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Video over BPON with Integrated VDSL

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The next generation of access networks will be required to support a wide range of services, both narrowband and broadband, including broadcast video. While IP is the dominant technology at the network layer, ATM is the preferred technology for the data link layer because of its ability to support quality of service. At the physical layer, a hybrid architecture such as a BPON optical feeder and VDSL for the final drop offers a cost-effective solution for providing the necessary bandwidth. The Full Service Access Network group and the Full Service VDSL Committee are actively working to generate contributions to the International Standards bodies in support of BPON and VDSL respectively. This paper summarises the work of these groups and discusses solutions for the next generation of access networks with particular emphasis on support for video services.

1. Introduction

Access networks are entering a new era. Broadband services, including Internet and video, will become an important part of the overall service bundle and the network architecture needs to be optimised to provide the most cost effective solution for delivering this package.

IP (Internet Protocol) has become dominant at the network layer and an integrated approach using IP for both the Internet and video offers the opportunity of cost reduction. An architecture with IP over optics or IP over DSL (Digital Subscriber Line) may be the ultimate goal, however there are certain important features, such as quality of service which are of particular importance for video services, that are currently best provided using ATM. For this reason, it is anticipated that the next generation of access networks will incorporate ATM at the data link layer.

At the physical layer, the access network is still dominated by twisted copper pairs. Although optical access technologies have been developed and proven, the considerable capital costs involved in providing universal fibre connectivity has encouraged operators and vendors to explore the broadband potential of copper based solutions. Hence the considerable interest in xDSL technologies which are able to support a range of both narrowband and broadband services over copper.

Asymmetric Digital Subscriber Line (ADSL) technology is now considered to be mature and many operators are rolling out equipment into their networks. ADSL has a long reach (approximately 5 km) which means that most customers can be reached from a Digital Subscriber Line Multiplexer (DSLAM) co-located with a local switch. The transmission rates, however, are typically limited to about 2 Mb/s downstream and 640 kb/s upstream which limits the range of services that can be supported.

VDSL (Very high bit rate Digital Subscriber Line) is a new generation of xDSL and offers a higher bit-rate, plus support for symmetric applications. VDSL chipsets are now commercially available which offer a high degree of functionality and integration together with low power dissipation. The range of a VDSL system is dependent upon the line rate; typically a reach of 1 km is expected for a downstream transmission rate of between 14 Mb/s and 22 Mb/s. The DSLAM therefore needs to be located closer to the customer than for ADSL and will need to be supported by an optical feeder. A suitable candidate for this feeder system is the Broadband Passive Optical Network (BPON).

There are now two groups, the Full Service Access Network (FSAN) group and the Full Service VDSL (FS-VDSL) Committee, that are actively working towards solutions for next-generation access systems based on BPON and VDSL. Their aim is to generate contributions to the International Standards Organisations and to promote a multi-vendor environment.

This paper considers the work being undertaken within FSAN and the FS-VDSL Committee towards the design of next-generation access networks, with particular emphasis on the support of video services. A number of physical layer solutions are analysed and the role of IP and ATM are discussed.

2. Overview of BPON standards and FS-VDSL Committee activities

2.1 BPON with WDM overlay

The Broadband Passive Optical Network (BPON) defined by the Full Service Access Network group of operators and vendors,[1] together with ITU-T Study Group 15, is seen as a promising optical access network solution for the delivery of legacy and broadband services. The BPON, as defined in ITU-T Recommendation G.983.1,[2] focuses on two interface options, 155 Mb/s symmetrical PON interface, and 622 Mb/s downstream with 155 Mb/s upstream asymmetrical PON interface.

