IP VIDEO TO THE HOME USING AN ETHERNET PASSIVE OPTICAL NETWORK

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One of the key challenges to Internet protocol (IP) video in the past has been the large amount of bandwidth needed to deploy it. Optical fiber is recognized as the most effective means for transporting voice, video, and data traffic; however, it is expensive to deploy and manage point-to-point (PP) fiber connections between every subscriber location and the central office. Ethernet passive optical network (EPON) is an emerging broadband fiber infrastructure that addresses the high cost of PP fiber solutions. Gigabit EPONs were also developed to address the shortcomings of asynchronous transfer mode passive optical networks (APON), which are inappropriate for the local loop as they are complex and expensive and lack sufficient video capabilities and bandwidth capacity. EPONs provide greater service capabilities and higher bandwidth at reduced costs. Though EPONs are in the early stages of development, they figure to become the primary means for delivering converged video, voice, and data over a single optical access system. This paper discusses the benefits, features, and technological foundation of EPON, in comparison with APON, as the best alternative end-to-end architecture for IP video.

The Case for IP Video Services

Video Delivery Options

Over the past few years, digital-cable and digital broadcast satellites (DBS) have created a new business revenue model for the television (TV) industry. Similarly, IP multicast has the ability to generate new revenue models for the Internet. There are many ways to deliver video to the home. Video delivery options to the home include the following: cable TV (CATV) over hybrid fiber/coax (HFC), DBS, digital cable over HFC with a set-top box, multi-channel multipoint distribution service (MMDS), IP video over digital subscriber line (DSL), analog video overlay over fiber, and IP video over optical EPONs. Despite this plethora of choices, the trend is toward convergence on two different layers (see *Figure 1*).

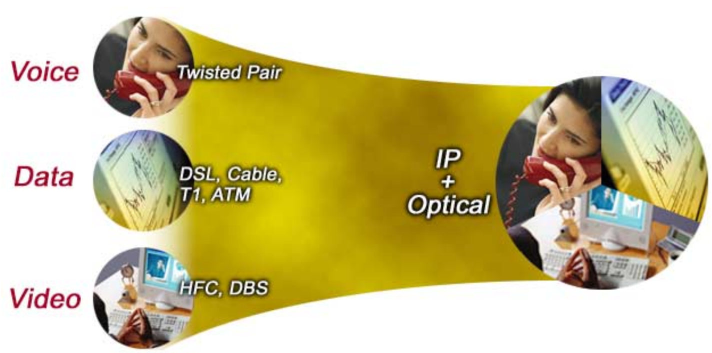

Figure 1: *Convergence of all Services over One Network*

In the first layer of convergence, three networks are converged into a single optical-fiber network. The second layer of convergence occurs in the IP layer. With the introduction of new services to IP, there is convergence to a single infrastructure on a single protocol. IP is thus the ubiquitous protocol for network convergence (see *Figure 2*).

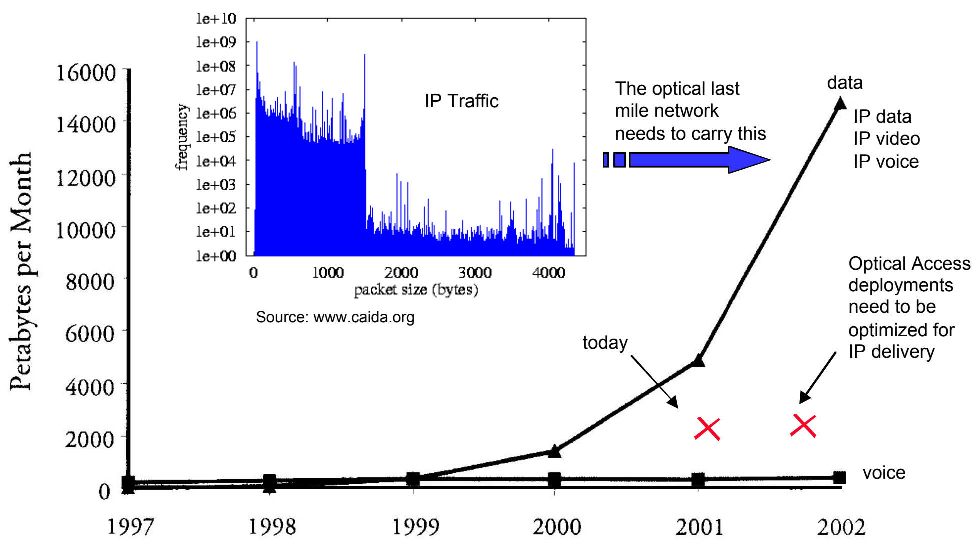

Figure 2: *IP Traffic Will Dominate the Last Mile*

Because of the increase in IP traffic on networks, service providers must be able to offer different types of services, such as video, data, or voice. Optical access deployments need to be optimized for IP delivery, and Ethernet is just that—a packet-based network, optimized to carry IP traffic.

