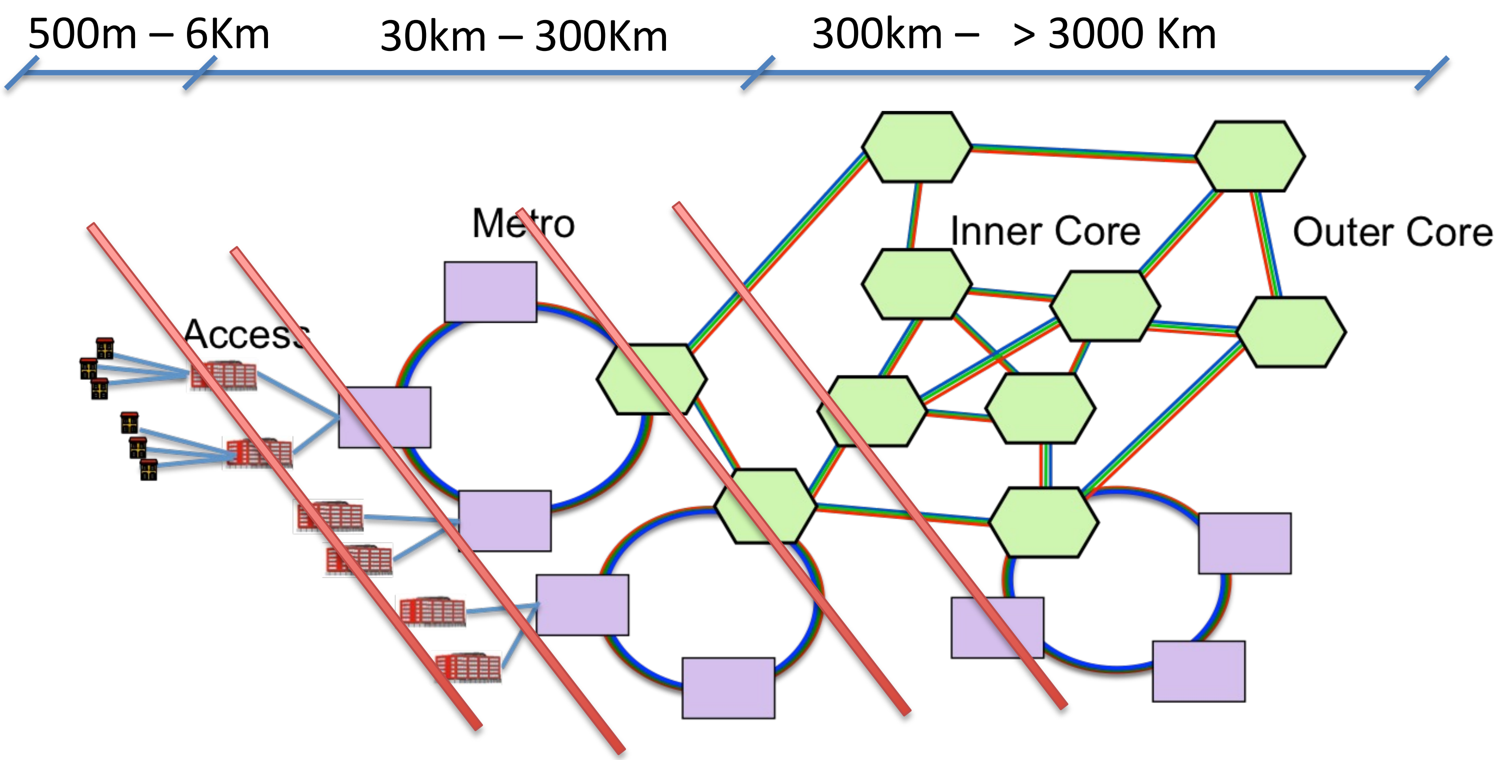
Fixed access networks

Network architecture (access/metro/core view)



Based on progressive customer traffic aggregation through Optical-Electronic-Optical (OEO) conversion

Cost vs. aggregation

- Optical communication technology developed from the core towards the metro, as there each fibre link would aggregate data from several thousands to several hundred million users.

	Access	Metro	Core
Aggregation factor	As low as 1:1 for CPE, 1:10K for CO	1:100K to 1:10M	1:1M to 1:100M+
Capacity	1 Mb/s to 1 Gb/s	10Gb/s to 100s Gb/s	100Gb/s to 10s Tb/s
Volume of expected sold units	Very high (even more than one per user)	Medium	Low (relatively few links)
Cost per unit	Must be very low	Medium	Can be high

Why is the aggregated link capacity (last row) lower than the product of the aggregation times access capacity?

	Access	Metro	Core
Aggregation factor	1-10K	100K-10M	1M to 100M
Aggregation times access capacity	1Mb/s to 1Gb/s	100 G to 1,000Tb	100Tb/s to 100,000Tb/s
Capacity	1 Mb/s to 1Gb/s	10Gb/s to 100s Gb/s	100Gb/s to 10s Tb/s

A. I made a calculation mistake (apologies!)

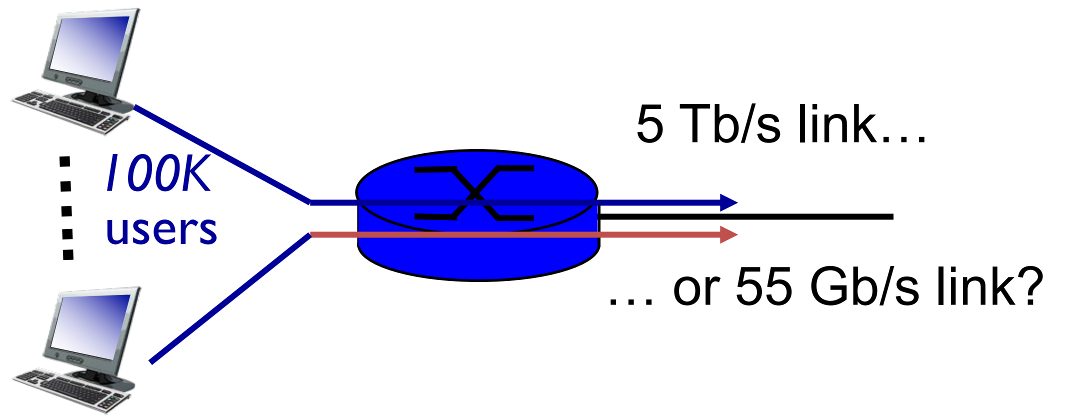
B. The network is not designed for every user to operate all together at maximum capacity

C. The network operates statistical multiplexing as it aggregates users

D. It would be too expensive for a network to support such high capacity

Statistical multiplexing

- We have:
  - 100K users,
  - Each uses 50 Mb/s when active
  - Only active 1% of time
- *If we provided 5Tb/s:*
  - All users always have access but the link is used at 1%
- *If we provided 55Gb/s*
  - Max number of users is 1.1K, if all were always active
  - probability that more than 1.1K users active is: <0.0009



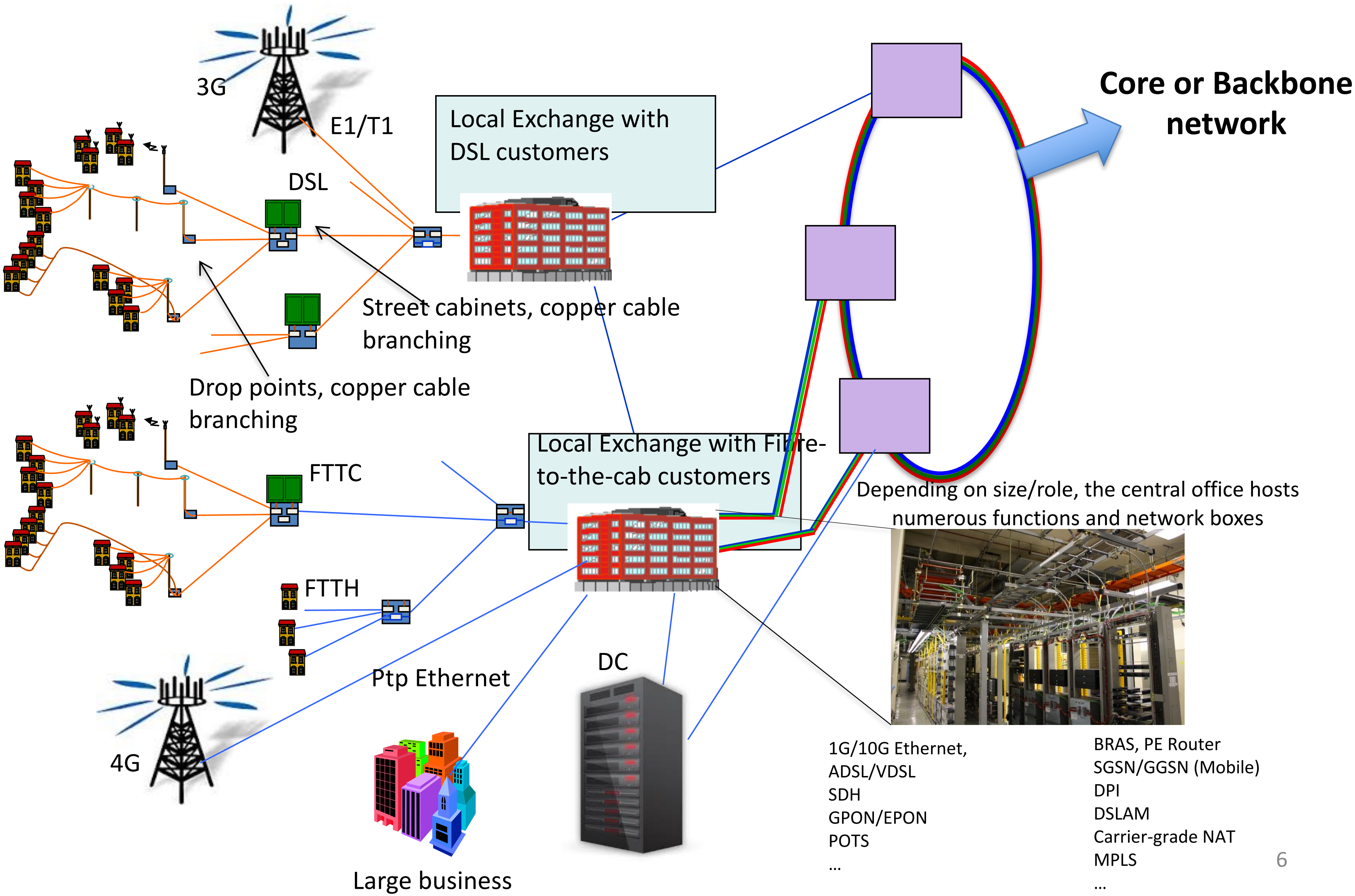
$$P(k\ successes\ in\ n\ trials) = \binom{n}{k} p^k q^{n-k}$$

with $\binom{n}{k} = \frac{n!}{k!(n-k)!}$

- k= No users for which probability is assessed (1,100)
- n= No of total users (100,000)
- p= probability of user in network (1%)
- q=1-p

We want the cumulative probability P (X >1,100) users are in the network: $\sum_{k=1,100}^{100K} P$

Access and metro network view



Access network speed

- Since metro are built on progressive aggregation of traffic, the capacity of access connections are typically lower than those in the metro and core.
  - Fastest access speed to the user 1-10Gb/s
  - Fastest core network link over 40Tb/s (over one fibre)

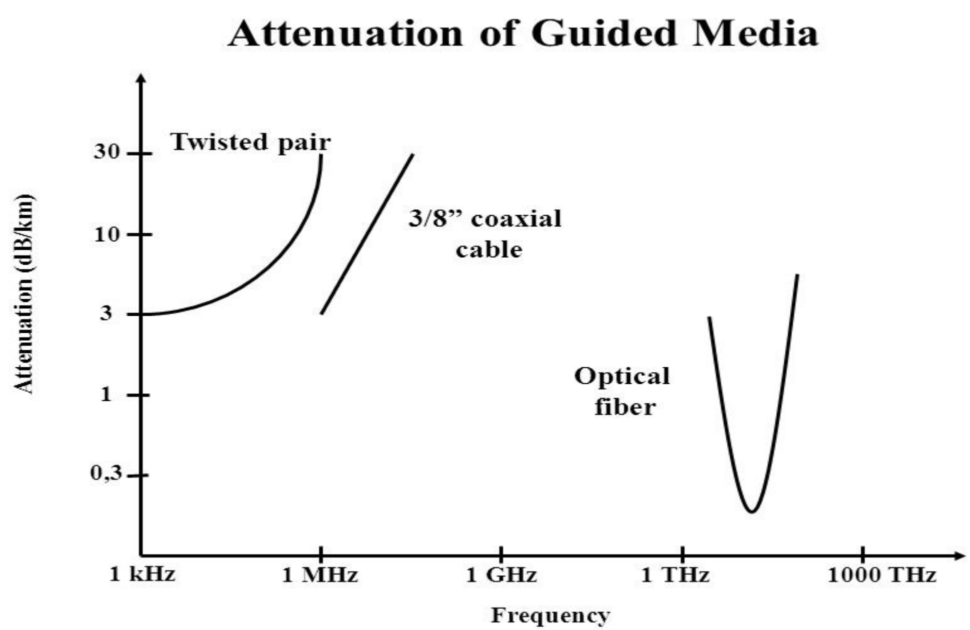
So, why are access networks such a big issue to upgrade:

A. The technology from the core does not work in the access
B. It is harder to lay fibre in the access than in the core
C. Each access link only feeds one user so the cost per user is high compared to the core, which instead aggregates many users
D. None of the above, there is no issue with access network and we all have 10Gb/s at home (including rural areas)

Issues with access networks

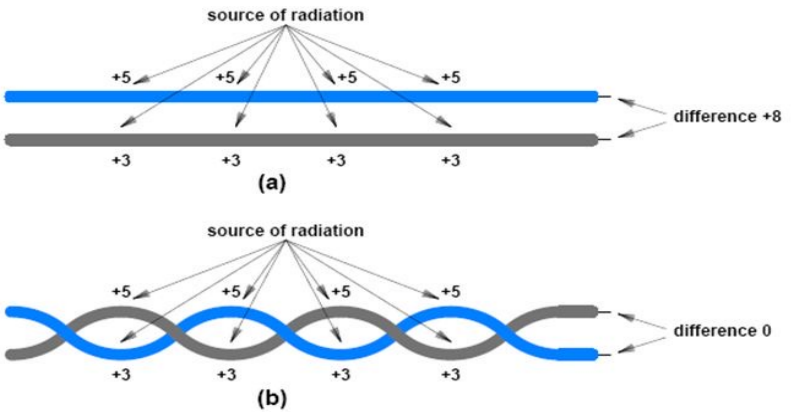
- The issue is the cost per connection upgrade, which is on a per-user basis.
- This explain why many connections, especially in the rural areas are based on copper.

