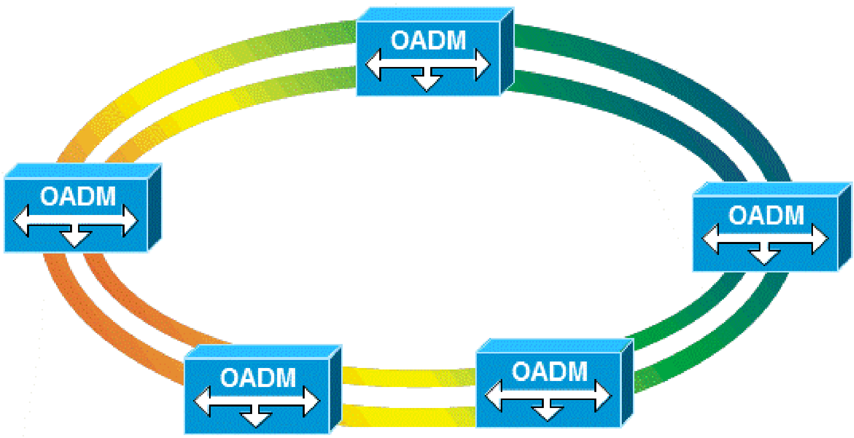
TransPacket white paper

CWDM and DWDM networking



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Increasing fibre-Optical network utilization and saving on switches/routers

Executive summary

From being primarily a technology for transport networks, optical technologies are steadily gaining terrain within both metro and access networks. Wavelength Division Multiplexing (WDM) is the technology enabling cost efficient upgrade of capacity in optical networks. This whitepaper explains the fundamental principles for optical networks, and discusses critical factors in deploying optical networks. Unnecessary use of routing and switching resources can be avoided using optical networking techniques for building an optical aggregation network.

CWDM and DWDM networking

INCREASING FIBRE-OPTICAL NETWORK UTILIZATION AND SAVING ON SWITCHES/ROUTERS

Wavelength Division Multiplexing (WDM)

In an optical fibre approximately 40 THz (40000 GHz) of optical bandwidth is available in the low-loss wavelength region. Since a gigabit or 10 gigabit data-channel being transmitted in an optical fibre only fills a few GHz of bandwidth, a much higher fibre-utilization is possible by dividing the optical spectrum into wavelength channels. Each of the wavelength channels may then carry a data-channel. Data transport in a wavelength channel is protocol independent enabling signals of different protocols like e.g. Ethernet, Fibre Channel, SDH/SONET and OTN to be transported side-by-side in neighbouring channels. For practical purposes, the transport is also bitrate independent, enabling easy transport of bitrates up to 10 Gb/s per channel.

Coarse Wavelength Division Multiplexing (CWDM)

