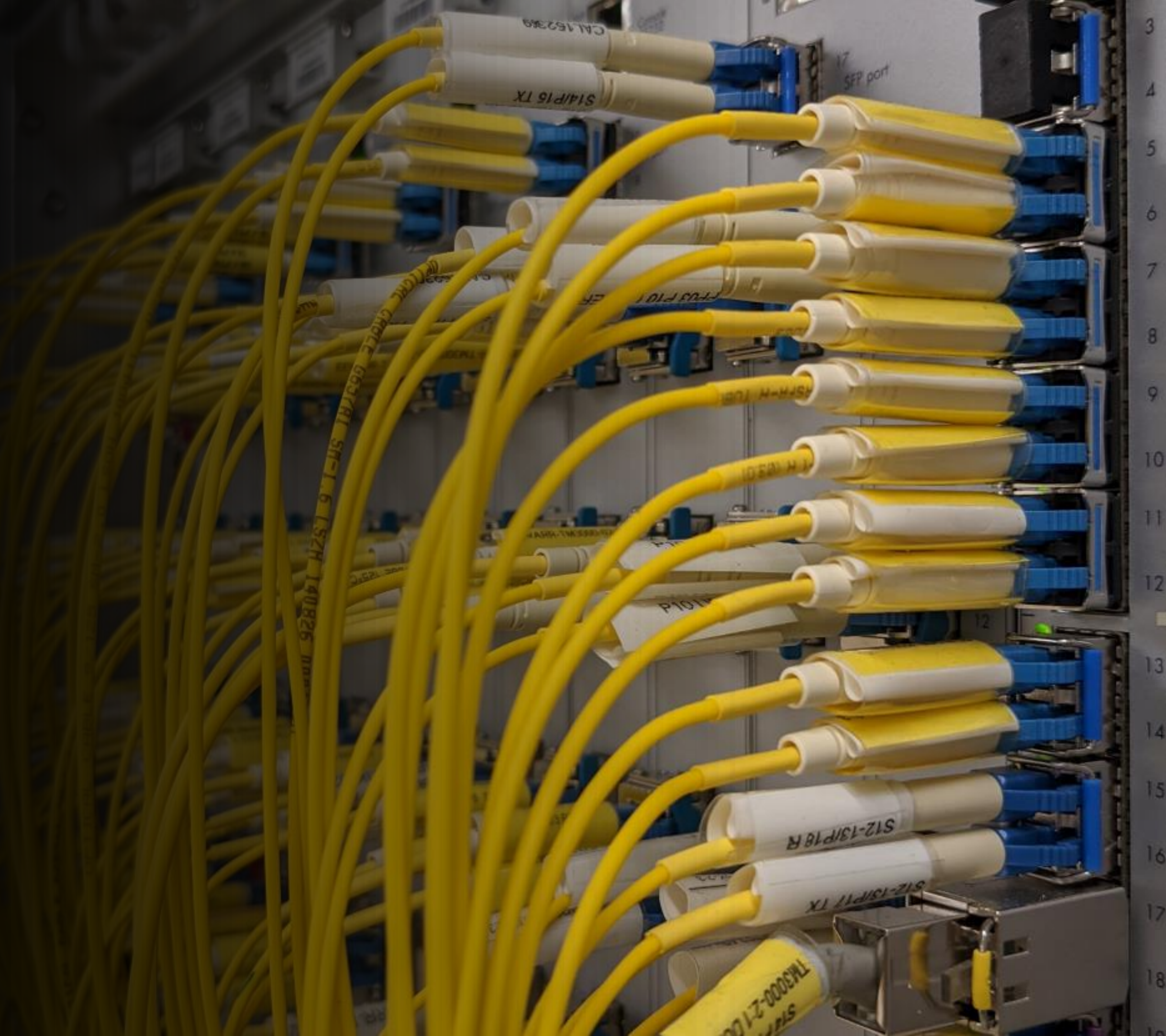
Fibre Optic Cables & Optical Networking - the optimal connectivity solution



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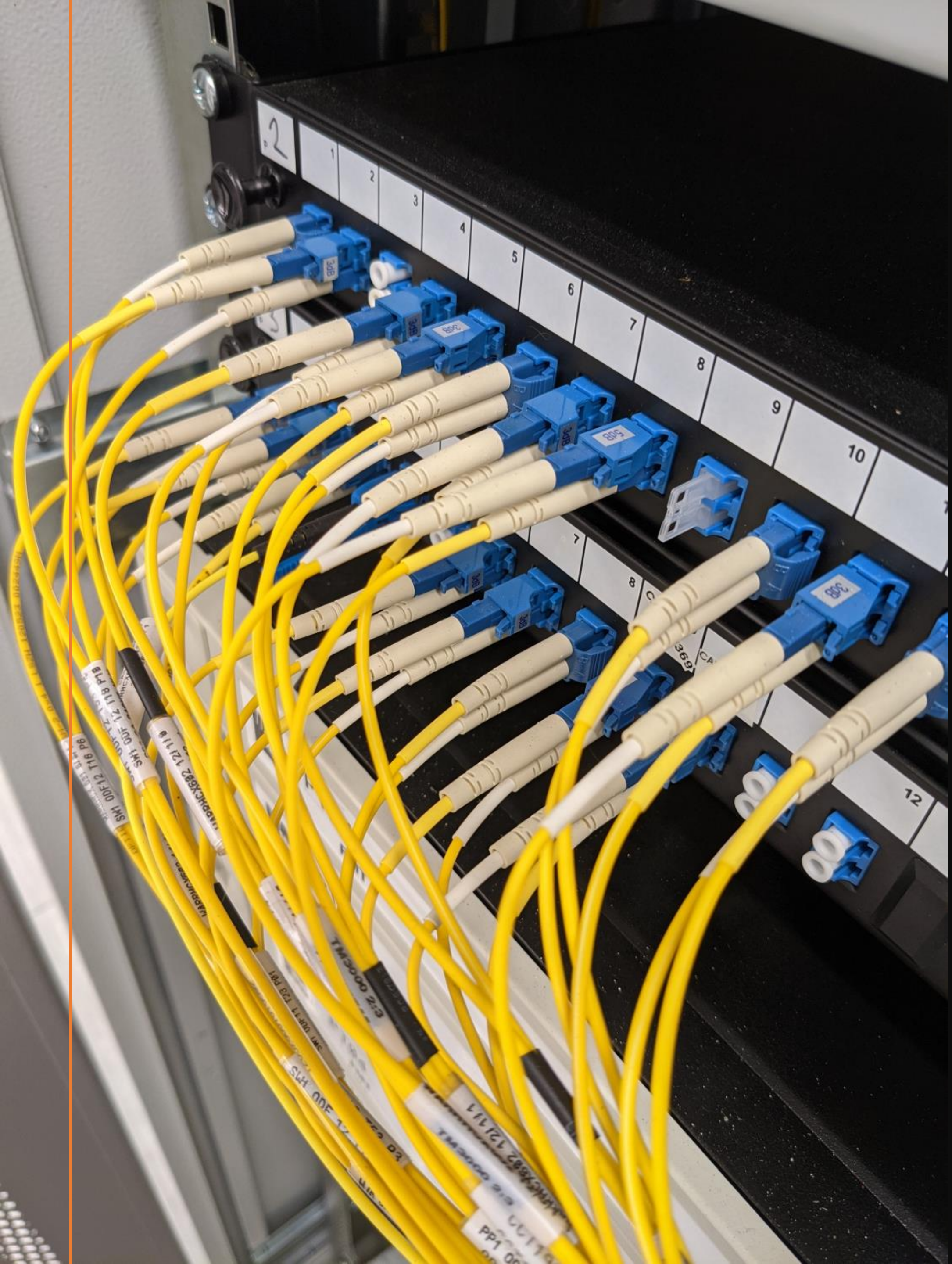
SO2 Tech Futures

Specialist Group Information Services (SGIS)

4th July 2024



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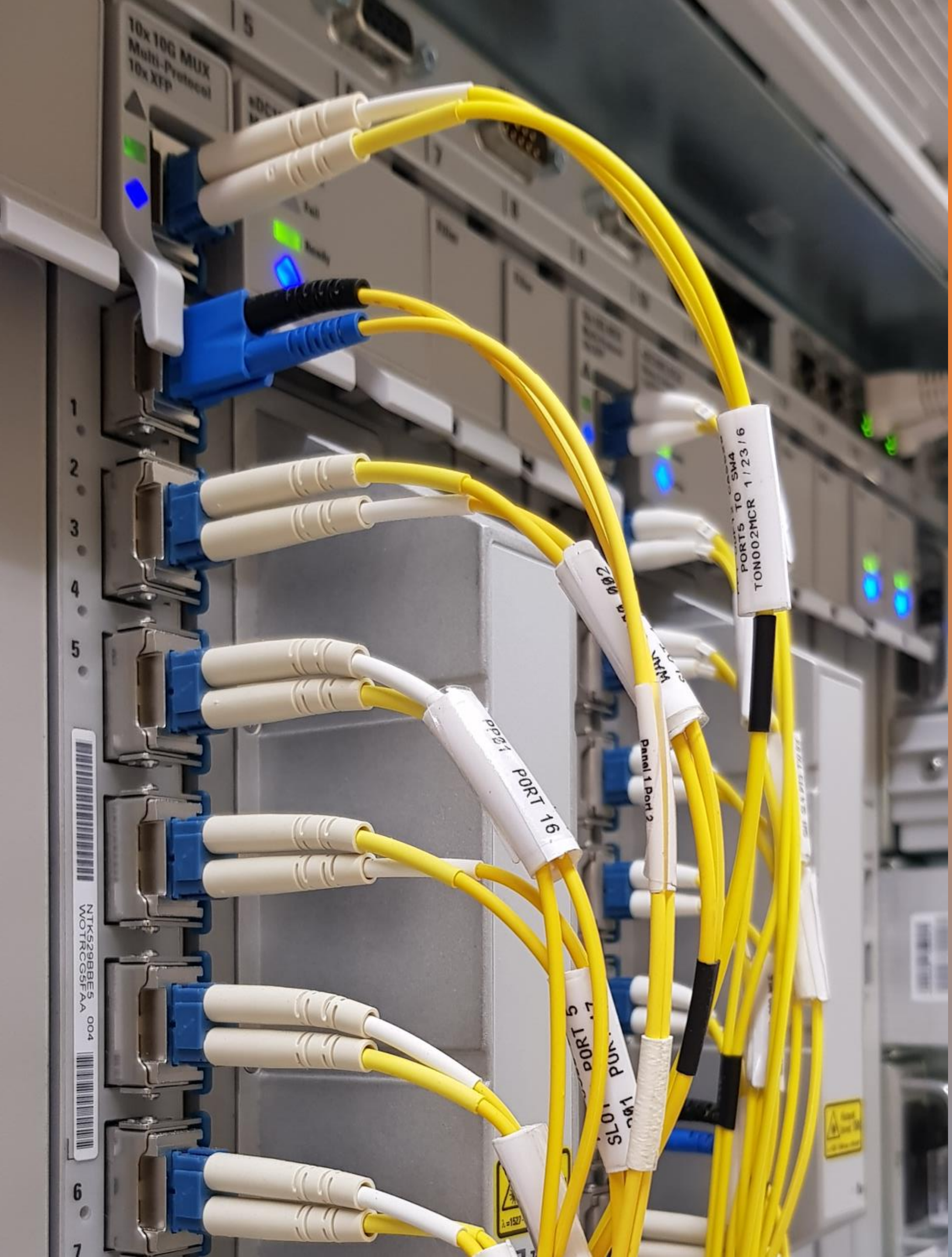
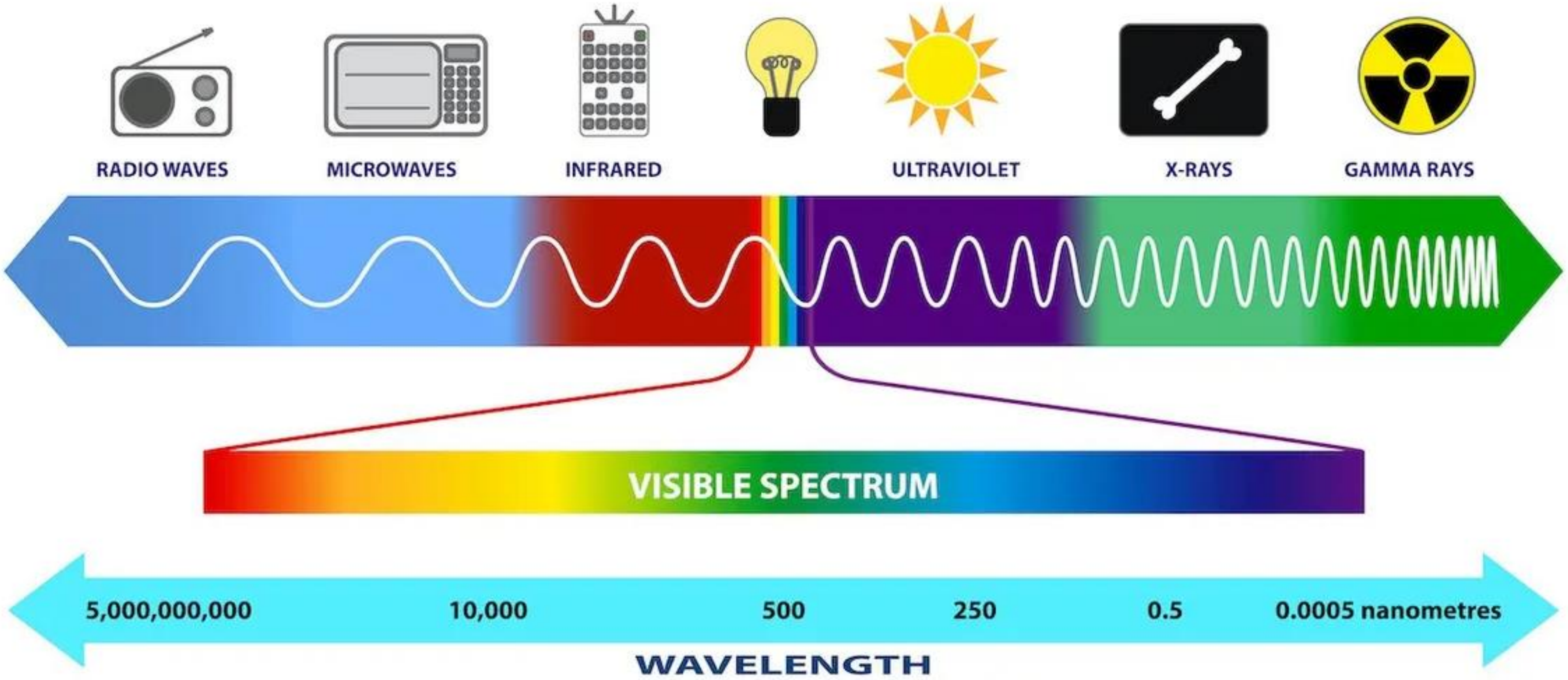
- A brief overview of optical fibre communications principles
- Dense Wavelength Division Multiplexing (DWDM)
- Fibre access solutions
- National core fibre networks
- Submarine fibre networks
- RF over fibre
- Summary



A brief overview of optical fibre communications principles

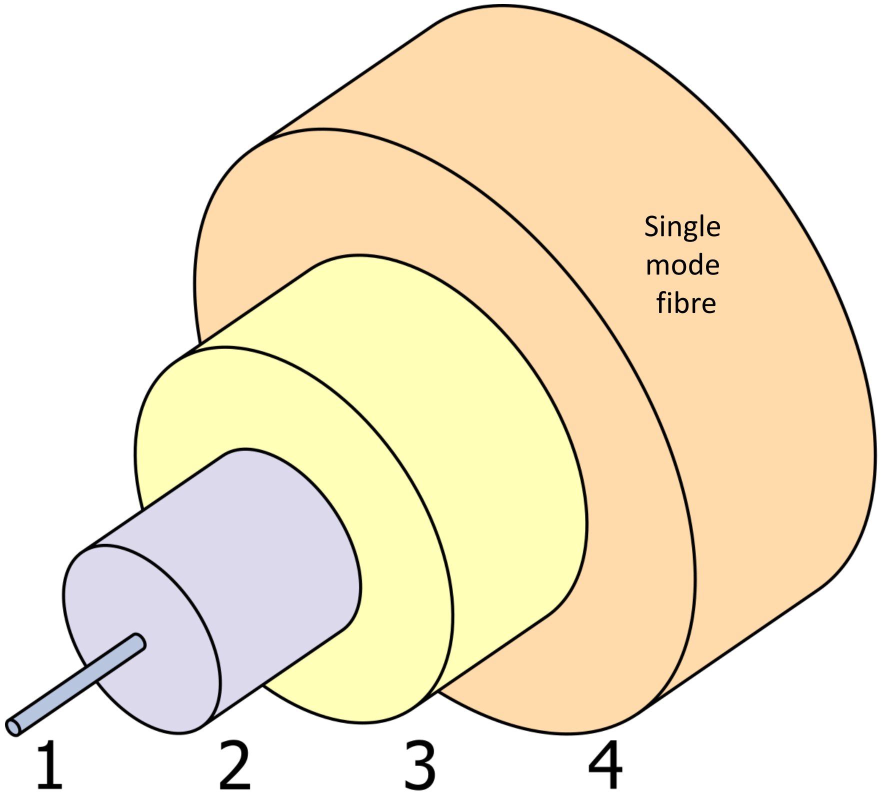
Optical transmission is in the infra-red electromagnetic spectrum band



- Source: https://www.space.com/what-is-the-electromagnetic-spectrum

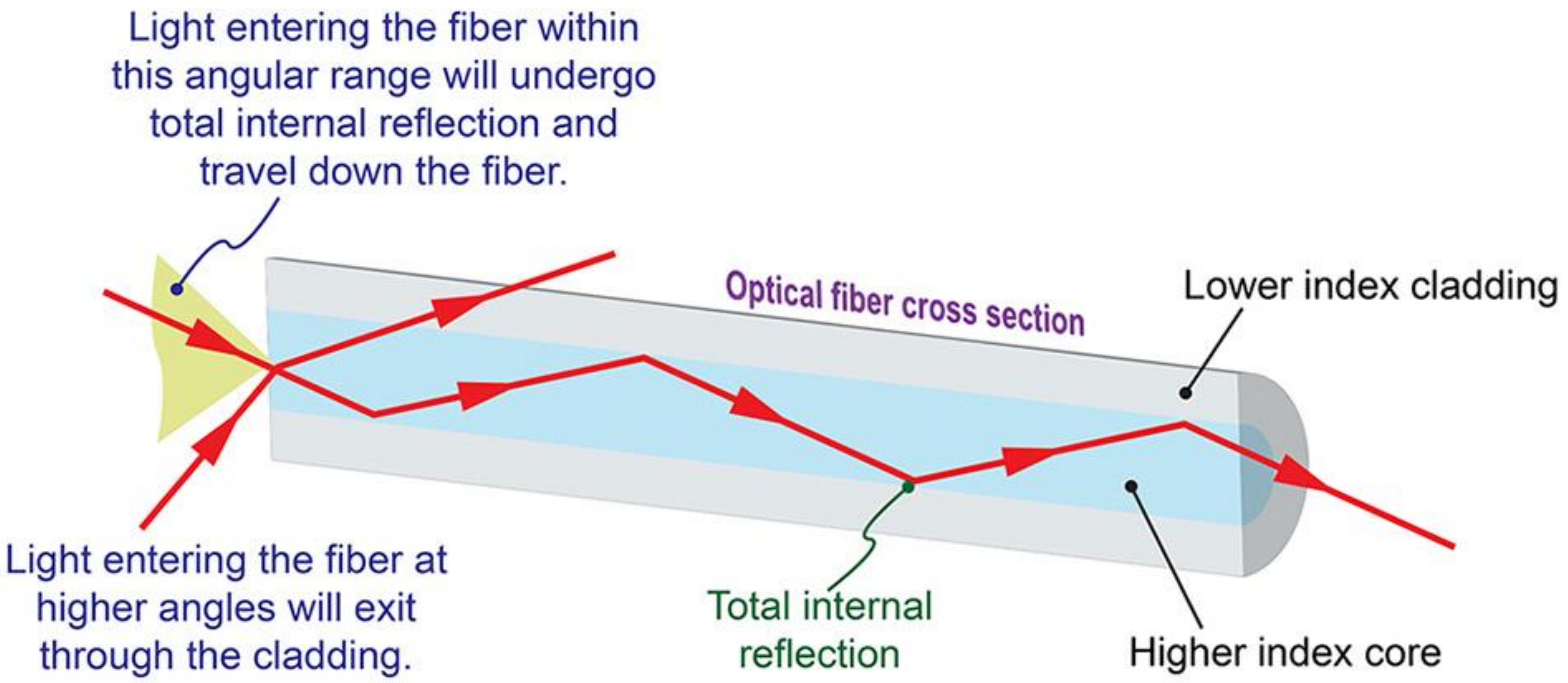
How does optical fibre work?