- As seen earlier the problem with copper is that the bandwidth (and thus capacity) is highly attenuated with distance

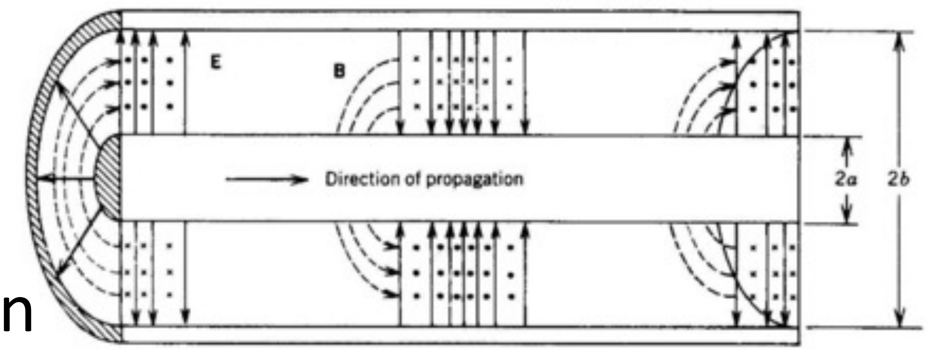


Twisted pair and coaxial

- Twisting the copper helps reducing interference from external sources

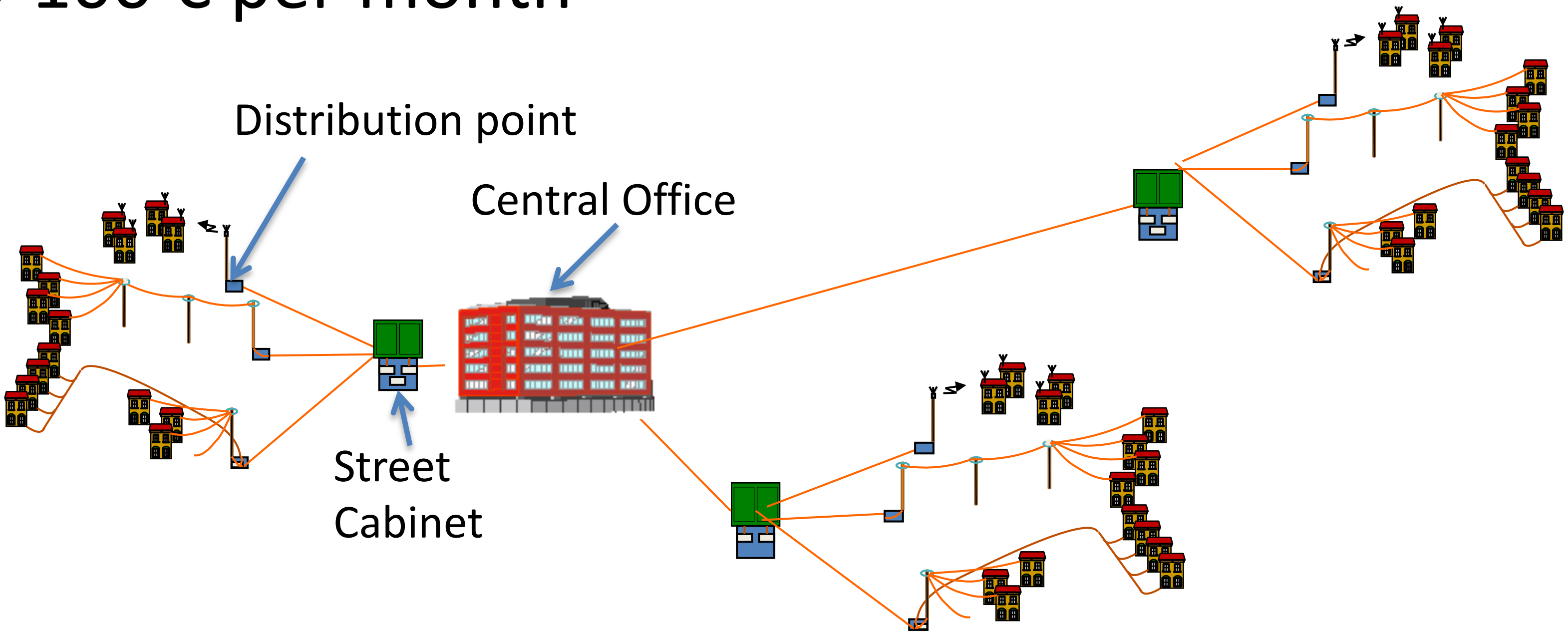


- However the coaxial uses the Faraday principle by using an external sheet to confine the radiation within the cable

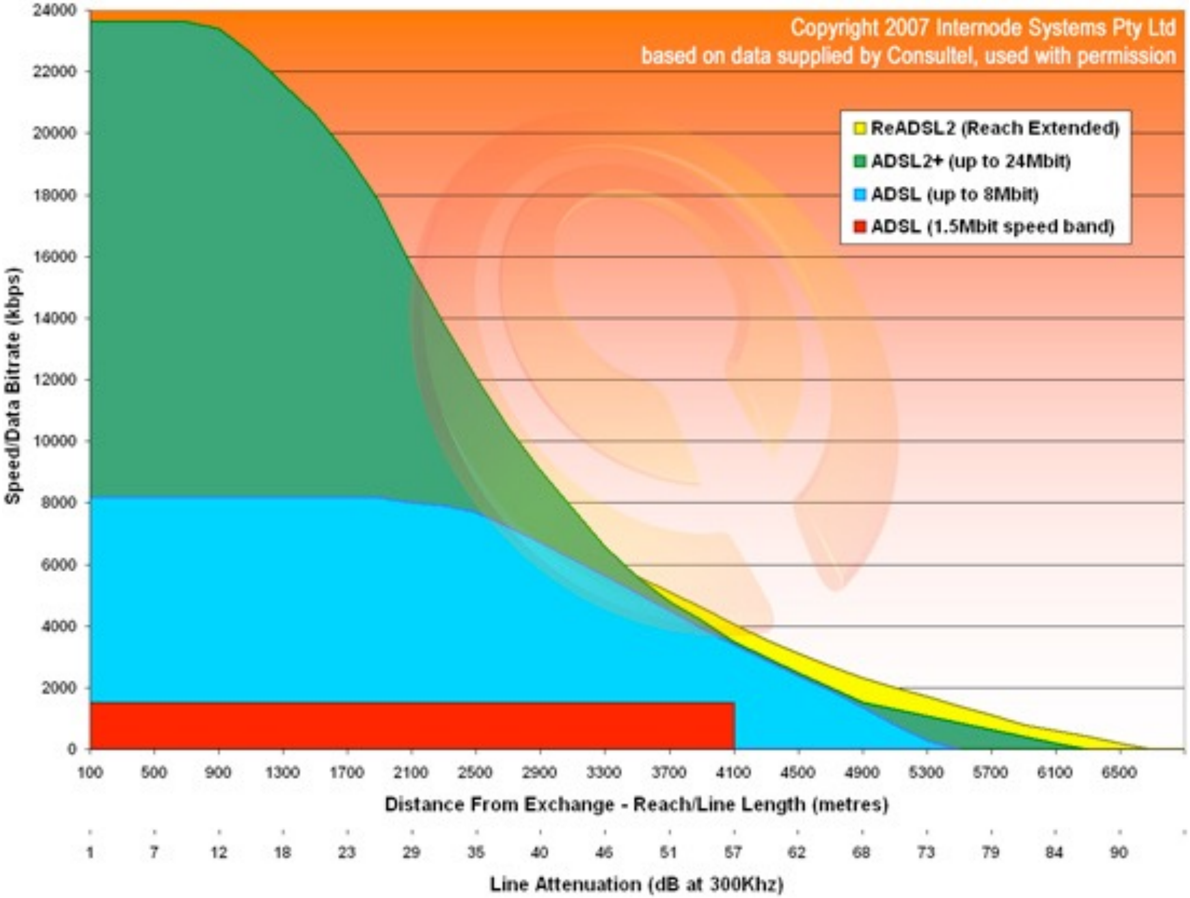


How do we solve this?

- You have a long copper line (between 500m and 6 km, 2 km in average)
- You don't have the money to replace all copper with fibre
- Users want more capacity but only willing to pay 50-100 € per month



Capacity vs. distance of DSL



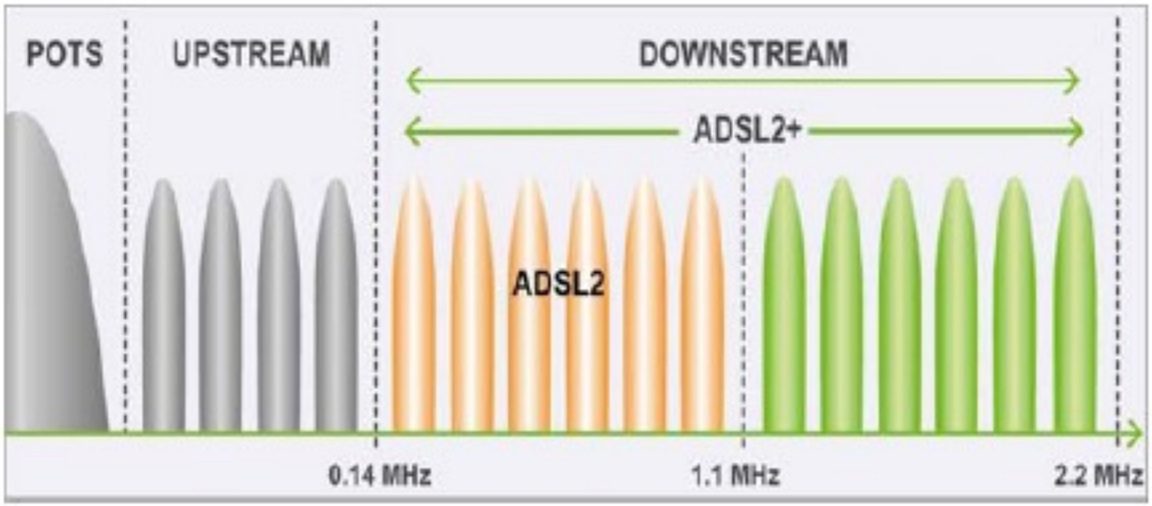
Shannon–Hartley theorem

$$C = B \cdot log_2\left(1 + \frac{S}{N}\right)$$

C = capacity [b/s]
B = bandwidth [Hz]
S/N = Signal to noise ratio [linear]

- The solution is obviously to reduce the distance of the copper link

DSL details



- ADSL occupies up to 1.1 MHz bandwidth, using Discrete Multi-Tone Modulation (DMT - similar to OFDM) with 256 channels
  - Achieves up to 8 Mb/s DS, 1.3 Mb/s US
- ADSL-2 also occupies up to 1.1 MHz bandwidth, using DMT but improving modulation efficiency, reducing framing overhead, ...
  - Achieves up to 12 Mb/s DS, 3.5 Mb/s US
- ADSL-2+ occupies up to 2.2 MHz bandwidth, using DMT
  - Achieves up to 24 Mb/s DS, 3.3 Mb/s US

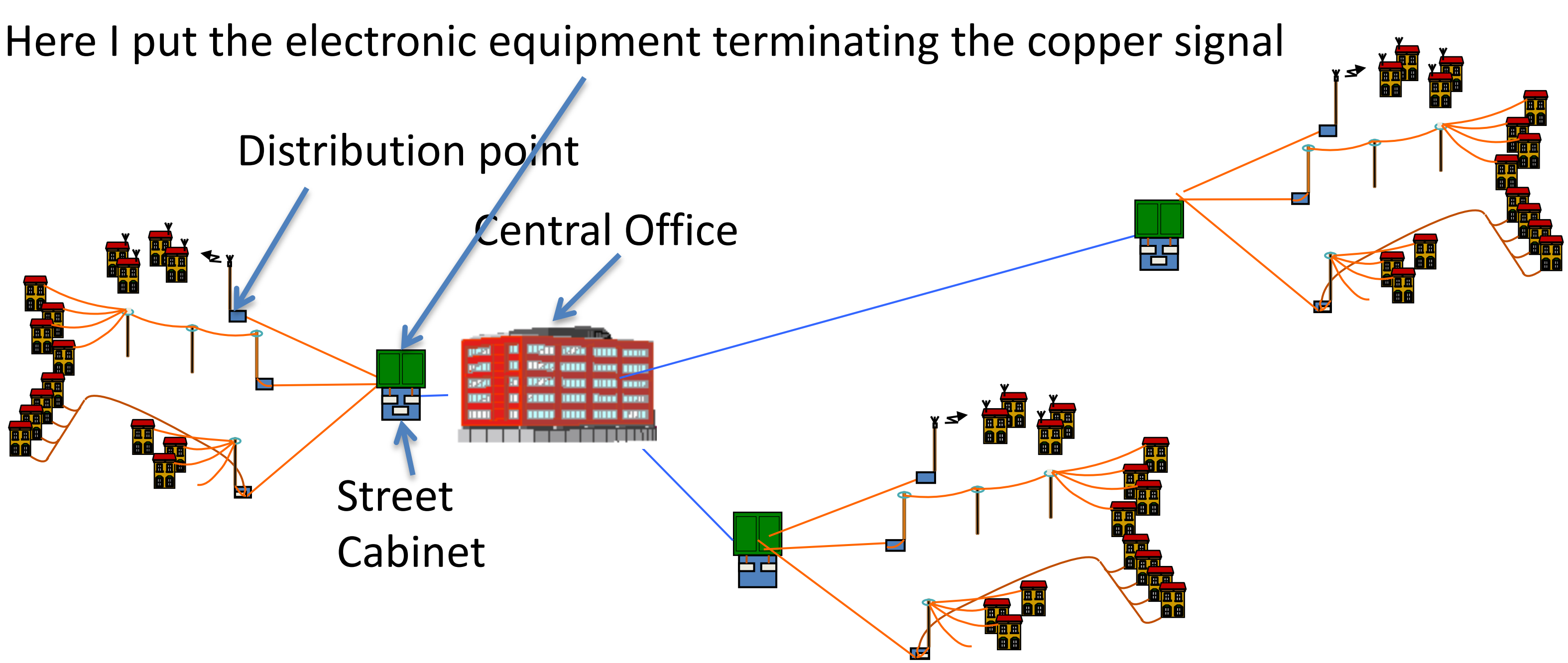
How can we reduce the distance of the copper link?

A. We move the houses closer to the central office
B. We invest in new technology hoping it will deliver higher capacity over the same copper distance
C. We shorten the copper length by start laying fibre in the side close to the central office.

Fibre-to-the-cabinet (FTTC)

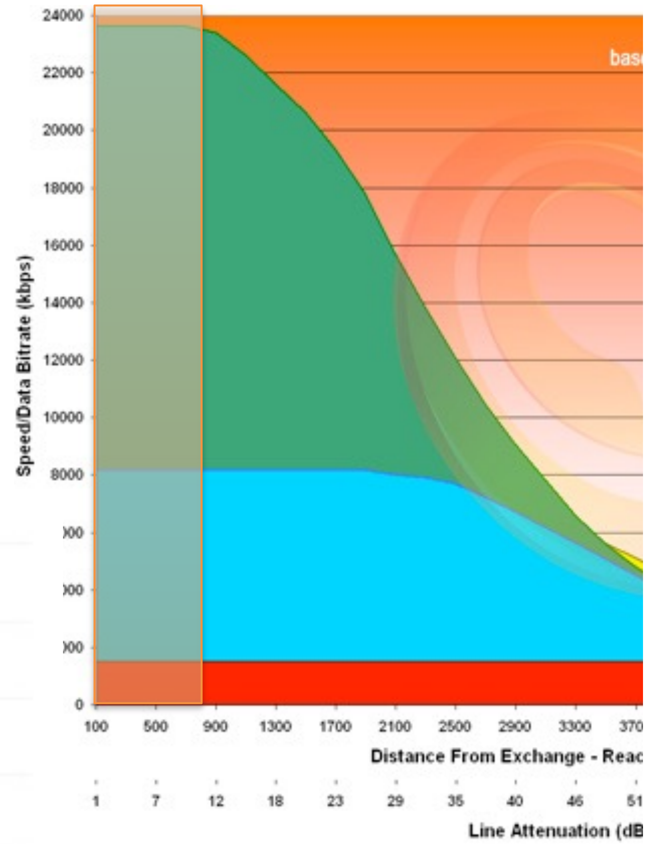
- Replace the first part of the copper (that shared by most users) with fibre

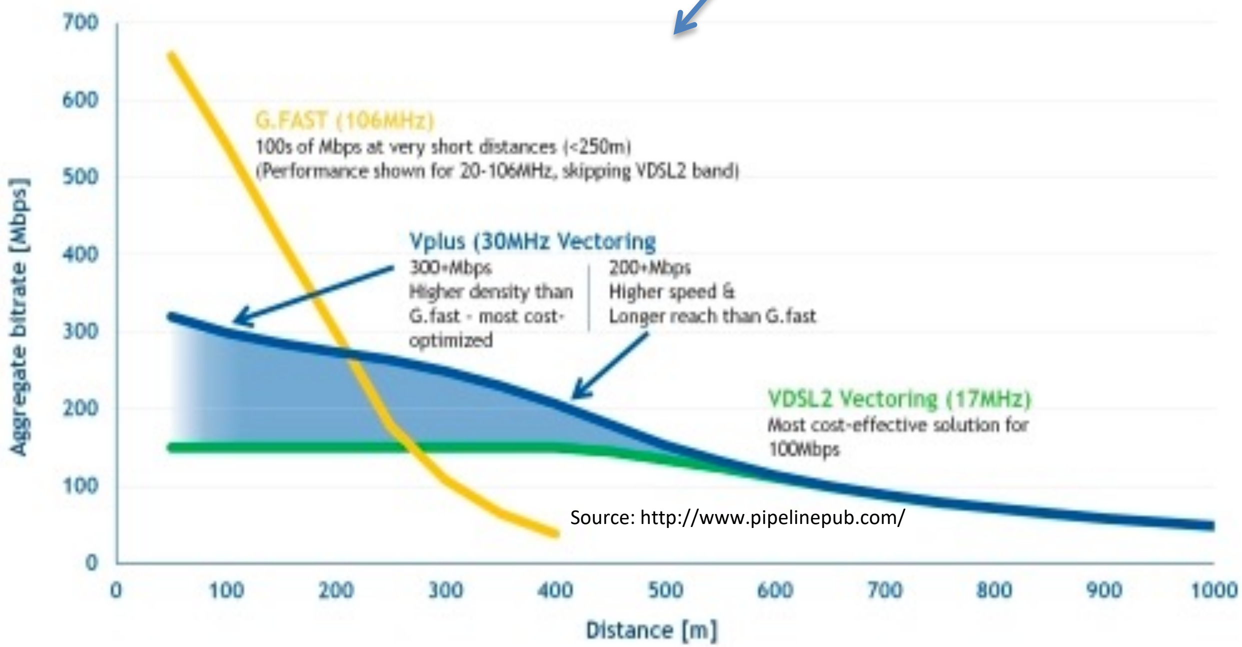
➔ The overall distance now decreases to about 100-700m, average 500m)



FTTC

- So DSL works on the fast side
- But the higher SNR allows to develop also better technology





