Optical filter type influence on transparent WDM network's size

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The number of nodes (size) of an optical transparent network-island is limited according to Bit Error Rate (BER) estimation of the optical signals that cross transparently the optical nodes. Three optical add-drop multiplexer – based on different filter technology and therefore different architecture – is cascaded and compared by BER-degradation estimation in a special network architecture environment.

Technologies and new concepts for optical networking are advancing rapidly as a result of notable progresses in all-optical technologies and emerging bandwidth greedy applications. Telecom operators are forced, in consequence, to adapt in the near future, their deployed optical fiber communication systems so as to cope with these challenging advances. Deploying "islands" wherein the optical signals benefit from the advantages of transparency may be more feasible than replacing totally the current conventional digital systems by all-optical technologies.

In this paper the size of a metropolitan "transparent island" (the "island" is in the non transparent network "ocean") is assessed by computer simulations depending on the architecture of the all-optical add/drop multiplexer (OADM) used. In effect, three architectures of OADM were on focus to compare between their performances after cascading several optical nodes. Optical signal quality represented by BER estimation is used as the metric that determines the size of a transparent island.

To the best of my knowledge, this is the first time an estimation of the size (hop number) of transparent islands is given depending on applied optical devices used and the target BER.

Three optical filter types

Multiplexing and demultiplexing functions both employ narrowband filters, cascaded and combined in other ways to achieve the desired result. Particular techniques that have been used to perform such filtering include thin film filters, fiber Bragg or bulk gratings and integrated optics (AWG).

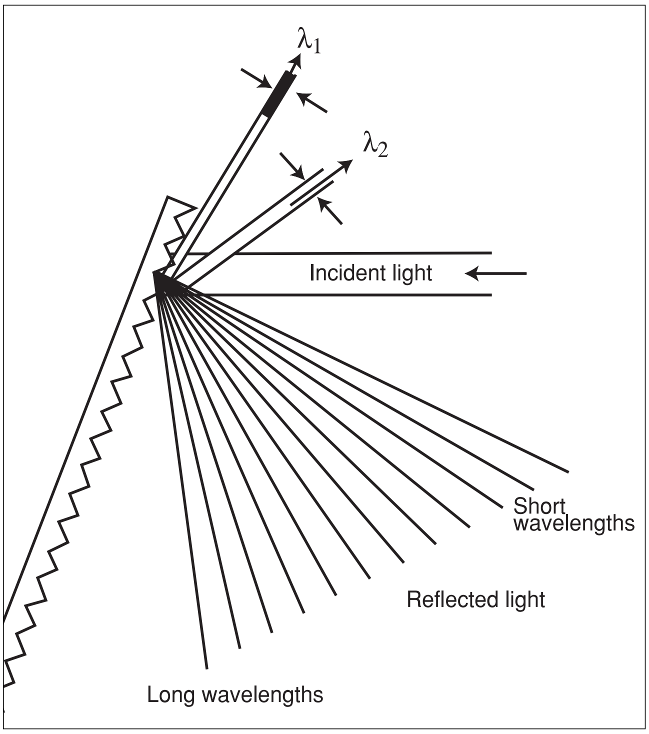
Diffraction grating (mux)

A bulk-optic diffraction grating [1] reflects light at an angle proportional to wavelength and the underlying physical principle is constructive and destructive interference.

For each wavelength of incident light, there is an angle for which light waves reflecting from individual grating lines will differ in phase by exactly one wavelength-spacing. At this angle, the intensity contribution from each line will add constructively, so this will be the angle of maximum transmission for that specific incident wavelength.

Designing a mux or demux using a diffraction grating is a matter of positioning the input and output optics to select the desired wavelength. Although they are difficult to manufacture and expensive, devices based on diffraction gratings have an insertion loss that is essentially independent of the number of channels, rendering this technology one of the more promising for high channel count systems. However, polarization control requires critical attenuation.

Fig. 1. Bulk diffraction grating



Arrayed Waveguide Grating

AWG [2,3] is also known as phased-array gratings (PHASARS), or waveguide grating routers (WGR). In the contrary of bulk grating filter, AWGs are wavelength insensitive (in a given range of optical frequencies of course) and therefore periodical. The performance of AWG is similar to multiplexer/demultiplexers, as it can separate and also multiplex different wavelength which are propagating in a SM fiber. Just the ways – how they do it – differ.

