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EPON Technology White Paper

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Content

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Abbreviations

CM	Cable Modem
DBA	Dynamic Bandwidth Assignment
DHCP	Dynamic Host Configuration Protocol
DSL	Digital Subscriber Line
DTE	Data Terminal Equipment
EFM	Ethernet in the First Mile
EPON	Ethernet-based Passive Optical Network
FTTB	Fiber to The Building
FTTH	Fiber to The Home
FTTN	Fiber to The Node
FTTP	Fiber to The Premises
IEEE	Institute of Electrical and Electronics Engineers
IPAQG	Integrated Periodic and Quasi-Periodic Grangting
LLID	Logical Link Identification
MAC	Media Access Control
MPCP	Muti-Point Control Protocol
MPMC	Multi-point MAC Control
OAM	Operation,Administration,Maintenance
ODN	Optical Distributed Network
OLT	Optical Line Terminal
ONU	Optical Network Unit
POS	Passive Optical Splitter
PtPE	Point-to-Point Emulation
QoS	Quality of Service
SLA	Service Level Agreement
TDM	Time Division Multiplex
VoD	Vedio on Demand

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1. Overview

In recent years, the telecommunication backbone network has been upgraded from time to time while more fibers are laid and devices of larger capacities have come into use. But as for the access network, the copper line is still the leading choice. The tremendous increase in Internet services has pricked up the shortage of the access network's capacity. The access network which is called "last mile" still remains the bottleneck between high-speed LANs and the high-capacity backbone network.

The most widely deployed "broadband" solutions today are DSL and CM networks. Although they are improvements compared to 56 kbps dial-up lines, they are still unable to provide enough bandwidth for emerging services such as video-on-demand (VOD), interactive gaming, or two-way video conferencing. A new kind of access technology is required for the time with following features: inexpensive, simple, upgradeable, and being able to provide bundled voice, data and video services. EPON, which merges the low-cost Ethernet technology and low-cost optic network architecture, is the best representative of the future-oriented next generation access network technologies.

As early as in November 2000, about 200 experts from 80 companies formed a study group of IEEE and this group was chartered with extending existing Ethernet technology into subscriber access area. Then in September 2001, this study group is officially named as Ethernet in the First Mile (EFM) study group and is focused on instituting EPON standards under the architecture of the IEEE 802.3 protocol. In June 2004, the IEEE 802.3ah standard is approved by IEEE Standard Board and then officially released.

2. Network Architecture

A typical EPON system is composed of OLT, ONU, and ODN (see Figure 1).

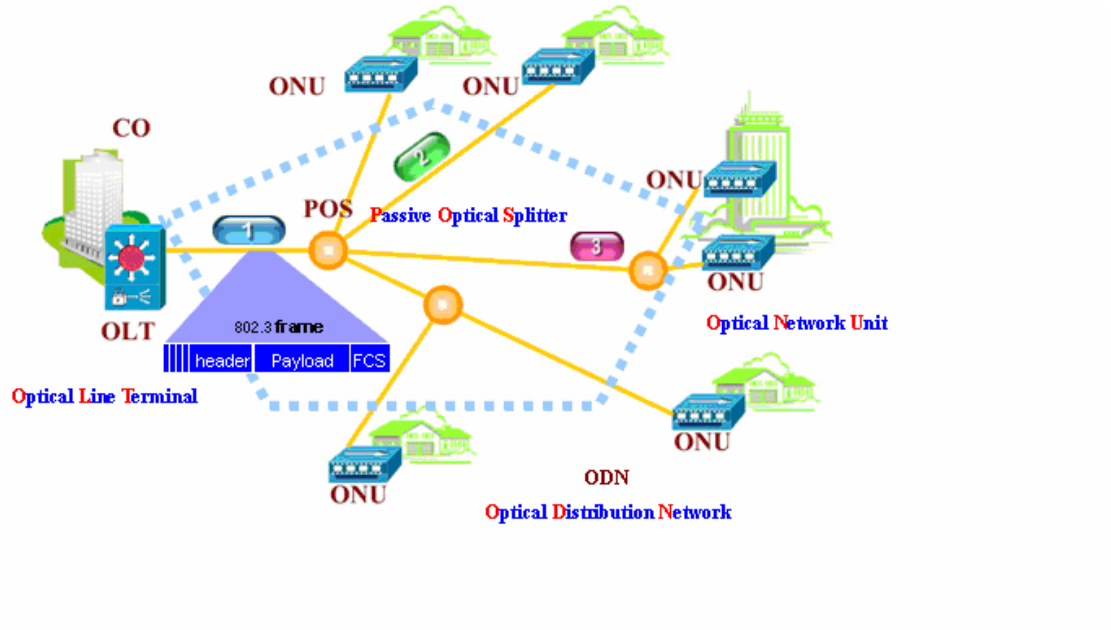

Figure 1 EPON Network Architecture

The OLT（Optical Line Terminal）resides in the Central Office (CO) and connects the optical network to the metropolitan-area network or wide-area network, also known as the backbone or long-haul network. OLT is both a switch or router and a multi-service platform which provides EPON-oriented optical interfaces. Besides the network assembling and access functions, OLT could also perform bandwidth assignments, network security and management configurations according to the customers' different QoS/SLA requirements.

