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Filterless Optical Networks: A Unique and Novel Passive WAN Network Solution

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Abstract
The concept of a Filterless optical network is introduced and validated. This passive WAN network solution is based on advanced transmission technologies and passive optical interconnections between nodes. The study looks at the cost reduction impact of this unique WAN architecture through a case study.

Introduction

The use of advanced modulation formats combined with electrical compensation technologies can permit significant changes on the architecture and management at the physical layer level of future optical networks through: Dispersion Compensating Module (DCM) - less optical line systems for up to 80 000 ps/nm dispersion compensation; tunable transceivers, an enabling technology for optical networks of broadcast & select type; increased system margin, which translates into improved flexibility for optical network design. This paper introduces the novel concept of a "Filterless" network architecture and looks at its cost reduction impact.

Filterless optical networks

Recent developments of optical wavelength selective switch (WSS) and optical cross-connects (OXC) and advances in the optimization methods for complex optical multi-branch optical system, have rendered possible the realization of long and ultra-long haul transparent networks. National scale all-optical networks are being deployed currently. But, in some cases, this first wave of deployment is limited by transmission impairments of optical subsystems. In current, optically agile wide area network (WAN) architectures, the agility is delivered at the network nodes. This agility is engendering additional system and network capital costs. In several cases, the additional capital costs are compensated by the operational benefit of the delivered agility.

In this paper we propose to examine an attempt to minimize the additional capital cost driven by the agility while maintaining (improving) the operational advantages of an agile network. We propose a passive network topology that eliminates or minimizes the active photonic reconfigurable component count in the optical line system. This alternate approach reduces the installed first cost (IFC) of the network by transferring the cost to the transmit/receive function at the terminals. Taking advantage of recent transmission technology breakthroughs such as electronic dispersion compensation[1], advanced modulation formats and tunable transceivers, the proposal takes on the premises that the need for agility can now be provided by wavelength tuning at the transmitter and wavelength discrimination at the receiver much like agility is achieved in radio networks.

The Filterless concept is a unique and novel passive WAN network solution based on the use of passive splitters and combiners for interconnecting fiber links. The resulting network does not require optically reconfigurable components as well as any coloured components, hence the name Filterless. The resulting network architecture can be expected to bring significant advantages such as lower cost, easiness of maintenance and reconfigurability, as well as good resilience and excellent multicast capabilities. The study looks at the cost reduction impact of deploying an optical network in which the photonic switching elements have been replaced by passive optical splitters and combiners.

Filterless network problem

A Filterless network is based on the construction of a set of physical optical links between all nodes of the network. Since all nodes are optically connected to each other, real-time delay sensitive broadcast and multicast transmissions are facilitated. The obtained Filterless physical topology depends on the splitters and combiners configuration at each node. As in a classical Routing and Wavelength Assignment (RWA) problem, the Filterless problem can be partitioned in two parts: (1) establishing the fiber connections; (2) routing and assigning the wavelengths according to the traffic demand.

Virtual topology design problem

A Filterless optical network can be represented by a graph G = (V, E) with:

- V: set of N network nodes;
- E: set of directed arcs connecting the nodes;
- Weight of the arcs representing the signal attenuation.

Table 1 summarizes the input parameters, the variables, the constraints and the optimization objective.

A fiber connection algorithm was developed for interconnecting the nodes using optical splitters and combiners without creating closed loops in order to avoid laser effects. Splitters and combiners were also used to add and drop wavelengths at each node. An algorithm was developed for routing and assigning the wavelengths according to the traffic demand between node pairs.

Table 1

Input parameters	Network physical topology
	Traffic matrix
Variables	λ assignment to nodes for a traffic stream launched on a given color
	Number and positioning of optical splitters, combiners, amplifiers, and reconfiguration devices
Constraints	Signal SNR vs distance
	No lasing loop at any given λ
	Maximum of 80 wavelengths per fiber
	Traffic requests
Objective	Minimize the overall network cost

Case study

A 7-node subset of German optical network[2] was used to validate the Filterless network concept and to perform a comparative cost analysis with respect to opaque and photonic switching network topologies. The traffic matrix[2], expressed in number of 10 Gb/s wavelengths per link, can be found in Table 2.