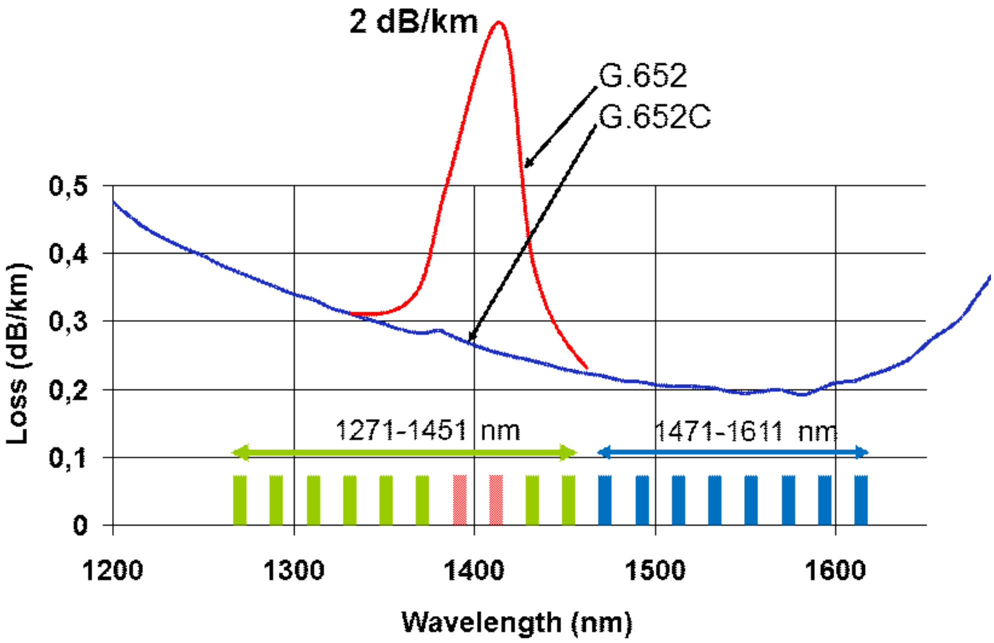

Figure 1, CWDM channels and attenuation in G.652 and G652.C fibre.

CWDM was introduced as a low-cost approach to increasing bandwidth utilization of the fibre-infrastructure. By using several wavelengths (colours) of the light, 18 channels are viable and defined in the ITU-T standard G.694.2. Figure 1 shows the 20 nm spaced CWDM wavelength channels and the attenuation curve as a function of wavelength for the most widely deployed fibre type G.652, also known as standard Single Mode Fibre (SMF). Because of the absorption-peak (also known as the water-peak) centred at 1410 nm, two of the ITU-T defined wavelengths, 1391 and 1411 nm, are not applicable. A fibre more optimized for CWDM applications is the low water peak G.652.C fibre. As shown in figure 1, this fibre-type has a much lower attenuation in the 1350-1450 nm wavelength range, enabling transport of all the ITU-T defined CWDM channels. Because of the relatively large channel spacing, a wavelength drift within each channel is allowed, enabling the use of uncooled CWDM transmitters. Figure 2 shows a typical application of CWDM, increasing the capacity by a factor of nine. The most important component in this system is the optical MUX/DMUX unit which is a passive device, very reliable and simple to use. These devices are available with a variety of wavelength combinations, where the 8+1 channel unit is the most common. TransPacket's C1- 8+1 unit is a MUX/DMUX unit with eight channels ranging from 1471-1611 and an extension port applicable for a ninth 1310 nm channel. The extension port also enables easy upgrade to 16 channels adding an extra C1 specified for the 1271-1451 nm range.

