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What is WDM?

Wave Division Multiplexing

Point to point connections over Fibre

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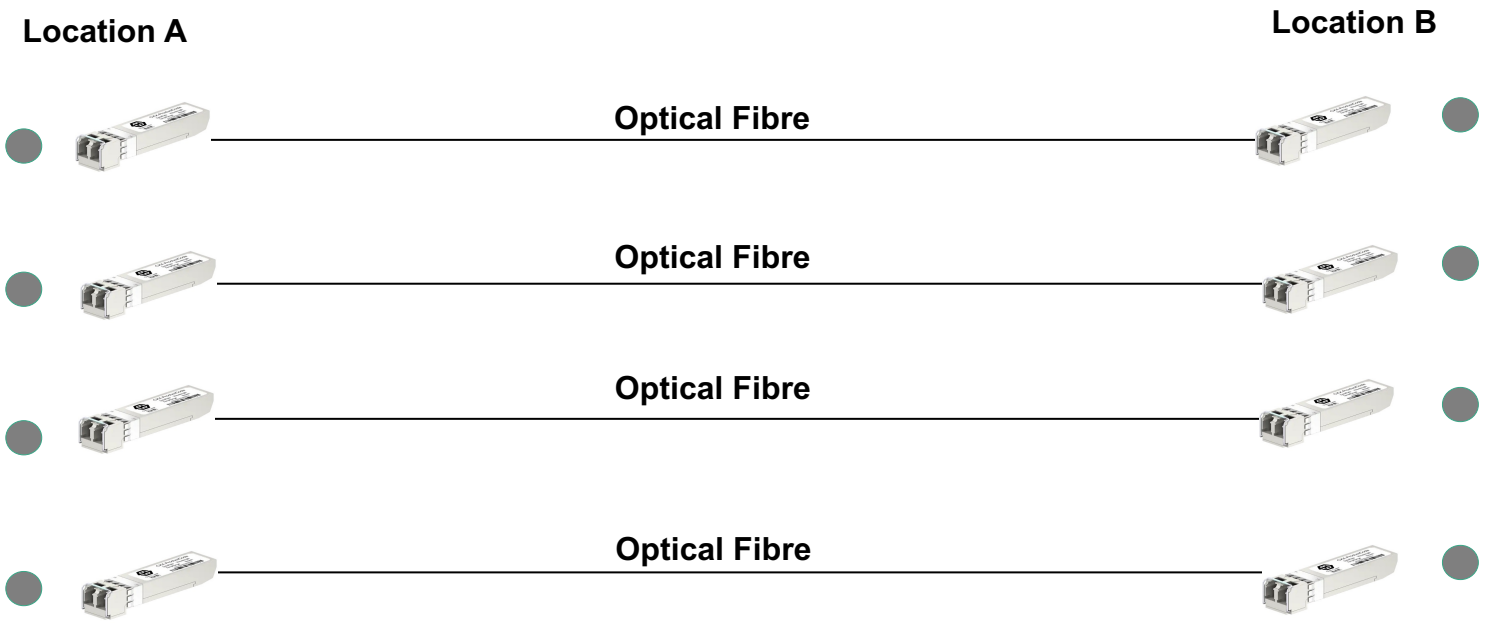
Plug in a *transceiver into the switch/router - using a separate fibre for each connection

*often referred to as ‘Grey’ transceivers – typically wideband 1310 or 1550



Great if you have lots of fibre

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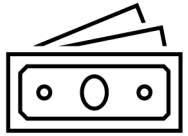
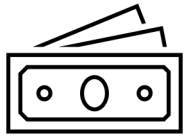
What if you don’t have enough fibre capacity?

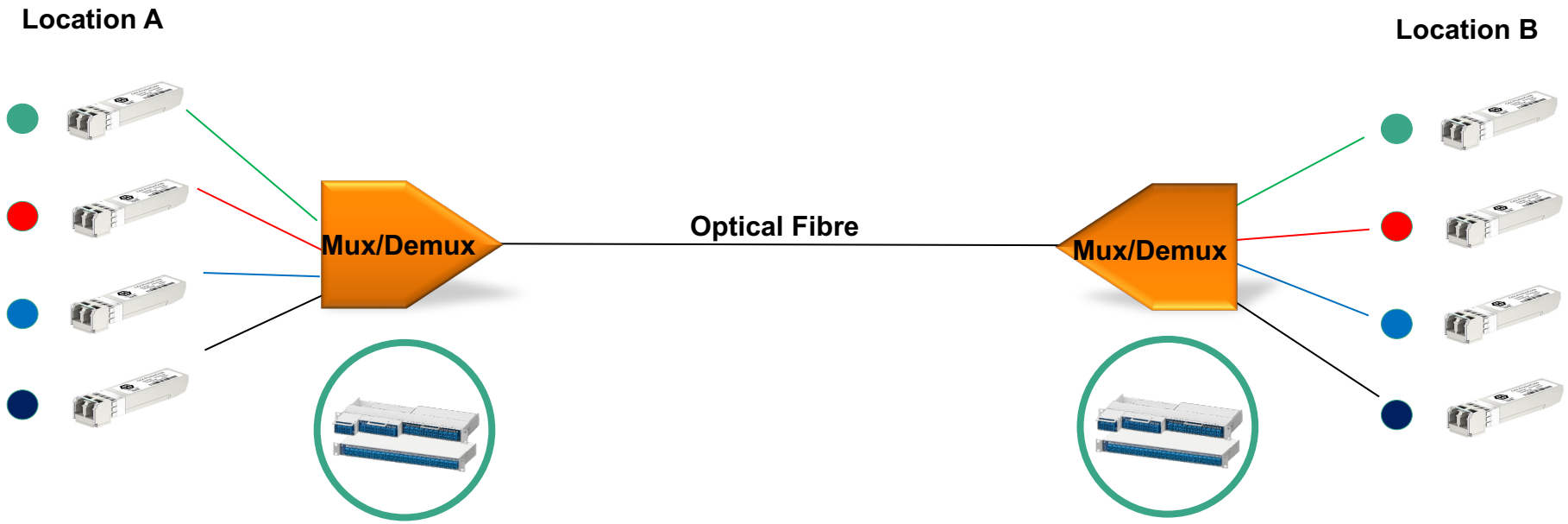
You could dig & install more fibre .... 

You could rent more fibre .... 

Or what about combing more connections over one fibre?

What if we could combine the colours (lambdas)?

