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Assessment of Flex-Grid/MCF Optical Networks with ROADM Limited Core Switching Capability

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Outline

- Motivation
- Transmission Reach Estimation in MCF-enabled Networks
- Proposed ROADM Architecture
- Case Study and Results
- Final Remarks

Motivation

- Flex-Grid takes advantage of flexibility at the transceiver, while ensuring efficient utilization of the optical spectrum.
- Space Division Multiplexing (SDM) is the prime candidate to overcome the nonlinear Shannon's fundamental limit of single-mode fiber capacity.
- Weakly-coupled Multi-core fibers (MCFs) are an attractive SDM fiber candidate given their extremely low Inter-core Crosstalk (ICXT).

MCF	Worst ICXT [dB/Km]
7 [1]	-84.7
12 [2]	-61.9
19 [3]	-54.8

[1] J. Sakaguchi et al.,JLT 30(4), 2012. [2] A. Sano, et al., Opt. Express, 21, 2013.

[3] J. Sakaguchi et al.,Opt. Express, 22, 2014.

Motivation (1/4)

- SDM Reconfigurable Optical Add/Drop Multiplexers (ROADM) design is a challenge taking into account several degrees of freedom.

- Having full interconnection at ROADMs between input ports and output ports is very expensive, and even more with new space dimension → fully non-blocking architecture (FNB-ROADM architecture).
  - FNB architecture assumes that signals can be freely switched from any input fiber (& core) to any output fiber (&core).

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Motivation (2/4)

- Joint-switching (JoS) [4] relaxes the hardware requirements of the ROADMs and it is mandatory for strongly-coupled SDM fibers (some MCFs, FMFs, FM-MCFs…). Spatial super-channel allocation (Spa-SCh) policy is mandatory.

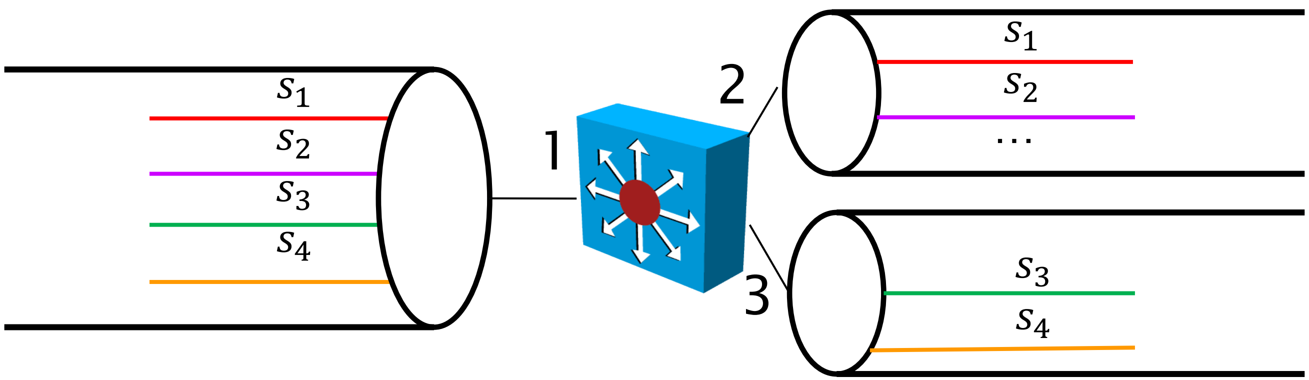
- Architecture on Demand (AoD) [5] shares the hardware modules on demand via node programmability. It assumes core switching capabilities → Different super-channel allocation policies (Spe-SCh, Spa-SCh, S2-SCh).

[4]L.E. Nelson et al.,JLT 32(4), 2014.