Table 2

Node	A	B	C	D	E	F	G
A	-	6	3	2	3	5	2
B	6	-	6	3	6	9	4
C	3	6	-	2	3	4	2
D	2	3	2	-	2	2	1
E	3	6	3	2	-	4	2
F	5	9	4	2	4	-	3
G	2	4	2	1	2	3	-

Filterless solution example

A Filterless solution example on the 7-node reference network is shown in Figure 1. By using splitters and combiners, physical optical links are created between nodes. Splitters and combiners are also used at each node to add and drop wavelengths.

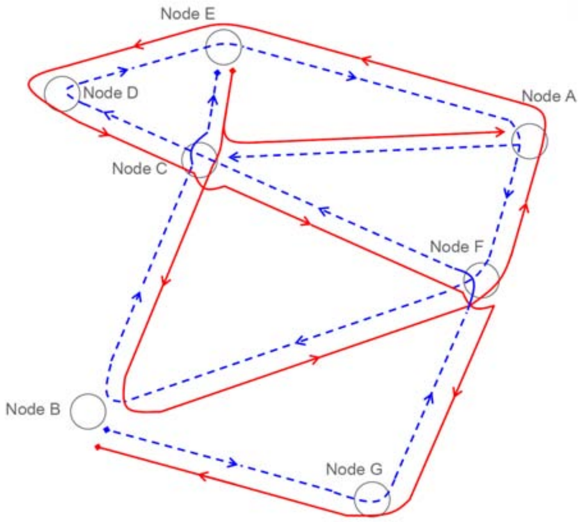

Figure 1

Once the fiber connection matrix determined, wavelengths were assigned to meet the traffic requirements between all node pairs. For cost comparison purposes, an opaque solution based on OEO regeneration at every node and an active photonic solution based on the use of an optical reconfiguration device were also considered.

Performance evaluation and comparison

The network cost was evaluated by computing the cost of extra components added to the network. The results are shown in Table 2. Although an active photonic network solution is already a very good improvement over an opaque network solution, a Filterless network solution is even more interesting with a further cost reduction by a factor of 47.

Table 2

Network solution	Extra Components	Quantity	Unit cost (a.u.)	Total cost (a.u.)
Opaque	Transceivers	130	1	130
	Total Added Cost			130
Active photonic	Optical reconfiguration device	9	2	18
	Optical amplifiers	18	1	18
	Total Added Cost			36
Filterless	Optical splitters	38	0.02	0.76
	Total Added Cost			0.76

In a Filterless network solution, all the traffic demands can be met with 148 wavelengths, corresponding to 296 transceivers. The added cost of the opaque network solution comes from the 130 extra regenerating transceivers while the added cost in an active photonic network comes from the use of 9 optical reconfiguration devices and associated 18 optical amplifiers (one per direction) to compensate for their insertion loss.

Conclusions

This paper presented a novel concept of Filterless optical network. The concept has been validated through a case study. This case study is intended for illustrative purposes only and might not take into account all factors affecting the results like deployment scenarios, actual growth rate or competitive pressure. A Filterless network is found to be more cost effective and more reliable at the expense of greater wavelength utilization. Consequently, the bandwidth/fiber efficiency of a Filterless network is lower than that of opaque and active photonic network. With the increasing availability of wavelengths (1000 to 2000 wavelengths per fiber forecasted in 5 to 7 years) the reduced bandwidth efficiency issue is not seen as a major issue. The presented solution examples were obtained from a broadcast traffic matrix. Because every node of the Filterless network is multicast-capable, the bandwidth efficiency is much higher in the case of multicast transmission.

References

1. J. McNicol et al., Proc. OFC 2005, paper OThJ3.
2. A. Betker et al., MultiTeraNet Report, July 2003.