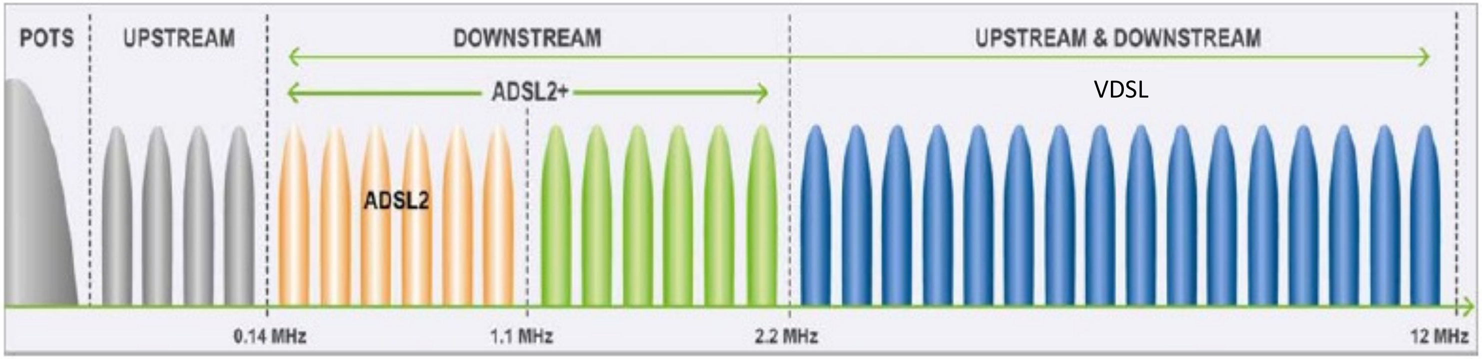
Source: http://www.pipelinepub.com/

FTTC technology

- <u>Main feature is that a twisted copper pair is used in some part of the connection.</u>
- VDSL/VDSL2
- Vectoring
- G.FAST

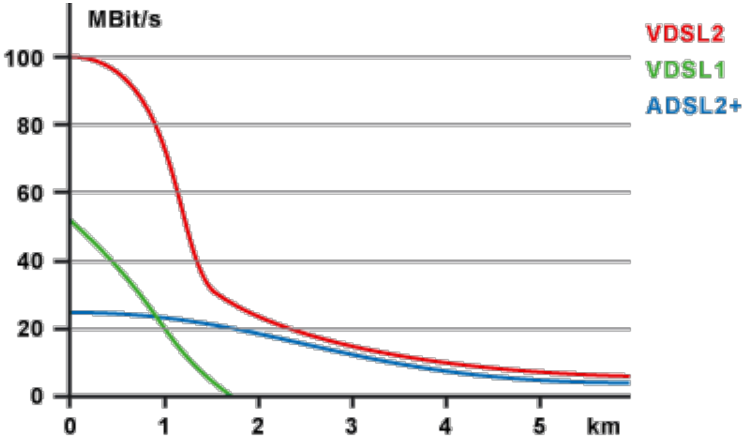
VDSL / VDSL2

- VDSL and VDSL 2 have many different profiles that were developed over the years
- A typical VDSL maximum rate is of 52 and 16 Mbps, respectively in DS/US (ITU-G.993.1 year 2001), using frequencies up to 12 MHz



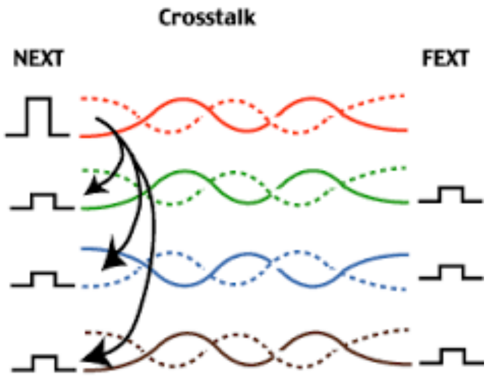
- VDSL2 (ITU-G.993.2 year 2006), uses frequencies up to 30 MHz to achieve symmetric 100MB/s capacity.

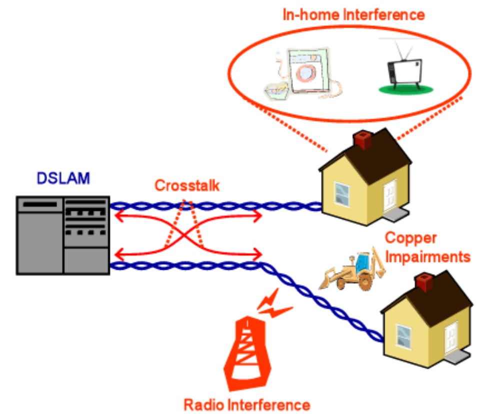
The higher the frequency used, the shorter the reach, although VDSL2 adapts to the ADSL2+ performance over longer loops



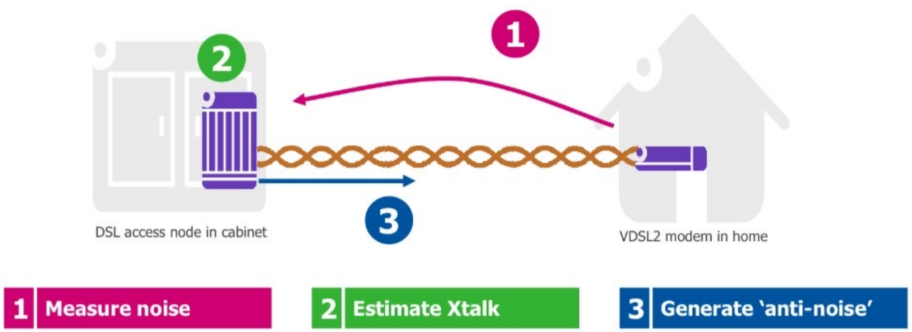
Vectoring

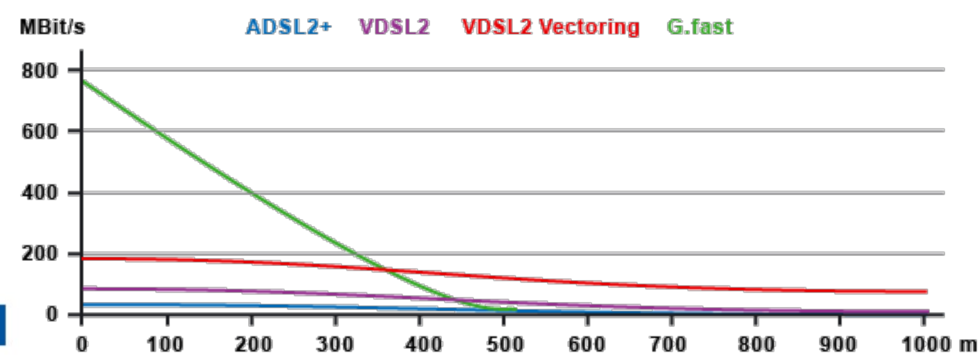
- It turns out that a significant portion of the noise in the line is due to cross-talk between adjacent copper pairs





- Vectoring (ITU-T-G.993.5) applies noise cancellation to the line, but it needs to have access to all interfering lines





G.fast

- G.fast increases the rate by using much larger bandwidth, up to 106 MHz
  - Notice that it overlaps with FM radio!
  - Also, due to overlap with ADSL and VDSL, the starting frequency can be set between 2 and 30 MHz.
- Initially targeting distances up to 250m, was then extended to up to 500m.
- Duplex is in the time domain (TDD) so the DS/US ratio can change (e.g., 90/10 or 50/50)
- **<u>This technology can work both for FTTC and FTTDp</u>**

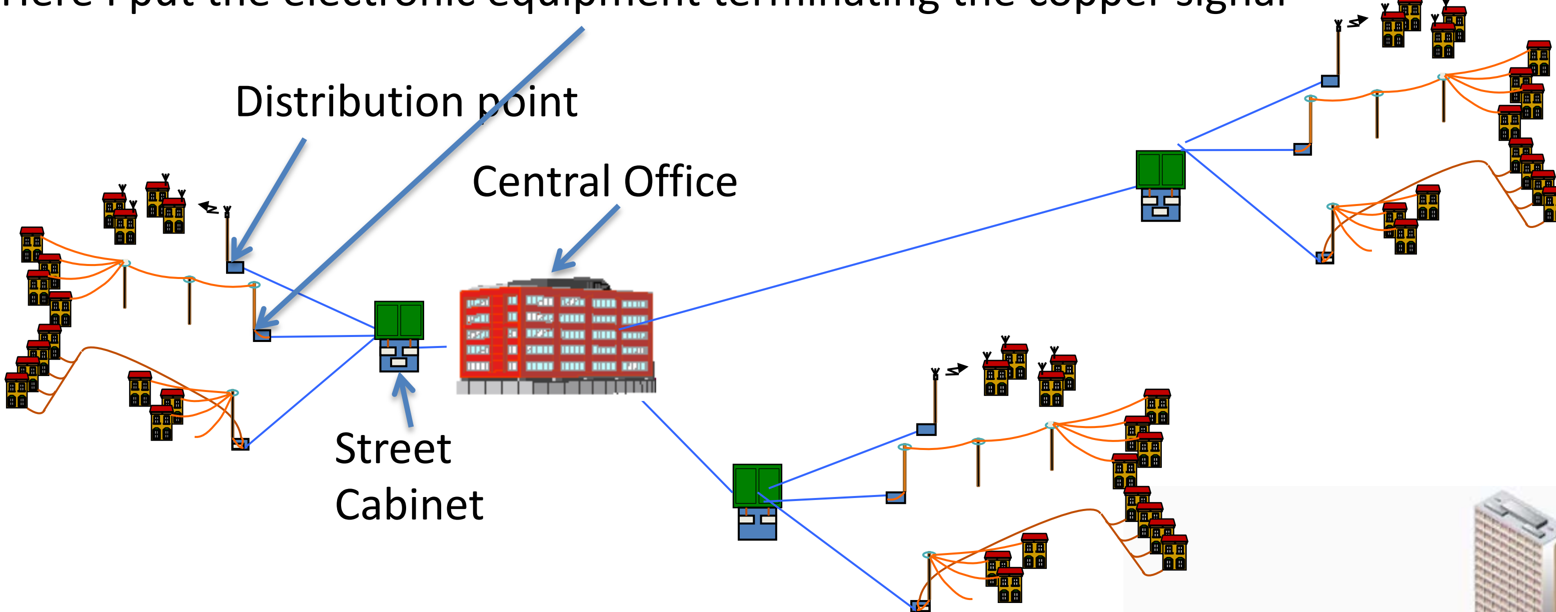
Distance	Performance target
<100 m, FTTB	500–1000 Mbit/s
100 m	500 Mbit/s
200 m	200 Mbit/s
250 m	150 Mbit/s
500 m	100 Mbit/s

Fibre-to-the-distribution-point (FTTDp)

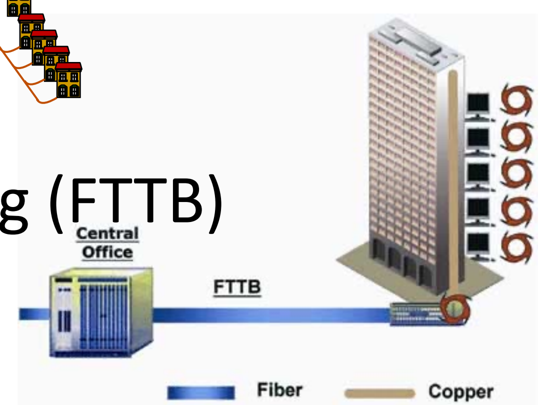
- Replace the copper all the way to the DP (that shared by most users) with fibre

➔ The overall distance now decreases to about 50 -100m

Here I put the electronic equipment terminating the copper signal



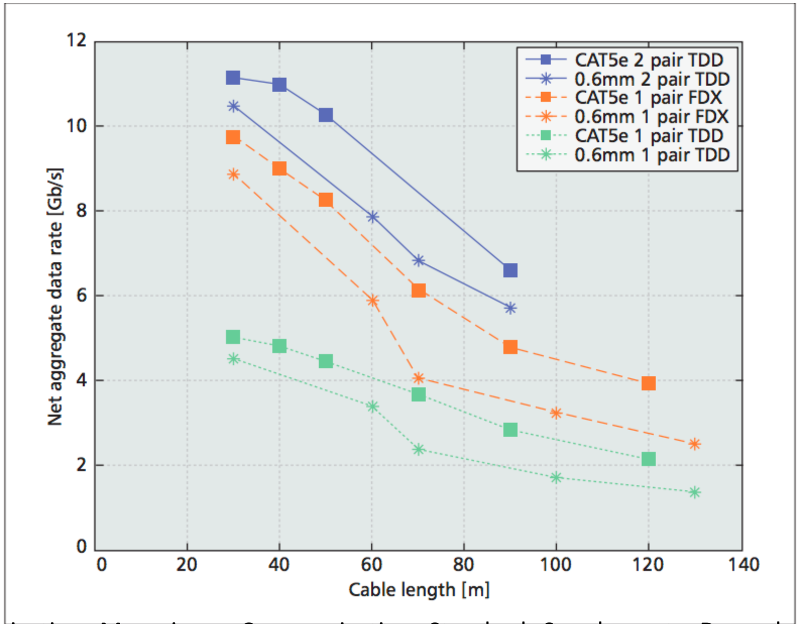
- This is also referred to Fibre-to-the-building (FTTB)



FTTDp technology

- G.FAST (as mentioned before)
- XG.FAST
  - Towards 10Gb/s symmetric over very short copper distance
  - Technology:
    - It uses bandwidth up to 500MHz
    - Bonding: use of two copper pairs per users (where available)
    - Phantom mode: create a third virtual pair of two physical copper pairs
    - Adanced cross-talk cancellation
    - Full-Duplex transmission (FDX): use same bandwidth both DS and US with echo cancellation

Notice that in a building you could use Gigabit Ethernet or 10GE, but **this means installing new Cat-5 or Cat-6 cables**



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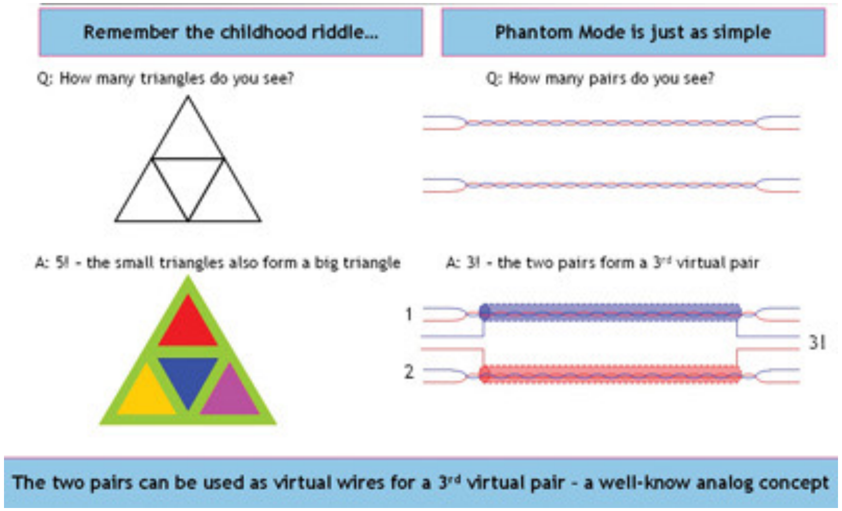
XG.fast

Technology curiosity:

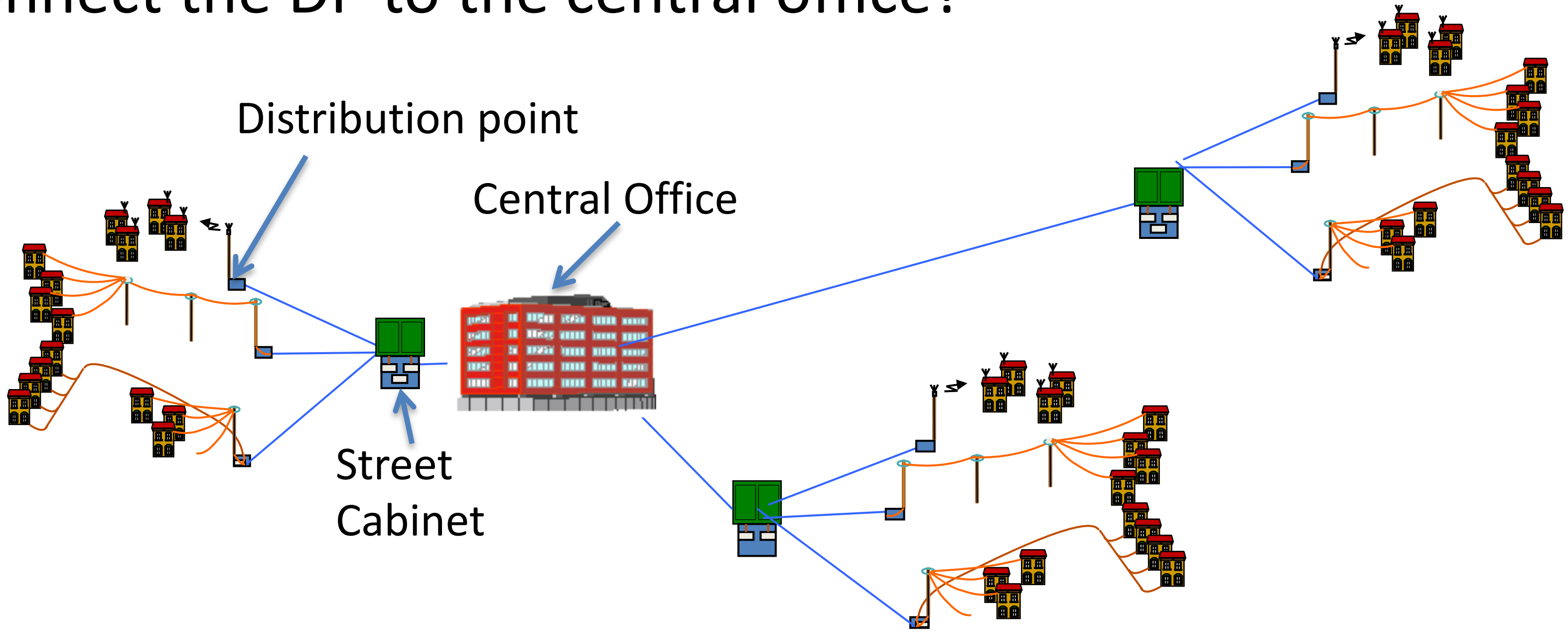
- Phantom mode??



