WHY USE PASSIVE OPTICAL NETWORKS FOR BROADBAND ACCESS?

The passive optical networks (PONs) will solve the existing bottlenecks for broadband access. Here is what makes them so attractive followed by the design of the customer premise equipment used in these networks and the advantages of Ethernet-based PONs over ATM-based PONs

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We are witnessing a great diversity of broadband services like electronic commerce, video on demand, high-speed Internet and videoconferencing. More and more bandwidth is required for these communication networks. The objective of a large bandwidth cannot be achieved by the copper-wire-based technology of accessing the network.

Use of new broadband services has made service operators to consider various alternative technologies. For example, telephone companies have installed copper lines for the x-digital subscriber line (xDSL) technology that uses advanced modulation techniques with very high bandwidth between 128 kbps and 1.5 Mbps. Here, the hybrid fibre-coaxial backbone network is shared among a lot of subscribers. Then, coaxial cables are used at the customer premises with the lowest cost. But since the limitation is maximum bandwidth, this solution cannot be considered as the final one.

Fibre-optic cable appears as a strong candidate due to its unlimited bandwidth. But in a fibre-to-the-home (FTTH) environment, extending fibre all the way to the home or office is not a cost-effective solution.

In this scenario, passive optical networks (PONs) are the most attractive fibre-communications infrastructure as these use the point-to-multipoint topology and require less power.

A peep into the history

PONs were first envisioned by the Full Services Access Network Society in 1995. At that time, they were defined as a common optical-access system that was cost-effective and supported voice, video and data services. After that, PONs were based on the ATM protocol because of its capacity to integrate different types of traffic with guaranteed quality of service.

Here we'll discuss the customer premise equipment from design point of view, such as the optical network unit, which requires a PON architecture. It will provide voice, video and data services.

Earlier, the growth of the Internet protocol (IP) data traffic had led to some sectors claiming that ATM is not appropriate for the access network. ATM requires segmentation of variable-length (max. 1518-byte) data packets into fixed-length (53-byte) ATM

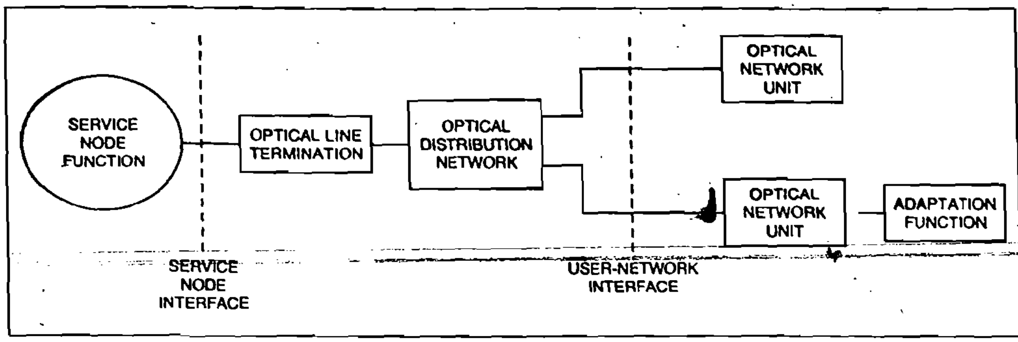


Fig. 1: Reference configuration for a PON

cells, which causes a considerable delay in the communication process.

A main differentiator of these new PONs is the use of higher available bandwidth (1 Gbps vs 622 Mbps for ATM). Since Ethernet is one of the most widely used local-area network (LAN) protocols in the world, if Ethernet were used in the access network, it would eliminate the conversion between protocols required in ATM-based networks.