The ONU（Optical Network Unit）is located either at the end-user location or at the curb and provides optical interfaces which are connected to the OLT and service interfaces at users' side such as voice, data and video.

The ODN（Optical Distributed Network）is an optical distribution network and is mainly composed of one or more passive optical splitters which connect the OLT and ONU. Its function is to split downstream signal from one fiber into several fibers and combine optical upstream signals from multiple fibers into one. Optical splitter is a simple device which needs no power and could work in an all-weather environment. The typical splitters have a splitting ratio of 2, 4, 8, 16 or 32 and be connected to each other. The longest distance the ODN could cover is 20Km.

3. Principles

As an access and transmission system, EPON adopts TDM (Time Division Multiplex) mechanism in the upstream direction. Each ONU transmits the customers' Ethernet frames to the OLT in the transmission timeslot which is assigned by the OLT (see Figure 2).

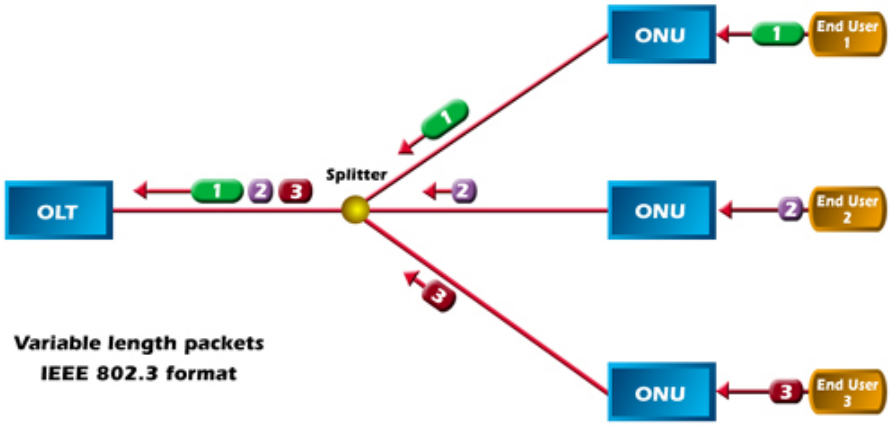

Figure 2 EPON Upstream Direction Principle

EPON system adopts the broadcast method in downstream direction. Ethernet frames of different ONUs are transmitted in one downstream timeslot. The packet which carries all the ONUs' data reaches different ONUs and each ONU only extracts its own data frames and transmit them to the users while others frames are discarded (see Figure 3).

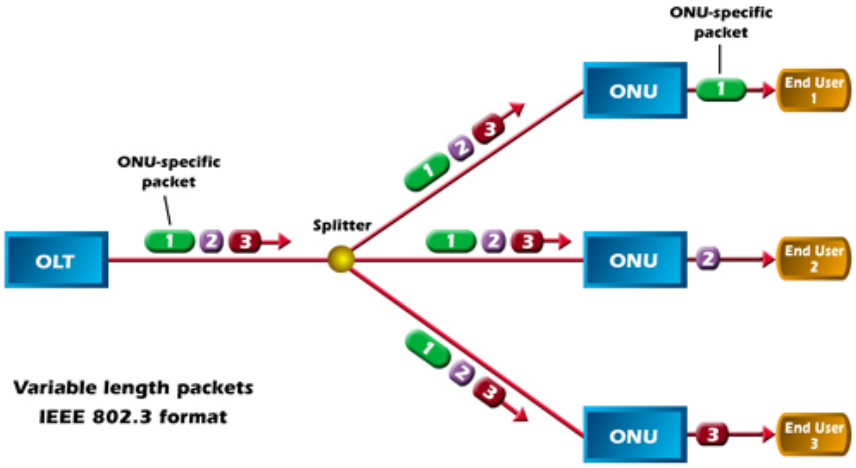

Figure 3 EPON Downstream Direction Principle

4. Features

PON is a new medium for the Ethernet technology. 802.3 group defines a new physical layer but makes little modifications to the Ethernet MAC layer and above to support new applications and mediums. The hierarchical model of EPON is defined in IEEE 802.3ah (see Figure 4).

