Architectures and components for metro DWDM networks

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Abstract: A Dense Wavelength Division Multiplexing (DWDM) system can be viewed as a parallel set of optical channels, each using a slightly different light wavelength (as defined in the ITU-T normative G.692), but all sharing a single transmission medium. Each signal is modulated by different data sources (text, voice, video, etc.) and travels within its own unique color band (wavelength). This new technical solution can increase the capacity of existing networks without the need for expensive recabling and can significantly reduce the cost of network upgrades. In the long-haul network DWDM has a clear value proposition because it affords customers a much cheaper way to expand capacity, whereas in metropolitan areas the DWDM technology can use passive components: this enables several technical capabilities such as protocol transparency that makes DWDM a viable solution to the new requirements of metropolitan networks.

Key-Words: metro DWDM, access network, OADM, protection mechanisms, optical network, OXC.

1 Introduction
Emerging demands for advanced, higher-quality communication represent a challenge to the operators of global public telephone networks. Originally designed to primarily carry circuit-switched voice traffic, these networks are now being asked to carry heavy data loads, deliver streaming video and provide internet access to a rapidly growing numbers of business and private users. Therefore, an enormous amount of bandwidth capacity is required to satisfy the service demand by customers. Metro DWDM can facilitate the deployment of high-speed data networks.

A router or ATM switch can connect into a DWDM transport network by mapping packets or cells directly into a wavelength without using a SONET or SDH TDM multiplexer. DWDM can defer or completely eliminate the need to deploy extra fibers and can easily coexist with today’s SONET/SDH network or with old fiber-optic terminals operating on asynchronous protocols.

This paper first analyzes the advantages of using a metropolitan DWDM system, outlining the position of this new technology in existing network and the compatibility with existing protocols; it then focuses on the components needed to improve a DWDM system and describes possible architectures by outlining the protection aspects for each of them. Finally, a snapshot of the state of art and possible future improvements of DWDM network are shown.

2 Metropolitan networks and DWDM
The overall network infrastructure can be subdivided in three domains: backbone network, metro network and access network, as shown in figure 1. The metro network serves as connection between the backbone (transport network) and the access network and has traffic aggregation functionalities. In the first implementation, it might connect large business customers and concentration/aggregation points residing in the access network such as access multiplexers, access routers, OLTs, etc.

![Fig. 1: General network domains](image-url)
3 Metro DWDM components

We analyze here only the devices used to combine and separate the various wavelength channels. They include multiplexers, demultiplexers, optical add/drop multiplexers, and devices based on a new emerging technology called optical cross connects (OXC). As DWDM technology achieves tighter and tighter wavelength spacing, the requirements and performance specification for wavelength-selective components become increasingly demanding.

3.1 Multiplexer & Demultiplexer

A multiplexer is used to combine different wavelength signals onto a single optical fiber. We could consider a standard broadband coupler as a MUX; it would work fine except that the insertion loss would be ~4 dB for 2-channel systems, ~7 dB for 4-channel systems, ~13 dB for 16-channel systems and so on [1]. Instead DWDM MUX is a device used to combine multiple wavelengths onto a single fiber while keeping the signal loss as small as possible. The demultiplexer is a device that separates a multiple wavelength signal into its individual wavelength components. It is important for the DEMUX to have low insertion loss, but it is much more important for it to reject the unwanted wavelengths so the channel receiver will have a signal with a high S/N ratio. As channel spacing becomes smaller and smaller, the wavelength selectivity of the DEMUX becomes of primary importance [1].

3.2 OADM

OADMs are the most critical enablers of metropolitan optical networking and permit selective adding or dropping of a precise number of optical wavelength channels of any rate, format, or protocol into the DWDM network. The most straightforward configuration for implementing a fixed OADM is the following: all the \( N \) wavelength channels in the aggregate\(^1\) traffic are demultiplexed into their wavelength tributaries. The tributary signals are then multiplexed again to form the outgoing aggregate signal. By using these two devices, one can access the desired tributaries and add or drop any wavelengths [3]. The most important component the enables OADM realization is the optical translator unit (OTU) used to convert the client’s standard wavelength to a different one. Figure 2 shows the operation of an optoelectronic OTU.