- WDM is combining the matching colours (lambdas's) onto a single fibre pair
- We call that Multiplexing (combining) and DeMultiplexing (separating)
- Matching colours (Lambdas) at each end

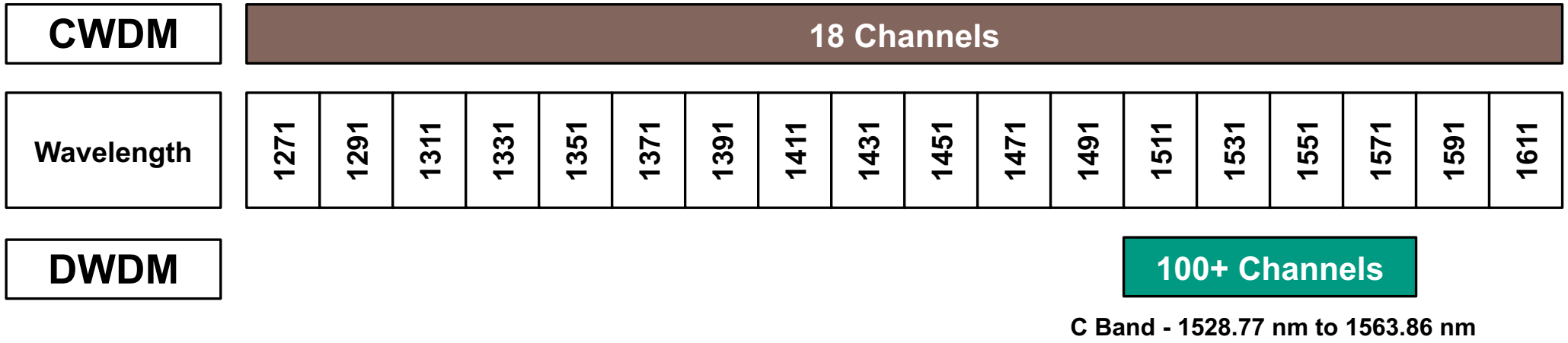


Types of WDM

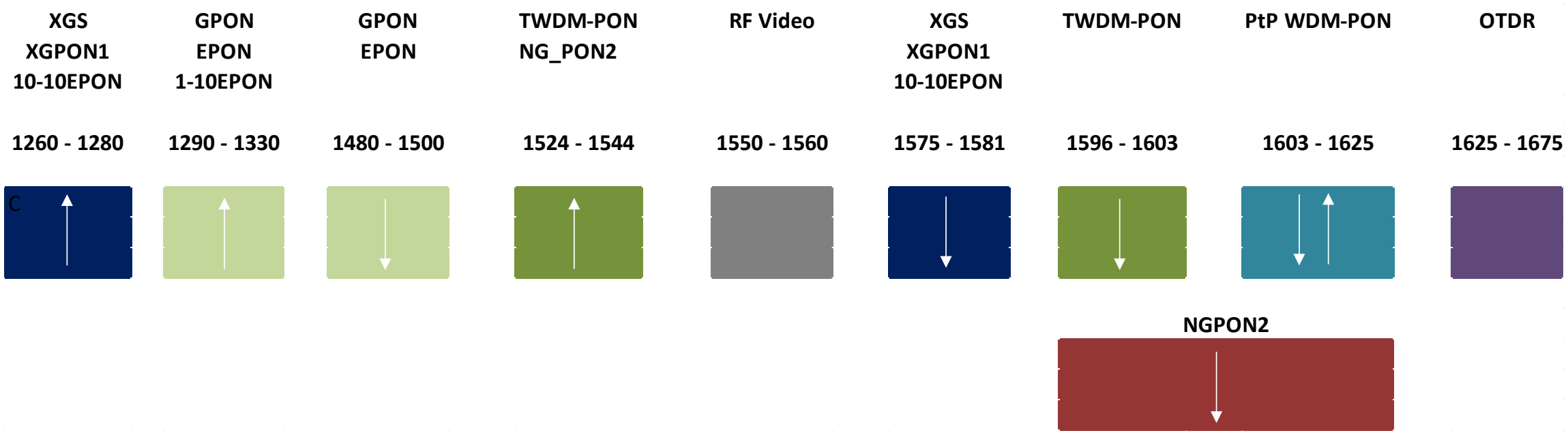
Coarse Wavelength Division Multiplexing (CWDM) 18 channels – ITU-T G.694.2

Dense Wavelength Division Multiplexing (DWDM) more than 100 channels - ITU-T G.709

DWDM channels are located towards the end of the CWDM spectrum. Therefore you can combine CWDM and DWDM on the same link.



What about PON?



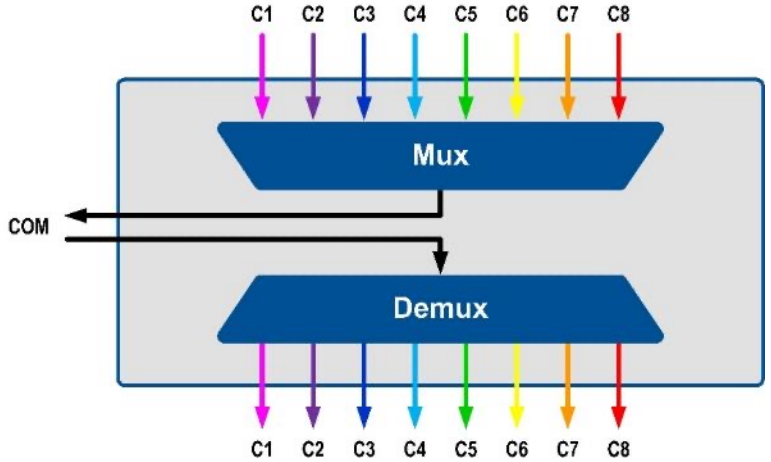
You can run WDM in conjunction with PON, Incl OTDR port

ITU-T G.984.5 (05/2018) Recommendation

WDM Types Mux/DeMux

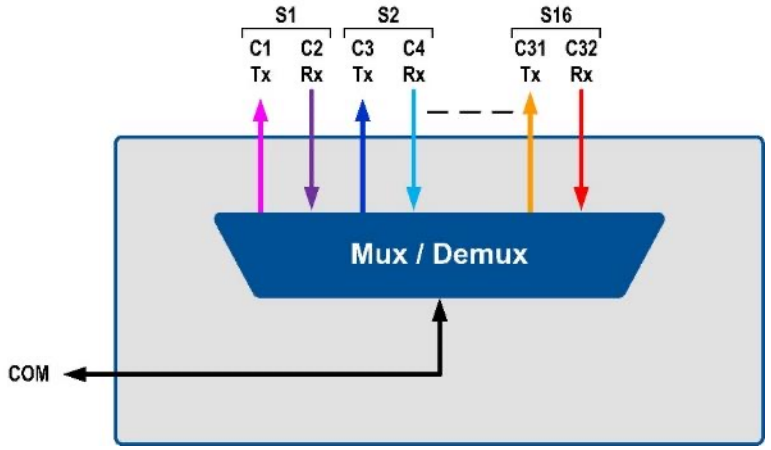
Dual fibre optical multiplexer/demultiplexer

- Uses two separate fibre connections for transmission (TX) and reception (RX).
- The number of wavelengths therefore is identical to the number of TX/RX channels.