- Fibre is essentially a waveguide for light
- Uses a principal known as total internal reflection
- Fiber cables are internally composed of two layers
  - the core and the cladding
- The core layer is surrounded by the cladding layer
  - the cladding layer has a higher index of refraction than the core
- When light tries to pass from a lower to a higher index of refraction, at the correct angle, it is reflected back
- This causes light to be continuously reflected into the core, allowing the light to travel to the other end of the fibre



1 - Core 8–9 μm diameter
2 - Cladding 125 μm diameter
3 - Buffer 250 μm diameter
4 - Jacket 900 μm diameter

Basic operation of an optical fibre



- Source: https://www.coherent.com/news/glossary/optical-fibers

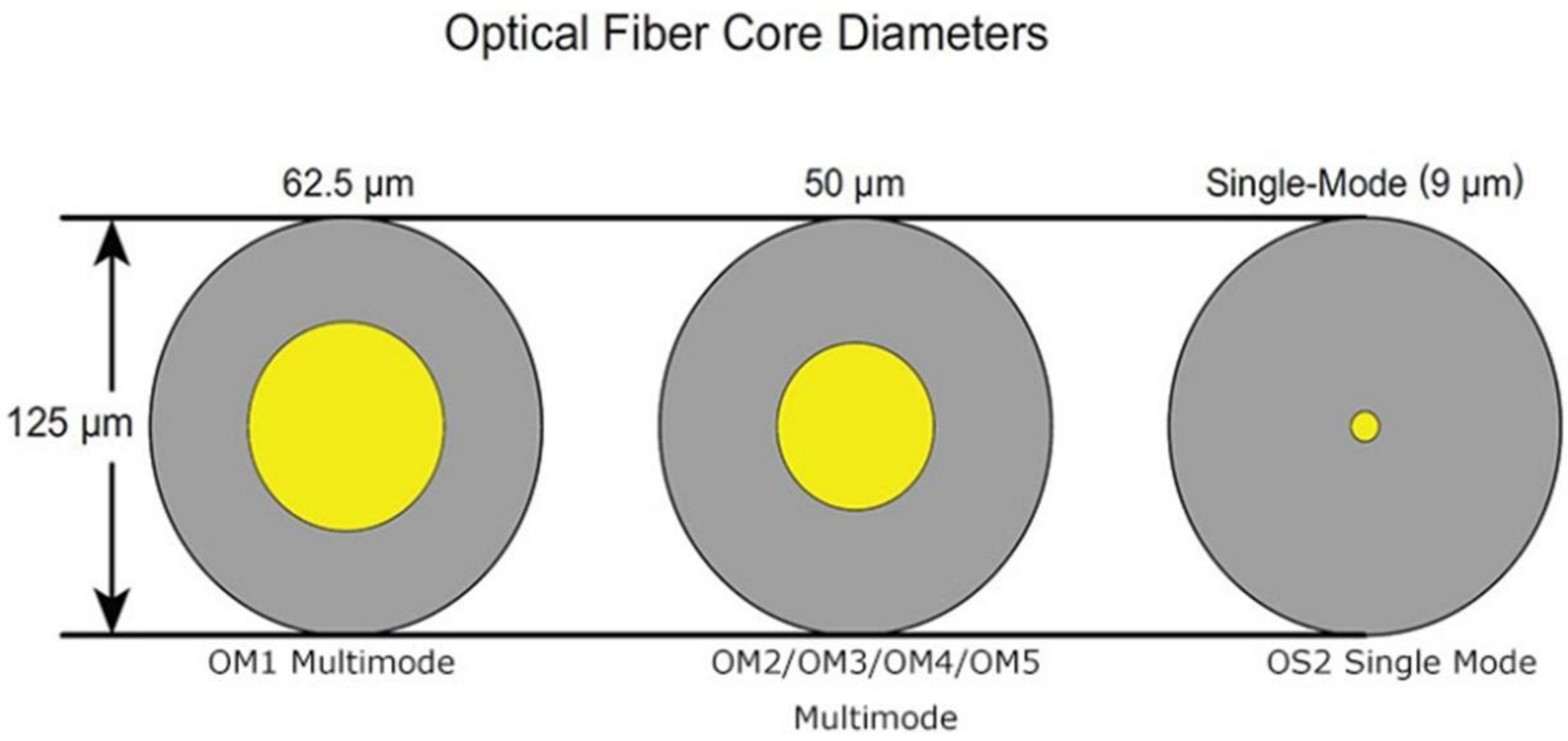
Types of fibre

- Single-mode

- Single-mode fibres have a core diameter that is so small that only the lowest (and physically smallest) transverse mode can propagate
- This impacts performance in several ways:
- For telecommunications applications, it reduces fibre attenuation and dispersion
- This is why single-mode fibre is the most widely used type for long-haul telecommunications
- The output of a single-mode fibre can be focused to the smallest possible spot size
- This makes them useful for many scientific and industrial laser applications, particularly in the construction of fibre lasers
- Typically, in the 1270nm to 1625nm range

- Multi-mode

- These have core diameters large enough to permit higher-order transverse modes to travel through the fibre
- This typically enables them to transmit more optical power, but they also suffer from higher dispersion
- They’re also typically less costly to manufacture than single-mode fibres
- Together, these characteristics make them popular for short-haul data-comms applications (often within data centres)
- They’re also widely used for beam delivery with higher-power lasers in materials processing, surgical, and spectroscopic applications
- Typically operates at 850nm or 1310nm



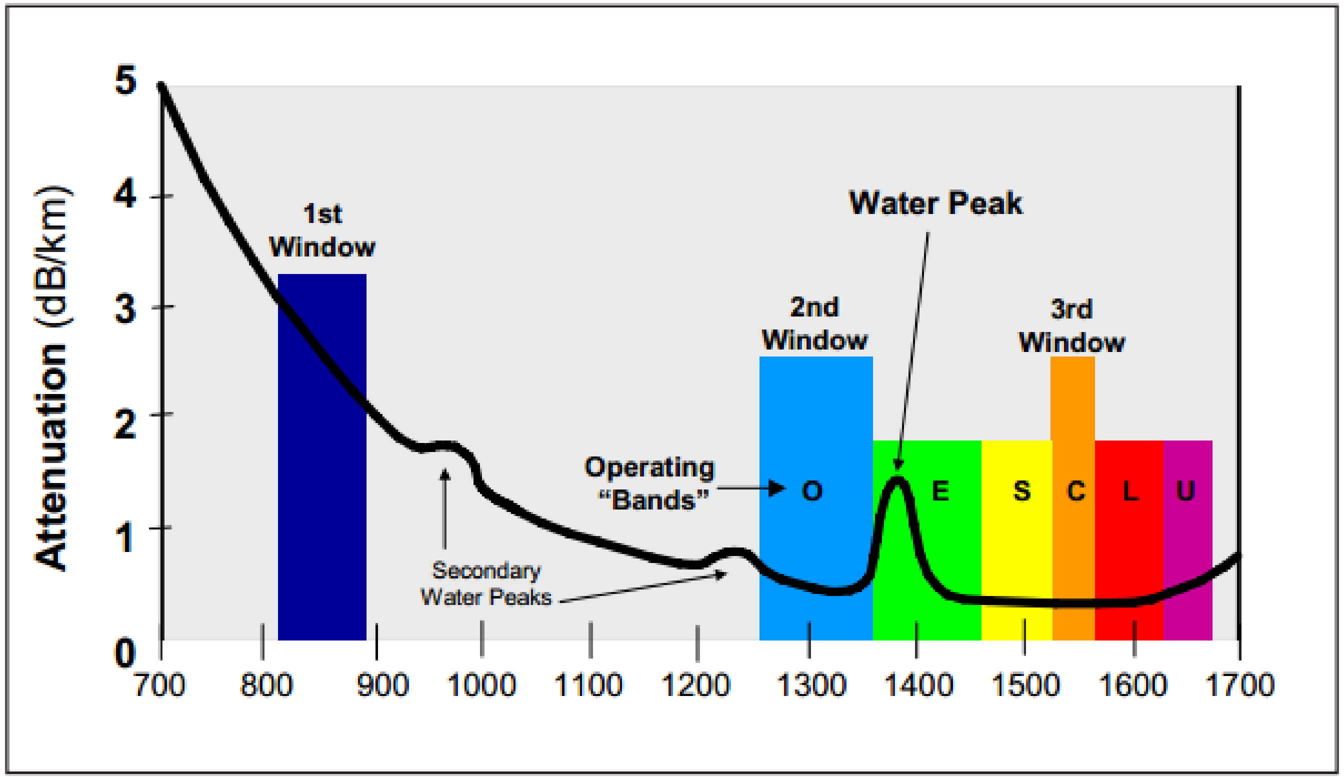
- Source: https://community.fs.com/article/single-mode-cabling-cost-vs-multimode-cabling-cost.html

Attenuation in optical cables

- Single-mode fibres usually operate in the 1310 nm or 1550 nm regions, where attenuation is lowest

- This makes single-mode fibres the best choice for long distance communications. Multimode fibres operate primarily at 850 nm and sometimes at 1300 nm

- Multimode fibres are designed for short distance use; the higher attenuation at 850 nm is offset by the use of more affordable optical sources (the lower the wavelength, the less expensive the optics)



- Source: http://fowiki.com/b/understand-fiber-attenuation/

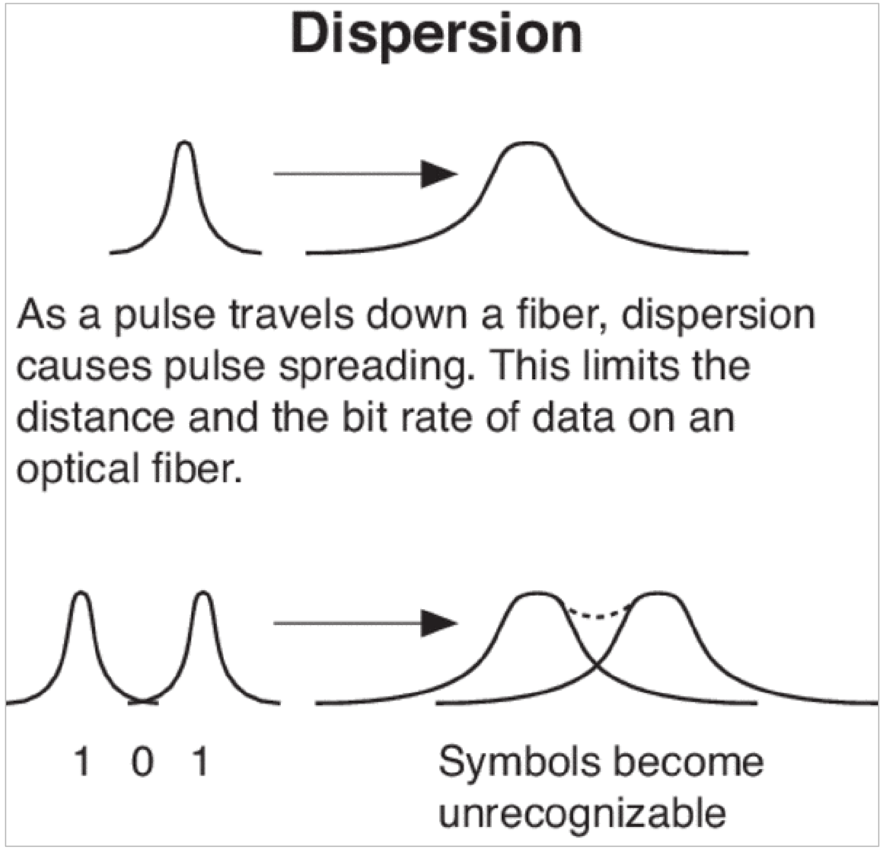
Dispersion in optical cables

- Dispersion simply means to spread out - In optical networking, this results in signal degradation

- There are two main types of dispersion to deal with:

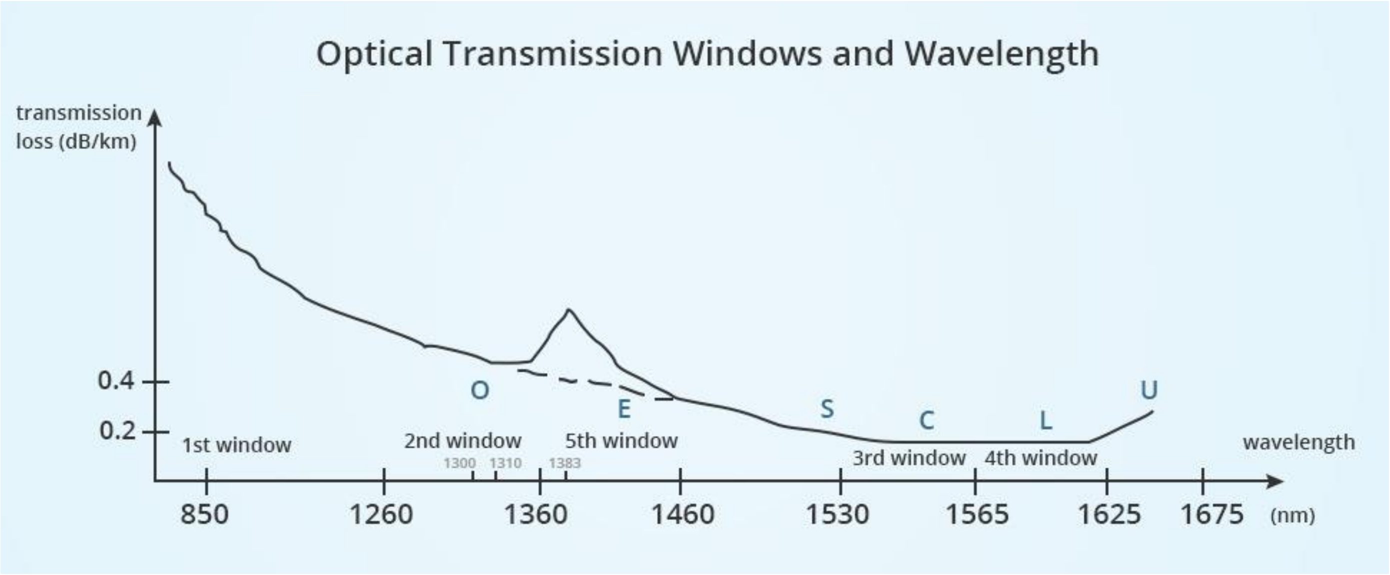
- Chromatic Dispersion
  - Different frequencies of light propagate through a non-vacuum at slightly different speeds. This is how optical prisms work
  - But if one part of an optical signal travels faster than the other part, the signal will eventually “smear out” over long distances

- Polarisation Mode Dispersion
  - Caused by imperfection in shape of the fibre (not perfectly round)
  - One polarisation of light propagates faster than the other
  - Older fibre is particularly affected, may get worse with age



- Diagram source: https://www.newport.com/t/fiber-optic-basics

Fibre optic transmission frequency bands



- • 850nm - The First Window
- • Highest attenuation, only used for short reach applications today
- • 1310nm - The Second Window (O-band)
- • The point of zero dispersion on classic SMF, but high attenuation
- • Primarily used for medium-reach applications (up to 10km) today

• **1550nm - Third Window (C-band)**

• Stands for “conventional band”, covers 1525nm - 1565nm

• Has the lowest rate of attenuation over SMF

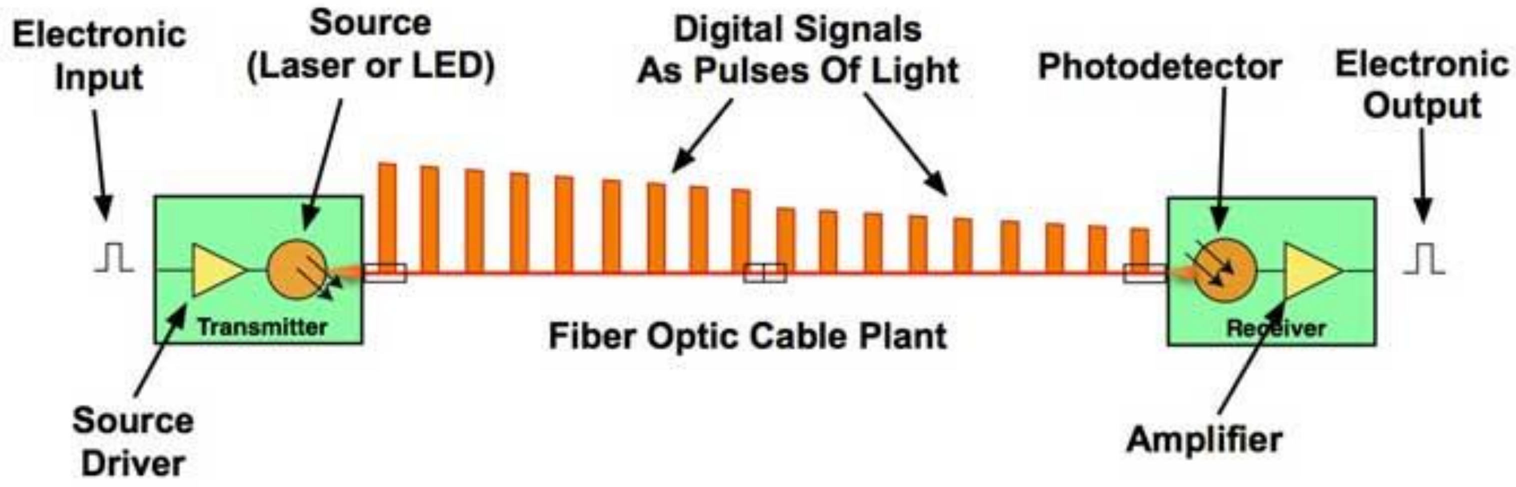
• Used for almost all long-reach and DWDM applications today

• **Forth Window (L-band)**

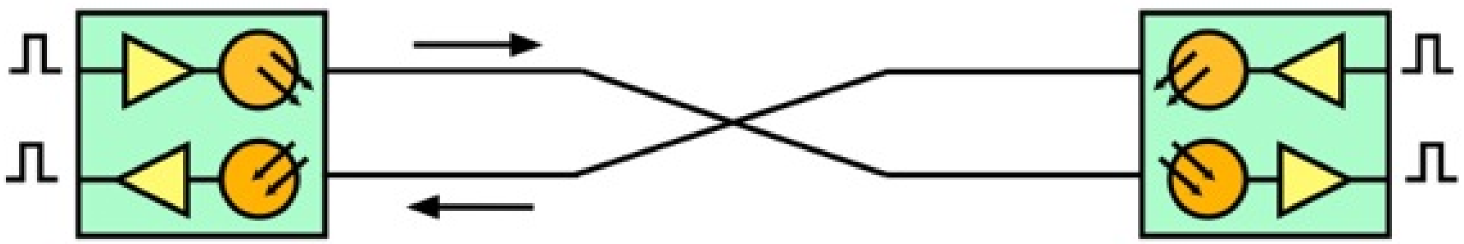
• Stands for “long band”, covers 1570nm - 1610nm

- Diagram Source: https://community.fs.com/article/the-bandwidth-and-window-of-fiber-optic-cable.html

Optical systems engineering (1 of 3)