Services Enabled by IP Video

IP video enables a growing number of services. Existing services for real-time video include broadcast and pay-per-view TV, and streaming video is an example of buffered video on the Internet. The simple act of adding bandwidth enables new video services. New services for real-time video include interactive TV, on-demand TV, videoconference, integrated Web content, digital TV (DTV), and high-definition TV (HDTV). New services in the buffered video space include personal videocassette recorders (VCR), time-shifted TV, and full-screen streaming video. Viewers can now enjoy interactive features of video, Web-based video, and services that allow them to watch programs at their convenience. The market for personal VCRs is growing at the moment because of TiVo boxes, which act locally or remotely in an IP video head-end. As this technology matures, more enablers will become available. Service providers benefit from IP video services, as it is easier to manage a converged single network for voice, data, and video. IP video services create multiple revenue streams, improved competitiveness, and a simplified network at reduced cost that is easy to manage, administer, and customize. IP video is in the process of becoming an incremental investment over data and voice, which are already in IP format, and it allows service providers to amortize the cost of broadband buildout over multiple services. IP video reduces provisioning costs for the service provider, as interactive media allows the subscriber to perform self-provisioning relatively easily. Converged networks minimize equipment and network management costs and eliminate the need to train a large number of technicians to maintain the network. The benefits of IP video services for the end user include more video services, better picture quality, bundled service packages, Web-enabled services, and ultra-fast Internet access. In addition, end users can choose from a large team of service providers to provide any service at any time.

EPON Primer

There are three primary ways to run fiber to a home. The first option is to establish PP links (see *Figure 3*).

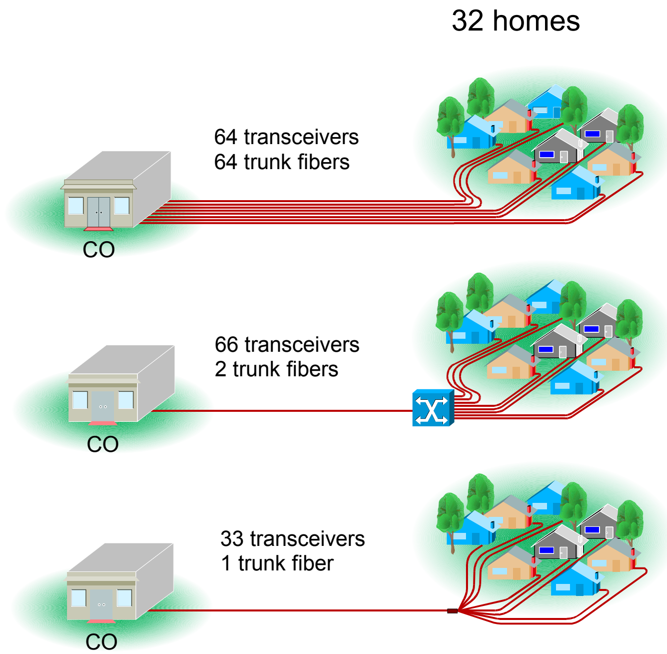

Figure 3: *PON—a Natural Step in Access Evolution*

In *Figure 3*, each of the 32 homes uses two fibers, which correspond to 64 transceivers and 64 trunk fibers. Convergence to a single fiber reduces the number of fibers and transceivers to 32 and 64 respectively. Because it is a fiber-rich infrastructure, companies have begun to install curb switches, such as Ethernet switches, in the network. A potential problem with these switches is that they require power, which creates a separate network with power needs. Using a curb switch reduces the number of trunk fibers; however, the number of optical transceivers is not diminished. The cost of curbside switch boxes is dominated by the cost of the optical transceivers. Therefore, the most logical solution would be to replace this box with an optical splitter to serve as a passive directional coupler. The optical splitter reduces the number of transceivers needed by nearly 50 percent and conserves fiber in the trunk, on the order of 1 to 64. PON is therefore a natural step in access evolution, as it simplifies the infrastructure and requires little maintenance.

PON Architectures

Bandwidth is increasing on long-haul networks through wavelength division multiplexing (WDM) and other technologies. However, there is a gap between metro-network capacity and the end user's needs, separated by this last-mile bottleneck. PONs respond to this last mile of the communications infrastructure between the service-provider central office, head-end, and customer locations. PONs are point-to-multi-point (PMP) networks, which have the capacity to downstream broadcast media to residential homes. The following figure illustrates PON architecture (see *Figure 4*).