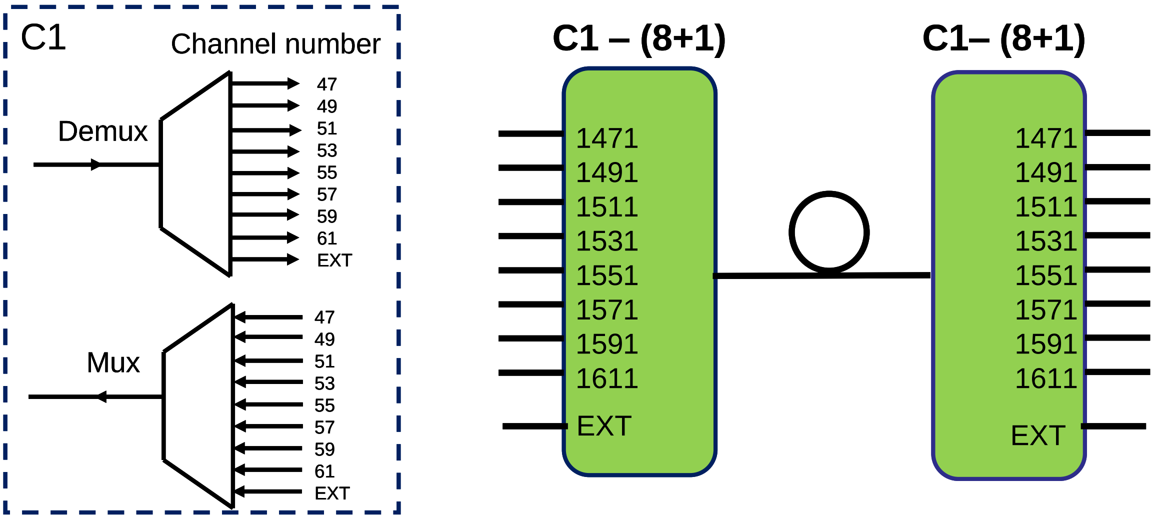

Figure 2, Nine times capacity upgrade by using TransPacket's C1 units. C1 is a MUX/DMUX unit with eight channels ranging from 1471-1611 and with an extension port applicable for a ninth 1310 nm channel or for upgrade to 16 channels.

Combined with active pluggable transceiver modules, the passive MUX/DMUX units constitute a complete CWDM system. Transceiver modules covering a large range of bitrates and distances are available from TransPacket in SFP, SFP+, XFP, Xenpack and X2 formats. Transmission distances ranges from 40-160 km for Gigabit speeds, and 10-70 km for 10 Gigabit speeds.

Dense Wavelength Division Multiplexing (DWDM)

By packing WDM channels denser than in CWDM systems, 100 GHz spacing (approx. 0.8 nm), more channels and higher capacity can be achieved using DWDM. ITU-T recommendation G.694.1 defines the DWDM channel spectrum. Using TransPacket's DWDM MUX/DMUX units, upgrade to 40 wavelength channels is viable. Figure 3 shows a 16 channel DWDM system using two D1 series low insertion loss MUX/DMUX units. DWDM Transceiver modules are available from TransPacket in SFP, SFP+, XFP, Xenpack and X2 formats. Transmission distances range from 100-180 km for Gigabit speeds, and 40-80 km for 10 Gigabit speeds, without the use of optical amplifiers. The low insertion loss of the MUX/DMUX unit increase power budget, enabling use of the most cost-effective distance variant among the transceivers.

