Passive Optical Networking

This lecture introduces Passive Optical Networking (PON), the access technology providing "Fibre To The Home" (FTTH) and the highest data rates currently available.
After this lecture you should be able to: explain the advantages of PON relative to HFC or DSL and solve problems involving optical link power budgets.

Introduction

The graph below[1], shows the estimated growth in global traffic and traffic per subscriber.

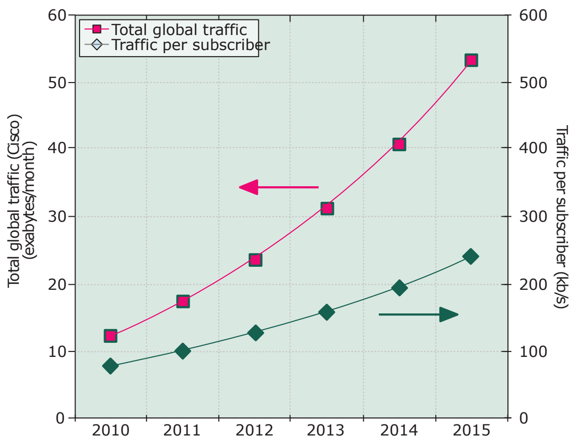


Figure 1. *Consumer Internet traffic forecast.*

As shown above, the growth in traffic is exponential. Different estimates of the growth rate range between 25% and 50% compound average growth rate (year-on-year increase).

Exercise 1: Assuming a growth rate of 30% per year, how long does it take for traffic to increase by an order of magnitude (a factor of 10)?

For HFC and VDSL systems to meet increasing traffic demands the fiber links linking the CO and head end to remote DSLAMs and optical nodes will have to move closer and closer to the subscriber.

A number of "FTTx" acronyms are used for this. In these acronyms 'x' is the first letter of Neighbourhood (FTTN), Node, Curb, Premises or Building. The limiting case is that fibre reaches all the way to the customer, or Fiber to the Home (FTTH).

[1]From E. Harstead and R. Sharpe, "Future Fibre-To-The-Home bandwidth demands favor Time Division Multiplexing Passive Optical Networks," *IEEE Communications Magazine*, November 2012.

The economics of deploying FTTH vary. In new developments (so-called "Greenfield" applications) it makes sense to install fiber directly to each house or apartment. When there is sufficient demand for sufficiently high data rates it may be less expensive to connect users directly with fibre than to install more DSLAMs or optical nodes. In other cases telephone companies are installing FTTH for strategic reasons.

Initial deployments of FTTH are at Gigabit speeds (about 2.488 Gb/s downstream, 1.244 Gb/s upstream) but there are plans to migrate to 10 Gb/s and higher rates to keep up with the exponential growth described above.

Passive Optical Networks

Almost all FTTH system currently being deployed use the Passive Optical Networking architecture shown in the diagram below[2].

The architecture is similar to that of the hierarchical CATV cable system. Different upstream and downstream frequency ranges (optical wavelengths) are used but the cable is single-mode fiber whose low loss allows passive (optical) signal splitters to be used without amplifiers.

At the service provider premises, typically co-located with a CO or head end, an Optical Line Terminal (OLT), transmits a downstream signal that is received by several Optical Networking Units (ONUs) at the customer premises. An ONU serving a single users is sometimes called an ONT (Optical Network Terminal).

The downstream uses one transmitter at the OLT and optical splitters to distribute the signal to many ONUs. The total split ratio varies from 1:16 to 1:256 but is typically 32 or 64, depending on the link budget.

[2]From Effenberger, et al, "An Introduction to PON Technologies," *IEEE Communications Magazine*, March 2007.

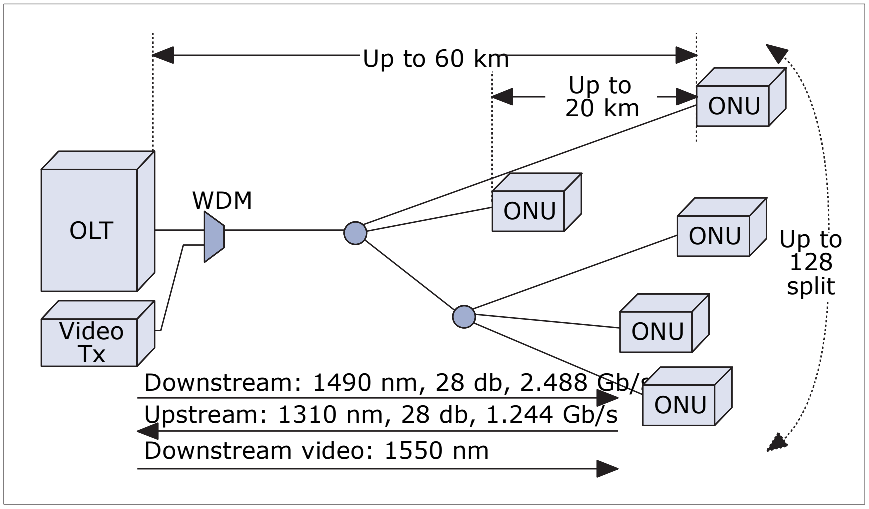


Figure 1. *G-PON physical network architecture.*

The circles between the OLT and ONUs represent optical splitters at locations called Fibre Distribution Hubs (FDH). These are simply enclosures where fibers are spliced to passive splitters.

