
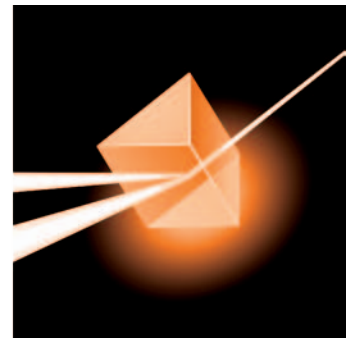


White Paper



Ethernet Point-to-Point vs. PON –
A comparison of two optical access network technologies and the different impact on operations

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Foreword

The telecommunications industry has now had ten years' experience with active and passive optical networks. And debate about the pros and cons of each has been raging for just as long. Optical connections into the home (Fibre-to-the-Home [FTTH]) can be implemented with both passive optical networks (PONs) and Ethernet Point-to-Point (PtP) fibre optic networks. In the mid 1990s, the first large-scale PON installations were commissioned in Japan. In many other parts of the world, FTTH concepts were a long way off. The Internet was still in its infancy, attractive online packages for residential customers were virtually unavailable and the technology was far too expensive anyway. As a result, the majority of end customers did not clamour for more bandwidth (i.e. more than ISDN was capable of at the time) until the turn of the millennium.

The subsequent explosion in bandwidths, driven by the availability of broadband DSL connections via the traditional telephone line,

turned the Internet and other Internet-based services into an unparalleled success story. Nowadays, advanced new services, like high-definition IPTV, online programs (web applications) and data storage on the web have driven service providers to seek even more powerful access network solutions for the post DSL era. Due to the physical attributes of the copper cable in the last mile, VDSL2 has reached the boundaries of its technical potential on existing access lines. This continues to be the case, although a complementary technology called DSM (Dynamic Spectrum Management) is being developed. DSM enables a further increase in the transmission capacity on copper cable. Wireless solutions, such as WiMAX or LTE in the mobile telephony sector, reach their limits even more rapidly due to the even more restricted transmission capacities in comparison with copper cable. As a result, from today's point of view, only fibre optics are capable of providing unlimited bandwidths.

1 Basic facts

PON and Ethernet Point-to-Point technology want to position fibre optics as close as possible – ideally right into the subscribers' homes. As regards transmission quality and bandwidth, FTTH/FTTB is the most sustainable option in terms of technology.

The major difference between active and passive access technology is the use of passive splitters for passive optical networks, enabling simultaneous usage of a single laser source by several subscribers. The splitter distributes this optical signal into fibre optic paths or subscriber connections. The Optical Network Terminal (ONT) then filters out the part of the signal destined for a particular subscriber. In the other direction, the ONT transmits in time slots (TDM procedure), so that the signal can be clearly allocated on the OLT to the subscriber in question.

Ethernet Point-to-Point systems do not distribute the signal via a splitter and there is a dedicated fibre optic path between

subscriber network terminal (CPE) and the central office (optical multiplexer).

1.1 PON systems

From the core network, the OLT (Optical Line Terminal) is the first network element in a PON network that provides $n \times 1$ Gbps or $n \times 10$ Gbps Ethernet interfaces towards the core network and PON interfaces towards the subscribers. These days, the PON types used in this case are normally Ethernet-PON (EPON), Gigabit-PON (GPON) and in future 10 Gigabit-Ethernet PON (10GE-PON) or wavelength division multiplex PONs (WDM-PONs). Nowadays, EPON installations tend to occur more in the Far East and GPON more in the US and Europe. Consequently, we will be looking at the GPON-type (ITU-Standard G.984) below.

Subscriber access is implemented via an optical network terminal (ONT). The ONT terminates and converts the optical signal

into one or several electrical interfaces, such as 100BaseTx, POTS or ISDN for example. Despite existing GPON standardisation, the ONT is still very often system specific. In other words, ONTs made by different manufacturers cannot be used or only to a limited extent.

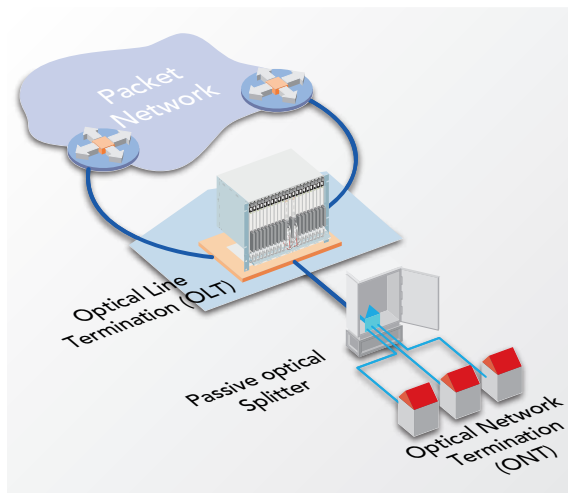


Figure 1: Subscriber connection in a PON

1.2 Ethernet Point-to-Point (PtP) systems

Today, Ethernet Point-to-Point systems are often used in the communications section of telecommunications networks (Metro Ethernet switches, IP edge routers). However, optical Ethernet technology can now also be used economically for direct subscriber connection via fibre optics. To date, existing systems in the IT world were simply converted and therefore not cost effective.

Current FTTx systems offer very high fibre optic port densities, low power consumption and functions specifically for FTTH/FTTB applications. In contrast to previous systems, today's FTTx systems are cost effective and designed specially for use in harsh environmental conditions in public networks. Ethernet PtP systems use standard Ethernet technology for transmitting services to the end subscriber. Commonly available components, such as switches and routers with optical interfaces, can therefore be used for the subscriber as CPE (Customer Premises Equipment).