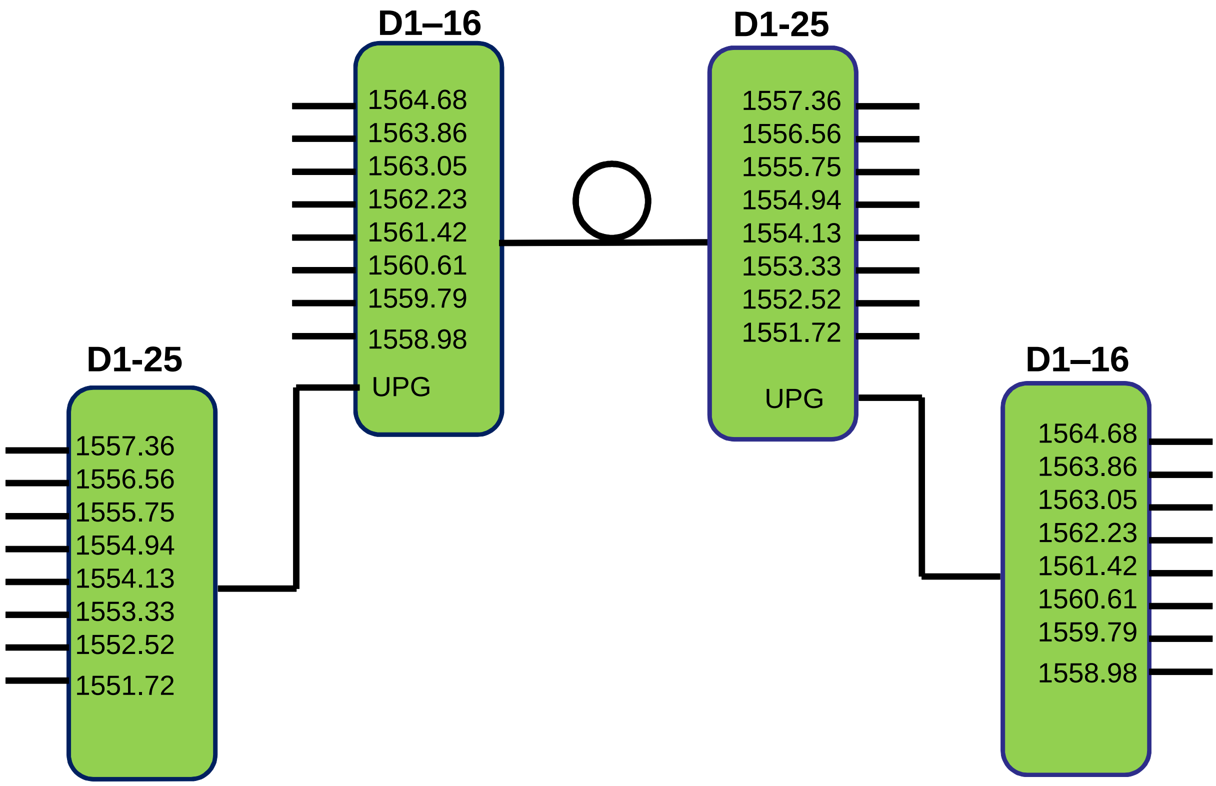

Figure 3, 16 channel DWDM system using two D1 units on each end of the link. Total insertion loss and non-uniformity on channel insertion loss is minimized through asymmetric chaining of the MUX/DMUX units at the two end-points of the link. The figure shows that the the D1-25 unit is connected to the UPG at the left and in the other end of the link at right, the D1-16 unit is connected to the UPG.

Single-fibre capacity upgrade using bidirectional transmission

If only a single fibre is available, transmitting simultaneously in both directions on the same fibre is possible. For separating the signals in the two directions, different wavelengths must be applied for each direction. For single channel bidirectional transmission, bidirectional SFPs with different wavelengths for upstream and downstream direction are applied, enabling direct connection to the transmission fibre without intermediate components. A further capacity upgrade is viable using WDM. Using TransPackets C1 – 8 BiDi, 16 CWDM wavelengths are applied for creating an eight channel bidirectional connection. Each of the eight dual-ports on the C1 – 8 BiDi then has different wavelengths for upstream and downstream communication.

Hybrid DWDM and CWDM

If the network is already built with eight channels of CWDM, expanding to more CWDM channels may be a problem if using G.652 fibre (not G.652 C). As illustrated in figure 4, an alternative solution is to combine CWDM and DWDM, inserting eight DWDM channels in the 1531 nm CWDM channel. Combining the use of D1 and C1 units, this allows easy upgrade to 15 channels.

