Agile Filterless Optical Networking

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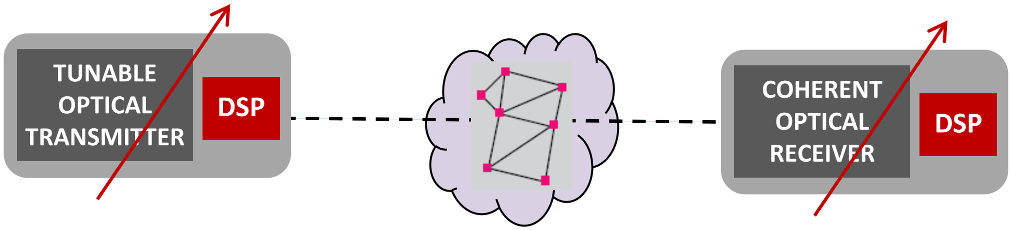
Coherent transmission as enabling technology



Higher-order modulation formats and digital signal processing (DSP) can bring significant changes to the architecture and management of optical networks through:

- coherent systems with DSP capability
- simplified optical line systems
- Increased system margin and spectrum usage

The concept of a **filterless optical network** has been introduced as an attempt to reduce the capital cost of agility while maintaining (improving) the operational advantages of an agile network.

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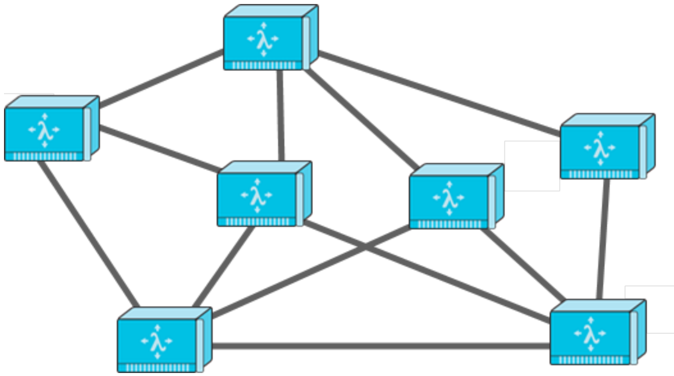
What have we learned on filterless optical networking?

- Cost-effective network architecture
- Agility can be realized but with some trade-offs
- Promising approach for software defined networking (SDN)
- Inherently suitable for elastic optical networking
- Trialed and deployed by network operators

Outline

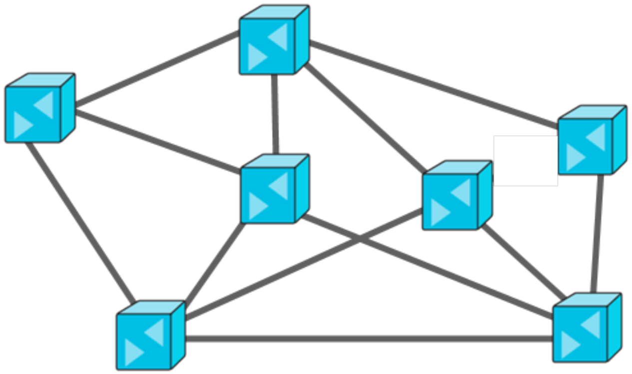
- Introduction
- Filterless network concepts and advantages
- Performance analysis and design trade-offs
- Challenges with filterless optical networks
- Conclusions

Contrasting active photonic switching and filterless photonic networks



ROADM-based networks are created using

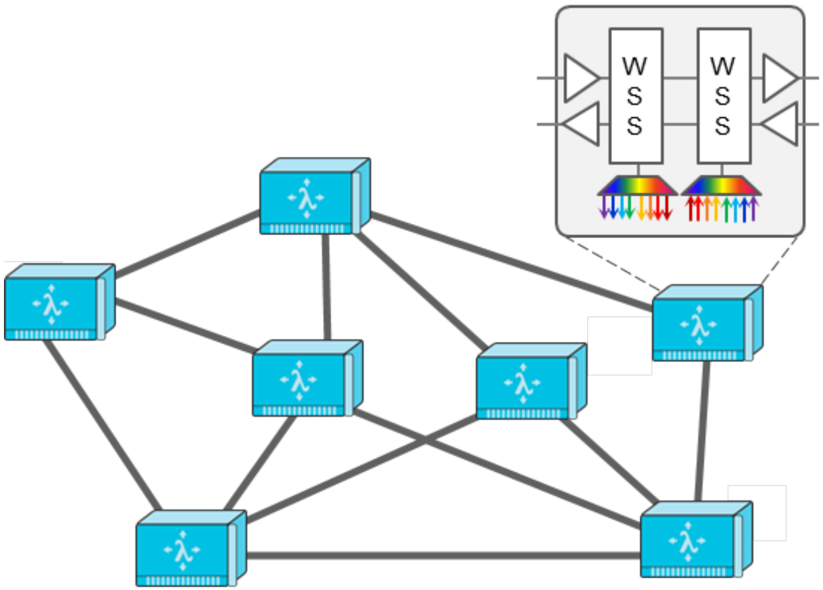
- **Tunable coherent transceivers**
  - Simplified link engineering
  - Fiber impairment compensation
  - Selectivity
- **Wavelength selective switches (WSS)**
  - Wavelength add-drop at terminals
  - Wavelength switching at intermediate sites