Single fibre optical multiplexer/demultiplexer

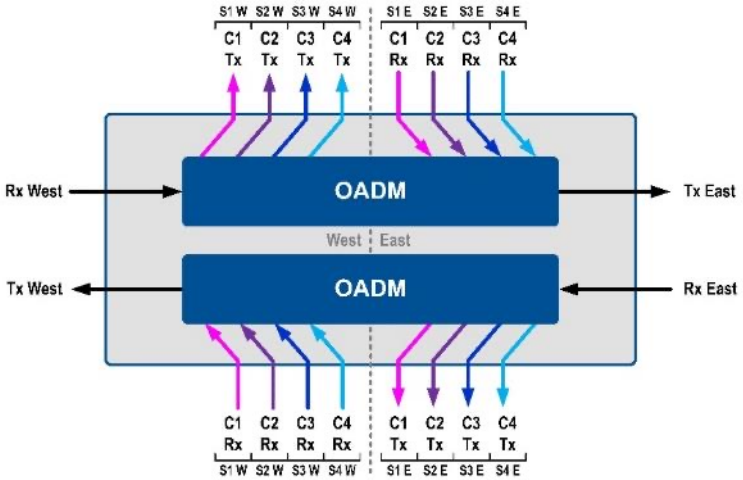
- Requires a single fibre for both transmission (TX) and reception (RX).
- The number of required wavelengths therefore is double the number of TX/RX channels.



WDM Types OADM

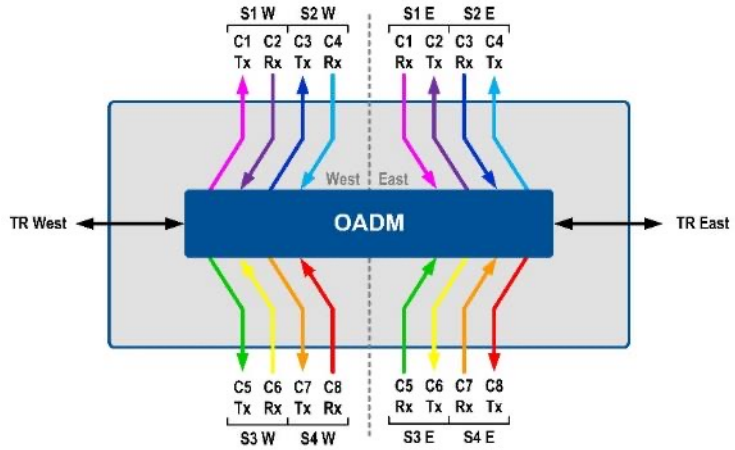
Dual fibre optical add/drop multiplexer

- East and West connection each uses a separate fibre for transmission (TX) and reception (RX).
- The number of add/drop channels is identical to the number of wavelengths.



Single fibre optical add/drop multiplexer

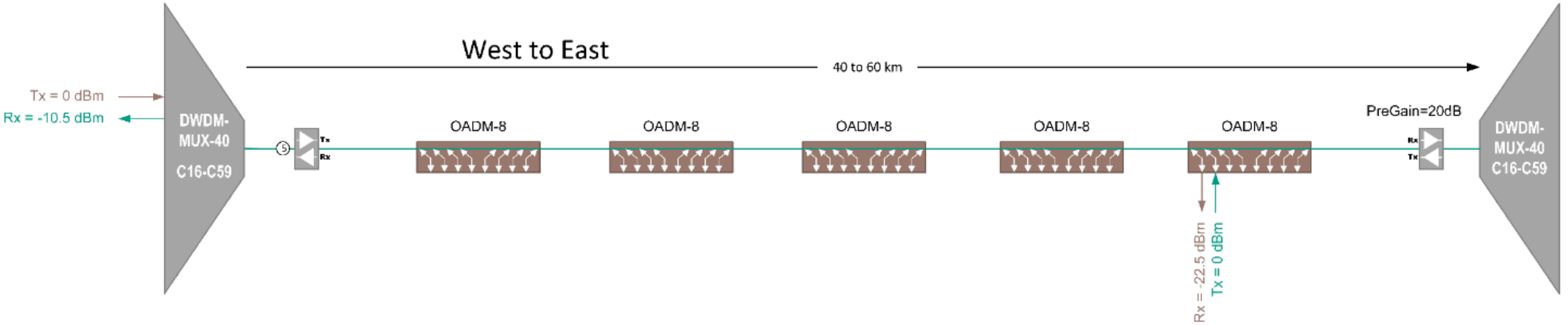
- East and West connections each only require a single fibre for TX and RX.
- The number of add/drop channels therefore is double the number of wavelengths.



Project Example

Customer requirements

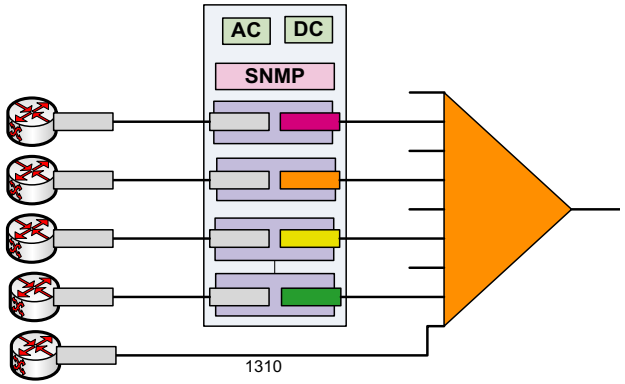
- Metro access DWDM link
- Reach 40 – 60 km
- Up to 5 intermediate drop nodes with 8 redundant services
- Monitoring channels at each node



Passive vs Active WDM

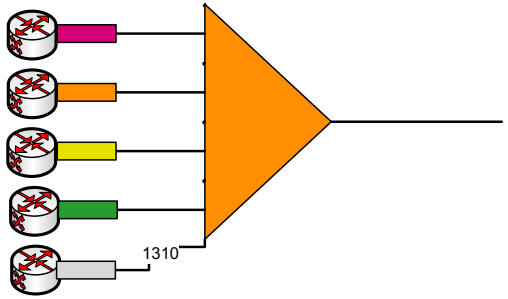
Active Transport System

- Conversion from client (“grey transceivers”) to line (“coloured transceivers”) signals by transponder cards
- Requires additional hardware, eg a chassis with power supplies and management system
- Cards are fixed to service type & speed
- Ideal if you need a remote demarcation device