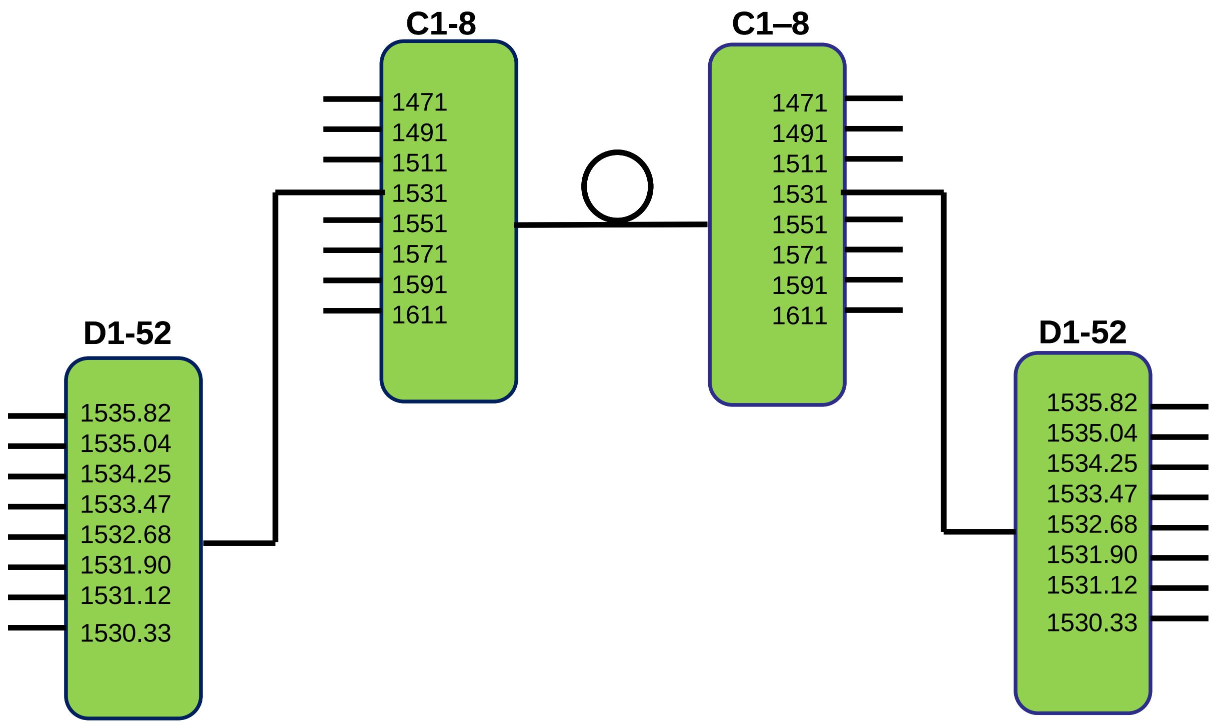

Figure 4, Combining CWDM and DWDM for capacity upgrade to 15 channels on G.652 fibre.

Advanced XFP transceivers reduces spare-parts

A large variety of different standard XFP transceivers for Ethernet/SDH/SONET/FC with a fixed laser wavelength are available. TransPacket offers additionally two special XFP modules, the tunable-XFP and the OTN-XFP. The tunable-XFP is a XFP module with a tunable laser enabling the module to transmit and receive in any DWDM channel. This considerably reduces the need for spare-parts. Rather than keeping in stock a dedicated XFP-module for each of the DWDM –channels, only a single tunable XFP module can be stored and configured to the required DWDM channel at the time it is needed as a spare part.

The OTN-XFP transceiver from Menara Networks enables equipment with 10 Gb/s Ethernet XFP interfaces to frame Ethernet in the G.709 OTN format. The OTN-framer is integrated in the XFP and because of the embedded Forward Error Correction (FEC) code in OTN, longer distances with better power-margins is enabled. The OTN-XFP may also be supplied with a tunable laser, enabling easy configuration of the desired DWDM wavelength.

CWDM and DWDM network design

Power budget

The most important factor to evaluate in the network design is the power budget. Power budget is as a characteristic of the transceivers (XFP's/SFP's) which are available with different power-budget values. When designing an optical link, the power-budget value of the transceiver must be higher than the total end-to-end link attenuation. The link attenuation "L_i" is given as:

$$L\_I = A\_tf + A\_linkmux + (N \times A\_p)$$

Where:

A_tf = Attenuation in transmission fibre at the transceiver wavelength.

A_linkmux = Link attenuation in the MUX/DMUX pair.

A_p = Attenuation in a patch-cord.

N = Number of patch-cords.

A_linkmux is the attenuation given from the insertion loss of a MUX/DMUX pair. Because of the design of the MUX/DMUX units, this value may typically be lower than twice the maximum insertion-loss of a MUX/DMUX. This is achieved through designing the MUX/DMUX by letting the channel with the highest insertion loss on the MUX experience the lowest insertion loss in the DMUX.

A_p is the attenuation caused by a patch-cord. Typically this value may be as low as 0.3 dB (or lower) for a new and clean patch-cord. In practical network designs, the attenuation may be higher, and 0.5 dB may be used as a rule-of-thumb value. If high attenuation values are observed, the patch-cord should be cleaned, or replaced if a reasonable value is not achieved. High-quality patch-cords, fibre-splices and connectors have shown to be especially critical in 10 Gb/s channel systems. Not only attenuation is critical, but also reflections may cause problems with the signal quality.

