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Quality of Service in Multioperator GPON Access Networks with Triple-Play Services

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***Abstract*—**Recently, in some places, optical-fibre access networks have been used with GPON technology belonging to organizations (in most cases public bodies) that act as neutral operators. These operators simultaneously provide network services to various telecommunications operators that offer integrated voice, data and television services. This situation creates new problems related to quality of service, since the interests of the users are intermingled with the interests of the operators. In this paper, we analyse this problem and consider solutions that make it possible to provide guaranteed quality of service for voice over IP, data services and interactive digital television**.**

***Keywords*—**GPON networks, multioperator, quality of service, triple-play services.

I. Introduction

PUBLIC networks with shared access are being developed in order to cover areas where it is not profitable for commercial operators to provide service.

In January 2003, the ITU approved Recommendation G.984.1/2/3, commonly known as GPON (Gigabit Passive Optical Network) [2]. This recommendation, which was based on work of the Full-Service Access Network (FSAN) working group, made it possible for PON networks to operate at up to 2,488 Mbps and support the ATM and TDM Ethernet protocols.

At the same time, the IEEE 802.3ah Ethernet in the First Mile (EFM) task force developed standards for EPON (Ethernet over PON) networks [4].

While standard GPON allows both asymmetric and symmetric configurations, EPON only allows the latter. The binary configurations of GPON are maintained in the configurations established for the Synchronous Digital Hierarchy (SDH) [3], but EPON configurations are aligned with the Gigabit Ethernet standard.

Additionally, while standard GPON allows three split ratios (1:16, 1:32 or 1:64), EPON only allows the first two. Both GPON and EPON allow Reed-Solomon Forward Error Correction (FEC), but they use different line codes: Non-Return to Zero (NRZ) for GPON and 8B/10B for EPON. [10]

The Ethernet-native protocol presents certain limitations (it has no reserve capacity and therefore does not guarantee the delay, etc.). Ethernet over Multiprotocol Label Switching (EoMPLS) technology promises to correct this.

In the upstream direction, EPON bandwidth efficiency can be as low as 61% for Ethernet traffic, which means that just 730 Mbits/sec of actual bandwidth is available for Ethernet packet transport. In contrast, GPON bandwidth efficiency is around 93% or approximately 1,160 Mbits/sec. In the downstream direction, EPON efficiency is 73%, with 875 Mbits/sec of bandwidth for Ethernet packet transport. GPON efficiency is 94% or 2,250 Mbits/sec. This efficiency, combined with a higher line rate, gives GPON a significant advantage, especially for service providers looking to deliver high-bandwidth services like IPTV [1].

The GPON standard is therefore being applied in the development of access networks of this type.

GPONs take advantage of wavelength-division multiplexing (WDM). They use one wavelength for downstream traffic and another for upstream traffic. This allows for two-way traffic on a single optical fibre. The latest specification calls for downstream traffic to be transmitted on the 1,490 nm wavelength and upstream traffic to be transmitted at 1,310 nm. The 1,550 nm band is purposely left open in case the service provider wishes to share the PON fibre with a Hybrid Fibre-Coaxial (HFC) network, which is the traditional cable TV architecture. Traditional operators of HFC systems can also use shared GPON networks.

II. GPON Quality of Service

The GPON standard guarantees quality of service using the MAC protocol, which controls concentration and multiplexing by assigning slots of variable length for each user and service [7].

By themselves, higher bandwidth and greater efficiency in Ethernet transport cannot ensure the delivery of high-quality voice, data and video across a GPON network.

It is necessary to distinguish between different services by classifying traffic flows with IP DiffServ Code Points (DSCPs). Priorities must also be set in Ethernet traffic (IEEE 802.1p) and police functions and queues must be used to prioritize traffic [1].

The GPON Encapsulation Method (GEM), with identification of ports, makes it possible to separate up to

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eight different types of traffic at the entrance and exit of the network. Thus, traffic can be queued according to service.

The average-access system used by GPON networks prevents collisions. The GEM protocol, which allows the multiplexing of traffic, is used for this purpose. GEM packets, which allow the payload to be fragmented, can transport as much Ethernet traffic as TDM allows. The upstream resource-allocation algorithm is based on a polling system, although the exact implementation has not been standardized by FSAN. The generated traffic is distributed among various queues with different priorities based on Ethernet Bridging (IEEE 802.1q).