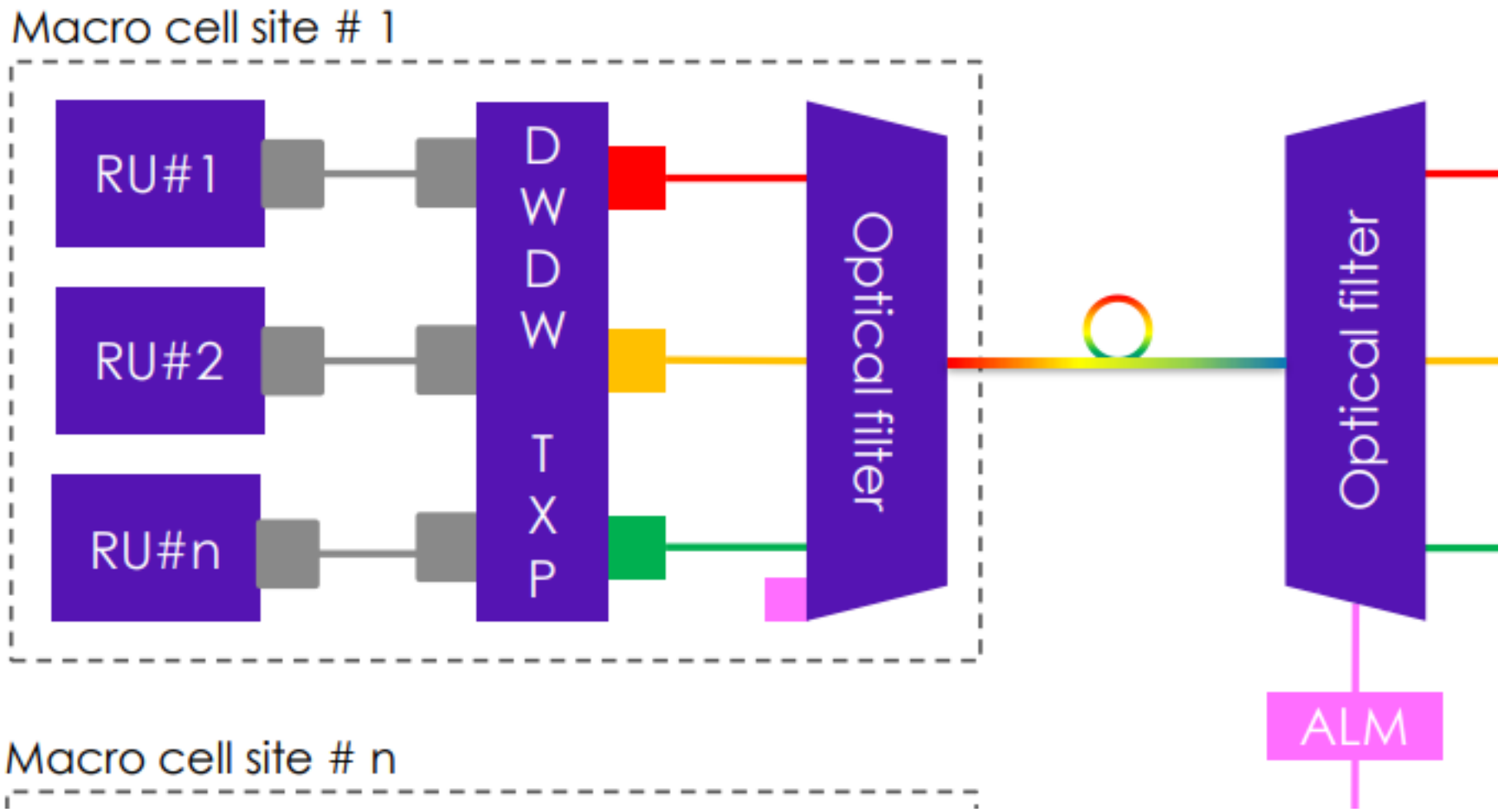
Passive Transport System

- Agnostic to service type, eg 1G, 10G, 25G, 100G, 400G….
- Fewer active elements => higher reliability, lower latency
- Passive system >80% power savings vs Active system
- Transceivers must be installed in end equipment (Switch/Router etc.)



Source: xHaul Technology & Economics (macro-cell centric)