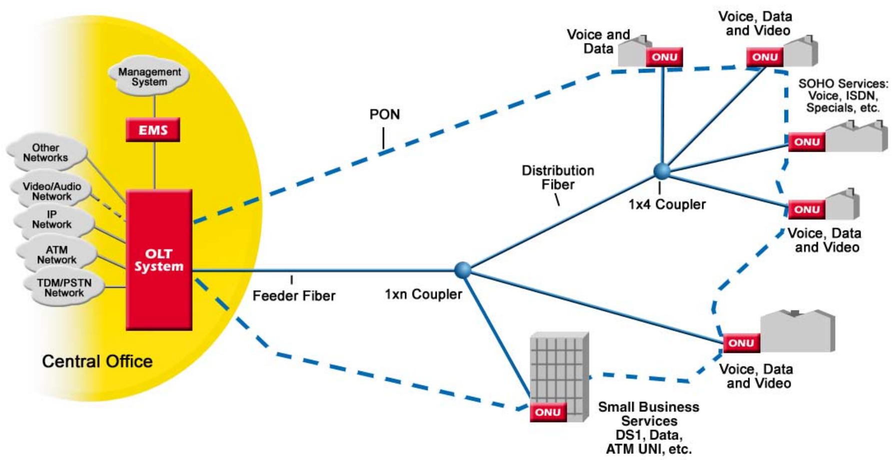

Figure 4: *PON Architecture*

There are some benefits to using PONs for video overlay. Although there is a cost to install an amplifier, which is shared by multiple locations, PONs are passive and eliminate all power in the field. The two primary types of PON technology are APON and EPON.

APON

APONs were developed in the mid-1990s through the work of the full-service access network (FSAN) initiative in the interest of extending high-speed services, such as IP data, video, and Ethernet over fiber, to homes and businesses. In APONs, protocol conversion is required for Ethernet. APON has been the traditional choice, especially the optical carrier (OC)–3, which has a bandwidth of 155 megabits per second (Mbps). In APONs, data is transmitted in fixed-length, 53-byte cells with a 48-byte payload. At the time that APON was developed, ATM was considered best suited for multiple protocols, and PON appeared to be the most economical broadband optical solution.

EPON

EPON was developed in 2000 and 2001 through the Ethernet in the First Mile

(EFM) initiative, the standardization effort of the Institute of Electrical and Electronics Engineers (IEEE). EPON was developed because the APON standard proved to be an inadequate solution for the local loop. EPON has a gigabit-per-second (Gbps) bandwidth and yields eight times more bandwidth than APON. While EPON offers greater bandwidth and broader service capabilities at reduced costs than APON, it has a similar fiber infrastructure. It is most effective to transport data, video, and voice traffic via fiber. However, EPON has a point-to-multipoint (PMP) architecture, which eliminates the need for regenerators, amplifiers, and lasers from an outside plant and minimizes the number of lasers required at the central office. Unlike PP fiber-optic technology optimized for metro and long-haul applications, EPONs respond to the needs of the access network in a simpler and more cost-effective manner. EPONs allow service providers to run fiber into the last mile at lower cost in order to provide an efficient, highly scalable, end-to-end fiber-optic network that is easy to manage. Ethernet has evolved significantly in the past 15 years, and everything about it has changed except the frame. *Figure 5* illustrates how Ethernet has evolved for metropolitan-area-network (MAN) and wide-area-network (WAN) applications.

	1985	2001
Speed	10 Mbps	10,000 Mbps
Cable	Coax	Fiber, CAT5
Network	Shared	Dedicated
Topology	Bus	Star
Protocol	CSMA/CD	Full Duplex PTP
Application	LAN	LAN + MAN + WAN
Distance	Building (m)	Metro (km)

Figure 5: *Ethernet Has Evolved for MAN and WAN Applications*

In EPONs, data is transmitted in variable-length packets of up to 1,522 bytes per packet in a 1,500-byte payload (according to the IEEE 802.3 protocol for Ethernet), distinguishing it from APONs. Ten-gigabit Ethernet (10 GbE) products had begun to appear in the market before standards. Ethernet has evolved into a different medium as a dedicated PP, full-duplex-type lens and is beginning to challenge metro networks and local area networks (LAN) quite rapidly. Ethernet also eliminates protocol conversion. An important industry objective is full-service fiber to the home (FTTH) for delivering data, video, and voice over a single platform. The first instances of broadband in the home appeared with the advent of DSL and cable modems. Ethernet acts as an end user for these boxes. The paradigm shift in the industry has occurred with the use of Ethernet as the ubiquitous broadband port with a registered jack (RJ) 45 connector (see *Figure 6*).

