COMP3310/6331 – #4

Media: Fiber

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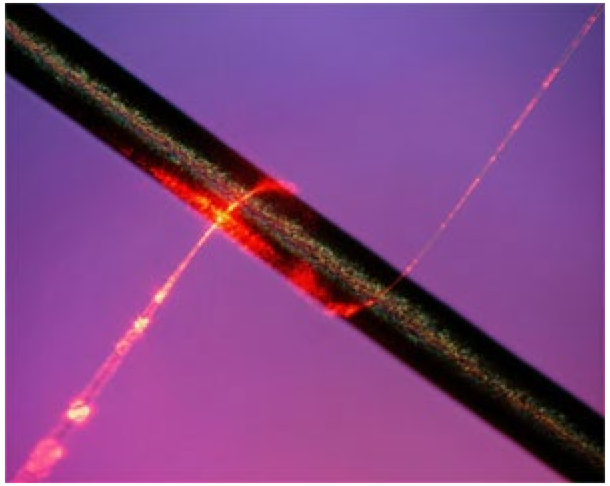
Optical Fibre Characteristics

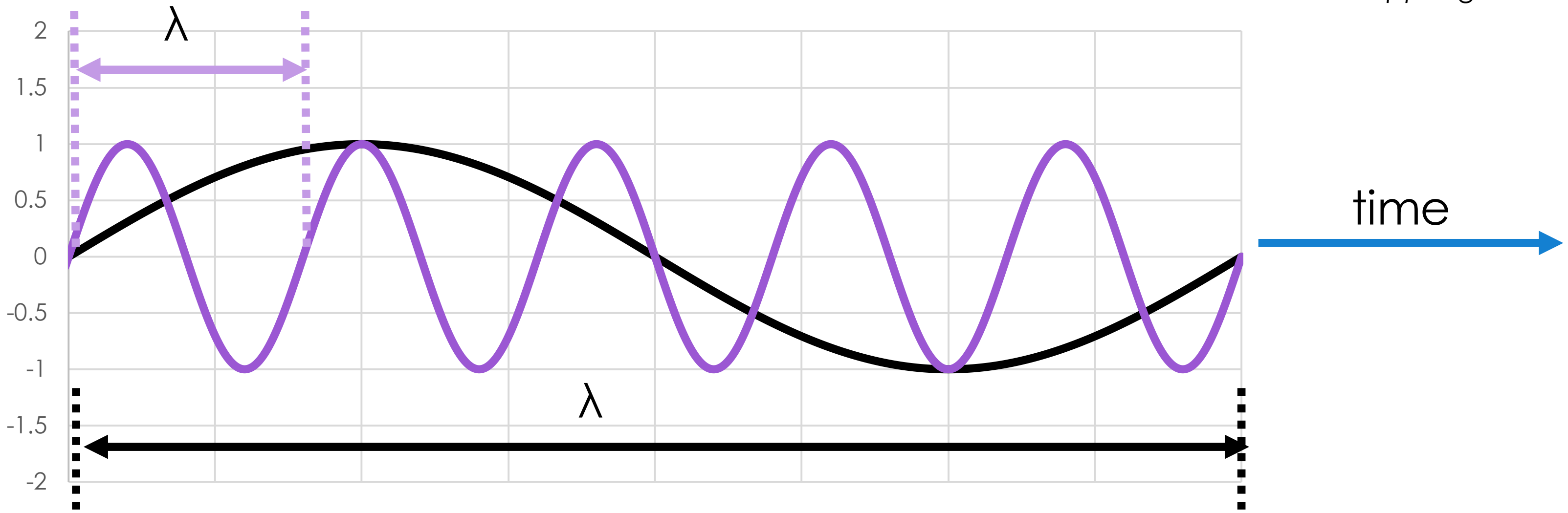
- When copper just won't do…
- Light (weight), very robust to oxidation, water, electrical interference, …
- Can go a long way
- But
  - not very flexible (it breaks, cracks),
  - not easy to join (need to melt it)
- Easy to make thin cables
  - Copper down to 0.03mm diameter
  - Standard Fibre down to 8micron diameter (0.008mm)
    - And can go well below 1micron in the lab
- Not as cheap(?)



