FTTx Networks

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Introduction to FTTx

Physical Technologies for Communication

- The twisted pair copper wire is the oldest, and still widely deployed technology that supports a single analog telephone line to the home.
- Digital Subscriber Line (DSL) technology is used to transport digital data.
- The TV signals are brought into homes by using coaxial cable from a master antenna which are called community antenna television (CATV) systems.

(contd...)

Physical Technologies for Communication

- But now a days, there is an evolution of the technology from coaxial cable emanating from the central receive point, to hybrid fiber-coax (HFC) systems in which the signal is taken by the fiber optic cable from the headend or hub to a node.
- The low signal loss compared to that of coax is the advantage of fiber.
- Hence, the signal is transmitted to larger distances without amplifying it.
- Therefore, this technology provides better reliability, better quality, and lower operational expenses (op-ex).

(contd...)

Physical Technologies for Communication

- HFC extension to the smallest node that serves only one home brings the third technology called fiber-to-the-home (FTTH).
- Only passive components are used to build FTTH systems that improves reliability and no need to made provision to obtain power from commercial sources and no need of backup power.
- As a result, there is reduction in both capital and operational expenses and enhancement in the reliability and quality of the received signals.

(contd...)

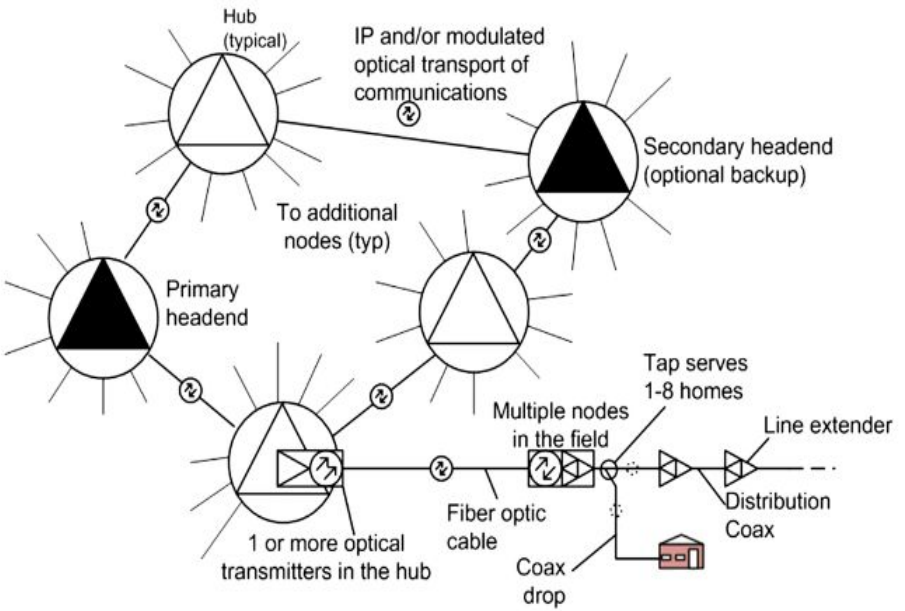
Terminology

- In telephone background, a central office (CO) is the point where signals are assembled to go to subscribers and is called headend in a cable TV background.
- A digital subscriber line access multiplexer (DSLAM) or a hub is a field-mounted terminal where signal formats are converted and sent to a home from the last distance.

(contd...)

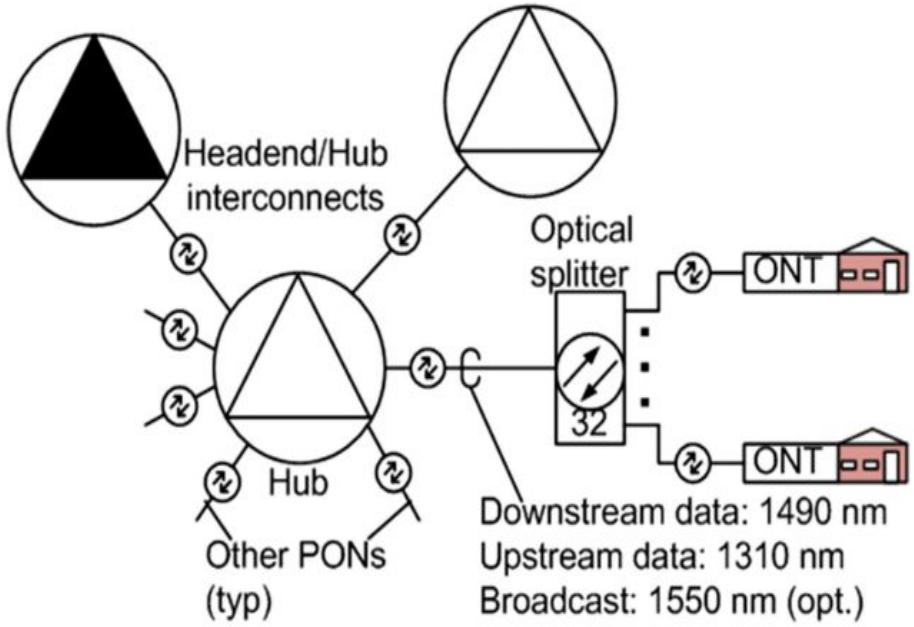
Terminology

- A high-level HFC system is illustrated in the figure.



Common FTTH Systems

- A passive optical network (PON) is the common type of FTTH system to which HFC network may be contrasted.
- The PON starts at the hub and 32 homes are served by it.
- 64 homes are served by some systems.
- The hub is illustrated in the given figure.



Common FTTH Systems

- A number of PONs are served by this hub.
- A single fiber strand defines each PON that feeds a passive optical splitter.
- 32 homes are served by each splitter, with some serving 64 homes.
- The optical network terminal (ONT) is an interface on the home which is also known as the optical network unit (ONU).
- The optical signals are received by the ONT and then converted to the electrical signals.

(contd...)

Common FTTH Systems

- Ethernet for data is the most basic electrical signal and one or more Ethernet ports are contained in the ONT.
- For plain old telephone service (POTS), analog voice ports are there and one or more RF ports for video are also included.
- The PON uses several wavelengths to transport optical signals.
- For downstream data, 1490 nm and 1577 nm are used for GPON and XGPON systems, respectively.

(contd...)

Common FTTH Systems

- For upstream data, 1310 nm, or 1290 nm for 10 Gb/s links are used.
- A 1550nm optical carrier is used to broadcast video.
- The data signals are handled by the equipment, called an optical line terminal (OLT).

(contd...)

Other FTTH Physical Architectures

- The physical layer architecture is used by most systems whereas some use a point-to-point (P2P) architecture where a fiber is run directly from the hub to each subscriber.
- For downstream and upstream communications on different wavelengths, a single fiber is used.
- The advantage of P2P is that the data pipes are not shared by the users due to which each user can have more bandwidth.

(contd...)

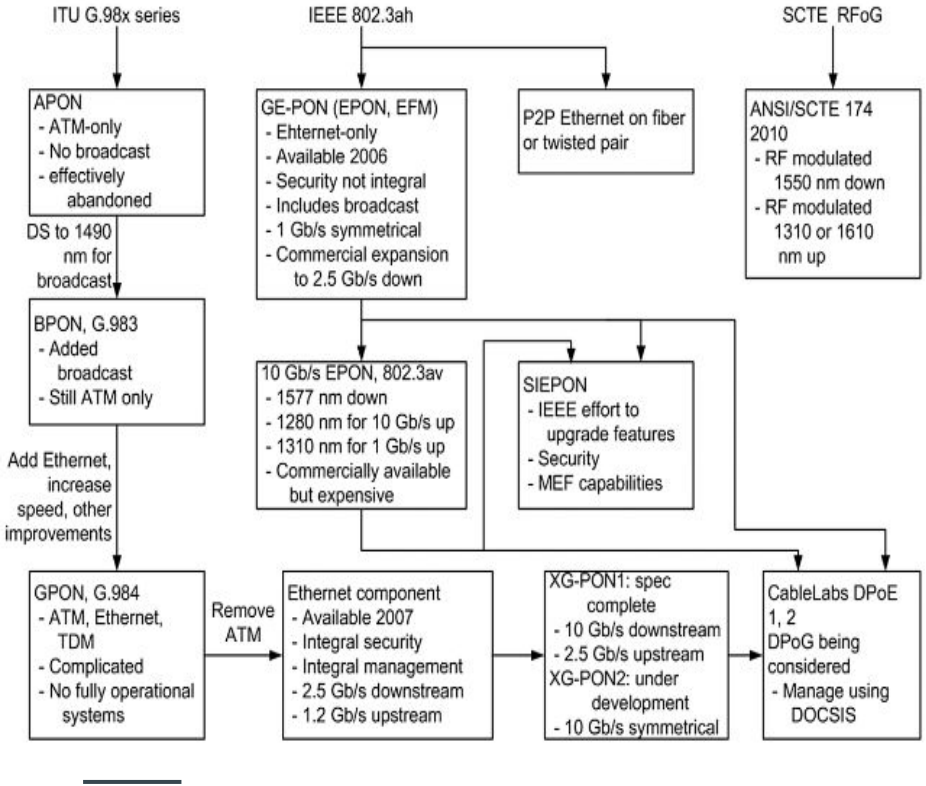
Other FTTH Physical Architectures

- But the concentration of data at the switch in the hub can negate this perceived advantage.
- The low cost ONUs are used by P2P networks .
- The need for more fiber, and higher fiber splicing costs are the offsetting factors that lower the ONU cost.

(contd...)

Other FTTH Physical Architectures

- The FTTH systems are summarized in the given figure.