A_tf depends on the wavelength of the transceiver as well as the fibre-type, new fibre types generally having lower attenuation than older fibre types. As an example, the G.652 fibre is specified to have a maximum insertion loss of 0.35 dB/km at 1550 nm. The attenuation is however typically lower, as illustrated in figure 1 for G.652 and G652.C fibre. For achieving satisfactory margins, the minimum-value of A_tf that can be used in the power-budget calculations should be the attenuation value for the wavelength channel with the highest insertion loss.

All in all, because of the uncertainties in calculating the attenuation of a link, the recommended and most accurate method of dimensioning the transmission system is to measure the attenuation of the link including the patch-cords and then add the contribution from the multiplexers, A_linkmux.

Choosing CWDM or DWDM

The cost-difference between CWDM and DWDM is known to be large, favoring CWDM as the low-cost alternative. Using TransPacket's WDM technology, this is however not through. For channel counts beyond eight channels, DWDM may be a preferred technology because:

1) Flexible upgrade: DWDM are more flexible and robust with respect to fibre types. DWDM upgrade to 16 channels is viable on both G.652 and G.652.C fibres. This stems from the fact that DWDM always employs the low-loss region of the fibre, while 16 channel CWDM systems involves transmission in the 1300-1400 nm region, where attenuation is remarkable higher.
2) Scalability: TransPackets DWDM solutions allows upgrade in steps of eight channels to a maximum of 40 channels, allowing a much higher total capacity on the fibre than a CWDM solution.
3) Cost: CWDM still shows to be cost-efficient for 8 channel systems. Using TransPackets low-insertion loss MUX/DMUX (Maximum 1.7 dB insertion loss) avoids adding extra cost to transceivers for achieving satisfactory power-margins. However, for higher channel counts than 8, the higher attenuation in the fibre may prove DWDM to be a better alternative than CWDM. Comparing the cost of TransPacket's CWDM and DWDM 16 channel systems for e.g. a link length of 20 km, DWDM is found to have approximately the same cost.
4) Long spans: DWDM employs the 1550 wavelength band which can be amplified using conventional optical amplifiers, Erbium Doped Fiber Amplifiers (EDFA's), enhancing transmission distance to hundreds of kilometers.

Hence, before deciding to go for CWDM or DWDM for the link upgrade, a careful evaluation should be performed that includes a cost comparison for the specific case of upgrade as well as future upgrade scenarios. TransPacket offers system-design services for preparation of CWDM and DWDM upgrade proposals enabling valuable cost-performance evaluations.

Design guidelines for 10 Gb/s transmission and beyond

While transmitting gigabit Ethernet in optical fibres is straight forward and comes without a strong influence of chromatic dispersion and Polarisation Mode Dispersion (PMD), this is different for 10 Gb/s transmission. At 10 Gb/s, power margins are smaller, sensitivity to reflections are higher, and chromatic dispersion comes into play. Because of smaller power-margins and higher sensitivity to reflections, high quality patch-cords and splices as well as cleaning of connectors becomes very important. If the chromatic dispersion is not compensated, transmission distance is limited to approximately 80 km at 10 Gb/s. PMD is mostly caused by inaccuracies in the shape of the fibre core, inaccurate old production processes typically made the fibre-core not perfectly circular but a bit elliptic. Hence PMD may especially for old fibre be a problem on long distance (typically beyond 100 km) 10 Gb/s transmission. For bitrates of 40 Gb/s and beyond, PMD becomes a critical factor and each fibre-link should be characterized, finding the fibre suitable or not.