Quick change in language

- In copper we talk about <u>frequency</u> (f or ν) *[in Hz or s^{-1}]*
- In Fibre we talk about <u>wavelength</u> (λ) *[in meters]*
- High frequency ≡ Short wavelength
- c (speed) = f * λ *(speed in that media)*

c_{vacuum} = 300,000km/s
$c_{copper,glass} \approx$ 2/3 c



Huge change in performance

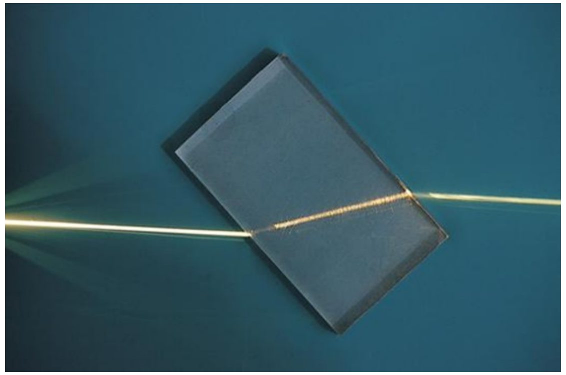
- Copper we use **kHz** (10^3) to **MHz** (10^6), Wireless to **GHz** (10^9)

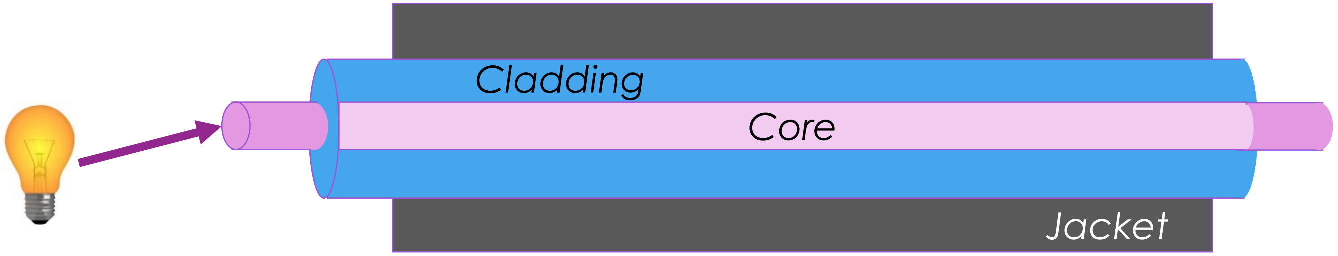
- Optical we start at **THz** (10^{12}) and up

- *VDSL 12 MHz = 25 m*
- *Wifi 2.4GHz = 12.5 cm*
- *Yellow light = 600nm = 500 THz*

How it works – Physics!

- Index of refraction = c/*(speed of light in that material)* = “n”
- Cross from one material to the other
  = change of speed = change of direction
- Make a fibre cable:
  - Take a glass fibre core,
  - Wrap it in different glass
  - Protect it with a plastic jacket

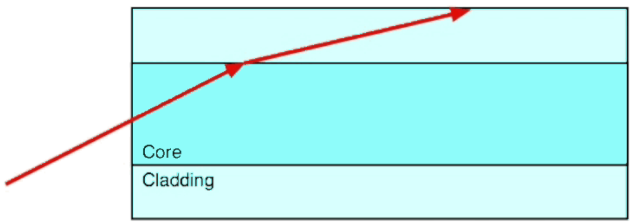


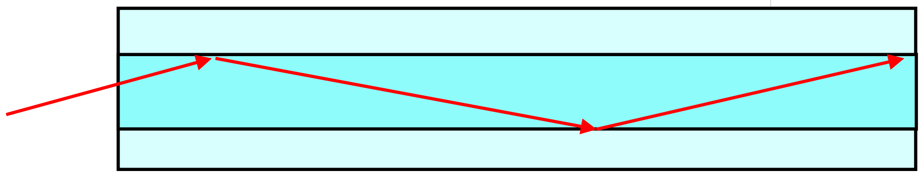


$n_{cladding} < n_{core}$

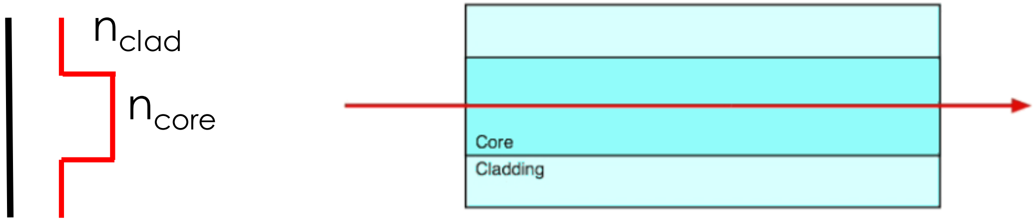
How it works

- Get the angle and change of material right:
  - Total internal reflection
    - Within a ‘critical angle’