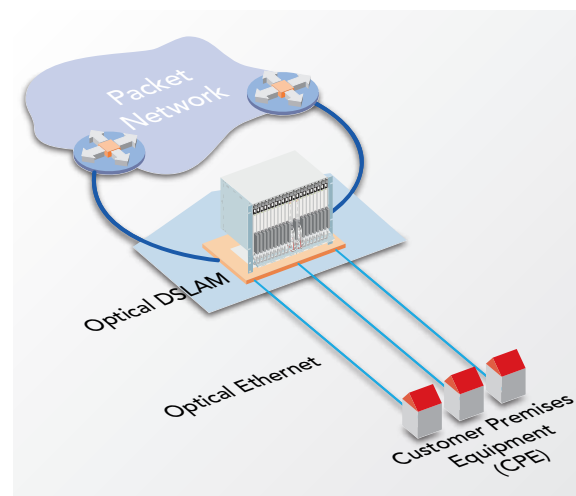


Figure 2: Subscriber connection via Ethernet PtP

2 Ethernet PtP and PON suitability in various scenarios

2.1 Infrastructure comparison: Point-to-Multipoint (PtMP) vs. Point-to-Point (PtP)

Establishing a new infrastructure is a major investment without doubt. During the planning phase it is important to consider how to refinance the investment over several years

while it is operating – apart from the active components currently available. The new infrastructure should have a useful life of more than 25 years (compared to copper wire >50 years) in order to achieve sustained added value. If we also consider that about 80% of the expense of laying a new infrastructure is not absorbed by the materials, but by labour

and manufacturing costs of cable trays and laying cables in buildings etc, a new FTTx must be able to offer maximum sustainability.

Let us take a look at installation in office buildings back in the 1990s. At the time, office buildings were gradually fitted with a data cable infrastructure (Ethernet). Initially there was just one cable with several users sharing the bandwidth because it was thought that bandwidth was more than sufficient. Now, some 20 years later, virtually no buildings exist with shared medium cabling (Point-to-Multipoint). It was impossible to predict that demands for bandwidth in an office network would mushroom in the way they have and make Point-to-Point cabling vital.

Today broadband demand in 10-20 years is a much-discussed topic. And any forecasts will probably be equally as inaccurate. Again customers can currently choose between Point-to-Point and Point-to-Multipoint topology.

If experience with office building installation is applied to fibre optic infrastructures in FTTB and FTTH applications, there are several arguments in favour of the PtP structure with a dedicated fibre optic line for each customer - at least where sustainability of the investments is concerned. When expanding public networks, this aspect is possibly even more important because changes in the network structure in built-up areas are much more costly than in office building installations.

2.2 PON and PtP network topologies

Both PON and Ethernet PtP can implement network topologies such as Fibre-to-the-Curb (FTTC), Fibre-to-the-Building (FTTB) and Fibre-to-the-Home (FTTH). We will be looking at FTTH and FTTB, as only these are possible with truly future-proof bandwidths.

In real world conditions, both FTTH and FTTB structures will be used for expanding networks in the majority of areas. FTTH is a better choice for detached and semi-detached houses. But in multi-apartment houses, it is cheaper to terminate the fibre optics in the building's technology room and then use the existing cables in the building for the subscriber lines (FTTB).

2.3 Fibre-to-the-Home (FTTH)

FTTH are fibre optics which are fed directly into the subscriber's home. In other words, all customers have their own optical fibre in their home. The ONT in GPON, or the optical CPE in Ethernet PtP, is only used by one single subscriber.

Both GPON and Ethernet PtP systems have equipment for this topology. If the network operator selects a 32-fold splitter for GPON, the customer has 78 Mbps bandwidth downstream, while Ethernet PtP connections start at 100 Mbps.

2.4 Fibre-to-the-Building (FTTB)

FTTB are topologies where the fibre optics end in the installations room (e.g. basement) of the building and this connection is used by several customers. In terms of the bandwidth available, this means that the bandwidth provided at the optical terminator divides up again to the number of users connected. If the network operator wants to offer at least 50 Mbps per customer, connection to a 32-port splitter in a GPON system is already inadequate for even two subscribers, or the nominal bandwidth provided is already oversubscribed at this point. Therefore, the network operator must use several fibre optics or splitters with a lower splitting factor. Where the splitting factor stays the same, the operator has to keep ports on the splitter unused in order to supply more bandwidth into a multi-apartment home. The number of apartments in multi-apartment houses varies hugely (from two to more than 20). As a result, when using GPON systems, it is vital to plan the different splitter types and ONTs required. If there are changes in customer behaviour (bandwidth, change of services) the network operator might have to exchange these components (see Figure 3 at page 7).

Ethernet PtP systems offer much better scalability in the FTTB structure. Without any drop in quality, up to 20 households can be supplied at 50 Mbps by increasing the physical bandwidth to 1000 Mbps and using an appropriate optical CPE (see Figure 4 at page 7).