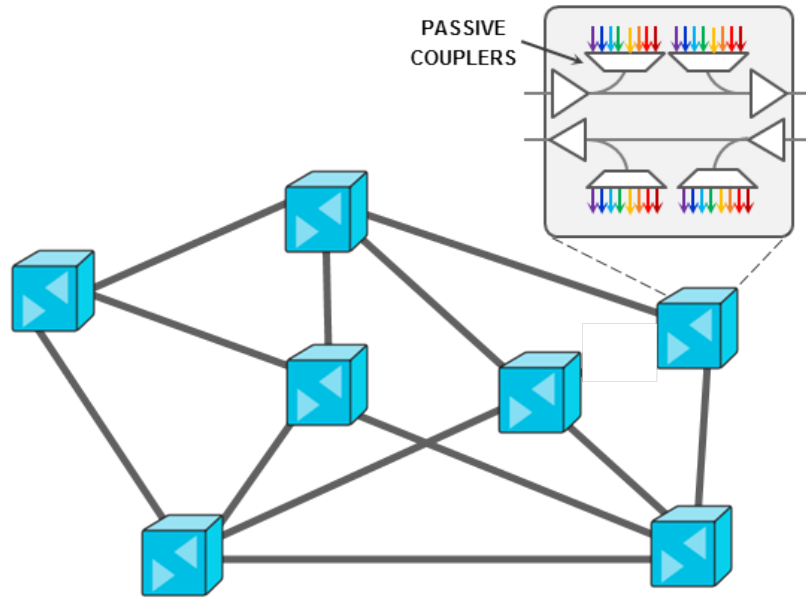
Filterless networks are created using

- **Tunable coherent transceivers**
  - Simplified link engineering
  - Fiber impairment compensation
  - Channel selectivity
- **Passive optical splitters/combiners**
  - Wavelength add-drop at terminals
  - Fiber interconnection at intermediate sites

Active photonic switching and filterless node architectures



Active switching architecture

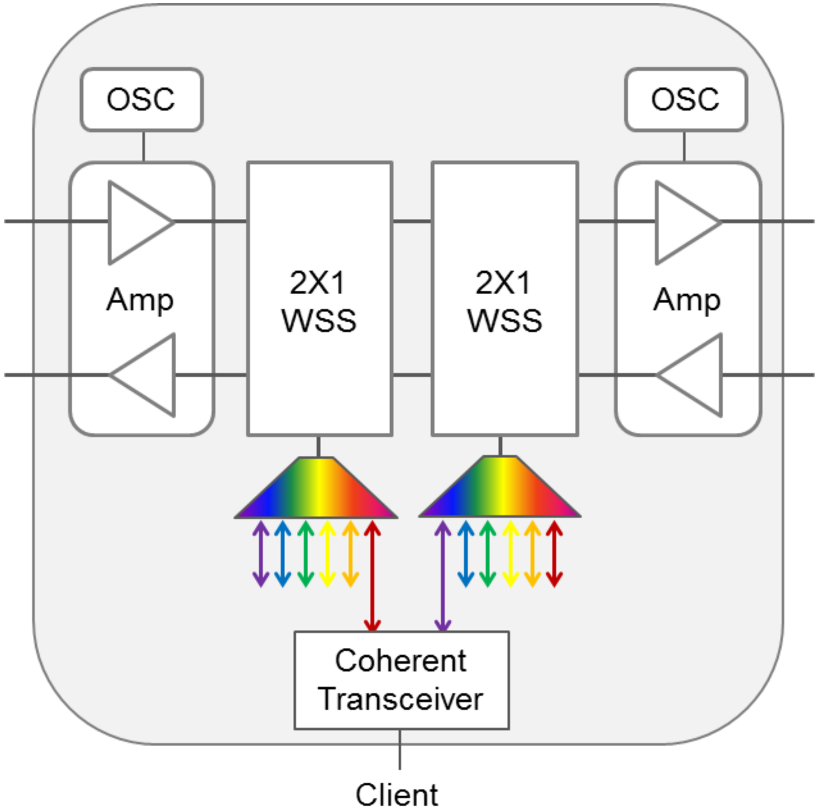


Filterless network architecture

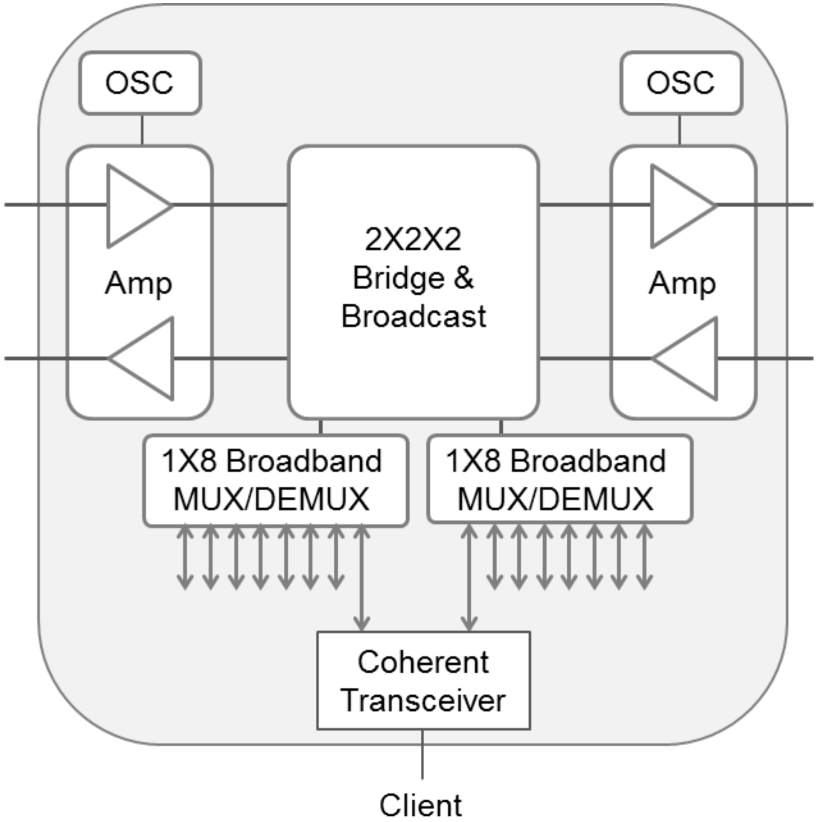
The elimination of active switching and filtering components creates a broadcast and select architecture in which the agility is provided at the edge terminals by the coherent transceivers.