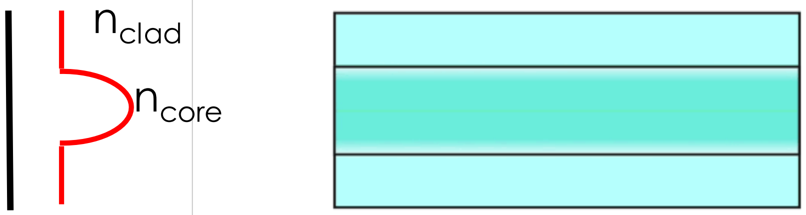


- Step-index fibre



Each ray = a “mode”
<u>*Modal distortion*</u>

- Graded-index fibre

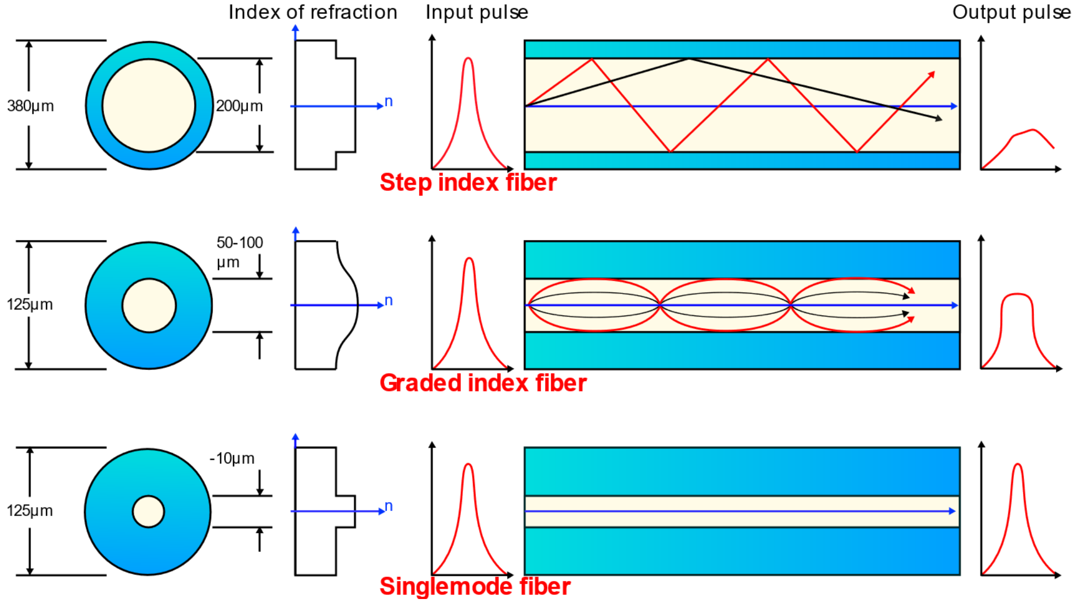


Straight line is slowest
Reduces modal distortion

Animations from http://www.thefoa.org/tech/ref/basic/fiber.html

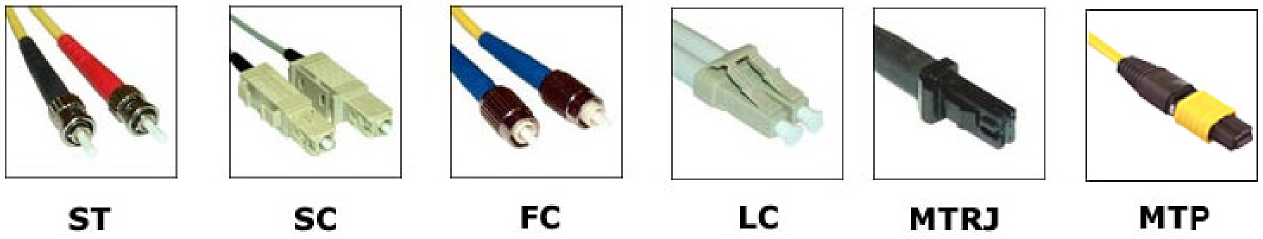
Multimode vs Singlemode

- These are "multi-mode" fibres
  - With significant modal distortion
- Make core much narrower
  - a few wavelengths?
  - "single mode" fibre
- Performance goes way up
- So does Cost