[5] [N. Amaya et al.,Opt. Express 21(7), 2013]

Motivation (3/4)

- In this work, we propose an alternative architecture to reduce the node complexity and cost:
  - Limit the core switching capabilities at the intermediate nodes: forcing the *core continuity constraint* (CCC-ROADM architecture)



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TR Estimation

- TR depends on many different variables like the type of fiber, the amplification scheme, the dispersion map, the nonlinear effects compensation capability…
- TR in MCFs is limited by Signal-To-Noise Ratio (SNR) and ICXT.
  - SNR: We consider the Gaussian-Noise (GN) model and with parameters according to "Link 1". [6]
  - ICXT: We consider the worst-aggregate ICXT among cores.

Overall Transmission Reach [km]

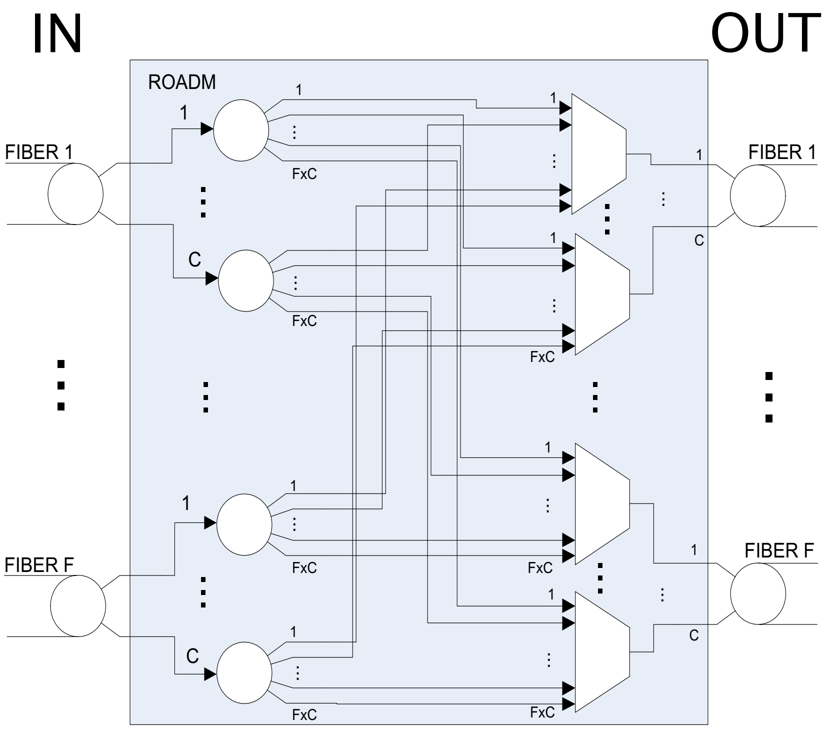
C	BPSK	QPSK	16-QAM	64-QAM
7	>20000	9000	2000	600
12	>20000	9000	2000	600
19	4755	2383	599	150

[6] P. Poggiolini et al.,JLT 30(4),2014

Proposed Architecture (1/4)

(B&S) FNB-ROADM Architecture:

- The number of splitters and SSSs is *FxC* and grows linearly with the number of cores
- The number of input ports of each SSS is *FxC* and grows linearly with the number of cores
- The attenuation caused by the splitters is approximately 10 log *(FxC),* thus growing logarithmically with the number of cores