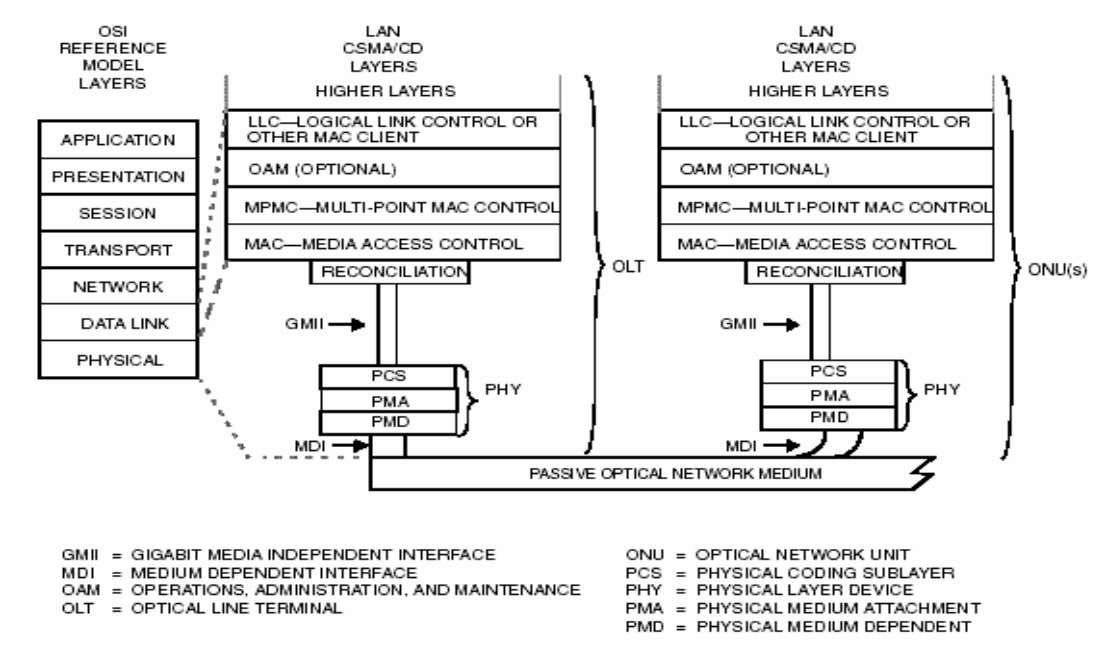

Figure 4 IEEE 802.3ah Hierarchical Model

The EPON system connects many DTEs through a single shared fiber and its topology is a tree architecture based on the POS. MPCP is the mechanism which makes this topology fit for the Ethernet.

EPON, as a part of the standards discussed by EFM, is based on MPCP (Muti-Point Control Protocol) which is a function of MAC control sublayer. MPCP uses messages, state machines, and timers to control which ONUs are able to access the P2MP topology structure. In the P2MP topology, each ONU contains a MPCP entity to communicate with a MPCP entity of the OLT. As the base of EPON/MPCP, EPON achieves a P2P emulation sublayer which makes the P2MP network topology seems like an ensemble of many P2P links for the higher layers.

This sublayer is achieved by adding a LLID (Logical Link Identification) ahead of every frame. The LLID replace two bytes in the preamble. The OLT could distinguish frames of different ONUs by the LLIDs and thus the LLID equals the logical identification of the ONU.

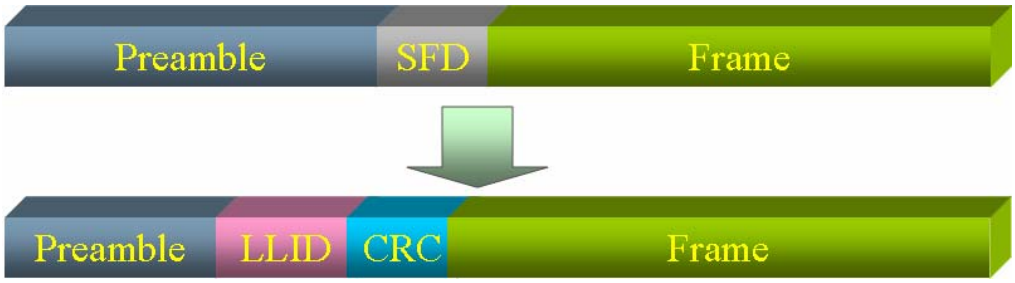

Figure 5 Ethernet Frame Structure Change of EPON System

The ONU's upstream transmission is controlled by the Grant which is assigned by the OLT. First the ONU cashes the upstream data from the users and then report the required bandwidth to the OLT. The OLT will assign bandwidth fairly according some algorithms and the result of bandwidth assignment is sent to each ONU by Grant. The ONU will send data to the OLT at full speed in the timeslot specified by the OLT's Grant after receiving it.

The main content of the MPCP protocol is: upstream bandwidth assignments to different ONUs;

discovery and register processes of ONUs; reporting bandwidth requirements to the upper layer protocol entities and performing dynamic bandwidth assignment achieve statistical multiplexing. The MPCP protocol does not deal with the contents of bandwidth assignment algorithm, access authentication, QoS definition, service provider and management. These functions are realized by the upper layer and MPCP is just a supporting protocol.

5. Key Technologies

5.1 ONU's Autodiscovery

The purpose of ONU's autodiscovery is to complete discovery and register of newly connected ONUs without manual intervention and make them join the EPON system without affecting other ONUs. Please see Figure 6 for the autodiscovery and register of newly connected ONUs.