A Sutton

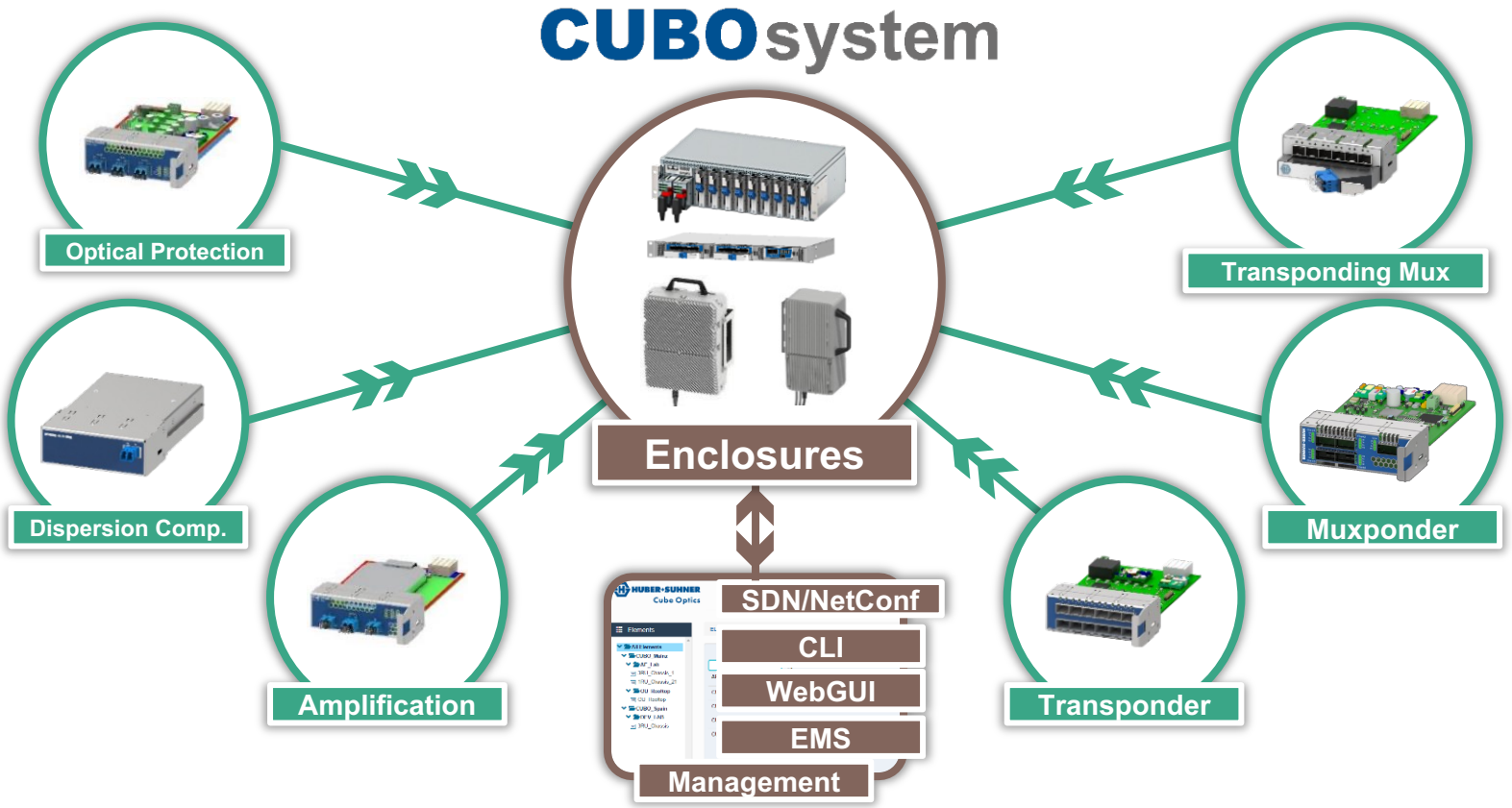


Active system at Macro site.

Passive system at Central Office

What about…..

- Transponder
- Muxponder
- Amplification
- Dispersion Compensation
- Optical Protection
- Power supplies
- Management



These are important if building an Optical Transport System, but not strictly WDM

Some additional parts for Optical Transport Networks

- **Transponder**
  - Transponds one wavelength (lambda) to another wavelength (lambda), eg Grey to Coloured
- **Muxponder**
  - Combines more than 1 wavelength onto 1 wavelength, (eg 4 x 100G onto 1 x 400G)
- **Dispersion Compensation**
  - Cancelling/limiting the chromatic dispersion
- **Amplification**
  - Amplifies signal. Most Amp's work around 1550 (DWDM). You can amplify at 1310 (CWDM)
- **Optical Protection**
  - Automatic switch over to another fibre. Quicker than L2/3 re-route

You can choose:

- Vendor lock-in

or

- Open Line System

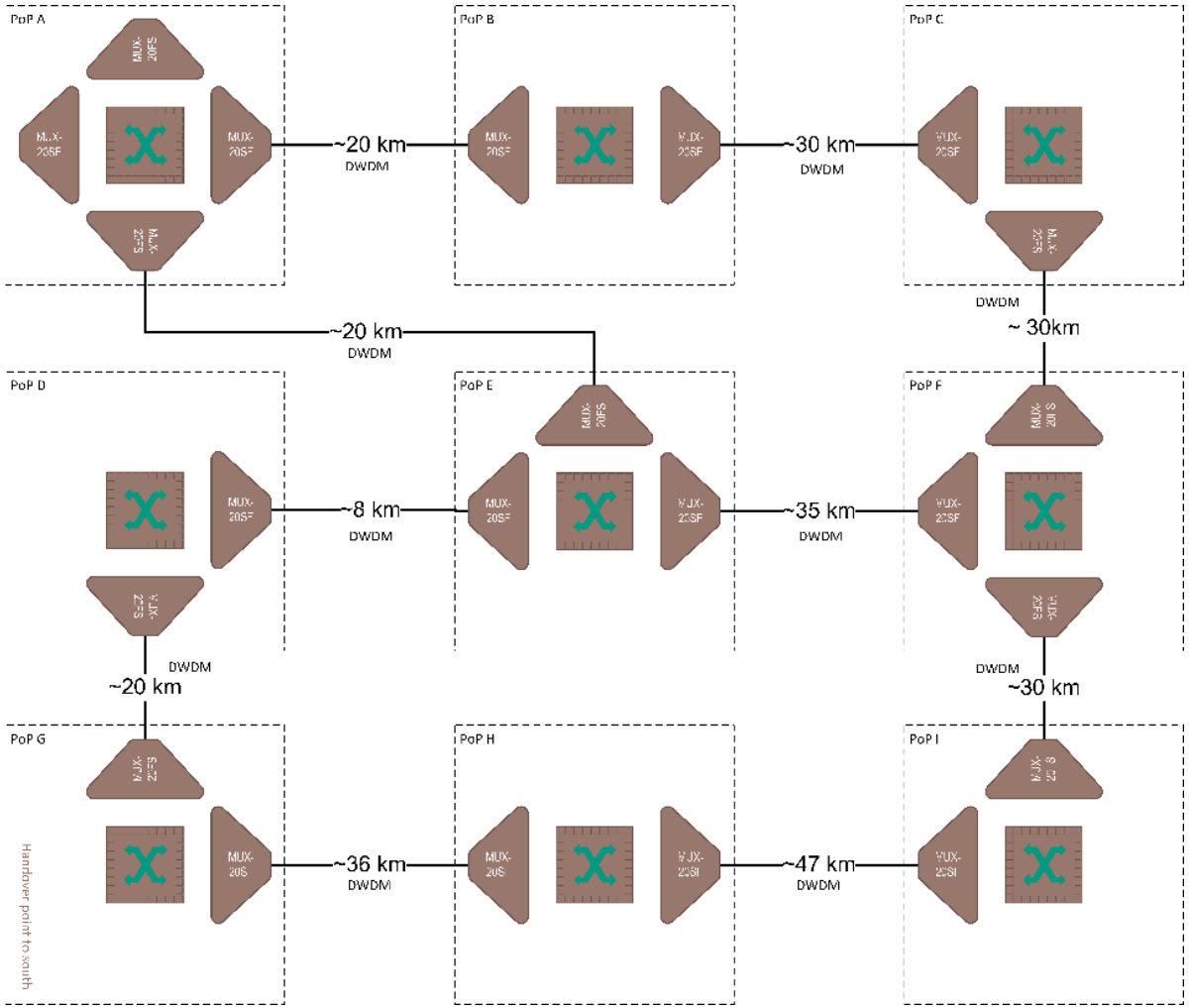
Project Example – ISP backhaul (PON network)

WDM Units

- **Passive DWDM ‘Single Fibre’**

Active Units

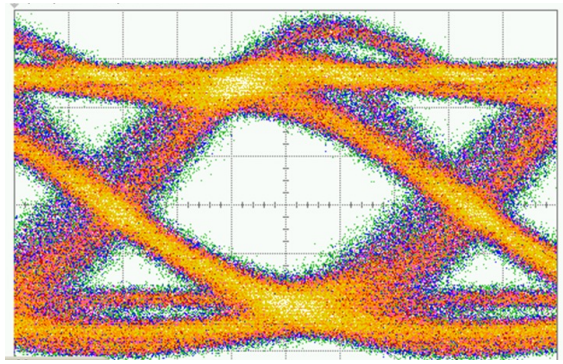
- **EDFA modules**
- **Dispersion Compensation modules**



So how do you get higher speeds …100G, 400G etc?