One of the market drivers for BPON is the economic delivery of video services to business and residential customers. The 155 Mb/s symmetrical PON will allow a limited number of MPEG-2 video channels to be delivered to either the Optical Network Unit (ONU) located in the access network or the Optical Network Termination (ONT) located at the customer premises. This scenario is typically point-to-point video channel delivery over the point-to-multipoint PON fibre network, such that a separate video channel is transported over the PON for each ONU. Such an approach quickly utilises the available bandwidth (at a rate of 4-6 Mb/s, or more, per MPEG-2 video channel) thus limiting the number of video channels that can be sent over the PON interface and consequently the number of customers that can be served. However, to compete with existing CATV operators, it is necessary to consider alternative methods of delivering a number of video channels far larger than can be carried over a 155 Mb/s symmetrical PON.

One method is to use the asymmetrical 622 Mb/s downstream option defined in ITU-T G.983.1. This approach would provide up to approximately one hundred 6 Mb/s video channels, which equates to three video channels per household on a 32-way split Fibre to the Home (FTTH) PON. (Note that this does not allow much headroom for data services.) To allow for situations where it is required to deliver a larger number of video channels per customer, the FSAN OAN group has defined a Wavelength Division Multiplexed (WDM) overlay solution that is defined in the ITU-T Recommendation G.983.3.[3]

G.983.3 specifies an Enhancement Band (EB) of between 1539 nm and 1565 nm which allows the use of wavelengths in addition to those specified in G.983.1, both downstream and upstream, between the OLT and ONU (**Figure 1**). There are two EB options 1539 nm-1565 nm, and 1550 nm-1560 nm, which can, for example, be used for Dense Wavelength Division Multiplexed (DWDM) and Broadcast Video services respectively, although their use is not restricted to these examples. The wavelength window specified in G.983.1 has been compressed to the range of

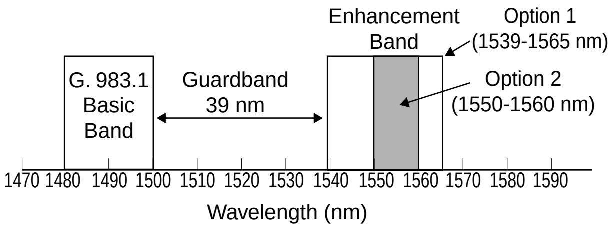

Figure 1
ITU-T G.983.3 wavelength allocation for basic and enhancement bands.

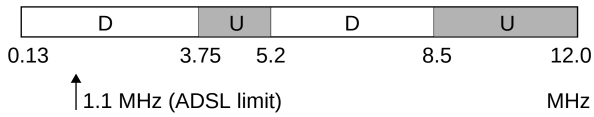

Figure 2
VDSL Plan 998.

1480 nm to 1500 nm in G.983.3. This is now referred to as the Basic Band (BB).

The use of the EB wavelengths is not specified, meaning that any services can be transmitted over the additional wavelengths provided that there is sufficient isolation between the EB and BB at the receiver. One possibility is for video services to be transmitted downstream over a single wavelength within the EB. The video channels could be sub-carrier multiplexed, in the same manner as for CATV delivery, or they could be carried within the payload of a SDH/SONET connection. Both methods allow a large number of video channels to be shared amongst all users. It is likely that the sub-carrier multiplexing method will be the more economic delivery method for FTTH applications, as it is akin to the cost-effective CATV HFC methods that are employed by most CATV networks around the globe. Both the sub-carrier multiplexing and SDH/SONET delivery solutions are considered below in more detail.

2.2 FS-VDSL Committee

VDSL is under study within ITU-T SG15 (G.vdsl), ETSI (TM6) and ANSI (T1E1). However, the body that is actively progressing VDSL issues in the area of a full end-to-end system specification primarily focussed at video applications, is the Full Service (FS)-VDSL Committee.

The FS-VDSL Committee[4)] was formed as a sub-committee of FSAN to promote standardisation, implementation and deployment of a full-service network which would economically deliver an attractive bundle of services including video, high speed internet and voice to the consumer and Small and Medium-sized Enterprise (SME) markets. The FS-VDSL Committee, although comprised mainly of telecommunications operators and equipment vendors, is an open organisation, which does not restrict membership.