Optical Add/Drop Multiplexing (OADM)

As illustrated in figure 5, using optical add/drop techniques, wavelength channels may be added and dropped at intermediate nodes using passive optical components only. This technique enables connectivity between all the nodes using a single pair of fibre only. Using a pair of MUX/DMUX'es at the intermediate node enables manual selection of the wavelengths to add and drop, using patch-cords for configuration. Gradual and flexible upgrade is then possible, adding capacity between the nodes according to where an increased need for more bandwidth is observed. When dimensioning an optical network using add/drop multiplexing, insertion loss of the MUX/DMUX units becomes a critical parameter for the link budget since several devices are coupled in series. In figure 5, using TransPackets low insertion loss C1 units, the maximum contribution from the MUX/DMUX units equals 4 X 1.7 dB = 6.8 dB.

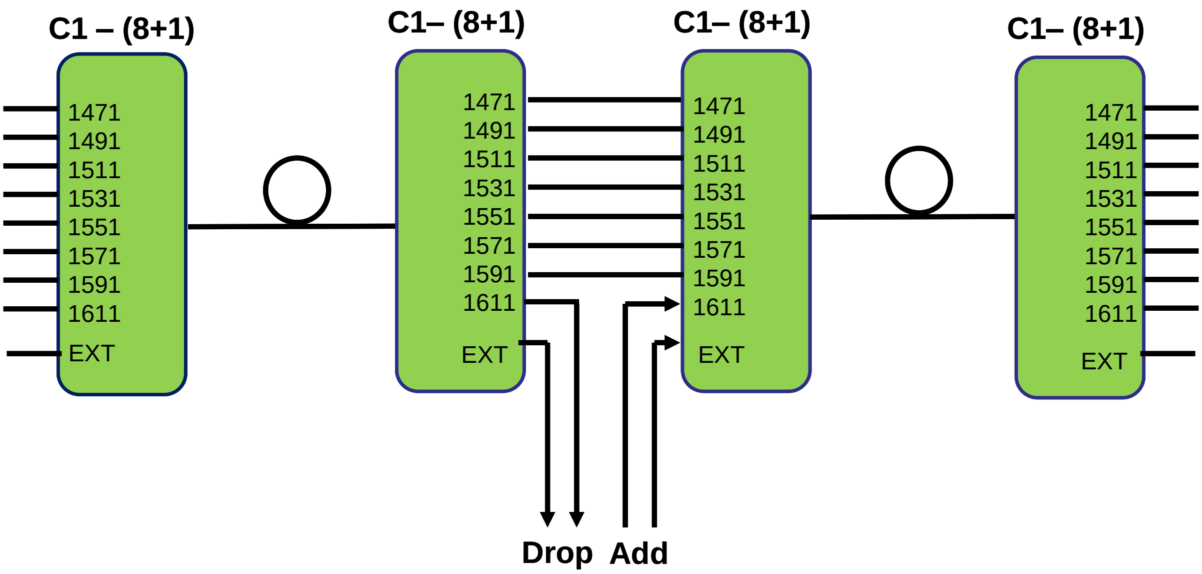

Figure 5, Adding and dropping of wavelength channels at intermediate nodes using two C1 – (8+1), MUX/DMUX units for maximum flexibility. In this example the 1611 wavelength along with a 1300 nm wavelength from the extension port is dropped. Alternatively, if a reconfiguration option is not required, a static optical add/drop unit may be applied.

Optical ring network for aggregation

Using optical add/drop techniques, optical aggregation rings can be implemented, avoiding unnecessary routing or switching at intermediate nodes. Aggregation is achieved through dedicating one or more wavelengths to each edge-node and adding these wavelengths along the ring. In the more powerful central aggregation node, all the added wavelengths from the edge-nodes are dropped. Using this technique, the logical network topology becomes a star with the central aggregation node in the centre. Redundancy can be achieved in the ring using one or more dedicated wavelengths for each direction in the ring. Figure 6 illustrates an example configuration with an 8 wavelength CWDM aggregation ring using four wavelengths for aggregation in each direction. Each of the edge nodes employs a single dedicated wavelength for transmitting in the two directions of the ring. At the central node, all four wavelengths from the respective four nodes, from each direction, are dropped.

