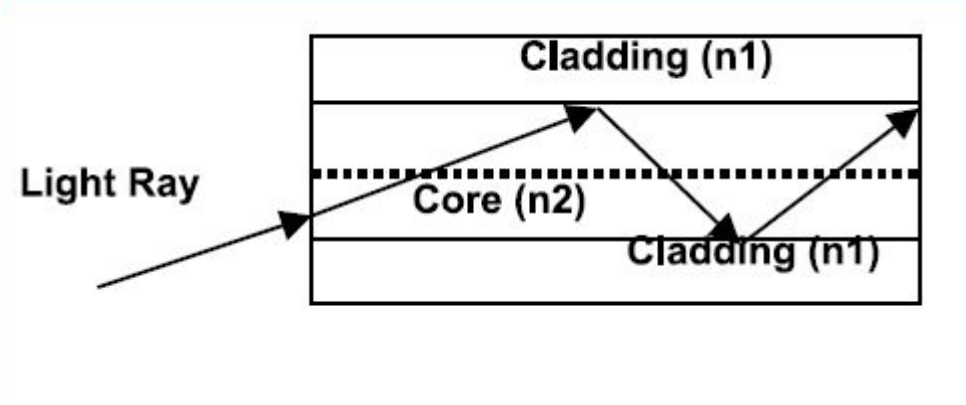
- How to overcome the Optical Networks Capacity Crunch?

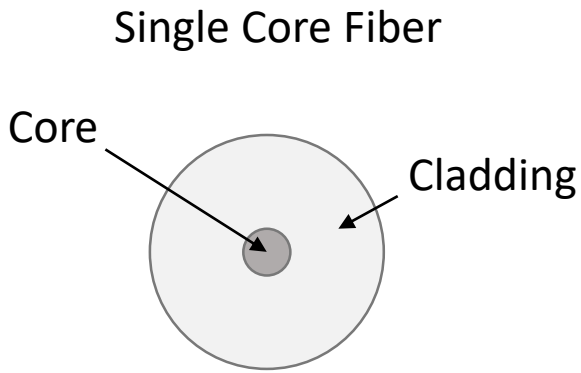


Source: M. Dècina, 2014, based on data by Bell Labs, G. Fettweis, and others

Introduction (2)

- Parallelization is the answer
  - Multiple fibers per link
  - Multimode fibers
  - Multicore fibers





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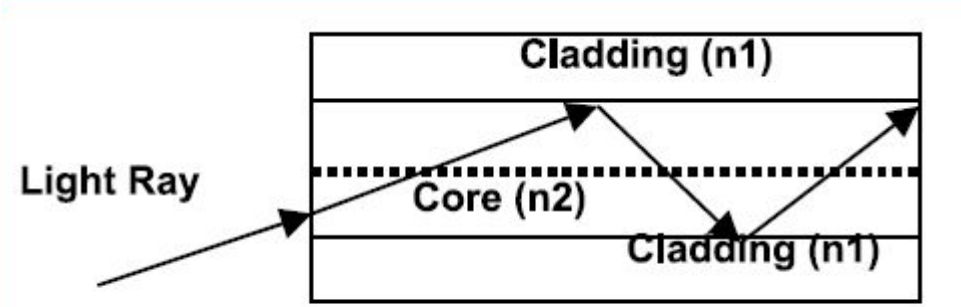

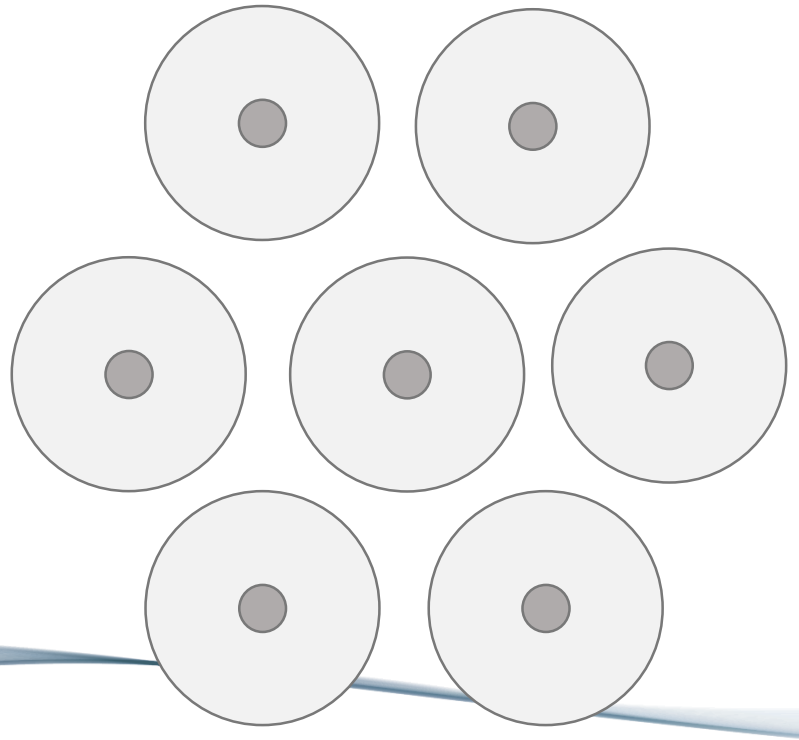

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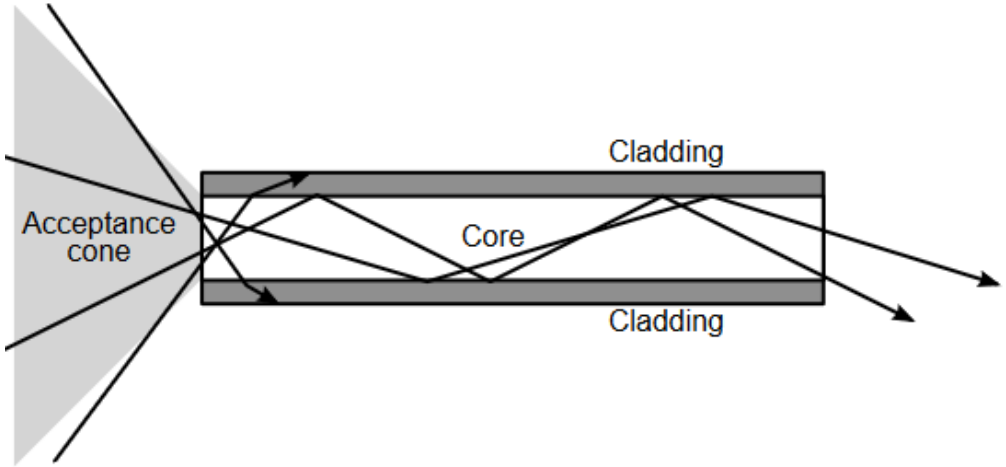