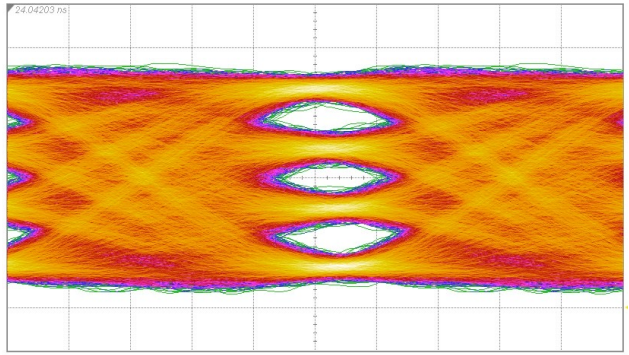
Modulation formats

Direct Detect: NRZ



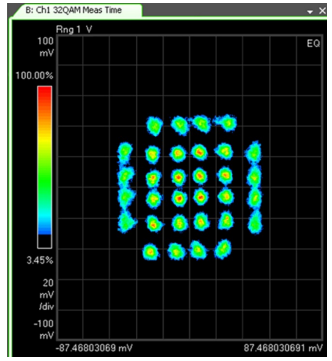
- Uses two states 1 and 0 in amplitude.
- Higher attenuation allowed compared to PAM4.
- Base modulation for direct detect for up to 25G per lane.

Direct Detect: PAM4



- Uses four states 00,01,10 and 11 in amplitude.
- Allows double the data rate compared to NRZ with same baud rate.
- Standard modulation for direct detect > 25G per lane.

Coherent: QAM

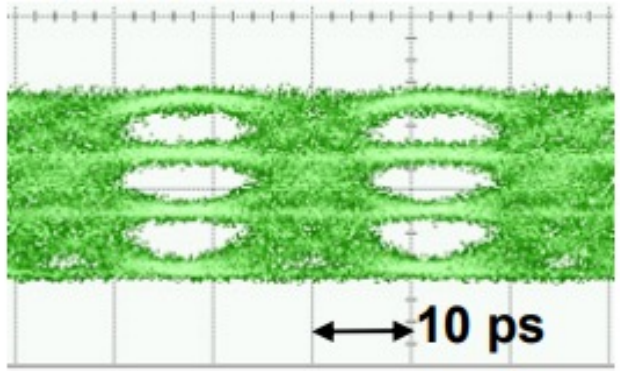


- Uses multiple states in amplitude and phase.
- Allows higher data rate for similar baud rate than NRZ and PAM4
- Coherent requires more complex modulation and demodulation than direct detect.

