Deploying CWDM to Overcome Bandwidth Limitations of FTTH Access Networks

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Introduction to CWDM for PONs:

FTTH networks in North America are being built using various PON architectures fed from a common backhaul. As networks grow in terms of geographic reach, subscriber counts and the scope and number of services offered, Coarse Wave Division Multiplexing (CWDM) has clearly become the preferred method for increasing the bandwidth of these optical access networks quickly, simply and at lowest cost.

Passive CWDM requires absolutely no electrical power and the technology has proven itself to be sufficiently robust and reliable for installation in the most demanding environmental conditions. Products recently released to the market allow enhanced flexibility in terms of network planning and installation while preserving scalability to handle far higher data transmission volumes as bandwidth needs expand. Since CWDM is inherently transparent to protocol, coding and bit rate, it is ideally suited for aggregating bandwidth over fiber. It is fully compatible with Broadband PON (BPON ITU-T G.983.x), Gigabit capable PON (GPON ITU-T G.984.x), or Ethernet PON (EPON IEEE 802.3ah). Passive CWDM elements are interoperable with configurations applying ATM, TDM / TDMA, SONET / SDH and accommodate 1310 nm and 1550/1490 nm analog modulation as well as digital modulation overlays. Very important of course: passive CWDM is low cost – especially when compared with the cost of leasing dark fiber or laying additional fiber lines not to mention the expense of purchasing and maintaining active network equipment.

During the 1980’s, CWDM technologies were introduced to transport multiple channels within the 850 nm 1st window at typical spacing of 25-20 nm over multimode fiber. Today, ITU G.694.2 standardized CWDM technology operates over the complete optical fiber communication spectrum from 1270 nm to 1610 nm at wavelength spacing of 20 nm. The ITU G.695 recommendations specify a 14 nm pass band per channel. Figure 1 shows the standard CWDM grid together with the loss curve for single mode fiber.

![Fiber attenuation as a function of wavelength and channel spacing](image.png)
Formerly, the two wavelengths (1390nm and 1410nm) nearest the OH ion “water peak” could not be used over extended transmission distances due to the high optical propagation loss in that region of the spectrum. This situation appears today only with legacy installations using older optical fiber. Zero Water Peak Fiber exhibits low optical attenuation in this spectral region and permits the full 18 wavelengths to be used for data transport.

The diagram of Figure 2 shows how individual data streams at different wavelengths are added onto a single fiber using a passive optical multiplexer. A passive demultiplexer is then used to separate out the individual wavelengths at the opposite end of the fiber link. This ability to aggregate multiple wavelengths over a single fiber allows data transfer capacity to increase by factors of up to 18 depending on the level of multiplexing.

![Figure 2. Transporting several channels over a single fiber using CWDM](image)

Other technologies such as Dense Wave Division Multiplexing (DWDM) offer greater channel capacity but are typically more expensive to own and operate. For example, basic CWDM components cost less than their DWDM counterparts because the narrower channel spacing of DWDM systems (200 GHz or less) require that transceiver lasers are thermally compensated to confine emission within the narrower optical pass bands of the DWDM channels. To maintain these tighter wavelength tolerances, DWDM transceiver lasers need expensive control circuitry to stabilize transmission wavelength. In addition, DWDM laser transmitters require more electrical power to realize this active stabilization. Passive DWDM multiplexer or demultiplexer footprints are typically larger than their CWDM counter parts which complicates space planning, especially regarding retrofits of legacy cabinets and enclosures. However, if tremendous capacity increases should be required, proven hybrid DWDM / CWDM schemes that transport the DWDM C band channels within the CWDM wavelength grid may be implemented. For applications beyond the Metro Core, the need for such DWDM bandwidth expansion tends to be quite rare.

Table 1 below shows how manufacturers normally segment their product portfolios according to wavelength. This segmentation has more to do with history and practical aspects of applying CWDM than current technical limitations. In earlier generations of optical fiber in which water peak attenuation effects could not be mitigated, designers divided the useful CWDM spectrum. They tended to work for the most part either on the shorter wavelength side of the water peak, the blue channels, or favor the longer wavelength red channels. With demand for ever higher transmission capacities, thin film filter architectures were devised to
address the water peak absorption and other spectral limitations. Application of thin film technology facilitated a seamless channel selection extending from 1270 nm to 1570 nm. By way of example, channels at 1310 nm, 1370 nm, 1490 nm, and 1550 may all be grouped onto a single four channel CWDM component.