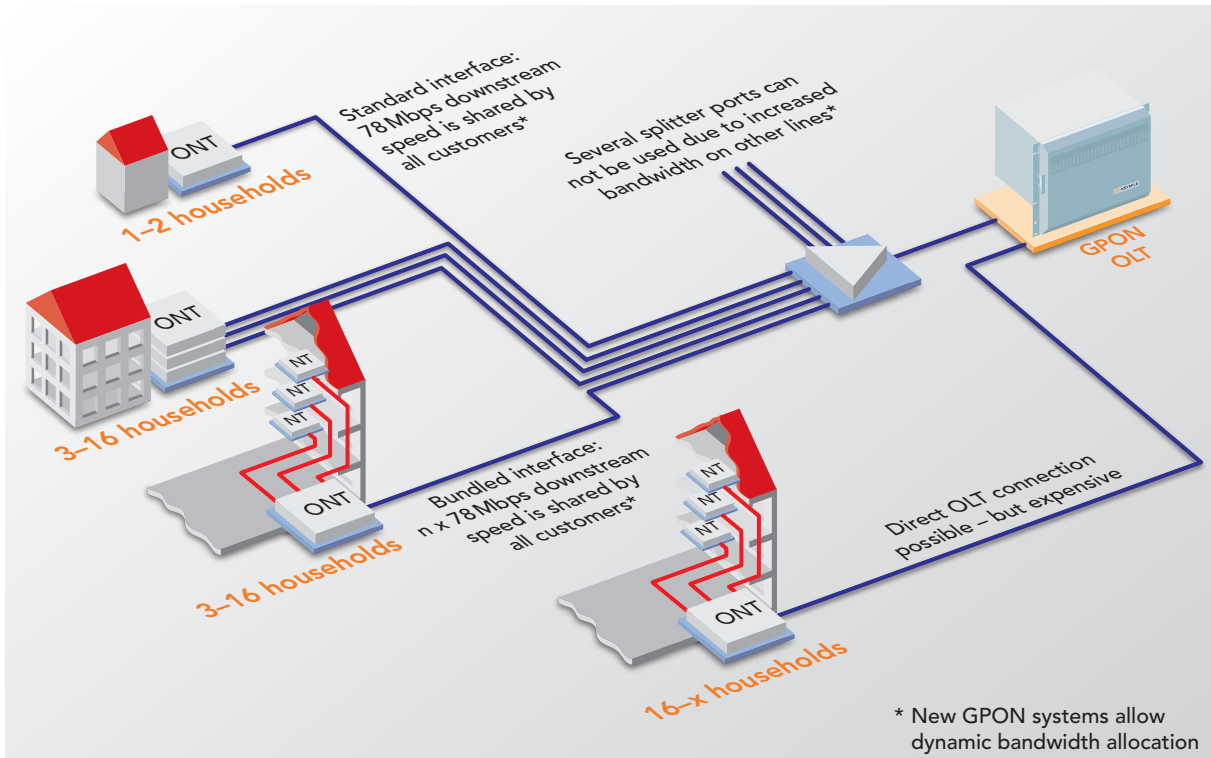


Figure 3: Fibre-to-the-Building in PON networks

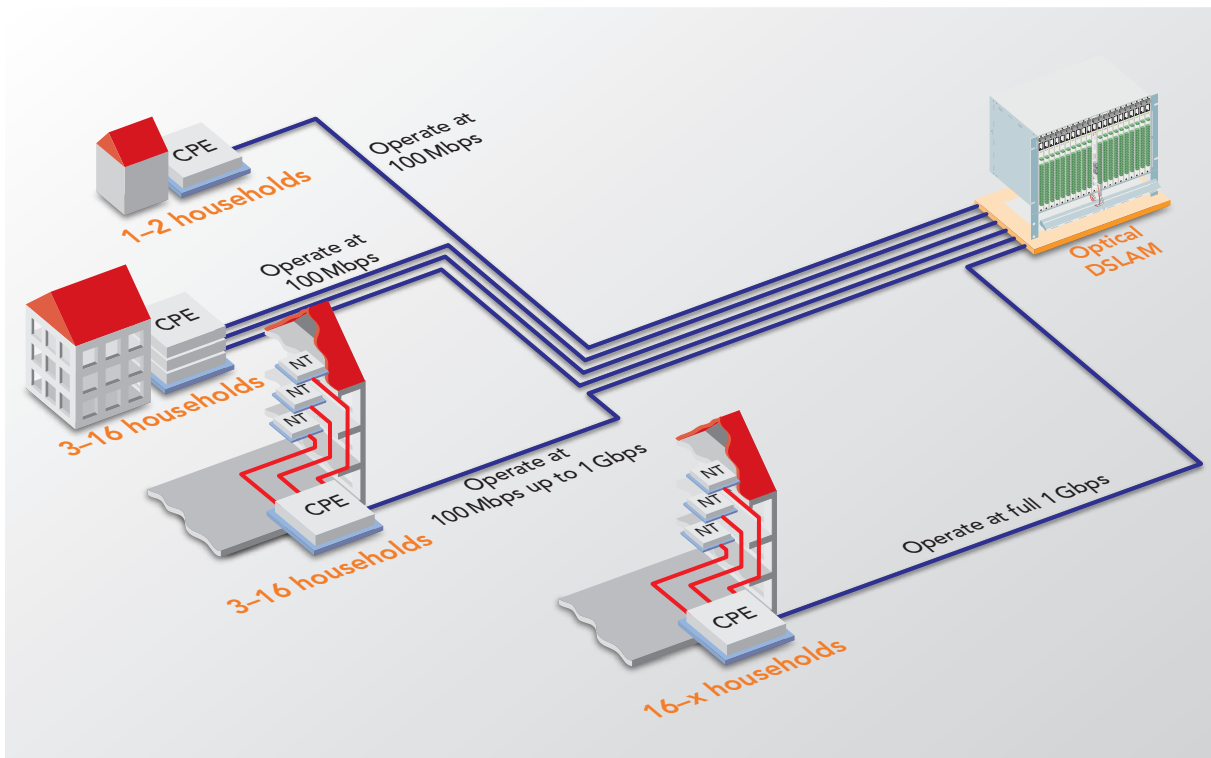


Figure 4: Fibre-to-the-Building in Ethernet PtP networks

2.5 Suitability for business customers

When laying a new fibre optic infrastructure, business customers' requirements are of course important as well. Depending on the size of the company, requirements for telecommunications services will vary. While SMEs are currently satisfied with GPON and Ethernet PtP systems, large customers and those with special requirements (e.g. confidentiality in the case banks) have more specific requirements. Because of the stringent requirements on security, a bank is unlikely to consent to connecting to a passive optical network. The reason is that a PON is a shared medium and therefore all data sent to the bank is also

passed to other network termination points. Similarly to any shared medium, there is also a risk that the data could be analysed by hackers (see chapter on security aspects). Thanks to its enhanced flexibility and broadband symmetry, Ethernet PtP technology is also much better for large companies with demands for very high bandwidths. Network operators choosing PON technology for standard subscriber lines, should therefore also allow for PtP connections - as a parallel infrastructure for business customers - when laying fibre optics.

3 A comparison of PtP v. PON technologies

3.1 Technical aspects

The following chapter includes a comparison of the different technologies, based on key criteria for installing and operating fibre optic networks.

3.2 Bandwidth

The trend towards increasing bandwidth is still unbroken. Due to the introduction of television via IP (IPTV), bandwidth growth is not about to go into a decline - in fact quite the opposite. With the launch of high-definition TV (HDTV) and other technically complex services, such as online programs or data storage on the Net, network operators are coming under pressure to provide increasingly higher bandwidth packages.

Today, the end customer is already demanding high-definition TV (HDTV) because basic functions are already implemented in the new flat screens. The standard two TV channels simultaneously available in DSL packages is a restriction for a family of four that will be unacceptable in the long term. Furthermore, current packages including several telephone lines and 16 Mbps Internet access via ADSL are already being marketed to residential

customers. Web applications provided by Google for example, such as word processing and spreadsheet calculation, are becoming increasingly popular. However, these applications require sufficient bandwidth to operate smoothly. The resolution of video telephony is currently very low, but this will also advance. Higher resolution and better quality will soon be required. The above-mentioned applications easily require top rates of over 50 Mbps per subscriber line. Today, standard VDSL2 access would not be able to cope.