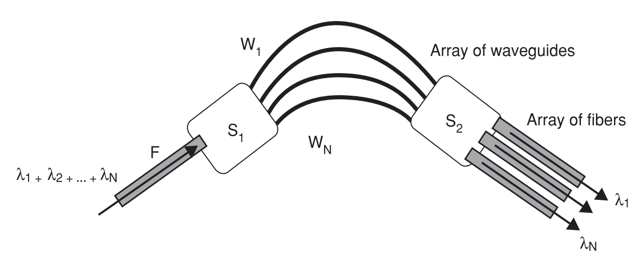


Fig. 2. Arrayed Waveguide Grating

AWG is based on interferometry. The architecture of AWG is depicted in *Fig. 2.* The incoming beam-carrier-fiber guides several different wavelengths to the first cavity (S_1), which is coupled to an array of waveguides. As many wavelength there are in the fiber, as many waveguides are set up in S_1. The lengths of these waveguide-fibers are different. Because of the optical lengths are not the same, wavelength-dependent phase shifts can be achieved in the second cavity (S_2), where an array of fibers is coupled. The phase difference of each wavelength interferes in such a manner that each wavelength's intensity contributes maximally at *one* of the output fibers. Considering that all points on the emerging wavefront must have the same phase (modulo 2π), two adjacent optical path form the incident wavefront to the emerging wave front must have optical path length difference. This difference is equal to an integer multiplied with the wavelength.

AWGs can be used as all optical routers too when not only one input port is manufactured. Considering a 2x2 AWG with two inputs and two output port both fibers carries λ_1 and λ_2. Thus the input on A port is λ_{1a} and λ_{2a} at input B λ_{1b} and λ_{2b}. AWG routers are able to interchange same wavelength without mixing the containing modulation. Therefore upper output port can transmit λ_{1a} and λ_{2b} while second output λ_{1b} and λ_{2a}. These type of routers are very promising candidates in future transparent networks, moreover a special network architecture is under patent request in the US for the Technical University of Berlin, where these type of routers play the most important role in network architecture (Ringostar).

Fiber Bragg Grating

These components are filters, which let all wavelengths through with low attenuation, expect one, which it is designed for and will be reflected. FBG can be tunable or fixed. In contrast of its name, it is not a grate. It is called so after all because light behaves like it would have met with a grating.

The reflection of a specific band of wavelength can be reached by periodical refractive index changes in the core of the fiber. This is what light feels like a grating. There are at least two technologies to create it. One is more popular and is called: UV technology. The Germanium doped core is exposed by an ultraviolet pattern, which causes interference, and also refractive index periodical variation in the core. This pattern is in strong relationship with the selected wavelength. Different patterns are for different wavelength to reflect. The longer the FBG is manufactured, the narrower the reflected wavelength-band is. On the other hand the longer an FBG is manufactured, the higher its insertion loss is.

Different FBGs can be cascaded to reflect more than one wavelength. To combine an FBG with a circulator it is easy to drop wavelength from the WDM fiber. Another application is to use FBG's for chromatic dispersion compensation. These types are known as 'chirped FBGs' and have the grating linearly variable "chirped".

Architecture of the optical nodes

The test bed features an ASON/GMPLS network formed by a transport plane of three reconfigurable optical add/drop multiplexers (OADM), a control plane and a management plane to allow for dynamic and intelligent optical channel provisioning.

Three different implementation of an OADM architectures are considered. The first one uses a multiplexer and a demultiplexer (based on bulk gratings) in addition to a set of 2x2 optical switches, and the second one uses an AWG and a set of 2x2 optical switches, the third one 4 FBGs *(Fig 3)*. Eight ITU channels with 100 GHz (0.78nm) spacing can be allocated [from 193.0 THz (=1553.33nm) to 193.7 THz (=1547.715nm)]; however, up to four channels can be added/dropped locally within each optical node but in the simulation no channel has been dropped out at the nodes.

The investigation aim also to explore to which extent the all-optical test bed metro network can evolve to future extension and/or transparent interconnection with other test-beds.

Results and discussions

It is considered in the simulations [4], an optical signal traveling along several optical nodes in a metro optical network composed by one of the three described OADM architectures (based on the use of Mux/Demux or AWG or FBG architectures) with an EDFA pre-amplifier at each node and a fiber length between adjacent nodes of 35 km. All the components data introduced in the simulations are in accordance with the worst-case experimental data of the optical component's datasheets.