Both ETSI and ANSI have agreed upon two frequency plans for VDSL. The frequency plan adopted by the FS-VDSL Committee is known as Plan 998. **Figure 2** shows the Upstream (U) and Downstream (D) frequency bands and also the upper limit of possible interference from ADSL signals.

Frequency Plan 998 was chosen by FSAN as it is optimised for asymmetrical data rates and is therefore better suited for video distribution applications. In this case there is no problem with a reduced upstream data capability. The alternative Frequency Plan (Plan 997) is better suited to VDSL applications that require symmetrical data rates. (Note that the two frequency plans (997 & 998) are spectrally incompatible and it is expected that the decision for a VDSL frequency plan will need to be made at a national level.)

3. BPON-VDSL solutions for video delivery

This section discusses physical layer solutions using BPON and VDSL capable of supporting broadcast video services.

3.1 Solution based on G.983.1 PON interface

Figure 3 shows the configuration of a system that was assembled to provide a demonstration during the WTC/ISS2000 conference in the UK (7th-12th May 2000). The system

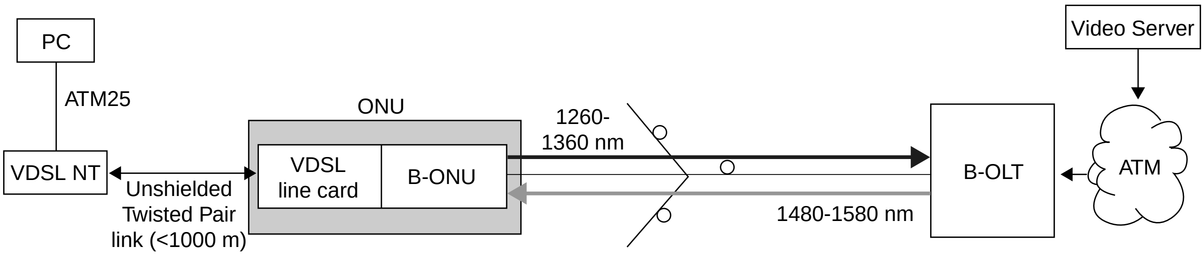

Figure 3
Baseband video delivery.

demonstrated the transport of MPEG-2 video data from a video server, across an ATM PON network, and finally delivered to a PC via an integrated VDSL solution. Encapsulated video data was successfully delivered across the BPON/VDSL link at various bit rates up to a maximum value of 7.3 Mb/s. The demonstration system is similar to the Basic Band solution (except for the wavelengths used) where the video is delivered over the 155 Mb/s symmetrical G.983.1 PON interface.

One of the key features of the system as shown in Figure 3, was the integration of a VDSL line card into the BPON ONU.[5] This line card has a single line of VDSL and an image of the line card is shown in **Figure 4**. The VDSL line card contains an integrated POTS splitter and thus the two main interface ports visible in the figure are the connection to the VDSL line (RJ45) and the connection to the narrow-band services (RJ11). Ports are also included for local management purposes.

The VDSL line card was developed in accordance with FSAN recommendations, ETSI requirements and the emerging ITU-T and ANSI VDSL standards and has the following key features:

- Single-carrier QAM modem.
- Frequency Division Duplexing with one carrier per direction of transmission.
- Blind training for fast start-up (< 150 ms).
- Spectral flexibility for operation in different environments (Frequency Plan 997 or 998) compatible.
- ATM or clear channel operation for support of new data networks.
- Symmetric or asymmetric operation (up to 10.12 Mb/s in either direction).
- Power back-off for support of mixed services.
- 512 cell buffer in both transmit and receive directions.
- Recognition of up to 20 arbitrary ATM connections.
- Four arbitrary ATM connections dedicated to OAM/DCC purposes.
- ATM cell insert/extract mechanism for OAM/DCC purposes.

Figure 4
VDSL line card for BPON ONU.

Higher VDSL line densities will be possible when multi-channel chipsets become available. It is expected that octal density ONU VDSL chipsets (designed to operate to Frequency Plan 998) will become available during 2002.