A passive optical network

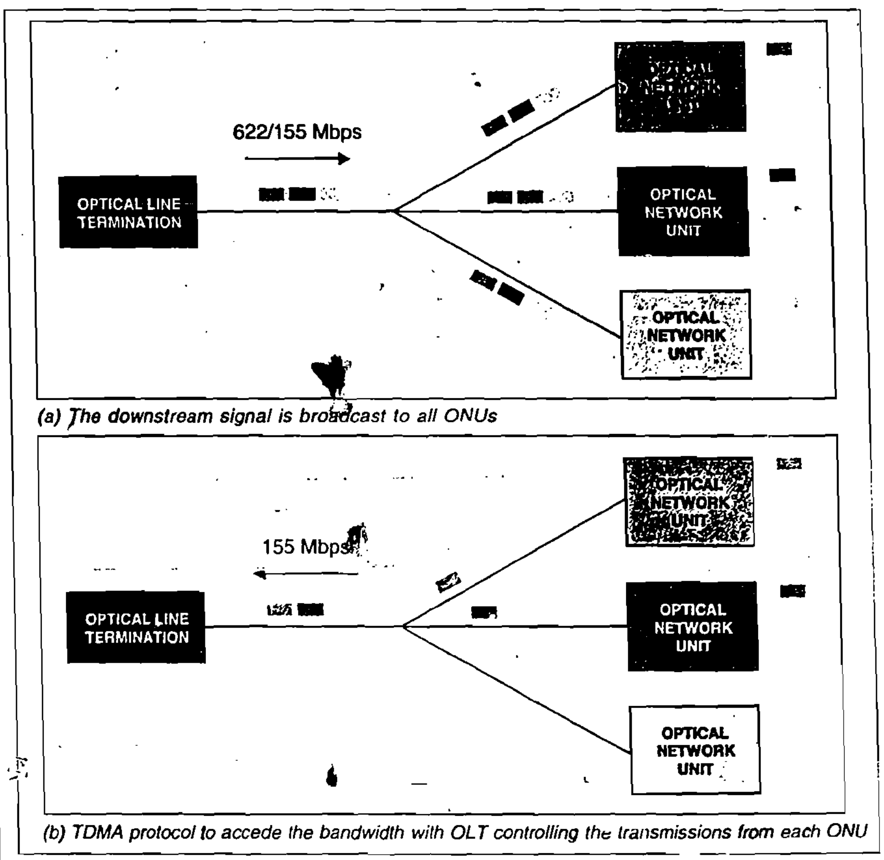
The existing access-network bottleneck is solved in the passive optical networks by bringing the fibre closer to users and by taking advantage of the unlimited bandwidth of the fibre to provide the complete range of present and future broadband services. A PON is a point-to-multi-point optical-access network that allows the service provider to share one optical fibre between a number of users.

Fig. 1 shows the reference configuration for a PON. The system consists of an optical line termination (OLT) located in the operator's central office, the optical network units (ONUs) located at the customers' premises for FTTH connections, and the optical distribution network between the OLT and ONUs. The OLT is connected by a single fibre to an optical power splitter, which supplies the optical signal to several ONUs.

Optical network units

The main feature of a PON is that, in the ODN, between the OLT and the ONUs, there does not exist any active element. Only passive optical elements such as optical connectors, single-mode optical fibres, attenuators and splitters are used at this point. Thus, the cost relative to maintenance and power is reduced. Also, a PON can be easily upgraded only by changing electronics at both extremes of the network, the infrastructure remaining the same. Thus it is a highly flexible system in the sense that a broad range of future services can be easily added.

The ODN, for simultaneous transmission on the same fibre, is enabled by using different wavelengths. Here, the wavelengths used are 1550 nm for downstream and 1310 nm for upstream. Fig. 2 shows an ATM cell-based PON, where the downstream signal is broadcast to all ONUs and depending on the cell header addressing, each ONU discards or accepts the incoming cells. Encryption is necessary to maintain privacy, since the downstream signal is broadcast and each ONU receives all the information. In upstream direction, time-division multiple-access (TDMA) protocol is used to accede the bandwidth. The OLT controls the transmissions from each ONU by sending grants or permissions to them. In order to avoid collisions between transmissions from different ONUs, a technique called 'ranging' is used to measure the logical distance between the ONUs and the OLT. It also adjusts its transmission time properly and this way the effects of propagation delays are over-



(a) The downstream signal is broadcast to all ONUs

(b) TDMA protocol to accede the bandwidth with OLT controlling the transmissions from each ONU