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Building an FTTx Network

Introduction

- It is not an easy task to build a new physical network.
- It is an expensive proposition to install a physical plant regardless of the technology used.
- The fiber-to-the-home (FTTH) systems are built by many types of organizations, each has different motivation and different financial expectations of that network.
- The FTTH networks are built by the municipal and utility companies in competition with cable TV providers.

(contd...)

Introduction

- 5 Mb/s data service is offered by the FTTH provider which is slower for any FTTH network.
- But the provider thought it plenty, and sized his Internet connection accordingly.
- Moreover, the download speed was increased by the cable operator to at least twice.
- As a result, the FTTH operator was losing the speed race.

(contd...)

Types of Organizations Building FTTH Networks

- FTTH networks are built by a number of different types of organizations depending on the location.
- They are built by large telephone and cable TV companies but smaller telephone companies, municipalities, and independent for-profit utility companies built them in North America.
- Several successful but different early systems built in different countries are the following:

(contd...)

Types of Organizations Building FTTH Networks

- US Municipal Electric System
- Incumbent Local Exchange Carrier, Small European Country
- Northern European Municipal Power Utility
- US Municipality-Owned Utility

(contd...)

The Decision-Making Process

- Great success has been achieved by making proper decision to build an FTTH network.
- There are business, technology, and organizational factors to consider.
  - Business Considerations
  - Technology Considerations
  - Organizational Considerations

(contd...)

Industry Organization

- Firstly, join the FTTH council to get involved with the FTTH industry.
- An annual conference has been sponsored by them which offers training seminars, a chance to meet vendors, and a chance to meet and learn from those who have already put in systems.
- The statistics related to FTTH installations are accessed through the council and training access can also be provided.
- An additional information of interest can be offered to people installing FTTH by the broadband communities.

(contd...)

Industry Organization

- There are many consulting engineering firms who can help with everything from preparing budgets to overseeing construction of the network.

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FTTx Technologies

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EPON I

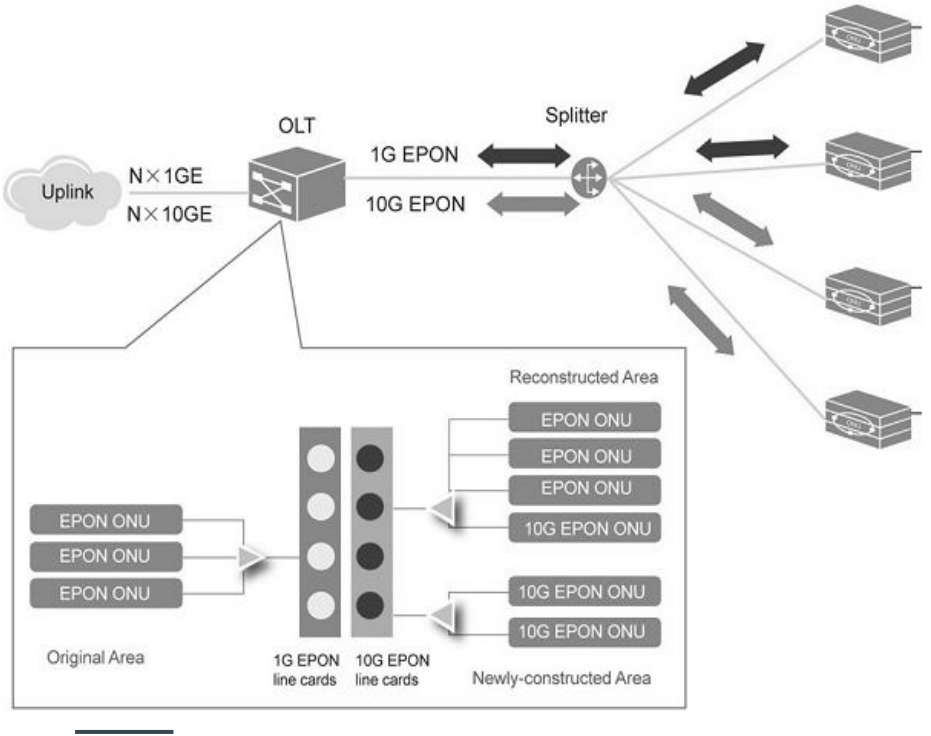
Introduction

- A new type of optical access network technology is GEPON (Gigabit Ethernet Passive Optical Network) that relies on point-to-multipoint architecture and a variety of services are provided over Ethernet by using passive optical fiber transmission.
- It is also known as EPON (Ethernet Passive Optical Network).
- In this, the data is encapsulated with Ethernet and 1 Gbps to 10 Gbps capacity can be offered.

(contd...)

Introduction

- The original PON architecture is followed by EPON.
- There is a connection of DTE to the trunk of the tree which is called Optical Line Terminal (OLT) as shown in the figure.



(contd...)

Introduction

- Its location is at the service provider and connected to Optical Network Unit (ONU) which is the DTE branches of the tree whose location is in the subscriber premises.
- In order to achieve the ONU, the passive splitter is used to pass the signals from the OLT and vice-versa.

(contd...)

Ethernet in the First Mile

- Ethernet in the First Mile (EFM), a new study group, began the standardization process that was established in November 2000 and is based on IEEE 802.3ah standard.
- An access to a P2MP topology has been controlled on the basis of Multi-Point Control Protocol (MPCP) which is a function within the MAC control sub-layer.
- The point-to-point (P2P) emulation sub–layer contains the EPON/MPCP protocol.

(contd...)

Ethernet in the First Mile

- The transmission rate of EPON is symmetric 1.25G, distance is 10KM/20KM, and splitter ratio is > 1:32.
- There are many advantages of EPON that are pointed out by the EFM based on Ethernet as core technology that includes
  - Protocols maturity
  - Technology simple
  - Extension flexibility
  - Users' oriented

(contd...)

Ethernet in the First Mile

- The expensive ATM hardware and SONET equipments are chosen by the EPON System so that it becomes compatible to the existing Ethernet network.
- The system structure can be simplified, cost can be decreased and upgrade flexibility can be improved.
- The main focus of equipment vendors is on optimizing the function and practicability.

(contd...)

BPON ATM Systems

- Large IP Frames and variable sizes are consisted in the vast majority of traffic across the access network that makes the BPON ATM based systems very inefficient.
- Therefore, the opportunity has been created to develop pure Ethernet based EPON, QoS of GigE password, and integrating other emerging Ethernet equipment in a cost-effective manner.
- Ethernet has been becoming the ideal transporter for IP traffic over time.

(contd...)

BPON ATM Systems

- After proposing the FSAN members (Quantum Bridge, Al) for an ATM/Ethernet PON solution, Passive Optical Network (GPON) development has began.
- The popularity of Gbps in the IEEE 802.3ah working group is low.
- G.983, the standard of BPON, is used to draw EPON and GPON for the general concepts that work well.
- The version of enhancements is offered by both of then so that better size IP/Ethernet frames can be accommodated at variable rates Gbps.

(contd...)

Concept of EPON

- The concept of EPON has been introduced by EFM by implementing a point-to-multipoint (P2MP) network topology with passive optical splitters.
- The highest bandwidth is offered by the Ethernet point-to-point fiber at a reasonable cost.
- Relatively high bandwidth has been provided by Ethernet Point-to-multipoint fiber at a lower cost.

(contd...)

Concept of EPON

- The extension of the application of Ethernet was the purpose of the IEEE Std 802.3ah in which access subscriber networks were included so that a significant increase in performance was provided while minimizing operation and maintenance equipment costs.
- The range and reach of Ethernet transport has been significantly expanding for the IEEE 802.3ah EFM standard conclusion so that they can be used in the metro networks.

(contd...)

Concept of EPON

- A variety of flexible and cost effective solutions is allowed to service providers by this standard so that broadband Ethernet services are provided in the access and the metro networks.
- A family of technologies is covered by EFM that has different type of media and signaling speed.
- Any IEEE 802.3 defined network topology can be used on the subscriber premises and after that connection is provided to an Ethernet subscriber access network.

(contd...)

Concept of EPON

- Maximum flexibility can be achieved by using different types of topologies in the EFM technology.

(contd...)

IEEE Std 802.3ah

- In IEEE Std 802.3ah, specifications are included for Ethernet access networks of the subscriber and a nominal rate of 1 Gb/s (expandable to 10 Gb/s) has been supported by IEEE Std 802.3ah EPON for each channel.
- The two wavelengths define these:
  - A downstream wavelength
  - For the shared upstream direction between the user devices

(contd...)

IEEE Std 802.3ah

- The full duplex links are supported by EFM to define a full duplex simplified Media Access Control (MAC).
- Ethernet architecture divides The physical layer is divided in a Physical Medium Dependent (PMD), Physical Medium Attachment (PMA), and Physical Coding Sublayer (PCS) by ethernet architecture.
- A P2MP network topology can be implemented by EPON with appropriate extensions to the undercoat and reconciliation sublayer MAC control.

(contd...)

IEEE Std 802.3ah

- This topology has been supported by the optical fiber under layers physical medium dependent (PMD).
- Physical Layer
  - For P2MP topologies, EFM introduced a family of signaling systems has been introduced by EFM for P2MP topologies for the physical layer that are derived from 1000BASE-X.
  - The extensions of the RS, PCS, and PMA are included with an optional forward error correction (FEC) capacity.

(contd...)

IEEE Std 802.3ah

- The characteristics of the interface are mapped with the 1000BASE-X PCS and PMA sublayers.
- The expected services by the undercoat reconciliation are the PMD sublayer, including MDI.
- There is an extension of 1000BASE-X so that other full duplex media can be supported.
- It is required that the consistent environment is there with the PMD level.

(contd...)