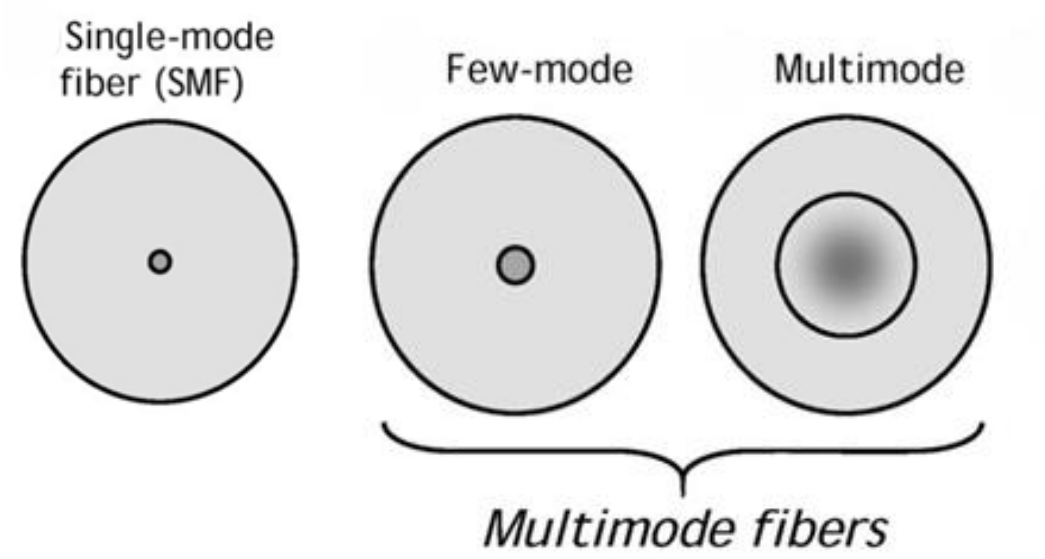

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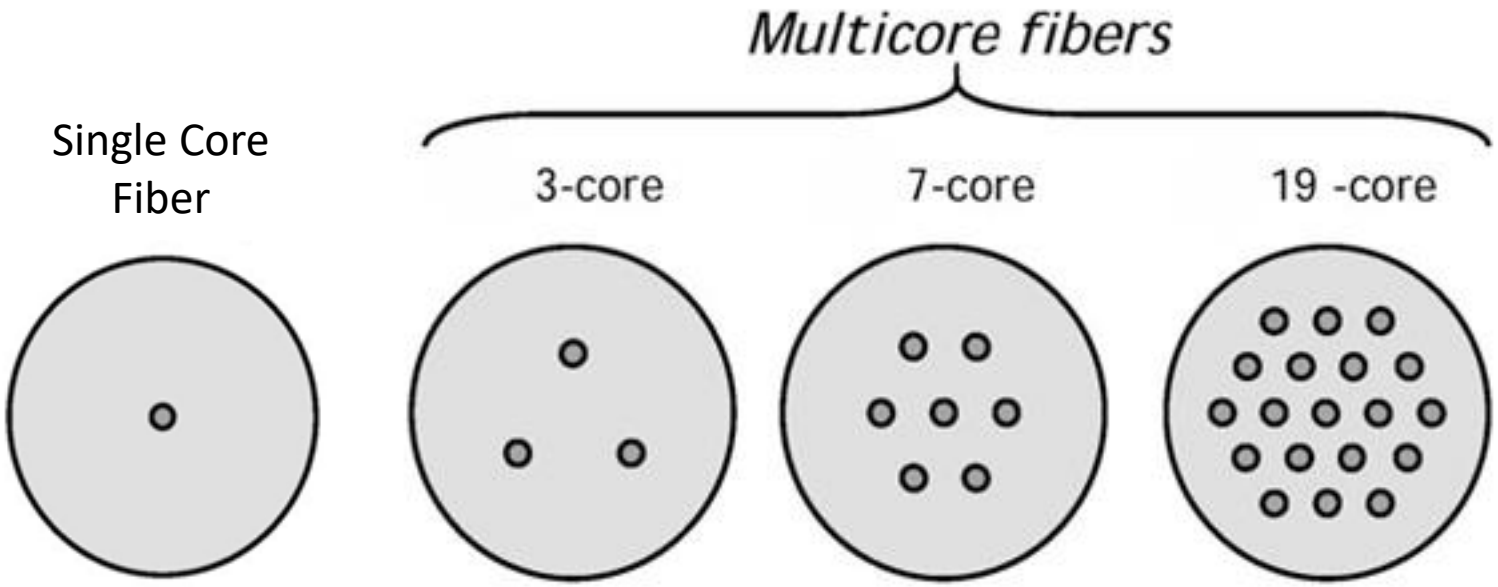

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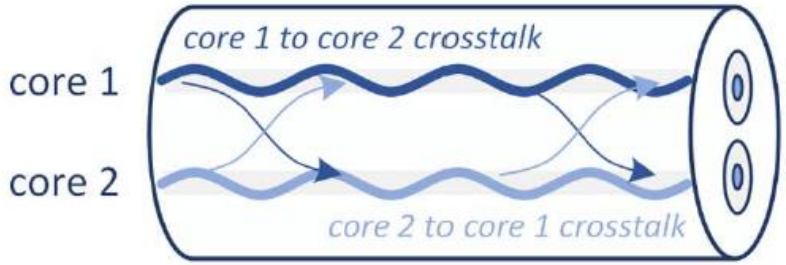