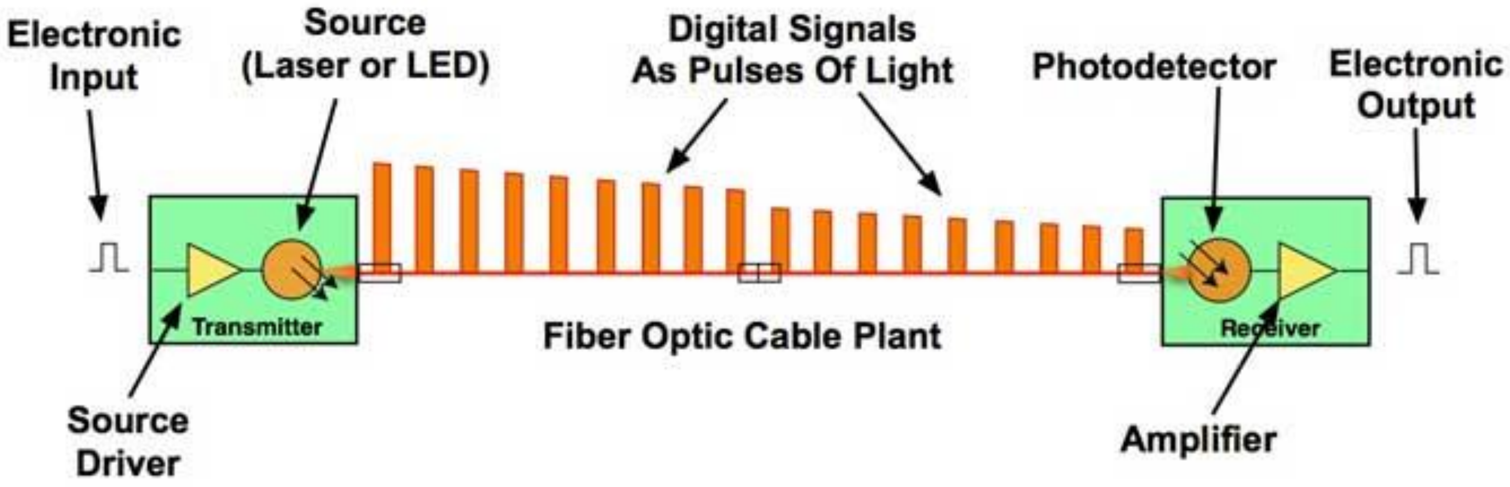


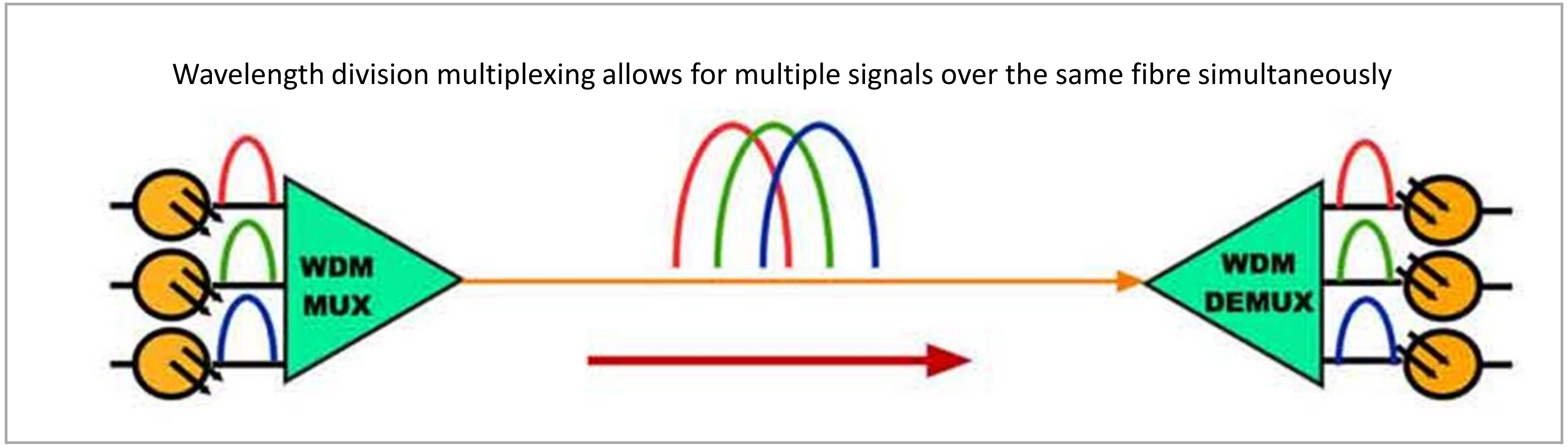
Components of a fibre optic link using 2 fibres for full duplex operation



- Source: https://www.thefoa.org/tech/ref/appln/datalink.html

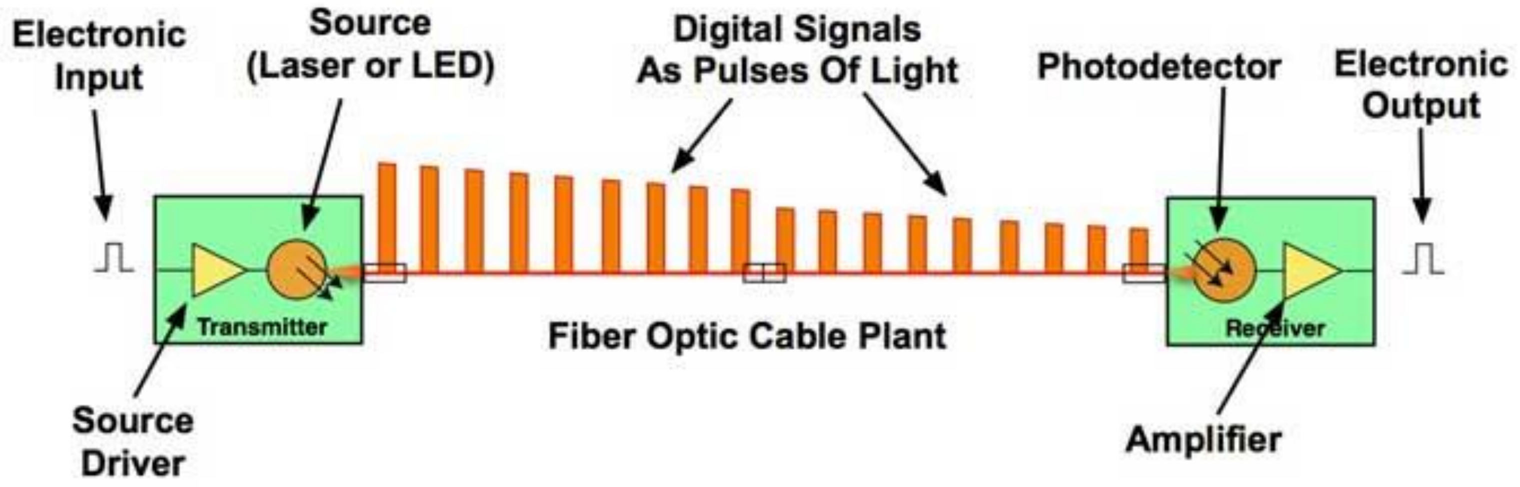
Optical systems engineering (2 of 3)





- Source: https://www.thefoa.org/tech/ref/appln/datalink.html

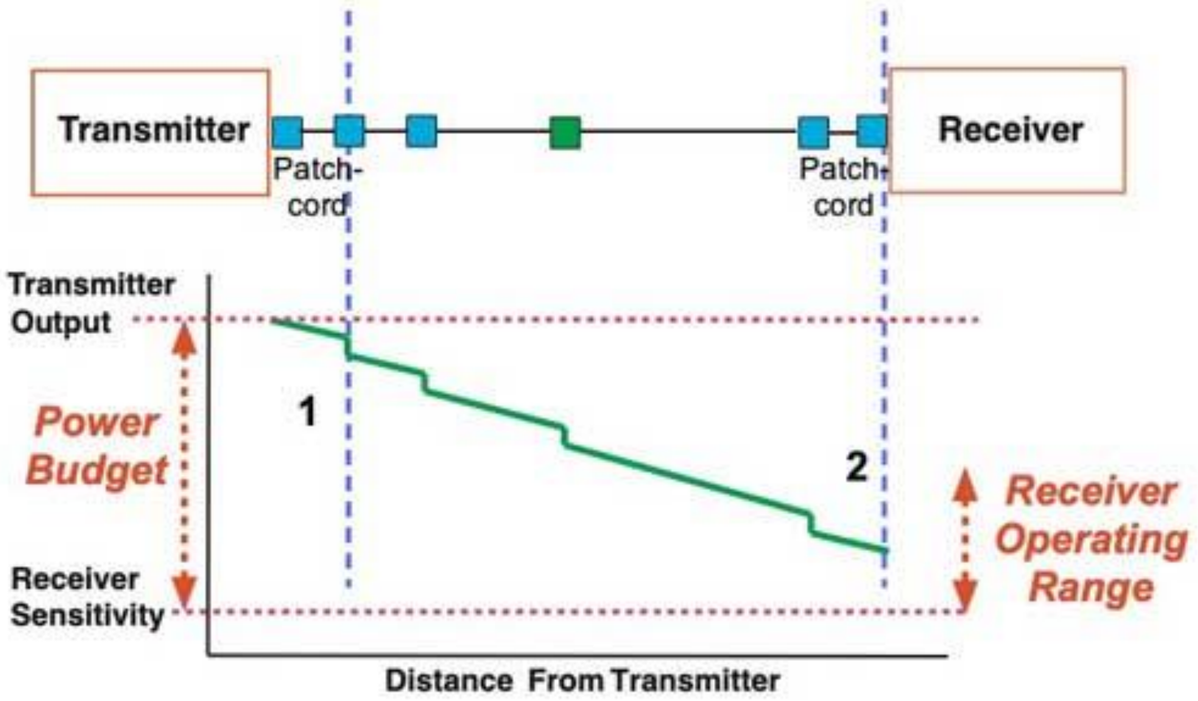
Optical systems engineering (3 of 3)

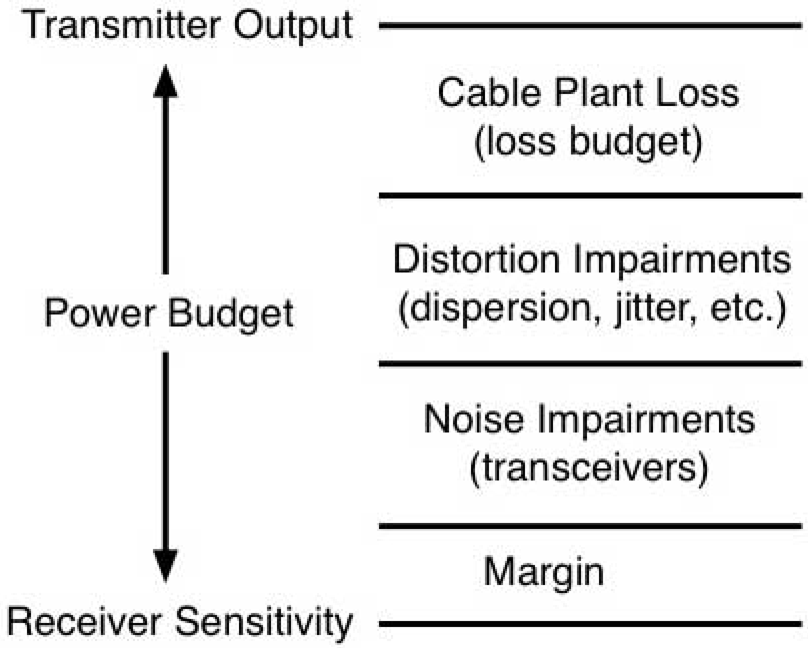


Components of a fibre optic link using a single fibre - Single Fibre Working (SFW)

- Source: https://www.thefoa.org/tech/ref/appln/datalink.html

Optical power budgets (1 of 2)

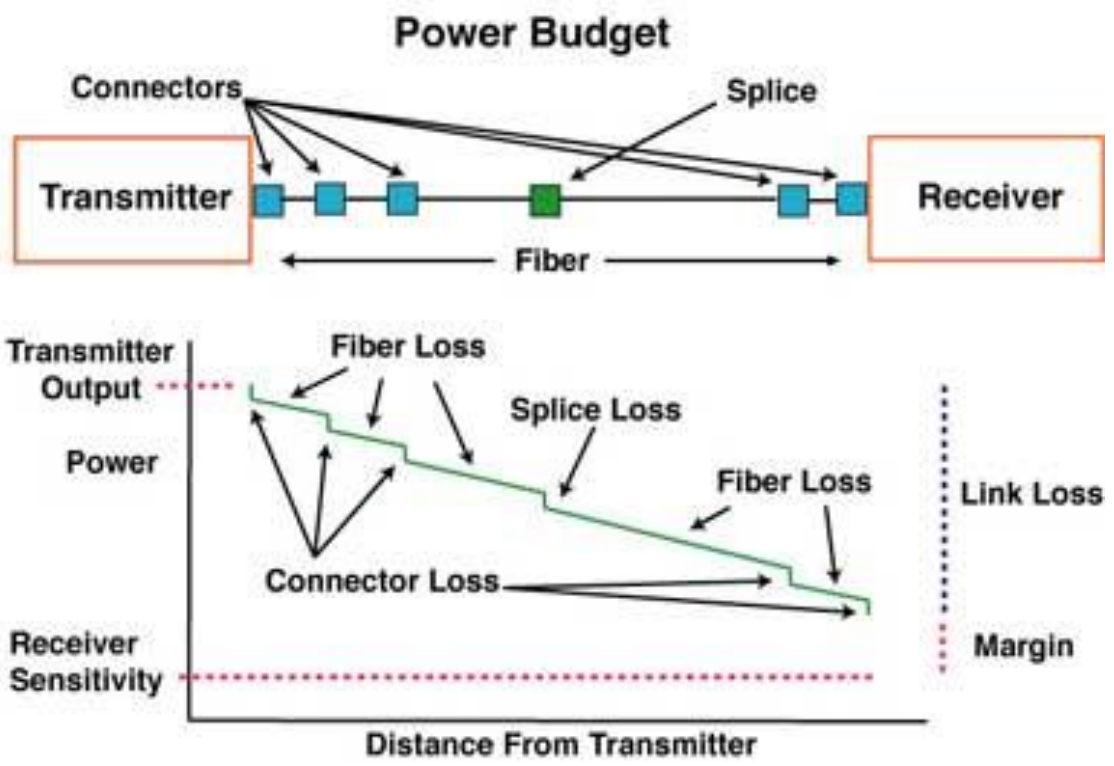




Note: Forward Error Correction (FEC) is used to maximise link length for a given bit error rate.

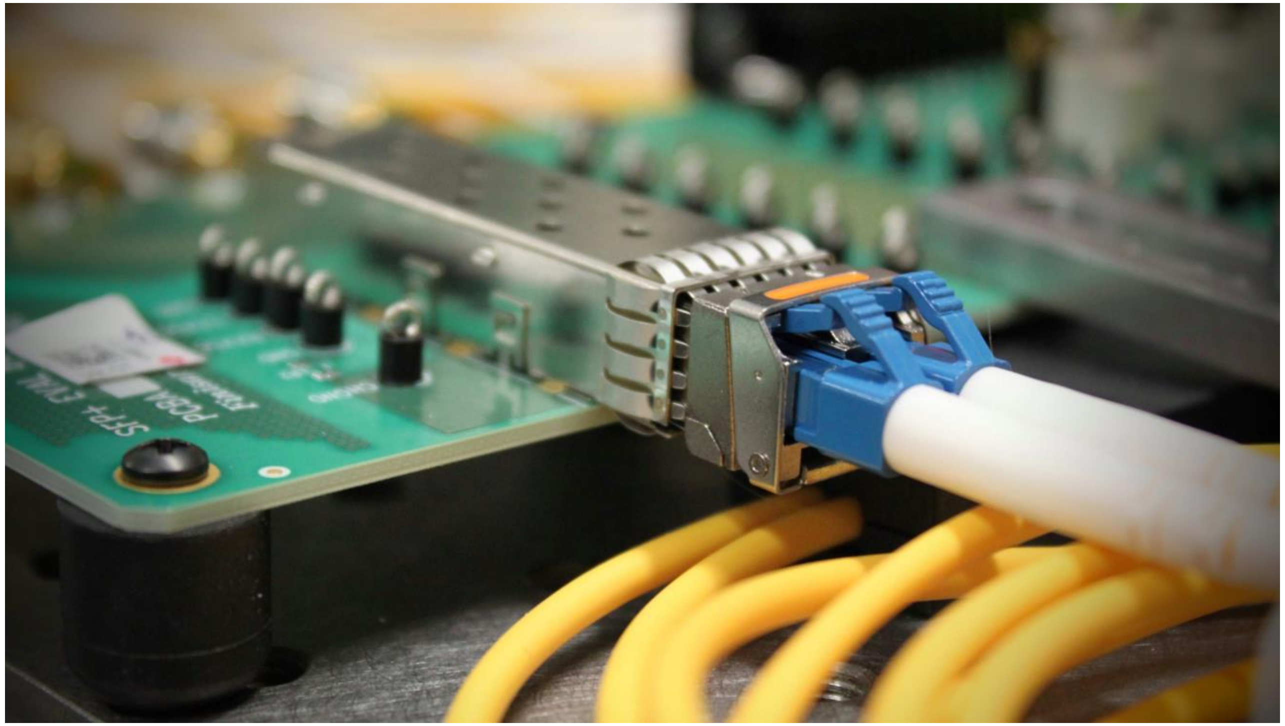
- Source: https://www.thefoa.org/tech/ref/appln/datalink.html

Optical power budgets (2 of 2)



- Source: https://www.thefoa.org/tech/ref/appln/datalink.html

Small Form-factor Pluggable (SFP) transceivers

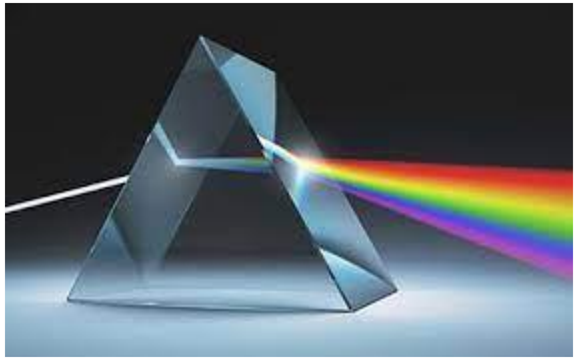


- Small Form-factor Pluggable (SFP) is a compact, hot-pluggable network interface module format used for both telecommunication and data communications applications
- An SFP interface on networking hardware is a modular slot for a media-specific transceiver, such as for a fibre optic cable or a copper cable
- The advantage of using SFPs compared to fixed interfaces (e.g. modular connectors in Ethernet switches) is that individual ports can be equipped with different types of transceivers as required

- Source: https://en.wikipedia.org/wiki/Small_Form-factor_Pluggable

Wave Division Multiplexing (WDM)

- What is Wave Division Multiplexing (WDM)?
- We know that light comes in many different colours
- These different colours can be combined on the same fibre
- The goal is to ensure the signals do not interfere with each other
- The most common types of WDM are coarse and dense
- Essentially, they both do the same thing in the same way
- The key difference is the channel spacing



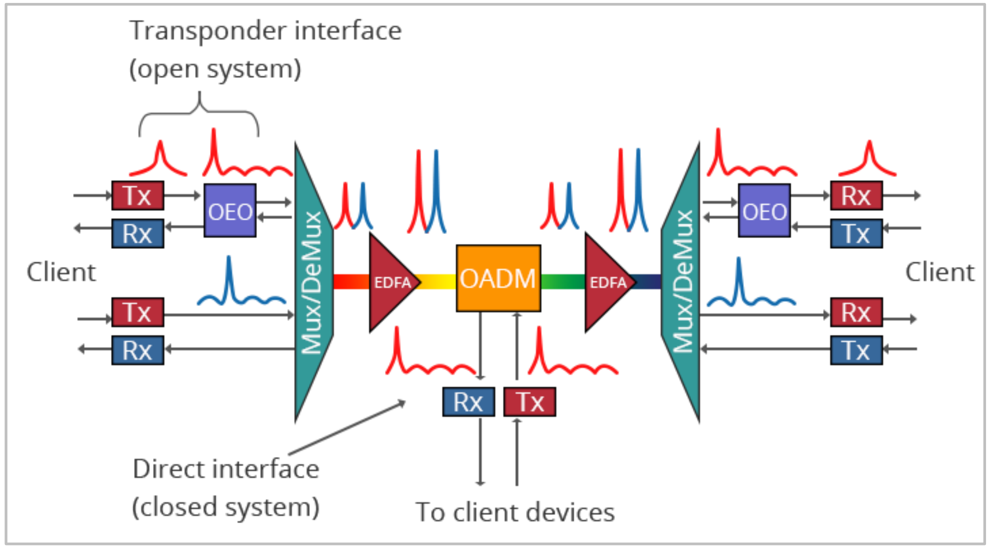
- Image sources: http://www.sorrentonetworks.com/what-is-wdm & https://www.ciena.com/insights/what-is/What-Is-WDM.html