In order to ensure the minimum delays, backbone access bridges/routers must be non-blocking and the traffic aggregation must be based on Virtual Private LAN Service (VPLS). This guarantees the identification of traffic by means of IEEE 802.1p-bit and/or DSCP marks, which act as the gateway to a IP/MPLS network.

This is important in a conventional GPON network. However, it is even more important in a multioperator network, where priorities are set not only among services but also among operators and network customers. Network commercial operators and neutral providers typically enter into a contractual agreement called an SLA (Service Level Agreement), which specifies the ability of a network or protocol to give guaranteed performance, throughput or latency bounds based on mutually agreed measures, usually by prioritising traffic.

III. Multioperator Network Model

The model analysed in this paper is based on a GPON network shared by several operators and managed by a neutral operator. The network consists of a generic router that provides access to the wired networks, data IP networks, interactive digital television networks, and analog and digital (DTT) television broadcasting distribution networks of each operator that shares the network.

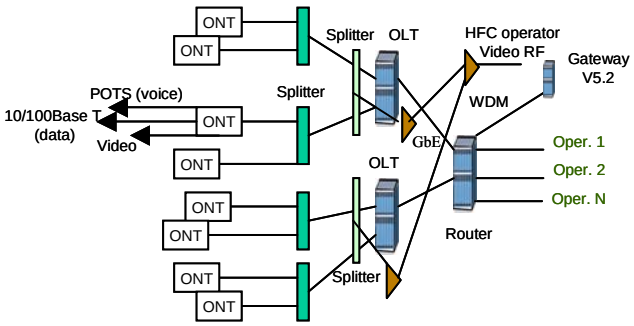


Fig. 1 GPON multioperator network architecture

From this router, in the direction of the user, the equipment is connected via a Gigabit Ethernet (GbE) connection to the Optical Line Termination (OLT), which is where the proper GPON network begins (see Fig. 1). The OLT executes GEM and manages the quality of service offered by the network. With an integrated splitter, the OLT can have up to 32 optical fibres, each of which provides service to a splitter cabinet near the end user with up to 8 optical fibres, which connect to the Optical Network Termination (ONT), also known as the Optical Unit Network (ONU), which is the final device to which each user connects. [9]

The structure of the network allows up to 1,024 users for each OLT.

The network can also have a system for transporting the signals of HFC operators by transmitting video RF along the fibres of the GPON network. As a result, HFC networks do not influence the quality of service of a network. Therefore, some networks will offer HFC networks.

The end user connects to the ONT for triple-play service using the 10/100BaseT interface for data/internet and video IP and using the RJ11 interface for POTS.

A. Level 2 Protocols

The traffic that circulates through a GPON network is Ethernet traffic. This traffic is the payload of the MAC network protocol, based on GEM, which makes it possible to define the GPON framing and the MAC control fields and contains all the necessary elements to define the Medium-Access Control concept. The queue status reporting, the slots and the treatment of the various classes of traffic are defined in the MAC using a mechanism of the Gigabit Ethernet (GbE) connection: round-robin polling. The traffic flows are handled based on priority and operation is based on connection by means of Alloc-Id identification.

The OLT manages access and distributes priorities at the MAC level using the GEM protocol. The GEM header contains the following fields (see Fig. 2): a payload length indicator (PLI), used for delineation; a Port ID, which allows multiplexing of flows; a payload type indicator (PTI), which shows whether the fragment contains user data or OAM and whether it is the last fragment of a user frame; and a HEC field, for error detection and correction as well as delineation [7].

PLI 12 bits	Port ID 12 bits	PTI 3 bits	HEC 13 bits	Payload Ethernet QinQ

Fig. 2 GEM encapsulation

Level 2 traffic—Ethernet traffic between the OLT and the router, encapsulated by GEM—allows us to identify the user, operator and service. This is done using QinQ Ethernet labels. Thus, label 1 identifies the user and label 2 defines the operator and the service. The connection between the router and the network of each operator is also level 2 Gigabit Ethernet traffic. Label 3 of 802.1Q is used to identify the user and the service. Between the router and the OLT, there is a VLAN VLL for each user/service.

B. Triple-Play Quality of Service

Internet traffic generally consists of access to websites, e-mail, file transfer, peer-to-peer and other forms of data transfer. At level 2, either PPP over Ethernet or the Dynamic

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Host Configuration Protocol (DHCP) can be used.