IEEE Std 802.3ah

- Medium Load Interface (MDI)
  - The interface between PMD and the physical media.
  - The signals, the physical media, and the mechanical and electrical interfaces are defined by MDI.
- Physical Medium Dependent (PMD)
  - The interface to the transmission medium is provided by the PMD.
  - Depending upon the connected physical medium's nature, the electrical or optical signals are generated by it.

(contd...)

IEEE Std 802.3ah

- PMD is indicated by D and U suffixes at each end of the link in a PON Ethernet, which transmits in these directions and receives in the opposite direction, i.e., 1000BASE-PX10-D identifies a single downstream PMD and 1000BASE-PX10 U PMD identifies the upstream.
- There can be a simultaneous use of same fibers in both the directions.

(contd...)

IEEE Std 802.3ah

- There is a connection of a 1000BASE-PX-U PMD or 1000BASE-PX-D PMD to the appropriate PMA 1000BASE-X and MDI can support them.
- There is a combination of PMD with management features so that the access can be provided via the management interface.

- Physical Medium Attachment (PMA)
  - The transmission, receipt, clock recovery, and align functions are included in PMA.

(contd...)

IEEE Std 802.3ah

- The PMA provides An independent middle way is provided by PMA for PCS so that the use of a range of bit-oriented physical media series can be supported.
- The codifications bit functions are comprised in the PCS sublayer.
- The Gigabit media independent interface (GMII) is the PCS interface, by which a uniform interface to the Reconciliation sublayer for all implementations of 1000 Mb/s PHY is provided.

(contd...)

IEEE Std 802.3ah

- Gigabit Media Independent Interface (GMII)
  - The interface between the Gigabit MAC layer and the physical layer is referred as the interface GMII.
  - It allows multiple DTE mixed with a variety of implementations from the speed gigabit physical layer.
  - MAC and repeater is included by PCS customers.
  - The Gigabit Media Independent Interface (GMII) precisely defines the PCS interface.

(contd...)

IEEE Std 802.3ah

- The matching of GMII signals is ensured by the Reconciliation sublayer (RS) that defines the service access control medium.
- The independent media is provided by GMII and RS to use an access controller identical media with any type of copper and optical PHY.

- Data Link Layer (Multipoint MAC Control)
  - The standard was supported by the MAC control protocol.
  - There can be implementation and addition of new functions.

(contd...)

IEEE Std 802.3ah

- It is the case of multi-point control protocol (MPCP).
- The Multi-Point Control Protocol defines one of the functions as the management protocol to P2MP.
- The devices of the subscriber are accessed by implementing the multipoint MAC control functionality that contains physical layer devices point to multipoint.
- A point-to-point service is provided by MAC emulation jurisdictions between OLT and the ONU

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EPON II

EPON and Variations

- EPON
  - Original IEEE specification
  - Available after BPON and before GPON
  - 1 Gbps data rate is provided in each direction
  - The ad hoc 802.3ah Working Group has done the EPON specifications within the IEEE 802.3 Subcommittee and is referred to as 802.3 ah

(contd...)

EPON and Variations

- 2.5 EPON
  - Implemented at roughly GPON speeds
  - Uses GPON optics
  - Referred to as Turbo EPON
- 10G-EPON
  - Offers 10 Gbps data rate in downstream and 1 Gbps or 10 Gbps in upstream
  - Uses 1577 nm for downstream data and 1270 nm for upstream data

(contd...)

EPON and Variations

- SIEPON
  - A bridge that extends the abilities of EPON to meet the needs of commercial data carriers

(contd...)

EPON and Variations

- The gap between existing hybrid fiber-coax (HFC) technology and PON technology can be bridged by using the several efforts within the cable TV community:
  - Radio frequency over glass (RFoG)
  - DOCSIS provisioning of EPON (DPoE)
  - EPON Protocol over Coax (EPoC)

(contd...)

MPCP (Multi-Point Control Protocol)

- MPCP is very flexible, easy to implement.
- Five types of messages are used by MPCP where each message is a MAC Control frame and the multiple packet boundaries are reported by ONU/ONT, no delineation overhead has been granted by OLT on a packet boundary.
- The system between an OLT and ONUs associated with a Point-to-Multi-Point (P2MP) PON portion is indicated by MPCP so that the information can be transmitted productively in the upstream heading.

(contd...)

MPCP (Multi-Point Control Protocol)

- The following functions are performed by MPCP:
  - Controls Auto Discovery process.
  - Timeslot/Bandwidth assignment to ONTs.
  - Provides Timing Reference to synchronize ONTs.

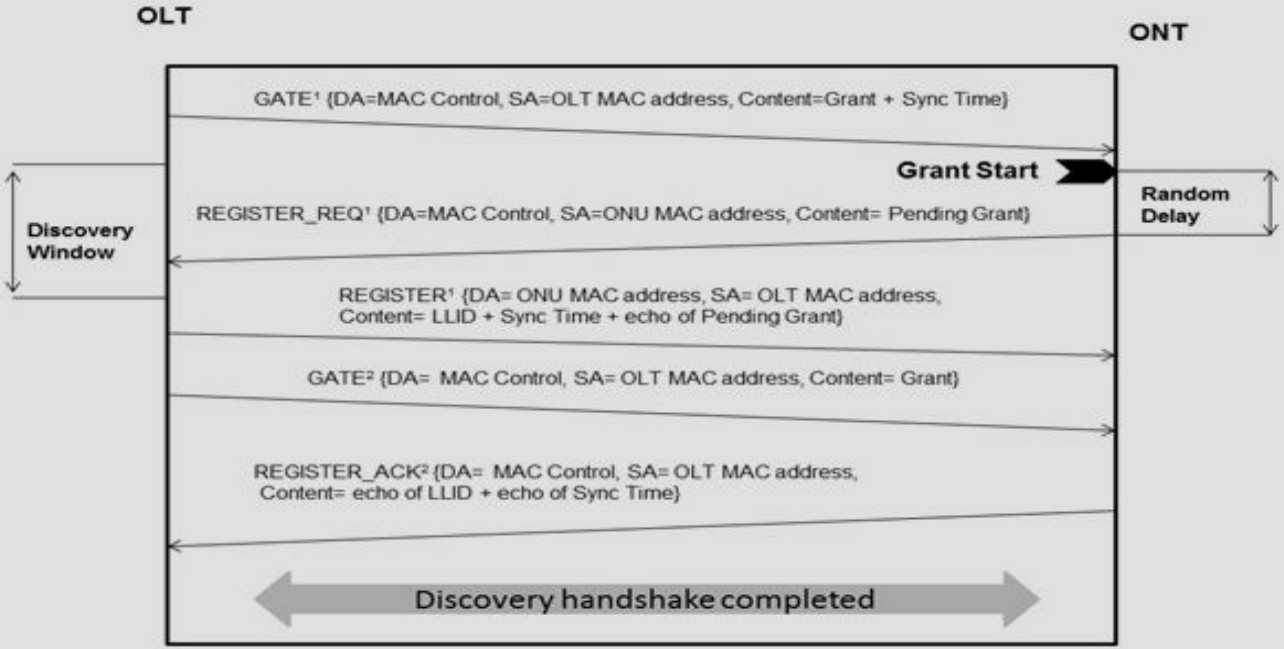
(contd...)

MPCP (Multi-Point Control Protocol)

- Five new MAC control messages introduced by MPCP are:
  - Gate, Report
  - Registered REQ
  - Register
  - Registered ACK
  - Auto Discovery

(contd...)

Message Discovery Sequence Summary



[1] Message sent on broadcast channels
[2] Message sent on unicast channels

DBA EPON

- In EPON, the downstream is indicated by the communication between OLT and ONT, the entire bandwidth is used by OLT to broadcast downstream data towards ONT and on other end, the frames are received by ONT using information available on Ethernet Frames.
- The communication from ONT to OLT is regarded as the upstream that uses single channel communication such that multiple ONTs use one channel which is regarded as data collision.

(contd...)

DBA EPON

- The effective bandwidth allocation scheme is required to avoid this problem by assigning equal resources to ONTs and ensuring the QoS at the same time.
- This scheme is known as Dynamic Bandwidth Allocation (DBA) algorithm.
- The report and gate messages are used by the DBA so that transmission schedule can be built and conveyed to the ONTs.

(contd...)

DBA EPON

- DBA Characteristics
  - Different services are provided by EPON with optimum QoS and effective allocation of bandwidth by using different DBA allocation so that the demand of current and future applications can be easily met.
  - The two different types of DBA algorithms for the EPON are the following:
    - Accommodation of traffic fluctuations.

(contd...)

DBA EPON

- Provides QoS to different types of traffic.
- Avoiding Frame Collisions, Managements of Real Time Traffic through QoS and Management of Bandwidth for each Subscriber along with Decrease Delay on Low Priority Traffic.

- EPON Frame Format
  - EPON operation is based on the Ethernet MAC and EPON frames are based on GbE frames, but extensions are needed

(contd...)

DBA EPON

- Clause 64
- Clause 65
- They transmit when granted.
- Constant time through MAC stack
- Maintain accurate local time

(contd...)

DBA EPON

- EPON Header
  - Standard Ethernet starts with an essentially content-free 8B preamble
    - 7B of alternating ones and zeros 10101010
    - 1B of SFD 10101011
  - Some of the preamble bytes are overwritten by EPON to hide the new PON header.

(contd...)

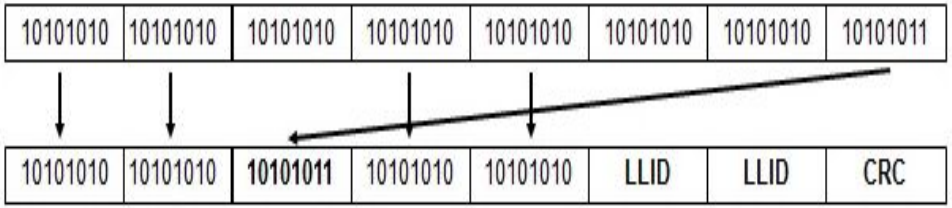
DBA EPON

- The following factors are contained in the LLID field:
  - MODE (1b)
    - Always 0 for ONU
    - 0 for OLT unicast, 1 for OLT multicast/broadcast
  - Actual Logical Link ID (15b)
    - Identifies registered ONUs
    - 7FFF for broadcast

(contd...)