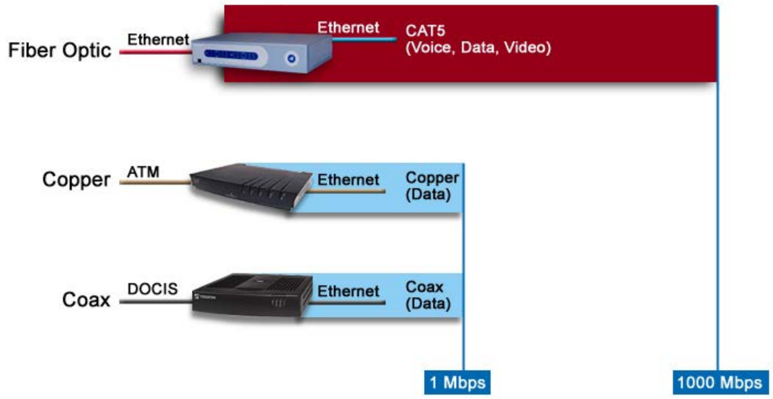

Figure 6: *Ethernet to the Home—the Only Choice*

With regard to these FTTH networks, there must be some consideration for the cost and size of these units. These boxes can be decoupled, leaving a simple box outside and another inside the home.

EPON Downstream

APON can only carry IP traffic by breaking packets into 48-byte segments, which is a time-consuming, complicated, and expensive task. EPON can carry IP traffic more effectively without overhead costs. In EPON the process of transmitting data downstream from the optical line terminal (OLT) to multiple optical network units (ONU) is different from transmitting data upstream from multiple ONUs to the OLT. EPON broadcasts data downstream to all ONUs, which use media access control (MAC) addresses to extract designated packets. *Figure* 7 illustrates the techniques used to manage downstream traffic in an EPON.

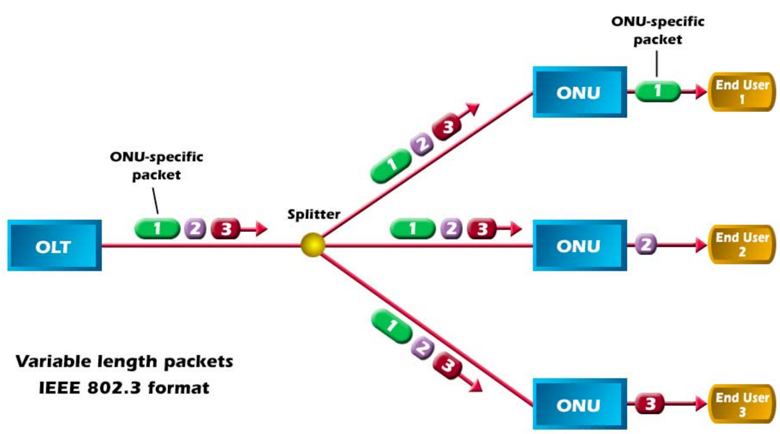

Figure 7: *Ethernet PON Downstream*

Data is broadcast downstream from the OLT to multiple ONUs, and each packet is able to designate the data to the appropriate ONU. The splitter divides the traffic into three separate signals, each one transporting ONU–specific packets. The ONU accepts only those packets that are intended for it and leaves the other packets for other ONUs. The process for EPON downstream is the same as it is for any shared-medium Ethernet LAN.

EPON Upstream

The transmission of data upstream over an EPON is largely the same as downstream transmission, with one key difference: ONUs transmit data upstream to the OLT in Ethernet frames with *ONU–specific time slots* to avoid transmission clashes. Statistical multiplexing is achieved by adjusting the size of a time slot to the amount of available data (see *Figure 8*).

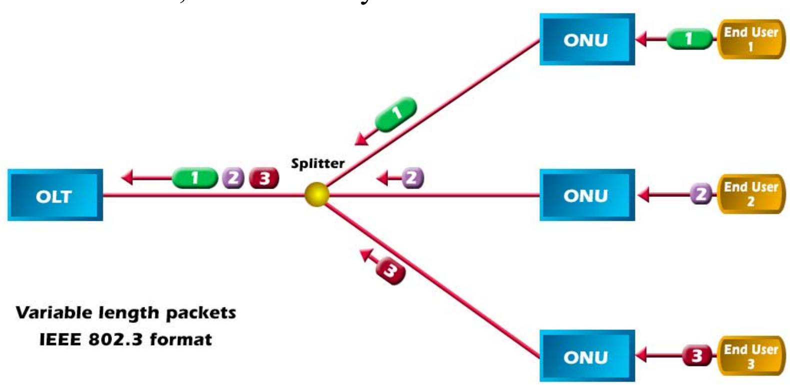

Figure 8: *Ethernet PON Upstream*

The time slots are synchronized to prevent upstream packets from interfering with one another once the data are joined to a common fiber. Each ONU has a separate time slot, the upstream traffic is divided into frames, and each frame is then separated into ONU–specific time slots.