Fig. 2: ATM cell-based PON, where (a) the downstream signal is broadcast to all ONUs and (b) a TDMA protocol is used in the upstream with OLT controlling the transmissions from each ONU

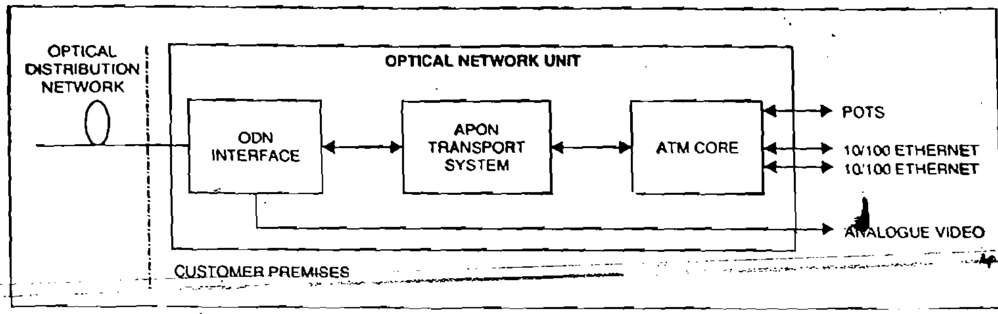


Fig. 3: ONU functional blocks

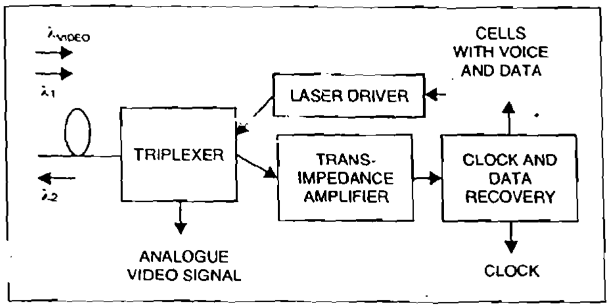


Fig. 4: The ODN interface

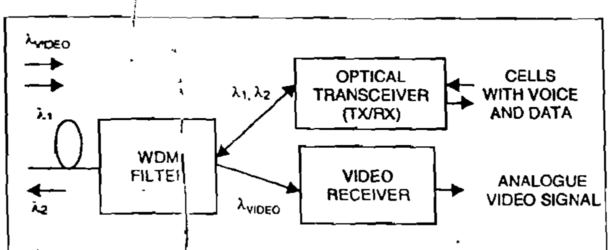


Fig. 5: Triplexer module

come.

At present, many communication companies offer well-equipped OLTs. The main objective has been the design of an ONU for an FTTH connection, whose features were specially adapted for the planned requirements. The fibre, using a PON architecture, only reaches the cabinet, i.e., the FTT cabinet, and the modified ONU, ONU-headend, would be located at this point. Power-line communications technology would be used from the cabinet to the customer premises to take advantage of the high penetration of electrical networks.

Designing of ONU

The design of the ONU is adjusted to the requirements of an FTTH connection. It provides various services like:

1. Plain-old telephone service
2. High-speed data (Ethernet 10/100Mbps)
3. One-way analogue video service (broadcast from the OLT to the ONUs)

The interesting point is that the ODN provides the one-way analogue video service. It could be provided in an integrated manner with the rest of services; in other words, using the ATM protocol to carry it to the ONUs and sharing the available bandwidth in the downstream direction. However, a wavelength-division multiplexing (WDM) technique is used to multiplex the optical signal that transports information relative to voice and data with the one carrying information relative to video.

Fig. 3 shows the design of the ONU with well-defined functions. The first block, i.e., the ODN interface, basically performs the required optical-electrical conversion between the ODN and the customer's network. The APON transport system has a special importance because it is responsible for controlling all the management and operation functions. The ATM core will adapt into ATM cells the voice and data traffic coming from the user's network, in order to carry it to the OLT.

Optical distribution network interface. The basic function of the ODN interface is optical-electrical conversion between the optical distribution network and the customer premise.

