ENABLING MULTICASTING FOR ACCESS NETWORKS

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Abstract

This paper focuses on establishment of multicast mechanisms in Access Networks (AN). Multicast is deemed to be an appropriate instrument to relieve communication networks, to save resources and, therefore, to improve global network performance. Multicast mechanisms are analysed and evaluated for their usage in Access Networks. The general structure of an Access Network and necessary measures to design multicast-capable Access Networks are described. In addition, the complexity of new embedded multicast functions is discussed, and effects by unicast and multicast connections on Access Network are exemplified. As a result, a design suggestion of a multicast-capable Access Network is given.

1 Introduction

Modern communication networks will be used more and more to transmit multimedia content like audio and video streaming e.g. Broadcast TV in addition to web browsing, e-mail or file transfer to customer premises. In addition the penetration rate of xDSL-based high speed Internet access is expected to rise in the next years. In this context, these bandwidth-intensive multimedia applications need advanced and new functionality, respectively, in the underlying communication networks and systems. The requirements and effects on broadband ANs are analysed and evaluated in this publication. Multicast is assumed an adequate instrument to reduce the number of simultaneous data streams and to meet the growing demand. This analysis suggests locations and devices within the AN where new multicast functionality should be placed. Advantages and drawbacks of several options are analysed, demonstrating the necessity, benefit, and feasibility of multicast.

1.1 Motivations for Multicasting

Multicast can be defined as sending the same data to several receivers, a group. In this process packets should be sent only once over the same link and only if there are receivers at this path. Furthermore, multicast solutions have to be scaled well to work with many receivers. The general motivation to use multicast is to save network resources like bandwidth and to relieve network equipment of switching packets. Thereby, switching delay can be reduced and, thereby, end-to-end delay is decreased without increase in throughput in network equipment. Thus, data reach their receivers faster in average, compared to the same amount of data sent as unicast. Another point of view is the delay caused by sending the same data multiple times in case of unicast, compared to multicast. If unicast is used it will be possible that data reach several receivers in very different time. Service classes such as video conferencing could be strongly affected by this. For these reasons, multicast is particularly advantageous for large groups with many receivers and for large amounts of data. Example applications for this aspect are Broadcast TV or Radio or Video on Demand.

1.2 Ethernet and IP Multicast survey

Ethernet as a medium with shared access is well suited for multicast communication. If one frame passes the line, in case of bridged networks every connected network adapter will detect it and will be able to receive it. In switched networks, layer 2 switches separate connected adapters and transmit the frames to its ports. Because Ethernet is a medium for transporting network layer datagrams such as IP and multicast communication is also supported in IP, an address mapping for IP multicast addresses into Ethernet multicast addresses shall be provided. Figure 1 shows the respective mapping.

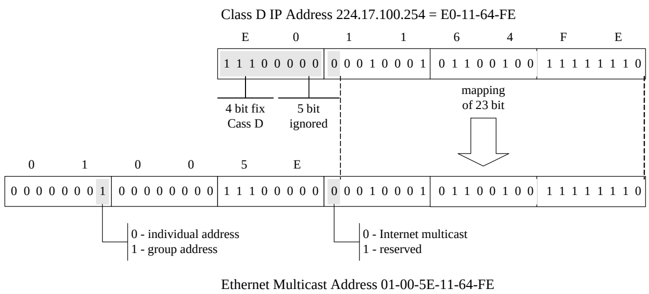

Figure 1: Mapping of IP to Ethernet Multicast Addresses

In the IPv4 address space a class D address block 224.0.0.0/4 is reserved for IP multicast. This one is further divided into several blocks, e.g. the 224.0.0.0/24 assignment for “Local Network Control” or 224.0.1.0/24 for “Internetwork Control” [4]. Furthermore, several addresses are predefined [5].

