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.
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

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

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.
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

<table>
<thead>
<tr>
<th></th>
<th>Active</th>
<th>Filterless</th>
<th>Active</th>
<th>Filterless</th>
<th>Active</th>
<th>Filterless</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative cost of extra components</td>
<td>92</td>
<td>0.3</td>
<td>123</td>
<td>0.4</td>
<td>194</td>
<td>1.0</td>
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<tr>
<td>Wavelength count for equal traffic demand</td>
<td>30</td>
<td>37</td>
<td>22</td>
<td>28</td>
<td>56</td>
<td>88</td>
</tr>
</tbody>
</table>

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

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 ($\leq 10 - 12$) and size (with respect to system reach), as well as good connectivity ($\geq 0.8$) and high average nodal degree ($\geq 3.0$).
- Additional 20-30% savings in spectrum consumption (at minimal upgrade cost) are possible through flex-grid operation in filterless networks.
A programmable filterless network architecture based on optical white boxes can reduce the spectrum consumption at a lower cost than ROADM-based approaches.
Filterless networks can enable significant transceiver and spectrum savings through dynamic resource allocation in long haul networks with time-varying traffic load.

11 and 17% of transceivers can be saved when x varies between 1.4 and 2.2.
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 funnelling 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.*
Filterless solutions perform well in metropolitan, regional and core applications when the demand is relatively low compared to the network capacity.
Applications

Data Center Interconnect

Mobile Backhaul

Residential & Business Backhaul
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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