- Full duplex transmission??
  - If you are at the drop, then your wire is "alone" i.e. it does not run in together with other users' cables, so there is no cross-talk.
  - Vectoring is used to cancel echo within the copper pair and to cancel cross-talk between multiple pairs of the same user

FTTDp backhaul

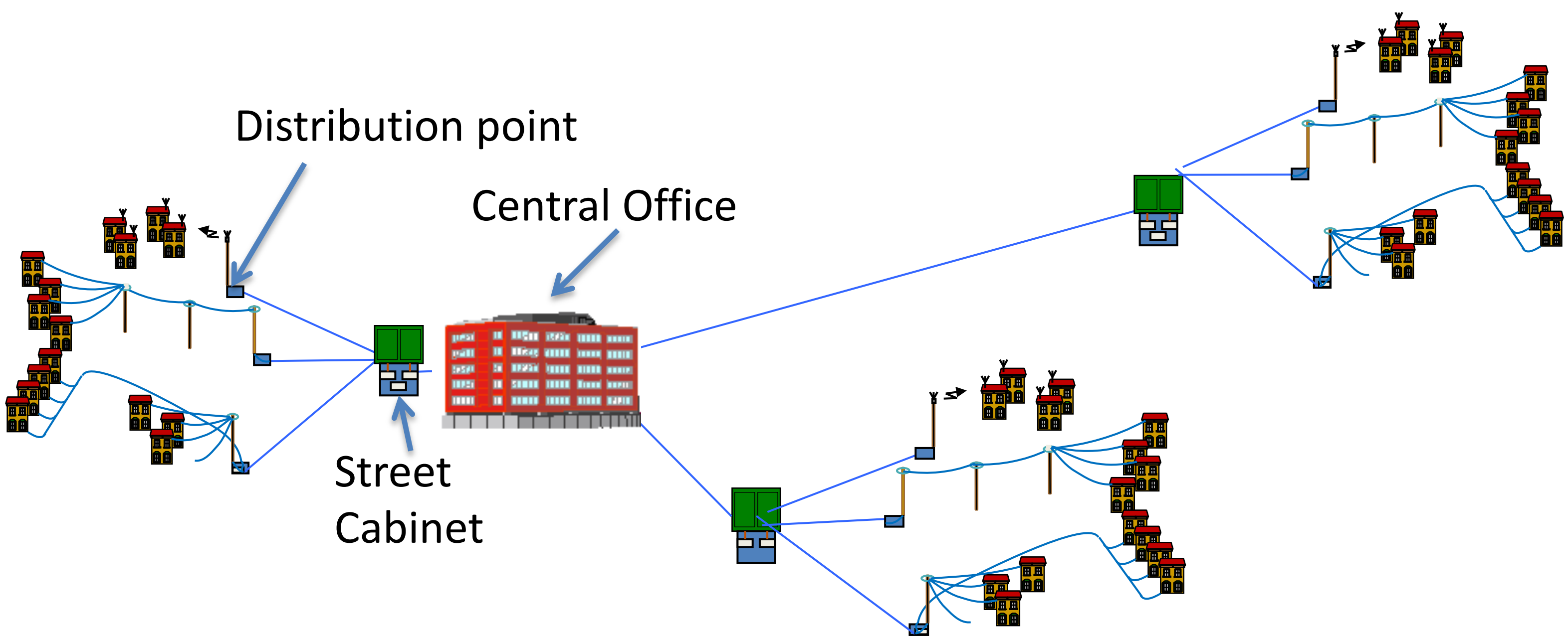
- The closer you put fibre to the home the higher its cost.
- FTTDp can provide very high rate, but how do we connect the DP to the central office?



- You can do point-to-point (PtP) fibre…
- … but you can achieve cost saving by using Passive Optical Networks (PON)
- We'll see both PtP fibre and PON solutions next

Fibre-to-the-home (FTTH)

- Replace the copper all the way to the house (or premises – FTTP)
- **No copper remains**, and the user can avail of the full speed of optical technology



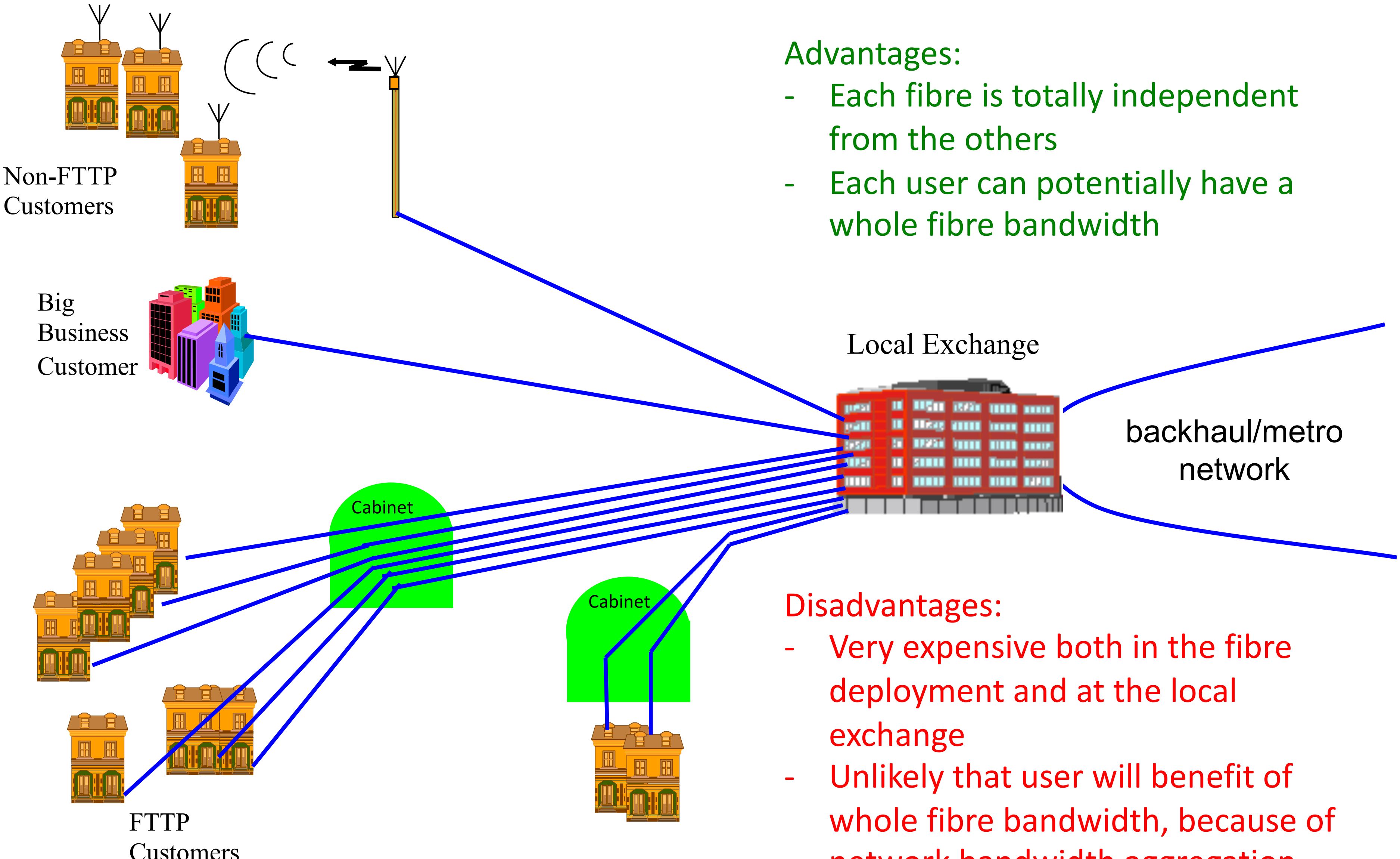
FTTH technology

- Point-to-point fibre

- Passive Optical Networks (PON)
  - Time division multiplexing PONs
  - Wavelength Division Multiplexing PONs
  - Time/Wavelength Division Multiplexing PON

  - Implemented in several standards:
    - IEEE (EPON, 10G-EPON)
    - ITU-T standards (GPON, XG-PON, XGS-PON, NG-PON2)

Point-to-point fibre



Advantages:
- Each fibre is totally independent from the others
- Each user can potentially have a whole fibre bandwidth

Disadvantages:
- Very expensive both in the fibre deployment and at the local exchange
- Unlikely that user will benefit of whole fibre bandwidth, because of network bandwidth aggregation

Point-to-point fibre

- In a point to point fibre development each user is served by an individual fibre connection
- The idea is simple: replace the copper with fibre and leave everything else as it is
- Each fibre has a termination at the user end and a termination at the network end (central office)
- The typical technology of use is Gigabit Ethernet (GE) over fibre or in some cases 10GE.
- This can easily be upgraded to 25G, 100G, etc., even on an individual customer basis as technology becomes available

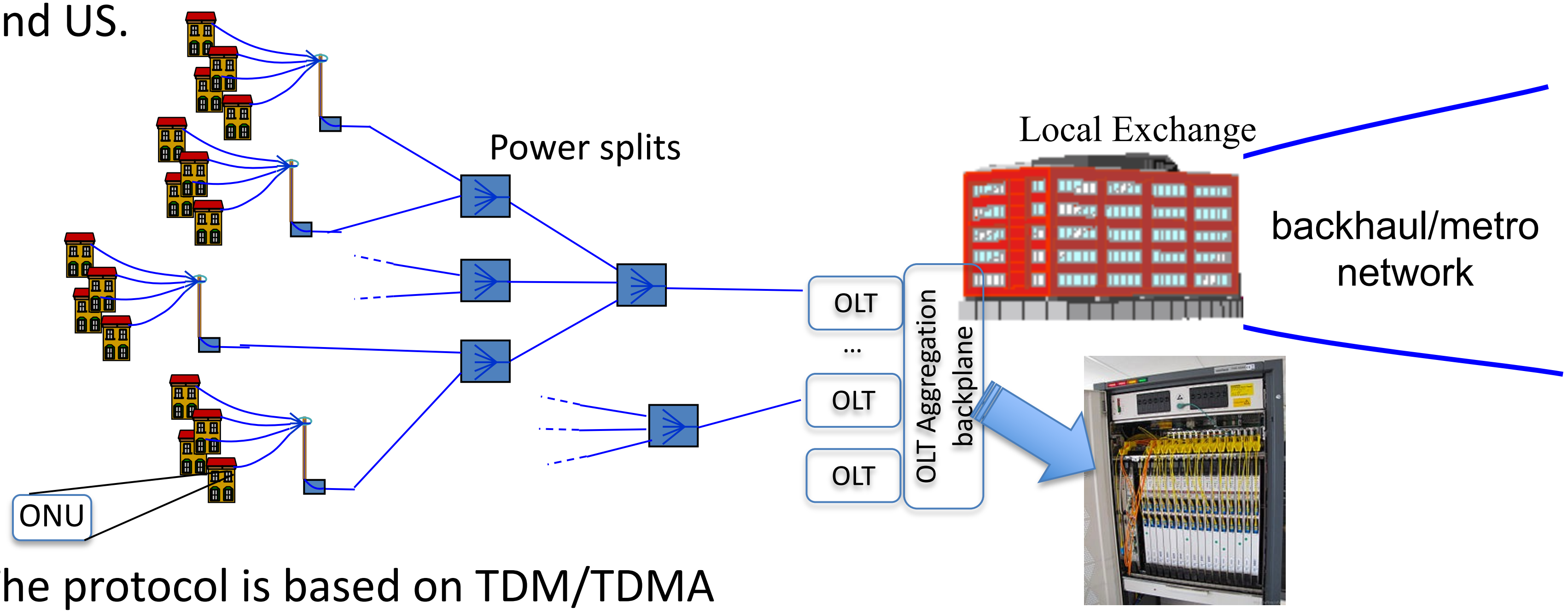
- The Ethernet MAC remains the same as previous 10 and 100 Megabit standards, while the PHY layer changes. GE technology is very cost effective and works both on copper (any laptop today) and fibre.

Passive optical network (PON)

- It is expensive to deploy fibre solutions to the access as the cost of each connection is not shared among users
- PtP fibre doesn’t help much as:
  - it requires one individual fibre per user
  - at the network end it requires one termination port per user
- PONs were invented to reduce the cost for Capital (CAPEX) and Operarional (OPEX) expenditures:
  - The idea is to share the optical fibre into a tree structure using passive optical splitters
  - It allows one network termination or Optical Line Terminal (OLT) to serve many Optical Network Units (ONUs) at the user side

Time Division Multiplexing PON (TDM-PON)

- There are both IEEE (EPON and 10GEPON) and ITU-T (GPON, XG-PON, XGS-PON) for FTTH
- IEEE PON standards are typically used in Asia, while ITU-T is used in Europe and US.

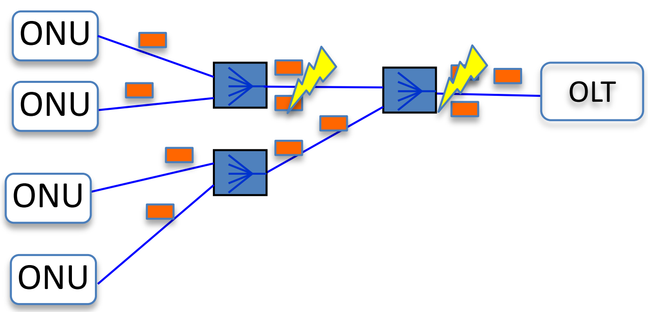


- The protocol is based on TDM/TDMA
- Downstream the OLT broadcasts data to every ONU, and each ONU filters out the data destined to it.
- Upstream is different as all data will converge into the same link to the OLT

  ➔ A MAC needs to be implemented for the upstream transmission

Downstream and upstream channels

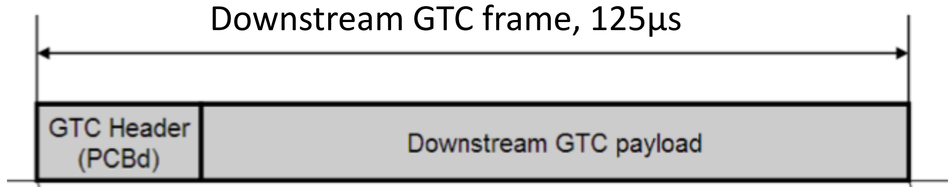
- Downstream transmission (OLT => ONU) is achieved through broadcast, the ONUs filter out the packets destined for them
- The downstream signal is continuous, and such receivers are not expensive.
- In the upstream direction a MAC is implemented to avoid collision of signals from different ONUs.