Fibre standards

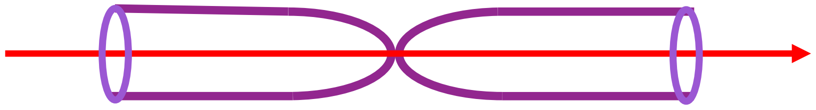
- For the cable
  - Multimode fibres, OM1 (62/125μm), OM2-OM5 (50/125 μm)
  - Singlemode fibres, ITU G.652-G.657 (9/125 μm)
  - *Performance expectations more than actual manufacturing*
- For the connector
  - So, so many standards
    - Vary by sector
    - 30+ on Wikipedia



- <u>Do not mix up your cables</u>
  - MMF into SMF does mechanically work, but “performance suffers”.

Fibre connectors

- Need to be “perfect”!
- Glass face to Glass face
  - Dust is a serious enemy
  - Most use curved (or sometimes angled) faces, reduce reflections at the end



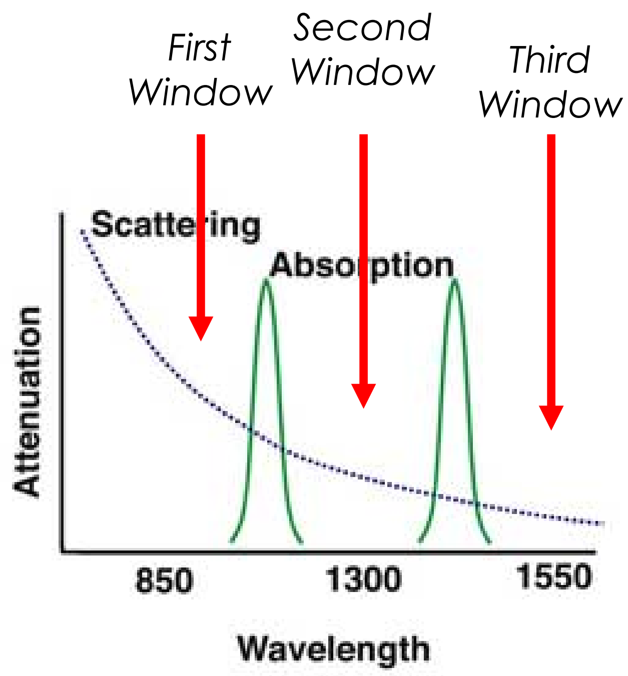
- Terminating copper cables involves scissors and pliers
- Terminating fibre involves melting and polishing glass/plastic
  - Thinner than a human hair
- Splicing fibre directly via melting (good), or glueing (less good)
  - But glue is cheaper…

Losses in fibre

- Attenuation 0.4-3 dB/km, due to
  - **Scattering** (structures+materials in the fibre)
  - **Absorption** (materials in the fibre)
  - Distances of many km are trivial
    - 8km still yields 75% of the original light.

- Attenuation depends on wavelength

- Fibres have multiple passbands
  - Due to various materials
    and manufacturing techniques
  - Always improving, both absorption and range



Other losses in fibre

- Chromatic dispersion
  - Index of Refraction varies with wavelength
  - A pure single wavelength is hard to do (even for a laser)
  - Soliton pulses fix it

- Polarisation mode dispersion
  - Core shape helps fix it

“Loss budgets”

- You have an energy budget
  - How much you can send
  - How much you need to receive (for a reasonably clear signal)

- Loss due to the fibre [0.4-1.0 db/km for SMF]
- Loss due to (mechanical) connectors [0.3dB each]
- Loss due to (physical) splicing [0.3dB each]

Going round corners

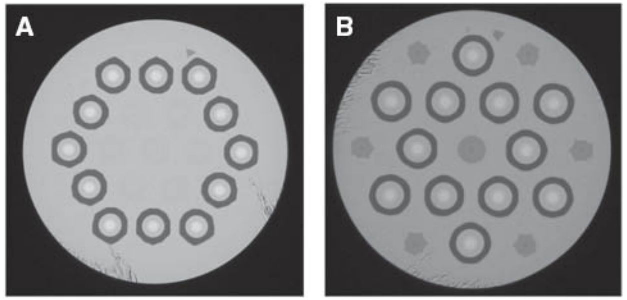
- Copper has tight bending radius
  - N times diameter