Example - add/drop node comparison

Conventional node architecture
2-Degree 50-GHz / 100-GHz ROADM



Filterless node architecture
2-Degree OADM



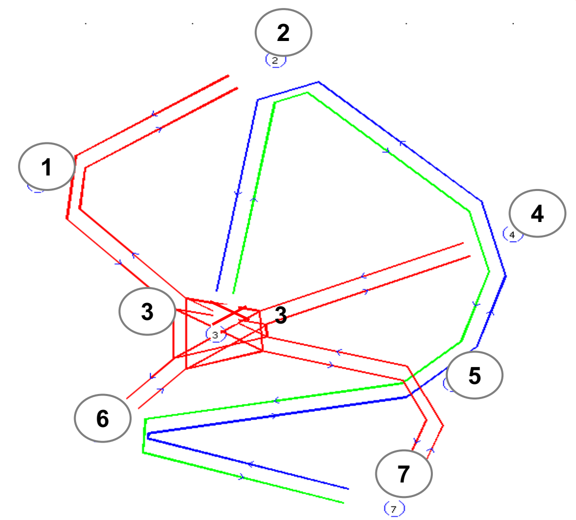
Advantages of filterless networks

- **Removal of WSS elements**
  - → simplified optical line systems
  - → Lower cost and footprint
  - → Reduced power consumption
  - → Improved robustness and mean time between failures (MTBF)
  - → Simplified impairment-aware design (and SDN control more straightforward)
- **Gridless architecture**
  - → Elastic optical networking
  - → Dynamic spectrum allocation
  - → Colorless node operation
  - → Transition from fixed-grid at minimal cost
- **Passive broadcast and select fiber trees**
  - → Multicast traffic support
  - → Easier network planning
  - → Simpler and faster connection establishment
  - → Key enablers for multilayer networking

Filterless network design

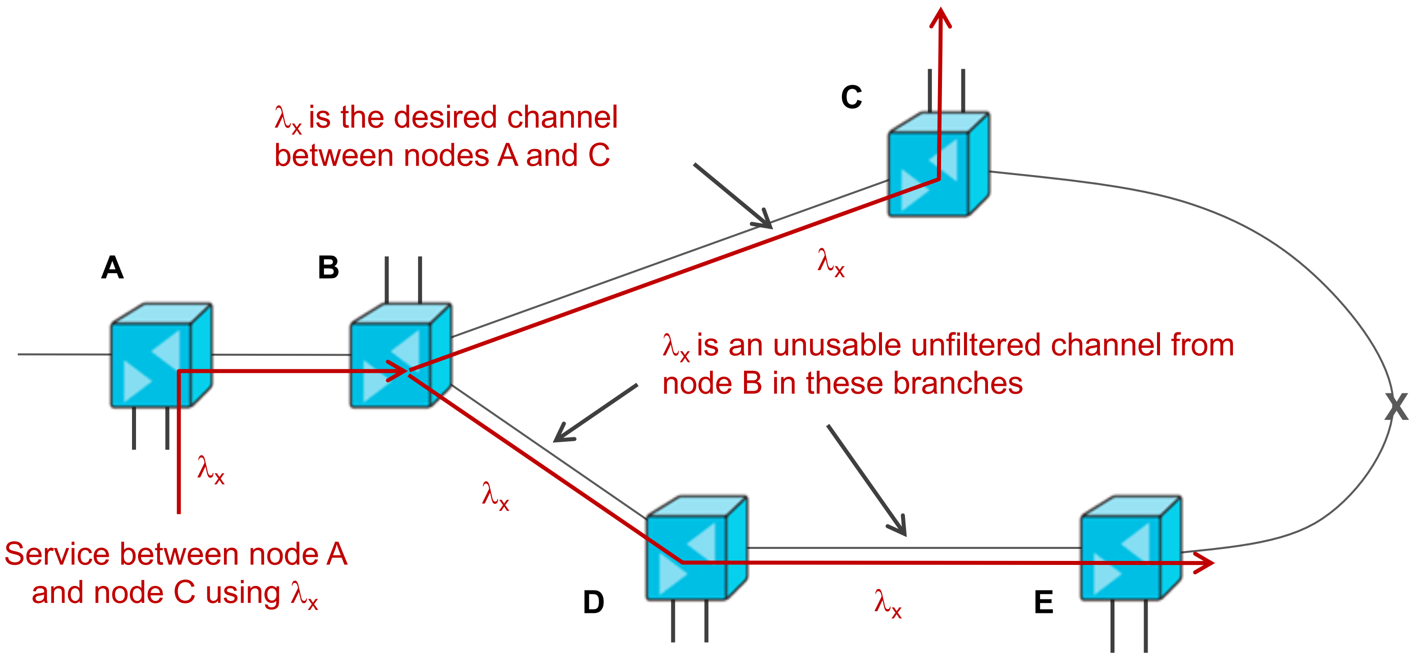
Two-step approach used:

- **Step 1**. Genetic algorithm applied to construct sets of fiber trees based on capacity demand and fiber topology.
  - Network connectivity created by using passive splitters and combiners at each network node.
  - Fiber tree design subject to constraints: network connectivity, laser loop avoidance , system reach.
- **Step 2**. Static shortest-path routing over the fiber tree performed and wavelength assignment made using graph coloring metaheuristic.