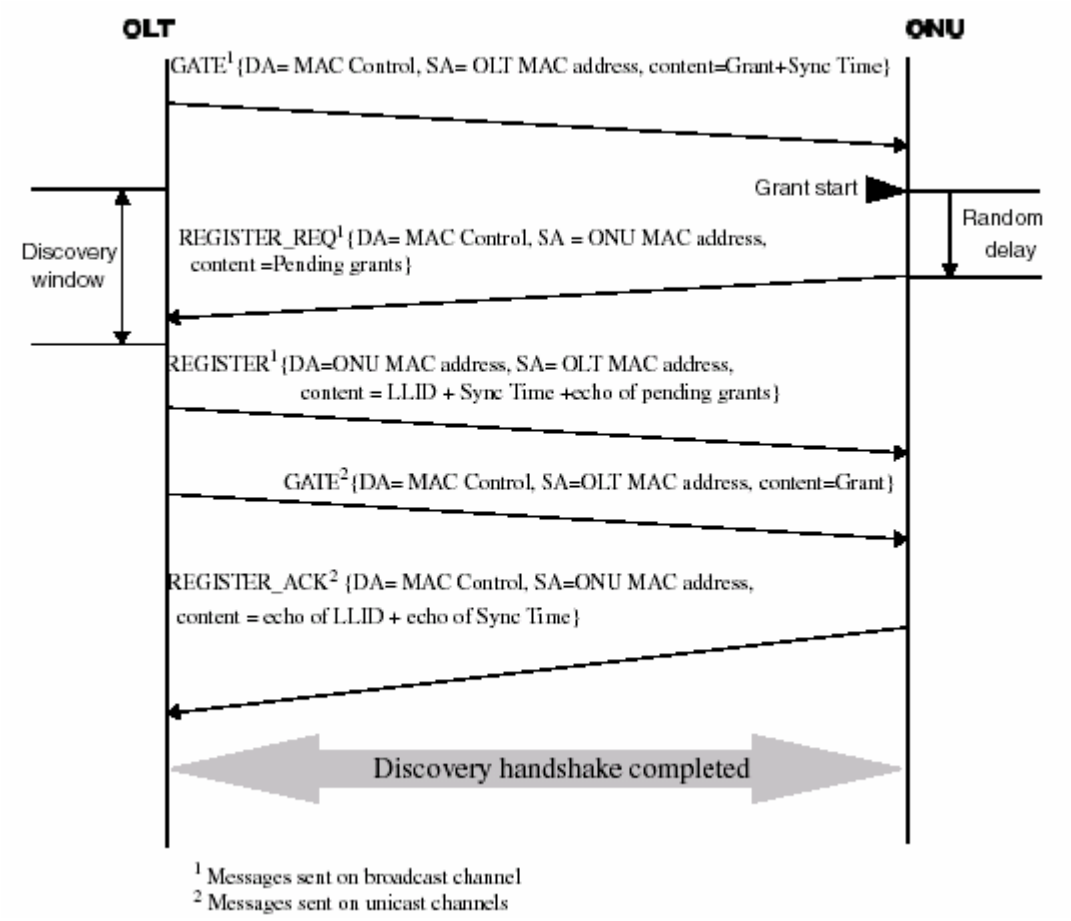

Figure 6 Autodiscovery and Register of ONUs

EFM provides two solutions for the register conflicts.

A. random delay：when register conflicts occur, the involved ONU will still respond to the register grant but will wait a random amount of time before responding (the response must be in the discovery window after random delay). This method could reduce the time which the ONU need to join the system but will also reduce the system's bandwidth utilization ratio by lengthening the

discovery window.

B. random overleaping ：when register conflicts occur，the involved ONU will respond again after overleaping several register grants. If the period of register grants is 1s, the ONU may wait 1～8s (could be configured) after conflicts and then wait for another grant. This method will cost more time than the above one but not affect the system's bandwidth utilization ratio without lengthening the discovery window.

5.2 Synchronization and Ranging

Synchronization is required because every ONU's slot must accord with the slot assigned by the OLT to avoid collisions of their upstream data. For the OLT, every ONU has a different distance and the round trip time will change with the changes of time and the environment, thus transmission overlap of upstream data will also occur. See Figure 7.

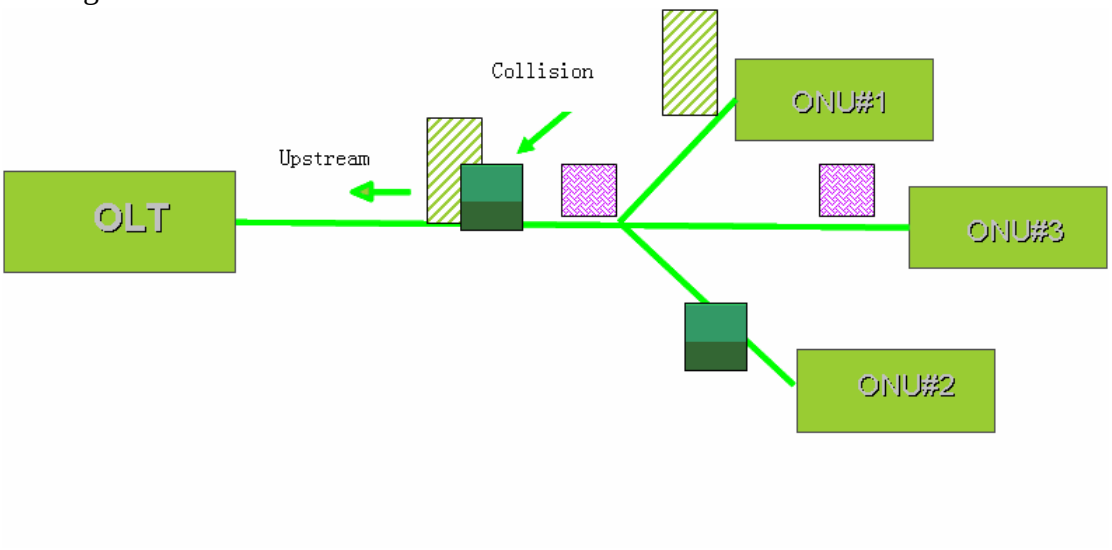

Figure 7 EPON Upstream Data Collision

To avoid the collision of upstream data, RTT between every ONU and the OLT is measured and inserted with the corresponding equalization delay to make the logical distances between the OLT and all the ONUs the same. See Figure 8.