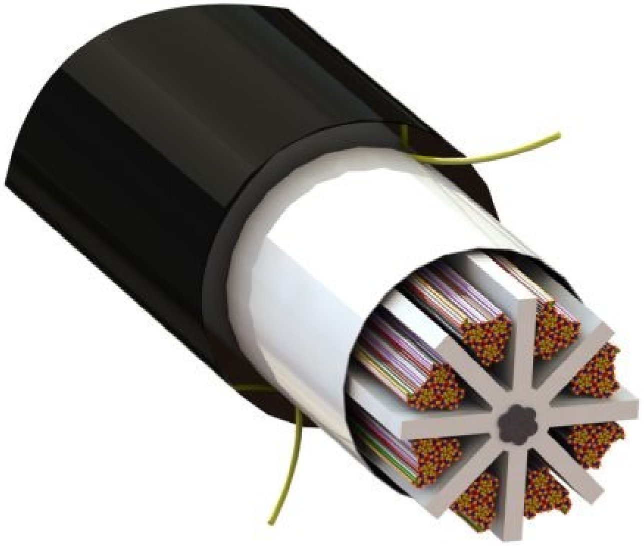
- Fibre does not
  - Fractures, causing attenuation and/or interference
  - MMF better than SMF

- Fibre testing
  - Send a pulse, look what gets through and what comes back!

Multi-core cable design

- Individual fibres are fragile
- Fibres with sub-fibres or hollow channels
- Cable bundles up to 1024 fibres
  - Business proposition:
    - Costs as much to bury/hang as a single fibre
    - Each cable can carry the whole internet…
    - People often still want their own fibre path
      - Security
      - Guaranteed performance
      - New technologies
  - Concept of ‘**dark**’ and ‘**grey**’ **fibre**
    - An empty glass you can fill how you want, or
    - A slot alongside others to add your wavelength





THz channels

- A single wavelength of light at 500 THz can carry 1+Pb/s?

- Electronics can't (yet) keep up – better to slow down!
  - Use ASK, PSK
  - FDM becomes WDM – multiple wavelengths of light
  - *Can also do Polarisation Division Multiplexing*
- Signal muxing can be done optically – up to a point
  - Add-drop multiplexers (ADM) – add/separate a particular wavelength

- WDM can be coarse (CWDM) and dense (DWDM)
  - Usually use each wavelength as a separate channel

Transmitting over light

- Convert electronic data to optical signalling
  – OOK->QPSK++
- You can <u>pulse an led</u>
    - Fast-ish, and very cheap
    - Don’t get very bright or nicely shaped pulses
    - Too broad a colour range
    - Used in MMF
- You can <u>chop a laser</u>
    - Semiconductor lasers are now 100micron in size
    - And wavelength tunable on the fly
    - And use an “Optical Mach-Zehnder” modulator
    - Used in SMF

How fast can you go?

- Depends on "fast"
- <u>Highest absolute speed</u> (2012): 1Pb/s over 50km *(that's 1,000,000Gb/s…)*
  - *And (2017)10.2Pb/s over 11km*
- <u>High speed over long distances</u> (2009): 100Gb/s over 7000km ***times 155λ***
  - *And (2016) 65Tb/s over 6600km (?)*
- Various techniques, with multiple wavelengths, multiple cores, pre-distortion, …

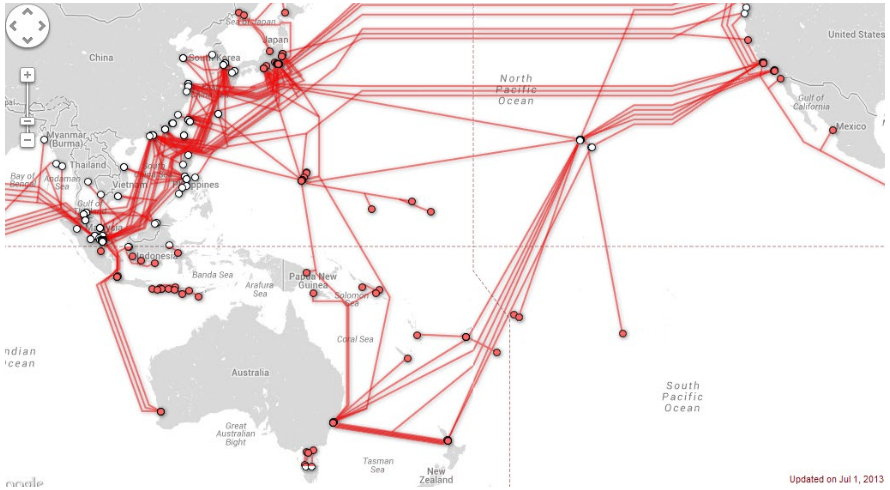
- Better measure: bandwidth*distance
  - 2016: $4*10^5$ (Tb/s).km
  - 2012: $5*10^4$ (Tb/s).km