F: node degree
C: core count

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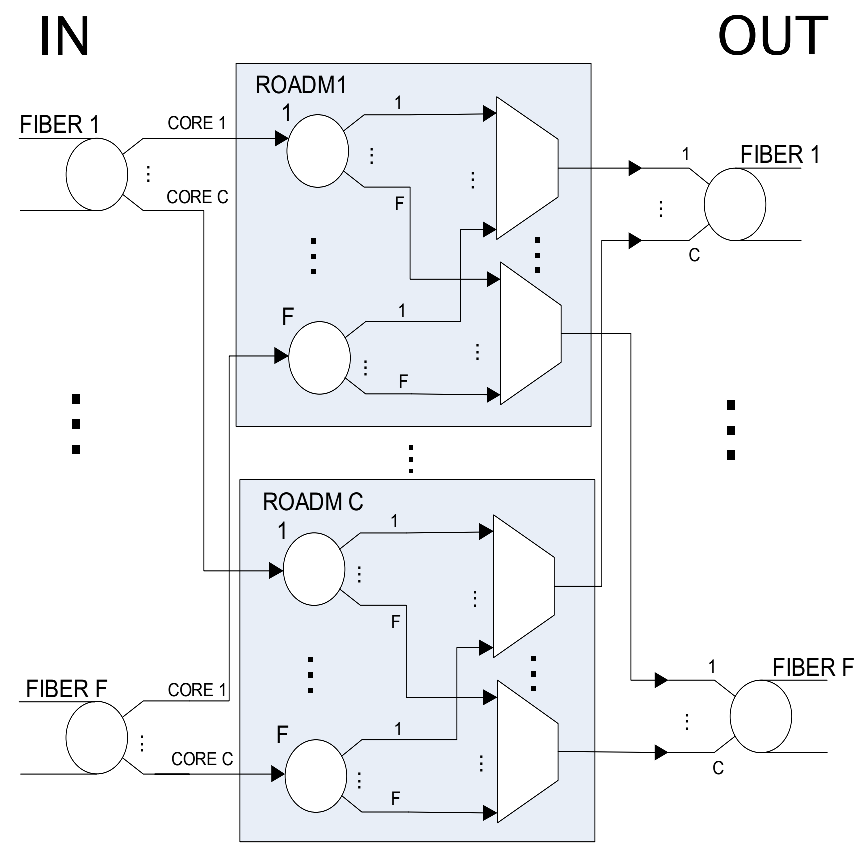
Proposed Architecture (2/4)

(B&S) CCC-ROADM Architecture:

- The number of splitters and SSSs is *FxC* and grows linearly with the number of cores
- The number of input ports of each SSS is now *F* instead of *FxC*, and **does not** grow with the number of cores
- The attenuation (in dB) caused by the splitters is approximately 10 log (*F*) instead of 10 log (*FxC*), and **does not** grow with the number of cores



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Proposed Architecture (3/4)

CCC-ROADM vs. FNB-ROADM Architecture

Splitter Atenuation in $[dB]$ (CCC, FNB)

C	F = 2		F = 4		F = 8	
	CCC	FNB	CCC	FNB	CCC	FNB
7	3.01	11.46	6.02	14.47	9.03	17.48
12	3.01	13.80	6.02	16.81	9.03	19.82
19	3.01	15.80	6.02	18.81	9.03	21.82

Number of Required Input Ports per SSS (CCC, FNB)

C	F = 2		F = 4		F = 8	
	CCC	FNB	CCC	FNB	CCC	FNB
7	2	14	4	28	8	56
12	2	24	4	48	8	96
19	2	38	4	76	8	152

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Proposed Architecture (4/4)

Decision Variable:

$x_{ps}, p \in \mathcal{P}, s \in \mathcal{S}$: binary decision variable; 1 if path p has a first slot s (the $s(t(p))$ slots occupied are contiguous); 0 otherwise.

$x_{pcs}, p \in \mathcal{P}, c \in \mathcal{C}, s \in \mathcal{S}$: binary decision variable; 1 if path p uses the core index c and it has a first slot s (the $s(t(p))$ slots occupied are contiguous); 0 otherwise.

FNB-ROADM ILP Model	CCC-ROADM ILP Model
$\min \sum_{p \in \mathcal{P}, s \in \mathcal{S}} s_p l(p) x_{ps}$	$\min \sum_{p \in \mathcal{P}, c \in \mathcal{C}, s \in \mathcal{S}} s_p l(p) x_{pcs}$
subject to:	subject to:
$\sum_{p \in \mathcal{P}_d, c \in C, s \in \mathcal{S}} r_p x_{ps} \geq h_d, \forall d \in \mathcal{D}$	$\sum_{p \in \mathcal{P}_d, c \in C, s \in \mathcal{S}} r_p x_{pcs} \geq h_d, \forall d \in \mathcal{D}$
$\sum_{p \in \mathcal{P}_e} x_{ps} \leq C, \forall e \in \mathcal{E}, s \in \mathcal{S}$	$\sum_{p \in \mathcal{P}_e} x_{pcs} \leq 1,$ $\forall e \in \mathcal{E}, c \in \mathcal{C}, s \in \mathcal{S}$