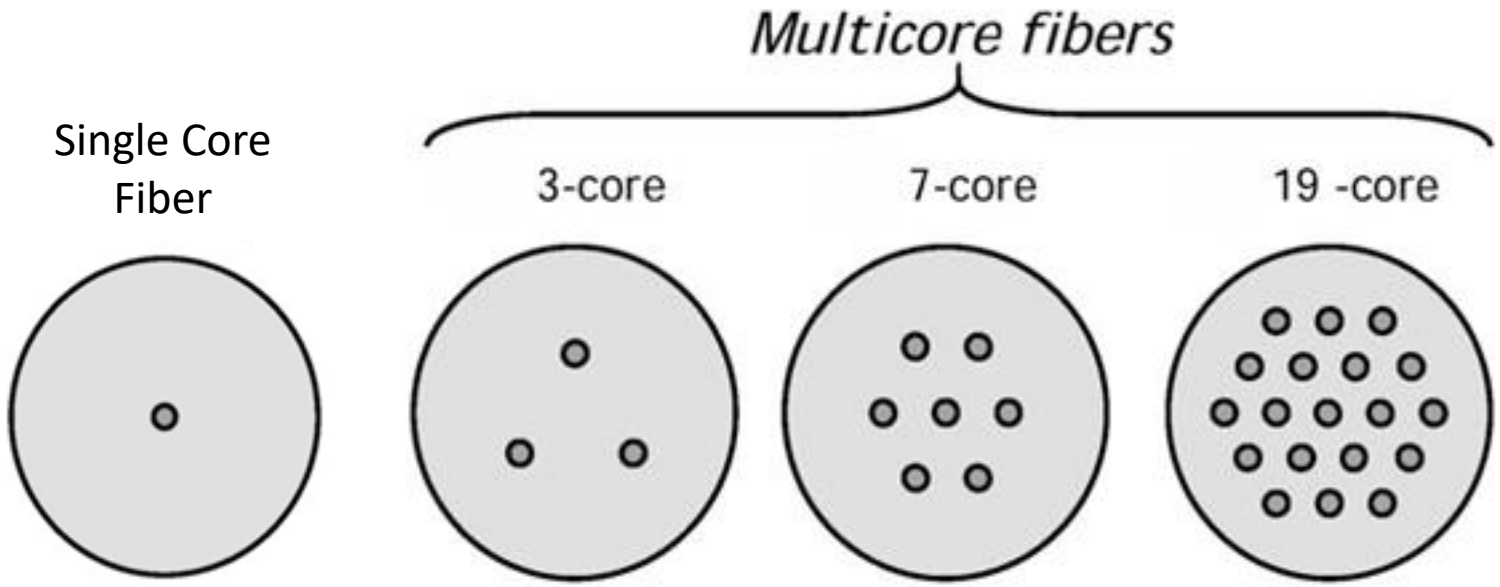

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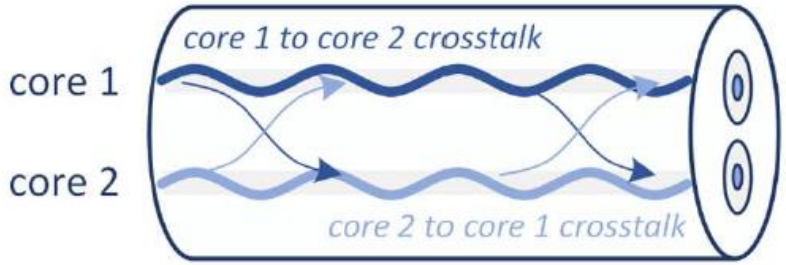
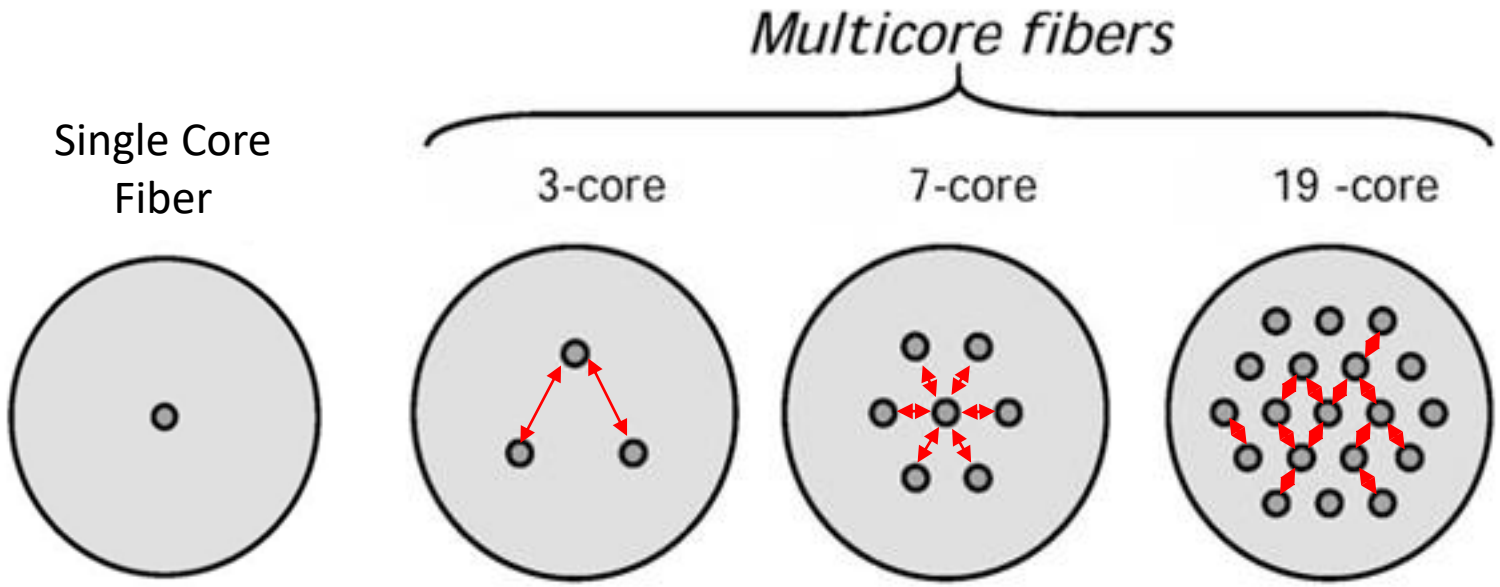