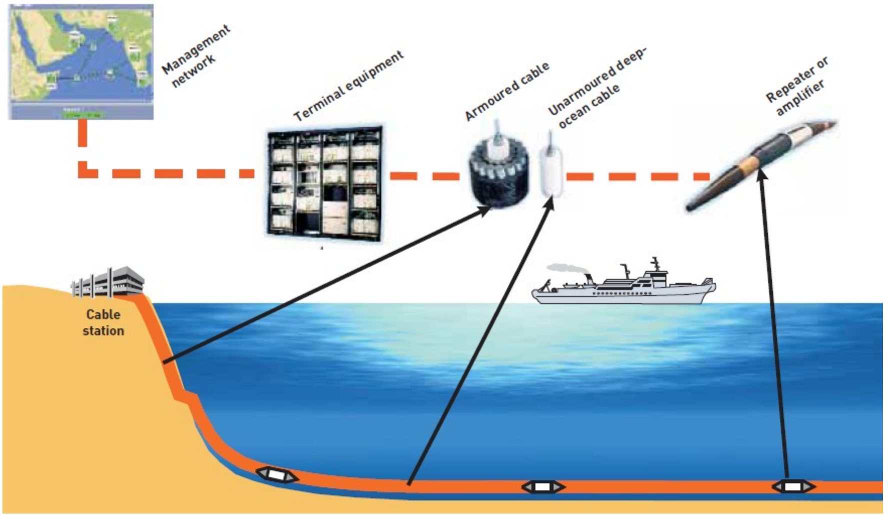
  - 2012 used very specialised fibre, 2009 was commodity fibre
  - 2017 Internet traffic estimate: 122,000PBytes/month = 0.5Pb/s…
  - And these measures don't include energy costs!

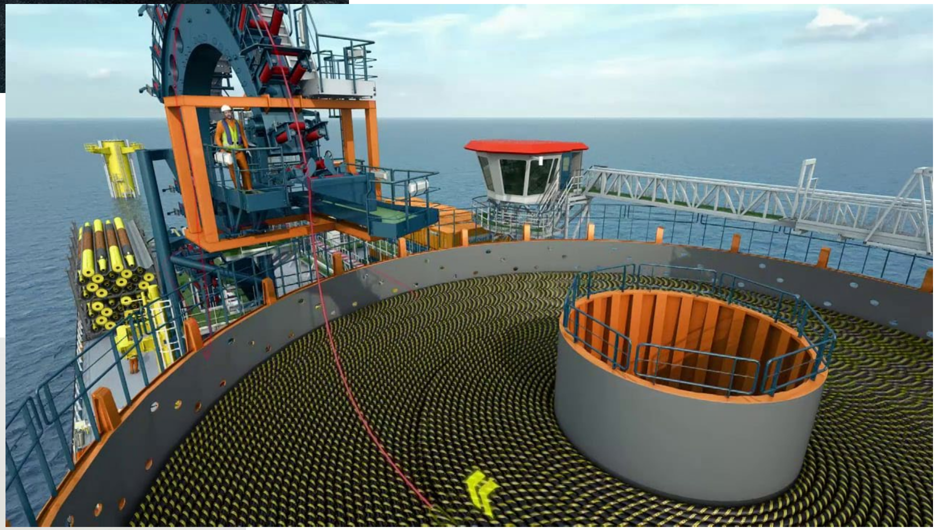
How far can you go?