The scenario described above indicates the typical residential customer profile in the near future. Sceptics might like to recall the situation about ten years ago when modern end customers still used 56 kbps dial-up modems for e-mails, faxes and home banking. Compared with today's standard 4 Mbps ADSL access, this equals an approx. 70-fold increase in broadband width.

In other words, we can assume that in three to five years 100 Mbps will be demanded as the standard speed. And in ten years even 1,000 Mbps will not be unusual for power users - even if this appears visionary by today's standards.

3.3 GPON bandwidth

Current GPON systems operate with a bandwidth of 2.5Gbps towards the subscriber (downstream) and 1.25Gbps towards the core network (upstream) on an OLT port. Towards the subscriber, the signal on the fibre optic is distributed by a passive splitter, placed either in an outdoor housing, a collocation room or in the end subscriber's property and divided up into n optical subscriber branches. Nowadays, with standard splitter factors of 32 or 64, customised bandwidth can be provided at the rates shown in the table below.

Splitter factor	Downstream bandwidth per subscriber	Upstream bandwidth per subscriber
32-fold	78Mbps	39Mbps
64-fold	39Mbps	19Mbps

As the downstream optical signal is only split passively, the terminal equipment (ONTs) always operate at the full data rate of 2.5Gbps. If you wish to increase the bandwidth on the OLT to 10Gbps for example (10GEPON), all terminal equipment has to be exchanged, even if end subscriber migration to new services is only carried out slowly.

3.4 Ethernet PtP bandwidth

Ethernet Point-to-Point networks use dedicated fibre optics to the subscriber and bandwidth can be customised. Physical interface bandwidths of 100Mbps and 1,000Mbps symmetrically (same downstream and upstream bandwidth) are now standard. However, software can of course adjust the bandwidth actually supplied to below the physical bandwidth to suit each customer. If you want to increase a particular customer's bandwidth, for example from 100Mbps to 1,000Mbps, you just exchange the terminal equipment and the interface from the central office. Today, modern systems already have Gigabit-compatible interfaces that can be easily reconfigured with software from 100Mbps to 1,000Mbps. In both cases it is possible to increase the bandwidth on an individual basis, i.e. driven by individual requirements or competition, without having an impact on other connections.

3.5 Standard compliance

Standards (IT-G.984 for GPON) have been established for key parameters of PON systems. However, it has still proved impossible to achieve true compatibility of one manufacturer's ONTs with another's. This is also unlikely in the future because Point-to-Multipoint processes entail modification of complicated algorithms between OLT and ONT and their reproduction in the network management system. Therefore, all OLT and ONT components and splitters in PON systems have to be supplied by one manufacturer to achieve the best possible performance.

Ethernet PtP systems on the other hand have been using IEE standardised transmission interfaces for years. The compatibility of these interfaces between manufacturers is no longer an issue and they are already used frequently in the metro and core network. As a result, terminal equipment and central office will be compatible in the long term. With regard to optical Gigabit interfaces, current trends indicate that these will become the standard in IT technology too and prices are expected to fall significantly due to the vast numbers required as a result.

3.6 Fail-safe features, fault clearance

If we compare the different technologies in terms of ease of handling during operation, there are significant differences as well. Processes for localising and rectifying faults in Ethernet PtP systems have been tried and tested for years because these systems are already being employed for business customers and transmission services. On the other hand, complicated network structures have to be maintained in PON systems due to the shared medium of the Point-to-Multipoint structure. If you measure the reflection in a PON tree, you do not just receive the reflected signals from the network termination, the splices and the connectors in a fibre optic path. You also receive the reflection signals of up to 64 ONTs, n x 64 splices, n x 64 connectors and the splitter. Consequently, swift analysis and identification of the faults is much harder and might make on-site visits necessary.

Faulty network termination in a PON tree (or one that has been intentionally interfered with) can hamper all data traffic if for example continuous light is fed into the fibre optic. Therefore, it is no longer possible to identify the signals belonging to the other subscribers connected to this tree. As a result, the entire PON tree is disrupted. Localising this type of fault might involve checking all ONTs locally to establish the cause. In many countries the ONT is installed in basements, so the service technician might have difficulty gaining access to the fibre optics.

3.7 Expansion potential, flexibility

Due to the fixed network concept because of the passive splitters, PON systems offer limited expansion potential and flexibility. Once network operators have chosen splitter factors and ONTs, the following options are possible if an upgrade in bandwidth is requested:

- Options to achieve more subscriber bandwidth:
 - The bandwidth is increased by configuring a subscriber at the cost of other subscribers' bandwidth, plus possible exchange of the ONT.
 - A subscriber's bandwidth is doubled, but the other subscribers' bandwidths stay unchanged > one port on the splitter can no longer be used and the ONT might have to be exchanged.
- Options when several subscribers receive more bandwidth:
 - The splitter can no longer be used and the ONT might have to be exchanged.
 - The splitter is swapped for two splitters with a low splitting factor and the ONTs might have to be exchanged.
 - The OLT is upgraded to higher bandwidth (e.g. 10GEPON) and all ONTs in the PON segment and possibly splitters might have to be exchanged.

- The original PON is overlain by additional PONs and by introducing wavelength multiplexing. As a result, the splitters might have to be exchanged and additional filters used locally for the subscribers.

In Ethernet Point-to-Point systems, changes in bandwidth have the following impact:

- The subscriber obtains more bandwidth
 - Central office: an upgrade of the customer port from 100 Mbps to 1,000 Mbps by switching over the interface (software), or switching the interface over. Modern systems might allow re-configuration to a higher bandwidth.
 - Customers: the customer's CPE is exchanged.

To put it in a nutshell, upgrading the bandwidth in Point-to-Point systems is much easier because only the components for the dedicated subscribers are affected. In PON systems, at best a whole segment, and at worst thousands of subscribers are affected by the upgrade.

3.8 Cable TV transmission

Service providers that offer classical CATV services (analogue or digital) in addition to Internet access, need to be able to transmit cable TV signals via the same fibre optics. In the past, it was much easier to combine both services on one optical network in PON systems, because the optical splitter made the distribution of signals possible. Integrated solutions are now offered for Ethernet PtP systems that make complex feeding in of the cable TV signals via an external WDM system superfluous.