DBA EPON

- CRC protects from SLD (byte 3) through LLID (byte 7).



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Security

- Downstream traffic broadcasts to all ONUs, so the reprogramming of ONU is easy for a malicious user and desired frames are captured.
- Upstream traffic has not been exposed to other ONUs, so there is no need of encryption. The fiber-tappers are not considered because any standard encryption method is not provided by EPON, but
  - Can supplement with IPsec or MACsec
  - The proprietary AES-based mechanisms have been added by many vendors.

(contd...)

Security

- Churning mechanism is used by BPON which was a low cost hardware solution (24b key) with several security flaws, such as:
  - Engine was linear - simple known-text attack.
  - 24b key turned out to be derivable in 512 tries.
- Therefore, AES support has been added in G.983.3, which is now used in GPON.

(contd...)

QoS – EPON

- High QoS is required in many PON applications (e.g. IPTV) and QoS is left to higher layers by EPON like:
  - VLAN tags.
  - P bits or DiffServ DSCP.
- In addition to these, there is a crucial difference between LLID and Port-ID
  - There is always 1 LLID per ONU.
  - There is 1 Port-ID per input port - there may be many per ONU.
  - This makes port-based QoS simple to implement at PON layer.

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GPON I

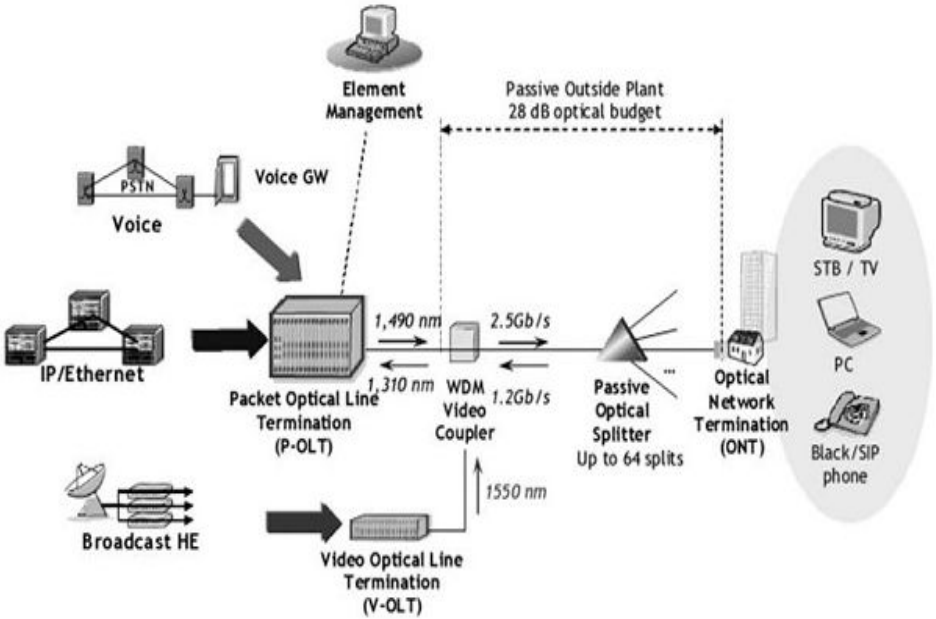
Introduction

- An Optical System for the Access Networks is called GPON (Gigabit Passive Optical Networks) which is based on G.984 series of ITU-T specifications.
- With a 28dB optical budget, a 20 km reach is provided by it by using class B+ optics with 1:32 split ratio.

(contd...)

Introduction

- Figure shows the typical GPON system.



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Introduction

- The following rates are supported by GPON:
  - 155 Mbps upstream, 1.24416 Gbps downstream
  - 622 Mbps upstream, 1.24416 Gbps downstream
  - 1.24416 Gbps upstream, 1.24416 Gbps downstream
  - 155Mbps up, 2.48832 Gbps downstream
  - 622 Mbps up, 2.48832 Gbps downstream
  - 1.24416 Gbps up, 2.48832 Gbps downstream
  - 2.48832 Gbps up, 2.48832 Gbps downstream

(contd...)

Introduction

- Both ATM and GEM encapsulation is supported by GPON.
- Both native TDM and Data are supported by GEM (GPON Encapsulation Method).

GPON Features

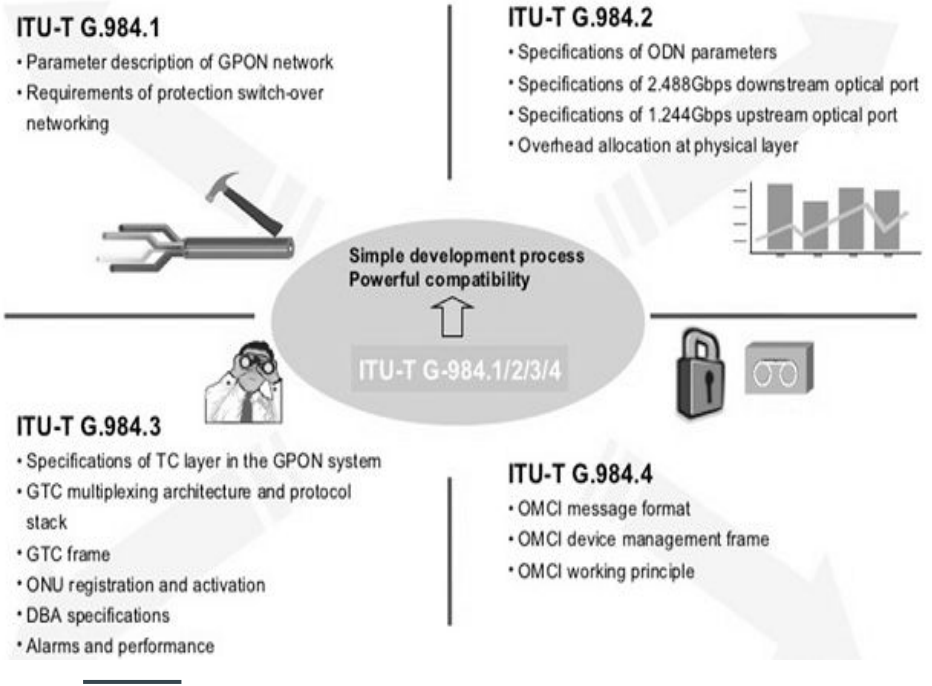
- Downstream transmission
  - 2.4 Gbps
  - BW for one ONT is sufficient for supplying multiple HDTV signals
  - QOS allows to delay sensitive traffic (voice)
- Upstream transmission
  - 1.24 Gbps
  - Guaranteed minimum BW can be
  - Heavy users are assigned with unused time-slots
  - QoS allows to delay sensitive traffic (voice)

Need for GPON

- Triple Play services are supported
- The high-bandwidth transmission is supported by it so that the bandwidth hurdle of the access over twisted pair cables can be broke down.
- The network nodes can be reduced.
- The service coverage of upto 20 km can be supported.

GPON Standards

- The previous BPON specifications are used to build GPON standards.
- The specifications are:
  - G.984.1 – This document describes the Gigabit-Capable Passive Optical Network general characteristics.



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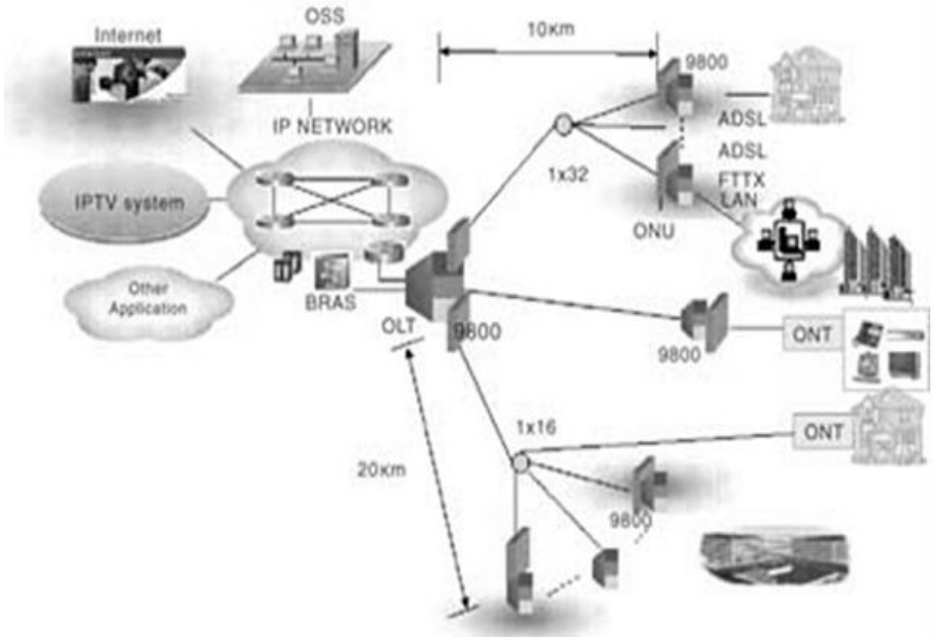
GPON Standards

- G.984.2 – This document describes the Gigabit-Capable Passive Optical Network Physical media-Dependent layer specification.
- G.984.3 – This document describes the Gigabit-Capable Passive Optical Network Transmission Convergence Layer Specification.
- G.984.4 – This document describes the Gigabit-Capable Passive Optical Network ONT Management and Control Interface Specification (OMCI).