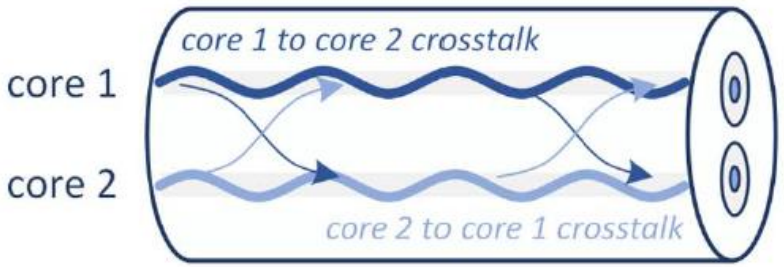
Motivation

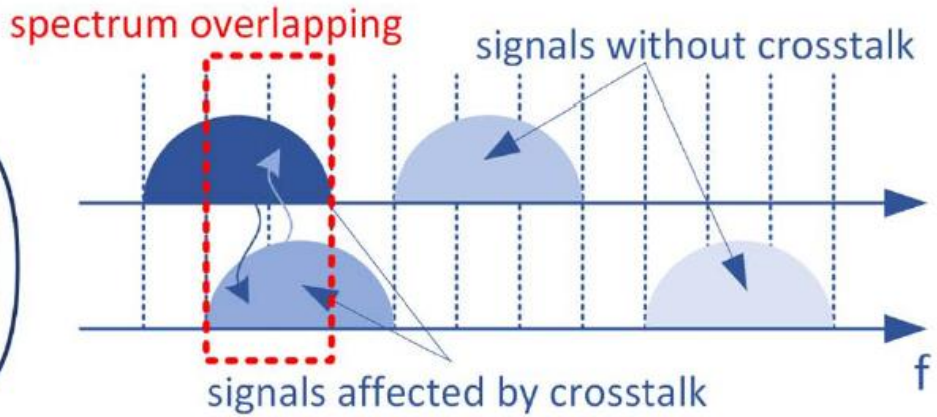
- Flex-grid Optical Networks (FON)
  - Routing
  - Spectrum

Routing and Spectrum Allocation (RSA) problem

- Spectrally-Spatially Flexible Optical Networks (SSFON)
  - Routing
  - Spectrum
  - Core

Routing, Core, and Spectrum Allocation (RCSA)





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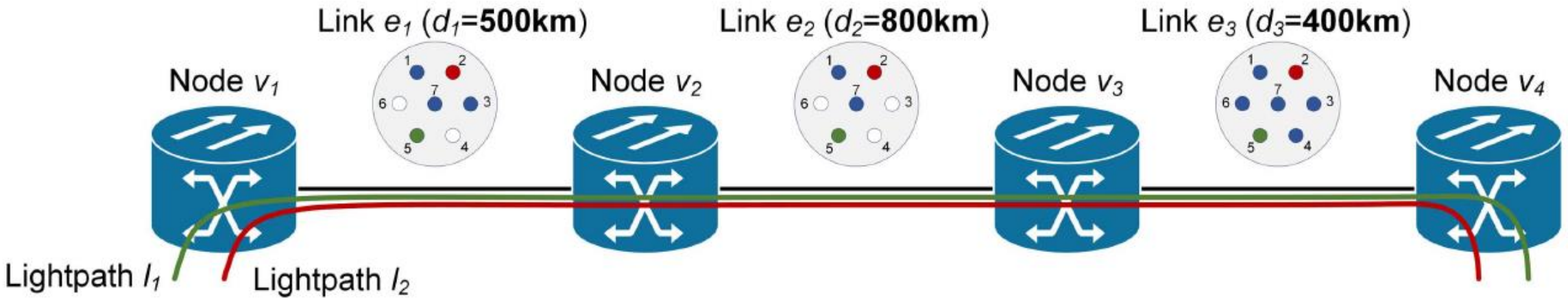
Motivation (2)

- The estimation of Cross Talk plays a fundamental role in multicore fibers networks lightpath provisioning
  - Modulation format
  - Transmission reach



Cross-Talk estimation approaches (1)

- A simple expression of mean cross talk on a core is:

$$\mathrm{XT}_{\mu} \cong K \cdot h \cdot L.$$

Where:

- K is the number of adjacent cores that are the source of XT in a given core and in a given spectrum band
- L is the MCF path length
- h is a constant, referred to as the power-coupling coefficient

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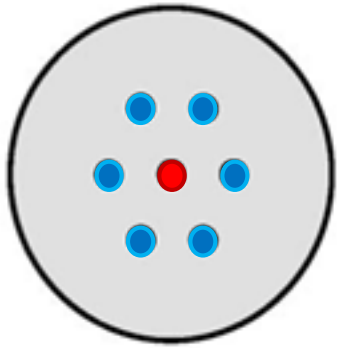
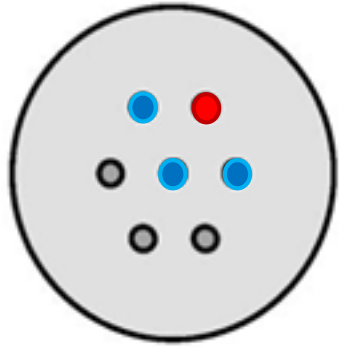
Cross-Talk estimation approaches (2)

- Worst case approaches
  - Per Fiber (WCF-XT)
    - XT is estimated for the most affected fiber core, e.g., the central core in a seven-core MCF
    - is applied to the remaining cores, even those less affected by the XT effect



  - Per Core (WCC-XT)
    - the XT levels are calculated for individual MCF cores assuming their particular location and proximity to other cores
    - Assumes slices of adjacent cores are utilized



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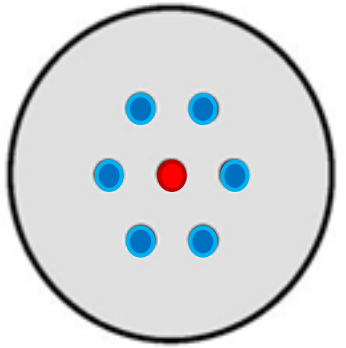

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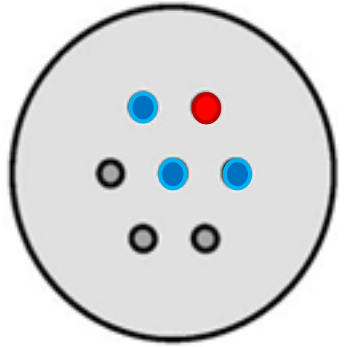