There are different hierarchical areas of multicast communication. The first one is the LAN section. Multicast data which are transmitted from a host to its designated multicast router or forwarded into the LAN by a multicast router are encapsulated and transported by Ethernet frames. If two network segments are switched the layer 2 network equipment has to be able to distribute multicast frames to all ports feeding corresponding receivers. Thus, the layer-2-switch must analyse the frames to recognise IGMP (Internet Group Management Protocol) [6] messages and temporary store these information for every port. This is called IGMP snooping. IGMP is very important for management of host's group memberships. There are three versions of IGMP. Version 2 [7] is still dominating as version 3 [8] has become an Internet standard only recently. Table 1 summarises the varieties.

message	IGMPv1	IGMPv2	IGMPv3
general-query	x	x	x
report	x	x	x
group-specific-query		x	x
leave-group		x	x
group-and-source-specific-query			x

Table 1: IGMP Versions

The second area is the routing section. Multicast routers are responsible for retrieving requested groups and relaying received data of this groups. They exchange information with other multicast routers. Multicast routing protocols establish a distribution tree such as a spanning tree, a source-based tree, or a shared tree between them. Multicast data travel along this tree. Replication takes place at its nodes. Protocols are divided into two main groups, dense mode (DVMRP [9], PIM-DM [11]) and sparse mode (PIM-SM [10], CBT) protocols.

Inside a multicast domain usually only one multicast routing protocol is used. Routers are used at the edges of a domain to route multicast data between different domains. This is the third area of multicast communication. Temporary inter-domain multicast routing protocols like Multicast Source Discovery Protocol exist. However, a standard-based protocol will be available with BGMP [12] for the first time.[1][2][3]

2 Structure of an Access Network

The following section describes the part of the AN which provides broadband access to IP networks for subscribers. The other function of AN, the POTS (Plain Old Telephone Service) network or ISDN (Integrated Services Digital Network) is not described here [1]. Figure 2 shows the fundamental structure of such network. The borders of an AN are represented by a network termination – NT (Network Termination), together with a splitter, at the subscriber side and a network access server – NAS – at the core side. Components within the AN are called optical network unit – ONU – or optical line termination – OLT, respectively. Beside a multiplexer, the ONU consists of several line cards. Each line card concentrates a number of subscriber interfaces. Customer's data are forwarded to the OLT after they are multiplexed. The OLT concentrates several ONU lines and switches data to a NAS or router.

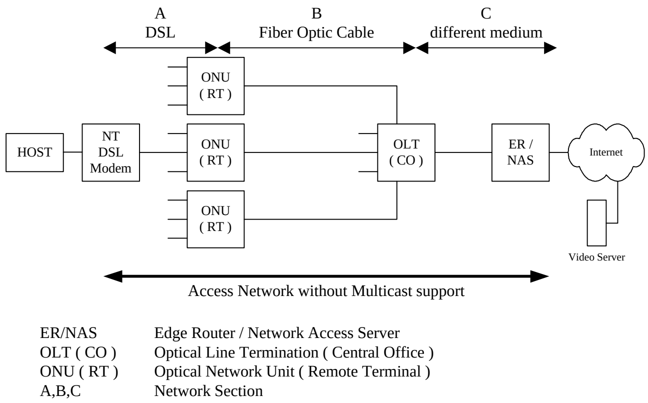

Figure 2: General Structure of an Optical Access Network

Within the last few years, a partial substitution of the copper wiring by fiber optic cable took place. These measures were carried out in the area of today's OLT and ONU. Hereby, network performance is improved, higher data rates are possible, a larger number of subscribers can be attached and large distances can be bridged. Use of xDSL and the possible rates of transmission depend fundamentally on the length of copper wiring. Therefore, length reduction of copper wiring is especially important. Fiber optics, including optical lines towards buildings, will provide for longer reach.