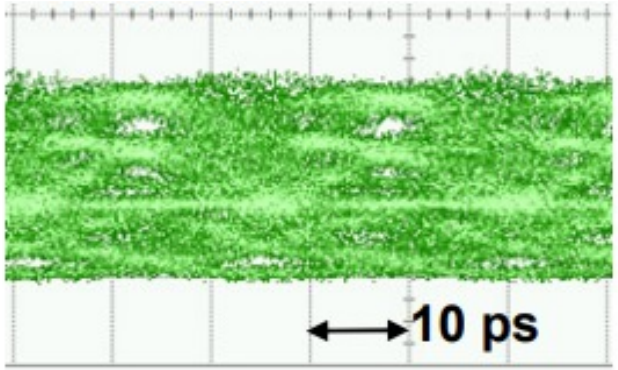
Dispersion & Attenuation

Dispersion on PAM4 signal

no dispersion

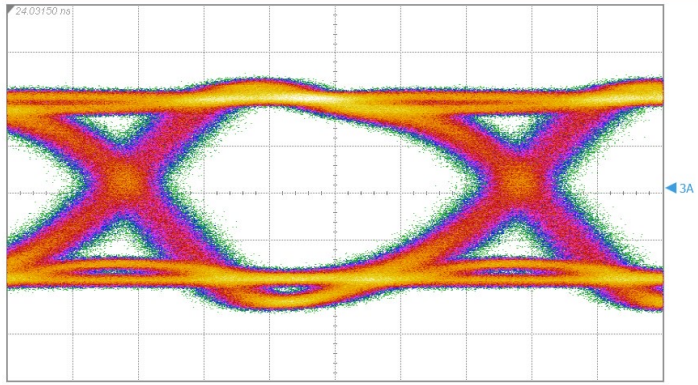


86 ps/nm dispersion

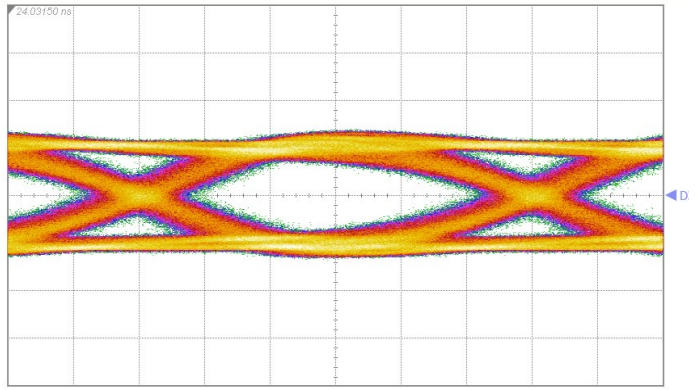


Attenuation 25G NRZ signal

-5dBm @ receiver



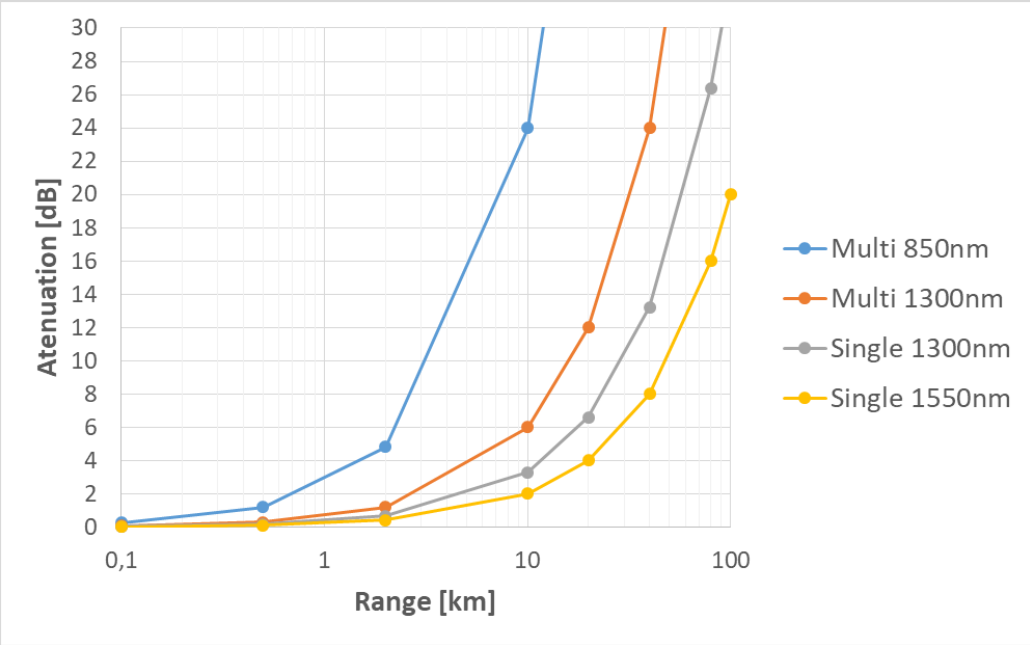
-10dBm @ receiver



- Dispersion causes Jitter on signal limiting reach.
- PAM 4 signal is more sensitive to dispersion and attenuation than NRZ.

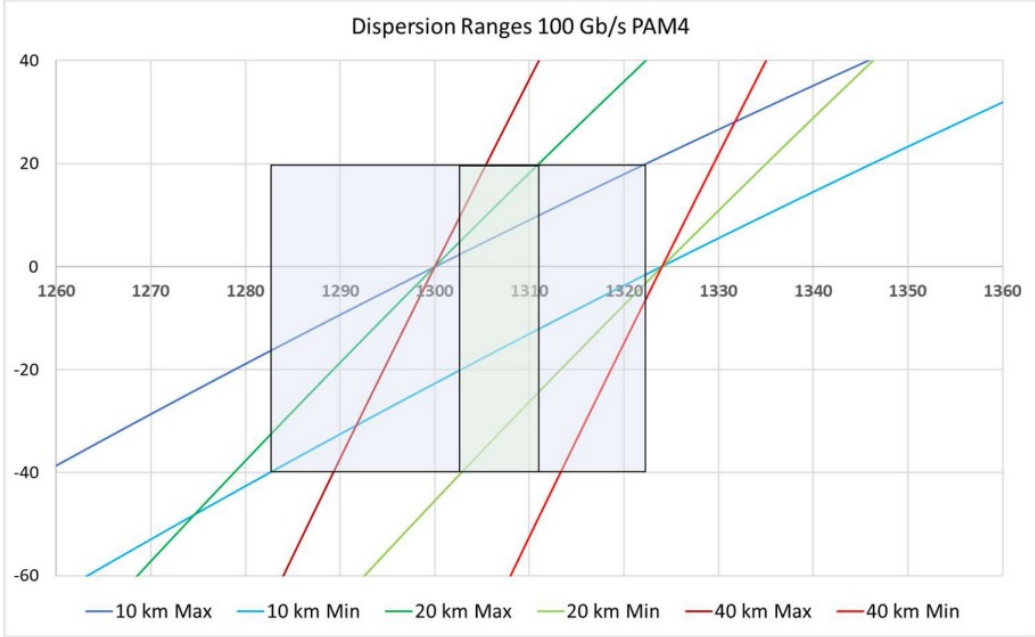
Dispersion & Attenuation for fibers

Attenuation for different fibers



- Lowest attenuation for single mode 1550nm.

Dispersion depending on reach



- Acceptable dispersion for 100Gb/s PAM 4 is -40 - +20ps/nm.
- Dispersion is lowest in 1310nm range
- Dispersion is limiting possible wavelength area for direct detect.

Conclusions

- Deploying WDM is much more cost effective & significantly quicker than installing new fibre
- An active WDM system is beneficial in certain circumstances, eg demarcation point
- A passive WDM system is beneficial in certain circumstances, eg lower power/lower latency
- Decide if you want a vendor lock-in (everything from one vendor) or Open Line Systems
- Transceivers/Transponders define the speed – not WDM
- Higher speeds – 100G, 400G..etc – modulation, disruption, attenuation, create challenges