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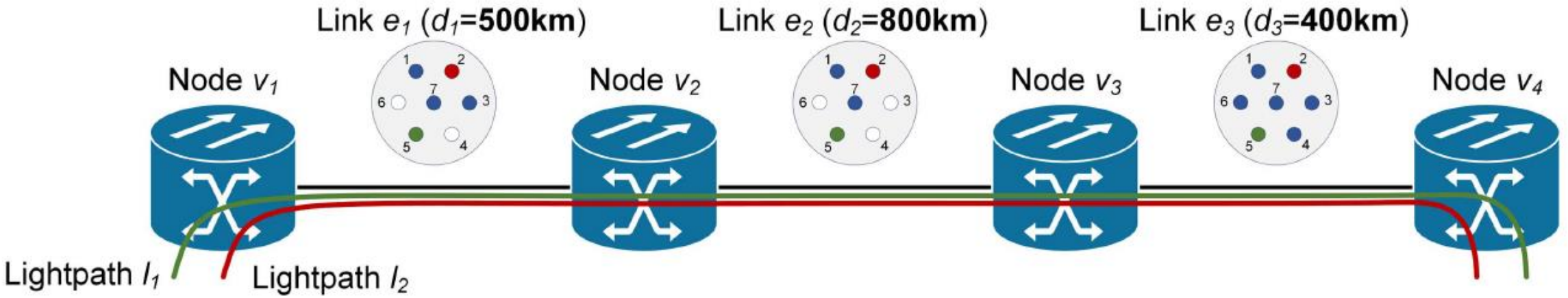
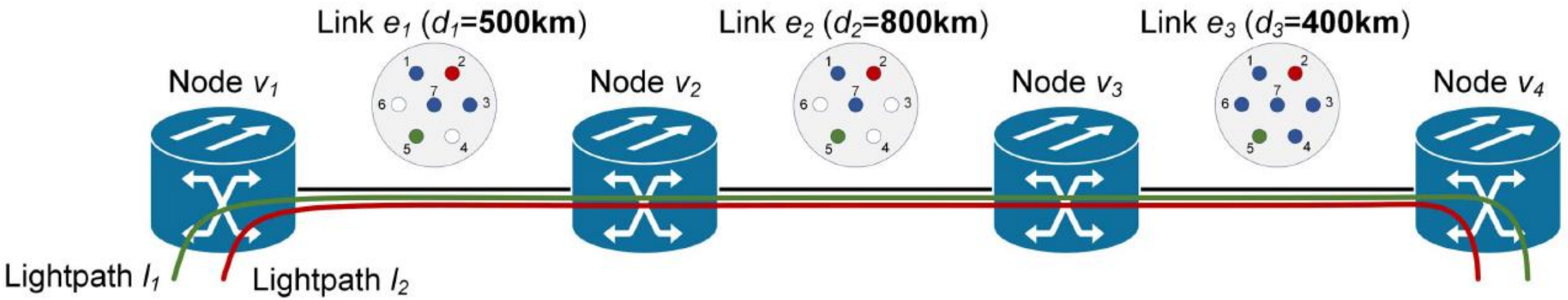
Cross-Talk estimation approaches (3)

- Precise XT estimation
  - Takes into account the actual state of the network
  - Precise Slice-Based XT (PS-XT)
    - Considers the level of XT on the most affected frequency slice belonging to the frequency slot of lightpath l_i



Cross-Talk estimation approaches (3)

- Precise XT estimation
  - Takes into account the actual state of the network
  - Precise Link-Based XT (PL-XT)
    - Effectively measures the maximum perceived XT levels in the links belonging to the lightpath and takes decision accordingly



Routing, Core, and Spectrum Allocation Algorithm (1)

Algorithm 1. XT-Aware RSSA Algorithm

Require: Network $\mathcal{G}$, Set of candidate paths $\mathcal{P}(d)$, Set of MCF cores $\mathcal{C}$, Set of frequency slices $\mathcal{S}$, Allocation state matrix A

best lightpath $l^* \leftarrow \emptyset$
for all route $p \in \mathcal{P}(d)$ **do**
  for all core $c \in \mathcal{C}$ **do**
    if pair (p,c) is allowable **then**
      frequency slice $s \leftarrow 0$
      while $(s \leq |\mathcal{S}|)$ **do**
      lightpath $l \leftarrow (p,c,f = (s, s + n(d,p,c) - 1))$
        $status \leftarrow SS(A,l)$
        if $status = 0 \wedge$ XT-METHOD = P-XT **then**
          $status \leftarrow XT(A,l)$
        if $status = 0$ **then**
          if $l^* = \emptyset \vee s_{begin}(l^*) > s_{begin}(l)$ **then**
            $l^* \leftarrow l$
            break
        else
          $s \leftarrow s + status$
Update network state in A assuming selected lightpath l^*
Ensure: Lightpath l^* for request d

Looks for slices with compatible XT level

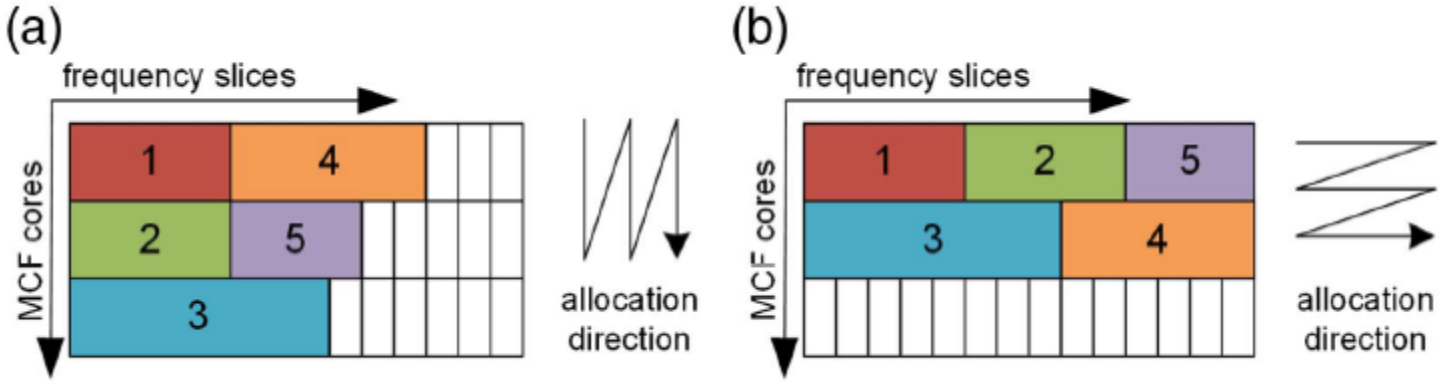
Checks if the added lightpath impacts on XT level of other lightpaths

Instantiates the lightpath

How to iterate over slices?