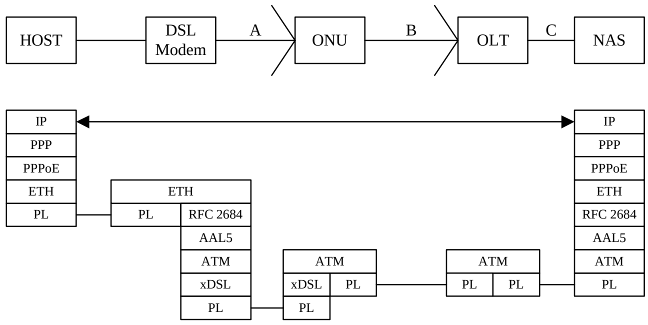

Figure 3: Access Network - ATM Based

At the fiber-based section B currently ATM (Asynchronous Transfer Mode) is used to transport several data flows over the same physical layer. Voice and IP data are encapsulated in ATM. As one upside of it, Quality of Service is supported by ATM very well. Figure 3 shows the protocol stacks involved.

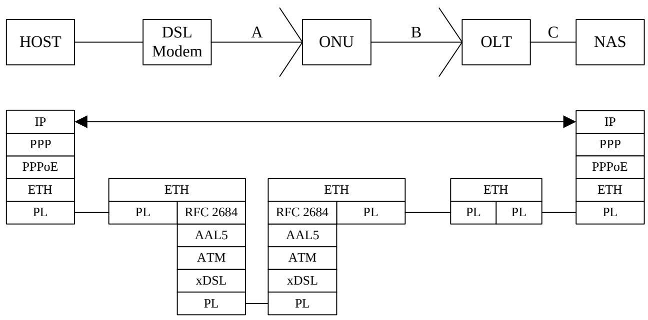

Figure 4: Access Network - Ethernet Based

However, research is going on trying to substitute ATM by Ethernet while still providing for traffic isolation and reasonable handling of a few service classes. In addition, cost savings shall be achieved. For the DSL based section there are IEEE working groups which are developing solutions to transport Ethernet directly over VDSL. Figure 4 shows an example scenario with Ethernet in section B and C.

3 Line Utilisation: Unicast versus Multicast

To show the limits of AN's capability in case of unicast and multicast traffic the following example scenario is assumed: An optical AN consists of the OLT in the central office, the ONU as the remote terminal as well as an edge router and network access server shown in Figure 2. The AN connects up to a few thousands subscribers to the Internet. These subscribers demand streaming video over IP over their DSL access. One video stream S may have a data rate S_{dr}= 1 Mbps. In case of multicast each different stream S_d represents an individual multicast group G in a 1:1 relationship. Network section C (see Figure 2) has a bandwidth of one Gigabit per seconds such as a Gigabit Ethernet.

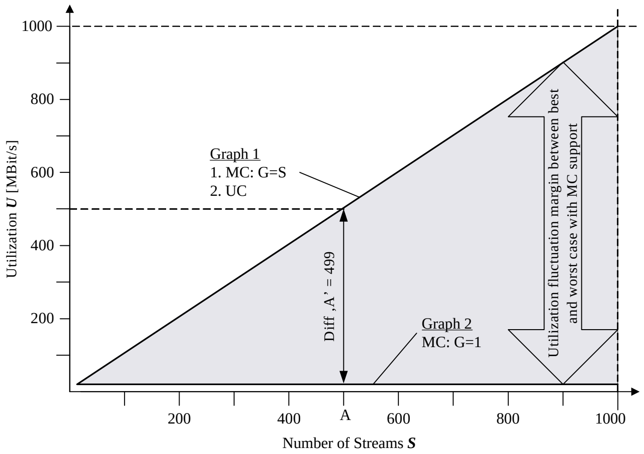

Figure 5: Utilisation of a Gigabit Ethernet

Figure 5 illustrates that there will be 100 percent utilisation U_{UC} in network segment C without multicast support if 1000 data streams S are received by subscribers. In this process it is irrelevant whether thousand times one and the same stream or thousand various streams S are transmitted at the same time.