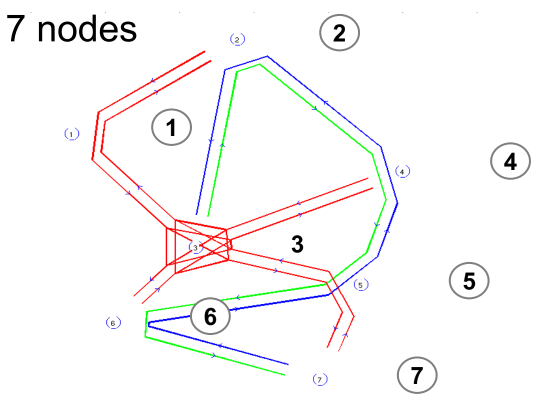
Filterless solution example with 3 fiber trees

Design constraints in filterless networks

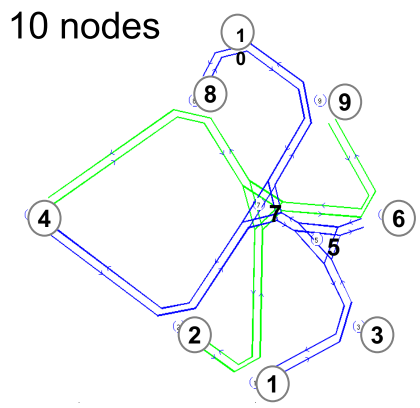


- Fiber-tree length is limited due to system reach and noise funneling
- Utilization is reduced due to propagation of unfiltered channels blocking channels in alternate paths
- Closed loops are disallowed to avoid laser effects in optically amplified links

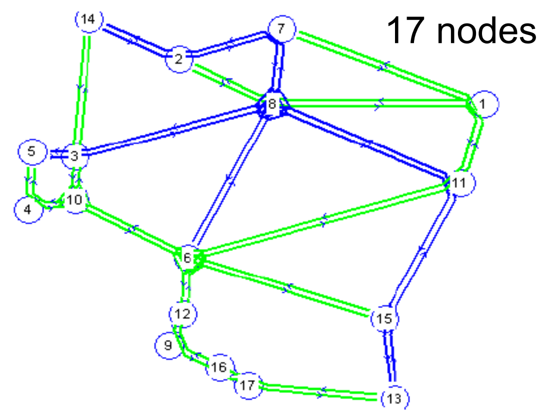
Terrestrial network comparison



Three-fiber-tree solution



Two-fiber-tree solution

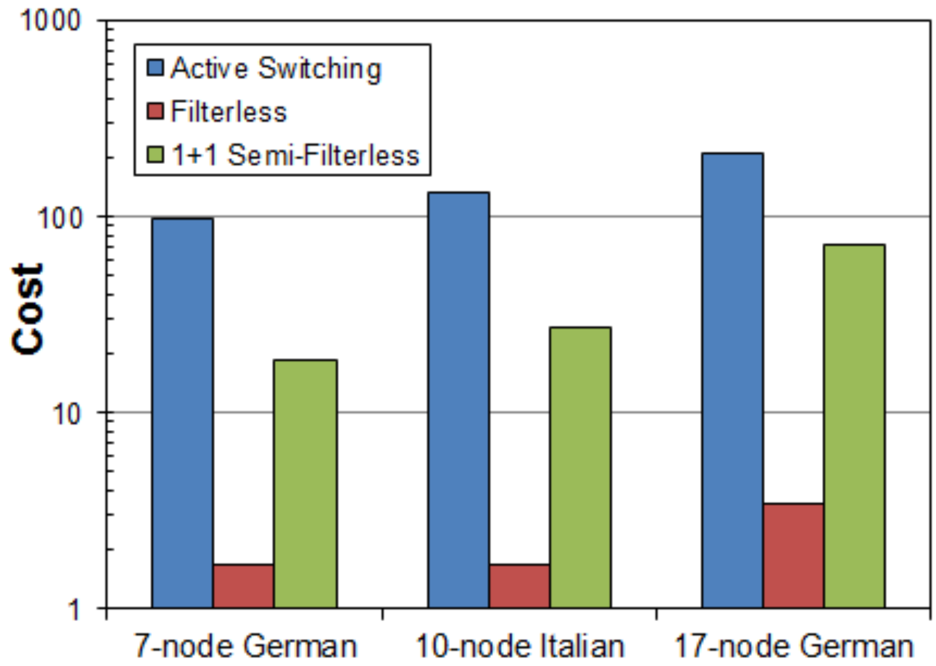


Two-fiber-tree solution

	Active	Filterless	Active	Filterless	Active	Filterless
Relative cost of extra components	92	0.3	123	0.4	194	1.0
Wavelength count for equal traffic demand	30	37	22	28	56	88

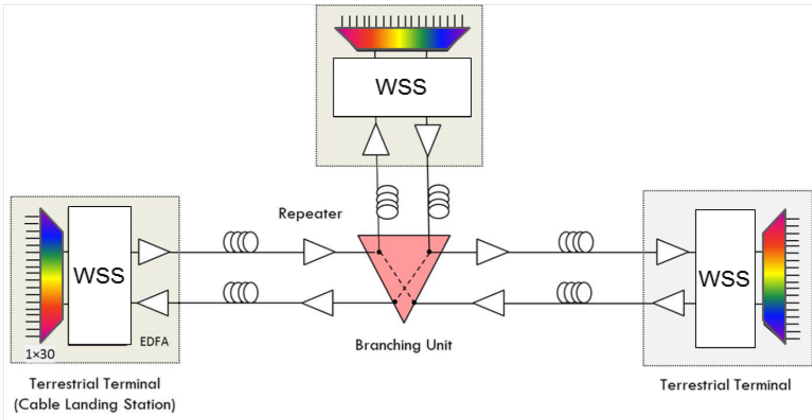
- Significant savings due to replacement of switching and filtering elements
- Magnified wavelength consumption due to unfiltered channels

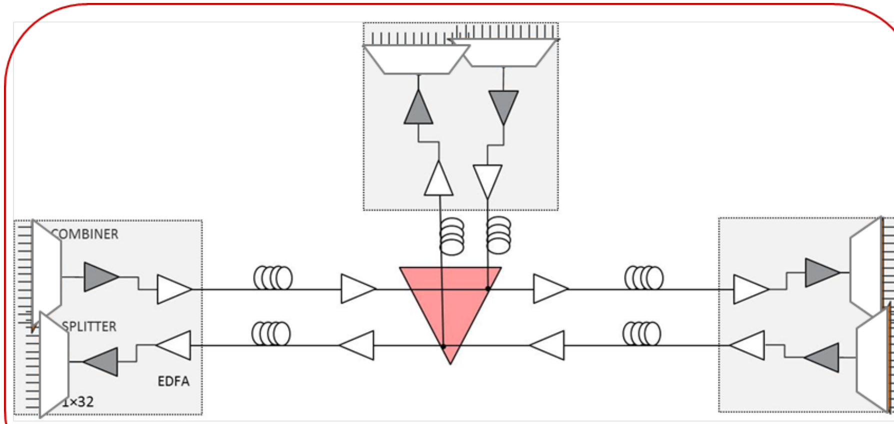
Comparative cost analysis



- Filterless networks can be deployed at a fraction of the cost of ROADM-based networks.
- Semi-filterless networks (using wavelength blockers or colored fixed passive filters in algorithmically determined locations) can provide extra capacity and connectivity alternatives between nodes.