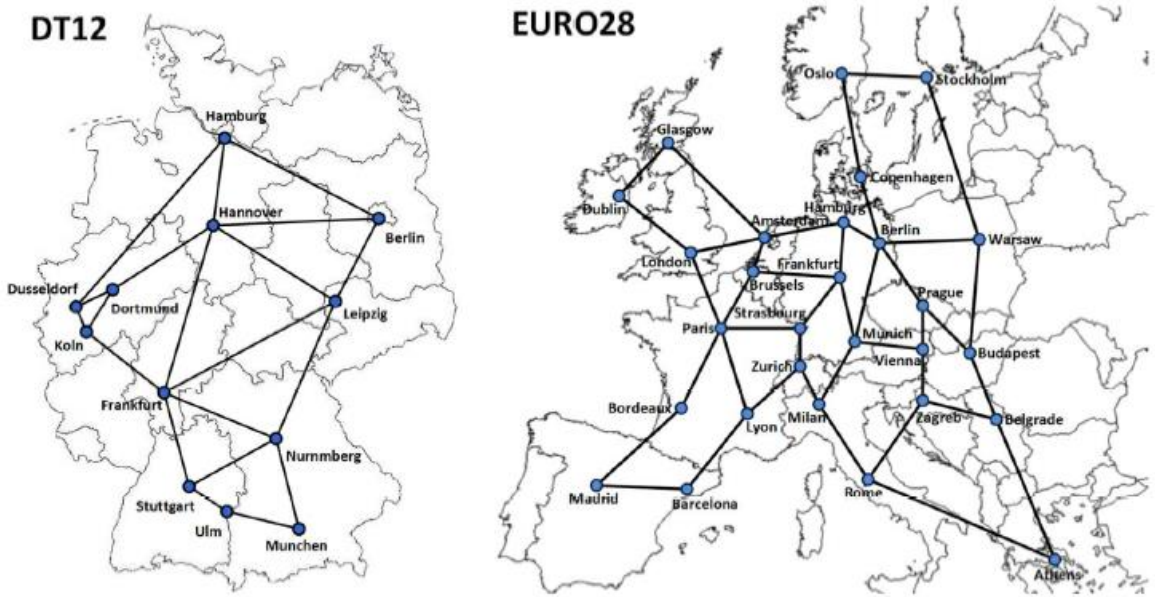
Routing, Core, and Spectrum Allocation Algorithm (2)

- Two policies that differ in the way the spectral–spatial resources are processed:
  - Spectrum first (SF)
  - Core first (CF)



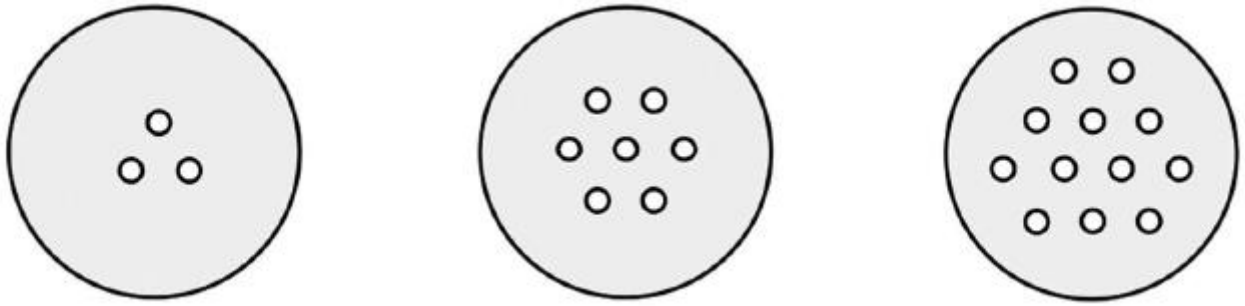
Scenario (1)

- RSSA algorithm and XT estimation methods considered in two realistic networks of different dimensions



Scenario (2)

- Three types of MCF: MCF-3, MCF-7, MCF-12
- Switching nodes operating without SDM lane change capability, i.e., the same core is allocated in each link of a lightpath
- No spectrum conversion capability
- Connection requests with randomly generated end nodes, and bit-rates uniformly distributed between 50 Gbit/s and 1 Tbit/s



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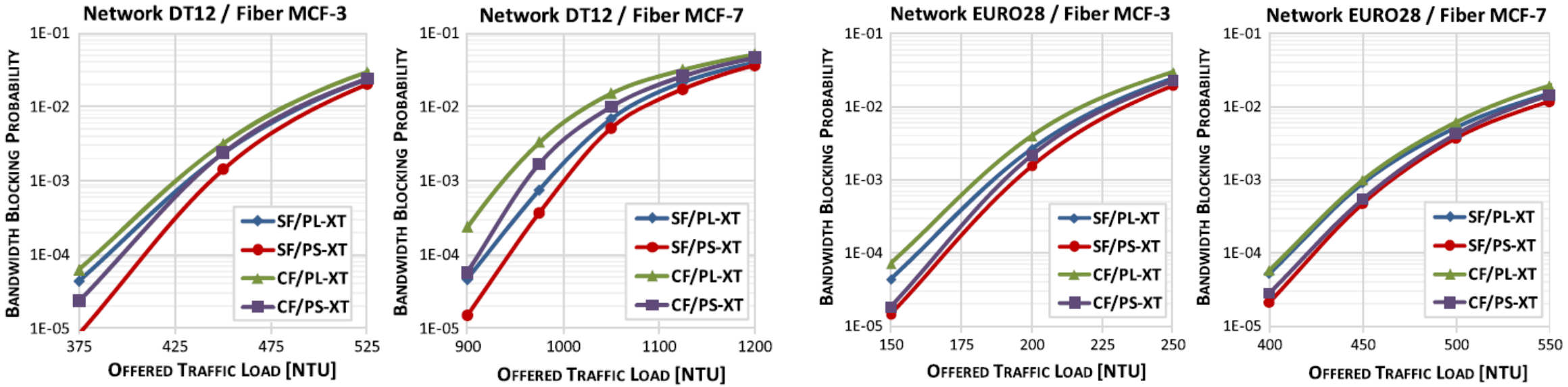
Results (1)