However, multicast is supported in best case network utilisation U_{MC} of section C and the link load of the gigabit links of network equipment can be reduced to a thousandth part. This case would occur exactly if the same group is requested and received by every subscriber. Graph 2 (G = 1) of Figure 5 illustrates this situation. With multicast, no longer the number of streams S but the number of different streams $S_d = G$ is of importance for utilisation. Consequently, utilisation U fluctuates depending on the number of groups respectively different streams between graph 1 and graph 2 of the diagram in Figure 5. A hundred percent utilisation is reached only in this case if thousand different streams or groups are requested and received by a maximum of thousand customers.

Utilisation U with unicast

$$\boxed{U_{UC}(S) = S_{dr} * S} \quad (3.1)$$

Utilisation U with multicast

$$\boxed{U_{MC}(G) = S_{dr} * G} \quad (3.2)$$

The descriptions of this chapter demonstrate the application dependent benefits to meet the required data rates produced. In the next chapter, we explain how to use multicast in the AN, and where it should be placed in the hierarchy.

4 Design Multicast-Capable Access Networks

The previous chapter has shown the necessaries to make AN capable of multicast. Because of the expected increase of bandwidth-intensive applications over the Internet, the AN with its PPP (Point-to-Point Protocol) unicast connections would be endangered to be overloaded easily. To integrate multicast support into AN, it has to be settled which points in the architecture have to be improved by which additional functionalities. The minimum complexity of these functions has to be defined. In any case, IGMP is needed for IP multicast to manage the groups for IPv4. It must be decided if an adequate multicast router should be established inside the AN, and which routing protocol provides adequate support. Furthermore, it is important on which communication layer multicast can be supported, e.g. data link layer and/or network layer. Another point is to analyse whether PPPoE/PPP can be used with multicast in a network and which modifications are implied. This chapter provides solutions for these issues. In the following, several conceptual options are analysed and evaluated.

4.1 Overview of Concept Development

Subscribers with DSL access are currently connected via PPP with their Internet service provider. PPP connections are established from subscriber's host interface to a NAS at the periphery of AN. PPP provides IP layer and Internet datagram transport to the subscriber. Along the whole AN, PPP is present below the IP layer. Because of this situation IP multicast is not possible at first in such a network configuration. As an exception multicast could be tunnelled over the network, but this does not relieve the network like real multicast.

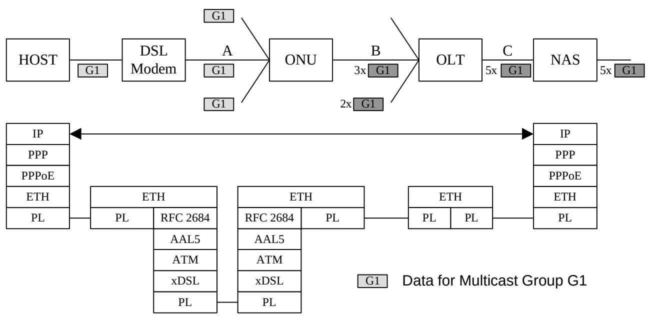

Figure 6: Ethernet Based Access Network without MF

Figure 6 depicts such a current scenario. A new multicast functionality, which is managing IP multicast and abbreviated Multicast Function (MF) in the following text, can be placed after or beside the NAS. This is because the IP layer/protocol is encapsulated in PPP which does not have any multicast function or option in its specification. To register which subscriber requests a group a MF must analyse IGMP which is covered in IP. Consequently, the following five options are examined in detail in the following chapters:

1. NAS is moved inside AN into the OLT,
2. or ONU to terminate PPP(oE) earlier. Thus, IP layer can be analysed earlier.
3. Because PPP handicaps IP analysis it is substituted by another method for user authentication and IP address allocation.
4. PPP connections are manipulated so that multicast requests can be recognised and MC packets can be inserted into PPP channels.
5. An additional network for multicast will be established besides existing AN.