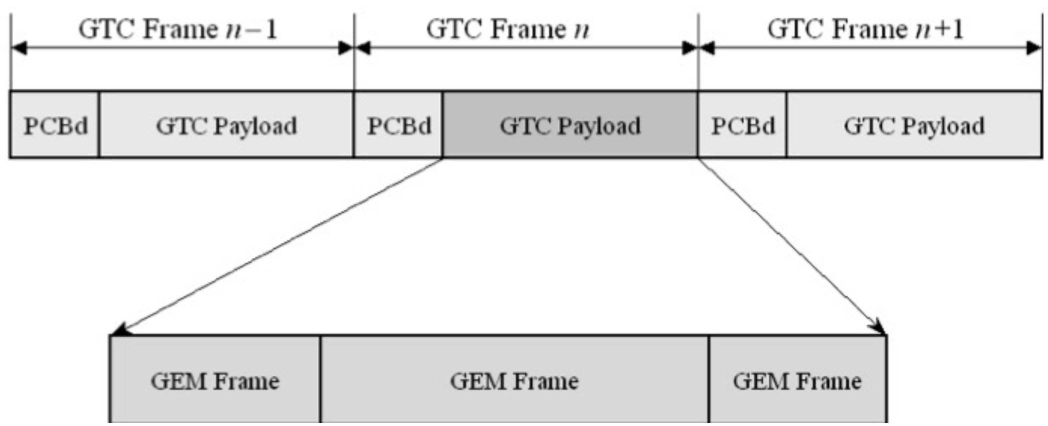
- The access to the upstream channel is TDMA.
- The OLT receiver operates in “burst-mode”, i.e. it receives short burst of data. A burst-mode receiver is much more complex and expensive than a continuous-mode one

Downstream frame

- Each frame is 125µs long (inherited from Sonet/SDH standards)
- The frame is scrambled, i.e., passed through a function that transforms it in a different sequence of bits.
  - The opposite function (de-scrambling) is applied at the receiver
  - Used to avoid too many 1s or 0s in sequence (can loose synchronization)

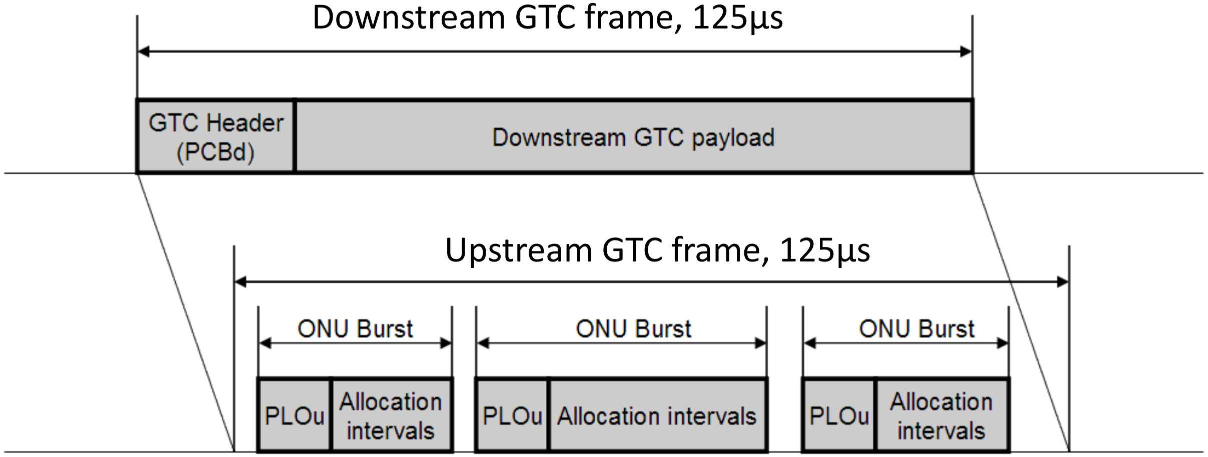


- Each GTC payload carries multiple GEM frames, each directed to a different GEM port



Upstream burst structure

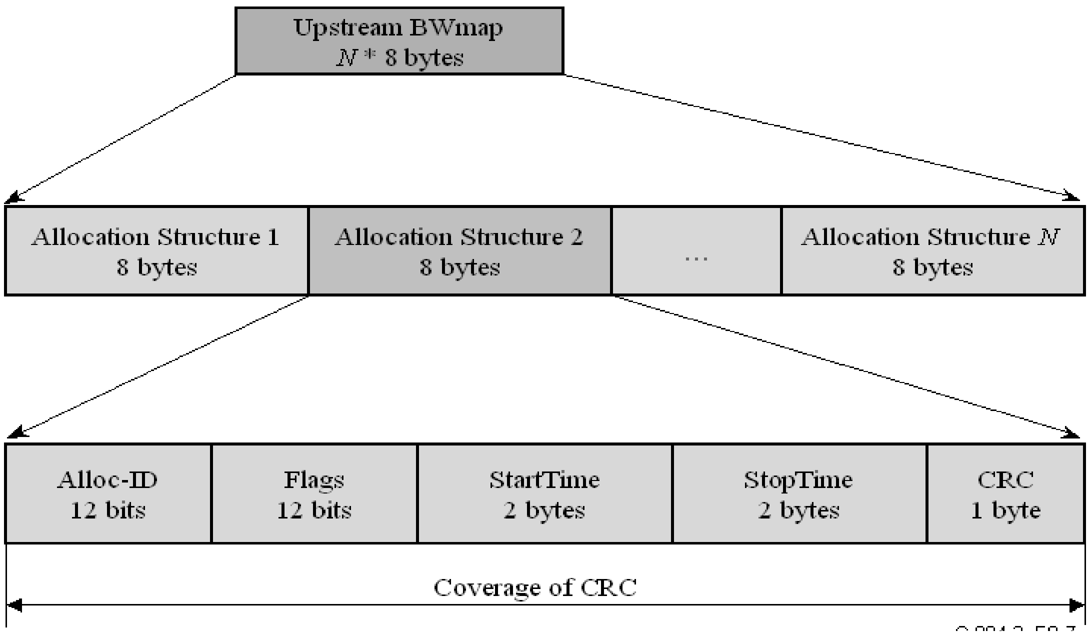
- Upstream transmission is arranged in bursts rather than continuous frames.
- However a sequence of burst is delimited within a frame of 125µs, for symmetry with the downstream frame
- The bandwidth allocation map sent in the downstream frame allocates all traffic for the corresponding upstream frame



- The upstream bursts are also scrambled

Bandwidth map for upstream traffic scheduling

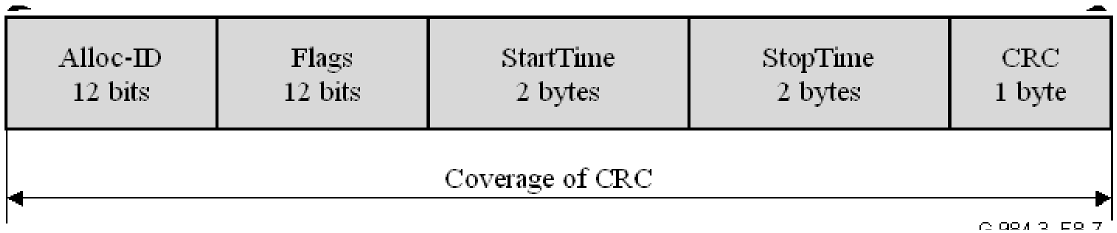
- It’s used to tell the ONUs when to transmit their payload upstream
- It’s at the base of the upstream MAC and is organized by the OLT



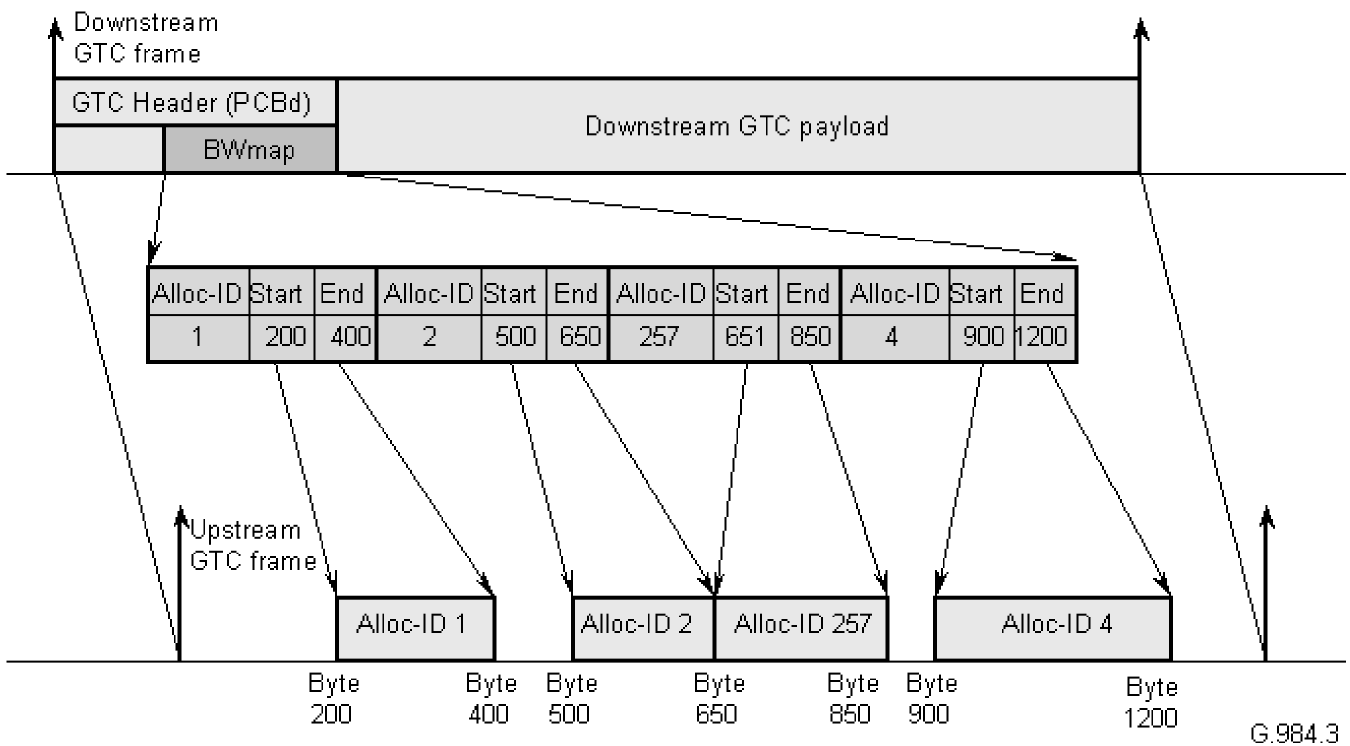
- Alloc-ID: indicates the recipient of the bandwidth allocation (the T-CONT)
- Flags: indicates whether the ONU should send a management packet, should use FEC, send a Dynamic Bandwidth Request

- StartTime: indicates the starting point of the frame allocation. It’s in bytes and the reference point is the beginning of the upstream GTC frame

Bandwidth map

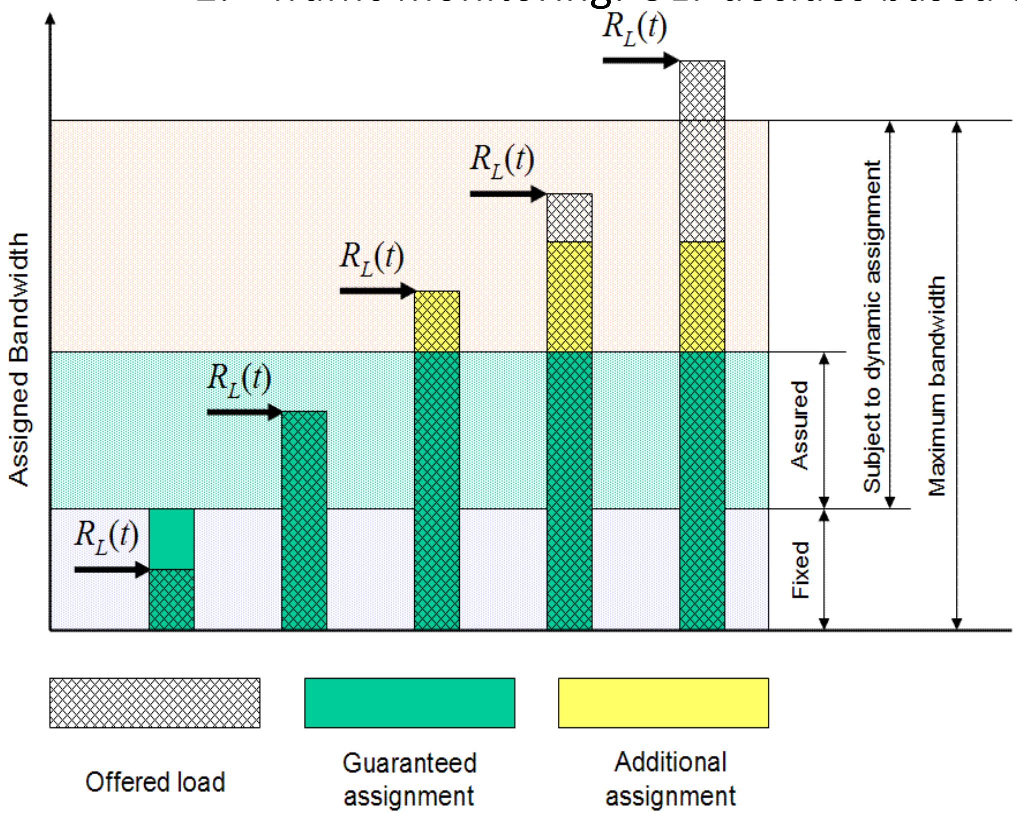


- StopTime: indicates the stop point of the frame allocation
- CRC: Cyclic redundancy code protecting the bandwidth allocation
- Example:



Dynamic Bandwidth Assignment (DBA)

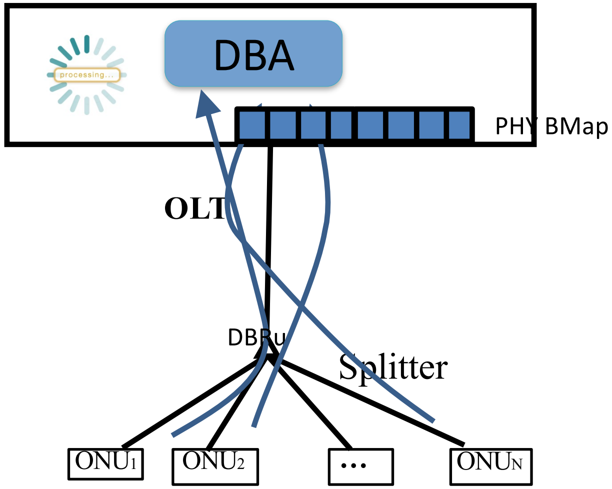
- DBA is the process by which the OLT decides how to assign upstream transmission opportunities (e.g., bandwidth) to the ONUs
- The mechanism works either by:
  1. Status reporting: the ONU informs the OLT on how much bandwidth it needs
  2. Traffic monitoring: OLT decides based on the observed traffic pattern



- A small fixed bandwidth is typically assigned to each ONU
- A variable bandwidth is assigned depending on demand
- The variable part is divided in:
  - Guaranteed: this is always available for the ONU when needed (e.g., by contract)
  - Additional: it can be assigned if there is enough spare bandwidth available

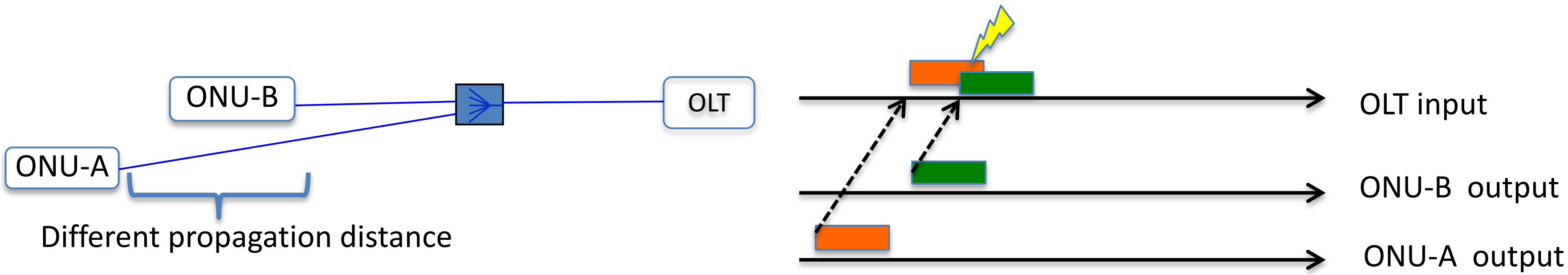
How status reporting DBA works

- ONUs send their DBRu (current queue size)
  - Most times this is attached to a previous data message
- The DBA calculates how much capacity each ONU should get (considering Fixed, assured, non-assured)
- It sends the bandwidth map which informs all ONUs when to transmit and how many bytes for the next upstream frame



Ranging operations

- The OLT has the task of synchronizing all ONUs for upstream transmission.
- However the ONUs have all different distance from the OLT
  => Their different propagation time needs to be considered
  Otherwise two burst might overlap at the OLT input



- The OLT operates “Ranging” operations to figure out the relative time shift of the ONUs
- This is operated whenever a new ONU joins the PON

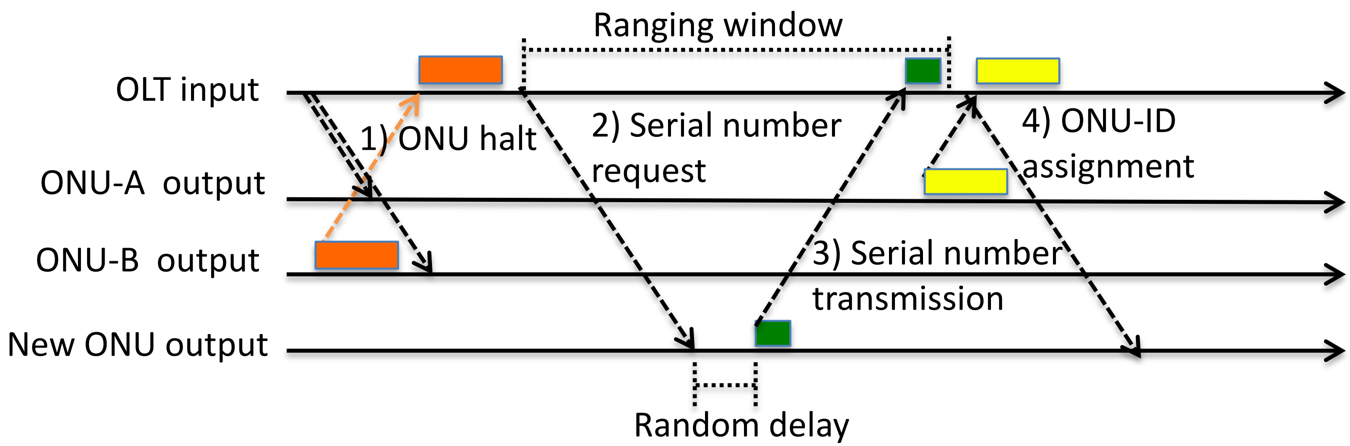
Light in fibre travels at about $2*10^8$ m/s ➔ it takes 5 ns to travel 1 m