Advantages of EPON for IP Video

EPON provides an Ethernet pipe that transports IP more effectively and at the lowest cost. It leverages off-the-shelf IP and Ethernet component solutions and a steep component cost curve. Ethernet is the most widely deployed network, with approximately 300 million ports worldwide; 80 percent of all networks in the world are Ethernet. LANs are approximately 95 percent Ethernet today, and have virtually eliminated all other networks including fiber distributed data interfaces (FDDI), asynchronous transfer mode (ATM), and token ring. Ethernet is a universal standard, with no variations. Another advantage of EPON for IP video is that it is scalable from LANs to MANs to WANs. Traffic is IP. Byte life begins and ends as IP and Ethernet, and cable and DSL modems have Ethernet interfaces. New competitive local-exchange carriers (CLEC), enterprise local exchange carriers (ELEC), and data local-exchange carriers (DLEC) can start with IP–centric networks. EPON is a plug-and-play environment with fewer arcane parameters. It is a reliable system with structured wiring and an optical plant that has management and troubleshooting tools. As equipment costs are decreasing, workforce costs are not coming down. EPON for IP video serves as a workforce solution, and many LAN technicians already understand and know how to work with Ethernet.

Quality of Service

There are cost and performance advantages to EPON as well, which allow service providers to deliver profitable service over an economical platform. There are a number of techniques that allow EPONs to offer the same reliability, security, and quality of service (QoS) as more expensive synchronous optical network (SONET) and ATM solutions (see *Figure 9*).

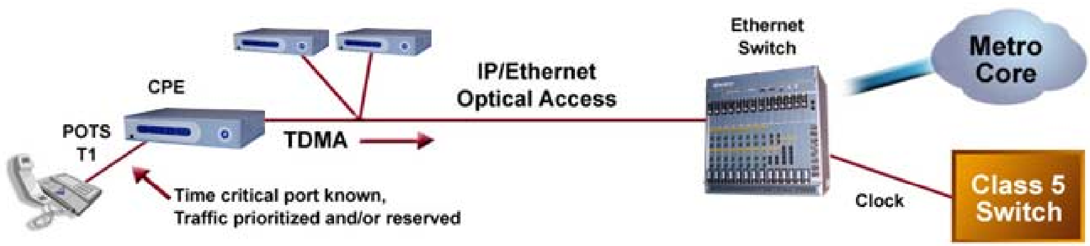

Figure 9: *Quality of Service*

The techniques include guaranteed QoS using type of service (ToS) field and differentiated services (DiffServ). Port-aware bandwidth reservation, queuing techniques, and traffic shaping are also necessary to guarantee QoS. Redundancy and security are other important aspects of QoS. Full system redundancy provides high availability and reliability. Diverse-ring architecture with full redundancy and path protection is another available element of EPON. Another important aspect of QoS is multi-layered security, such as virtual local-area network (VLAN) closed-user groups and support for virtual private network (VPN), Internet protocol security (IPSec), and tunneling.

How IP Video Works

A key element for successful IP video delivery is a high-bandwidth access network, such as GbE PON. High bandwidth is required to support high quality and also multiple channels being delivered to televisions in a household or a multi-dwelling unit. QoS, such as prioritization and bandwidth reservation and management, is another key element for successful IP video delivery. Another important factor is IP video processing, which includes video coding and compression, such as that defined by the moving pictures experts group MPEG–2 standard. A related video-processing standard, MPEG–4, provides features that are similar to those found in personal computer (PC) TV. A standard-definition quality TV (SDTV) will run at 2 to 12 Mbps in comparison, and a high-definition TV (HDTV) will run at 10–60 Mbps in compression. Another element of IP video processing is TV conversion, such as IP set-tops, home gateways and personal computers with traditional analog video output.

IP Multicast

IP multicast provides efficient delivery of selective broadcast IP TV by sending a single data stream (IP video channel) to multiple users simultaneously. IP multicast is more efficient than unicast as a protocol because it conserves bandwidth on the network. It sends only one copy of a channel regardless of the number of requests, and channels are forwarded only according to customer requests. IP multicast leverages broadcast features of PON (see *Figure 10*).

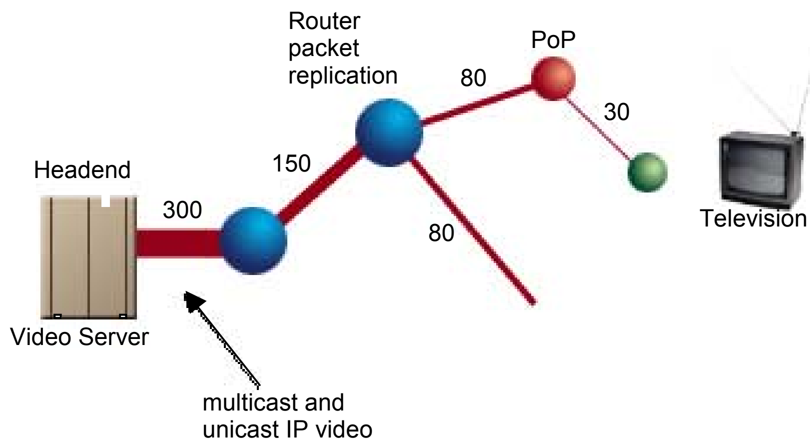

Figure 10: *IP Multicast*

For example, traffic, such as real-time video, comes in over broadcast satellite, and it might already be MPGEG-2 encoded or come in as off-air content. It passes through an encoder, which performs multiplexing and wraps it in IP packets. A stream flow of IP multicast is then released from the IP headend boxes.