A main MF can be implemented in two different ways:

1. Implementation corresponds to a full-function multicast router MR with a multicast routing protocol like e.g. DVMRP or PIM-SM/DM. This MR guarantees group management, copying, and forwarding of packets in a specific manner. MR constructs multicast distribution trees to other MR to forward multicast data.
2. Implementation is a proprietary multicast manager and forwarder. It analyses IGMP for IPv4, registers and manages group membership messages from customers, forwards these to the nearest MR, and manages distribution of all multicast data. Instead of analysing IP datagrams only, an address translation could be executed so that MF is 'one host' which is requesting groups.

4.2 Concept Specifications

In the following section we describe the first four of the five conceptual options mentioned above.

Concept 1: Multicast Support by OLT. The previous discussion on PPP has revealed that a direct IP multicast support is not possible in the current design of Figure 6. As one solution PPP must terminate earlier. In this concept PPP(oE) terminates in the OLT. Thereby, the encapsulated IP datagrams from subscribers can be analysed by an MF after termination. In the opposite direction, requested multicast data can be distributed to all hosts (PPP channels) which are registered by MF. Figure 7 illustrates this scenario.

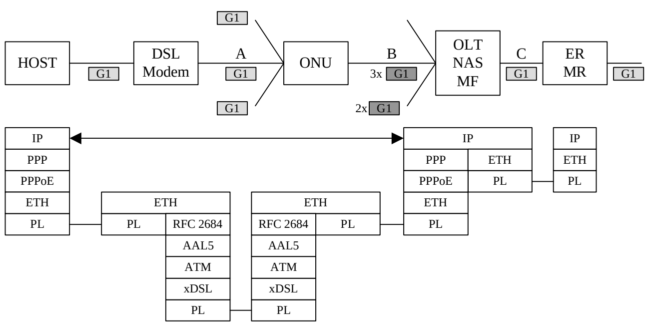

Figure 7: Access Network with MF inside OLT

As a result IP multicast is generally enabled in AN. The links of network section C can be relieved substantially. The MF which is also located in the OLT can be a multicast router or a proprietary multicast manager and forwarder which have been described in the previous section. It is now possible to register group membership requests in the OLT from any existing PPP channel. The MF itself requests the multicast data at the next MR and distributes incoming multicast data to the appropriate receiver. Figure 7 also demonstrates a disadvantage of this solution. Network sections B is still loaded with multiple multicast traffic of the same group. The load depends on the number of subscribers connected to the ONU.

Concept 2: Multicast Support by ONU and OLT. The concept described above can be extended by moving NAS into the ONU and implementing a MF1 into the ONU and MF2 into the OLT. Figure 8 explains this scenario.

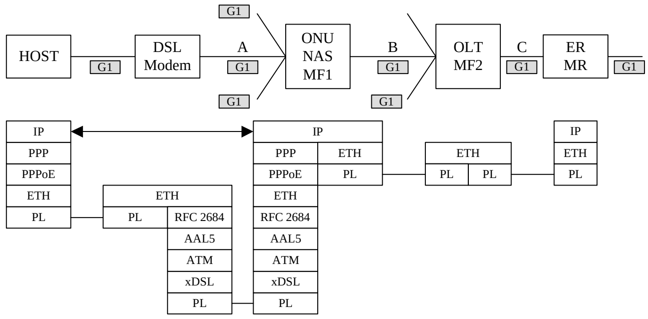

Figure 8: Access Network with MF in ONU and OLT

PPP(oE) is terminated into the ONU. Thereby, at this location a MF1 which is corresponding to MF of concept 1 can analyse IP datagrams and recognise IGMP or multicast IP addresses to identify membership messages and multicast packets. The MF2 into the OLT differs from MF1. At this location Ethernet frames must be analysed. MF2 has a functionality like link layer multicast methods, e.g. IGMP snooping. Figure 8 illustrates a design which offers full multicast support. Data of every group are transported over the same line only once a time. But this requires a full-scale complexity which can only be justified if many subscribers are connected to an ONU and a large number of these subscribers request multicast data.