Fig. 4 shows the ODN interface block. The triplexer module shown in Fig. 5 integrates a WDM filter, optical transceiver and optical receiver to capture the broadcast analogue video. Two multiplexed optical signals are received carrying the information relative to voice-data (at λ_1), and analogue video (at λ_{VIDEO}). The WDM filter will extract and separate both signals to guide them to the proper receivers. The analogue video signal is recovered and directly offered to the user; meanwhile, the ATM cells transporting voice, data and management traffic are passed to the APON transport system to continue with their processing.

In the upstream direction, this filter will only insert the optical signal carrying information relative to voice and data (at λ_2) in the optical fibre. Besides the triplexer, the ODN interface comprises the typical modules of an optical/electrical interface. Typically, this would consist of a laser driver to control the average power sent to the optical fibre by the optical transceiver's laser, an amplifier to recover the signal with sufficient amplitude, and a clock and data-recovery unit.

All the selected components must be fully compliant with the physical medium-dependent requirements of an ITU-T based APON.

Transport system. The APON transport system block is essential in the ONU since it is used for the cor-

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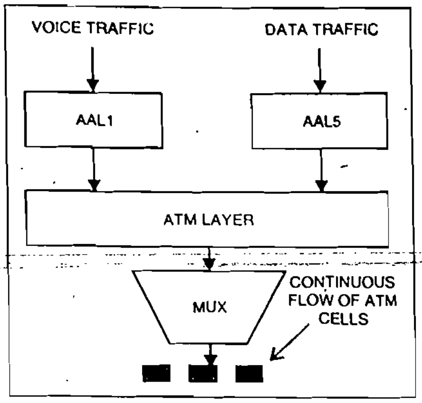

Fig. 6: ATM core block

After that step, and taking into account the header of each cell, PLOAM cells can be identified and guided to the module responsible for their processing.

The rest of ATM cells are passed to the module responsible for verification of the cells' header-error control code in order to detect incorrect or idle cells. The cell considered to be correct, after executing the opposite of the encryption done in the OLT, is passed through UTOPIA (universal test and operations physical interface for the ATM) to the ONU-block ATM core. Here, information carried in the cell will be extracted and sent to the proper interface.

The main objective of the intermediate modules relative to the treatment of PLOAM cells is the processing of the information carried by these types of cells. The proper actions are executed; for instance, the generation of messages to be included in the upstream PLOAM cells, and the control of the transmission time, taking into account the delay time obtained with the ranging function. For transmission, the main function is correct inclusion of the generated PLOAM cells into the flow of ATM cells to be transmitted to the OLT, which have been received through the UTOPIA interface from the ATM core for transmission.

ATM core. The ATM core supports the proposed ONU (Fig. 6). Its basic purpose is the adaptation into ATM cells of voice and data traffic coming from the user's network in order to transmit a continuous flow of ATM cells to the OLT. To perform this function, it includes, in addition to interfaces to the user's telephone line and data network, several operations. These operations are defined for the ATM adaptation layers type-1 (for voice) and type-5 (for data), along with the ATM layer, according to the ATM protocol stack.