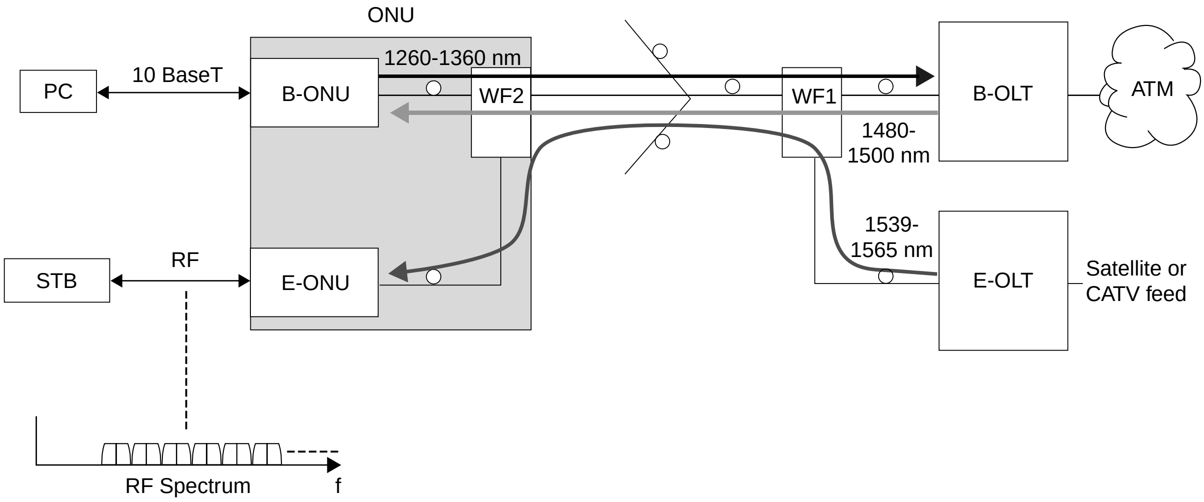

Figure 5
Enhancement band BPON.

3.2 Enhancement Band BPON

The Basic Band (BB) video delivery solution is restricted in the number of video channels that can be transported, especially if the PON interface is also being used to transport data services. The alternative is to use the Enhancement Band (EB) as a video-delivery overlay to the ONU/ONT. An outline of this solution is given in **Figure 5**.

The Enhanced Optical Line Terminal (E-OLT) transfers the satellite or Cable TV feed onto the PON using a wavelength between 1539 nm and 1565 nm. This is combined with the Basic Optical Line Termination (B-OLT) output, 1480 nm-1500 nm, using the WDM function WF1. At the ONU the EB wavelength is separated from the BB wavelength by using the WDM function WF2, and optically terminated at the Enhanced Optical Network Unit (E-ONU). The electrical RF signal is then output from the E-ONU.

By providing a CATV-like sub-carrier multiplexed video delivery, it is possible to utilise existing Set Top Box (STB) technology, with RF interfaces, to provide the customer premises equipment solution. For new network deployments this appears to be a future-proof solution, with the fibre infrastructure acting as a pipe for future services, where the bandwidth capacity is limited only by the optical technology placed at either end.

3.3 Enhancement band BPON with integrated VDSL

The Enhancement Band BPON can be used together with VDSL where the final drop uses existing copper wiring. An integrated BPON - VDSL solution raises many issues when delivering video using the EB, such as how the video is transported over the EB wavelengths, should more than a single EB wavelength be used, where is channel selection performed? One advantage of integrating VDSL with EB-BPON is that it allows many more customers to be fed by each BPON interface, as the DSLAM can provide many DSL lines per ONU-DSLAM.

In the following only transport over one EB wavelength is considered, furthermore it is assumed that channel selection takes place at the ONU. Two possible system solutions are described, the first uses Sub Carrier Multiplexing for transport of the video signals over the BPON and the second uses SDH/SONET transport.