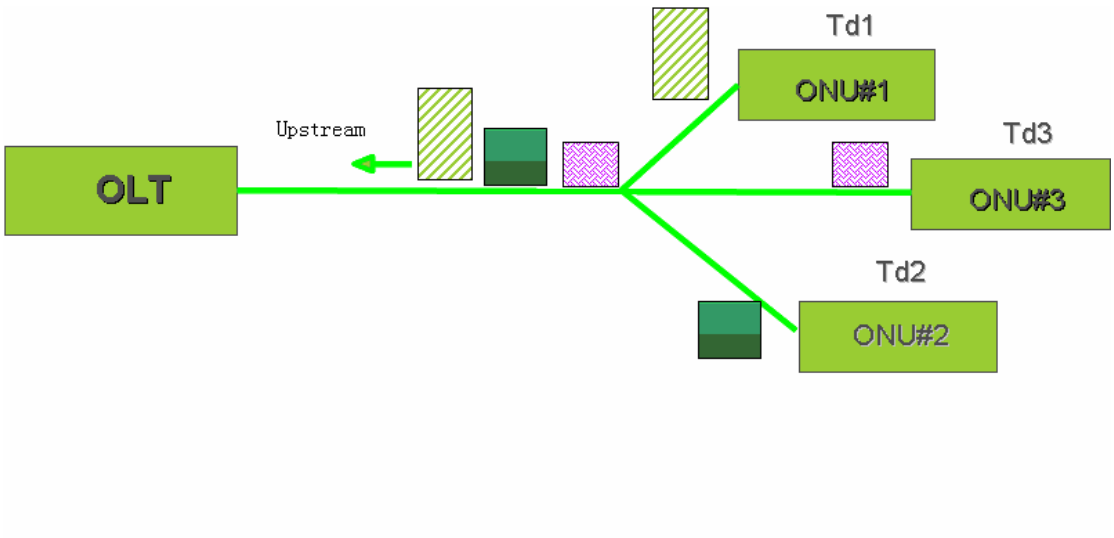

Figure 8 Ranging Guarantee

5.3 Point-to-Point Emulation（PtPE）

To comply with IEEE 802.1D and relevant Ethernet protocols, IEEE802.3ah group put forward PtPE. PtPE is to emulate a Point-to-MultiPoint network topology from the original Point-to-Point one.

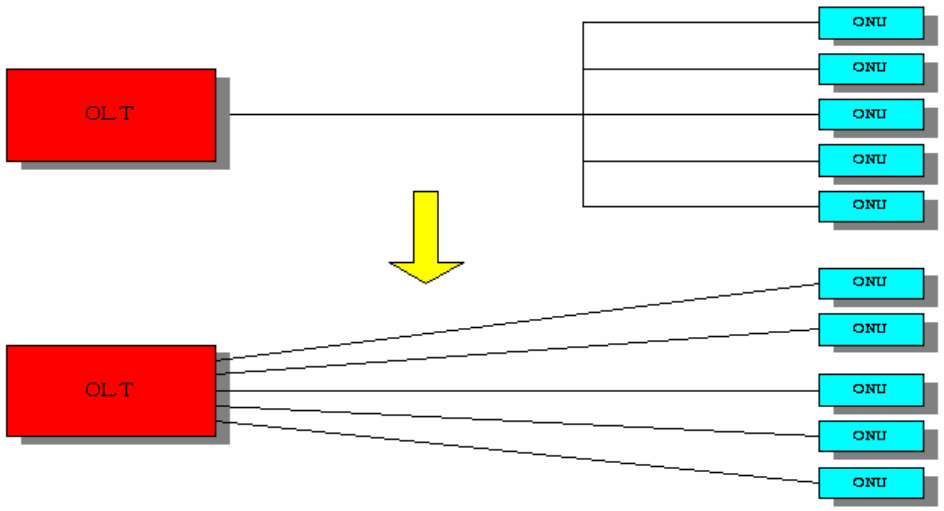

Figure 9 PtPE Network Topology

In P2P emulation mode, the OLT must have N MAC ports (interfaces), one for each ONU (see Figure 10). When sending a downstream frame (from the OLT to an ONU), the emulation function in the OLT insets the LLID associated with a particular MAC port that the frame arrived from (see Figure 10a). Even though the frame will pass through a splitter and reach each ONU, only one P2PE function will match that frame's LLID with the value assigned to the ONU and will accept the frame and pass it to its MAC layer for further verification. LTE (logical topology emulation) functions in all other ONUs will discard this frame, so the MAC sublayers will never see that frame. In this sense, from the MAC sublayer perspective, it appears as if the frame was sent on a point-to-point link to only one ONU.

In the upstream direction, the ONU will insert tis assigned LLID in the preamble of each transmitted frame. The P2PE function in the OLT will demultiplex the frame to the proper MAC port based the unique LLID (see Figure 10b).