3.9 Technical comparison summary

PtP assessment	PON assessment	Comparison
Bandwidth allocation		
<p>Good The bandwidth allocated to the subscriber is governed by the interface type, or by traffic shaping on the access node and is therefore adjustable in kilobit increments.</p>	<p>Average The GPON interface on the OLT today is 2.5/1.25 Gbps (downlink/uplink). The bandwidth per subscriber is determined by the splitting factor (usually 1:32 or 1:64). Modern PON systems allow bundling of several time divisions in dynamic bandwidth allocation; however the bandwidth in a PON segment is limited to 2.5Gbps.</p>	<p>PtP's advantage Because of its higher flexibility, PtP has a clear advantage. There are limitations in a PON network because only the segment bandwidth (2.5 Gbps) can be allocated to the subscribers.</p>
Maximum bandwidth per subscriber		
<p>Good As all subscribers can be connected with their own fibre optics, bandwidth of between 100Mbps and 1 Gbps per household or company can be achieved nowadays. PtP fibre optic topology means that it is easy to use systems with even higher bandwidths for special applications.</p>	<p>Satisfactory With regard to today's GPON standards, the maximum conceivable capacity of a fibre optic equals the total capacity of an OLT port, i.e. 2.5 Gbps (PtP connection without splitter). Realistically the bandwidth with splitter and a division of usually 1:32 is 78 Mbps, or 39 Mbps at 1:64 (all figures apply to downstream).</p>	<p>PtP's advantage In terms of bandwidth per subscriber, PtP enjoys a clear advantage. The maximum bandwidth per subscriber is a lot higher. The ability to allocate individual subscribers different bandwidths (e.g. in the case of business customers) is also more flexible than when PON systems are used.</p>
Bandwidth increase		
<p>Simple As the active access nodes have modular structures, the subscriber interfaces can be upgraded to higher bandwidths. It is often sufficient to just switch the fibre optic cable to be able to operate it again.</p>	<p>Difficult Depending on the system's technology, several time divisions could be bundled and therefore increased by a factor $n + 1$ at the cost of the maximum number of subscribers per PON branch. The bandwidth of the PON port on the OLT is the upper limit, i.e. 2.5/1.25 Gbps (down/up).</p>	<p>PtP's advantage In this case, PtP architecture is superior to the PON's PtMP architecture. Just by adding boards, subscribers can obtain an upgrade, without the network architecture or the service of other subscribers having to be changed.</p>
Effect of malfunctions and manipulation		
<p>Low Due to the PtP architecture till the end customer's CPE, each path can be clearly identified. In the worst case scenario, the laser on the access node can be deactivated for each subscriber by the control centre.</p>	<p>High Within a PON tree, all the subscribers are on the same optical point. If a faulty ONT causes faulty synchronisation, or produces an optically indefinable signal, a remote localisation of the malfunction in the ONT involved is not possible.</p>	<p>PtP's advantage In the worst case scenario, because of a technical fault or deliberate manipulation, a single ONT can cause an entire PON tree with up to 64 subscribers to fail for a lengthy period of time. A faulty subscriber path in the PtP system on the other can easily be identified and rectified.</p>
Risk of eavesdropping (espionage)		
<p>Low Each customer has dedicated fibre optics. In general, wire tapping is not possible.</p>	<p>High A PON tree is a shared medium, i.e. the signals of all subscribers are on a single fibre optic termination point. Data is separated by allocating the time division and encryption software. The setup is in the customer's network termination.</p>	<p>PtP's advantage Similarly to WLAN, data in the PON network can be encrypted individually. Nevertheless it is possible to tap into another subscriber on the same PON tree and hack the encryption.</p>

PtP assessment	PON assessment	Comparison
Reliability of the subscriber path		
Good In an active network, a customer can be connected in a ring or by dual homing, in other words a customer can be connected up redundant.	Poor To date, there are no plans to connect customers redundant in one PON.	PtP's advantage In terms of availability, PON is at a clear disadvantage compared with PtP.
Level of suitability for connecting large-scale/business customers		
Very good Advantages such as flexibility, security and performance come very much to the fore. A router or switch can be used as an optical network termination to separate services.	Poor The customers in a PON tree are all treated the same. Customised requirements are only possible above protocol level layer 3.	PtP's advantage Requirements from business customers are always special, PON network concepts tend to be more static. As a result, PtP is much a much better choice in this case.
Flexibility of usage regarding optical network termination		
Good As an Ethernet PtP uses standardised Ethernet interfaces, a wide range of equipment can be used to terminate networks.	Poor Right up until today, there is no real interoperability between competing PON technologies or within the same PON technology. The operator is forced to purchase the ONTs and ONUs from the OLT supplier (creating dependency).	PtP's advantage In this case, the operator of a PtP network can act more flexibly and exploit real cost benefits in the long term too (sustainability).

To summarise, Ethernet Point-to-Point systems have a clear advantages in terms of technical issues. Greater flexibility,

suitability for business customer services and sustainability are all key arguments.

	Bandwidth Standard conformity	Reliability Fault recovery Maintenance	Expansion capability Flexibility
PON	●	●	●
Ethernet PtP	●	●	●

4 Business aspects

4.1 Business case aspects

It is often difficult to put a business case to investors and supervisory boards. The root of the problem lies in the high investment costs involved in creating a fibre optic infrastructure and falling revenue at the same time. Nowadays the ICT industry still enjoys returns on investment of one to three years. Regardless of whether PON or Ethernet PtP technology is used, FTTH and FTTB expansions see returns on investment to an entirely different magnitude of more than ten years in some cases.

Nevertheless, applications and general conditions play a major role in the way the business case is considered. Depending for example on whether passive or active access technology is used for the fibre optic infrastructure. The main differences in investment costs (capital expenses, CAPEX) and operating costs (operational expenses, OPEX) are compared with one another below.

4.2 Cost drivers when laying fibre optic infrastructure.

If we consider the total investment made in a fibre optic infrastructure, it quickly becomes obvious that the key costs for the new network technology are not caused by the equipment. The majority of costs (about 85%) are channelled into creating the fibre optic trays, the connections in the buildings and the distribution points etc. These figures show that the passive infrastructure takes much longer to amortise (more than 15-20 years). Consequently, it would be inadvisable to invest in topology that is not sustainable and might not support tomorrow's technologies and demands.