- 100m difference translates into 500 ns
- At 10Gb/s one bit lasts 0.1 ns

➔ 100 m equals to 1000 bits difference

Ranging phase 1

- Phase 1 is used to register a new ONU

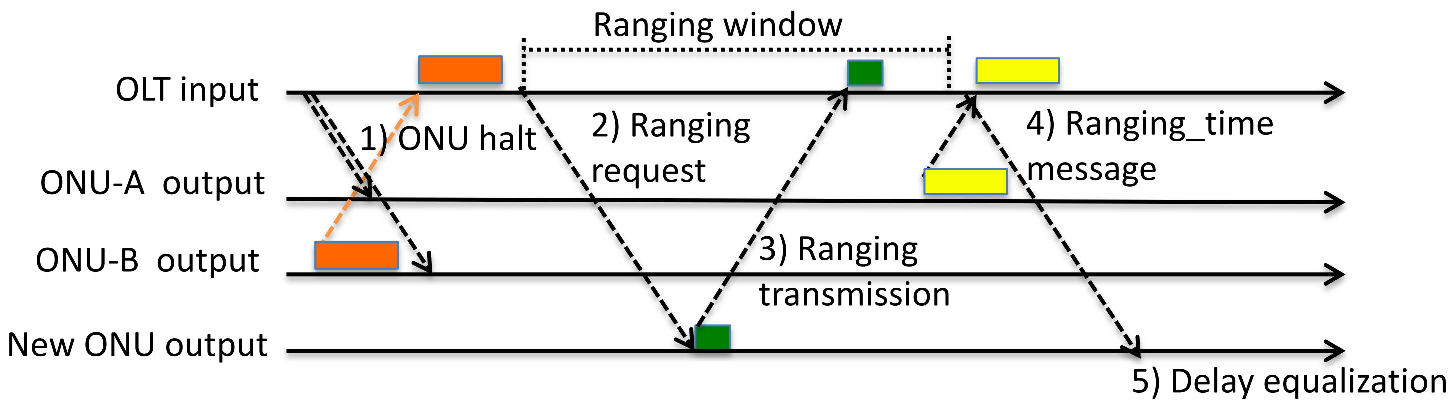


1. The OLT sends a halt msg to all ONUs to stop upstream transmission
2. OLT request serial number to unregistered ONU(s)
3. After receiving the request, an unregistered ONU transmits the serial number after waiting for a random time (up to 48 μs)
4. The OLT registers the ONU assigning it an ONU-ID value

The ranging window limits the distance between the OLT and furthest ONU. In GPON this is 20km => 200 μs (delay of 5μs for each Km, calculated for the round trip)

Ranging phase 2

- Phase 2 is used to measure the Round-Trip-Delay (RTD) to the ONU



1. OLT sends a halt msg to all ONUs to stop upstream transmission
2. OLT sends a Ranging request to a specific ONU (using ONU-ID)
3. The ONU with that ONU-ID sends back a Ranging message to OLT
4. OLT calculates the RTD for that ONU and notifies the ONU of its Equalization Delay(=Teqd-RTD), where Teqd is max RTD (e.g., 200µs)
5. The ONU stores the Equalization delay and uses it for all upstream transmissions

Difference between GPON and EPON upstream

GPON

Stricter specifications, rigid frame structure and strong QoS focus:

- uses traffic containers (T-CONT) as uplink traffic scheduling units to enable QoS service prioritization: Fixed, Assured, Non-Assured, Best-Effort.
- Each ONU can have multiple T-CONTs with different classes

Mechanism:

- ONUs send traffic report indicating their buffer occupancy whenever they have a transmission opportunity (typically every N frames)
- The OLT collects all such reports from a frame, then calculate a grant allocation for the next downstream frame.
- The allocation is sent at the beginning of the frame for all ONUs that will transmit in that frame, called Bandwidth Map

EPON

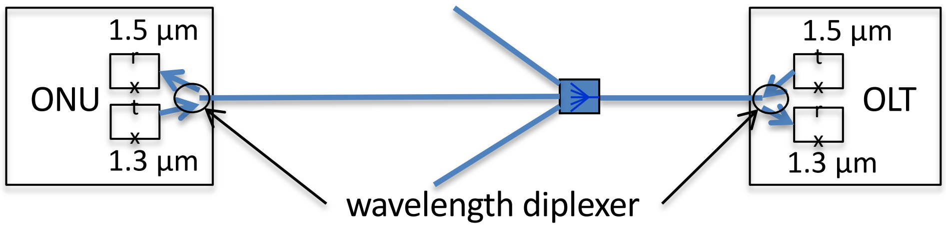
Looser standard definition, use of "packetized" Ethernet packets frame structure

Mechanism for IPACT algorithm (Interleaved Polling with Adaptive Cycle Time):

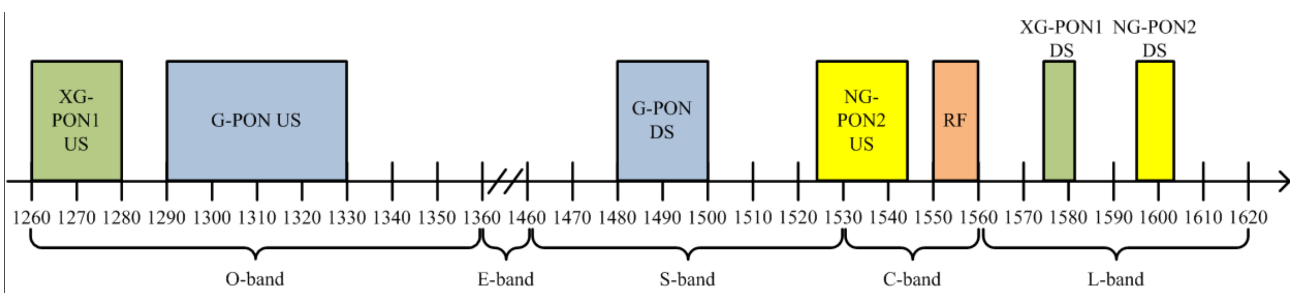
- The OLT sends a grant to a given ONU specifying the amount of data it can transmit
- Upon receiving it the ONU transmits immediately that amount of data and then indicates how much more data it needs to transmit.
- The OLT will iterate the process across all ONUs

Duplex scheme

- The most (economically) convenient duplex scheme is wavelength division duplex over single fibre, although two-fibre systems are allowed by the standard



- Different wavelengths are required to avoid that reflections from the transmitted signal adds to the received signals
- Since single-mode fibre has low dispersion at 1.3 μm, cheaper wider-linewidth lasers (FP) can be used at the ONU (customer side)
- More expensive DFB lasers need to be used at the OLT to limit dispersion at the 1.5 μm wavelength.



Split ratio

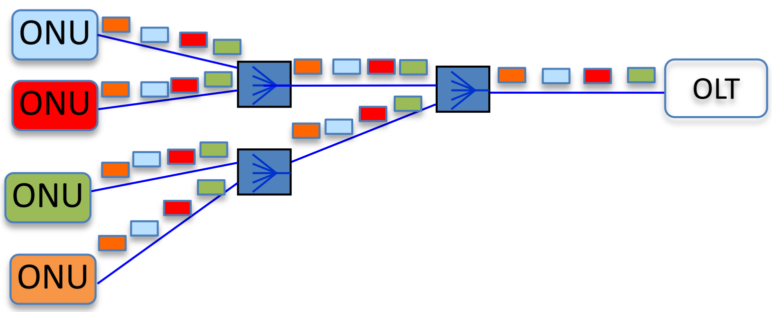
- Split ratio indicates the total number of ONUs that can be served by one OLT, i.e., the number of leaves of the PON tree
- Higher splitting ratios:
  - + Allow better cost sharing
  - − Lower capacity per user
  - − Increases the optical loss: each split has minimum loss measured in dB of $3 * \log_2(N)$, where N is the number of splits.

    Each doubling of the split increases the loss by 3dB

- If we examine a 1:32 system, with max 10km fibre length we obtain an ideal loss of: 15dB for the splitter + 3 dB for the fiber loss = 18dB
- In a practical system these could amount to 21-23 dB
- The GPON standard include split ratios from 1:16 up to 1:64, and max ONU-OLT distance of 20km
- Newer standards allow higher split ratios

Security Issues

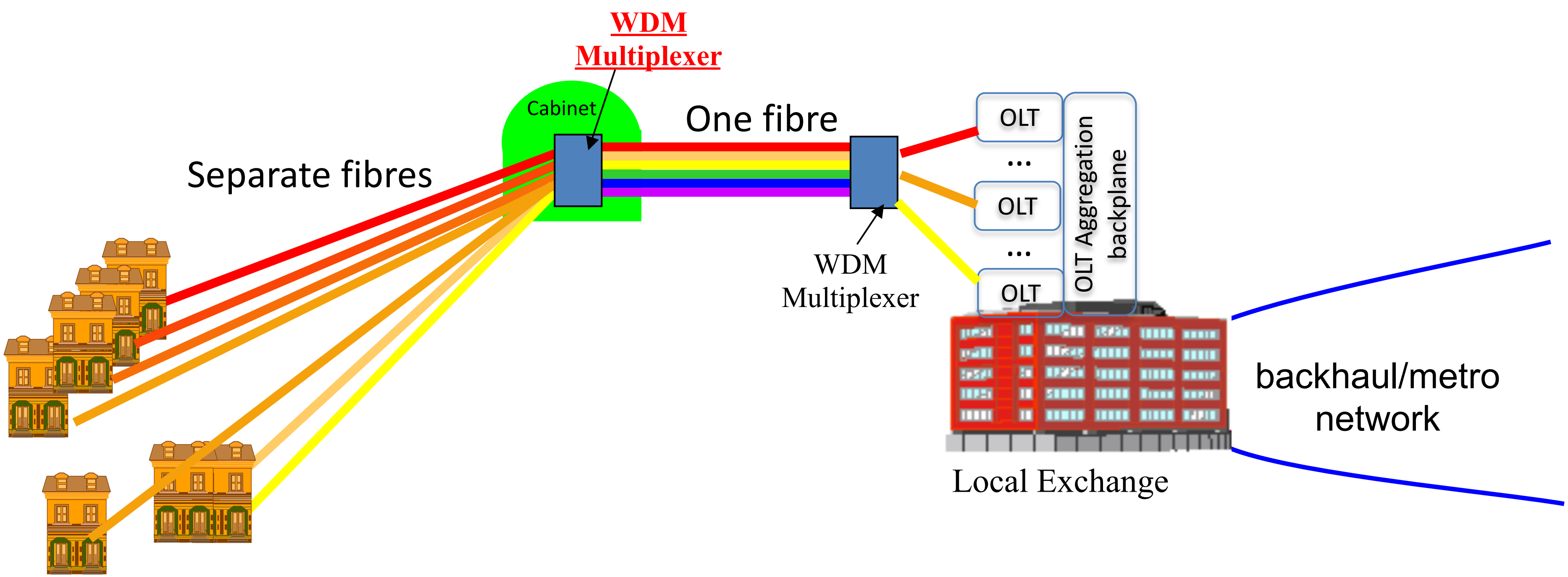
- The basic security problem with GPON, and other PONs based on power splitters is that messages are physically broadcast by the ONUs and filtered by the ONUs



- A user could tamper with an ONU to eavesdrop data destined to other ONUs
- The solution is to use cryptography, using an initial key that is pre-established
- Upstream this is not an issue, as the splitters do not reflect the signal back downstream

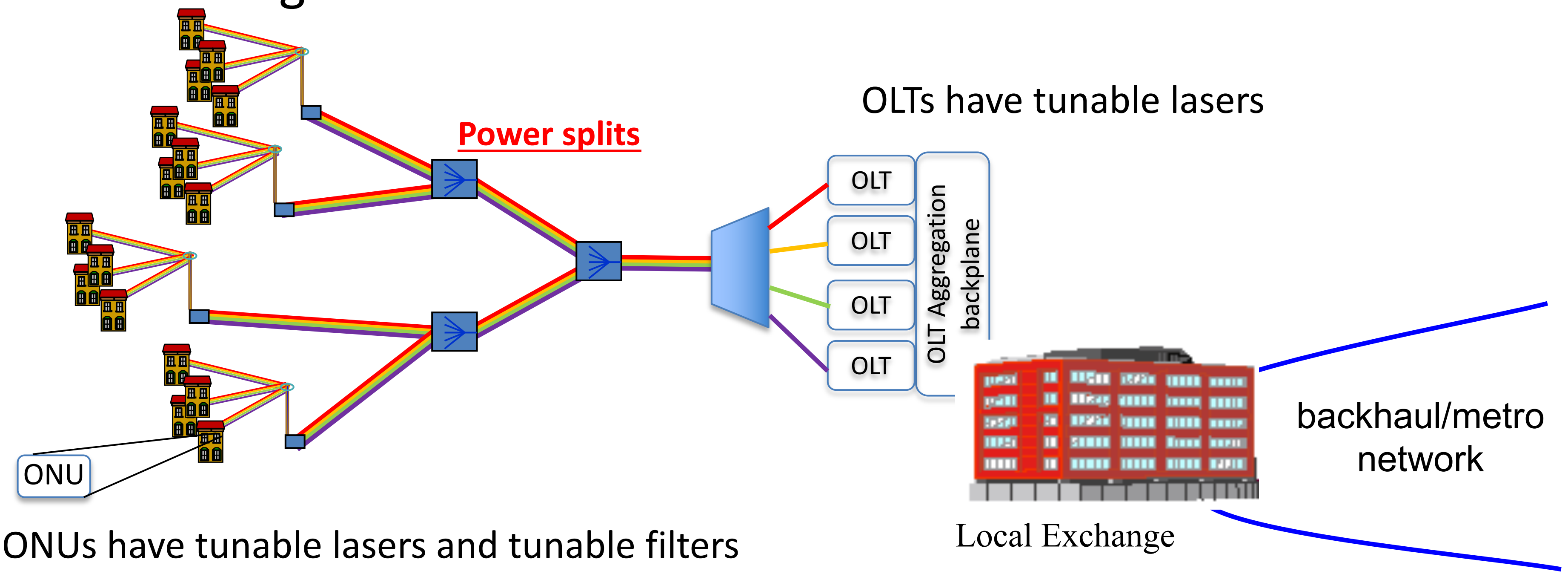
Wavelength Division Multiplexing PON (WDM-PON)

- In WDM-PON each user is served by a separate wavelength channel and a WDM splitter is placed in the cabinet to separate the wavelengths into different fibres
- Logically it is a point-to-point connection as each user is served by a different wavelength channel
- The channel would normally use 1GE or 10GE, although no WDM-PON standard exists
- The issue is that a wavelength is fixed to a destination, so there is little room for more arbitrary capacity allocation



Time/Wavelength Division Multiplexing PON (TWDM-PON)

- The concept is the same as the TDM-PON, but now multiple wavelengths are used over the fibre



- ONUs can tune laser and receiving filter to select a different OLT
  - For example if one OLT is congested, ONUs can be moved to a different OLT
  - Or one ONU can be linked to a dedicated OLT (logical PtP) for the time required to complete a service (e.g., 10G bandwidth-on-demand - BoD)
  - **Passive splitters and tunable end point is the most flexible solution as it can offer very different capacity, on demand, to different type of users**

Wavelength tuning issues

- NG-PON2 products started to appear in 2014, but ONUs were too expensive
  - The XGS-PON was developed: single wavelength 10G symmetric.

- Wavelength tuning is expensive, because tunable lasers require individual characterization
  - Tuning is achieved by injecting a number of currents, whose behavior depends on the individual physical component.