<table>
<thead>
<tr>
<th>Wavelength λ in nm</th>
<th>Blue Channels</th>
<th>Wavelength λ in nm</th>
<th>Red Channels</th>
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<td></td>
</tr>
<tr>
<td>1290</td>
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<td>1450</td>
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Table 1. Practical Segmentation of CWDM Wavelengths

Access platforms exploiting the latest miniature CWDM multiplexing components offer the unique advantage of being compact enough to easily retrofit into existing fiber splice cassettes for installation into street cabinets or other forms of outside enclosure. Ultra-compact CWDM components qualified to outside plant standards (according to Telcordia GR-1209/1221 CORE for uncontrolled environments) are routinely deployed in arctic to desert climates.

CWDM is very firmly established with all telecom carriers worldwide as well as Multiple System Operators (MSOs), Video Broadcast groups and SAN and LAN network operators. Many CWDM variations are presently in use. Some varieties are particular to a certain industry segment such as telecom, storage, CATV, Hybrid Fiber Cable (HFC) or certain geographic regions. Special configurations have been institutionalized by particular carriers, OEMs or system integrators. Advanced functions may be added for test and measurement or to perform other control functions. Some of the more common channel management configurations are:

- Skipping (not using) the 1390 nm channel (wavelength) and perhaps also the 1410 “water peak” channel of the blue band;
- Dedicating certain channels (wherever they are situated in the ITU grid) for control functions while preserving others for expansion even if it this entails skipping mid-band channels;
- Dedicating a band, for example the blue band, for analog transmission while reserving the red band channels for digital signals;
- Dedicating certain channels for downstream and others for upstream traffic (popular is 1310 nm for upstream and the red band (1450 nm… 1610 nm) for downstream;
- Tap fiber ports for non-disruptive maintenance and non-invasive test purposes; and,
- Reserving certain sections of a band – typically the 1510 nm to 1570 nm window – for future DWDM capacity upgrade.

Although the assignment, direction and coding of channels may vary, the wavelengths grid remains consistent with the ITU standards.
CWDM and Add/Drop with Access PONs:

Aggregating many optical channels of differing wavelengths is straightforward at the Central Office (CO). In general, whether in ring structures or point-to-point arrangements, not all capacity is needed at a single optical node. Data transported over certain channels therefore may be added and/or dropped from the fiber as required. Figure 3 below shows how this may be achieved.

Figure 3. Accessing capacity along the feed

An add / drop may be implemented at any CWDM node with one or two channels typically being added or dropped at any one location in the field. Supplementary add / drop nodes may be introduced or the number of channels added / dropped expanded as bandwidth demand changes. Large enterprise customers or government institutions for example sometimes request one or more CWDM channels dedicated specifically for their own use.

“Future Proofing” the network in areas where traffic is predicted to grow rapidly at a later period is also feasible and often desirable. For example, an eight channel upgrade may be installed with only a few channels brought into service or “lit” initially and the remainder of the capacity reserved for activation later. As demand increases, transceivers may be added incrementally to take advantage of ever more of the dormant channel capability. Another option at some suitable time might be to increase data transmission speed. Even during more exotic exercises such as an HFC analog / digital migration, additional channels may be conveniently added as the architecture develops and capacity needs change.

The advantages of the PON depicted above are: its low CAPEX, its low OPEX, that it requires no electrical power, that it accommodates any transmission coding or protocol scheme abiding by the ITU wavelength grid and that it may be quickly and inexpensively upgraded when additional bandwidth demands arise. The disadvantages, common to all PON architectures, is that bandwidth is shared among several subscribers. Luckily, increasing capacity by adding channels or wavelengths is exceedingly cost effective and simple to perform. In effect, a passive CWDM upgrade may be regarded as belonging to the optical fiber cable infrastructure rather than discrete deployment of additional network equipment.

Upgrading Access PONs Using Passive CWDM:

As Telecom FTTH deployment extends into less densely populated areas, upgrading telecom access networks between the Central Office (CO) and the subscribers becomes essential. The typical PON architecture depicted in Figure 4 uses an optical platform, traditionally located in the CO, known as an Optical Line Terminal (OLT) to transmit traffic to approximately 16 to 32 residential drop points. Passive optical devices called splitters / combiners are located at fiber
distribution hubs between the OLTs and subscribers’ Optical Network Terminals (ONTs). The ONT is normally the point where the access fiber line is converted to a twisted pair copper line. The splitters / combiners divide a single downstream transmission into multiple fiber drop streams as well as aggregate upstream traffic from multiple ONTs into a common stream travelling back to the CO.