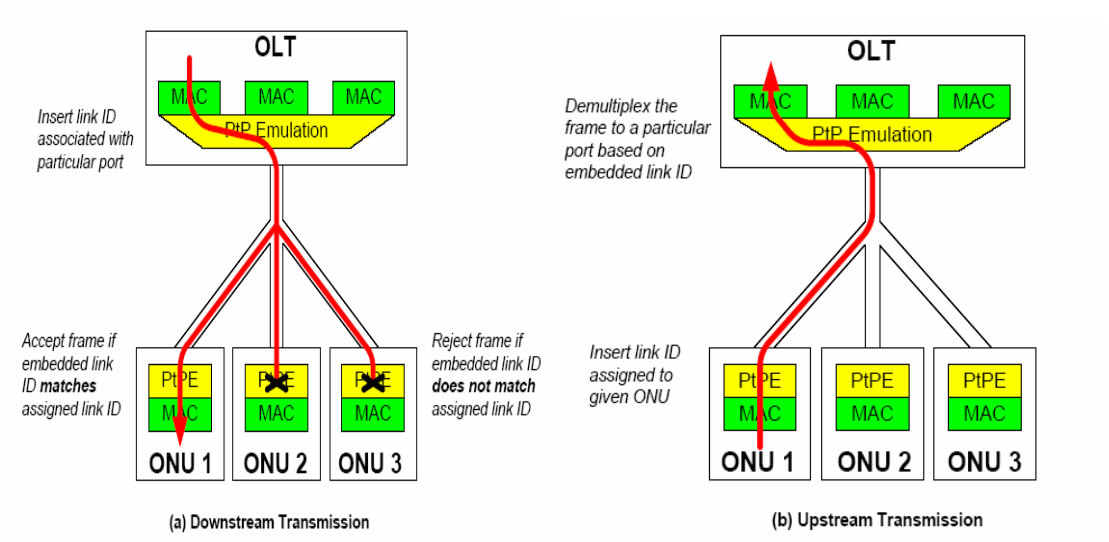

Figure 10 Point-to-Point Emulation

5.4 Dynamic Bandwidth Assignment

EPON performs upstream multiple access control through MPCP (Multi-point Control Protocol) on extended MPMC (Multi-point MAC Control) sublayer. It includes: assignments of ONUs' transmission slot, ONUs' autodiscovery and joining, reporting bandwidth requirements to the upper layer to dynamically assign bandwidth. As for how to perform dynamic bandwidth assignment, IEEE802.3ah makes no specification and suggest that manufactures should make their own definitions.

DBA(Dynamic Bandwidth Assignment) is a medium access control mechanism which is used to achieve the best utilization of available bandwidth in shared medium network. It adopts the Request-Grant method (see Figure 11).

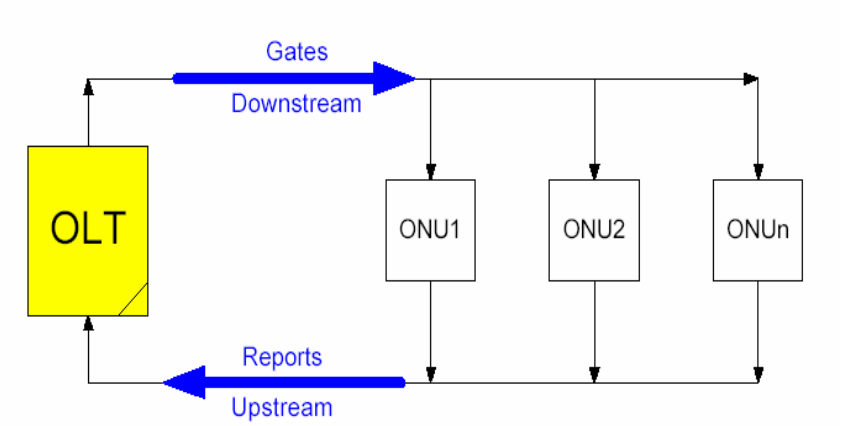

Figure 11 Request-Grant Method

Each ONU calculate its bandwidth requirement according the quantity of buffer contents, generate request frames and transmit them to the OLT. The OLT receives request frames from different ONUs and dynamically adjusts each ONU's bandwidth assignment according to a certain bandwidth assignment algorithm. The OLT send grants to each ONU through the downstream EPON link and ONUs send their frames in specified timeslots which is given in their grants.

Figure 12 shows an IPAQG (Integrated Periodic and Quasi-Periodic Granting) DBA algorithm which is a multi-service EPON upstream bandwidth assignment algorithm. This algorithm carries two types of services: Ethernet and TDM services. It uses the Quasi-Periodic Granting DBA algorithm for Ethernet services and the Periodic one for TDM services.