GPON Architecture

- The multiple ONTs are served by the GPON OLT through the PON port.
- TDM is used for downstream transmission i.e., from OLT to ONT and TDMA is used for upstream transmission i.e., from ONT to OLT.



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GPON Architecture

- There may be symmetrical or asymmetrical PON system.
- A one-way distributive service can be supported by using PON and fiber infrastructure, eg. Video at a different wavelength.

GPON Physical-Media Dependent Layer

- The physical layer specification of the GPON system is G.984.2.
- The areas addressed by the physical layer are:
  - Optical performance in terms of data rate
  - The class of optical fiber components
  - The timing and control of the optical power
  - Forward error correction

(contd...)

GPON Physical-Media Dependent Layer

- An optical system has one of the basic requirement of providing components with sufficient capacity so that the optical signal can be extended to the expected range.
- On the basis of power and sensitivity, there are three categories or classes of components, such as:
  - Class A optics: 5 to 20dB
  - Class B optics: 10 to 25dB
  - Class C optics: 15 to 30dB

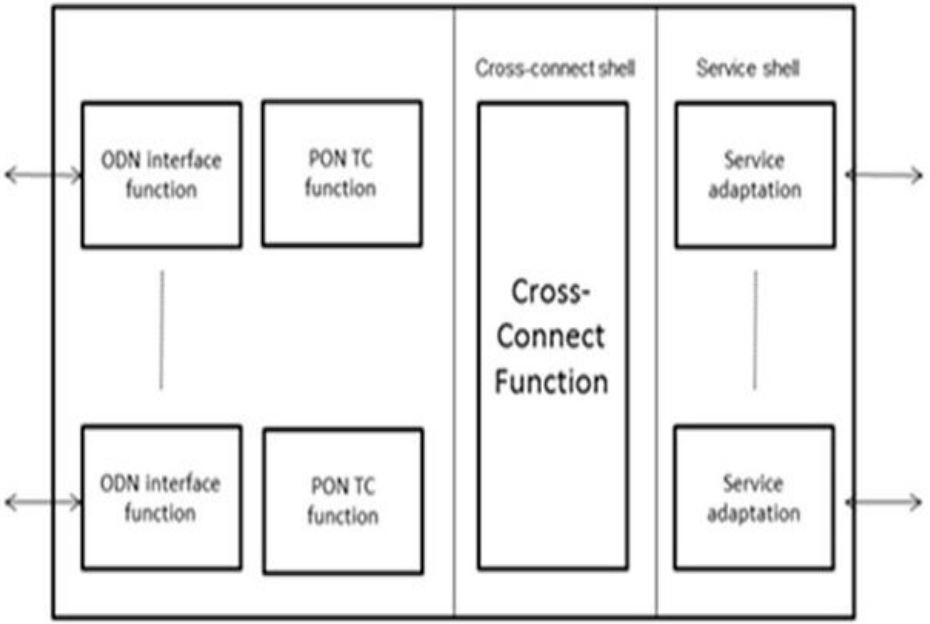
Optical Line Terminal (OLT)

- The service node interface (SNI) (typically 1 Gbps and/or 10 Gbps Ethernet LAN interfaces) is provided by the OLT towards the core network.
- GPON is controlled by the OLT.
- There are three major parts of OLT, such as:
  - Service port interface function
  - Cross-connect function
  - Optical distribution network (ODN) interface

(contd...)

Optical Line Terminal (OLT)

- Figure shows the functional block diagram of OLT.



PON Core Shell

- There are two parts of the core of the PON, i.e.,
  - ODN interface function
  - PON TC function
- OAM, media access control, framing, DBA, delineation of protocol data unit (PDU) for the cross-connect function and the ONU management are included in the PON TC function.

(contd...)

PON Core Shell

- Cross-connect shell – A communication path is provided between the PON core shell and the service shell by this shell.
- Service shell – The translation between service interfaces and the TC frame interface of the PON section is provided by this shell.

ONU/ONT

- A single PON interface is used with the Optical Network Unit (ONU) for operation or maximum two interfaces are also used for link protection purposes.
- If out of these fibers one is cut then other fiber is used to access the ONU and is known as PON protection or Link Protection.
- In link protection, the link is protected as well as the traffic is aggregated so it is also known as link aggregation.

(contd...)

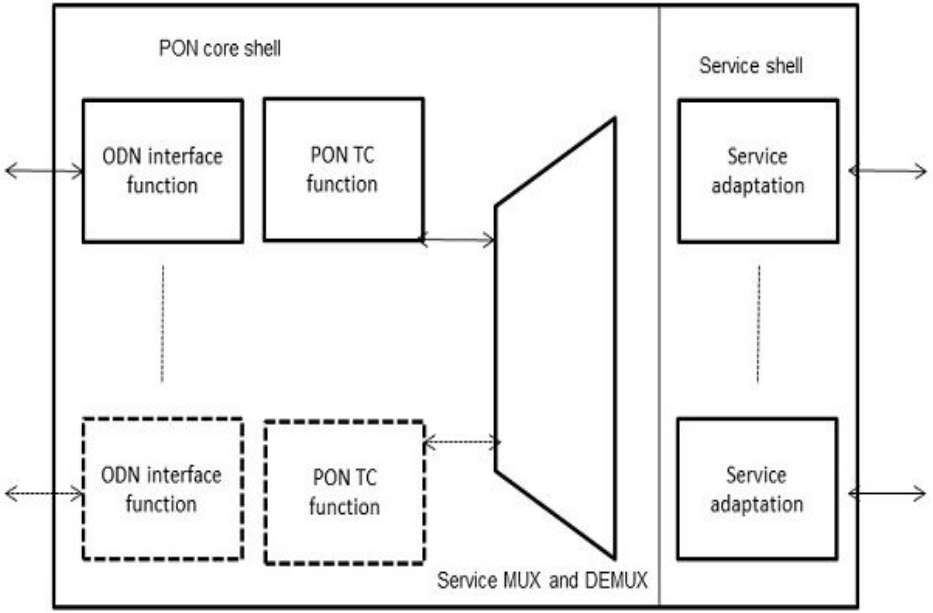
ONU/ONT

- the Customer devices are connected to the PON side by using the service MUX and DEMUX function.
- For single subscriber use, Optical Network Terminal (ONT) is designed and for multiple subscriber use, Optical Network Unit (ONU) is designed.
- The PON can be shared by up to 128 ONTs or ONUs by using splitters.

(contd...)

ONU/ONT

- Figure shows the functional block diagram of ONU/ONT.



ONU/ONT Interfaces

- There are many user-network interface ports of optical network terminal (ONT) to connect to the OLT at uplink side for SNI.
- Four FE/GE ports are there towards UNI i .e.
  - UNI Ports for Residential ONT
  - UNI ports for a business ONT
- The GPON fiber is terminated by the optical network unit (ONU) and for multiple subscribers there are much more user network interface (UNI).

(contd...)

ONU/ONT Interfaces

- UNI interface can be ADSL2+, VDSL2, Power Line, MoCA or HPNA.
- There may not a direct connection of UN UNI to a CPE equipment of subscriber according to the interface ports type.
- The network termination (NT), placed at the final location of the subscriber, is used to connect the UN UNI.
- The subscriber CPE equipment, such as a PC, Wireless Router, Telephone, IP Video Set-Top Box, or Set-Top Box, RF Video, and so on is terminated by NT.

(contd...)

ONU/ONT Interfaces

- the function of an ONU and an NT is combined by an ONT into a single device.
- Hence, the ONT becomes the most cost effective solution by combining these two so that GPON services are provided to local and single-family, small, and medium enterprises.
- A more appropriate solution,when CAT-5 copper cable is laid, is served by ONU for on campus clients as students, hostels, schools, colleges, hospitals, or corporate offices.

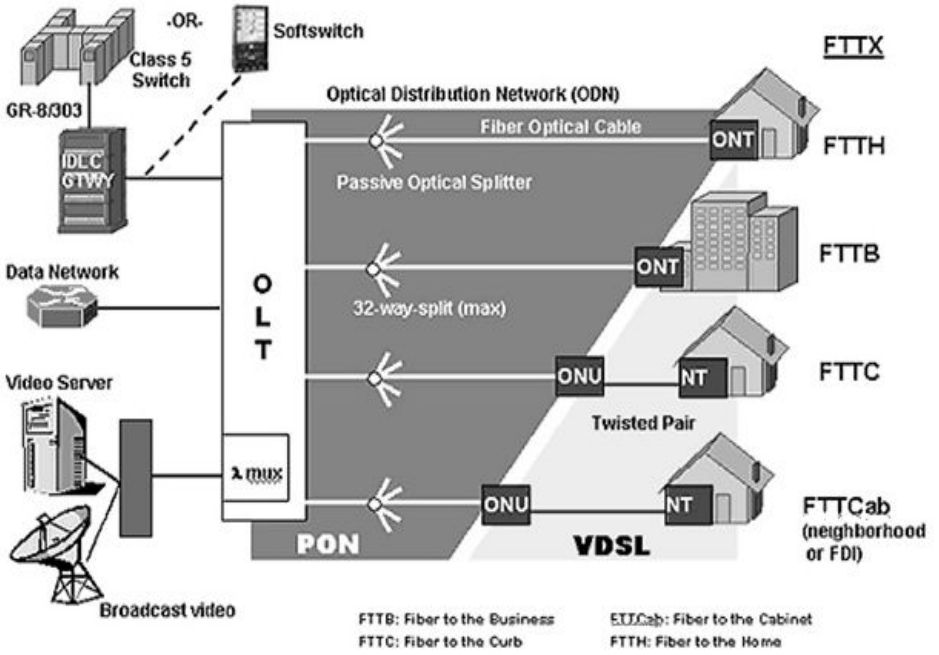
Optical Distribution Network

- A single mode optical fiber and cable; the optical fiber ribbon cables, splices, optical connectors, passive optical splitters and passive branching components are consisted in the GPON ODN.
- The single fiber is divided into multiple fibers by using the ODN optical splitters that will connect to different buildings and individual homes.
- The location of the splitters can be anywhere in the ODN, from the Central Office (CO)/ Local Exchange (LE) to the customer premises and the size may be variable.