3.3.1 CATV overlay – Sub-Carrier-Multiplexed (SCM)

The first BPON-VDSL scenario considered is the CATV-overlay solution, which is outlined in

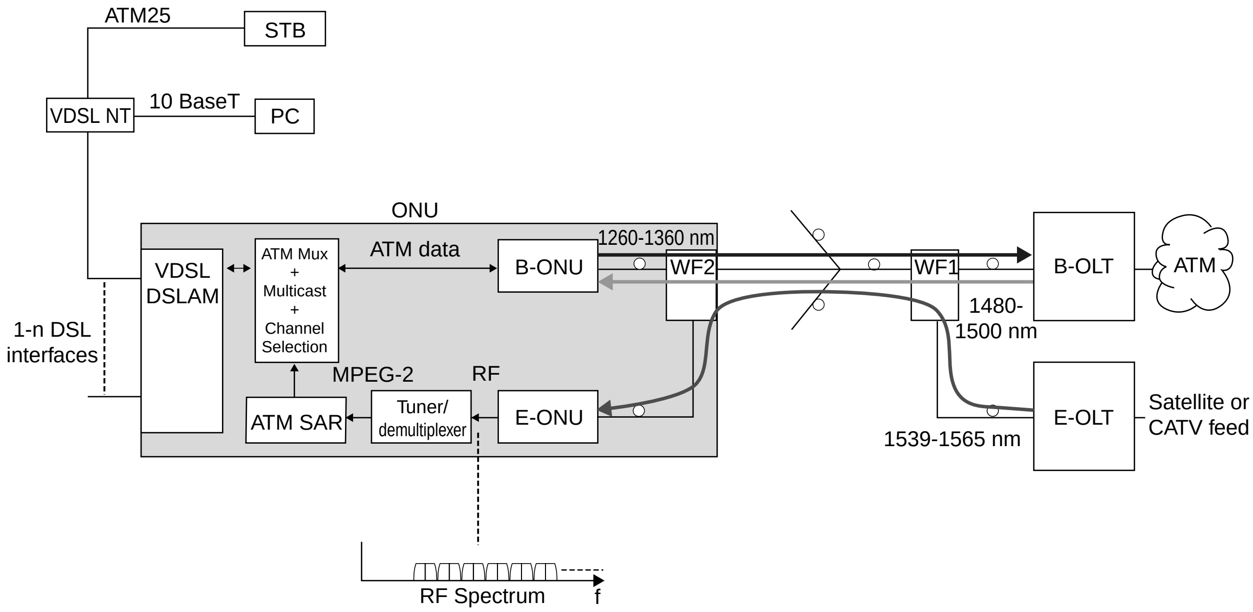

Figure 6
WDM overlay MPEG-2 over SCM video delivery.

Figure 6. Here multiple MPEG-2 channels are Sub-Carrier-Multiplexed (SCM) into a RF spectrum, which is transferred over a single wavelength to the E-ONU.

Once the E-ONU has terminated the EB wavelength, each MPEG-2 channel can be demultiplexed from the RF SCM spectrum and encapsulated into ATM before being passed to an ATM multiplexer. A multiplexer, which includes an ATM multicast function, is the ideal location for the channel selection function to allow multiple DSL customers to receive the same video channel. This means that only a single version of a video channel needs to be sent from the E-OLT to the E-ONU, thus providing efficient usage of the EB bandwidth. The ATM video channel is then passed over the appropriate VDSL line to the VDSL NT where the channel is routed to the STB for decoding.

The SCM technique for CATV overlay has an advantage if the video signals originate from a satellite or CATV video multiplex, as no conversion is then required at the OLT. The disadvantage of this approach is that the signal needs to be reformatted at the E-ONU. Video channels need to be selected and converted into ATM cells for multicasting and transporting over the VDSL link.

3.3.2 CATV overlay – SDH/SONET

The CATV Overlay SCM method appears quite complex, as it requires tuning, de-multiplexing and ATM SAR functionality at the ONU location. An alternative solution to the SCM RF solution is to use an ATM-over-SDH/SONET connection to transport the MPEG-2 channels over the EB wavelength. Instead of ATM, IP may also be used to transport the MPEG-2 video channels, over SDH/SONET or other transport technologies such as Gigabit Ethernet.