End-to-End Architecture for IP Video

Customers are also interested in video on demand, which comes from stored video. Upon request, video servers send IP unicast traffic out to end user subscribers. A converged switch then processes multicast and unicast traffic. An example of end-to-end IP video-network architecture is shown in *Figure 11*.

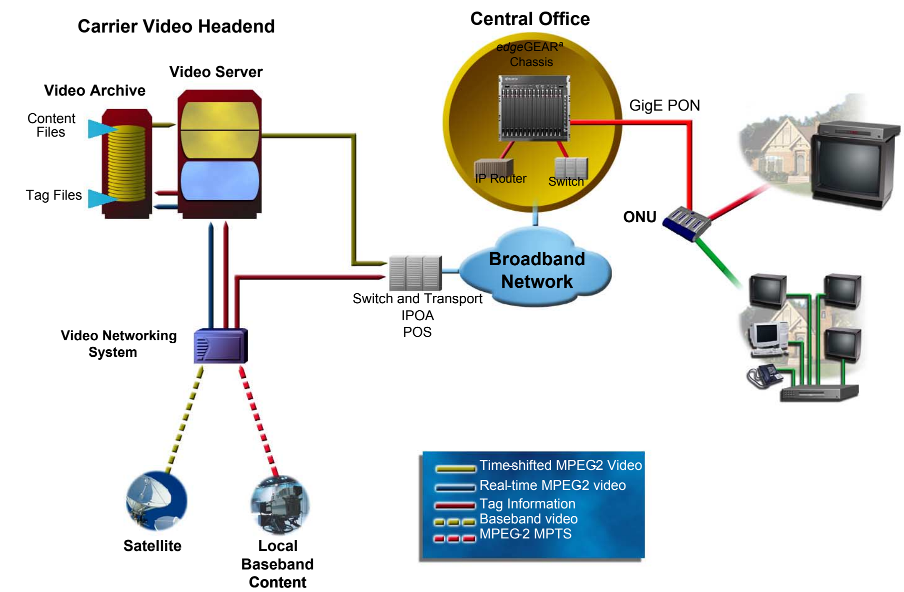

Figure 11: *End-to-End IP Video Network Architecture*

The Internet TV (ITV) manager is an important component, as it sends the menu and other elements to the set-top box. It interfaces with billing and orchestrates the workings of the IP head-end.

IP Video Head-End Equipment

IP video head-end equipment converts video content to packets and prepares it, adjusting bit rates for distribution across an IP video network. IP video head-end architecture is illustrated in *Figure 12.*