- Comparison of precise XT estimation approaches under different spectrum allocation policies shows SF and PS-XT outperform the other methods



SF: Slice first
CF: Core first
PS-XT: Precise Slice-Based XT
PL-XT: Precise Link-Based XT

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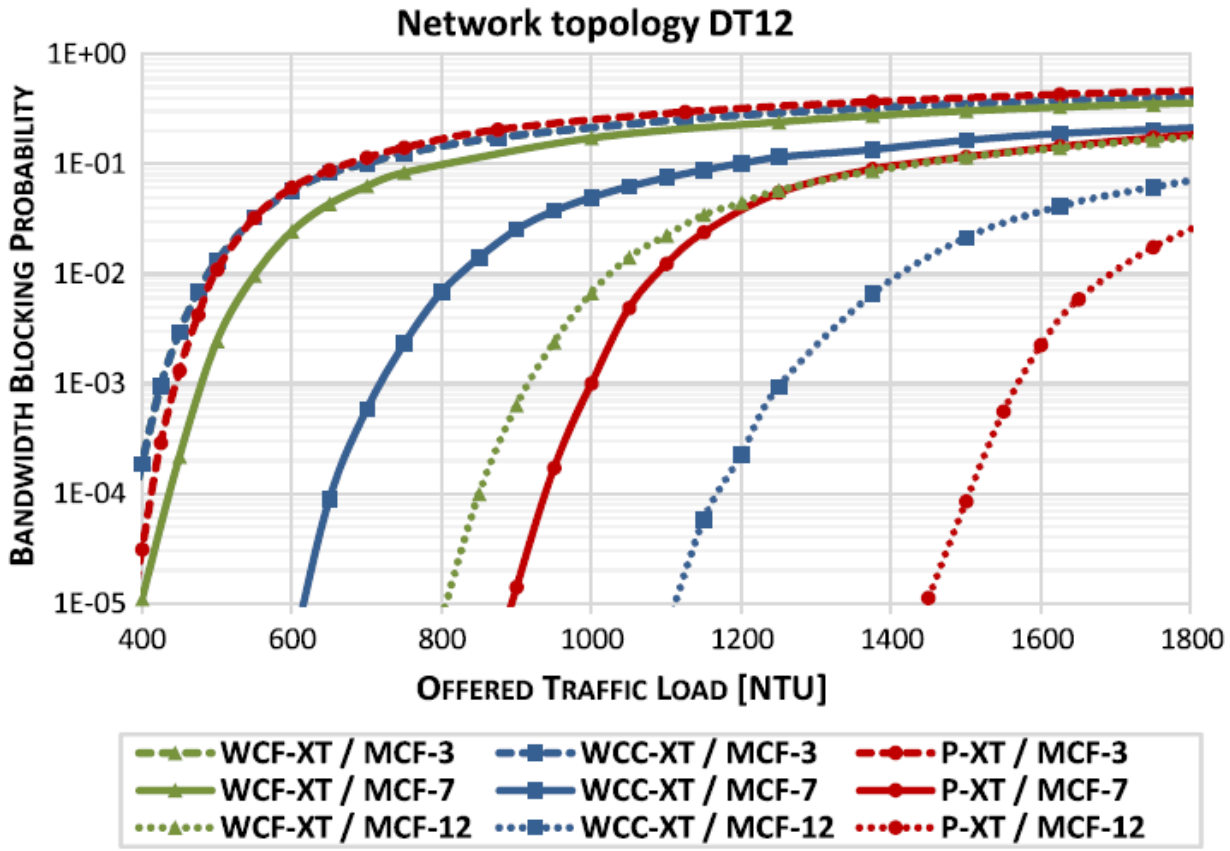
Results (2)

- P-XT significantly outperforms both worst-case XT approaches in the studied network



P-XT: Precise XT
WCF-XT: Worst-Case per fiber
WCC-XT: Worst-Case per core

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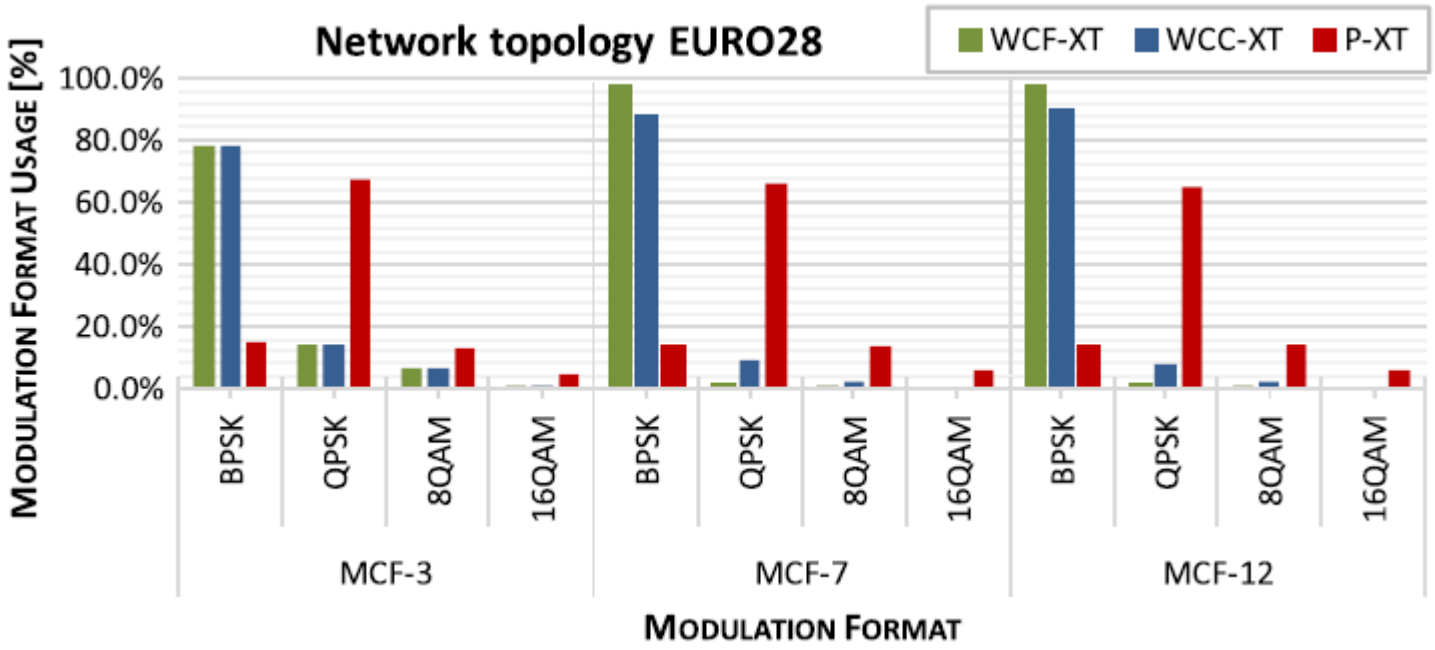
Results (3)