(contd...)

Optical Distribution Network

- The splitters are denoted by [n:m], where ‘n’ is the number of input (towards OLT) = 1 or 2, and ‘m’ is the number of outputs (towards ONT) = 2,4,8,16,32,64.
- Figure shows the typical ODN.



GPON Encapsulation Method (GEM)

- The GPON transmission convergence layer has the data transport scheme called GEM.
- A connection-oriented, variable-length framing mechanism is provided by it to transport data services over the passive optical network (PON).
- GEM is designed to not to be dependent on the the type of the service node interface at the OLT as well as the types of UNI interfaces at the ONUs.

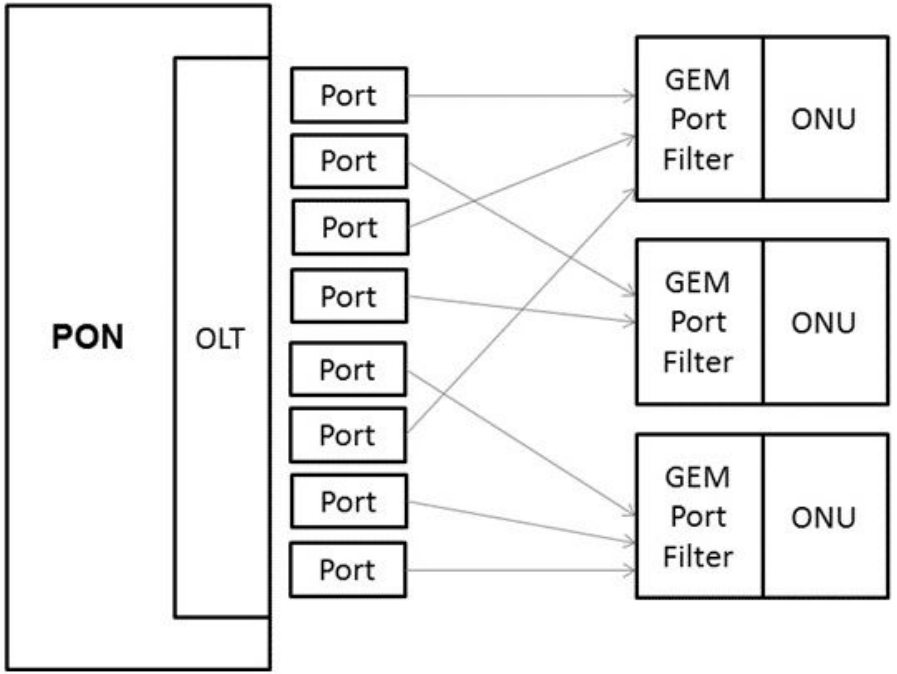
Downstream Traffic

- There is a centralization of the traffic multiplexing functions for downstream traffic in OLT.
- The GEM frames are identified by the GEM Port-ID, which is a 12-bit number assigned to the individual logical connections by the OLT.
- GEM frames are belonged to different logical connections of downstream.
- The downstream GEM frames are filtered by each ONU on the basis of their GEM Port-IDs.

(contd...)

Downstream Traffic

- Figure shows the downstream traffic i.e. from OLT to ONU/ONT.



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GPON II

Upstream Traffic

- The OLT granted upstream transmission opportunity or bandwidth allocation to the traffic bearing entities within the ONU.
- The allocation IDs (Alloc-IDs) identifies the traffic-bearing entities which is a 12-bit number assigned by the OLT to an ONU so that a traffic-bearing entity can be identified.
- Within the ONU, upstream bandwidth allocations are received by it.
- There is a multiplexing of the bandwidth allocations to different Alloc-IDs in time.

(contd...)

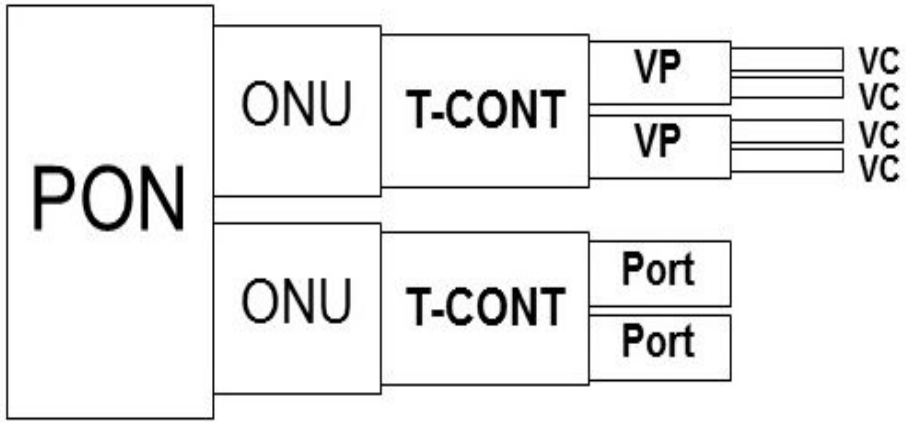
Upstream Traffic

- The GEM Port-ID can be used by the ONU as a multiplexing key within each bandwidth allocation so that the GEM frames belonged to different upstream logical connections can be identified.
- A group of logical connections is represented by a Transmission container (T-CONT) which is an ONU object.
- To assign upstream bandwidth on the PON, it acts as a single entity.
- There is a carrying of service traffic to different GEM ports and then to different T-CONTs on the basis of the mapping scheme.

(contd...)

Upstream Traffic

- There can be a flexible mapping between the GEM port and the T-CONT.
- A GEM Port is corresponding to a T-CONT or multiple GEM Ports are corresponding to the same T-CONT.



(contd...)

GPON Transmission Convergence Layer (GTC)

- The protocol suite of GPON contains a protocol layer positioned between the physical media dependent (PMD) layer and the G-PON clients.
- GTC framing sub-layer and GTC adaptation sub-layer is combined to compose the GTC layer.
- The GTC payload, arrives at all the ONUs, carries the GEM frames in the downstream direction.
- The frames are extracted by the ONU framing sub-layer.

(contd...)

GPON Transmission Convergence Layer (GTC)

- The frames are filtered by the GEM TC adapter on the basis of their 12-bit Port-ID.
- The GEM client function allows the only frames with the appropriate Port-IDs.
- One or more T-CONTs are carried by the GEM traffic in the upstream direction.
- The transmission associated with the T-CONT is received by the OLT.

(contd...)

GPON Transmission Convergence Layer (GTC)

- There is a forwarding of the frames to the GEM TC adapter and then to the GEM client.
- GTC Layer Framing
  - The duration of the downstream frame is 125 microseconds and its length is 38880 bytes.
  - It corresponds to 2.48832 Gbit/s data rate in the downstream.
  - The physical control block downstream (PCBd) and the GTC payload section are consisted in the downstream GTC frame.

(contd...)

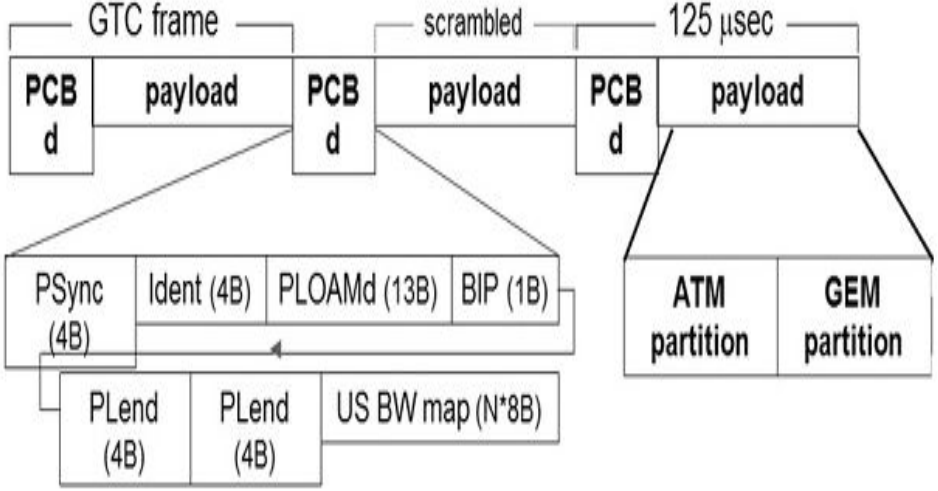
GPON Transmission Convergence Layer (GTC)

- The length of GPON Transmission Convergence frames is 125 Msec always i.e. 19440 bytes/frame for 1244.16 rate and 38880 bytes/frame for 2488.32 rate.
- The Physical Control Block downstream and payload are consisted in each frame of GTC.
- Information about sync, OAM, DBA, and so on is contained in the PCBd.

(contd...)

GPON Transmission Convergence Layer (GTC)

- Either ATM and GEM partitions or both are there in a payload.
- Figure shows the GTC frame.
- The duration of the upstream frame of the GTC is 125 µs.



(contd...)

GPON Transmission Convergence Layer (GTC)

- In GPON system, the size of the upstream GTC frame is 19,440 bytes with uplink of the 1.24416 Gbit/s.
- Number of transmission bursts receiving from one or more ONUs are contained in each frame of upstream.
- An upstream physical layer overhead (PLOu) section is contaied in each upstream transmission burst.