An high-speed photodetector converts the received optical signal \( \lambda_{in} \) to an electrical one and amplifies it to the desired level. The detected signal is then reshaped, regenerated and (optionally) retimed by the electronic circuits. The 3R process in shown in fig. 3. Clearly this electronic processing limits the operation to specific bit rates and formats. Bit-rate- and format-transparent OTUs have been developed by eliminating the retiming circuitry from the unit. The electronic signal then modulates a laser with the desired output wavelength \( \lambda_{out} \) (as defined in ITU-T G.692) using either an internal or an external modulator. As a result, the output optical signal is a “cleaned” (regenerated) replica of the input signal, but at the desired wavelength.

\[\text{Input Signal} \rightarrow \text{3R} \rightarrow \text{Output Signal} \]

The most promising bit-rate transparent all-optical translators are based on cross-phase modulation (XPM) in silicon optical amplifiers (SOAs), integrated into either a Mach Zehnder interferometer (MZI) or a Michelson interferometer (Mi) [2]. At the present time, optical networks use optoelectronic OTUs. All optical OTUs are very promising and may replace optoelectronic OTUs in the next generation of optical networks.

3.3 Optical Cross Connect (OXC)

The OXC is a device used to provide selective routing of DWDM channels; it uses optical switches in combination with other components that can be based on fiber-switching technology or on wavelength-switching technology [1]. The primary purpose for using an OXC is to keep all of the routing at the optical transmission layer without having to convert O/E and regenerate transmission signals. One of the emerging technologies in this field is the arrayed waveguide grating (AWG): an optical signal is routed to a specific output depending on the AWG input and on the wavelength it is using. Adding a control port allows selective wavelength routing [1].

3.4 Optical Amplifier (OA)

The advent of wideband fiber Optical Amplifiers (OA) has played a major role in enabling the practical implementation of metro optical networks. Since most wavelength add/drop elements are passive and present loss, the OA provides additional power gain to meet the losses associated with these devices. In some architectures the OAs must amplify the “add” and “drop” channels as well. Since the OA compromises network transparency, they must be used sparingly in the metro network. Any OA used in the metro ring must also possess the following key characteristics [4]:

- **Noise figure:** the OA must maintain a low noise level, because channels may pass through a series of several

\(^1\) We define tributary traffic the one that customers offers (at a fixed wavelength, i.e. 1310 nm or 1550 nm), and aggregate traffic the traffic carried into a DWDM network composed by several wavelengths.
amplifiers in the loop, and the noise and impairments accumulate; SNR values are generally 3-6 dB.

- **Bandwidth:** the amplifier bandwidth must be wide enough to cover the entire set of wavelength channels of the spectrum; for example an EDFA amplifier presents a bandwidth of 35 nm and gains in the range 25-51 dB.
- **Gain flatness:** in addition to providing sufficient gain, the OA must have gain uniformity for all channels, from one end of the spectrum to the other.
- **Per-channel automatic gain control (AGC):** even if the incoming multi-wavelength optical signals are not uniform in power, the OA should equalize the outgoing wavelength channels (aggregate traffic).

### 3.5 Optical Fiber

Most part of current networks have been built with **G.652 single mode (SM)** fibers. G.652 still provides the best balance between non-linearities and dispersion accuracy, being in this sense the most promising option for access network to carry DWDM signals. It is optimized to work in the second window and minimizes the non-linear four wave mixing effect. This fiber presents low dispersion (<3 ps/km/nm at 1.300 nm, but ~17 ps/km/nm at 1.550nm!) and attenuation (0.35 dB/km at 1.300 nm and 0.22 dB/Km at 1.550 nm); it can span over hundreds kilometers carrying signals up to 10 Gbps. Other fibers are the **G.653 dispersion shifted (DS)** and **G.655 Non Zero Dispersion (NZD)**.

### 4 Architecture and protection

An example of OADM for add/drop of a single tributary channel and its interconnection to the DWDM system is shown in figure 4. The aggregate signal is received from A (there are two incoming signals since the OADM is interconnected to a ring implementing the simplest way of protection) and the Fiber Protection Receiver Unit selects the best signal to be used (i.e. the signal with maximum power). The aggregate signal is then filtered to extract the desired channel that is converted to a standard output wavelength at the client interface (B).

Vice versa, the tributary traffic received at C is converted and introduced in the line interface in D. The splitter divides the signal in the two sides of the DWDM ring.