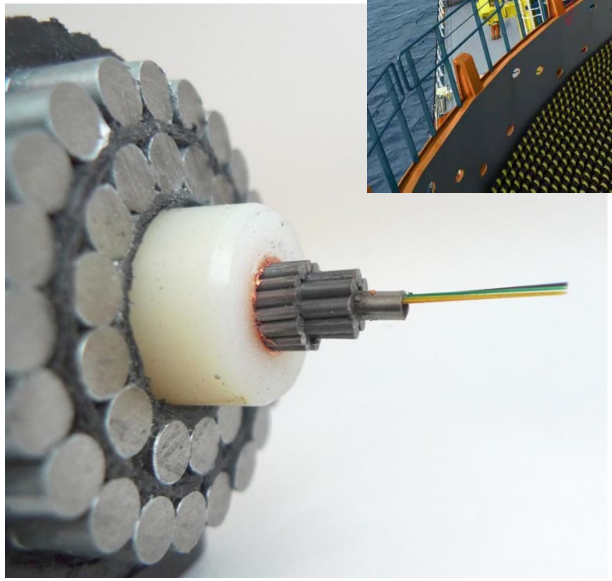
- Without effort, 1-2 km over MMF, 50-100 km over SMF
- Want more? Brighter lasers – gets difficult
- **Regenerate/Repeat** every 50-100 km
  - Expensive optics and electronics, reconstruct signal and retransmit – perfectly
  - Optical-electronic-optical “OEO” interfaces
- **Amplify** every 50-100 km
  - Cheap electronics, and can even be done optically (erbium doping)
  - Amplifies signal <u>and</u> noise.
  - *Record: 2015 - Melbourne to Melbourne, via Sydney&Perth = 10,358km @100Gb/s?*

Undersea cabling









Underwater cables are safe!

Doing more with less

- Unlike copper, fibre is not (easily) a shared medium
  - Point-to-point

- Can use a single fibre for RX and TX at the same time
  - Optical splitters at both ends
  - Can get crosstalk, in connectors, and within fibre

- Still more common to have a fibre pair though

Last mile and fibre

- Lots of discussion about ‘costs’
  - Compare capital costs of installing fibre vs copper
  - Compare running costs of fibre vs copper
  - Compare performance of fibre vs copper

- General approach – mix it up:
  - Push fibre as close as you “can” (afford, achieve)
    - To the home? To the driveway? To some nearby node?
  - then use copper for the last bit (with DSL)
  - While keeping an eye on the electronics

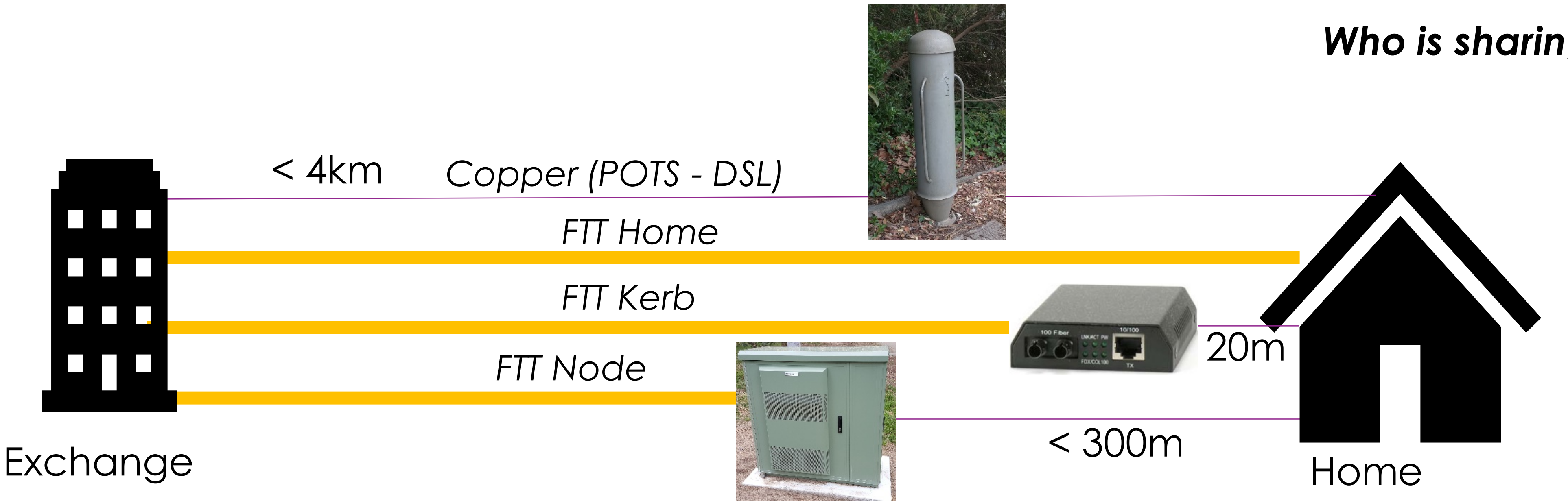
Some FTTx models

- Leverage what is already in the ground/on the poles
  - Most homes have landline phones = capital investment
- Reduce the average distance of copper
  - Push fibre as deeply as "affordable" (by who?)

What needs power?