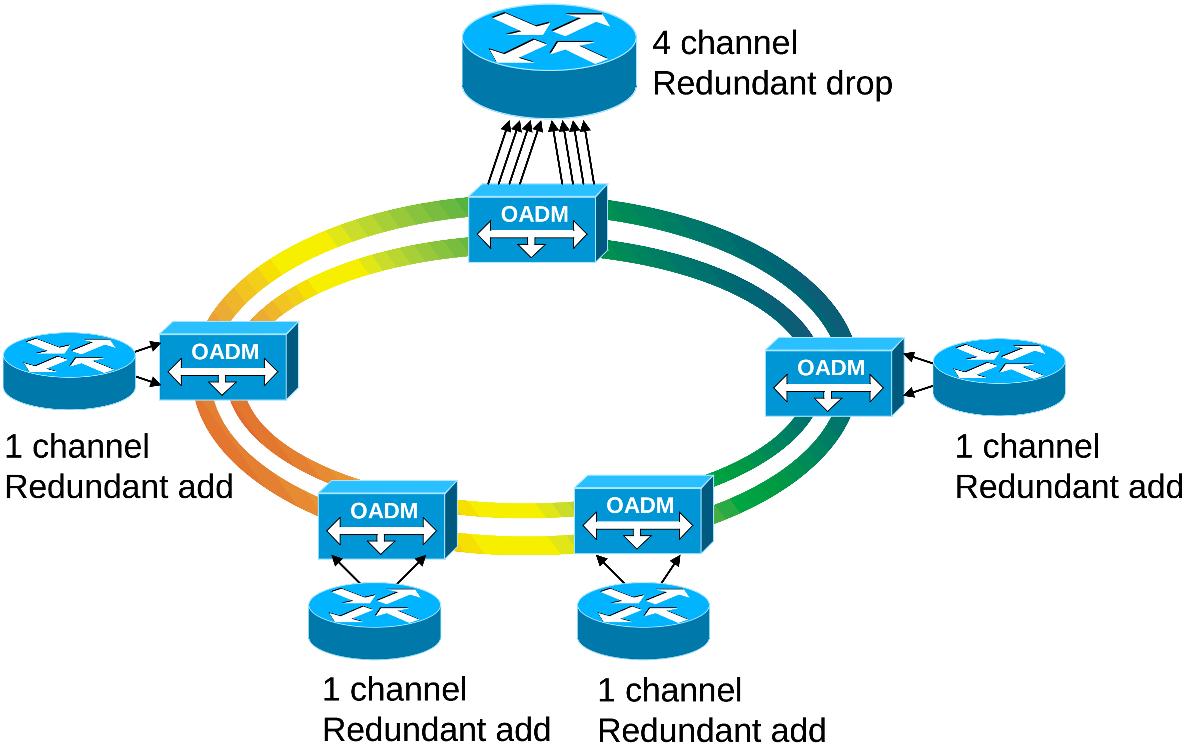

Figure 6, four node redundant optical aggregation ring using optical add/drop multiplexing. A single wavelength is dedicated to each of the edge nodes for each of the direction of the ring. A total of 8 wavelengths are dropped at the central aggregation node, achieving dedicated connectivity between the central node and each of the edge nodes.

Insertion loss of the MUX/DMUX units becomes especially critical for this type of application. Low insertion loss MUX/DMUX'es are required for achieving scalability with respect to transmission distance and the maximum number of add/drop nodes achievable in the ring. Using TransPacket's C1 low insertion loss MUX/DMUX in the add/drop implementation, the insertion loss contribution from the C1's will be a maximum of 4 X 3.4 dB = 13.6 dB. Using e.g. CWDM transceivers for Gigabit Ethernet with 32 dB power budget, there are still 18.4 dB left to tackle loss caused by attenuation in the transmission-fibre, patch-cords etc.