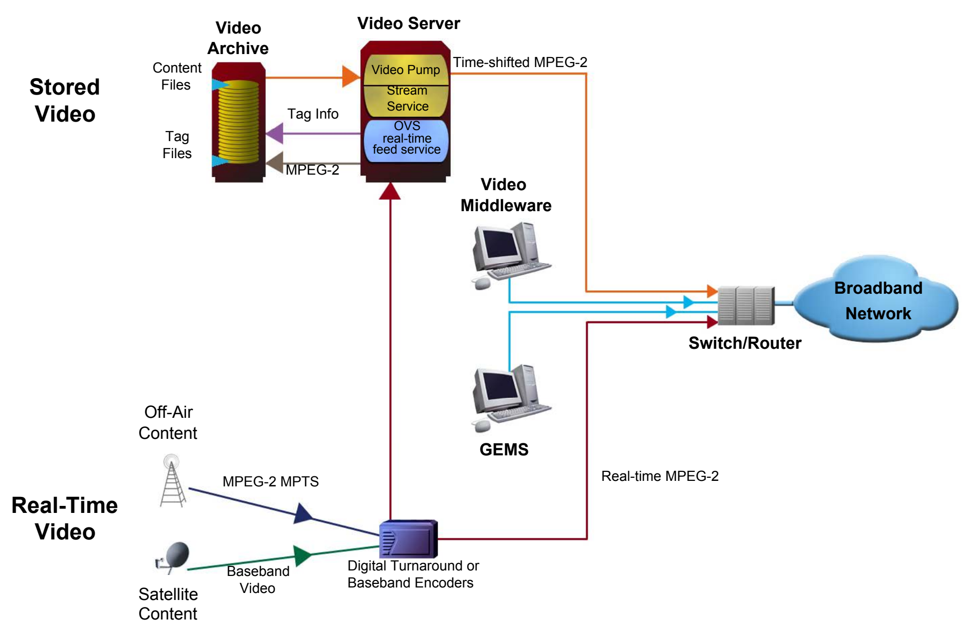

Figure 12: *IP Video Head-End Architecture*

IP video head-end equipment provides video content injection with real-time IP encoders and video servers, delivering satellite and off-air content to baseband encoders or digital turnaround. The video signals are then converted into individual MPEG packets, and video servers play out unicast video on request. Head-end equipment associates streams with unique IP multicast addresses. It also provides video content management through IP video middleware platforms and video customer premises equipment (CPE), which allows it to interface with video servers and billing systems. Head-end equipment authenticates and authorizes access to video content, and manages set-top boxes. Another important function of head-end equipment is its ability to provide video content distribution via core and metro IP multicast and unicast delivery. IP head-end culminates in the access network, which is a Gigabit Ethernet PON. IP multicast is a point-to-multipoint (PMP) network, which uses EPONs to deliver IP video. One key function of EPON is as a central office chassis that has a multi-service interface to the core WAN. It has a GbE interface to the PON with Layer-2 and Layer-3 switching and routing, and it handles QoS issues, service-level agreements (SLA), and traffic aggregation. Acting as a point to multipoint network, EPON splits optical signals traveling across a single fiber onto multiple fibers. It is a cost effective means of distributing high-bandwidth data, video, and voice traffic across the last mile of the network to customer-located ONUs (see *Figure 13*).

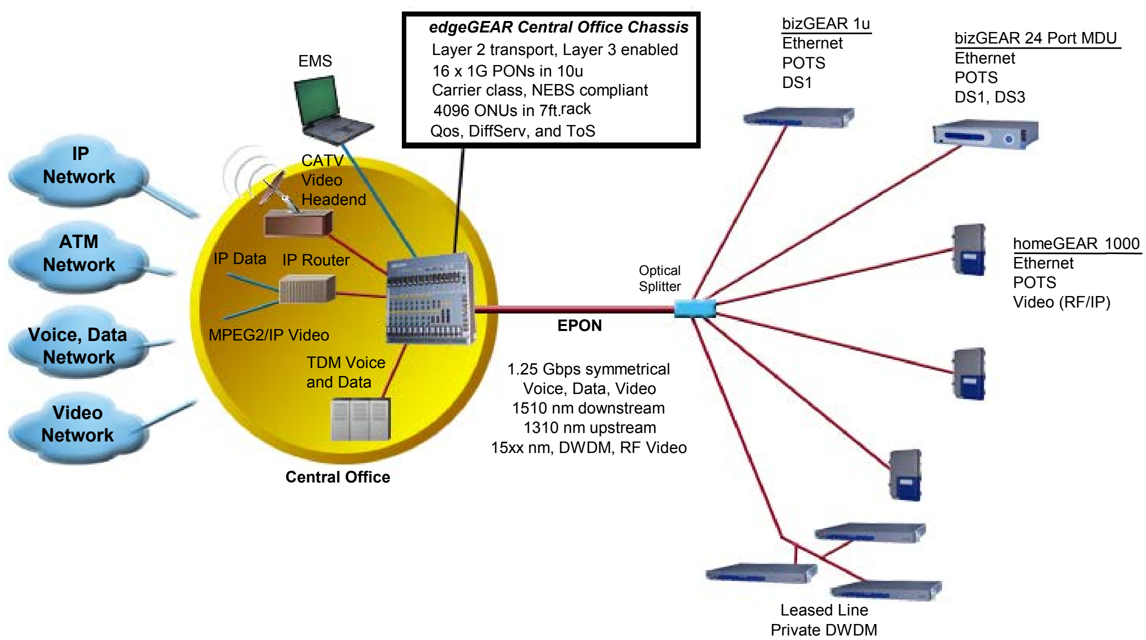

Figure 13: *Access Network and EPON Architecture*

Business and curb applications are possible with these types of networks, and it is possible to have up to 64 users on a single EPON fiber.

CPE

CPE includes ONUs, and a set-top box or a residential gateway. Traffic is received by the ONU, which acts as an interface between the EPON and a customer's data, video, and telephony equipment. It receives traffic in optical format and converts it to the customer's desired format. For example, an EPON ONU may have RJ11 POTs ports for voice, and RJ45 100 Mbps Ethernet ports for Internet access and IP video. The set-top box receives IP packets through a standard 10/100 Base T port and decodes the MPEG–2 stream for a single TV. In a sense, the IP set-top box acts like an Ethernet port, translating TV into a suitable format. A user can have a separate set-top box per TV or install a residential gateway that will connect to multiple TVs. The residential gateway decodes MPEG–2 streams for multiple TV sets and may offer value-added services (VAS). If a user receives 100 multicast streams, the ONU will only let one signal through to the TV, or up to four signals in the case of residential gateways (see *Figure 14*).