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Case Study and Results

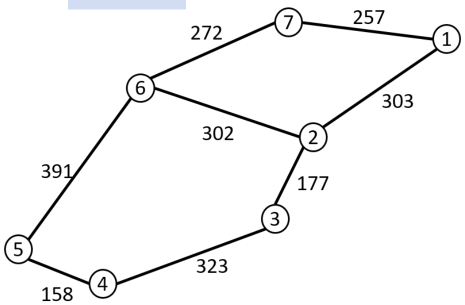
- We evaluate CCC-ROADM architecture implementing the ILPs formultations in Net2Plan tool and JOM library (CPLEX interface)
- Best sigle-mode (homogeneous) MCF protypes are assessed:

MCF	Worst ICXT [dB/Km]
7	-84.7
12	-61.9
19	-54.8

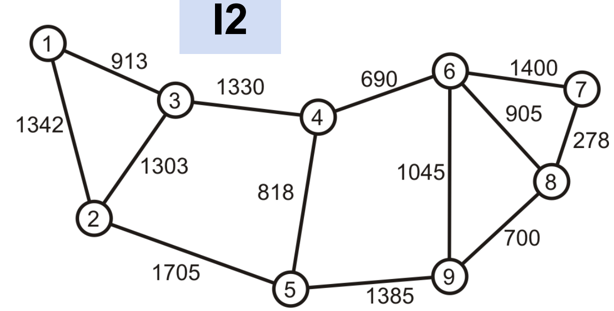
Spain network
7 nodes, 8 links
Avg. link: 273 km

US network
9 nodes, 13 links
Avg. link: 1063 km

T7S



I2



- 4THz C-Band, Δ_{fs}=12.5 GHz, 120 FSs/core
- GB = 10 GHz, flex. baud-rate, different modulation formats: PM-BPSK, PM-QPSK, PM-16QAM, PM-64QAM.
- Different transponders at line-rates R={40, 100, 400} Gb/s