CWDM & DWDM

- CWDM
  - Cheaper, less precise lasers can be used
  - The actual signal in a CWDM system isn't really any wider
  - But the wide channel allows for large temperature variations
  - Cheaper, uncooled lasers, can more easily stay within the window

Historically yes, but not nowadays as DWDM benefits from mass market volume economics…

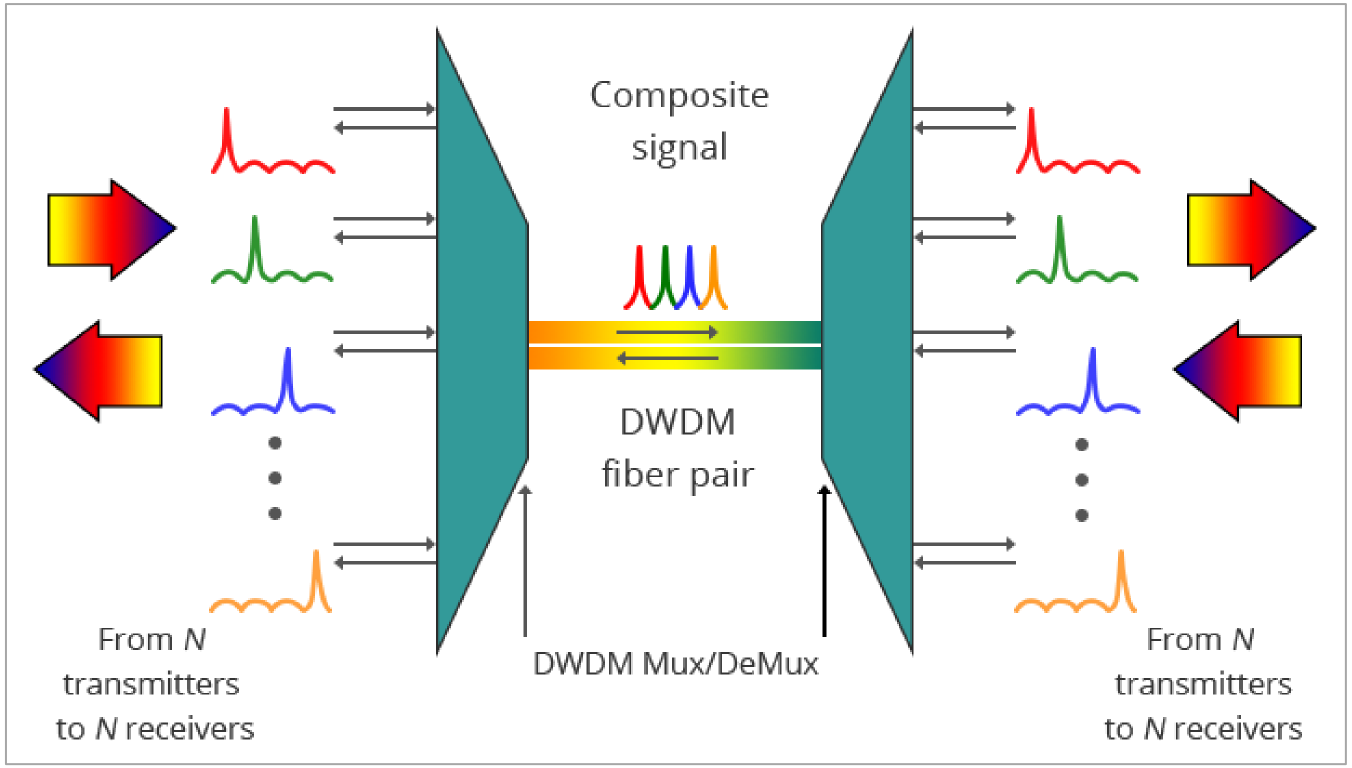
- DWDM
  - Far more channels are possible within the same fibre
  - 160 channels (at 25GHz) in 32nm of spectrum, vs. 8ch in 160nm
  - Stays completely within the C-band
  - Where attenuation and dispersion are far lower that other bands
  - Where Erbium Doped Amplifiers (EDFAs) work
  - And where dispersion compensation can be applied



- Diagram source: https://community.fs.com/article/an-overview-of-dwdm-technology-and-dwdm-system-components.html

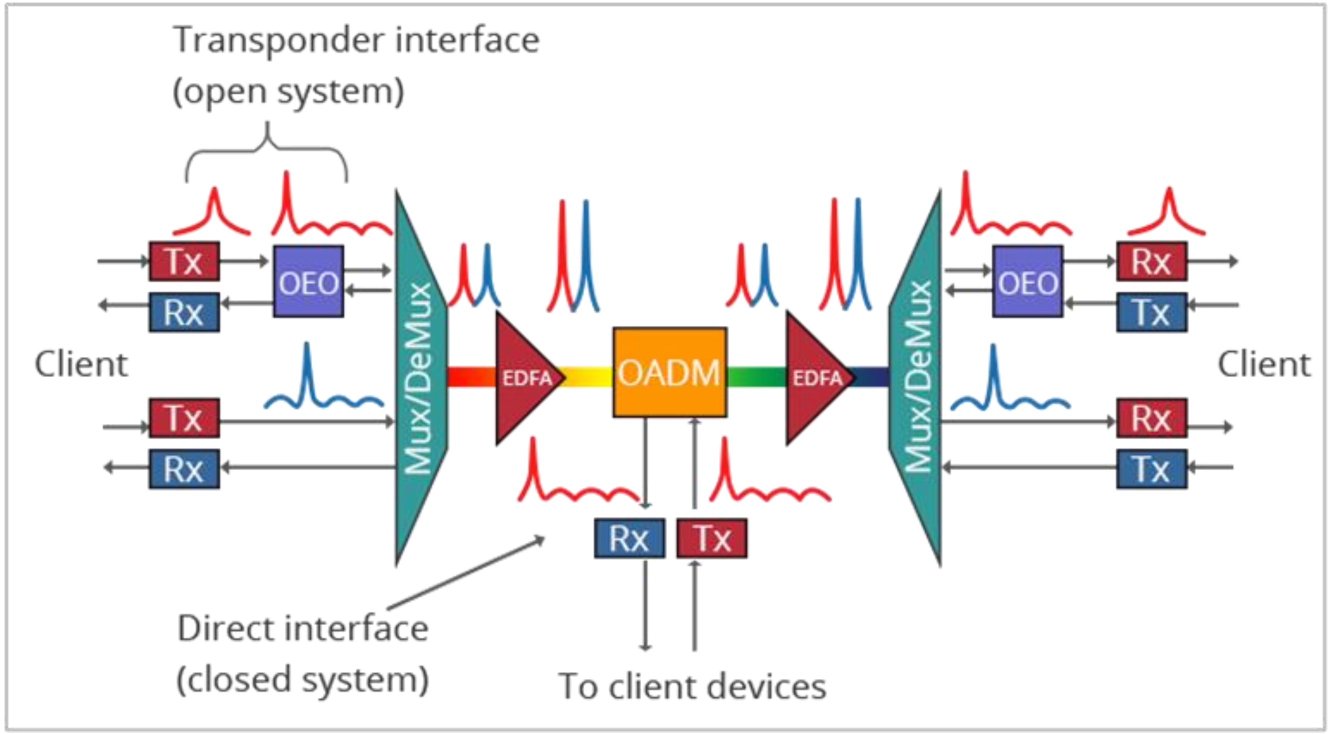
What exactly is Dense WDM (DWDM)?

- A much more tightly packed WDM system
- Typically used for commercial long-haul systems
- Typically based in the C-band
- Specific channel sizes are standardized in an "ITU Grid"
- Within C-band, these channel spacings are common:
  - 200GHz - 1.6nm spacing, 20 channels possible
  - 100GHz - 0.8nm spacing, 40 channels possible
  - 50GHz - 0.4nm spacing, 80 channels possible
  - 25GHz - 0.2nm spacing, 160 channels possible



- Diagram source: https://community.fs.com/article/an-overview-of-dwdm-technology-and-dwdm-system-components.html

DWDM system with amplification & add-drop mux



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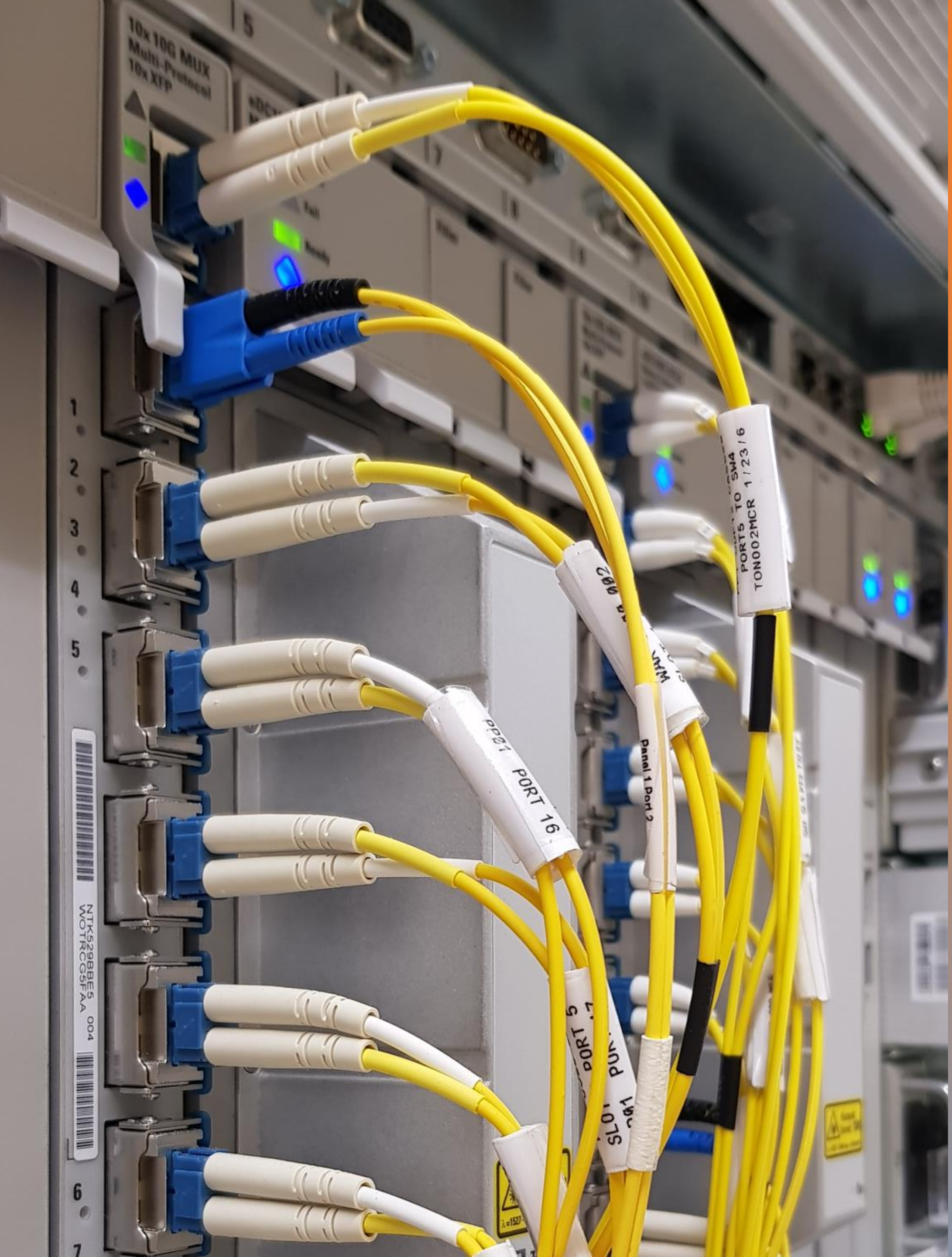


Fibre access solutions

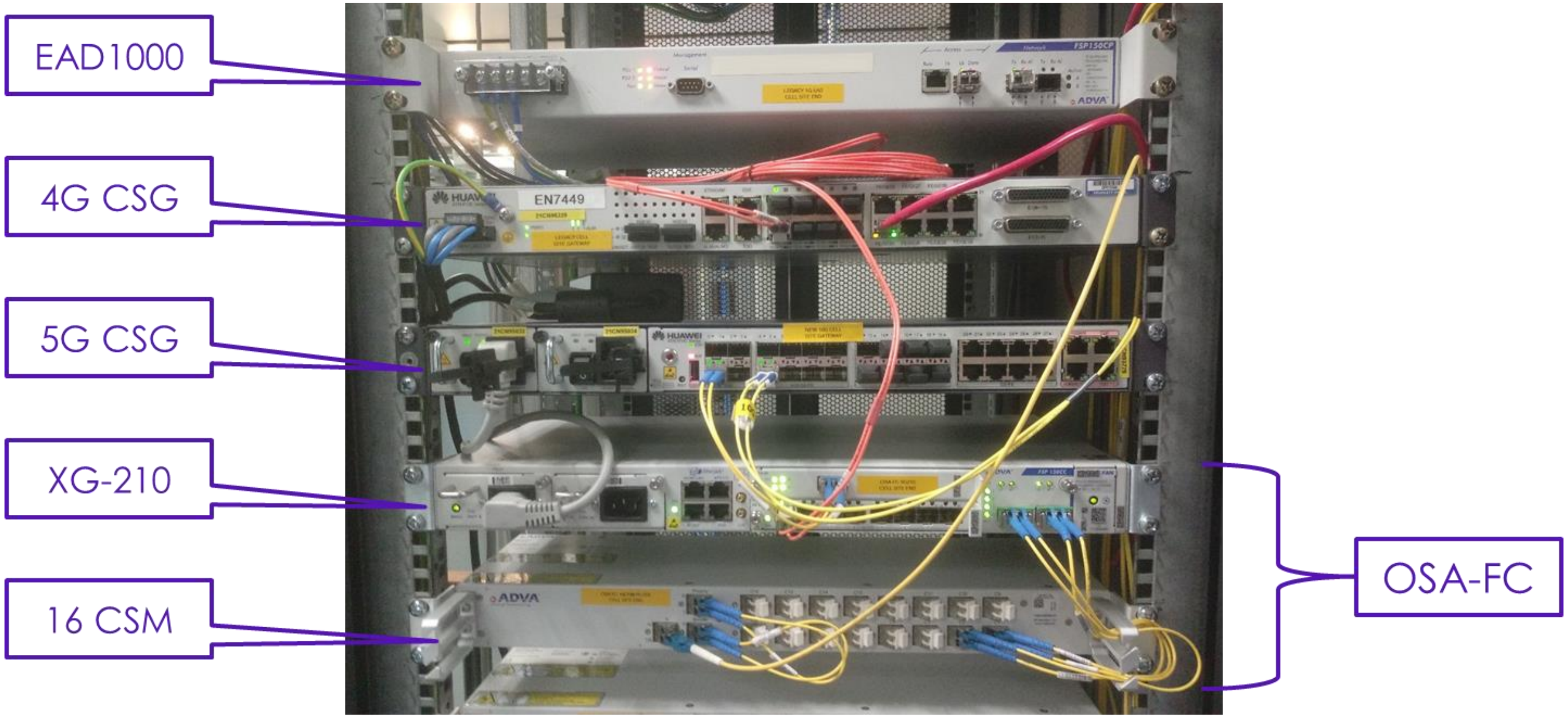
Ethernet Access Direct (EAD) from Openreach

Variant	Speed	Local access	Standard	Extended reach
EAD 10	10Mbps	Y	Y	Y*
EAD 100	100Mbps	Y	Y	Y*
EAD 1000	1000Mbps	Y	Y	Y*
EAD 10000	10Gbps	Y	Y	N

The standard radial distance is up to 25km, with a maximum route distance of 40km.
Extended reach options are available with a radial distance of up to 45km and a maximum route distance of 86km.

- Source: https://www.cvf.openreach.co.uk/cpportal/products/ethernet/ethernet-access-direct

Access network equipment



Note: Photo from lab environment, doesn't represent actual deployed configuration

Optical access for small cells

Street Access 1000 - now, EAD Rugged 1Gb…

- An evolution of what was the SA100 product
- Provides a 1Gbps point to point Ethernet circuit
- Used for small cells in lampposts, telephone kiosks and other street furniture
- Support time and frequency synchronisation

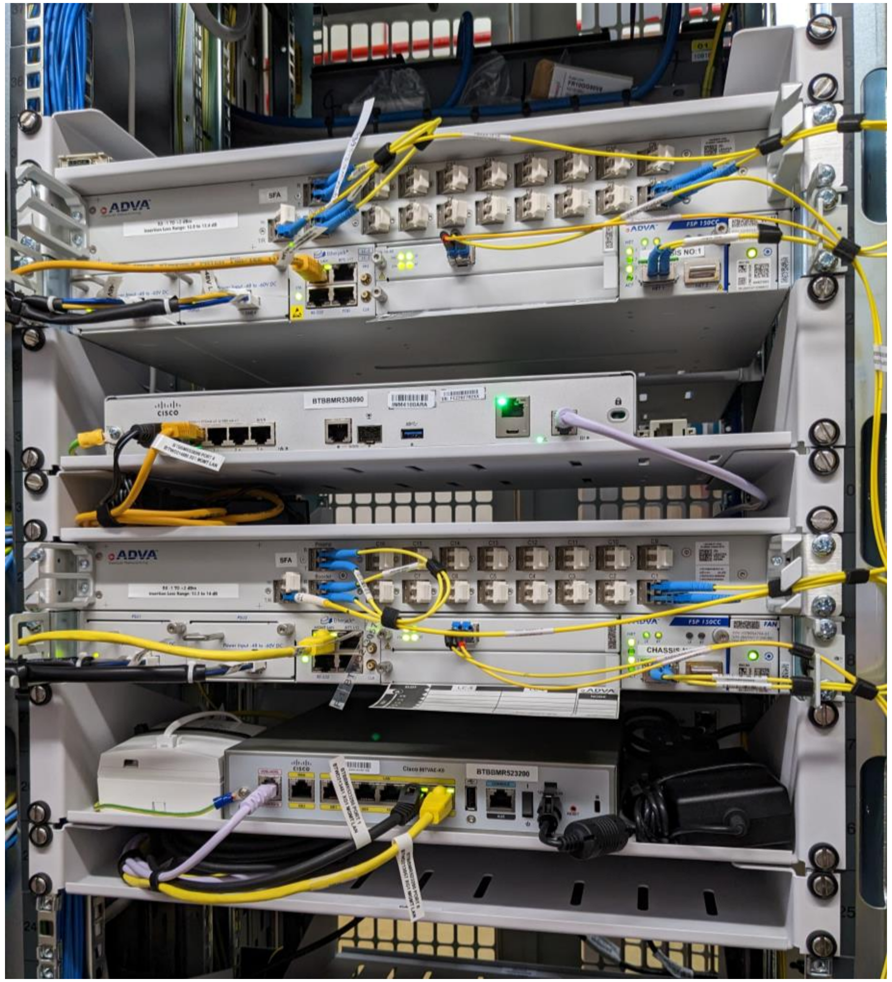
FSP 150-GO102 Series overview

	Access ports	Network ports	Sync.	Power supply	PoE output	Power consumption (maximum)	Size	Operating temperature
[1]FSP 150-GO102Pro (S)	2	1	SyncE, PTP	Integrated AC, DC or PoE PD	–	12.95W	Compact Outdoor	-40°C to +70°C
[2]FSP 150-GO102Pro (SP)	2	1	SyncE, PTP	Integrated AC or DC	2x access ports	80W including PoE subtended devices	Compact Outdoor	-40°C to +65°C
[3]FSP 150-GO102Pro (Sm)	2	1	SyncE, PTP	External AC	–	12.95W	Ultra compact Outdoor	-40°C to +65°C