- Also, burst transmission can cause transient change in wavelength (need gating)

- Some proposals involved a coarsely characterized device, whose tuning would be adjusted during operation:
  - When the ONU comes up it can appear at any wavelength

  → Need to synchronize quite windows across all wavelength channels

Standards

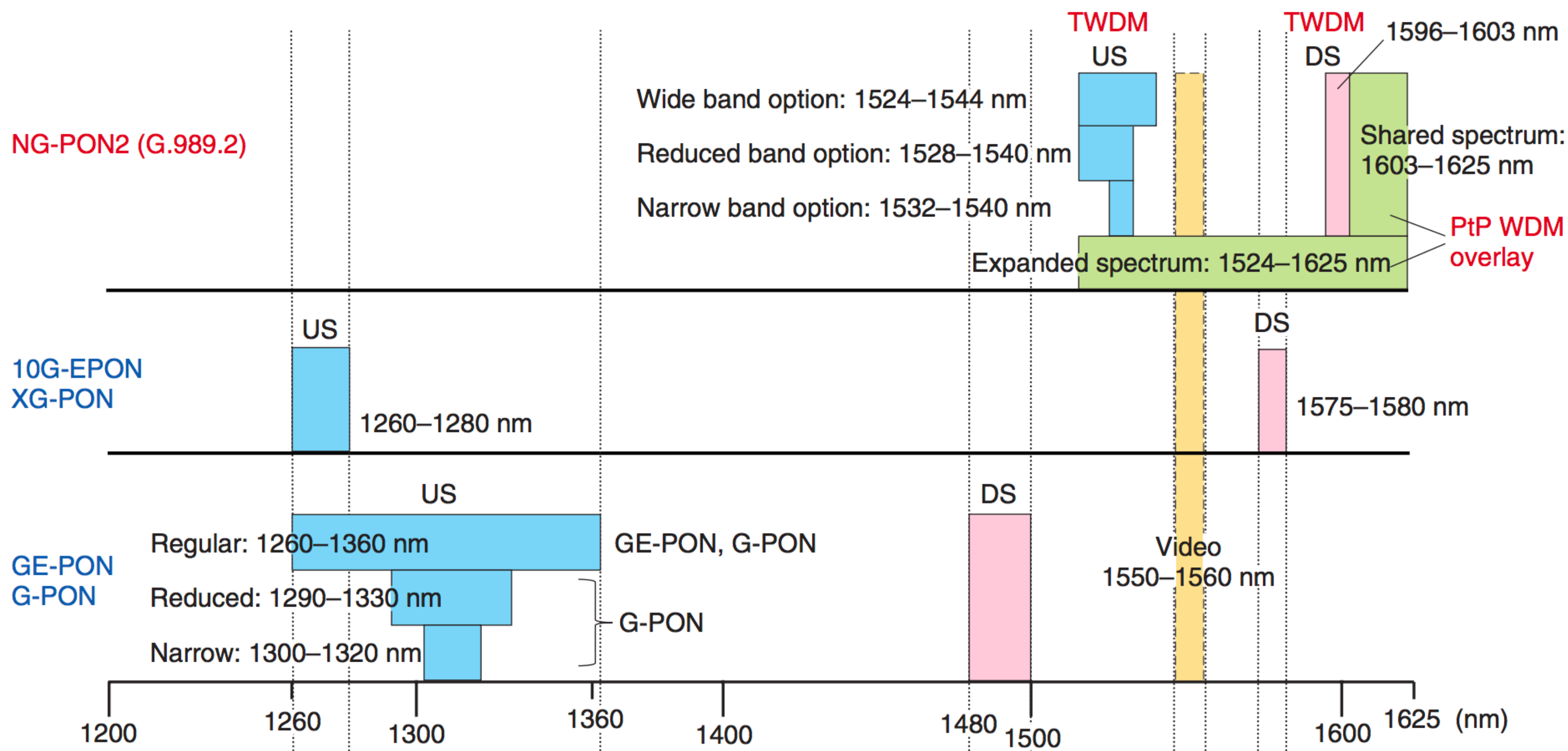
	Standard	Year	Typical Rate DS/US [Gb/s]	Power budget [dB]	Split ratio	Logical/ Differential/ Fibre reach	DS Wavelength	US Wavelength
ITU-T	GPON G.984	2008	2.5/1.25	21-31	Max 64, typical 32	60/20/10-20 km	1480-1500	1260-1360
	XG-PON G.987	2012	10/2.5	29-31	Max 256, Typical 64	60/40/10-40 km	1575-1580	1260-1280
	XGS-PON G.9807	2016	10/10	--	128	--/--/--	--	--
	NG-PON2 G.989	2015	10/10 x 4 PON + 10/10 x 4 PtP	29-35	Max 256, Typical 64	60/40/20-40	1596-1603	1524-1544
IEEE	EPON 802.3ah	2004	1.25/1.25	20-33	Typical 32	--/10/10-20	1480-1500	1260-1360
	10G-EPON 802.3av	2009	10/1.25-10	20-33	Typical 32	--/10/10-20	1575-1580	1260-1280

- IEEE P802.3ca task force and ITU-T working on >10G speed. This is strongly driven by low-cost optical Ethernet components.

- IEEE 25G-EPON recently standardized (two wavelengths for 50G, 1342 and 1358 nm)
- ITU-T 25G-PON standardized, 50G in the working

- Research is ongoing for higher rates (how to tackle dispersion, the lower power budget, etc.)
- At what point does the PON become coherent?

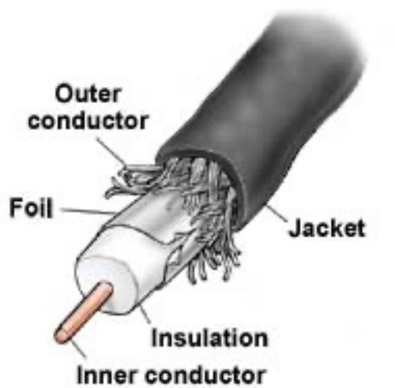
PON wavelength plan

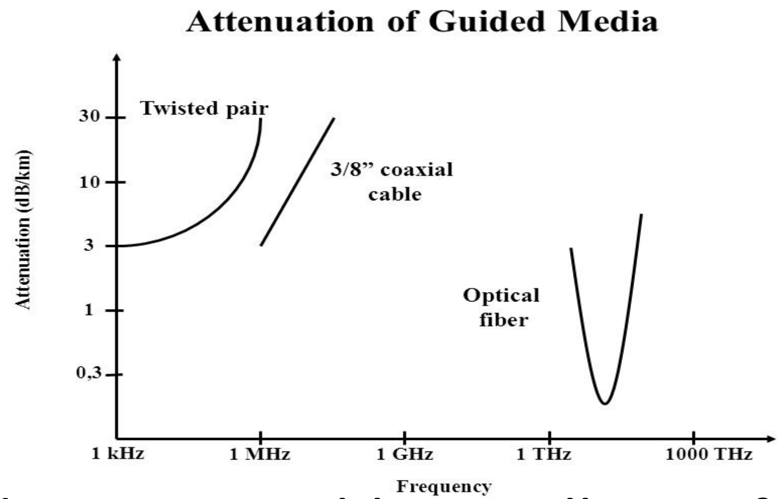


Source: https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr201503gls.html

Did we miss anything?

- Currently the service offering highest speed to most users is Virgin media (previously UPC) i.e., cable internet.
- It's a **copper service**, but offered over a **coaxial cable**, which can transport higher bandwidth with less attenuation and interference.

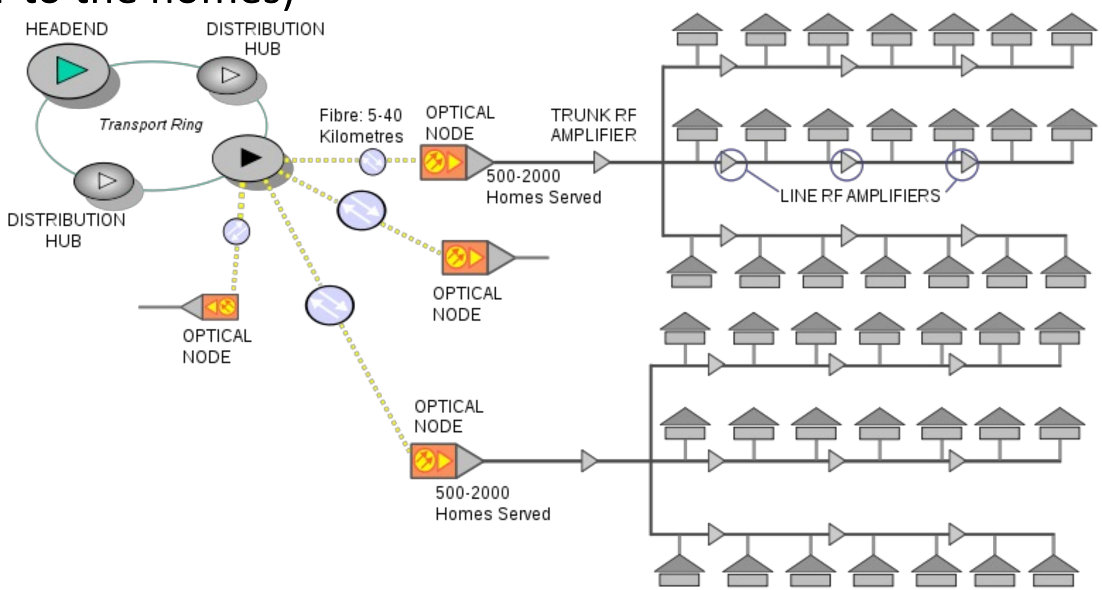




- Since some country had previous cable installation for TV, they can reuse the cable network to transport broadband signals

DOCSIS

- **<u>This is a copper technology. But it utilizes a coaxial cable nstead of a twisted copper pair!</u>**
- The cable network is different from the telephone network, as cable in not point-to-point, but is shared among a number of houses.
- The standard for cable broadband is called DOCSIS (Data Over Cable Service Interface Specification).
- Different version of DOCSIS have been released over time, providing higher speed, but also requiring a shorter cable loop (i.e., the fibre termination was progressively brought closer to the homes)



DOCSIS PHY

Version	Year	Max DS channels	DS ch width [MHz]	DS Modulation	DS rate [Mb/s]	Max US channels	US ch width [MHz]	US Modulation	US rates [Mb/s]
1.0	1997	1	6	64/256 QAM	42.88	1	0.2-3.2	QPSK/ 16QAM	10.24
2.0	2001	1	6	64/256 QAM	42.88	1	6.4	QPSK/ 8-128QAM	30.72
3.0	2006	32	6	64/256 QAM	1372.16	8	6.4	QPSK/ 8-128QAM	245.76
3.1	2013	2-5	25/50KHz OFDM 192MHz block	64-4096QAM	10 Gb/s	2	25/50KHz OFDM 96MHz block	QPSK/ 8-4096QAM	1,000

- The European version EuroDOCSIS has different channel bandwidth (8MHz instead of 6 for the 1.0 to 3.0 versions)
- The full-duplex DOCSIS 3.1 (renamed DOCSIS 4.0 provides symmetric 10Gb/s and uses up to 1.8GHz of bandwidth in the cable)

Which operator is best positioned in Ireland?

A. Eir because it’s the incumbent and own all infrastructure
B. Virgin media because it owns cable TV infrastructure
C. ESB because it owns electricity infrastructure
D. Vodafone because it owns mobile infrastructure
E. SIRO because can offer PON-based fibre to the home

Which broadband?

- Very difficult question… depends on social and economic factors, government push, city and towns layout, existing technology, market players...

- The main question for an operator is:
  - Will I have enought return on investment?
  - What will my cash flow look like? E.g., expenditure vs. income over the years.

- The market players, i.e., competition, plays a huge role

- The market is regulated by the national regulator (ComReg in Ireland, Ofcom in the UK, Berec in the EU, FCC in USA,...)

- **Should we have some discussion??**
  - Which operator, considering the different technologies, do you think is in the best position in Ireland?
  - If you are a telecomm operator what would you choose to upgrade your network?

Socio-economic issues with access broadband

- Broadband is a commodity in our information age
- Digital divide is a big social issue for all governments
- This means that governments are under pressure to make sure their country will meet these expectations
- In addition, a broadband infrastructure is essential for our information-based economy
  - Hard to attract foreign investment if your overall infrastructure is poor
  - Study have shown that doubling broadband speed brings 0.3% GDP growth
- So how do governments convince (force?) operators to upgrade broadband?
  - Incentives (e.g, National Broadband Plan – NBP)
  - Foster (force) competition

Fixed access speed stats

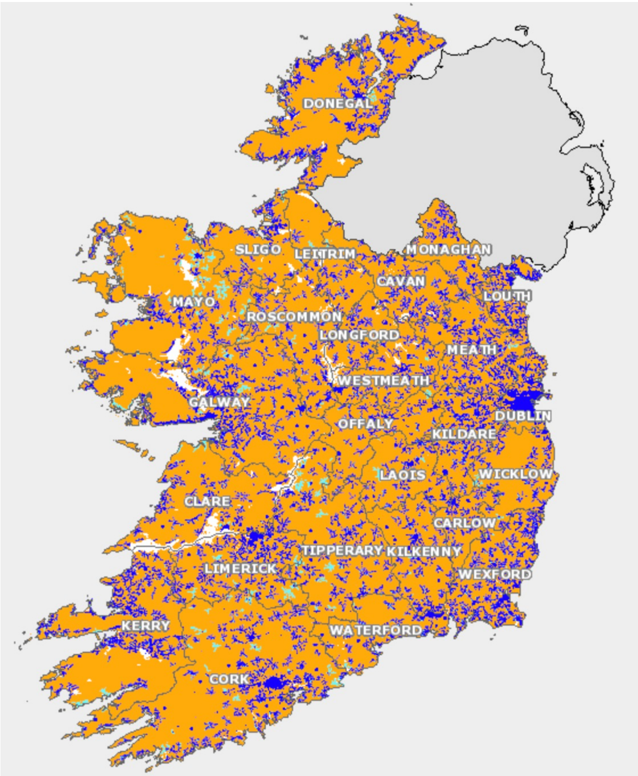
- Speedtest results, just based on customer tests
- DOCSIS presents the fastest access in Dublin

Dublin

- As of today, FTTH is coming in at high speed, although mostly focused outside of Dublin

Letterkenny

Broadband in Ireland



70% of population in 17% of territory

30% of population spread over 83% of territory

The problem with rural broadband is that the cost per user is too high and might not be covered in a reasonable time

National Broadband Plan (NBP):

- Government subsidises the operator, but the network needs to be shared
  ➔ Open-access models are very important for national broadband plans (need to foster competition)
- Blue is where it is expected that the operators will build fast broadband infrastructure
- Amber is where state intervention is expected

Regulations

- Problem: it is difficult for a new operator to build an access infrastructure, because the cost per user of a new deployment is very high
  - As a consequence there is no competition and the network becomes a monopoly

- Solution: the government forces the national operator (the one with Significant Market Power – SMP) to share their access infrastructure

- In Ireland for example Eircom owned the twisted copper pairs. The National regulators forced them to give access to other operators **at a price that was decided by the regulator.**

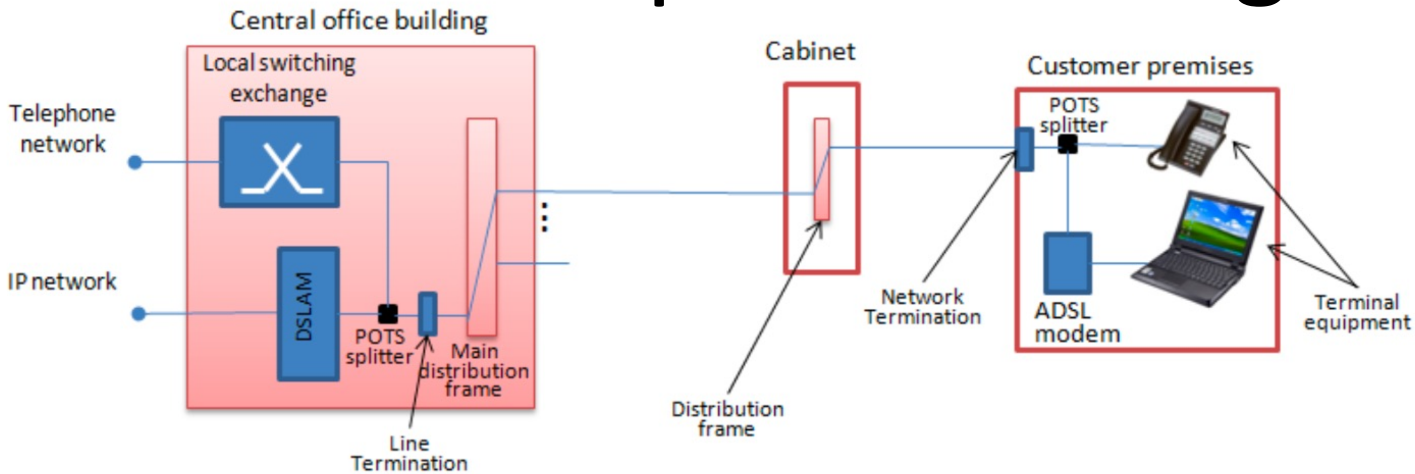
- This was sanctioned by the telecommunications act in 1996 in the U.S., and is known an Local Loop Unbundling (LLU).
  - Access sharing has evolved to provide more options

Access network sharing

- Copper access
  - Local Loop Unbundling (LLU)
  - Sub Loop Unbundling (SLU)
  - Bitstream
  - Virtual Unbundling Line Access (VULA)
  - Bitstream Next Generation Access (NGA)

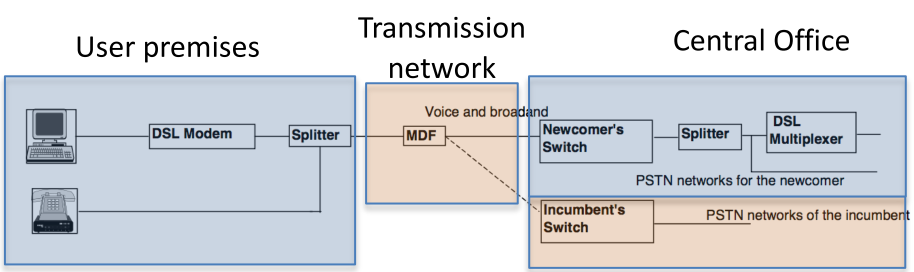
- Fibre access

Local Loop Unbundling

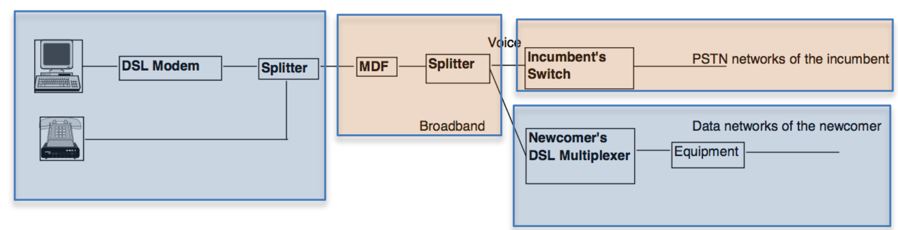


- The local loop is the transmission medium from the central Office to the end user, hence the name
- Local Loop Unbundling gives new operators (Other Licensed Operators –OLO) access to the network of the ex national operator (incumbent operator)
- This is a physical connection as the OLO physically connects the end user to its own equipment in the central office