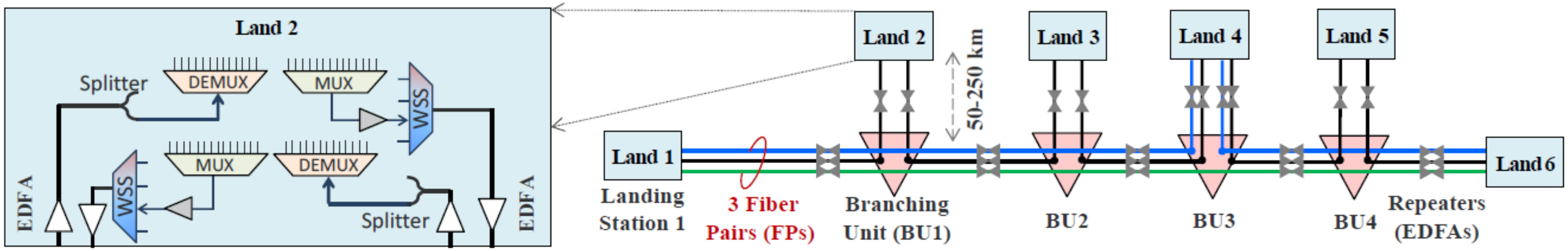
Filterless architecture for submarine networks



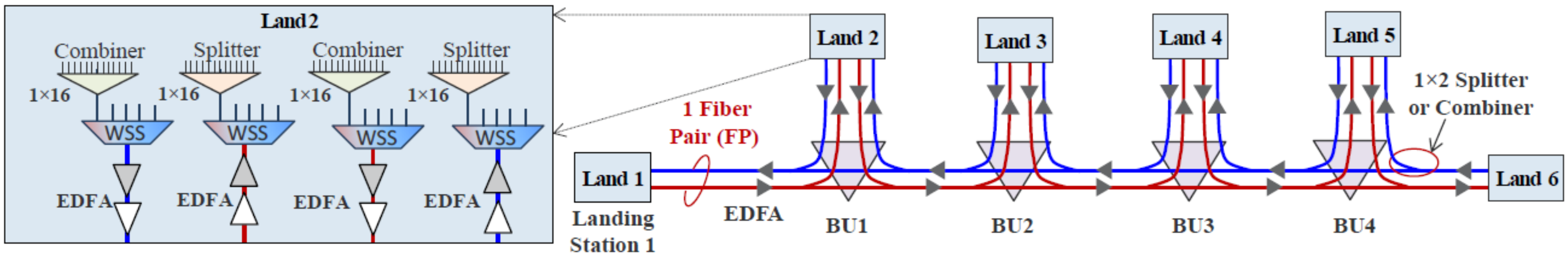


- Current submarine optical networks have limited flexibility, compared to terrestrial ROADM networks:
  - ROADMs can be deployed at the cable landing stations only.
  - Fixed or power-switched fiber joints, or fixed OADMs, are deployed at branching units.
- *Can the filterless architecture based on passive components already qualified for undersea applications be used for delivering agility in submarine networks?*

Filterless solution for a submarine network



Conventional three-fiber-pair network solution



One-fiber-pair filterless network solution

Submarine filterless networks: cost analysis

Cost and Wavelength Consumption of Conventional and Filterless Submarine Solutions

Solution	Traffic distribution	Fiber pair (FP)	Average demand length (km)	Number of transceivers	Number of wavelengths (shortest path)	Total terminal cost (a.u.)	Total line cost (a.u.)
Conventional	Dedicated fiber (realistic case)	Black	3,612	58	16		
		Green	7,900	28	14		
		Blue	5,423	52	24		
			Total :	138	24	29.92 + 4	18,330
	Distributed over 3 FPs (ideal case)	3 FPs	5,188	134	24	29.92	18,330
Filterless	Total traffic	1 FP	5,184	134	67	18.72	16,113
		3 FPs	5,184	134	23	56.16	18,905