As shown above, the wavelength 1490 nm is used for downstream and 1310 nm for upstream. As with cable systems, the component at the OLT and ONU that separates upstream and downstream wavelengths is called a "diplexer."

Typically a (Distributed Feedback, DFB) single-wavelength laser is used for the transmitter and a photodiode (Avalanche Photo Diode, APD) is used for the receiver.

Since the downstream is point-to-multipoint and can be received by all ONUs, it requires encryption.

Like DOCSIS, the uplink uses TDMA and requires that the OLT coordinate upstream transmissions. As with DOCSIS, this requires that ONUs do ranging and power adjustments.

It is also possible to transmit an optical carrier modulated by a wideband RF signal carrying multiple TV channels. This is the same method used by HFC systems but in this case each ONU acts as an optical node.

The ONT typically provides telephone, cable TV and internet interfaces and services. ONTs are often plain-looking gray boxes mounted near where TV and telephone wiring enter the customer premises so they can be connected to the premises wiring more easily. If there is fiber already in the premises, ONTs can also be mounted next to a computer similar to a cable or ADSL modem. The following photo shows a desktop ONT showing the GPON optical connector (green), co-ax TV connector (on left), two POTS interfaces for telephones and four Gigabit Ethernet ports (RJ-45).

Since it is not possible to supply power over fiber, the ONU must have its own power supply, possibly including battery backup to allow operation during power failures.

Advantages

The lower loss of fibre means that longer distances can be spanned without using repeaters or amplifiers. In the G-PON example above, the reach is 60 km maximum with a 20 km maximum variability in OLT-ONU distances.

"Passive" means there are no electronics "in the loop" between OLT and ONU. This means PONs can be less expensive than alternative architectures (HFC, DSL or switched fibre) because they eliminate electronics "in the loop" (field) that require space, power, and maintenance.

PONs are also relatively easy to upgrade to new technologies and higher speeds by replacing the OLT and ONU equipment.

The higher bandwidth of fiber also allows much higher data rates than twisted-pair or co-ax cable.

Optical Power Budgets

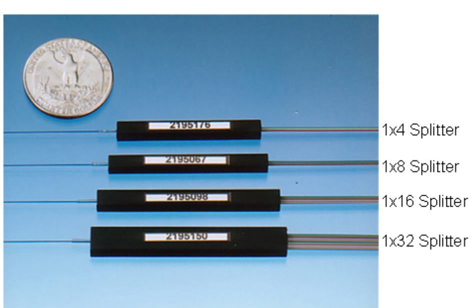
In the design of PON systems it's important to keep the optical signal levels within the range that the ONU can accept. If the level is too high it will distort and if the level is too low the BER will be too high.

The factors affecting the received signal level include:

- the transmit power: typically between 0 and +5 dBm
- the attenuation of the fibre: this depends on the type of fiber and the length. ITU G.652 is a specification for single-mode fibre. It specifies maximum cable loss of 0.4 dB/km although most cables perform better (about 0.3 dB/km). Typical maximum distances are around 20km.
- the optical split ratio and additional loss in the splitter: for example, 3dB for 2-way splitter plus and additional 1 to 3 dB depending on the design and size of the splitter. Splitters commonly used are powers of two (1:4, 1:8, 1:16 and 1:32).
- connectors (about 0.5 to 1 dB for each connector pair) and splices (about 0.5 to 1 dB for mechanical splices, 0.05 dB for fusion splices)

The receiver sensitivity (for BER 10^{-6}) is typically about -27 dBm.

The picture below (from NTT Electronics) shows some typical passive splitters. The "pigtails" are connected using mechanical or fusion-splices. These devices are simple, inexpensive and rugged.



Exercise 2: What is loss of an ideal N-way splitter?

The system design should allow some margin (about 3 dB is typical) for performance degradation over time and possible additional splice losses caused by repairs that may need to be made in the future.

Exercise 3: Assuming a transmit power of 0 dBm, 10 km of 0.4dB /km cable, two 4-way splitters with a loss of 8 dB each, four connectors with a 1 dB loss each, and a receiver sensitivity of -27 dBm what is the margin? What if the cable was 20 km long?

Optical signal powers can be measured with optical power meters. ONUs and OLTs can also be used to monitor received signal levels and bit error rates once a link has been established.

Protocols

Two PON protocols are widely used: Ethernet PON (EPON) and Gigabit (GPON). Future PON systems may use WDM Wavelength Division Multiplexing (WDM-PON).

Both protocols use the same fibre infrastructure, can use FEC to improve the link budget margin and use a TDMA upstream MAC that is coordinated by the OLT.

GPON

GPON is defined by ITU-T standard G.984 and was designed for telecom carriers. It uses a a protocol layer to encapsulate Ethernet, TDM (for isochronous data) and management frames.

EPON

EPON is defined in IEEE standard 802.3ah. It is based on the Ethernet 802.3 data networking protocol and uses the same frame format.

The data rates are 1 Gb/s up and down although there are extensions to extend that to 10 Gb/s downstream together with 1 or 10 Gb/s upstream.

The nominal loss budget is 24 dB with a 1:16 split ratio although ONUs with better performance can operate with higher losses and split ratios.

WDM-PON

Wavelength Division Multiplexing is seen as a future way to increase capacity by using multiple wavelengths. The OLT can transmit to each ONU on a different wavelength thus greatly increasing the capacity of the PON plant. There is some debate as to when this will actually be required.