Full unbundling



Line sharing

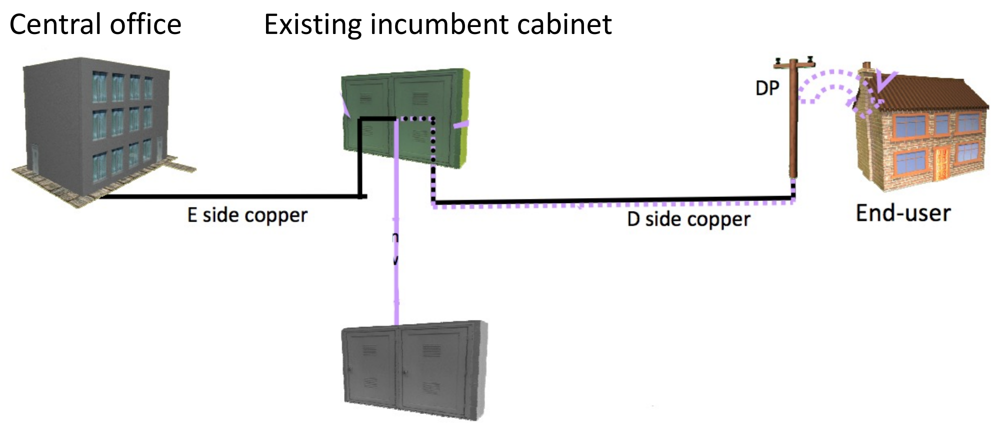


= incumbent responsibility

= OLO responsibility

Sub Loop Unbundling (SLU)

- LLU is useful for DSL, but technology like VDSL2 that use FTTCabinet need to share copper from the cabinet to the end user (i.e., the sub-loop)
- SLU then deals with sharing of the copper from the cabinet to the user

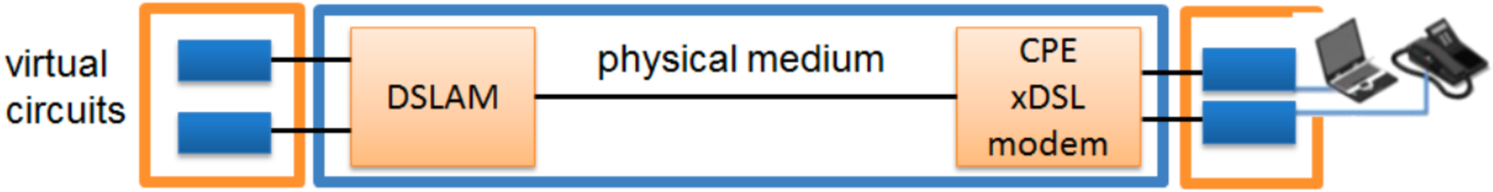


- With SLU an OLO terminates the copper pair of an end user to its cabinet. This creates problems with vectoring:
  - Vectoring works by carrying out signal processing across all the copper lines sharing a common cable
  - If different OLOs terminate the line this cross-processing is not possible anymore, thus the higher rates of vectoring cannot be achieved.

Bitstream access

- Bitstream access involves the creation of virtual circuits so that an OLO can offer broadband to an end user through a virtual circuit
  - The virtual circuit is created through VLANs
  - The OLO does not need to physically terminate the user at the MDF

- The interconnection point can be at the local exchange although often is only at the regional Point of Presence (PoP) of the incumbent



- The advantage is that the OLO does not need to provide physical infrastructure to terminate the copper lines
  - The capital cost for providing the service is lower
  - It increases competition

So, what is the problem with network sharing?

A. Neither LLU nor bitstream can deliver high capacity
B. LLU is expensive and bitstream doesn’t allow operators to fully control their service
C. Bitstream cannot work with vectoring because operators’ traffic flows are divided
D. Regulators are against access network sharing

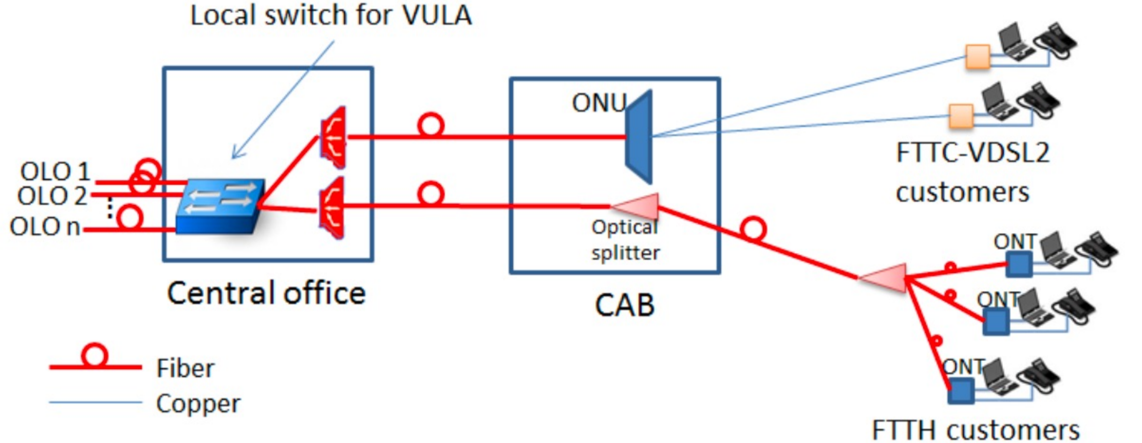
Is more needed?

- So with bitstream access an OLO can provide services to an end user without owning access infrastructure..
  - Why considering other options?
  - Is this not the best option?
  - What else could an OLO possibly want?

- The problem with bitstream is that it offers a standard rate connection to the OLOs without service differentiation:
  - All OLOs can only offer to the end user the same type of service
  - An OLO cannot differentiate their product from other OLOs or the incumbent
  - The only competition can be on price or on leveraging their brand, but the service provided is exactly the same as other OLOs

Virtual Unbundling Line Access (VULA)

- VULA was born to allow OLOs to differentiate their product by:
  - Putting the interconnection at the first aggregation point
  - Having uncontended access between user and interconnection point
  - Being able to decide quality of service parameters
  - Being in control of the Customer Premises Equipment (CPE)



- In VULA, the OLO can put the interconnection in the central office, similarly to LLU.
  - This allows better control over the service offered
  - But it requires more investment by the OLO

Next Generation Access (NGA) Bitstream

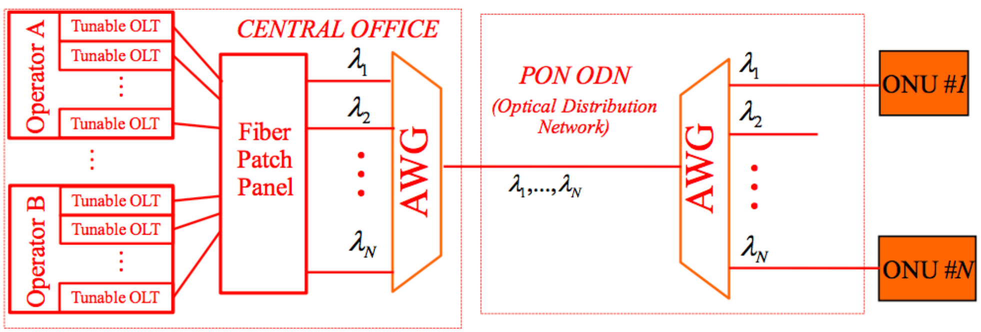
- It provides a way for OLOs to avoid the need to interconnect at every Local Exchange, while offering better service than legacy bitstream
- Interconnection points can be Metro, Regional or National PoPs
- Improved service compared to legacy bitstream include:
  - Higher bit rates and FTTH technology
  - IPTV
  - Multicast
  - Layer2 access
  - Traffic QoS classification
  - Ability for the user to subscribe to multiple OLOs

PON unbundling

- As access network progresses towards fibre access, the question raises on how to unbundle them
  - Point-to-point fibre is easy as it allows for LLU
    - For this reason a number of countries have adopted this strategy (e.g., Sweden), but the cost is high. In Switzerland they have deployed 4 fibres per home…
  - PONs are more difficult, but it depends on the technology
    - For WDM-PON in principle wavelength unbundling could be done so the OLOs could access different wavelengths…
    - For TDM-PON, the issue is that the signal from multiple ONUs goes to the same OLT, so it cannot be physically split, but needs to be accessed after the OLT
    - TWDM-PON offers the best options, on an infrastructure with power splitters

Wavelength-routed vs. power-split PON

Wavelength-routed

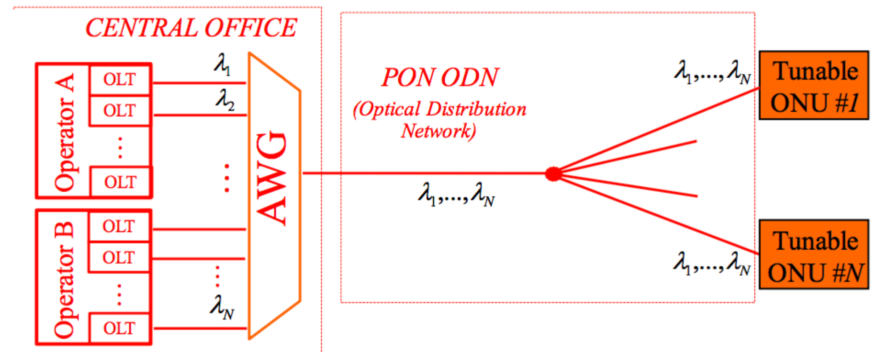


Clear separation, like LLU, as each user is set on a different wavelength and operators can access them at the central office by using specific wavelengths

Higher cost as each user is terminated on an individual port

Low flexibility has each user can only receive a wavelength

Power-split



It gives maximum flexibility:

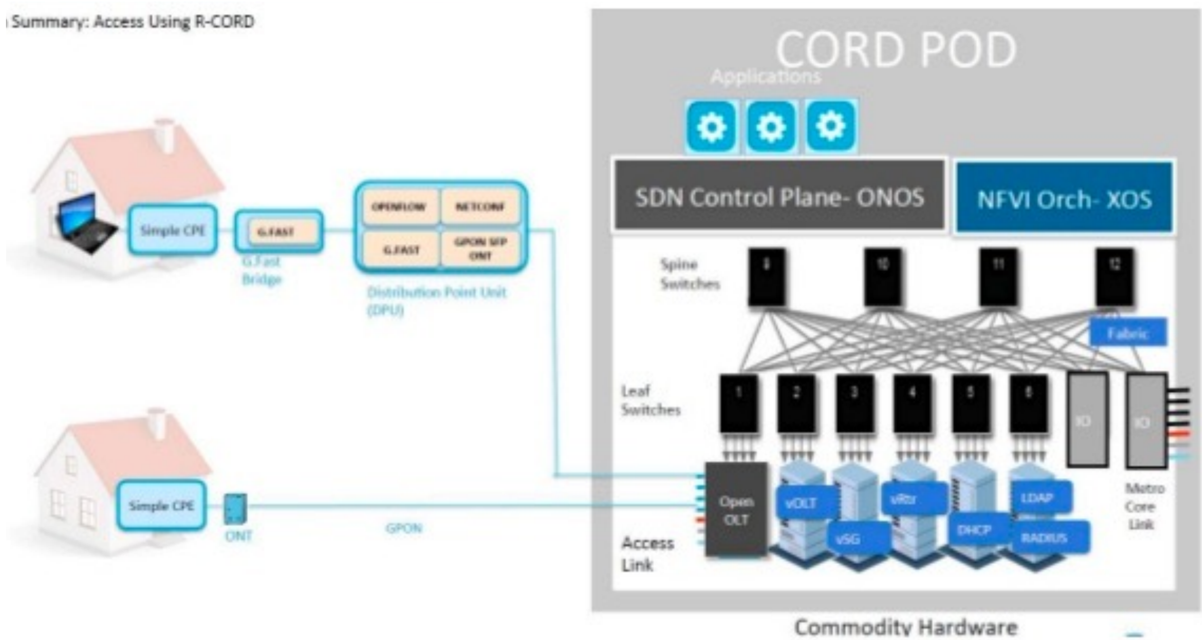
- OLOs can operate at specific wavelengths were end users can subscribe by tuning
- Capacity assignment is quite arbitrary, as OLOs can decrease the number of users per PON dynamically to give more capacity
- OLOs can assign more than one wavelength to a user, if the user has ONUs with more transceivers
- …

Lower cost as it allows multiplexing between users

What’s next?

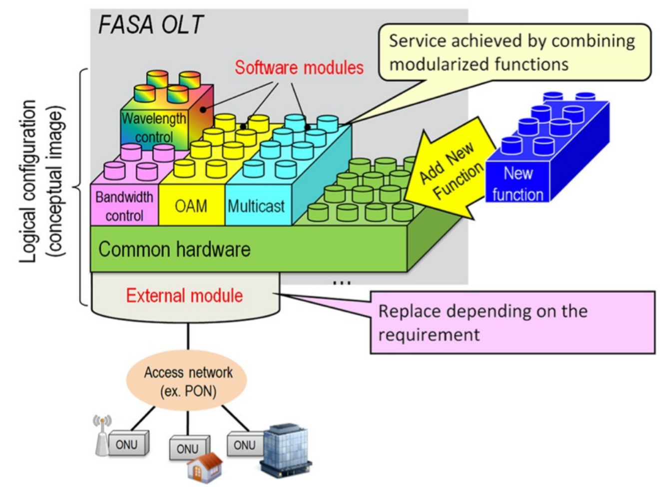
- As the concept of network virtualisation becomes more and more widespread, more ideas are developed for access network sharing
- The ideal situation is where any hardware can be completely virtualised so that OLOs can operate virtual slices with the same flexibility (or more) they had if owning the hardware
- Software Defined Networking (SDN) and Network Function Virtualisation (NFV) play a major role in this development
- Example of projects:

CORD™
Central Office Re-architected as a Datacenter

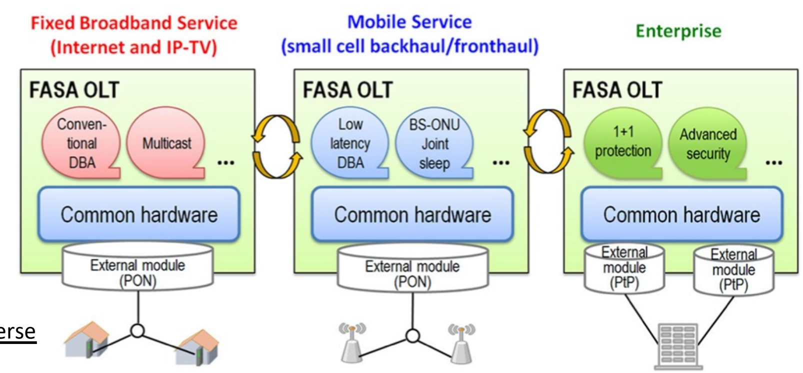


NTT's Flexible Access System Architecture (FASA)

- Disaggregate the OLT, using software functions



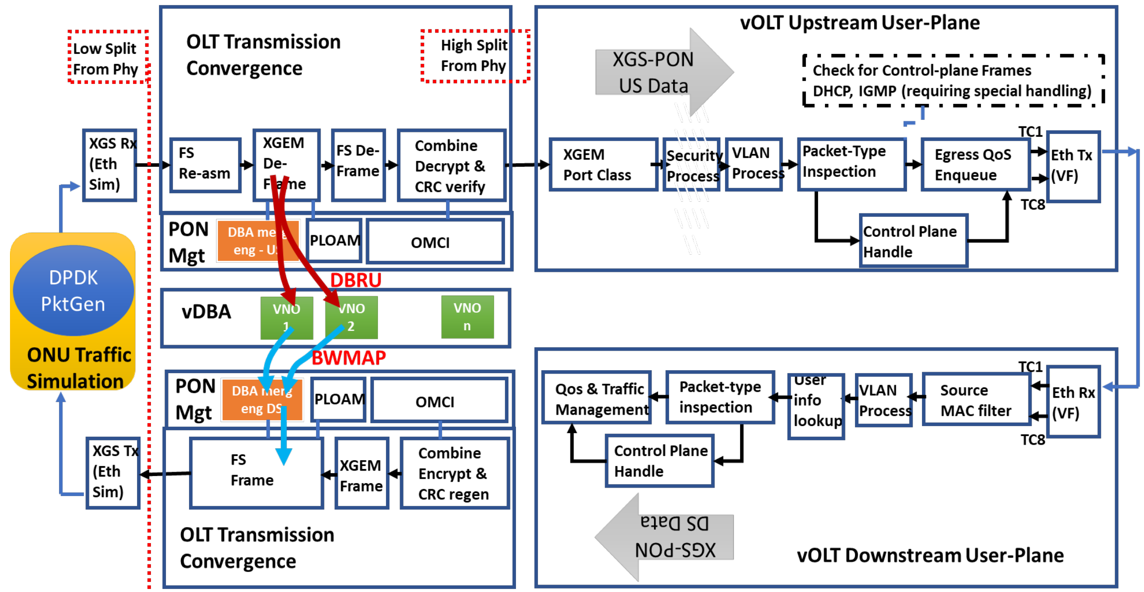
- The DBA is also software, so it can be modified, depending on the application



Included in BBF TR-402 standard "PON Abstraction Interface for Time-critical Applications"

June-Ichi Kani et al., Flexible Access System Architecture (FASA) to Support Diverse Requirements and Agile Service Creation. JLT, April 2018.

The virtual PON in practice



Fully Standard compliant with XGS-PON

F. Slyne et al., Experimental Demonstration of multiple Disaggregated OLTs with Virtualised Multi Tenant DBA, over General Purpose Processor. OFC 2020.