As fiber gradually penetrates deeper into the access edge, the OLT is moving into the wider subscriber territory. The reason for this shift out of the CO is to better extend the network to connect with more ONTs. Reaching more subscribers with higher bandwidths attains higher penetration densities and consequently greater revenue generation potential. Splitters / combiners promote high degrees of network utilization by enabling the price of one OLT port and laser transceiver to be shared across many drop points. The goal of the network operator is to provide ever more subscribers with service while containing the cost to reach each additional customer. Today, it is becoming practicable and economically viable to extend fiber directly to the premises in some instances. With fiber moving into the home and office, the optical network termination effectively moves all the way to the customer location.

![Generic PON network using remote OLTs](image)

Passive CWDM enables operators to better utilize fiber capacity and support far greater data traffic as the bandwidth demands from the ONTs increase. Passive CWDM permits network operators to implement many more optical nodes over multiple locations with minimal capital investment and virtually no additional operating cost.

Although the diagram of Figure 4 shows an FTTH access network where a pair of fibers serves each remote OLT, bidirectional single fiber PON architectures are also common. Distance from the CO to the furthest ONT normally lies in the range between 12 miles and 60 miles. The fiber distribution points contain passive splitters / combiners that connect the fiber lines among approximately 32 drop points (subscribers). This fan out number is highly dependant on the available signal power budget and the fiber attenuation accruing between the distribution points and the subscribers.
Figure 5 represents a situation where existing subscribers intend to upgrade to higher value-added bandwidth services. In order to satisfy customers attracted by IPTV, VoIP, video on demand etc., the 622 Mb/s downstream capacity between the CO and the OLT, providing roughly 20 Mb/s to each subscriber, must increase.

The target bandwidth adequate to address the existing demand and also satisfy expected new subscriber and service expansion requires a downstream CO / OLT link bandwidth of 2.5 Gb/s. Multiplying the number of bidirectional channels traveling between the CO and OLT by four corresponds to introducing four CWDM wavelengths. The passive CWDM enhancement relieves the fiber exhaust as shown in the upgraded network of Figure 6 below.

The upgrade - installing four CWDM channels at the original data rates - boosts the bandwidth of the CO / OLT link. The existing CO rack hardware, existing street cabinet OLT and the available fiber distribution panels all remain unaffected. The complete installation requires four channel-specific (color coded) transceivers plugging into the router / switch, the associated patch cables, the rack-mounted CWDM module and the snap in passive CWDM cassette located in the OLT. Service interruption is necessary at the CO to make the connection of the CWDM module to the router and at the OLT when the pre-packaged CWDM cassettes are mounted into the outdoor cabinet. The cassettes typically arrive ready for splicing although cassettes may be specified that include connectors. Only minimal training of the field service personnel is necessary. The passive CWDM modules may be installed in much the same way as any fiber management cassette used in distribution hubs or street cabinets.
The business case to upgrade CO / OLT fiber capacity using CWDM instead of installing additional fiber is compelling. Physically laying and commissioning the cable, exclusive of expenses incurred during negotiating rights of way, upgrading street cabinets etc. can easily cost $10,000 per mile. Drawing cable through existing conduits is normally a less costly endeavor than laying cable but could also become prohibitively expensive when; 1) navigating complicated trajectories; 2) accommodating difficult and marginally documented pathways; or, 3) encountering unexpected maintenance issues involving the legacy infrastructure.

The passive CWDM upgrade is in the rule comfortably accomplished within hours after some modest investment in network planning. The sum of material, labor, equipment and training expenses amount to far less than the cost of laying a new fiber cable. Enterprise and private business users of LAN and data storage area networks experiencing fiber exhaust also install passive CWDM for the reasons listed above.

**Using CWDM to Expand EPON Bandwidth:**

PON systems come in many flavors. Nearly each equipment vendor offers a different variation in terms of performance / price tradeoffs, scalability and network management capability. Network operators then add another layer of diversity when deploying PON networks depending upon the economics, expansion priorities and the market demographics of the particular situation.

Designers and implementers of EPON (Ethernet PON) may benefit from using passive CWDM on the client side of the OLT. A simple EPON architecture is represented in Figure 7 below.

The EPON of Figure 7 was conceived to service up to 64 subscribers, all sharing a single 1.25 Gbps bidirectional optical Ethernet feed line - the upstream and downstream network speeds are symmetrical. The theoretical maximum sustainable data-rate for each subscriber is a little over 16 Mb/s. As subscriptions for IPTV, HDTV and other higher bandwidth services become available, the 16 Mb/s downstream capacity will certainly prove insufficient.