4.3 A comparison of Ethernet PtP and PON infrastructure costs

By using optical splitters in the access network, infrastructure designed for PON needs substantially fewer fibre optics than if a dedicated fibre optic were provided for each customer from the connection in the building to the central office - as is the case in an Ethernet PtP system. However, if you consider that a 144 filament cable is only approx. 8mm in diameter and now sold at a very low price, the advantage is small because you still of course need all cable trays and distribution points in a PON.

4.4 A comparison of Ethernet PtP and PON equipment costs

4.4.1 Central office

The outlay for a fully-used GPON port divided by the number of customers connected is usually cheaper than in an Ethernet Point-to-Point system because not every customer requires a dedicated laser module. However, in future the prices for Gigabit-Ethernet laser modules in particular should fall significantly. The reason is that IT technology has also discovered these interfaces for its applications and therefore very strong sales are expected in the next few years. A similar effect was observed when copper wire-based Ethernet networks were launched to link up offices in the 1990s.

The initial investment in Ethernet PtP is still cheaper (see section 4.5 at page 14). The reason is that only customers receiving a service need to be connected up to an active port.

4.4.2 Splitters

Optical splitters are only used in PON architecture. Splitters only account for a very small fraction of the total costs of a system. However, the risk of using splitters entails a possible exchange at a later date when a network upgrade is carried out. Splitters are usually installed in the access network directly in the cable trays to save expense. As a result, exchanging splitters is usually costly because road works are necessary. If splitters are placed on distribution points and are easily accessible, it is vital that extra costs for outdoor housings and inspection shafts are being spent in the first installation. In the end, the price no longer seems so attractive. With Ethernet PtP no splitters need to be inserted in the cable trays.

4.4.3 Subscriber equipment

Equipment installed on the customer's premises can be used for optical network termination (ONT). The equipment terminates the fibre optics and provides all the necessary interfaces and functions for TV, telephony and Internet access for the customer. Because of the different requirements as regards the network topology (FTTH or FTTB), features specific to particular countries (e.g. ISDN) and the different technical requirements in the network, a wide range of ONTs and CPEs are required.

As stated in section 3.5 at page 9, PON systems have to select ONTs from the manufacturer of the systems technology. As a result, the network operator becomes very reliant on the products marketed, in terms of functions and price, for the whole life cycle of a PON system.

Due to the standardised Ethernet interfaces and the resulting compatibility with other manufacturers, the range of CPEs that can be used in PtP networks is a lot broader of course. As a result, competition between the CPE providers and falling prices are a given. And the network operator is not dependent on just one manufacturer.

4.5 A comparison of initial investment for Ethernet PtP and PON

If we examine the typical scenario of subscriber connection with fibre optics, key differences during the installation and operational phases become apparent.

If a new area is connected with fibre optics, the infrastructure is of course designed in such a way (e.g. with fibre optic cable, sleeves, flexibility points...) that all customers in the area can be connected with services via fibre optics. However, because not all customers immediately select the network operator (services provider), the industry talks about "homes passed" and "homes connected". Homes passed means the existing fibre optic infrastructure can connect the customer up at a low cost, but the customer does not yet use (or pay for) any service transmitted via fibre optics. Depending on how the infrastructure was prepared, low cost means:

- Laying the fibre optic connection from the main cable in the road to the building or
- providing the necessary equipment and the service if the connection in the building is already available.

Homes connected refers to the number of customers that already use the service via the fibre optic infrastructure. The ratio of homes connected (HC) to homes passed (HP) plays

a major role in business success and should of course be as large as possible. In the real world, figures vary between 10 and 40% HC/HP after a period of one year and clearly depend on the services offered, the price and other competitors on the market.

If infrastructure operators design their networks for PON systems, the optical splitters are usually installed in the access network (in other words in the road). And each splitter port is allocated to a potential customer. If we assume a splitter has 32 subscriber connections and an HC/HP ratio of 20%, six to seven ports in a splitter are occupied with paying subscribers. A 2.5 Gbps port must also be installed centrally for each of these splitters. In other words, all splitters and OLT fibre optic ports have to be installed for the entire infrastructure as soon as the network starts operating, although only 20% of the potential customers actually use the service (see Figure 5 at page 14).

These high initial investment costs in GPON networks can only be avoided if a low number of splitters are used at the beginning and only the homes connected are actually attached. When activating new customers, new splitters have to be installed – in the road, pavements or outdoor housings. This is a significantly more complex job and incurs additional costs.

On the other hand, a Point-to-Point fibre optic infrastructure offers huge advantages because