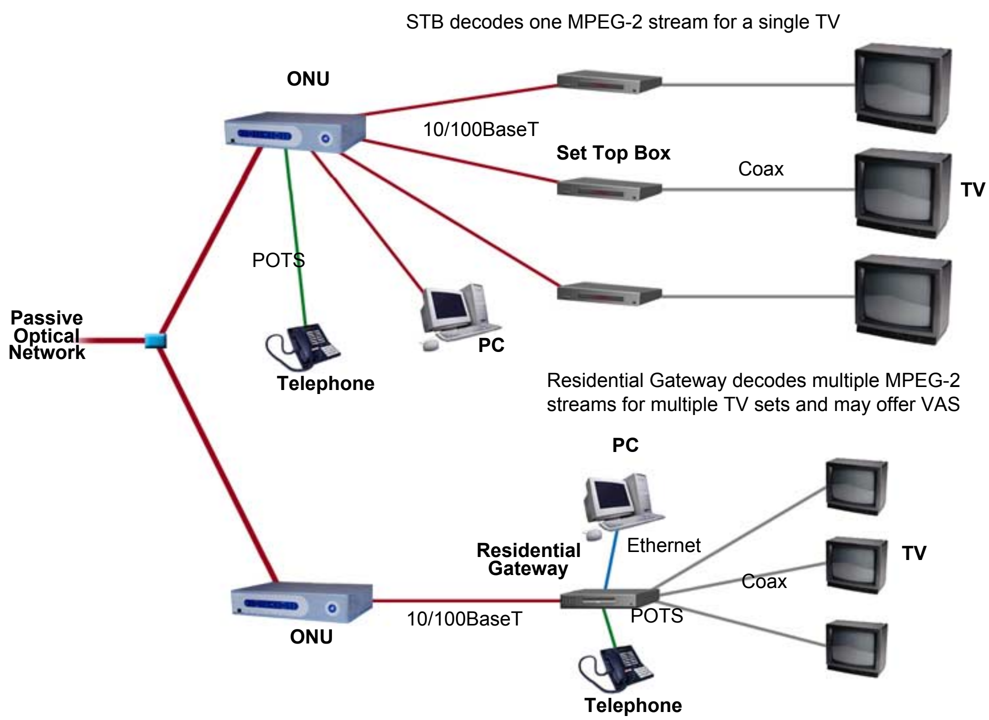

***Figure 14:** IP Video CPE*

The end user's experience is similar to watching CATV, as the IP streams, at around 4 Mbps, are indistinguishable from analog video.

Summary

IP format treats video as data and supports any type of TV service. It fits into a unified, single-network solution, though it requires significant bandwidth and QoS techniques. IP video enables integrated and interactive Web applications. EPON is an IP–based Ethernet broadband network, which delivers 1,000 times the speed of DSL or cable modems. EPON is available at a low infrastructure maintenance cost. It is scalable and designed to be a plug-and-play network. *Figure 15* provides an IP video demonstration to further illustrate the equipment being used.

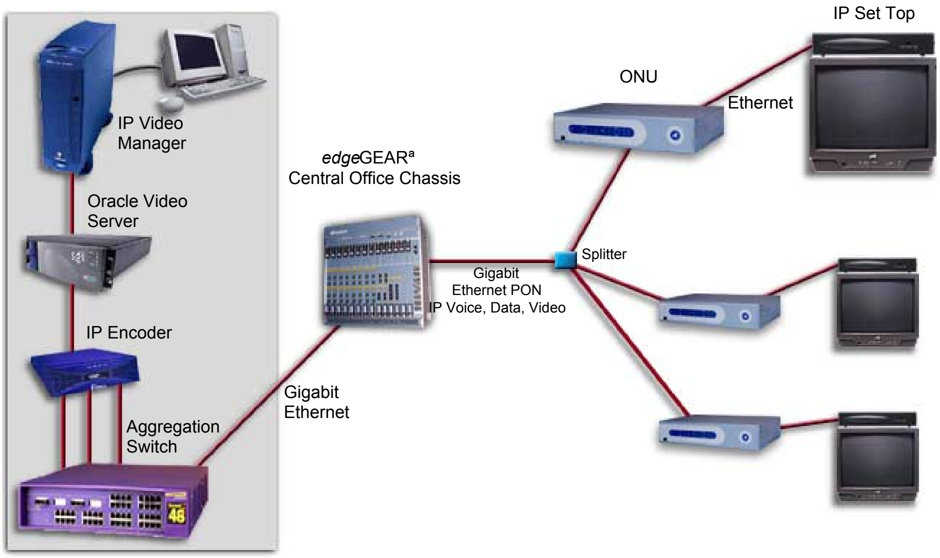

Figure 15: *IP Video over EPON Lab Demo*

The equipment includes IP set-top boxes, the ONU, and a box that sits in the local exchange. Servers store video, and encoders take real-time traffic and code it as IP. The aggregation switch gathers it together into a single GbE port and delivers it over the metro access. EPONs systems are in deployment/trials; a significant number of the trials underway will quickly migrate into full deployment. Many companies view this optical IP Ethernet architecture as the most effective means for transporting voice, data, and IP video services over a single network.