- P-XT applies more spectrally efficient Modulation Formats than the other methods



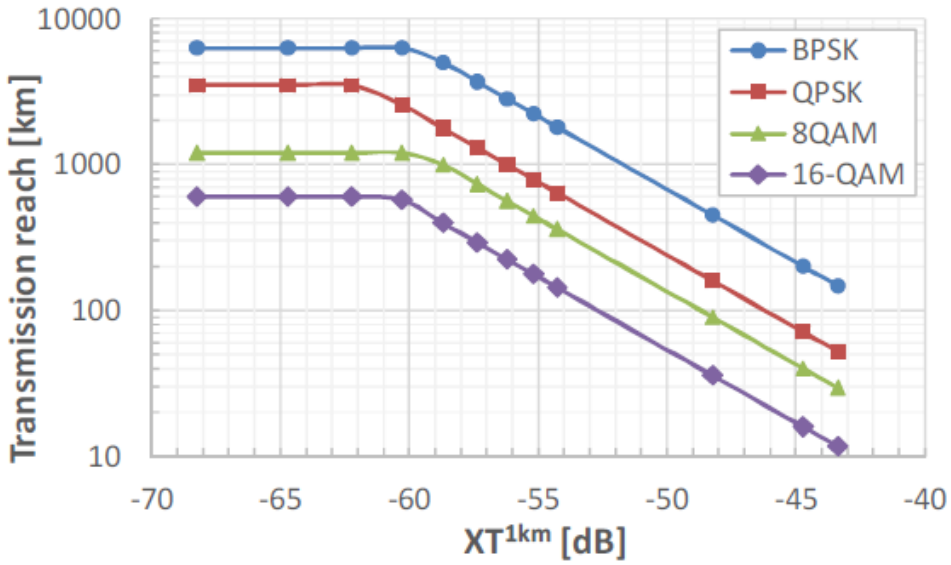
P-XT: Precise XT
WCF-XT: Worst-Case per fiber
WCC-XT: Worst-Case per core

Conclusion

- The problem of dynamic crosstalk-aware lightpath provisioning in spectrally and spatially flexible optical networks
- Distance-adaptive and spectral super-channel transmission is realized over multicore fibers
- Switching nodes operate without SDM lane changes
- Lower Bandwidth Blocking Probability may be achieved with precise XT estimation (P-XT)

Multi Core Fibers in Metro Networks

- High Modulation Formats (32-QAM, 64-QAM) have maximum transmission reach which can be critical also for metro applications



- MCFs could be utilized for slice provisioning in 5G optical transport networks

A test-bed for multi-core fiber experimentation

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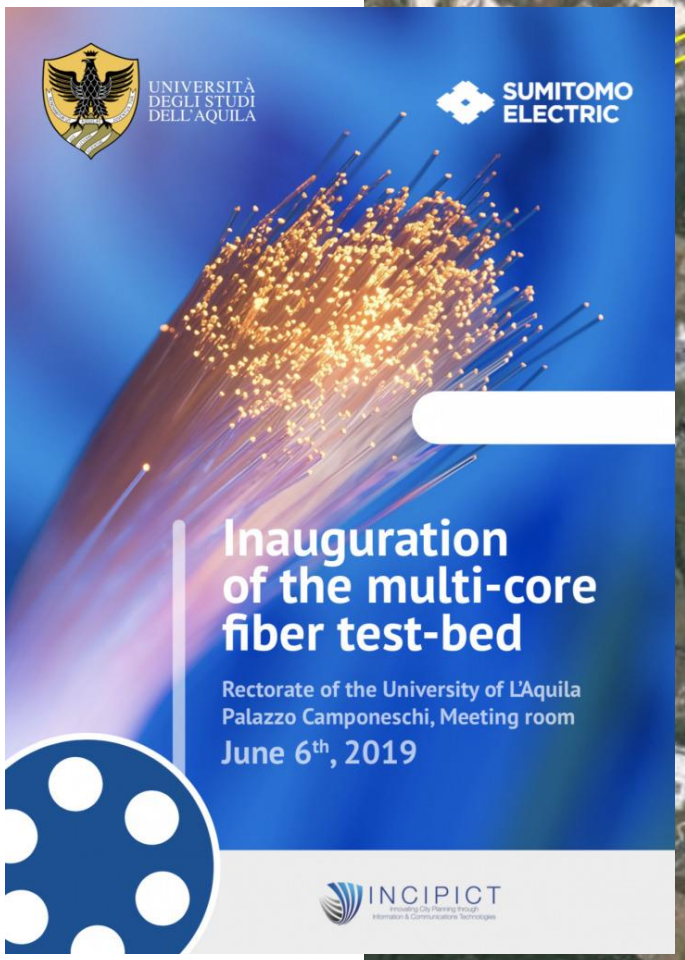
A test-bed for multi-core fiber experimentation



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Thank you