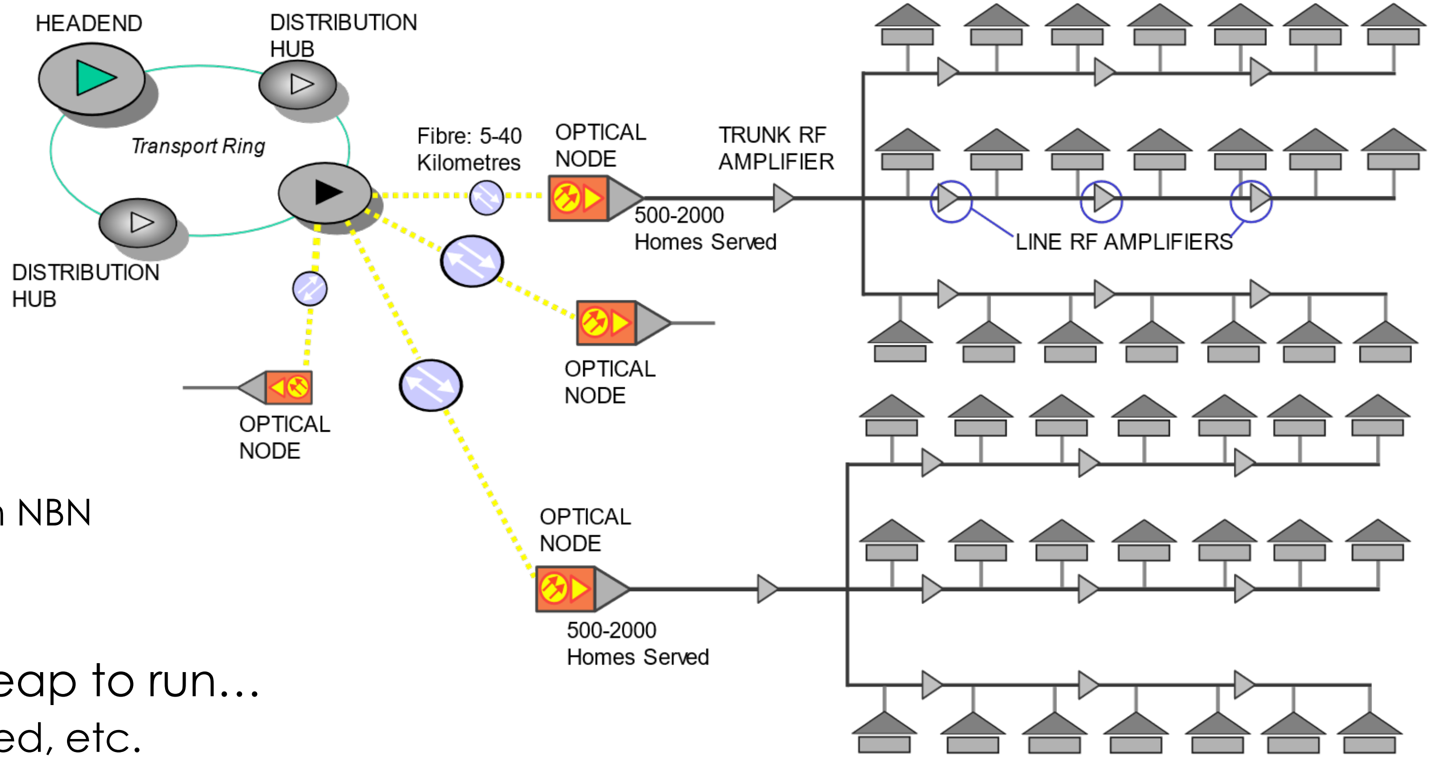
What needs managing?

Who is sharing?



Compare FTTx with HFC

- **Fibre To The … (FTTx)**:
  - FTTP/FTTH,
  - FTTB,
  - FTTC/K/F/dp,
  - FTTN



- **Hybrid Fibre Coax (HFC)**
  - "FTTN" to get you close,
  - Then shared (coax) copper
    - To a lot of houses, 50-100's in NBN

- And again try to make it cheap to run…
  - What is active, smart, powered, etc.
  - And what isn't.

(G)PON

- (Gigabit) Passive Optical Networking
- Using the flexibility of optics
  - And the allure of cheap broadband
- TDM out to the active Optical Network Units or Terminals (ONU/ONT)
- TDM out to the (passive) splitters
  - From the Optical Line Terminals (OLT)
- WDM: RX and TX on a single fibre,
  - SDM: Make more money out of the cable