The delivery of an ATM-over-SDH/SONET connection over the EB removes the requirement for a tuning function, a de-multiplexing function and an ATM SAR functionality in the ONU. This solution is outlined in **Figure 7**. The capacity of the ATM multiplexer, the requirement for channel selection and the requirement for multicasting functionality is the same as for the CATV Overlay (SCM) solution. The video delivery over VDSL to the customer premises equipment would also be the same.

The SDH/SONET technique transports vid-

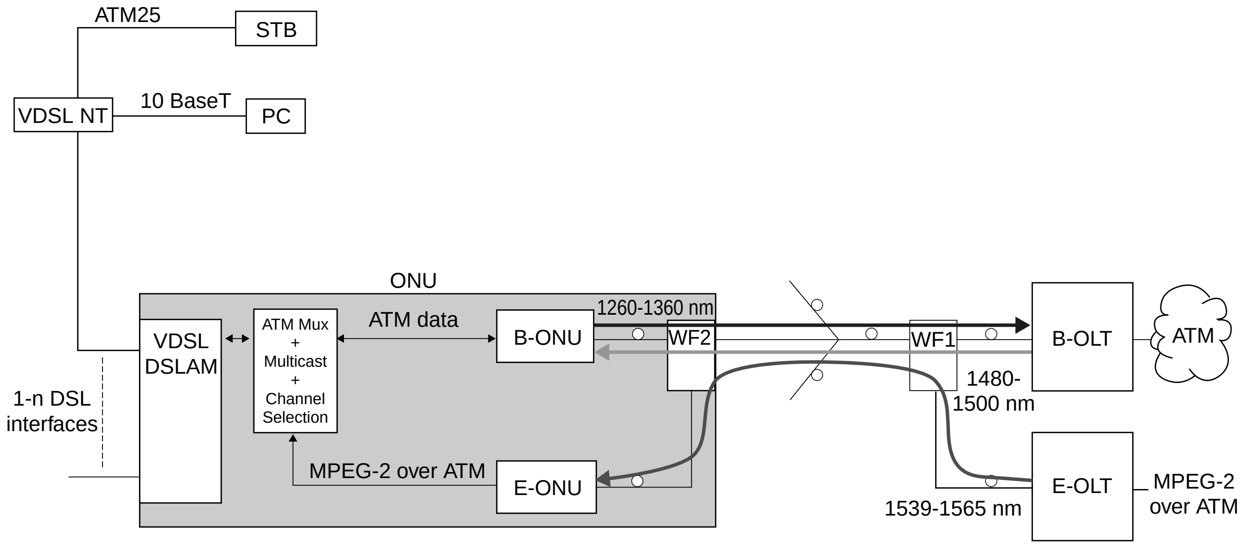

Figure 7
WDM overlay MPEG-2 over SDH/SONET video delivery.

eo channels in ATM format from the E-OLT to the ONU. This has the benefit that tuning and ATM cell Segmentation and Re-Assembly (SAR) are not needed which reduces the complexity of the ONU. This approach requires the video information to be in ATM format at the E-OLT. If the video signals originate from a video server then no conversion will be required, but if the video is taken from a satellite or CATV source, then conversion to ATM at the E-OLT is required.

The OLT is less cost sensitive than the ONU because it is shared between a larger number of customers. The SDH/SONET approach therefore has an advantage because conversion to ATM takes place either at the video source or at the OLT.

4. Role of IP for video delivery

IP has become the dominant network layer protocol for data services. In a full service network, it may be possible for the service provider to offer a more competitive service package if the video services are also IP based, as there are potentially cost savings through integration.

A full IP solution (IP over optics or IP over DSL) may eventually provide the solution to multiple-channel video distribution. Quality of Service is a key issue for video services; currently this is best supported using ATM because IP standards for Quality of Service are still immature.[6] Hence, a network solution using ATM at layer 2 is most suitable for next-generation access networks. This also allows for specific services requiring a direct access to ATM (e.g. Voice over ATM).