- Source: FSP 150-GO102Pro data sheet

Access DWDM optical transmission

OSA-FC



- Point to point Openreach optical access product - SIN 489
- DWDM in the optical C-band
- Single fibre working solution with 16 circuits available, utilising 32 wavelengths
- Dual fibre working also available + other filter variants
- Configured with 1 or 2 x 10GE grey interfaces in typical config
- Some systems have an additional 2 x 10G coloured optical interfaces implemented in support of trials of radio access network architecture evolution
- A similar system (Optical Wave Access Service (OWAS)) is deployed by KCOM in Hull - CIP042

Frequency plan: 16CSM-SFW

- A-end / B-end as designated on filter card. A-end and B-end locations will be as defined by CP on the circuit order form
- The A-end 16CSM filter takes the input from the A-end Mux filter and carries 16 channels in the frequency band 196.00 - 194.20THz to the B-end
- Similarly, the B-end 16CSM filter carries 16 channels in the frequency band 193.80 - 192THz to the A-end
- Single fibre working is achieved by the use of a band filter module to multiplex the two bands over the same physical fibre

Channel / Client Port	A-end input			B-end input		
	ADVA Channel number	Frequency (THz)	Wavelength (nm)	ADVA Channel number	Frequency (THz)	Wavelength (nm)
C1	1	196.0	1529.55	17	193.8	1546.92
C2	2	195.9	1530.33	18	193.7	1547.72
C3	3	195.8	1531.12	19	193.6	1548.51
C4	4	195.7	1531.90	20	193.5	1549.32
C5	5	195.5	1533.47	21	193.3	1550.92
C6	6	195.4	1534.25	22	193.2	1551.72
C7	7	195.3	1535.04	23	193.1	1552.52
C8	8	195.2	1535.82	24	193.0	1553.33
C9	9	195.0	1537.40	25	192.8	1554.94
C10	10	194.9	1538.19	26	192.7	1555.75
C11	11	194.8	1538.98	27	192.6	1556.55
C12	12	194.7	1539.77	28	192.5	1557.36
C13	13	194.5	1541.35	29	192.3	1558.98
C14	14	194.4	1542.14	30	192.2	1559.79
C15	15	194.3	1542.94	31	192.1	1560.61
C16	16	194.2	1543.73	32	192.0	1561.42

Source: Openreach SIN 489 Optical Spectrum Access™ Service & Interface Description

Adva (now Adtran) 16 CSM filter channels SFW requires 32 λ to support 16 bi-directional channels

	A End Ports Input			B End Ports Input		
Filter port ID	Channel number	Frequency (THz)	Wavelength (nm)	Channel number	Frequency (THz)	Wavelength (nm)
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C15	15	194.3	1542.94	31	192.1	1560.61
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- Source: KCOM Customer Interface Publication: CIP042

Adva fixed coloured optical transceiver

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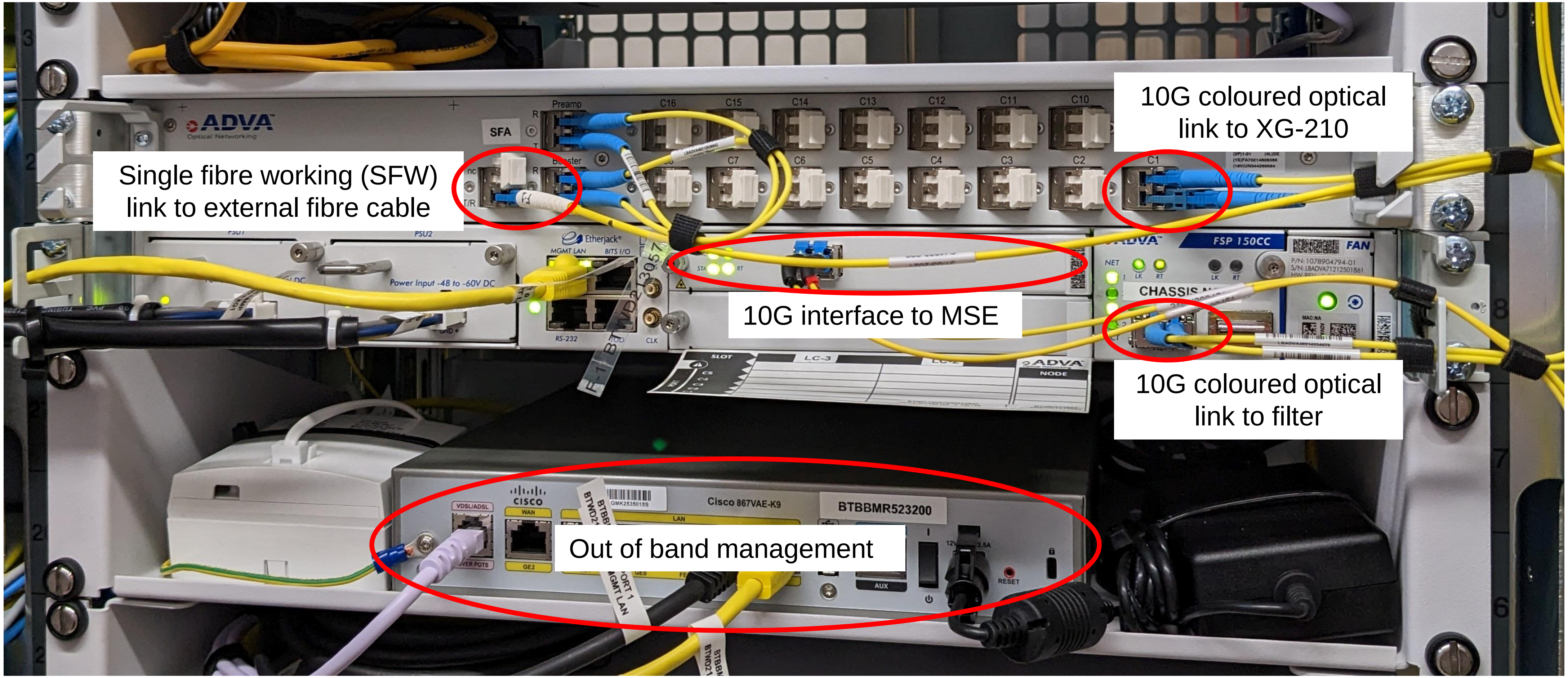
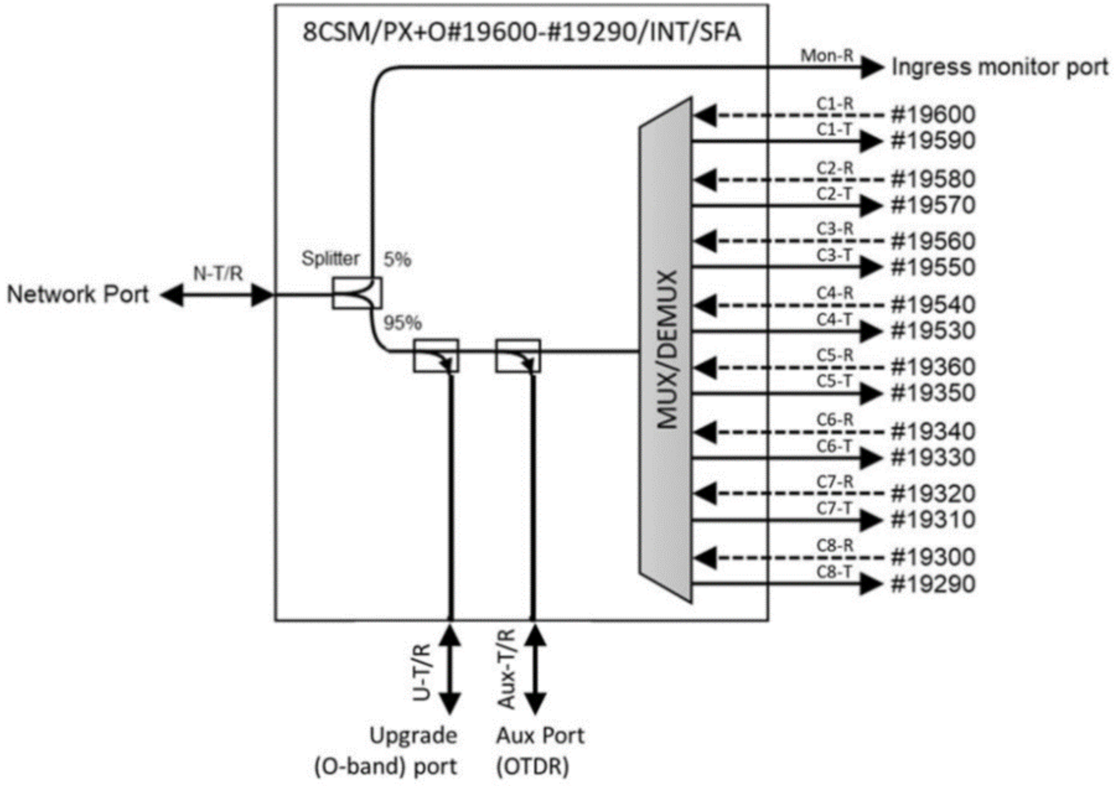
Openreach OSA-FC installation at an exchange

Openreach OSA-FC installation at an exchange



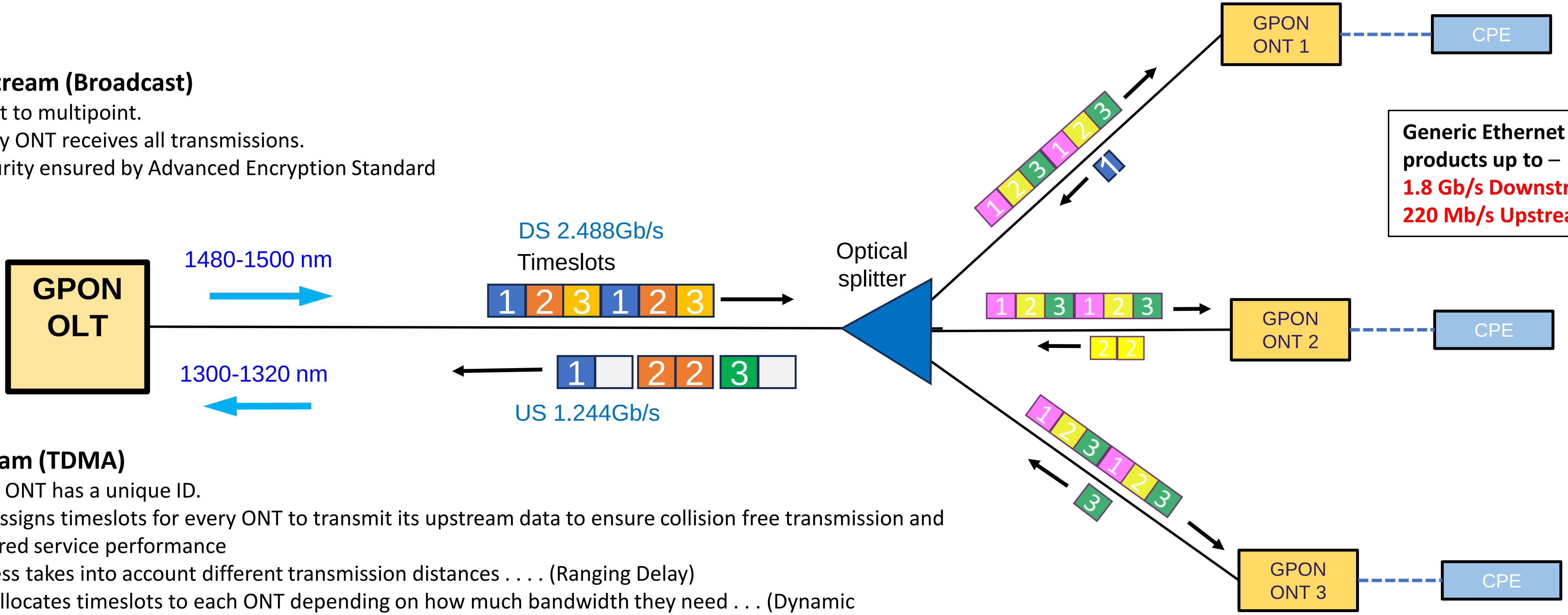
An alternative optical filter…

- ADVA 8CSM DWDM filter with O-Band port
- The filter has an interleaved channel grid to maximise symmetry thus minimising differential latency/ between the transmit and receive paths for any channel
- Single fibre C-band DWDM filter
- Duplex ports for 8 DWDM channels (16 lambda) C29-C36, C53-C60
- AUX port for ALM connection
- Dimensions 29x130x186mm



FTTP - GPON transmission

Downstream (Broadcast)
- Point to multipoint.
- Every ONT receives all transmissions.
- Security ensured by Advanced Encryption Standard

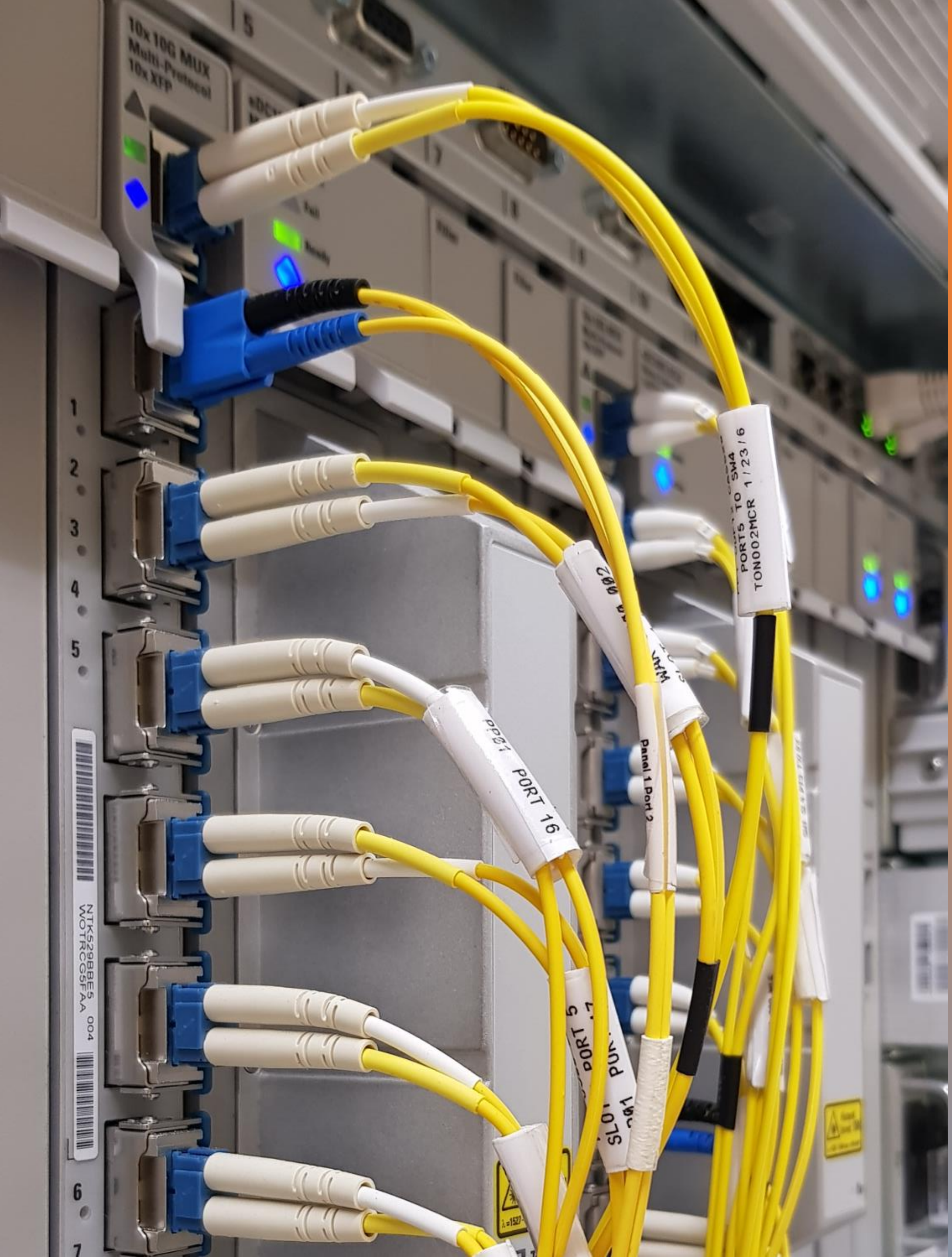


Generic Ethernet Access products up to –
1.8 Gb/s Downstream
220 Mb/s Upstream

Upstream (TDMA)
- Every ONT has a unique ID.
- OLT assigns timeslots for every ONT to transmit its upstream data to ensure collision free transmission and required service performance
- Process takes into account different transmission distances . . . . (Ranging Delay)
- OLT allocates timeslots to each ONT depending on how much bandwidth they need . . . (Dynamic Bandwidth Allocation)
- But there's more . . . . Timeslots are actually allocated to **T-Conts**

Traffic Containers (T-Conts)
- Represent groups of logical connections.
- Each ONT will have multiple T-Conts.
- 5 types of T-Cont are defined and are associated with different qualities of service

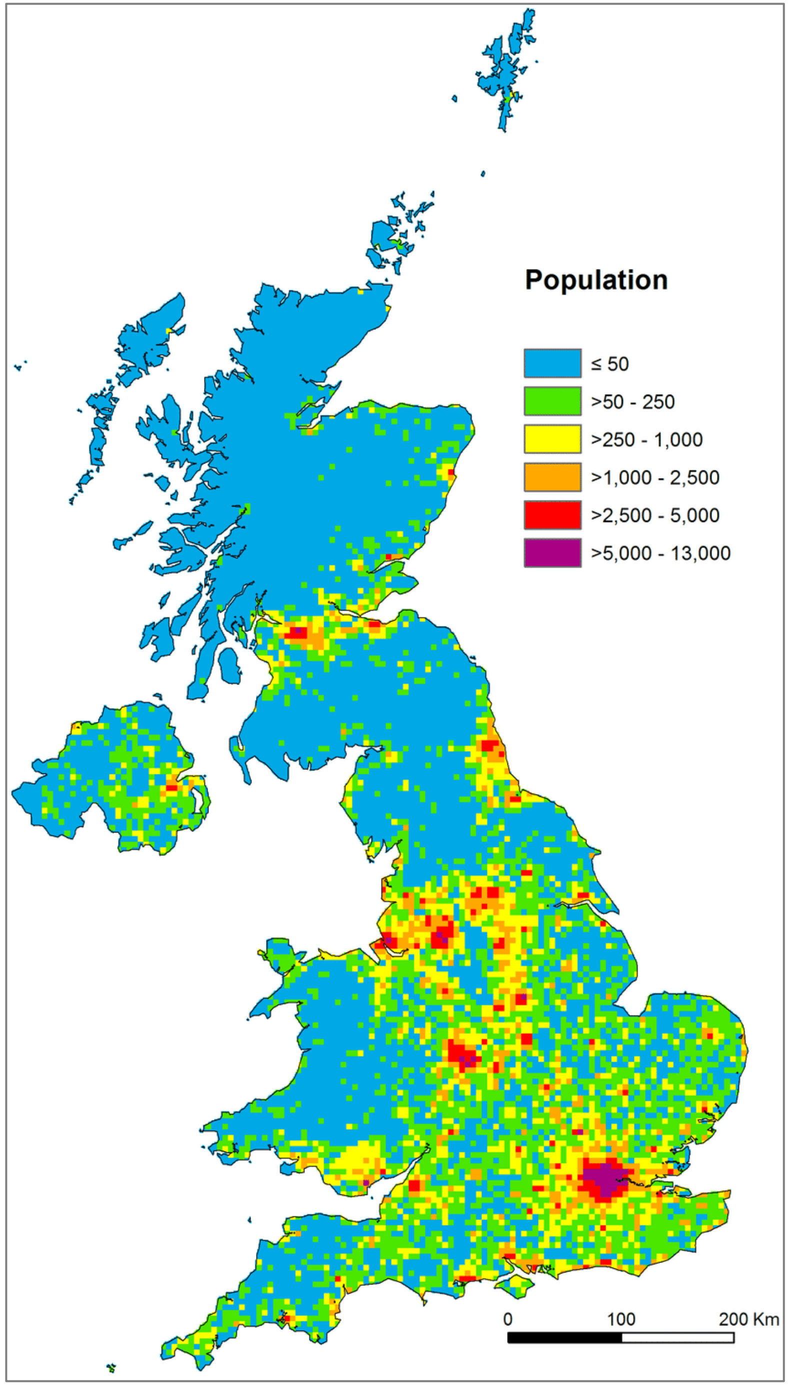
T-Cont quality of service types –
Type 1 – Fixed bandwidth
Type 2 – Assured bandwidth
Type 3 – Assured and Non-Assured bandwidth
Type 4 – Best Effort
Type 5 – Fixed, Assured and Non-Assured