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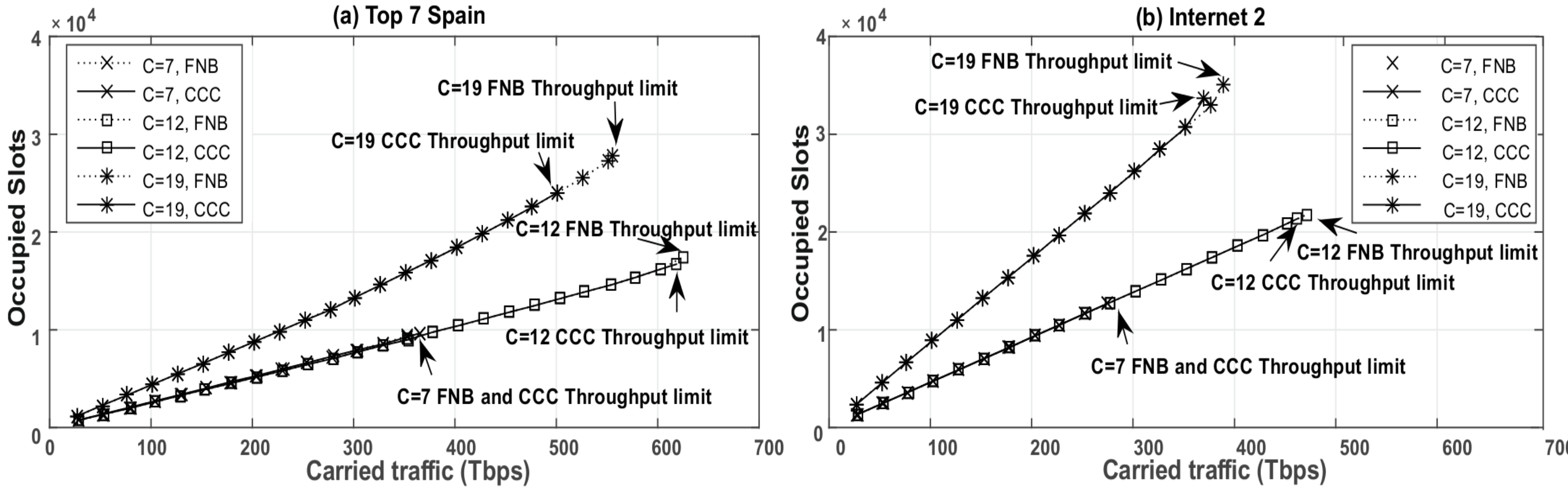
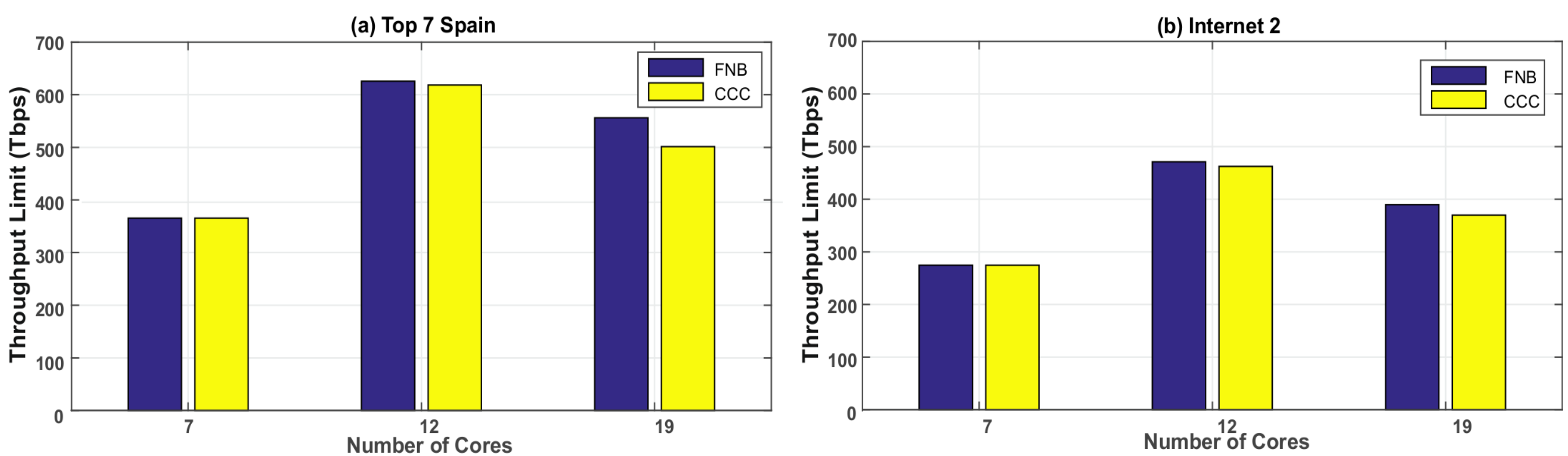
Case Study and Results (1/2)





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Final Remarks (1/2)

- The SDM ROADM architectures can be greatly simplified forcing the CCC with minimal impact on the network throughput
  - Reduce the SSS size and the attenuation caused by the splitters in a B&S scheme
  - Impact inexistent for C=7, around 1% for C=12 and between 10% and 5% for C=19 (in T7S and I2 networks, respectively)
- The best single-mode MCF protoypes, like the 7-core and 12-core MCF has a good relation throughput/(C*|E|) (as a metric of techno-economic efficiency)

Topology	C = 7	C = 12	C = 19
T7S	3.3	3.3	1.5
I2	1.5	1.5	0.8

- The 19-core MCF may compromise its feasibility unless a TR compensation mechanism is deployed

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THANK YOU
QUESTIONS?

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