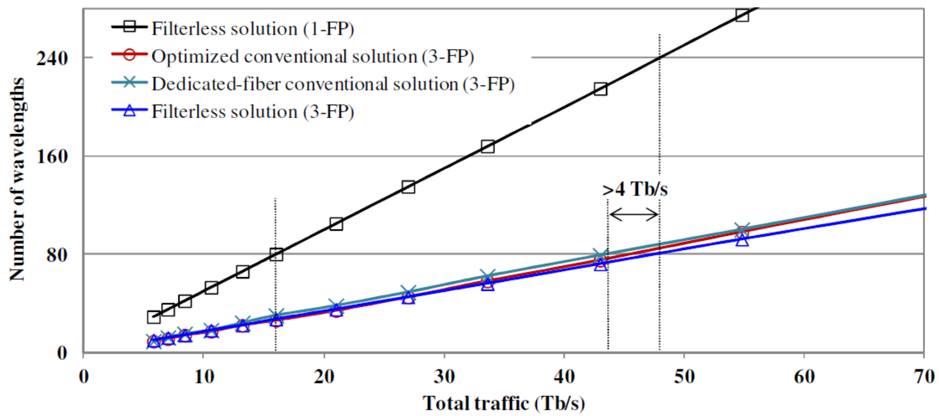
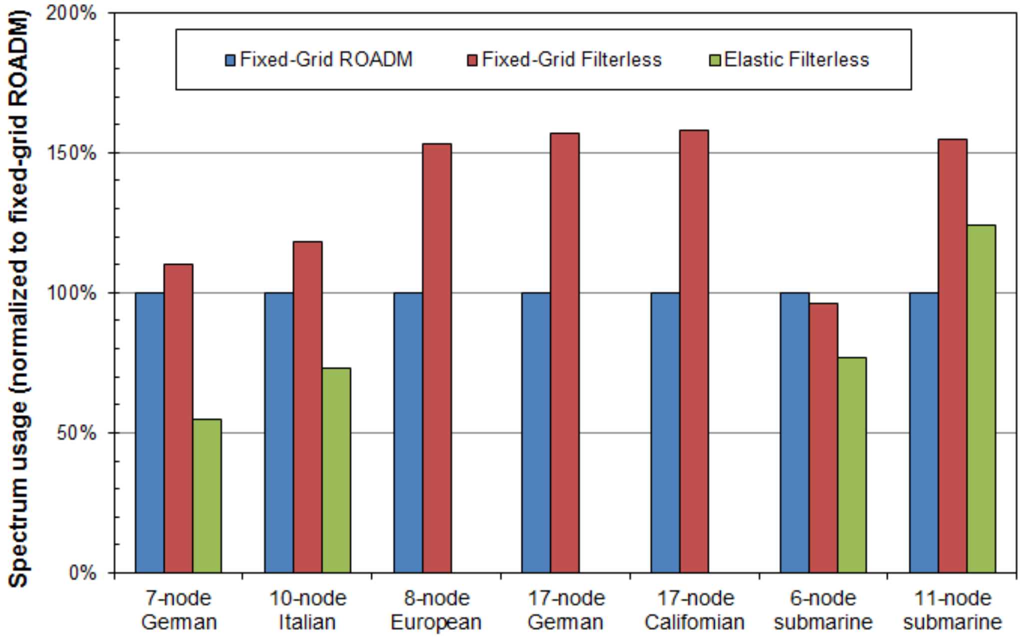


Fig. 3 Capacity limits of the filterless and conventional submarine solutions.

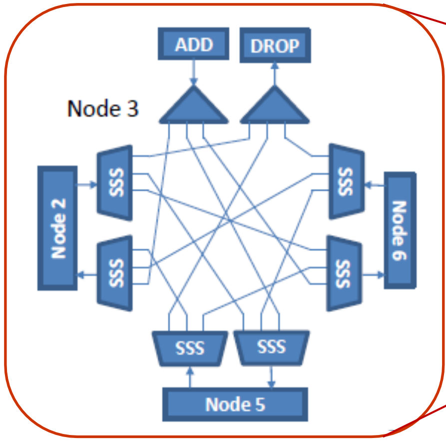
The filterless technology can reduce the terminal costs by 30-44% and the line equipment cost by 11-12% when compared to conventional submarine networks where WSSs can be deployed only at the cable landing stations.

Wavelength or spectrum consumption in filterless optical networks

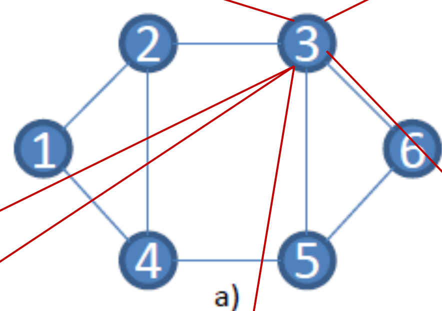


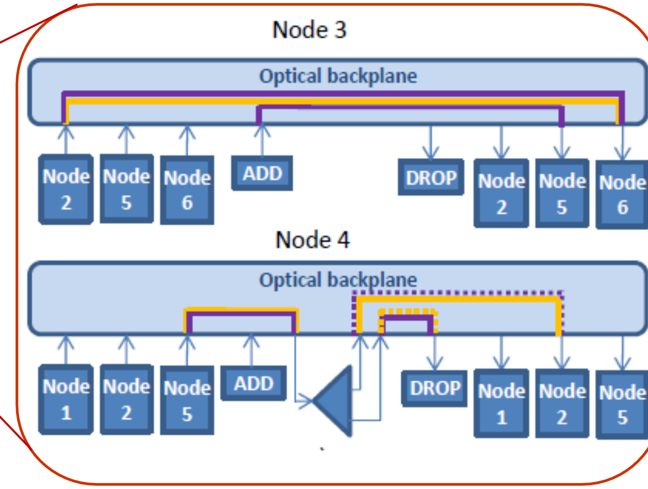
- Filterless solutions are good for networks with small number of nodes (≤ 10 -12) and size (with respect to system reach), as well as good connectivity (≥ 0.8) and high average nodal degree (≥ 3.0).
- Additional 20-30% savings in spectrum consumption (at minimal upgrade cost) are possible through flex-grid operation in filterless networks.