With voice IP traffic, the end user can use the H.248 protocol with the RJ11 interface in order to cross the V5.2 gateway and access the public operator telecommunications system (POTS).

The user can also use the RJ45 interface and H323/SIP protocol with transparent transport to cross the GPON network to the softswitch that is connected to the POTS by means of the H.248 protocol [11].

The system used depends on the type of operator: an incumbent operator with a developed POTS network or an incoming operator with an IP-based telephone network.

Baseline video traffic can be actual video streams or video emulated through the use of scripts. Both unicast for video-on-demand and multicast for broadcast services over UDP are required.

The transport of video over IP is based on IP multicast. The following elements are recommended: DVB-IPI with the MPEG-2 and MPEG-4 (HDTV) coding systems (digital TV) and the IGMP, HTML, and RTSP (video on demand).

In terms of types of traffic, different general circumstances may occur with triple-play service. Different types of isolated or combined traffic can be created. We will consider their performance in terms of latency, data loss and throughput.

In order to ensure that the traffic flows provide the proper quality of service and to implement police functions, we must measure the availability of prioritization of streams in a triple-play environment. Several quality-of-service parameters must be applied to quantify throughput and response times for different traffic combinations. Internet traffic is given the lowest priority, since data services are not drastically affected by packet delays. Video traffic has the next highest priority, since a minimum loss of video packets does not negatively affect the perceived appearance, as long as the streaming audio track is not broken. Finally, voice over IP will have the highest priority, since voice services are very sensitive to latency and loss of packets [12].

IV. Problems with Multioperator Quality of Service

In a GPON network like the one proposed in this paper, quality of service is guaranteed for each service and end user. Priorities are therefore set in accordance with this scheme and the GEM management procedure does not consider any another options.

In our case, however, the network is multioperator. The prioritization criteria need to take this fact into account. An end user may have more than one voice-over-IP line contracted through an operator. For data, an operator may offer its clients different access speeds and in some cases provide committed information rates (CIRs). As for video, operators can offer their clients simultaneous television with different channels or different video-on-demand sessions.

This range of possibilities cannot be generalized by all operators that share a GPON. Each operator's range of possibilities will depend on its IP backbone and video-server capacity. Quality of service is allocated based on priority queuing and bandwidth allocation by user in accordance with GEM. Downstream traffic is multiplexed using Time-Division Multiplex (TDM) and upstream traffic is multiplexed using Time-Division Multiple Access (TDMA), in accordance with the MAC protocol. This protocol manages user bandwidth by controlling police functions. The MAC protocol is therefore vitally important to controlling traffic and guaranteeing quality of service.

The GPON Encapsulation Method (GEM) is a protocol like MAC that was developed in GPON and makes it possible to transmit Ethernet frames and TDM and ATM cells using 125-microsecond fixed-size time slots. Therefore, the Ethernet frames may be fragmented [4].

In the header, the downstream frames contain the upstream bandwidth map with the allocations of all upstream frames. The MAC allocations indicate the length, time, queue and user for each frame. Due to traffic fluctuations, dynamic bandwidth allocation (DBA) is used. This system defines the BW for each frame [5] [8].

In summary, at the physical level the information is divided based on time. The encapsulated Ethernet frames are sent in the time slots using the GEM protocol, which has medium-access mechanisms and allocates the required bandwidth. This traffic is served to the network according to the service-based priorities: voice, then television and finally data. The GEM manager controls medium access in the OLT by assigning upstream and downstream slots to each terminal and service using the DBA algorithm. Each ONT can assign bandwidth using a round-robin polling procedure.

FSAN specifies five different types of traffic known as T-CONT [4]. These definitions are related to throughput and delay. The DBA algorithm makes it possible for the MAC controller of the OLT to create an image of the queuing situation for each type of traffic in the whole GPON network, thus enabling an effective allocation of throughput and control of delay [7].

Taking into account the above considerations, we deduce that the problem of quality of service in GPON multioperating networks is centered in which service offers the network adapted for each operator, knowing that already it offers it for each type of traffic and terminal.

V. Multioperator Polling Table

In a single-operator GPON access network, the MAC controller in the OLT manages the various services provided by assigning different priorities. In a multioperator GPON network, because each operator offers its own services, we must make some changes to the MAC controller.

We propose two simple modifications to manage this latter case. The first is to increase the number of priorities that are managed for each service. The second is to modify the polling table in order to consider the multioperator case and avoid unfairness.