There are many protocol options that can be considered for the delivery of IP services over ATM networks, including PPPoE (Point-to-Point Protocol over Ethernet) and PPPoA (Point-to-Point Protocol over ATM). PPPoE appears to provide a more flexible solution than PPPoA due to the fact that multiple PPPoE sessions can be carried within a single ATM connection thus simplifying ATM management requirements, and that an Ethernet based home network solution is more likely in the immediate future.

The delivery of IP-based video services over ATM using PPPoE requires consideration of the following issues:

- User authentication and service-access authorisation: The user authentication and service-access authorisation can be realised using Remote Authentication Dial In User Service (RADIUS), which provides Authentication, Authorisation, and Accounting (AAA) functionality for IP networks.

- Video-channel duplication functionality in the access network to provide efficient usage of bandwidth resources: The mechanism for video-channel duplication can be performed by strategically placing IP-multicast functions at the ONU and OLT.
- User control of channel selection: The IP-multicast functions can be controlled by the user for channel selection using a protocol such as Internet Group Management Protocol (IGMP) version 2, see Reference 7).

Figure 8 shows a realisation of an end-to-end IP-video delivery solution, using a Broadband Access Server (BAS) to terminate the PPPoE sessions and to make the IP connection to the appropriate Video Service Provider (VSP). As well as identifying the network elements involved, Figure 8 also identifies the protocol stacks used at the various points in the network for the following functionality:

- Channel selection: using IGMP. This assumes that multicasting only occurs at the ONU and the VSP, although additional multicasting points are possible, such as at the OLT.
- Broadcast Video delivery: using IP multicast.
- Video on Demand (VoD) delivery: using IP unicast.