Concept 3: Multicast Support without using PPP. Today, most DSL installations use PPP for user authentication and IP layer configuration purposes. This does not facilitate effective usage of the Ethernet multicast mechanism. As there are alternatives to PPP, still providing for authentication, authorisation e.g. IEEE802.1X [13], and IP layer configuration like DHCP, a future AN design could fit multicast better. This would be the case for virtually all IP-over-Ethernet implementations. Figure 9 shows such a scenario. For multicast purposes the ONU and OLT can now be handled as link layer switching systems. There is a direct IP connection between subscriber and multicast router whose IP datagrams are transported directly over Ethernet. To analyse these datagrams in ONU and OLT link layer multicast mechanisms must be used for MF in turn. After doing this a full multicast support is enabled in AN.

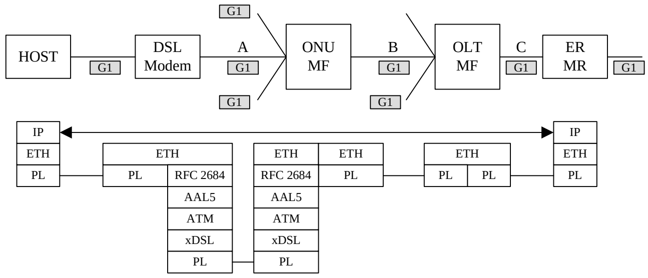

Figure 9: Access Network without PPP

All sections are relieved by a minimum of traffic only. Another advantage is the reduced complexity of MF in this concept compared to other designs. Link layer multicast can be supported trouble-free by e.g. IGMP snooping. Most of management and distribution tasks are executed by a MR outside.

Concept 4: Multicast Support by PPP(oE) Manipulation. PPP normally transports IP datagrams without encryption. It is possible to analyse all Ethernet frames, e.g. within the OLT, and to recognise and register all membership messages. Information for every PPP(oE) channel which differs by a PPPoE session ID can be saved and multicast can be managed. Multicast data for requested groups are now encapsulated in correct PPP(oE) and Ethernet frames and then transported to subscribers. Definitely, this solution does not seem to be the best, but a possible one.

4.3 Conclusions

Several methods of providing multicast support to ANs have been reviewed. These are different mainly by the extent and the number of needed multicast functionalities and, furthermore, by the resulting relief of the network. If a network is demanded with full multicast ability so that all network sections and links are not endangered to be overloaded, then a multicast support must be available in the ONU and in the OLT. The effort of a full support also can, however, exceed the resulting benefit. The variant of a partial multicast ability like discussed in Concept 1 seems to be the most practical way of implementing multicast. The main advantage of this is that changes must be carried out in the OLT only. The NAS function could be provided at the OLT. The effort of the support corresponds to the implementation of a multicast router. As a result multicast communication is possible in the AN and network section C and its links are relieved.

In conclusion it should be pointed out that the scenario in Concept 3 seems to be the most efficient solution. Available link layer multicast methods such as IGMP snooping can be used to support multicast in an optimal way. At present a detachment of PPP for DSL internet access seems to be impossible. But research is going on to provide such solutions.

5 Summary and Conclusion

Bandwidth-intensive applications such as audio and video streaming over the Internet are expected to increase in the next years. This growing demand for multimedia applications and the rise of the penetration rate of xDSL-based high speed Internet access technology require new services in communication networks. A service-oriented redesign also for access networks is needed. Multicast, particularly IP multicast, is one of these services. Multicast relieves communication network in an efficient way, improves the quality by reducing end-to-end delay and often saves network recourses to an extremely high degree. Both Ethernet and IP have standard-based support for multicast. We have provided several solutions to use this in access networks. It can be concluded that there is no such thing like THE optimum implementation. Unlike LANs, access networks have different requirements and the optimum multicast implementation has to be determined on a case-by-case analysis, taking the specific goals and needs of an installation into account. Specifically, this would become true if implementation efforts and resource savings have to be balanced.

Multicast, including IP multicast, is going to be further developed. Many multicast technologies are already adequate in use. But multicast research and development, such as in inter domain multicast routing e.g. BGMP, are still needed. Multicast could be a key technology for the Internet in future.

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