(contd...)

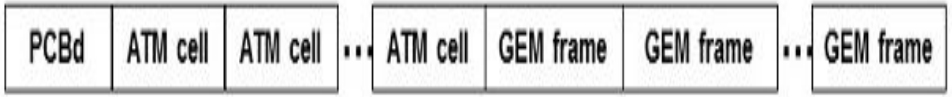
GPON Transmission Convergence Layer (GTC)

- The individual Alloc-IDs has allocation of one or more bandwidth allocation intervals.
- The common time reference is provided by the downstream GTC frame for the PON and provides the common control signaling for upstream.

(contd...)

GPON Payloads

- There are two sections of payload of GTC, such as:
  - ATM partition
  - GEM partition
- ATM partition
  - The PCBd is specified as Alen (12 bits).



(contd...)

GPON Payloads

- The number of 53B cells are specified by Alen in the ATM partition.
- There is no ATM partition if Alen = 0.
- There is no GEM partition if Alen = payload length/53
- GTC frame is aligned with ATM cells.
- In ATM header, ATM cells based on VPI are accepted by ONUs.

(contd...)

GPON Payloads

- GEM partition
  - Frames delineated with GEM can have variable length unlike ATM cells.
  - The GEM partition contains any number of GEM frames.
  - GEM frames are accepted by ONUs on the basis of 12b Port-ID in GEM header.

(contd...)

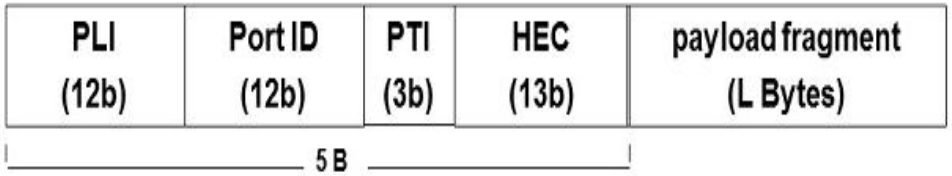
GPON Encapsulation Mode

- The inefficiency because of the ATM cell tax was a common complaint against BPON.
- GEM and ATM are similar.
- It has HEC-protected header with a constant size.
- The variable length frames helps to avoid large overhead.
- Any packet type and even TDM can be supported by GEM, so it is generic.

(contd...)

GPON Encapsulation Mode

- Fragmentation and reassembly can also be supported by GEM.
- GEM is GFP based and the following fields are contained in the header:
  - Payload Length Indicator
  - Port ID



(contd...)

GPON Encapsulation Mode

- Payload Type Indicator
- Header Error Correction field

(contd...)

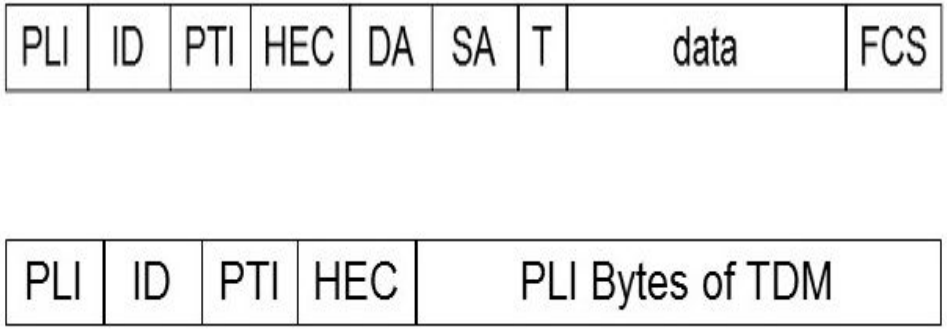
Ethernet/TDM over GEM

- When Ethernet traffic is transported over GEM:
  - Encapsulation of only MAC frame (no preamble, SFD, EFD)
  - Fragmentation of MAC frame
- When TDM traffic is transported over GEM
  - There is a polling of TDM input buffer every 125 Msec.
  - Insertion of TDM PLI bytes into payload field.
  - There is a variation in the length of the TDM fragment by ± 1 Byte because of frequency offset.

(contd...)

Ethernet/TDM over GEM

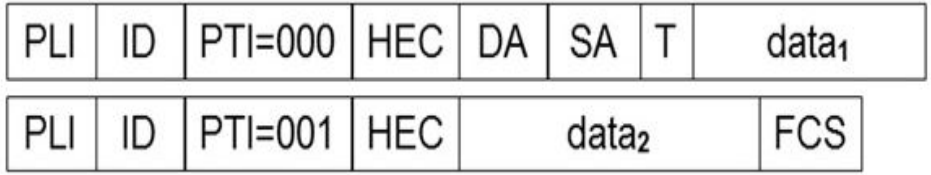
- 3 msec round trip latency.
- Figure shows Ethernet and TDM over GEM, respectively.



(contd...)

Ethernet/TDM over GEM

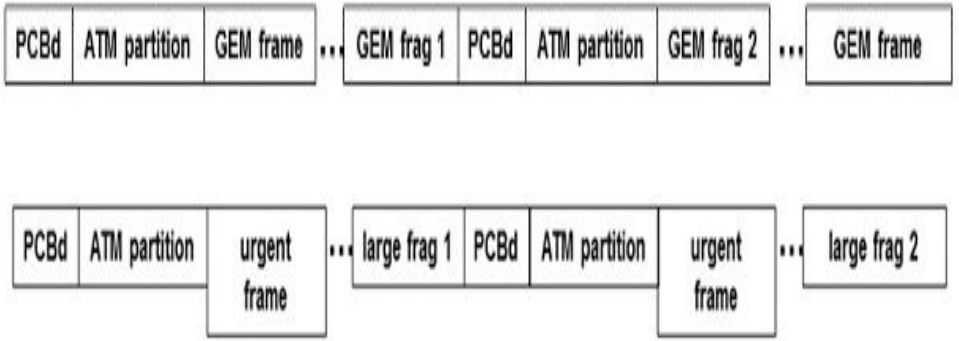
- GEM can fragment its payload.
- Figure shows the un-fragmented Ethernet frame.
- The fragmented Ethernet frame is shown in the second figure.



(contd...)

Ethernet/TDM over GEM

- Because of the following two reasons the payloads are fragmented by the GEM:
  - Reason 1 – GTC frame is not straddled by GEM frame.
  - Reason 2 – For delay-sensitive dataGEM frame may be pre-empted.



(contd...)

GPON Encryption

- In the counter mode, AES-128 is used to encrypt OLT.
- There is an encryption of payload only.
- There is an alignment of encryption blocks to the GTC frame.
- OLT and all ONUs share the counter as follows:
  - 46b = 16b intra-frame + 30 bits inter-frame.
  - Intra-frame counter increments every 4 data bytes.
  - Reset to zero at beginning of DS GTC frame.

(contd...)

GPON Encryption

- A unique symmetric key is agreed by the OLT and each ONU.
- ONU is asked by OLT for a password.
- ONU is informed by OLT about the precise time to start using new key.

(contd...)

QoS

- The QoS is treated explicitly by GPON.
- For time-sensitive applications, QoS is facilitated by constant length frames.
- Transmission containers are of 5 types, such as:
  - Type 1 – fixed BW.
  - Type 2 – assured BW.
  - Type 3 – allocated BW + non-assured BW.

(contd...)

QoS

- Type 4 – best effort.
- Type 5 – superset of all of the above.

- Several PON-layer QoS features are added by GEM such as:
  - Large number of low-priority frames are pre-empted by using the fragmentation.
  - The queuing algorithms are used PLI - explicit packet length.
  - Congestion indications are carried by PTI bits.

(contd...)

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Other Network Standards I

Introduction

- Other fiber-to-home standards are there besides the EPON and GPON standards.
- There are some standalone standards and some are supplementary standards that enhance other standards, or bridge standards.

(contd...)

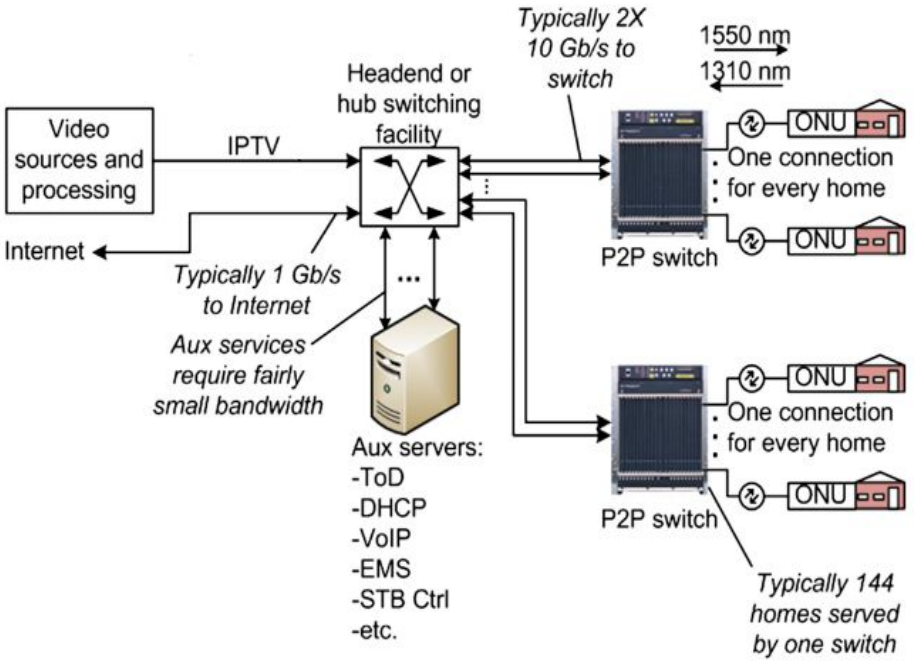
Point-to-Point Systems

- Some operators installed point-to-point (P2P) as an alternative to EPON and GPON.
- It is also referred to as Active Ethernet (AE).
- There is an installation of a single home-run fiber from the headend to each customer.
- There are low optical signal levels because no splitting losses are there to account for.