Figure 8 shows the same network retrofitted with a four channel passive CWDM extension, which effectively multiplies the downstream capacity by a factor of four without affecting the
upstream traffic. A rack-mounted CWDM unit in the CO and a miniature hardened CWDM module deployed in the fiber distribution hub increases the revenue earning potential of the feed line while minimizing OPEX and CAPEX. Compared to the cost of alternative upgrade scenarios, the passive CWDM solution wins by a very wide margin.

Figure 8. EPON deployment upgraded to 4Gb/s bandwidth capacity

In this case, deploying a four channel CWDM upgrade augments the throughput of the downlink toward subscribers by a factor by four while requiring minimal modification of the existing infrastructure.

**Upgrading HFC (Hybrid Fiber Cable) for Fiber to the Business (FTTB):**

MSOs seek to leverage their existing HFC networks to bring high bandwidth services to enterprise and business customers and then to new and existing residential subscribers. Passive CWDM can address the fiber scarcity in the feed lines between the Headend and the remote fiber distribution hub. Figure 9 shows the case when all traffic is transmitted and received over analog RF (Radio Frequency) modulated wavelengths.

Figure 9. FTTX CWDM deployed with an analog HFC
Whether native analog or native digital or a mix of both, CWDM performs equally well. Street cabinets, pedestals, aerial pods and handhole closures along the feeder cable may be treated as nodes where channels are dropped and added. Any protocol (SONET, GigE, Escon, Ficon, Fiber Channel, PacketCable, DOCSIS etc.) may be carried over any of the new channels. Similarly to telecom capacity upgrade scenarios, the passive CWDM multiplex and demultiplex functions become essentially integrated into the cabling and fiber connectivity. Analogous to the preceding EPON upgrade example, installing passive CWDM to increase bandwidth remains the far less costly alternative compared with adding feeder cables or leasing additional dark fiber.

MSOs are migrating to an IP-based bidirectional communications model and away form analog topologies. Digital transport, switching and routing equipment all use standard small form factor pluggable transceivers compatible with ITU grid CWDM wavelengths. Figure 10 below shows a network link where both the legacy analog downstream and upstream signals and the bidirectional Ethernet IP-based data occupy the same single fiber.

The digital streams may be gradually augmented unimpeded by the operation of the analog portion of the link. By the same account, bandwidth expansion of the digital services do not disturb the analog transmission processes. Bandwidth may be transferred from analog to digital technologies as customer demand and as operational and financial resources dictate.

**Conclusions:**

A passive CWDM approach offers the significant benefits of low CAPEX, minimal OPEX and very simple and straightforward upgrade planning and implementation. Deployed in the field, passive CWDM preserves scalability and network flexibility as the network grows and the bandwidth demands change. The major advantages of upgrading access network bandwidth using passive CWDM are.

- **Predictably low equipment and operating cost** - the network solution and the equipment deployed must promise both low CAPEX and economical OPEX. Passive CWDM
satisfies these requirements better than any other approach to upgrading bandwidth capacity on new or existing fiber lines.

- **Quick and efficient network upgrade** – rapid response is key to pre-emptively or defensively capturing and holding customers. Minimizing the period to reap the ROI is essential. In our experiences, passive CWDM building blocks comprising eight or more channels per fiber can be installed and fully operational within a day. In practical terms installing the multiplex / demultiplex capability reduces to an exercise in modifying the fiber cabling.

- **Simplicity of specification and simplicity of deployment** - an inherent attraction of passive CWDM solutions is the modest levels of technical expertise required to design, manage and execute the upgrade or green-field deployment. A CWDM approach allows operators room to manoeuvre when rolling out additional geographical coverage or services as the demand, competitive landscape and financial aspects dictate.

- **Sufficiently flexible solutions that facilitate expansion** - network COOs demand that resources associated with upgrade scenarios are predictable and may be partitioned into cost-manageable parcels. Deploying passive CWDM provides a wide scope for bandwidth upgrade: up to a factor of 18 times allocated in four-channel increments.

- **Open standards, nothing proprietary** – standard CWDM technology operates unconstrained with any of the routers, switches and DSLAMs available from major Telecom / Datacomm vendors or HFC and CATV equipment OEMs. As a passive element, CWDM modules are functionally transparent to all data transmission protocols and are immune to the incompatibility problems often encountered when connecting disparate equipment and accessories supplied by different vendors. The risk of becoming captive to any particular proprietary approach or attendant service agreement is virtually zero.