Programmable filterless network architecture

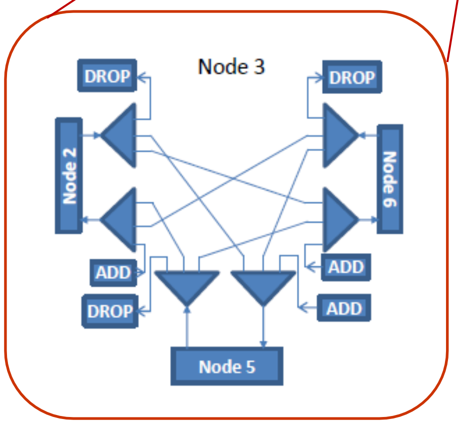


ROADM node

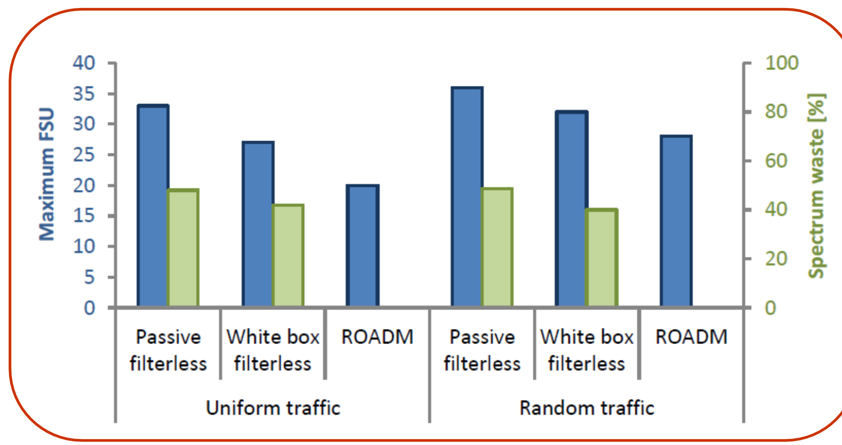




White box filterless node

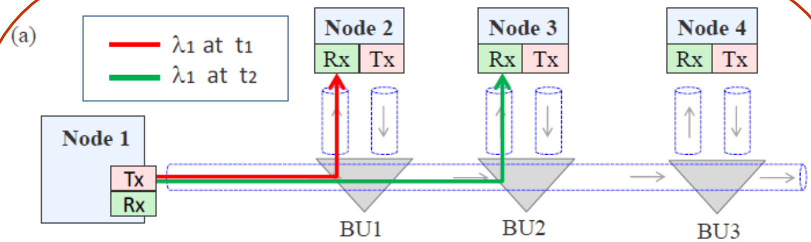


Filterless node

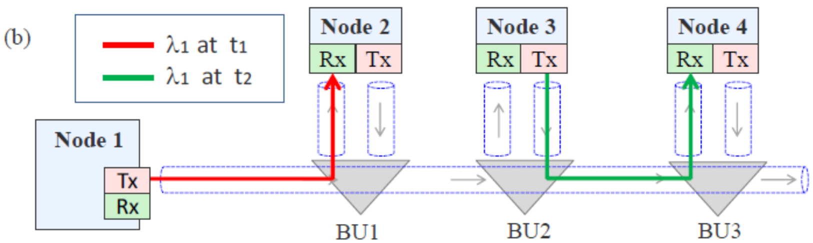


A programmable filterless network architecture based on optical white boxes can reduce the spectrum consumption at a lower cost than ROADM-based approaches.

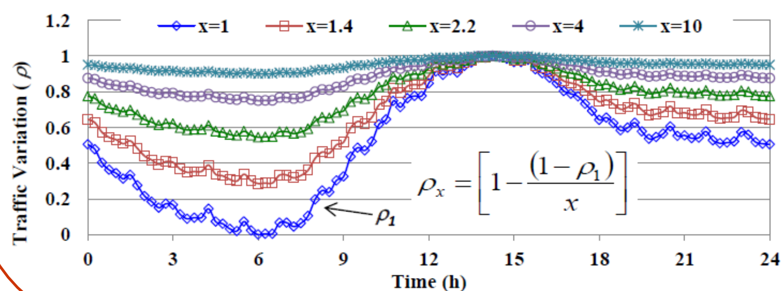
Dynamic network resource allocation scheme

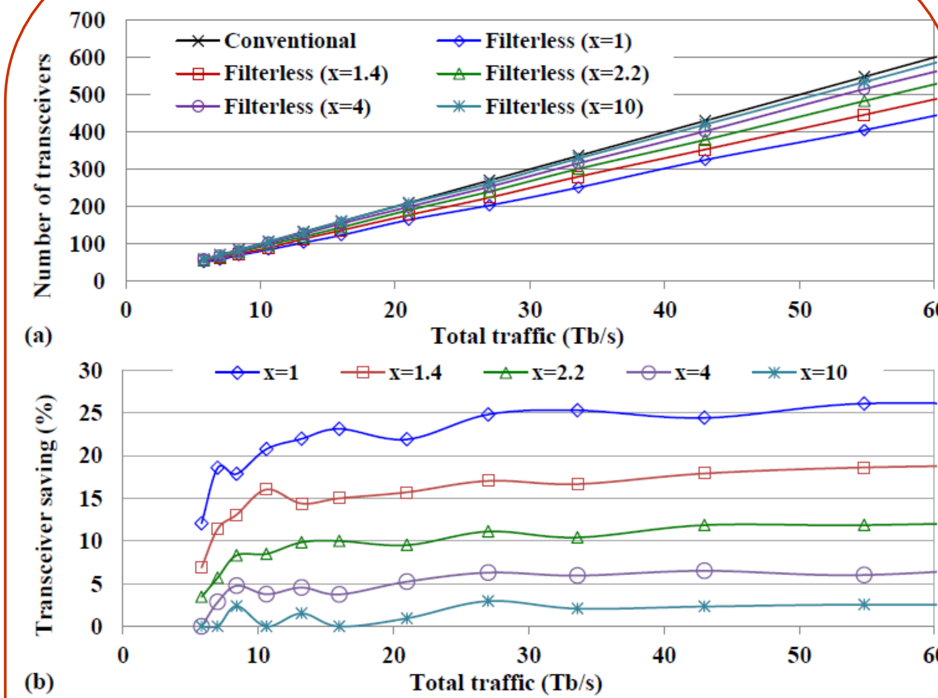


Transceiver and wavelength saving



Wavelength saving





11 and 17% of transceivers can be saved when x varies between 1.4 and 2.2.

Filterless networks can enable significant transceiver and spectrum savings through dynamic resource allocation in long haul networks with time-varying traffic load.

Challenges with filterless networks

Integrated control

→ Global network view is needed to understand blocking from unfiltered channels.