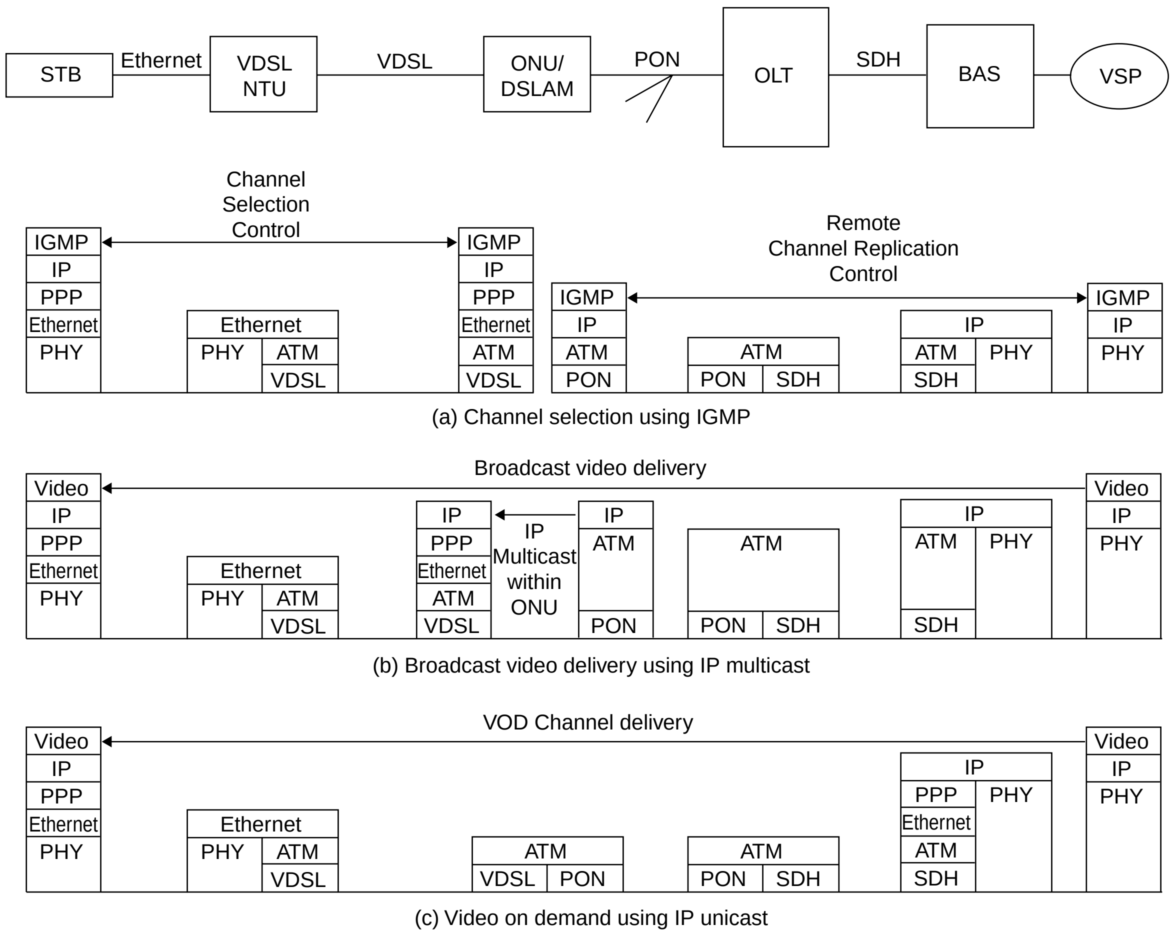

Figure 8
Example protocol stacks for the support of IP-Video services.

The solution detailed in Figure 8 implies that IP-multicast functionality and user-signalling termination must be supported in the ONU. A management channel is required between the VSP and the ONU to control broadcast video access on a user-by-user basis, e.g. for channel subscription verification, parental control restrictions etc. IP-multicasting is not required in the access network for Video-on-Demand (VoD) services as the VoD stream is dedicated to each individual user.

The IP-based video services can be supported by the in-band PON delivery solution described in Section 3.1 by delivering IP-video over ATM connections. It is also feasible to deliver the IP-video channels using the enhancement band PON solutions described in Sections 3.2 and 3.3.

5. Conclusions

This paper has considered the design of next-generation access networks capable of supporting a wide range of services including broadcast video. BPON integrated with VDSL offers a cost-effective solution for delivering both video and data services without the need to replace the copper wiring into the customer premises. FSAN and the FS-VDSL Committee are actively promoting these technologies and encouraging a common approach to the standardisation process. An enhancement band to support video services has now been standardised by ITU-T for BPON. It is anticipated that IP will be the network layer protocol. It is already widely used for data services and there are potential cost savings if IP is also used for digital video services. This paper has provided an example of how video services can be delivered using IP over ATM with PPPoE. Although a 'full IP' solution may eventually emerge (IP directly over optics or DSL), IP over ATM is considered the preferred choice for next-generation access networks as the technology is more mature and can provide the required Quality of Service.

Ultimately, the best solutions (for there may be more than one) for an operator are specific to their particular deployment scenarios. A balance must be met between installation costs, equipment capabilities, greenfield vs. brownfield sites and the types of service mixes to be delivered to the customer.

References

1) FSAN Web site: *http://www.fsanet.net*
2) ITU-T Recommendation G.983.1: Broadband Optical Access Systems based on Passive Optical Networks.
3) ITU-T Recommendation G.983.3: A Broadband Optical Access System with increased service capability by wavelength allocation.
4) FS-VDSL Web site: *http://www.fs-vdsl.net*
5) I. R. Cooper and M. A. Bramhall: ATM Passive Optical Networks and Integrated VDSL. *IEEE Communications Magazine*, pp.174-179 (March 2000).
6) N. E. Anderse, A. Azcorra, E. Bertelsen, J. Carapinha, L. Dittma, D. Fernandez, J. K. Kjaergaad, I. McKay, J. Maliszewski, and Z. Papir: Applying QoS control through integration of IP and ATM. *IEEE Communications Magazine*, pp.130-136 (July 2000).
7) IETF RFC 2236: Internet Group Management Protocol, Version 2.

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