National core fibre networks

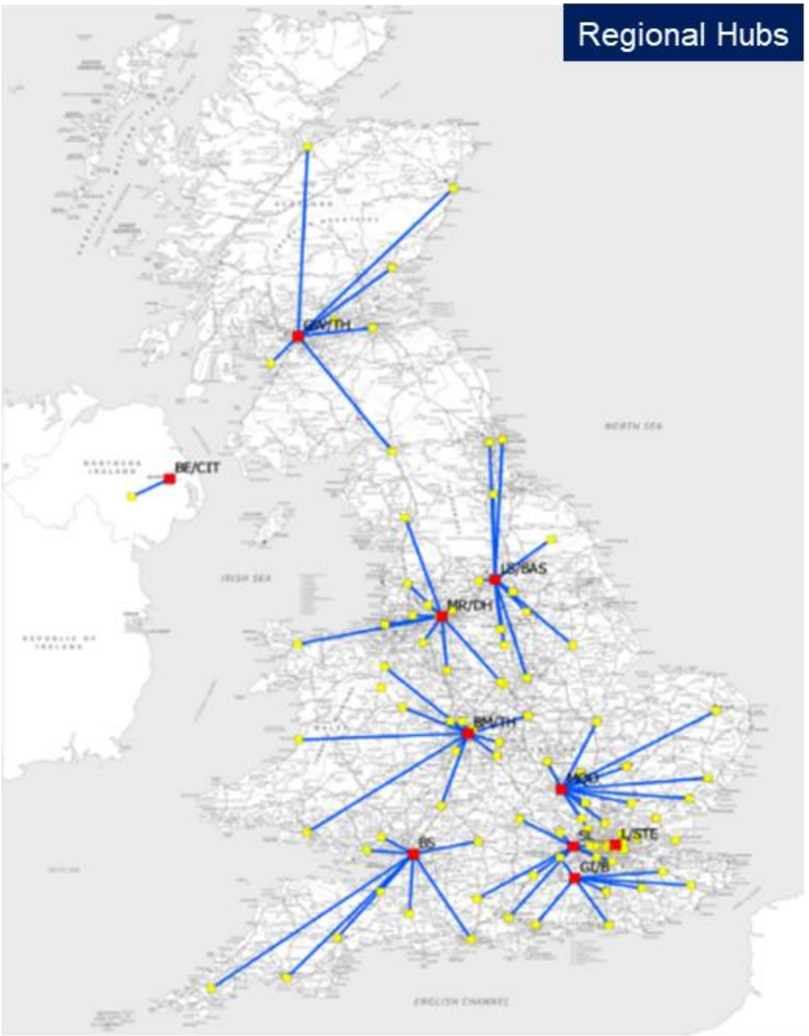
Source: https://www.nationsonline.org/oneworld/map/united-kingdom-map.htm

Source: https://www.nationsonline.org/oneworld/map/united-kingdom-map.htm



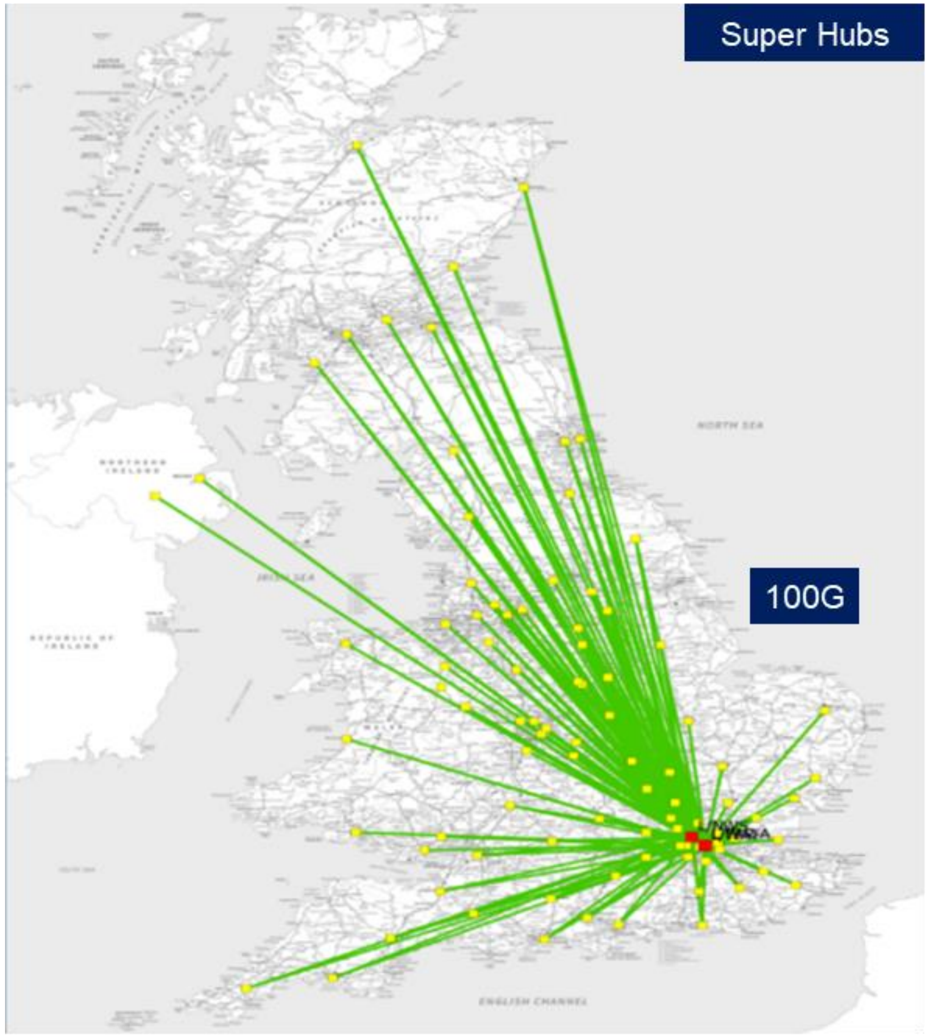
Source: https://www.researchgate.net/figure/Gridded-UK-population-density-based-on-the-UK-census-at-the-5-km-5-km-grid-spatial_fig8_281137363

National core transmission & transport network

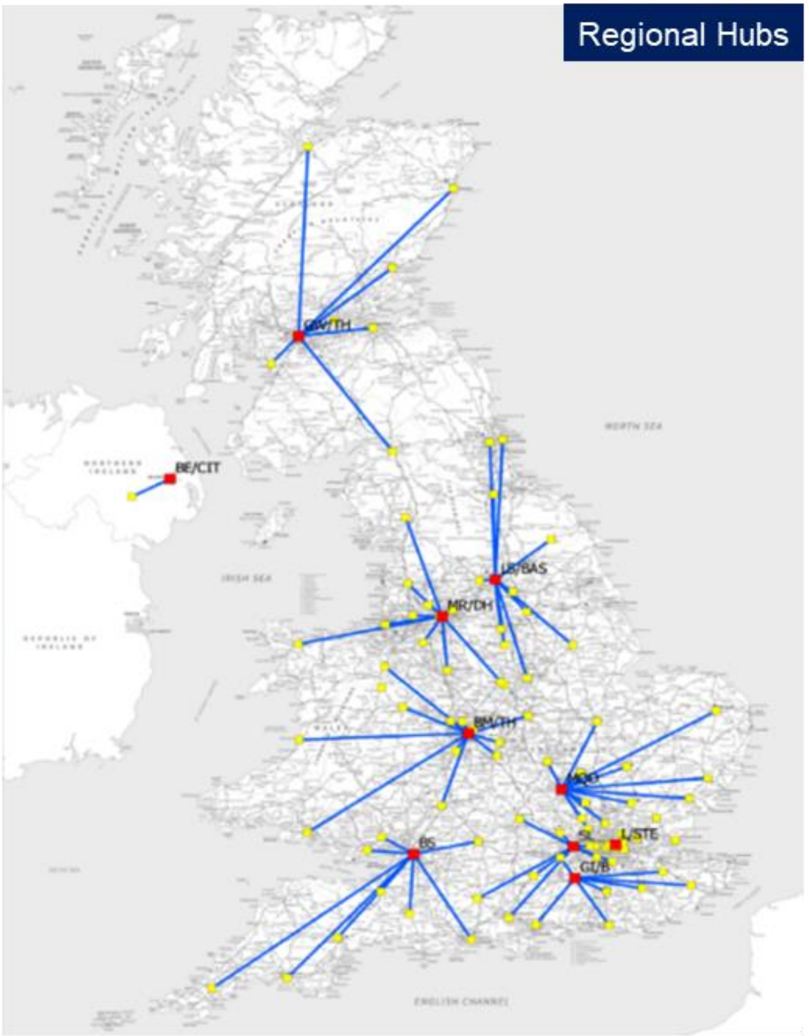


Regional hub connectivity

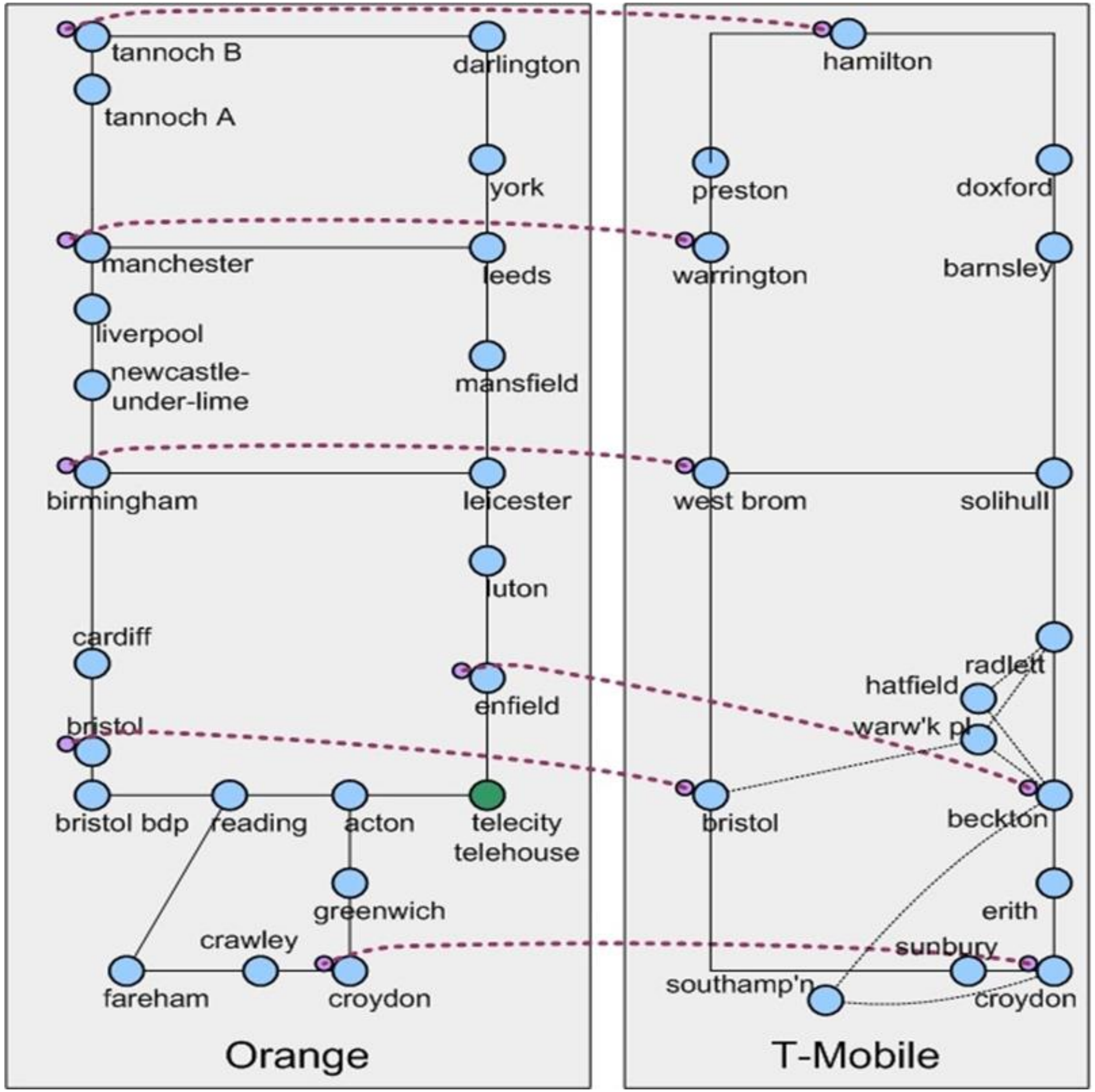
National core transmission & transport network