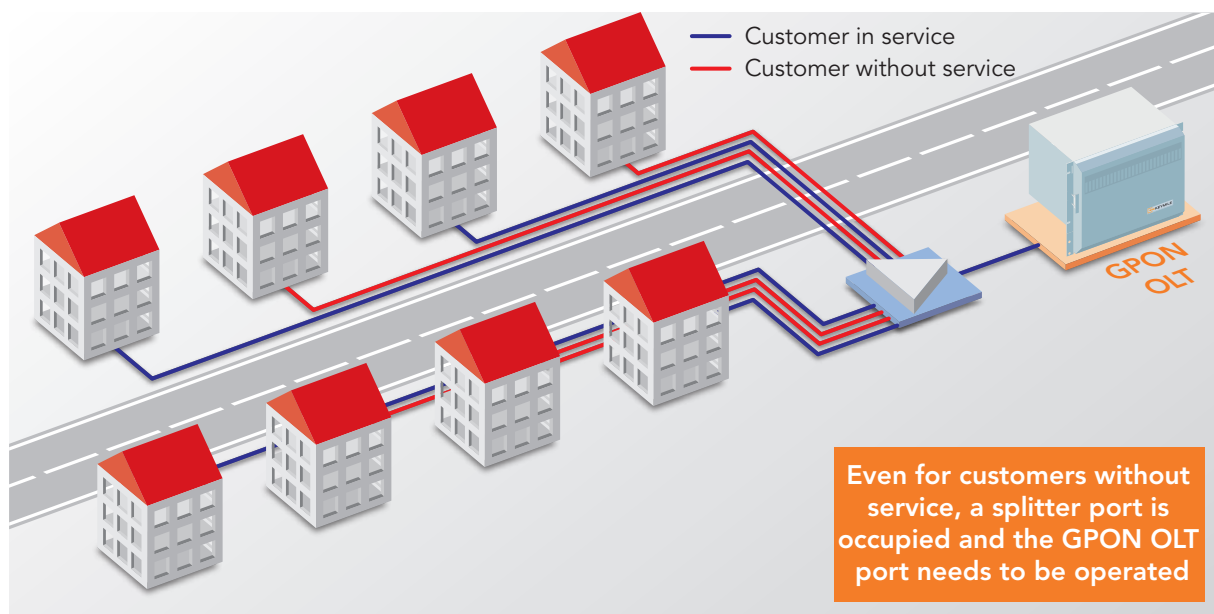


Figure 5: Homes Passed – Homes Connected influence in GPON networks

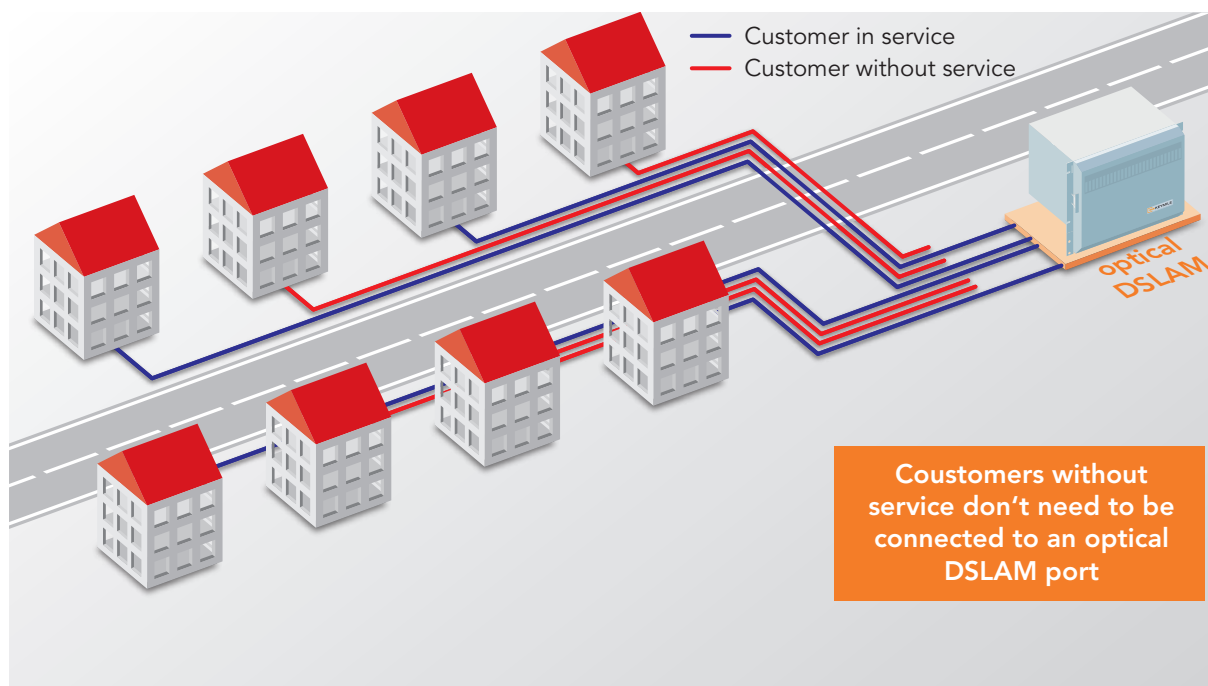


Figure 6: Homes Passed – Homes Connected influence in Ethernet PtP networks

only the homes connected subscribers have to be switched with active technology. Because each customer has a dedicated fibre optic, new customers can be easily connected to the optical MSAN without any outdoor installation being required (see Figure 6 at page 15).

4.6 Costs for buildings and flexibilisation points (aggregation nodes)

Flexibilisation points or aggregation sites are places where the fibre optics are merged, connected to active equipment and transmitted to the core network. They are responsible for a significant portion of the infrastructure costs in a fibre optic network.

When considering potential aggregation points in a fibre glass structure, the following factors are decisive in selecting the location:

- Does the network operator already own sites that could be used?
- What type of buildings does the target area have (detached houses, tower blocks)?
- Which aggregation points are suitable for the network topology (streets of houses with access roads...)

- How can the connection be implemented to the core network (communication network)?

The following places are possible as aggregation points:

- Technical buildings that already exist (local exchanges, main distribution frames, other company buildings)
- Leased basement rooms
- New containers to be erected
- Street cabinets

From a business standpoint, a balance has to be struck between the number of aggregation points and the quantity and length of the fibre optics required. The number of aggregation points should be kept as low as possible because:

- These contain active technology and therefore require a power supply.
- The locations should preferably be connected in a ring to the communication network in order to create redundancy should a transmission path fail.
- The costs for erecting and maintaining the building should be kept to a minimum.

The costs for long fibre optic paths and the installation costs for pipes, connections and laying work increase with the number of fibre optics.

Because of all the different parameters involved, it is impossible to predict the

different costs for aggregation points in a PON and an Ethernet Point-to-Point system. A precise plan in real world conditions is the only way of achieving a realistic result.

4.7 Financial comparison summary

Investment costs summary (CAPEX)		
PtP assessment	PON assessment	Comparison
Costs of the subscribers' terminal equipment (CPE)		
Average Because standard Ethernet technology can be used. Today simple CPEs (e.g. Ethernet media converters) are already under \$50 each.	Average ONTs are already produced in vast numbers, but there is no compatibility between different manufacturers.	PtP's advantage By using standard interfaces, PtP CPEs will probably have an edge on costs in future because of strong competition.
Costs of the network technology (active components, fully expanded network)		
Average Because each subscriber will occupy a dedicated laser port on the network node.	Low Because each port on the OLT will be shared by several customers as splitters are used.	PON's advantage Because optical paths can be used by several subscribers, PON is a bonus as regards the price per subscriber.
Initial investment in the network technology (active components, HC/HP 10–40%)		
Average Only paying customers will be allocated an active port.	High Each optical splitter is connected to an active OLT port.	PtP's advantage Only active customers have to be connected, in PON the OLT starts expanding fully.
Costs of the network technology (passive components and infrastructure)		
Not specified	Not specified	Depends largely on parameters concerned (see text).
Space required for systems technology		
Average Numerous active interfaces have to be accommodated at the central site. However, the space required decreases with each new generation of PtP systems.	Low Little space required at the central site, but the passive splitters have to be placed in the access network.	PON's advantage At the central site, the PON requires less space.