All vendors use the same ITU WDM grids

This presentation does not seek to address the complex commercial complications

Many thanks

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Backup slides

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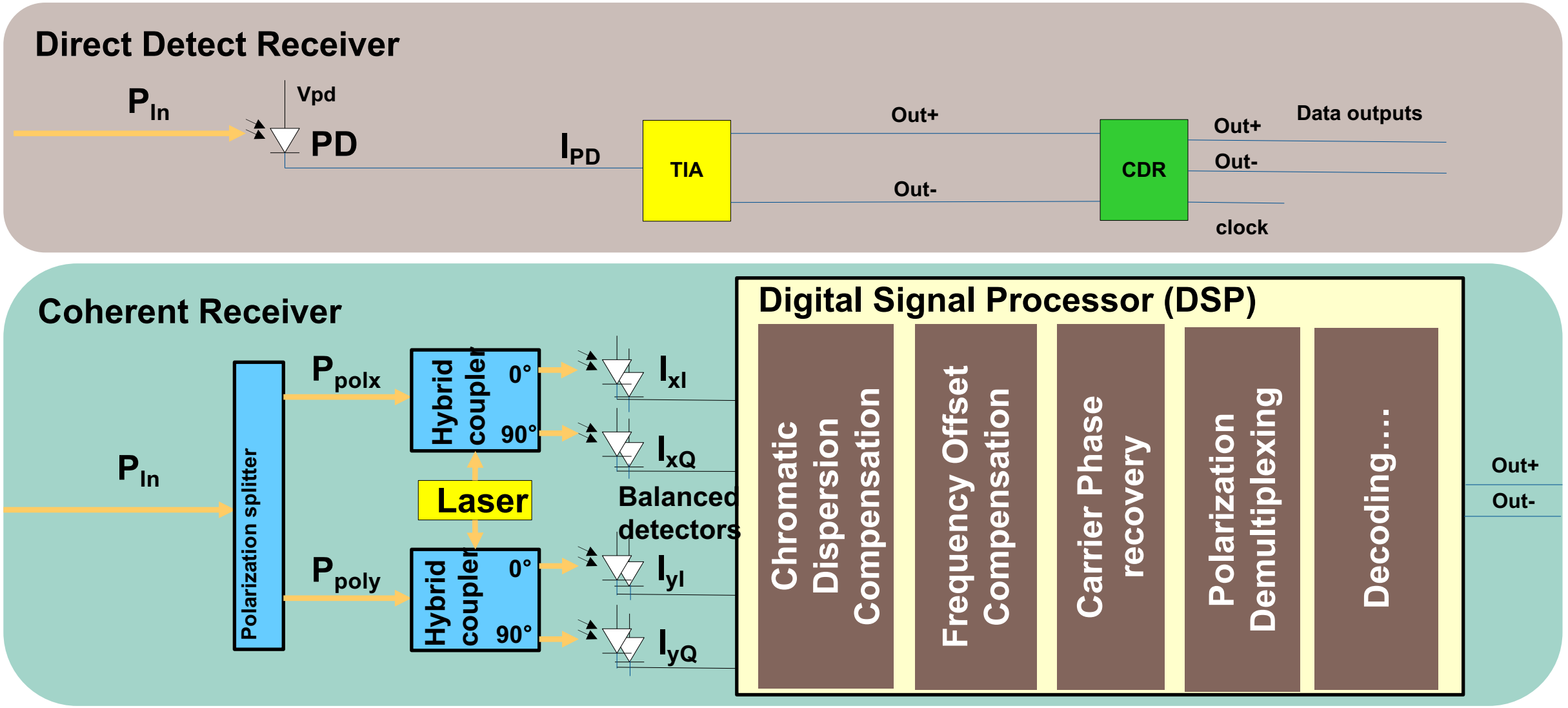
Direct Detect vs. Coherent Receiver



Coherent or Incoherent – Outline & Basics

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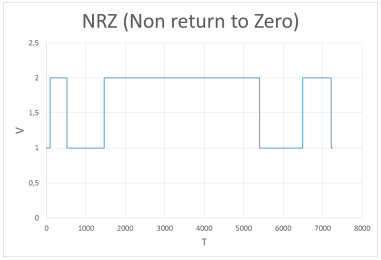
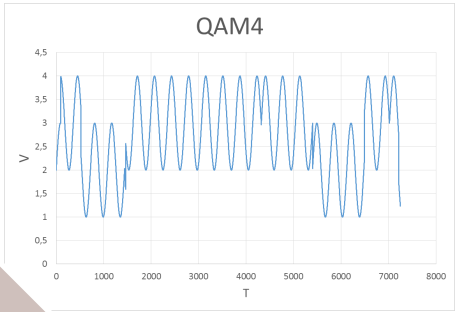
Direct Detect

- Simple modulation (Amplitude NRZ / On-off keying to Pulse Amplitude PAM4)
- Hence simpler (lower cost) electronics
- Sensitive to dispersion effects



Coherent

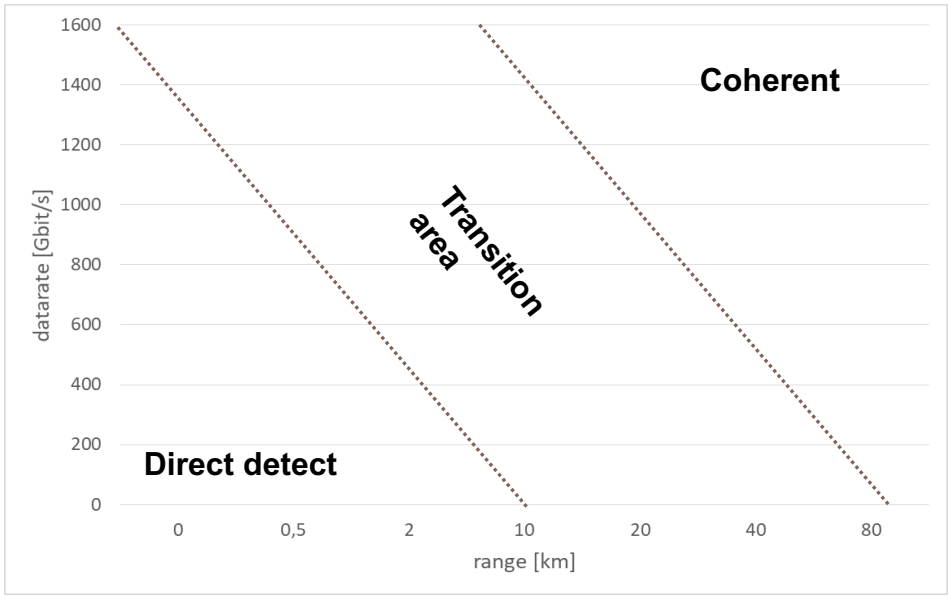
- Advanced modulation (QPSK, 8QAM,.. 64QAM to PM-QPSK), Amplitude, Phase and Polarization (12x capacity / lambda)
- Hence requiring high-end (higher cost) additional analogue electronics (additional laser oscillators, DSP chips etc)
- Compensates dispersion effects



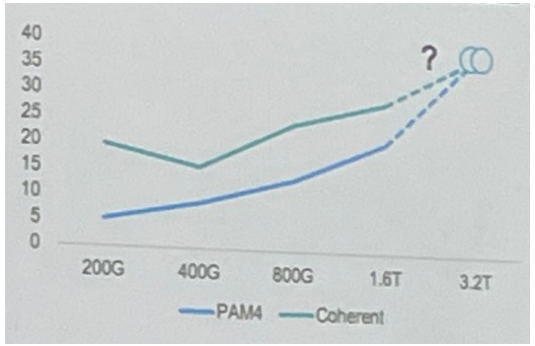
Dispersion effects grow with data rate and distance

The higher the bit rate &/ distance, the more DD is replaced by Coherent

Coherent vs Direct Detect Summary



Power consumption Im-DD transceiver projection



- For higher reach and data rate, direct detect is getting more and more complex increasing price and power consumption.
  - **DSP is required for equalization.**
  - **Dispersion needs to be compensated.**
- For higher data rate spectral efficiency is getting more important.
- Also coherent is significant improving price and power consumption due to integration and smaller IC structures.
- For transition area also other parameters are important for choice of available transceivers like available wavelengths, switches…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