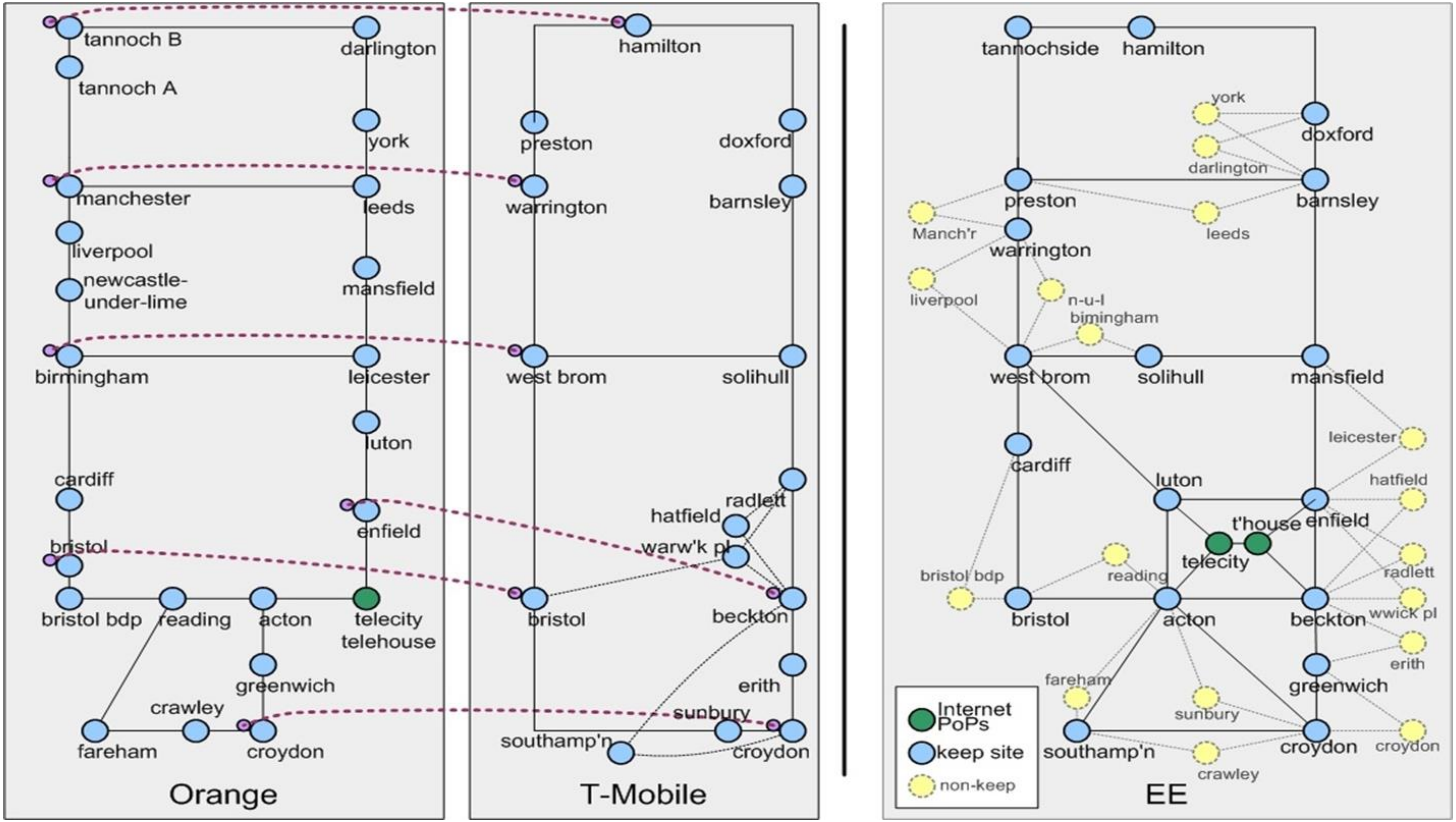
Express routes to super hubs

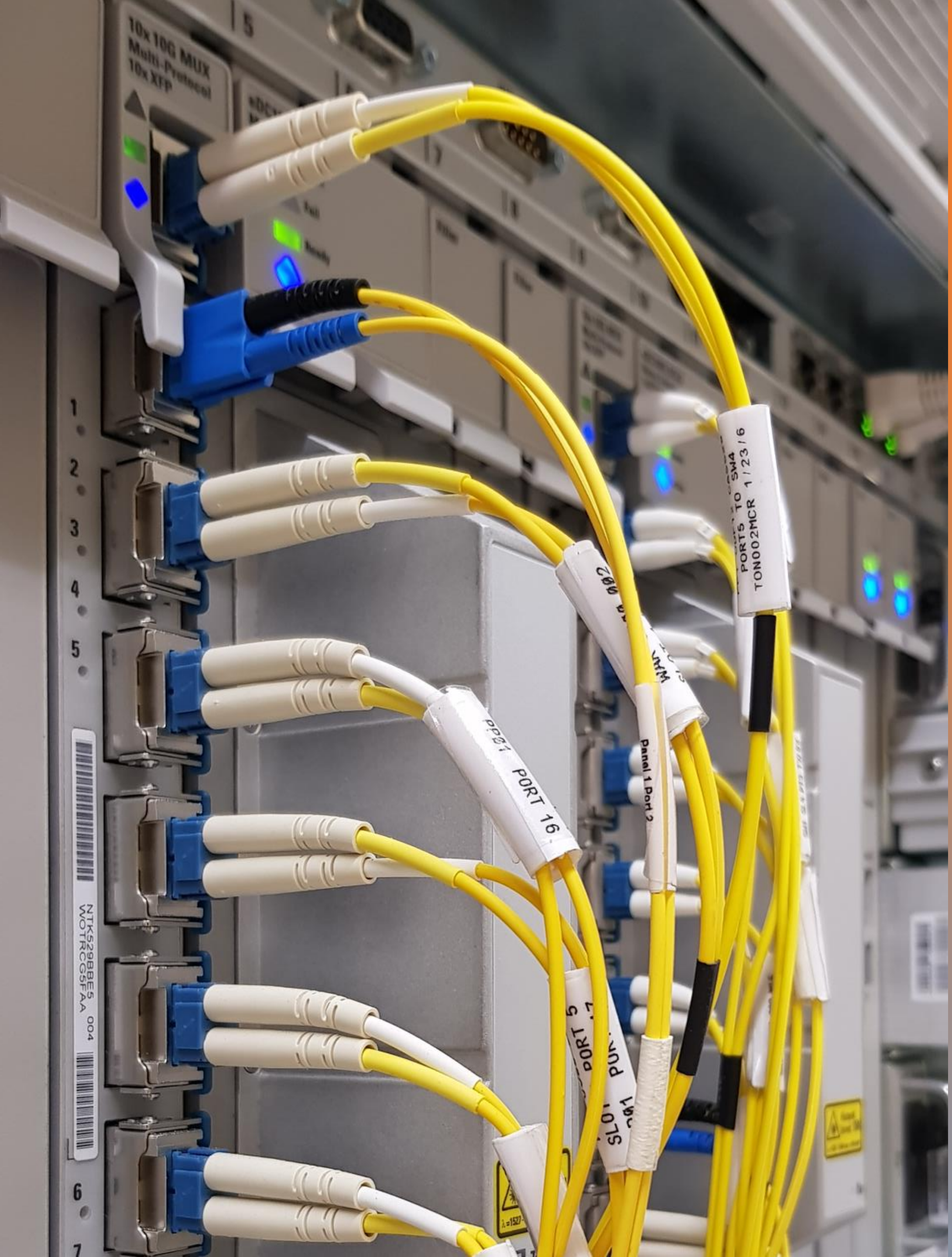


Regional hub connectivity



Examples of other national fibre networks…

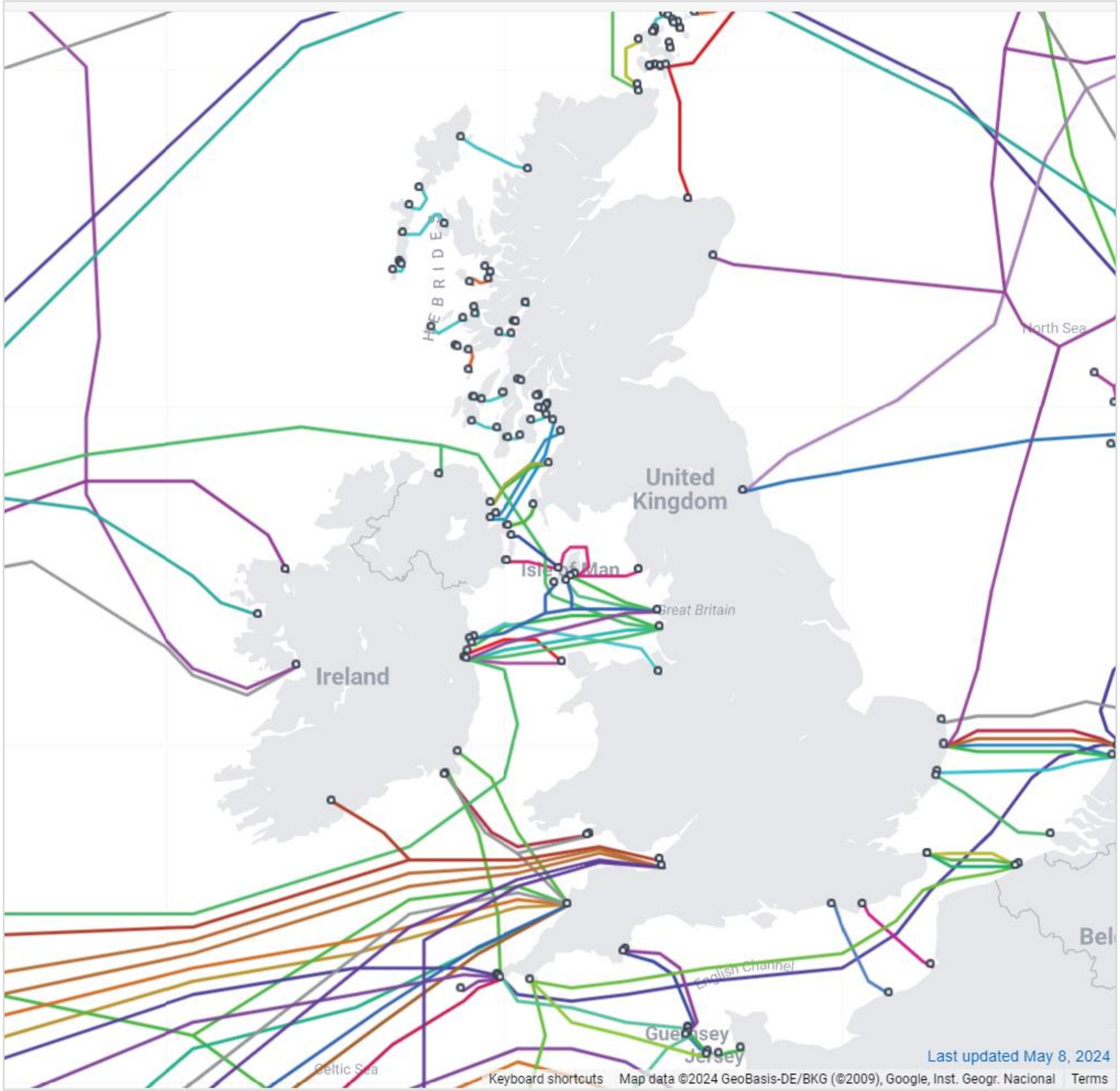

tannoch B
darlington
tannoch A
york
manchester
leeds
liverpool
newcastle-under-lime
mansfield
birmingham
leicester
luton
cardiff
enfield
bristol
bristol bdp
reading
acton
telecity telehouse
greenwich
crawley
fareham
croydon
Orange
hamilton
preston
doxford
warrington
barnsley
west brom
solihull
radlett
hatfield
warw'k pl
bristol
beckton
erith
sunbury
southamp'n
croydon
T-Mobile
tannochside
hamilton
york
doxford
darlington
preston
barnsley
Manch'r
leeds
warrington
liverpool
n-u-l
bimingham
west brom
solihull
mansfield
leicester
cardiff
luton
hatfield
t'house
enfield
telecity
bristol bdp
reading
radlett
bristol
acton
beckton
wwick pl
erith
fareham
greenwich
sunbury
southamp'n
croydon
croydon
crawley
Internet PoPs
keep site
non-keep
EE