#### 4.1 Architecture

Fig. 5 shows several architecture viable to implement a metro DWDM network. **Satellite** is an OADM dedicated to a single channel, and **HUB** is the composition of several OADMs, able to add or drop all the channels present into a DWDM system. The lines represent physical connections (fiber), instead the sketched arrows are the logical channels.

- **Ring:** it connects different clients with point-to-point connections. It is a protected configuration.
- **Hubbed ring:** it is used to collect traffic from different clients to a single point (HUB). This configuration is the most useful and it is used to collect traffic into a POP as a metro access network and so to enhance the service offered in the local pop.
- **Point to point:** this configuration is used to attain the largest capability: all the optical channels are carried point-to-point. It is possible to carry N protected channels or 2N unprotected channels.
- **Dual home ring:** it is possible to add/drop a single channel in different points. It is like having several overlapped rings, by relying on one physical structure.

### 4.2 Protection

Protection mechanisms are key features to guarantee continuity of networking operation and thus the availability of communication services. The traffic switching action is initiated by the detection of a defect, a performance degradation or an external management request. The protection schemes reviewed here regard only optical protection. There is anyway the possibility to protect traffic using protection mechanisms operated by higher-layer protocols, (i.e. SDH, ATM, IP, etc.).

In **ring architectures** the simplest protection architecture has one dedicated protection entity for each working entity (1+1). An example of ring protection mechanisms is MS-SPRing (Multiple Section Shared Protected Ring) [5]. The main characteristic of ring protection mechanism is that they are able to recover traffic very quickly. The ITU standard defines the target of 50 ms, but optical protection can operate in less than 1 ms!.

In **mesh networks** restoration makes use of any capacity available between nodes to recover traffic upon network failures. The algorithms used for restoration in mesh networks involve re-routing, that is some percentage of the transport network capacity will be reserved for re-routing traffic that cannot be carried anymore by the working path. Restoration in mesh networks turns out to be very effective if the network physical topology is reasonably well meshed [5].
5 Network evolution
The deployment of DWDM in the metropolitan and access segments and their convergence towards a wavelength transparent network is critically dependent on the maturity of network elements. Today, only solutions based on fixed OADMs are feasible. Manufacturers offer different solutions: from 8 to 64 channels spaced by 200 GHz, each one able to carry signals from 16 Mbps to 10 Gbps. Future applications will use “L” band (1620 nm) and will be able to transport nearly 200 channels (with 50 GHz channel spacing).

5.1 Components evolution
The bursty nature of data traffic drives the need for dynamic bandwidth allocation: this will enable network elements to increase or reduce bandwidth as needed and will help relieve temporary congestion in the network. This requires network elements from different layer to work together: in case of sudden demand of capacity between two routers, they would contact their associated optical cross-connect systems to set up the required additional paths [6].

There are two possible directions for OADMs evolution, driven from the new technology of tunable laser (tunable lasers can transmit at different wavelength):

- **Remotely reconfigurable OADMs**: they allow for flexible pre-planning of the networks and fast service provisioning. Each OADM site provide the capability to drop or add certain wavelengths by remote control [7].

- **Dynamic reconfigurable OADMs**: the OADMs themselves can do optical routing (intelligent OADM). They use the MPëS routing protocol (as deployed in OXCs). The network is able to balance automatically the traffic present in the system and so to improve the efficiency [7].

5.2 Towards all-optical networking
The Optical Transport Network (OTN) can be generally considered as a structure composed of nodes connected by optical links where channels at different wavelengths transport client signals. Each channel is transported leaving integer its information content and without any conversion to the electrical domain. In this new scenario a particular and relevant kind of transparency needed is the client independence, meant as the capacity of the network to transport signals coming from different clients (SDH, PDH, ATM, IP etc) all mapped directly into the DWDM layer, as shown in figure 6.

Figure 7 shows the present scenario of metropolitan networks and a possible future evolution. The primary functionality to be guaranteed by the OTN thus includes multiplexing, transmission and routing all at optical level.

6 Conclusions
In this paper the introduction of DWDM technology into the access network has been considered so as to fulfil the increasing bandwidth demand. The advantages of the DWDM solution have been first discussed, by also examining the state of the art of the components needed to build a DWDM system. Architectures and protection mechanisms for DWDM metro networks have been reviewed and a possible evolution of the network architecture has been presented.

References