4.8 Comparison of operating expenses

4.8.1 Energy consumption

GPON systems consume very little energy because - depending on the splitting factor - the optical signal is shared by several customers. The higher output required by the laser diodes does weaken the advantage over Ethernet PtP systems, but on the whole power consumed by a GPON system is lower than by a Point-to-Point system.

To date, manufacturers have not placed significant emphasis on the efficiency of laser diodes, but this could change with the development of green IT. There is definitely still potential for improvement.

4.8.2 Maintenance frequency

Modern systems require neither regular maintenance nor constant local inspections, thanks to their extensive network management systems. Malfunctions only have to be rectified locally if components are faulty. Optical laser modules are the components most at risk of failure. Compared with a PON, many lasers are used in an Ethernet PtP system, so the risk of failure is definitely higher. On the other hand however, the PON lasers operate with much higher output power and if they fail several subscribers are affected, so that this advantage is compensated for.

A comparison of operating expenses (OPEX)		
PtP assessment	PON assessment	Comparison
Energy consumption		
Average Because of the high number of laser interfaces. However, new systems achieve much better values than the last generation.	Low Because of passive splitting.	PON's advantage Because of the passive splitter and greater subscriber density on the OLT, PON is better in this case.
Level of difficulty in identifying and rectifying faults		
Low Because of the PtP topology and the dedicated optical transmission path is easy to measure.	High Because in the worst case scenario, a faulty ONT cannot be localised by the NMS centre. A local visit to the customer is necessary. Depending on how easy the ONT is to access, finding the fault can take some time.	PtP's advantage Identifying and rectifying faults is much easier in PtP topology than in the PON. Nevertheless, analysis capabilities in the PON can be improved by using optional monitoring systems.
Follow-up costs for upgrades		
Low Because the active components have enhanced scalability and customers can be separated, customised upgrades can be carried out in the PtP and the CPE can for example be exchanged.	High An entire PON tree is always affected by an upgrade. All ONTs have to be exchanged at the same time. As a result, individual upgrades are virtually precluded.	PtP's advantage Because of enhanced customisable flexibility, Ethernet PtP has an advantage in terms of upgrade capabilities.

4.8.3 Complexity and demands made on operators

Due to the greater complexity of the PON infrastructure and maintenance challenges, new and more complex demands are made on operating personnel in comparison

with Ethernet PtP which is already used today in the communication network. The design of the system concerned (network management, diagnosis tools...) can however help to keep operational costs low.

4.8.4 Identifying and rectifying faults

Chapter 3.6 at page 9 has already outlined the different technical parameters required to identify and rectify faults. As a result, higher operational costs are to be expected in a PON network due to the complicated Point-to-Multipoint structure.

4.9 Summary of operational costs comparison

When comparing the investment and running costs, no system really has a clear edge. When weighing up which technology is better, it really depends on the parameters in real world conditions and what the network operators' objectives are. The following table provides a qualitative outline stating which system is better when certain conditions prevail.

	Only residential customers, lower bandwidth, 3-year horizon	Residential and business customers, FTTB, average bandwidth, 5-year horizon	All applications, high bandwidth, sustainability, 10-20-year horizon
PON	●	●	●
Ethernet PtP	●	●	●

5. Summary

On a final note, it is important to say that a generic comparison of technologies, such as those made in this paper, cannot always be accurate and must be looked at on a case by case basis. The balance can easily shift from one side or the other depending on regulatory, commercial or structural constraints.

However, we can say that Point-to-Point network architecture is the most future-proof fibre optic topology in the long term. The risk of having to convert systems technology just a few years after installation because of new requirements is low. All FTTx network operators have to decide for themselves whether higher initial investment and sustainability can be reconciled with their business case objectives.

GPON systems offer enough bandwidth for the next 3-5 years and can be operated economically until then. As a result, they are a good choice for network operators with a strong focus on residential customers, minimal initial investment and a short to medium-term investment horizon.

On the other hand, Ethernet Point-to-Point solutions are a better choice for network operators that want to offer the entire range of services to both residential and business customers for some time to come. This system offers better scalability, reduces dependency on one manufacturer and can respond to consistently increasing customer demands.

6 Glossary

Abbreviation	Description
100BaseTx	100Mbit/s Ethernet, copper interface
3G	Third generation of the mobile telephony standard
4G	Fourth generation of the mobile telephony standard
ADSL	Asymmetrical DSL
AN	Access Node
AON	Aktive Optical Network
APON	ATM PON
ATM	Asynchroner Transfer Mode
BPON	Broadband PON
CaTV	Cabel Television
CO	Central Office
CPE	Customer Premesis Equipment
DSL	Digital Subscriber Line
DSLAM	DSL Access Multiplexer
EFM	Ethernet in the First Mile
EPON	Ethernet PON
FTTB	Fibre-to-the-Building
FTTC	Fibre-to-the-Curb
FTTE	Fibre-to-the-Exchange
FTTH	Fibre-to-the-Home
10GEPON	10 Gigabit-Ethernet PON
GPON	Gigabit PON
HDTV	High-Definition TV

ICT	Information Communication Technology
IP	Internet Protocol
IPTV	Television over IP
ISDN	Integrated Services Digital Network
ITU-T	International Telecommunication Union, Telecommunication Standardization Sector
LTE	Long Term Evolution
MDF	Main Distribution Frame
MDU	Multi Dwelling Unit
MSAN	Multi-Service Access Node
NMS	Network Management System
OLT	Optical Line Termination
ONT	Optical Network Termination
P(A)BX	Private (Automatic) Branch Exchange
PON	Passive Optical Network
POTS	Plain Old Telephony Service
PtMP	Point-to-Multipoint
PtP	Point-to-Point
QoS	Quality of Service
SDTV	Standard Definition TV
TDM	Time Division Multiplex
VDSL	Very high-speed Digital Subscriber Line
WiMAX	Worldwide Interoperability for Microwave Access

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