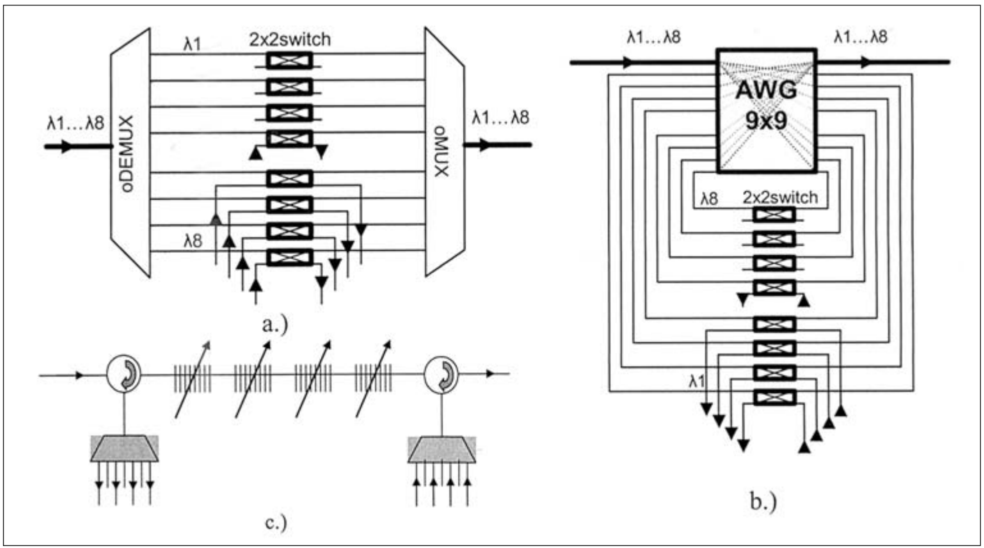


Fig. 3. OADM's architectures:
a. Diffraction grating (mux/demux) based; b. AWG based; c. FBG based

This is the "Variable Threshold Method" which is discussed in more details in ITU-T G.976 (1997) recommendation, and in the North American patent [7].

Fig. 5. shows the BER estimated values when the signals pass through a given number of optical nodes (we consider a limit of 10 nodes spaced by 35 km for our metropolitan optical network). Fig. 5. gives the extent of transparently crossed optical nodes versus the BER estimated value for each of the three OADMs architectures.

Mostly important for comparing between the three architectures, in our case, were the insertion losses of the FBG (2.8 dB) AWG (10 dB) and of the mux/demux components (4 dB) as the other data were similar in both cases. The optical signals, which are not to be dropped at a given node, undergo a double amount of attenuation due to the fact that they should be demultiplexed, first, and then multiplexed again at the passing through nodes.

The VPI program estimates the BER by the following equation:

$$BER = \frac{1}{2}\, erfc\left(\frac{Q}{\sqrt{2}}\right) \quad \text{where the} \quad erfc(x) = \frac{2}{\sqrt{\pi}} \int_{x}^{+\infty} e^{-t^2}\, dt$$

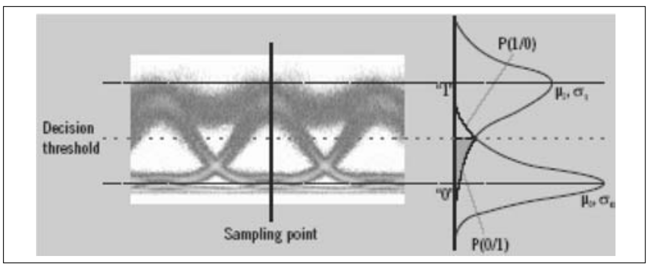
and Q is the quality factor [5].

The 'Q' factor is a measure of the digital signal eye aperture; it adopts the concept of S/N ratio in a digital signal and is an evaluation method that assumes a normal noise distribution [6] and can be calculated from the following formula:

$$Q = \frac{|\mu_1 - \mu_0|}{\sigma_1 - \sigma_0}$$

where in μ_1 is the average value of the logical '1' level and μ_0 of logical '0' level. The σ_1 and σ_0 are the standard deviation values of the noise distribution on the '1' and '0' rails, respectively as it is depicted on *Fig. 4*. By the variation of the decision threshold of the receiver diode, the sensitivity of the system can change. The estimation of the Q factor is based on this sensitivity change evaluation.

Fig. 4. An eye aperture is shown to illustrate the calculation of Q factor



After passing transparently 10 optical nodes, the optical signal quality decreases to 10^{-4} in case of the mux/demux (bulk gratings) based architecture, decreases to 10^{-6} in case of AWG based architecture, and decreases 10^{-9} in case of FBG based architecture of the OADMs.