→ *Best solved using an external (SDN/PCE) control system*

Physical aspects

→ Removal of per channel power adjustment in WSS can cause optical power management issues and potentially limit fiber tree size and optical reach.

→ *Can be mitigated by adjusting individual channel launch power levels.*

→ Optical loops must be avoided in creating the fiber trees to prevent laser effects.

→ Noise funneling due to absence of filtering needs to be taken into account in determining receiver penalty.

Security

→ Security can be considered as a concern due to the broadcast architecture.

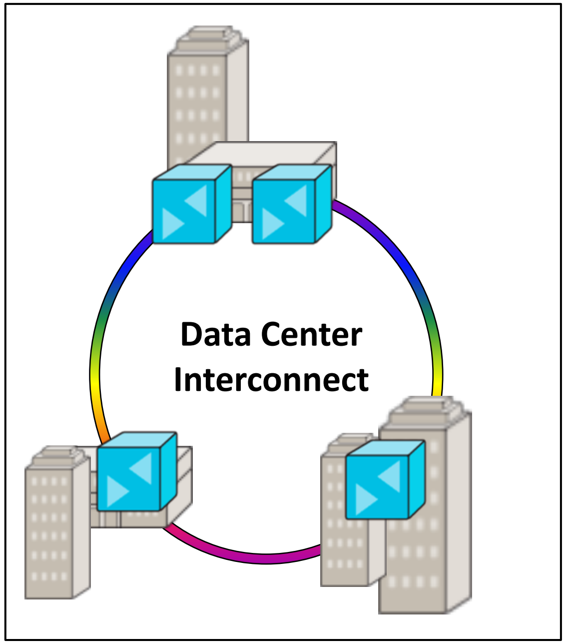
→ *Can be addressed by using data encryption with deciphering key exchange and dynamic distribution of propagation impairment compensation between transceiver pairs.*

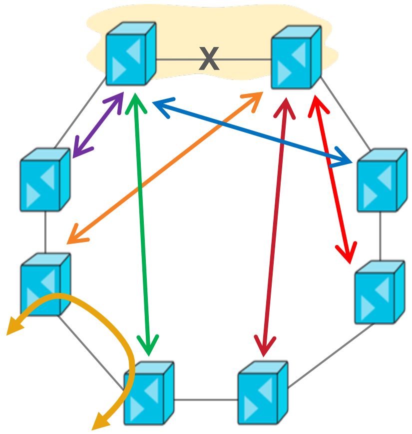
Summary

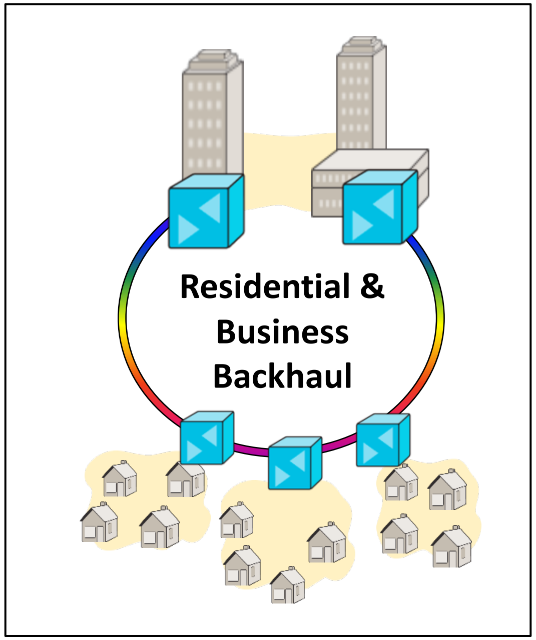
Characteristic	Metro – Regional – Core				Submarine				Backhaul – Distribution			
	Active		Filterless		Active		Filterless		Active		Filterless	
Demand relative to network capacity	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Agility	●●	●●	●●	● (yellow)	●●	●●	●	● (yellow)	●	●	●	●
Reliability	●	●	●	●	●	●	●	●	●	●	●●	●●
Operations	●	●	●	● (yellow)	●	●	●	● (yellow)	●	●	●	●
Spectrum consumption	●●	●●	●	● (red)	●	●	●	● (yellow)	●	●	●	●
Solution complexity	○	●	●●	● (red)	○	●	●	●	○	○	●●	●●

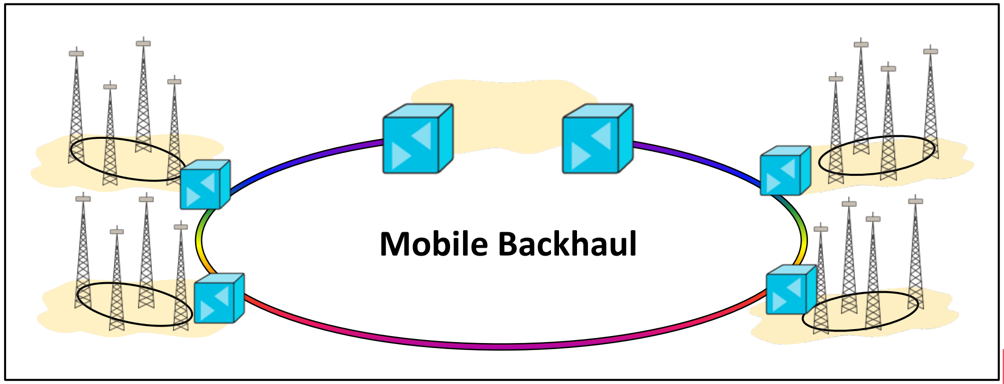
Filterless solutions perform well in metropolitan, regional and core applications when the demand is relatively low compared to the network capacity.

Applications









Conclusion

Core mesh networks

→ First in cost and functionality is good

→ Capacity constrained compared to ROADM-based networks

→ *Deploy with filterless and upgrade with ROADMs as capacity increases?*

Submarine networks

→ Promising economics – needs further practical evaluation

Metropolitan and aggregation networks

→ Valuable network technology

Thank you!

Questions?

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