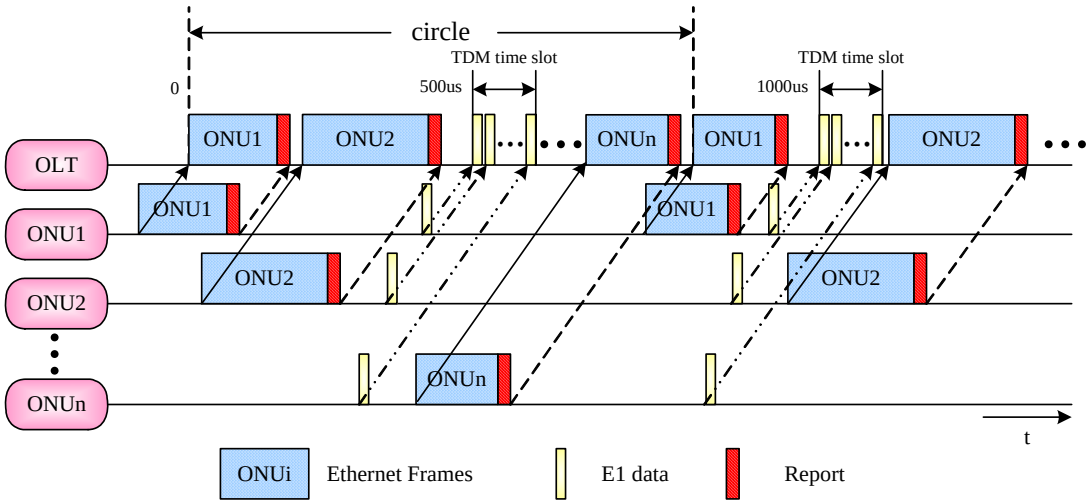

Figure 12 IPAQG DBA Algorithm

5.5 TDM Service Bear Capability

Although the bandwidth requirement for data services is increasing rapidly, current circuit services still has a great market and is playing an important role in a short term. It will still be the main profit source of service operators in next few years. So carrying circuit switch services, combining packet and circuit switch services are in favor of EPON's market applications and also satisfy the requirements of different services. The EPON people talk about today is actually a multi-service system which is able of network convergence. EFM makes no technological specifications of how to carry TDM in EPON except for the Ethernet frame structure compatibility. How to ensure the quality of TDM services actually becomes one of the multi-service EPON's key technologies.

The TDM over EPON method is fit for EPON because: it doesn't violate the Ethernet frame structure (TDM services encapsulation in Layer 2); easier for implement and IEEE802.3ah protocol compatibility; QoS assurance of TDM services.

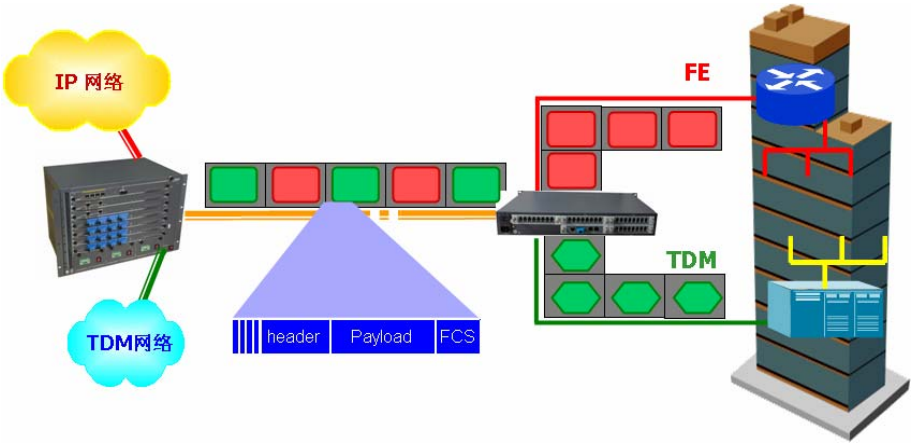

Figure 13 TDM over EPON

A group of test results of TDM services in EPON system is shown below: less than 0.2UI when output jitter is under the condition of LP+HP1; less than 0.05UI when output jitter is under the condition of LP+HP2

Figure 14-1 Output Jitter LP+HP1 Result

Figure 14-2 Output Jitter LP+HP2 Result

Test results of input jitter tolerance receive high scores. And rest results of jitter transfer in the HighQ template are comparably ideal.

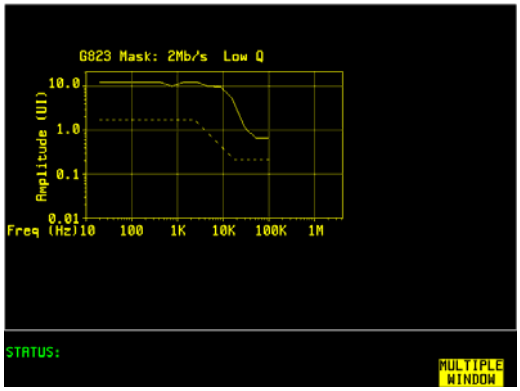

Figure14-3 Input Jitter Tolerance Result

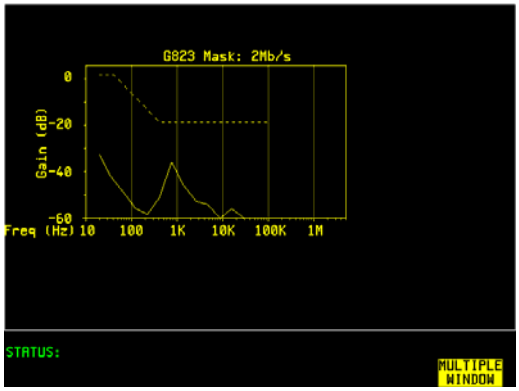

Figure 14-4 Jitter Transfer Result

The above test results all satisfy the objective requirements of G.823, which means TDM over EPON method fully realizes transparent transmission of TDM service in the EPON system and is able to provide circuit services of telecommunication level's QoS.