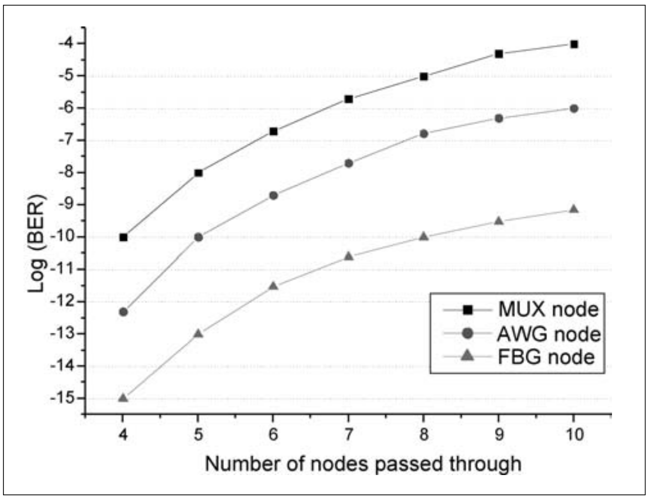


Fig. 5.
Number of crossed optical nodes vs. BER foreseen:
a. mux/demux based, b. AWG based, c. FBG based

If optical services were classified according to four categories, *Table 1,* in the limit of 10 optical nodes of a transparent island and according to Fig. 5., provisioning all services, even Premium services, which require the most stringent requirements of quality, could be expected for all OADM architectures (according to BER

Table 1.
Out-of-service criterion for different classes of services [8]

	Premium	Gold	Silver	Bronze
Out-of-service	Degraded BER=10^{-4}	Degraded BER=10^{-3}	Fault LOS	Fault LOS

estimated values). However, other criteria such as connection set-up times and recovery times should also be taken into account to actually ensure the provisioning of optical services.

On the other hand if BER were fixed to a higher quality level such as 10^{-9}, the situation is quite different for the three OADM architecture of the testbed, a transparent island based on mux/demux and AWG architecture would have a maximum reach of only four and five optical nodes, whereas for the FBG architecture, the transparent island would reach 10 optical nodes.

In case of 50 GHz channel spacing the BER estimation will give a bit worse result, especially at FBG node. This is due to that FBG node does not filter the incoming spectrum, while mux node and AWG node do it producing more or less the same result as in case of 100 GHz spacing.

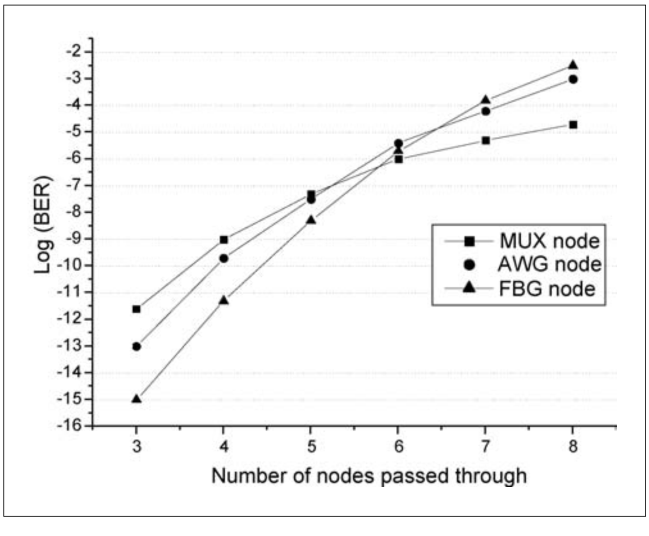
As the channels are closer to each other, the crosstalk and noise density is higher if there is no filtering when the light crosses an FBG node. Results based on this case are depicted on *Fig. 6.*

Conclusions

In the expectation of improving the cascading performances of all-optical components and systems, a migration path could be envisaged where in hybrid all-optical and opto-electronic technologies coexist. In this scenario, transparent “optical islands” would be conceived and could be bridged by 2R/3R regeneration systems. From an ASON/GMPLS network perspective [9], these “optical transparent islands” could be seen as different “domains” at the control and management planes to help distributing and/or partitioning the control and management tasks.

Correct sizing of these islands would be of prime importance for ensuring the desired SLS (service level specification) requirements (including quality measurement of BER).

Fig. 6.
Number of crossed optical nodes vs. BER foreseen when the channel spacing is 50GHz:
(a. mux/demux based, b. AWG based, c. FBG based)



In this paper, it has been demonstrated that the choice of the OADM architecture is a determinant factor in the size of an optical transparent island. In addition, for the considered cases, OADM architecture based on the multiplexers/demultiplexers and 2x2 optical switches is more advantageous than the AWG based architecture for enlarging the transparent island size.

It is worth noting that other reasons, besides technical aspects, may also contribute to limit the transparent islands’ sizes, such as regulation constraints, interoperability, cost and network management/control issues.

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