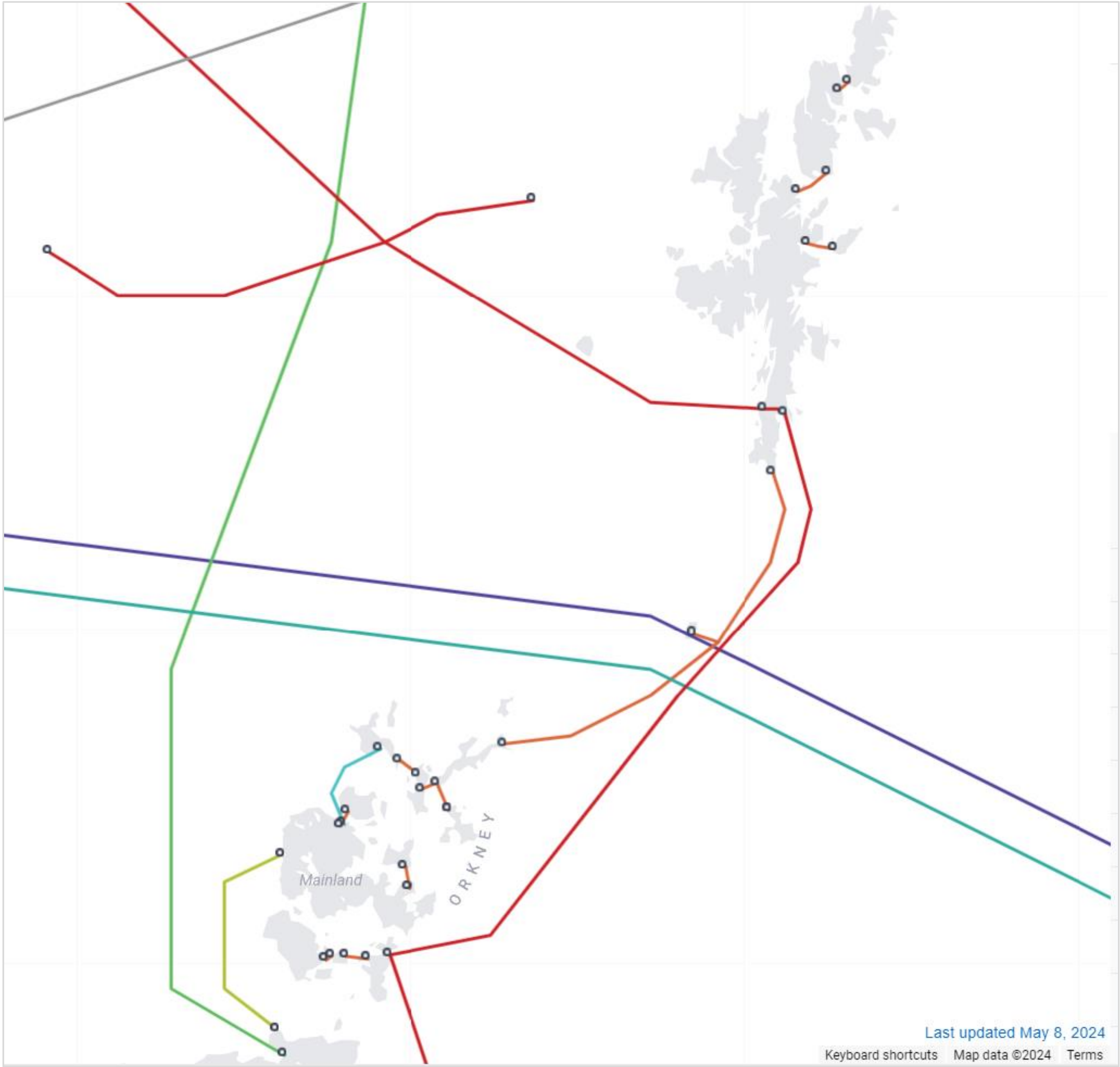
Submarine fibre networks

Submarine optical fibre map

Source: https://commons.wikimedia.org/wiki/File:Submarine_cable_map_umap.png

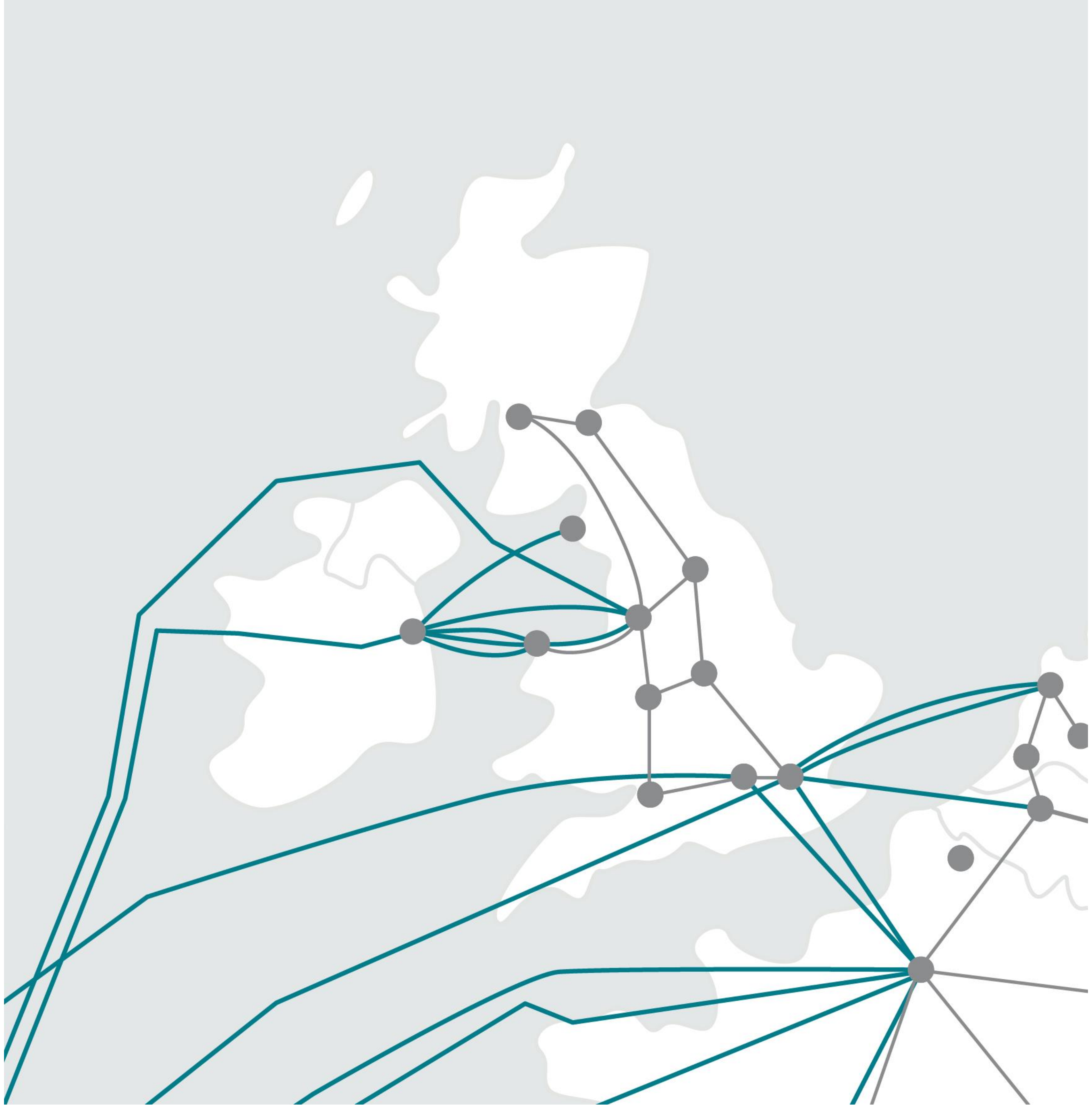


Source: https://www.submarinecablemap.com/

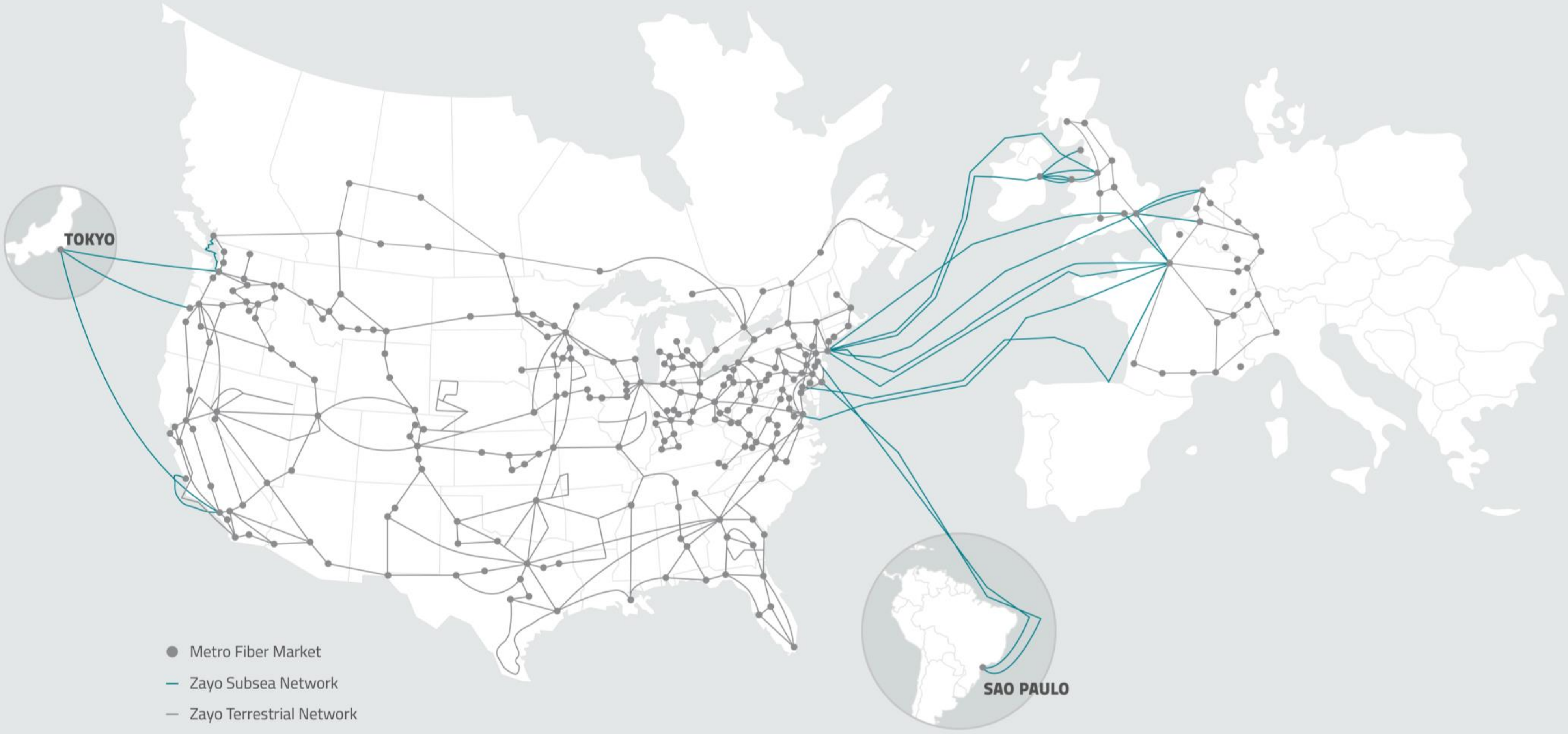


Source: https://www.submarinecablemap.com/

Source: https://www.nationsonline.org/oneworld/map/united-kingdom-map.htm



Source: https://www.zayo.com/network/



Source: https://www.zayo.com/network/

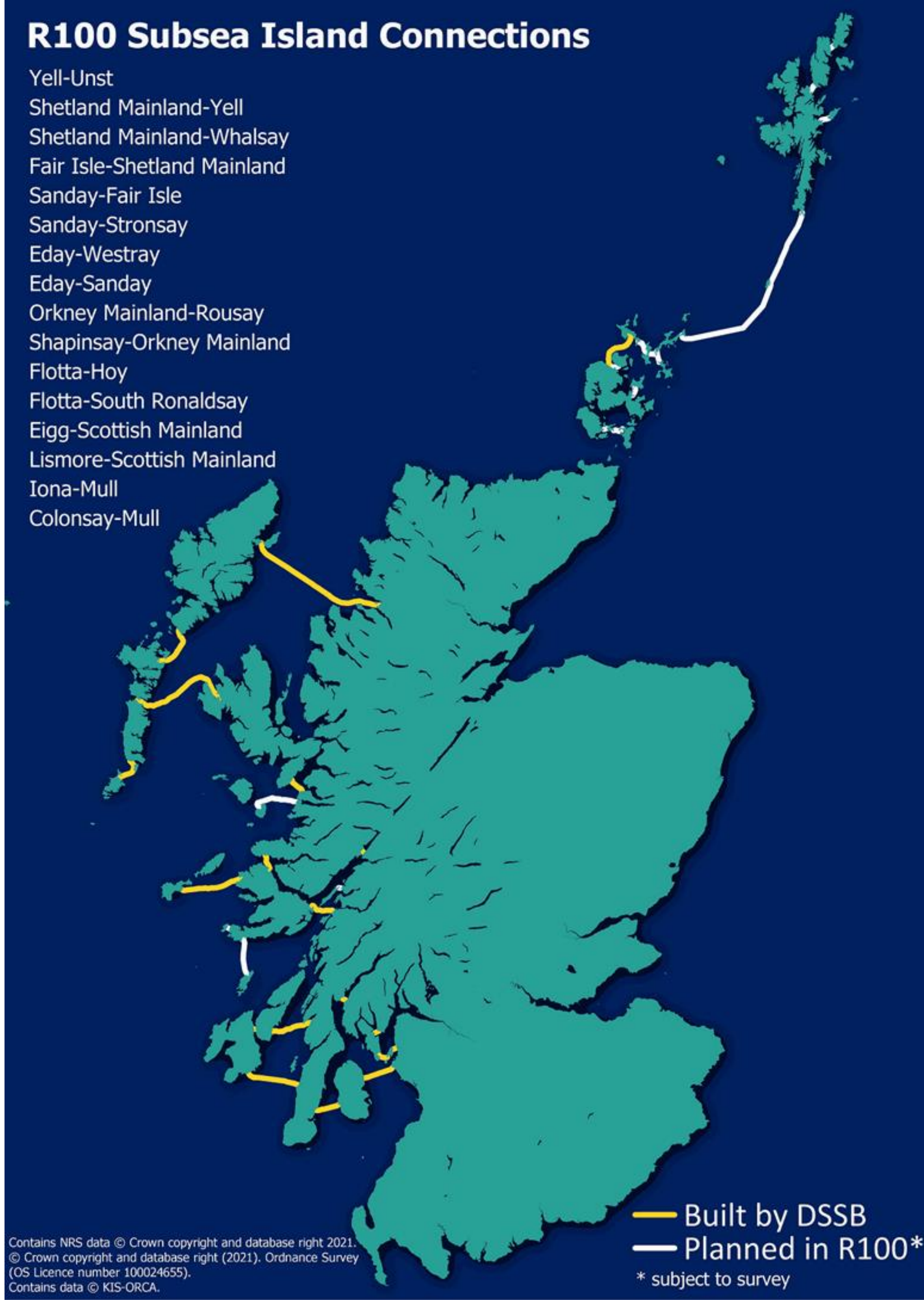
Sub-sea fibre cables

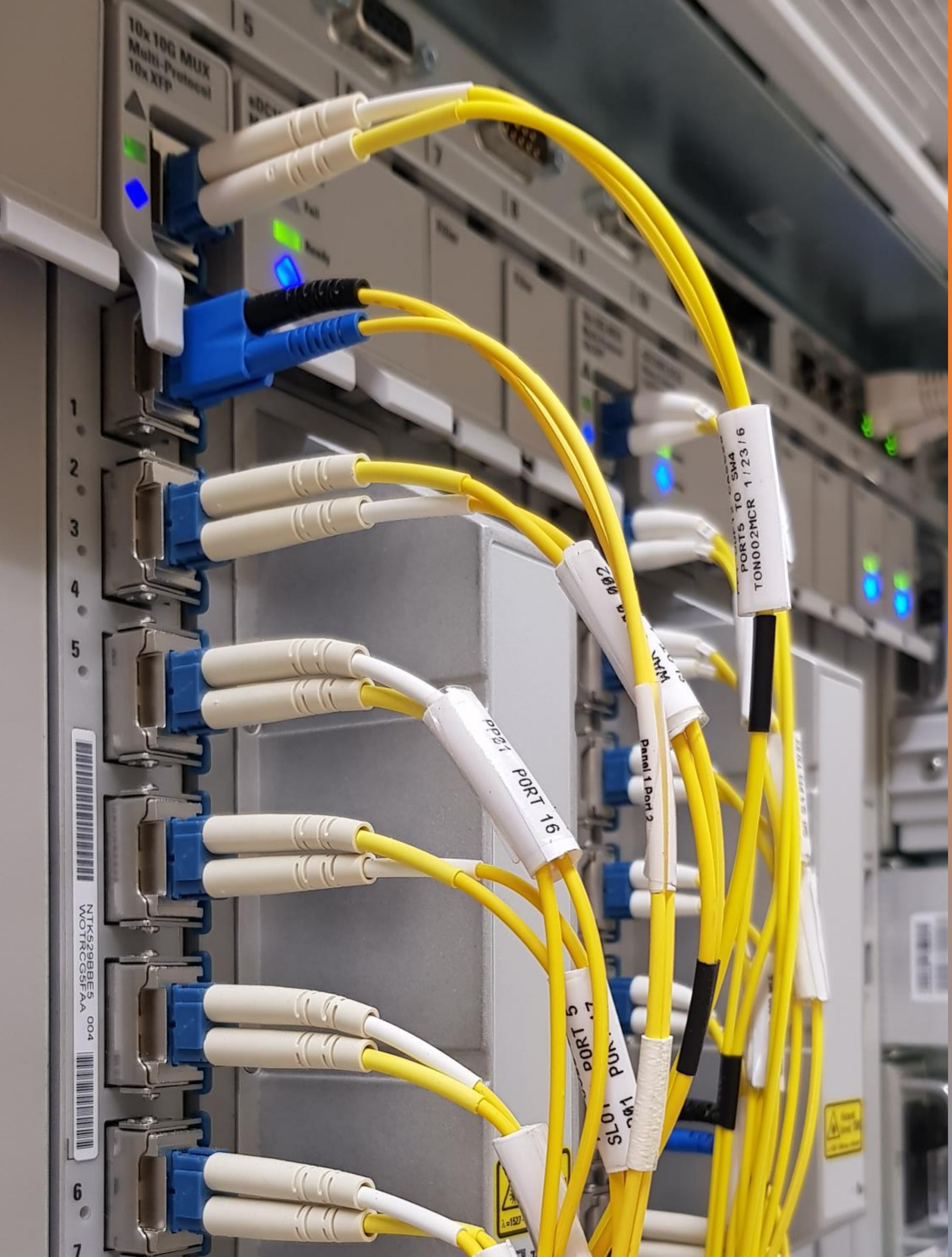
<u>Connecting 15 Scottish islands</u>

- During the course of 2022, vessels laid a total of 16 new R100 subsea cables connecting 15 Scottish islands to superfast broadband as part of the Scottish Government's Reaching 100% (R100) North contract

- The 16 subsea cables will help connect 15 Scottish islands:
- Colonsay, Iona and Lismore in Argyll and Bute Council - Eigg in the Highland Council area - Eday, Flotta, Hoy, Rousay, Sanday, Shapinsay and Stronsay in Orkney Islands Council - Fair Isle, Unst, Whalsay and Yell in Shetland Islands Council

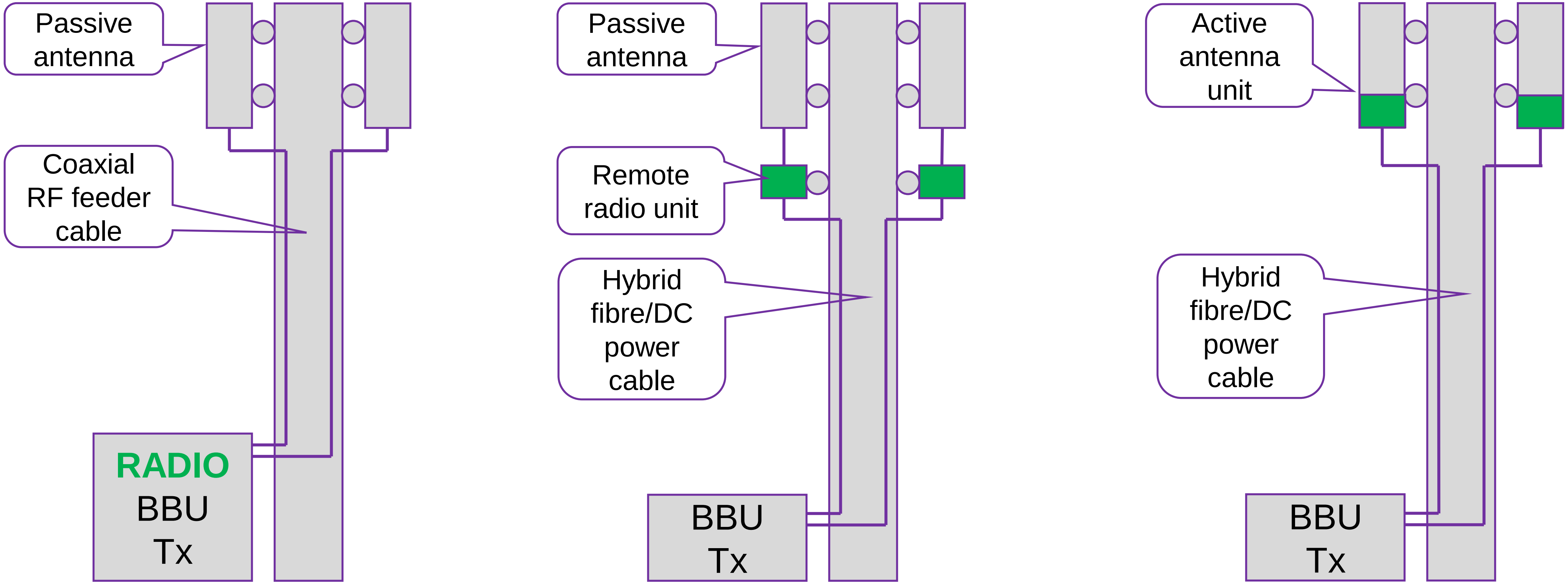
- All of the R100 North contract build will be gigabit capable – this is more than 30 times faster than the Scottish Government's original commitment to deliver 30Mbps





RF over fibre

Base station architecture evolution



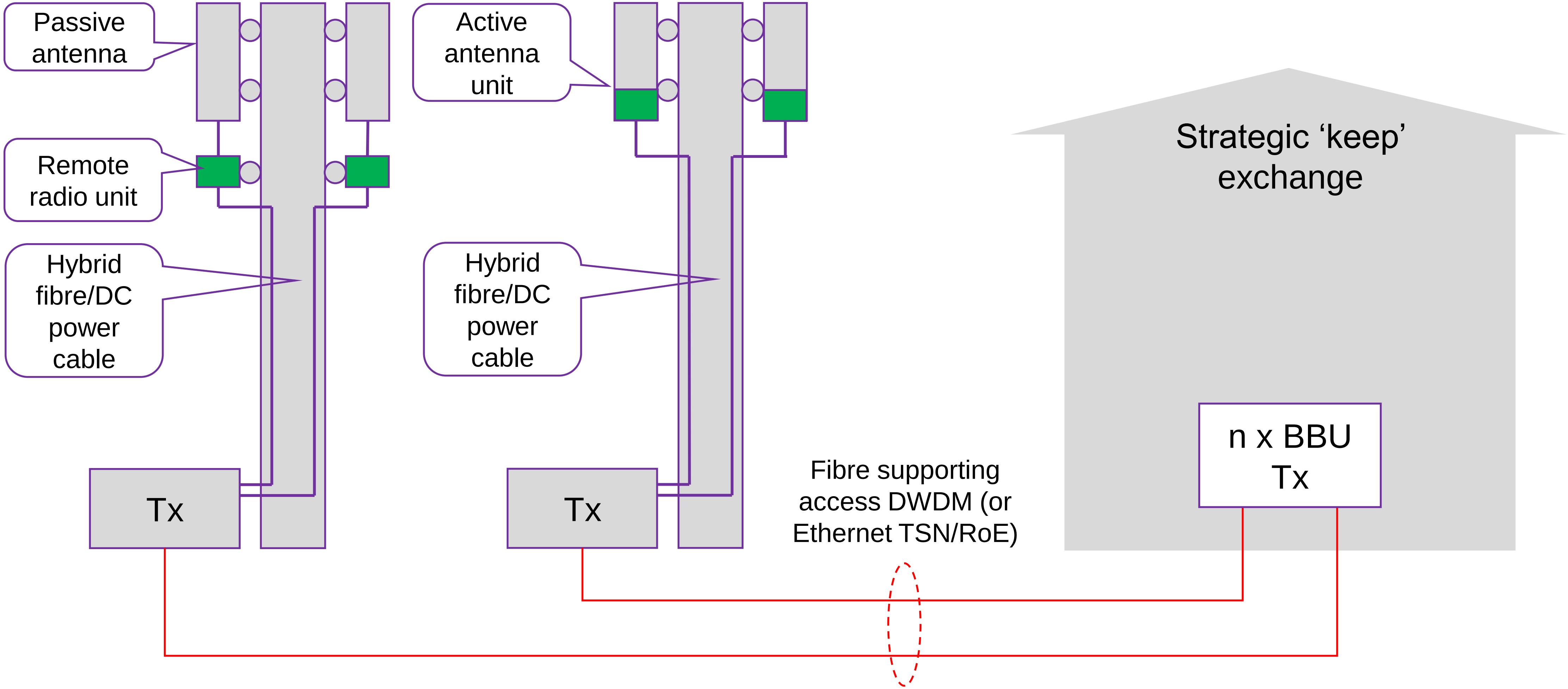
Traditional cabin mounted radio
(Mass head amplifiers not illustrated)

Tower-top remote radio units

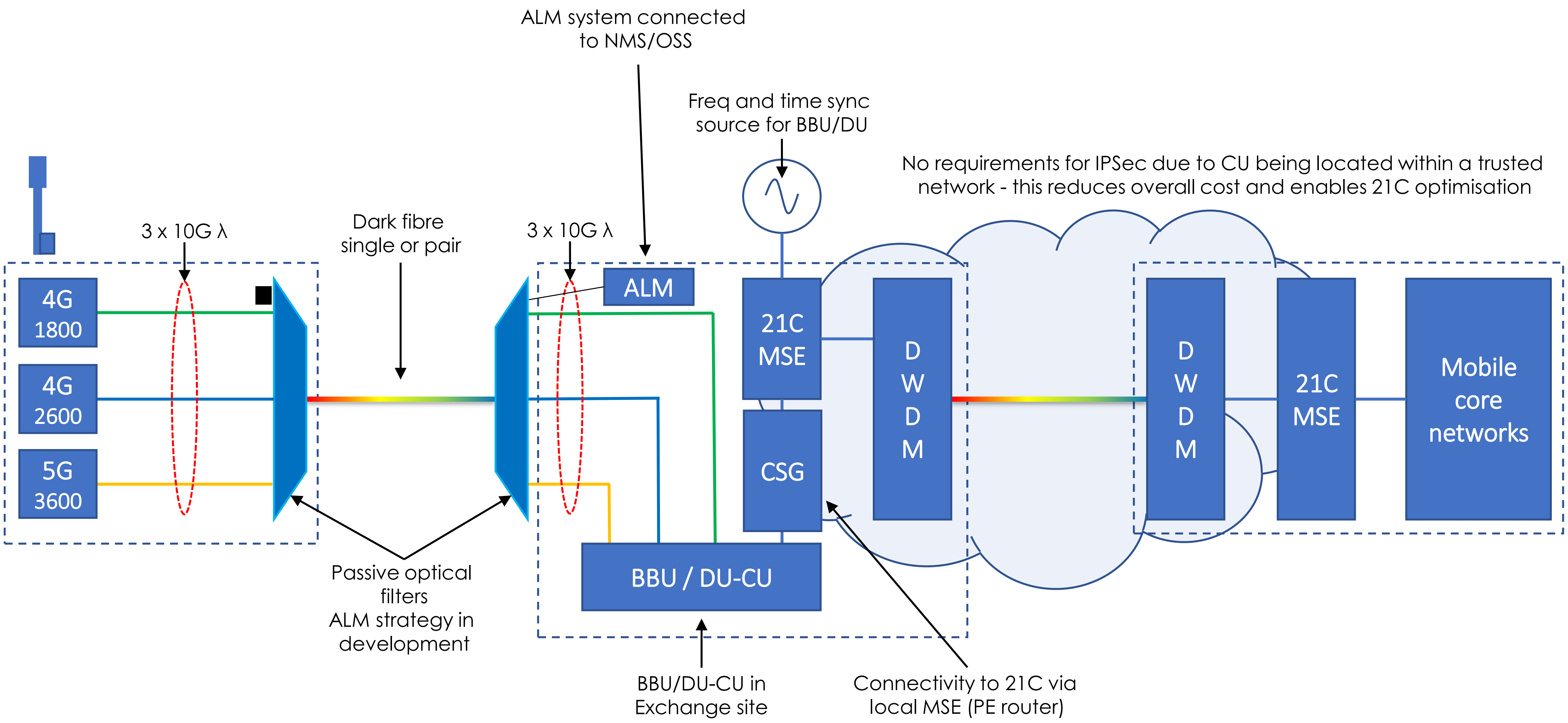
Integrated active antenna units

Fibre to the tower (FTTT) - fronthaul

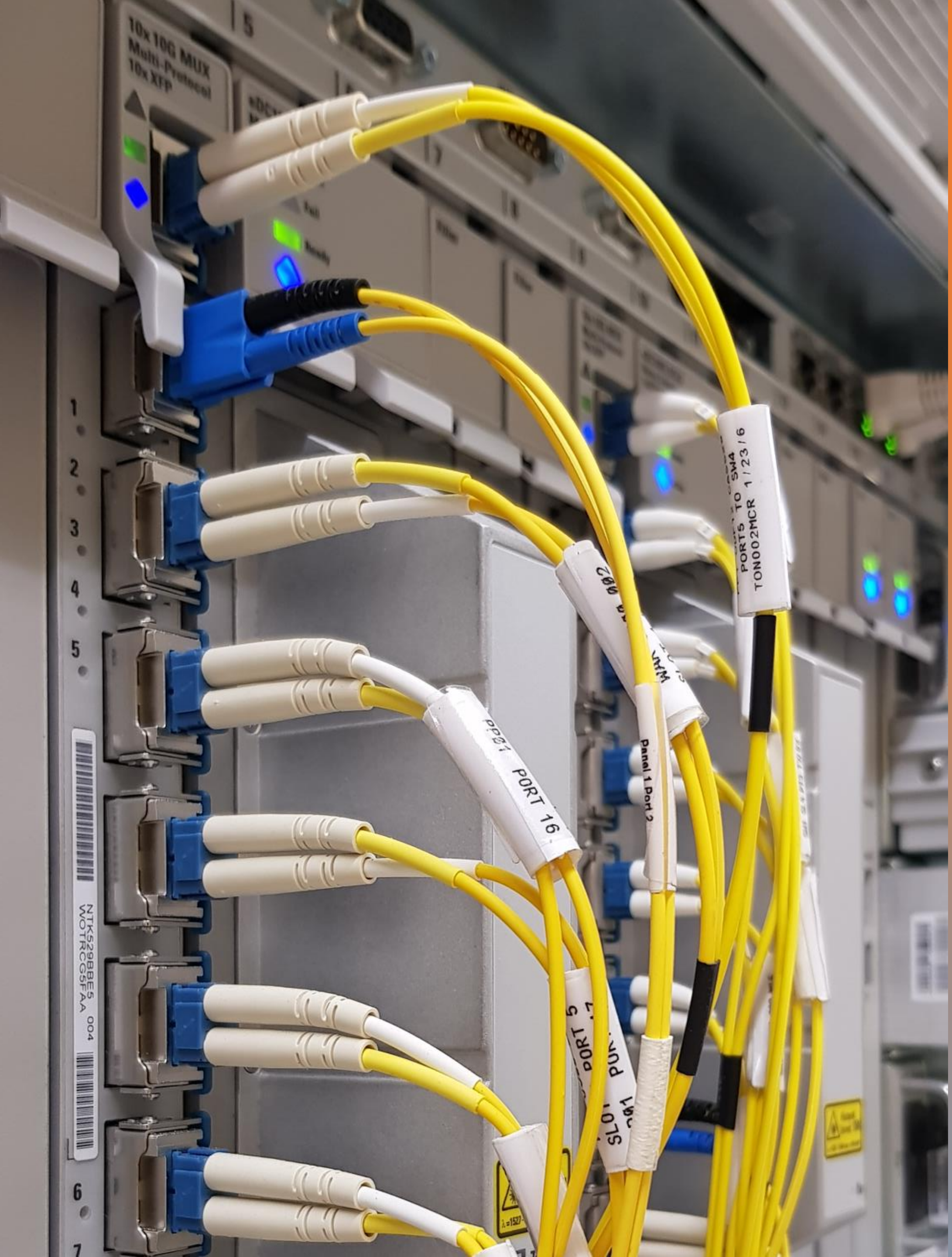
Base station architecture evolution



5G EN-DC Small Cell C-RAN trial



FareShare
MAILBOX
SECURE COURIER
enact
LIVE


10x10G MUX
Multi-Protocol
10xXFP
PORTS TO SW4
TON002MCR 1/23/6
PORT 16

Summary

Summary

- **Fibre optics and optical networking technologies have evolved at a rapid pace and now enable data-rates in the Gbps and even Tbps ranges, transmission distances are increasing, and diversity of supply enables ever greater network and service availability…**

- **Fibre optic cables and optical networking underpins our global digital eco-system**

- **Local access, national backbone, and international private leased circuits (IPLC) provide high-capacity connectivity and can be engineered for high-availability**

- **RF over fibre enables radio network optimisation in commercial cellular networks and offers a range of opportunities for deployed comms in the battle-space**

- **The integration of optical networking with wireless technologies enables truly heterogeneous networks, however, care should be taken to avoid shared fate…**