5.6 Survivability

In the survivability aspect, the main aim is to ensure that the physical link is working normally and the protection switch technology with redundant link backups. GW Technology Co., Ltd suggests an innovative resilient protection switch technology by aiming at the characteristics of data services. This technolo gy's basic features are that the OLT and ONUs's (with protection switch requirements) devices has two set of optical transceivers and PON interface modules and etc, and ONUs connect to the OLT through two different routes to form two PON links while each link is a backup to the other. In normal conditions, two PONs carry services at the same time. When one ONU or a PON link of several ONUs fails because of fiber or optical transceiver failures, this ONU or these ONUs will transfer all their services to the other available PON link. Switches are performed according the services' priorities: first transmit high priority services (such as circuit services) to ensure the QoS requirements; provide "As best as possible" services for lower priority services (normal Ethernet data services).

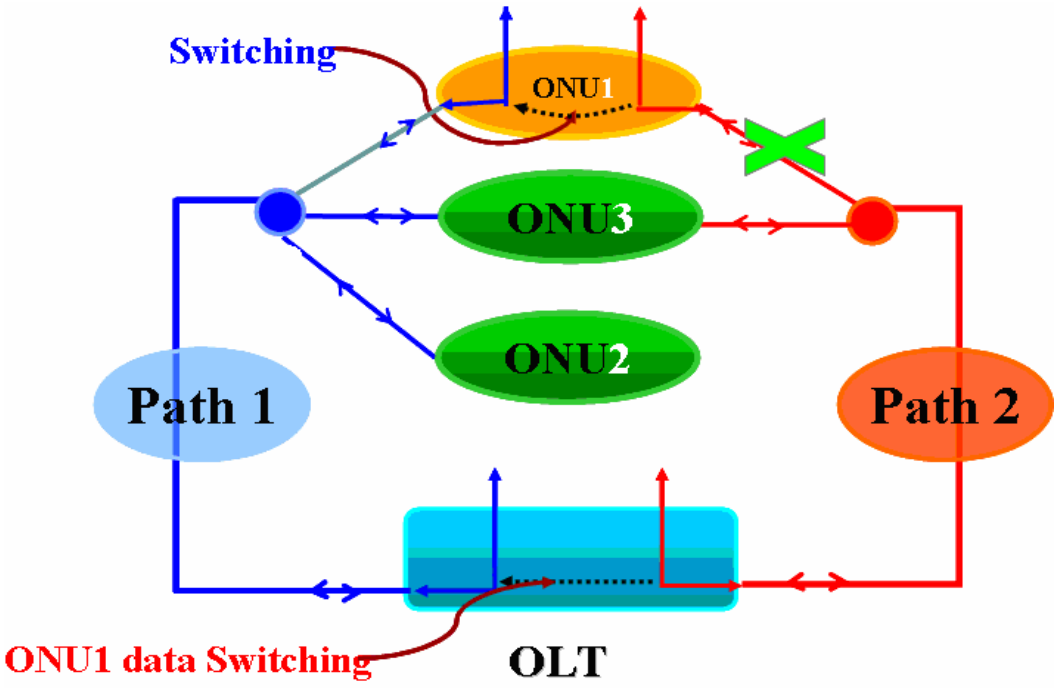

Figure 15 Resilient Protection Switch

5.7 Security

According to IEEE 802.3ah's specifications, EPON's physical layer transmits standard Ethernet frames and the 802.3ah standard provides a LLID for each connection. Thus each ONU could only receive the frames with its own LLID while other frames are discarded. Actually the LLID is mainly used for different connections, and it is not enough by all appearances if the ONU simply

filters frames by the LLID. This is because the transmitted data are standard Ethernet frames and users could obtain the information which doesn't belong to it by ignoring the LLID. As a result, the information is never secured.

EPON could perform churning encryption to upstream MAC control and OAM frames to ensure the integrality of EPON information; ensure the security of EPON by churning encryption to each link; ensure the information availability by performing user authentication through the use of the DHCP protocol.

5.8 Ethernet Management

First-mile access is a brand-new application for Ethernet because it requires an integrated telecom-level management. Different from traditional local area network, terminal users in First-mile are not configured according the requirements of Ethernet services providers and First-mile contains central office and remote devices. So central office device must be capable of monitoring some important information of physical links and devices between service providers and the places where users reside. The OAM functions which EFM group has decided to provide are: remote fault indication, remote loopback control and link monitoring. The OAM message channel adopts slow protocol frames with the Length/Type field being 8809 to transmit OAM messages. The OAM of 802.3ah provides flexible manufacturer- extended functions which could achieve the functions which are not supported in the standard by the manufacturer- extended instance reports or information frames.

4. Prospects

With the growing of EPON technology, interaction standards and EPON devices, EPON has entered the large scale application phase driven by the huge market demands. EPON is fit for the access market which is at the end of the fibers and which has a certain density and these markets include:

- FTTB (Fiber To The Building)：the residents' broadband access or integrated access (broadband+NGN voice) application；
- FTTP (Fiber To The Premises)： the enterprises' integrated access application；
- FTTH (Fiber To The Home)：the upmarket district application；
- FTTB：EPON+LAN or EPON+EoC application；
- FTTN (Fiber To The Node)：EPON＋CODEC application。

EPON becomes a very economical and effective broadband access solution because of its predominance in equipment investment and also the operations, maintenance and etc. It could be

said that the EPON technology has become the developing direction of access network's technologies in the future as an ideal solution for FTTH.

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