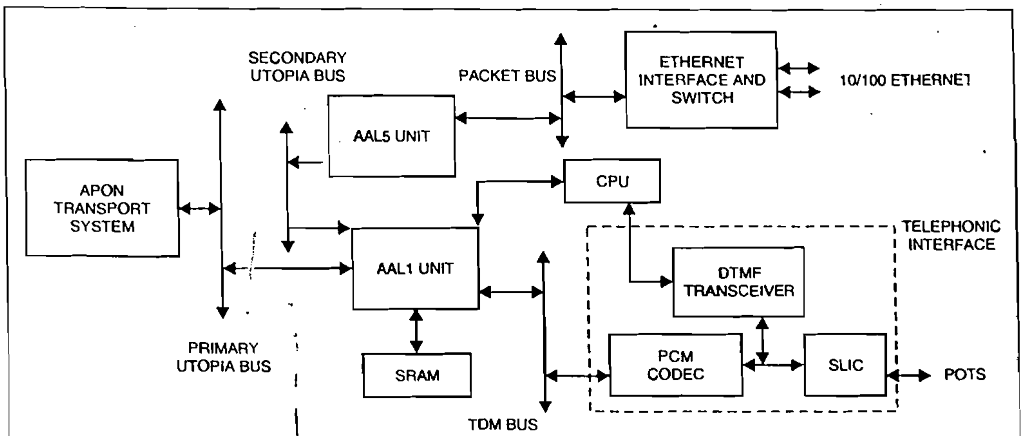

Fig. 7: Functional blocks of ATM core

Fig. 7 shows the functional blocks of the ATM core. The main function of the telephonic interface is to obtain a flow of 64 kbps of pulse-code-modulated (PCM) voice. This PCM flow is passed to the AAL1 unit responsible for the adaptation of this type of traffic into ATM cells. Voice traffic has special properties and requirements to be satisfied in order to be transmitted in a proper manner. The traffic has a constant bitrate and requires exchange of some kind of information that enables synchronisation between both extremes of the network.

Data traffic is received from two Ethernet interfaces running at 10 or 100 Mbps. The Ethernet interface and switch module receives the data packets and decides whether these packets are local to the user's network; if they aren't, the variable-length data packets are sent to the AAL5 unit, which

rect running of the entire APON system. It controls all the functions relative to system management and operation, which are performed via ATM physical-layer operation, administration and management (PLOAM) cells. In the downstream direction, this block will extract these PLOAM cells from the flow of ATM cells received, in order to process the information they transport so that the APON system can execute proper actions. In the upstream direction, this block will also insert PLOAM cells, generated locally in the ONU, into the flow of ATM cells to transmit and communicate some events to the OLT.

The APON transport system block requires defining the limits of each ATM cell to process it correctly for the cell delineation module. Once ATM cell delineation is complete, and before extracting PLOAM cells from the rest of received cells, the ONU acquires synchronisation on the downstream frame defined in ITU-T G.983.1.

The main difference between these PONs and ATM-based PONs (APONs) is use of the well-known Ethernet protocol, in its gigabit Ethernet version, to carry the information between OLT and ONUs. The topology and principles of the EPON system's performance remain the same.

adapts this variable bitrate traffic into ATM cells.

ATM cells have various requirements based on the traffic they transport. To get a continuous flow of cells, you must multiplex both cells. This function is performed in the selected AAL1 unit, in which a higher priority is given to cells carrying information relative to voice due to the fact that jitter and delay requirements are stronger for this type of traffic. Finally, the flow of ATM cells is passed through the UTOPIA interface to the APON transport system block, in which PLOAM cells are locally generated in the ONU.

EPONS Vs APONs

The Ethernet-based PONs (EPONs) are a new standard. The main difference between these PONs and ATM-based PONs (APONs) is use of the well-known Ethernet protocol, in its gigabit Ethernet version, to carry the information between OLT and ONUs. The topology and principles of the EPON system's performance remain the same. Advocates of EPON claim that ATM is not appropriate for use in the access network because:

Compared to other solutions, PONs offer more bandwidth to provide a broad range of services, and more reliability due to the use of optical fibre.

1. Transporting the IP data traffic in ATM is quite inefficient, since it requires the segmentation of variable-length (up to a maximum of 1518-byte) data packets into fixed-length (53-byte) ATM cells. By contrast, Ethernet is tailor-made for carrying IP data traffic.

2. The available bandwidth in APONs is a maximum of 622 Mbps, which is smaller than the bandwidth available in EPONs (1.25 Gbps).

3. Ethernet is a widely used LAN protocol all over the world. If Ethernet were used in the access network, it would be unnecessary to convert between protocols as required in ATM.

EPONs will become a major rival to APONs because of their numerous advantages. This type of network will be particularly useful in communication environments in which nearly all the traffic between the OLT and ONUs comprises data. The successful adoption of EPONs in place of APONs will depend on the development of technologies like video over IP or voice over IP. APONs are more appropriate for use in environments offering an integrated service of voice, video and data to subscribers, mainly due to ATM's capability of providing a high degree of quality of service. ●

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