A. Priorities

The previous sections have shown that priority is given to voice services, followed by TV services and finally by data services. Because each operator may offer more than one

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voice, TV and data service (for instance, with different CIRs), we need different priority levels for the overall set of services.

In multioperator environments, each operator must be able to offer multiple voice channels, television channels and CIRs for data. The quality of service provided by the network must be based on this possibility [13]. We propose modifying the number of priorities following two different approaches.

First, a different type of priority should be considered for each service (see Table I). We propose allowing up to four services because this is generally the maximum number of television sets per home, and four voice lines and CIRs is sufficient.

TABLE I
SERVICE PRIORITIES

Voice	TV	Data
1	2	3
4	5	6
7	8	9
10	11	12

For each ONT, each operator will define a certain priority for each service and will enter into an SLA with the network. If an ONT has two voice channels, one may have priority 1 and the other may have priority 4, or both may have priority 1. Three television channels can be seen simultaneously: two with priority 2 and one with priority 5. The priority is based on the service, not the user.

Second, if all the possible variations of the three services (see Fig. 3) are considered, then each user has a unique priority (broad, not service-based). The star in the figure indicates a user's priority with three televisions on, one voice line on, and data being transmitted with the third available CIR.

In this case, there are 64 different priorities.

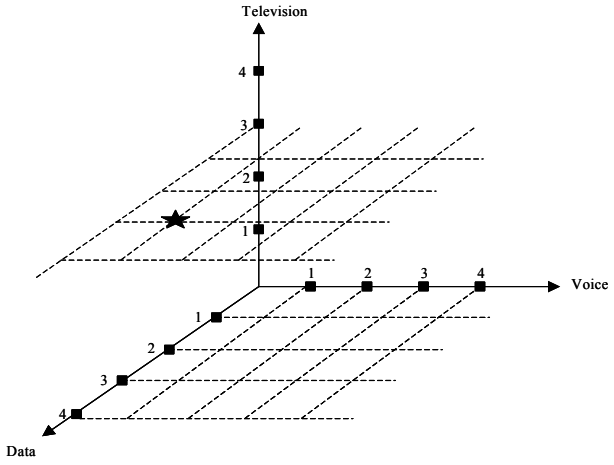


Fig. 3 Broad priorities

The neutral operator can choose the first or second priority table, as required by the SLA, and the order of priorities.

B. Polling

The polling table must be developed not only to maintain the quality-of-service parameters for each ONT, but also to satisfy the demands of the various operators that share the network (see Table II).

We propose a table that takes into account the number of ONTs per operator. Therefore, access is distributed and slots are allocated based on the number of users per operator. The regular, priority-based Dynamic Bandwidth Allocation (DBA) algorithms are applied.

RR indicates the execution of the round-robin process. Its value represents the polling sequence.

TABLE II
POLLING TABLE

Operator 1	# ONT 1	RR1
Operator 2	# ONT 2	RR2
Operator 3	# ONT 3	RR3
…	# ONT …	RR…
Operator N	# ONT N	RRN
Total	# ONT T	

In order to guarantee the SLA for each service and maintain fairness among services and operators, polling slots must be assigned to each operator based on the distribution shown below. Within an operator, regular round-robin polling is applied in the ONT.

If we consider N operators sharing a GPON access network and each operator has ONT_i users, then the total number of ONTs is

$$ONT_t = \sum_{i}^{N} ONT_i$$

Then, for each polling cycle, each operator will have RR slots, being

$$RR = ONT_i / ONT_t$$

This simple modification of the polling cycle guarantees both quality of service and fairness.

VI. CONCLUSION

Probably the development of GPON networks will be generalized. However, in places where this service is not commercially profitable, public organizations with social aims may act as neutral operators by renting their networks to commercial operators that offer triple-play services. We have considered a new quality-of-service which must be satisfied not only for each type of service but also for each operator.

In this work, we propose solutions for aspects that can be modified in all quality-of-service processes in a multioperator network, while maintaining all quality-of-service procedures established by G.984 for GPON and the standardized medium-access and bandwidth-management methods. Having analysed all the mechanisms (standardized and otherwise) for guaranteeing quality of service in GPON, we conclude that the two aspects that change when a network has multiple operators are the establishment of priorities and the management of the medium-access method (polling). We

propose solutions that make it possible to guarantee SLAs for operators and maintain the proper quality of service.

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