(contd...)

Point-to-Point Systems

- There has been a dedicated Ethernet port in the headend, a dedicated fiber to home or business, and a dedicated optical network terminal (ONT) at the home for each subscriber in the P2P architecture.
- A P2P architecture is shown in the figure.



(contd...)

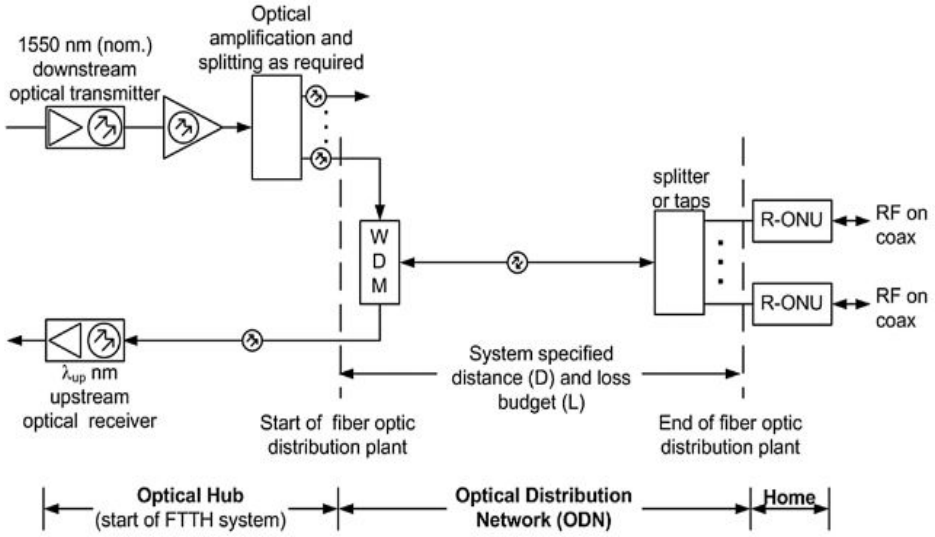
RF Over Glass

- This is a very different PON implementation, but it uses the same fiber configuration, with different equipment on the ends.
- In RFoG, there is a modulation of downstream carrier with many radio frequency (RF) carriers on 1550 nm.
- The upstream data is modulated onto RF carriers on either 1310 nm or 1610 nm.
- The advantage of RFoG for a cable operator is that it allows using termination equipment which is already being used.

(contd...)

RF Over Glass

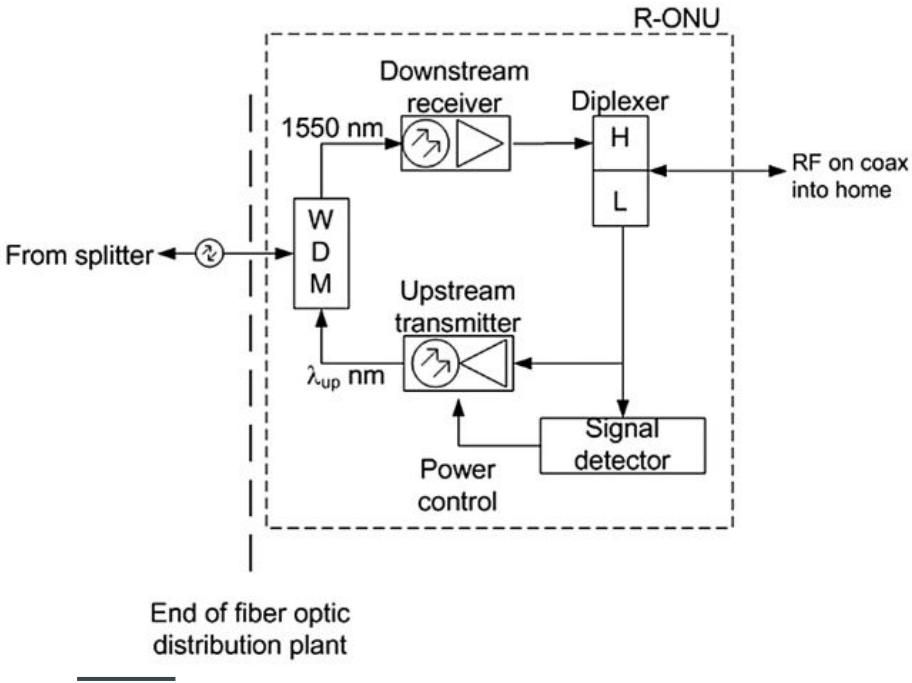
- The block diagram of the RFoG system is shown in the figure.



(contd...)

RF Over Glass

- The R-ONU is illustrated in the figure.



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Other Network Standards II

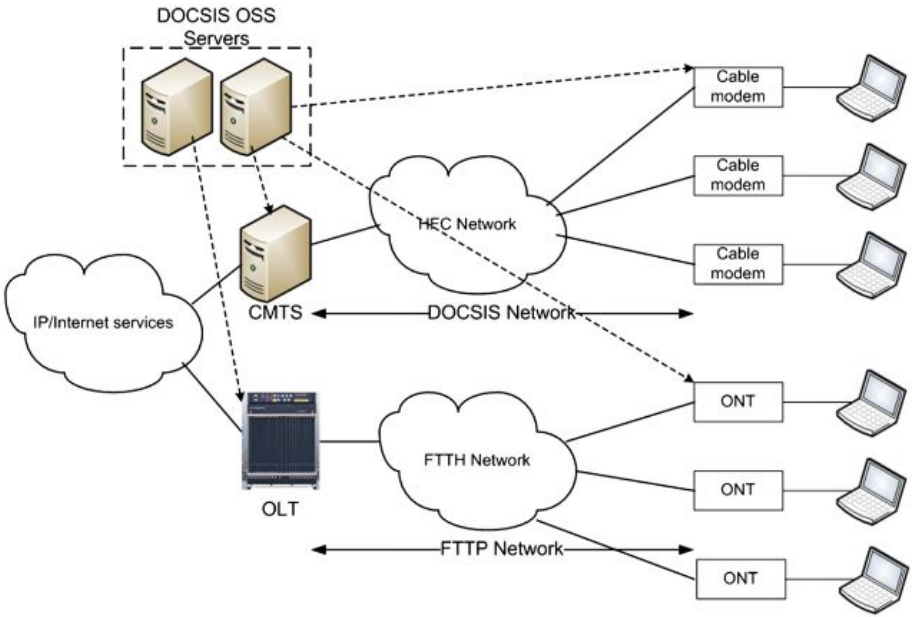
DOCSIS Provisioning Over EPON

- DOCSIS, a standards-based architecture, is used by the cable TV industry to deploy the broadband services.
- The two network elements are defined by the DOCSIS architecture beginning with the cable modem termination system (CMTS) at the headend and the cable modem (CM) placed within the premises of the subscriber.
- A network supporting DPoE service models such as IP HSD (high-speed data) or MEF (Metro Ethernet Forum) operate correspondingly to a similar DOCSIS network.

(contd...)

DPoE

- DPoE and cable modems are shown in the figure.



(contd...)

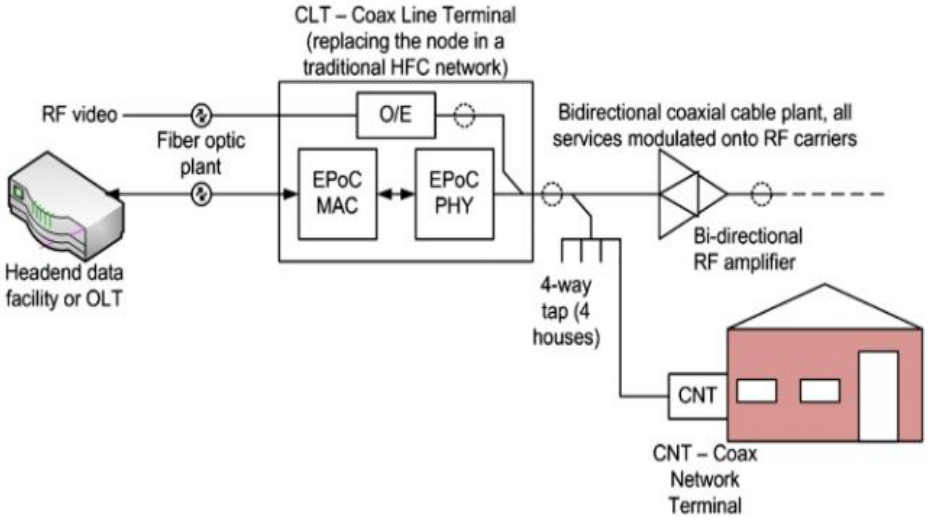
EPON Provisioning Over Coax

- A market requirement for the development of a standard so that the IEEE 802.3ah point-to-multipoint architecture can be extended to operate over a coax-based PHY (physical) layer has been seen by a group of operators in China which had joined by the operators of North America in 2011.
- The delivery of the same scheduling, management and quality of service (QoS) was the goal of this community so that the models can operate the same way regardless of an optical or coax connection to the subscriber.
- There was an initiation of a call for interest (CFI) during this period.

(contd...)

EPoC

- The IEEE 802.3 Working Group chartered the formation of the EPoC Task Force as the IEEE 802.3bn Task Force.
- The EPoC concept was shown in the figure.



(contd...)

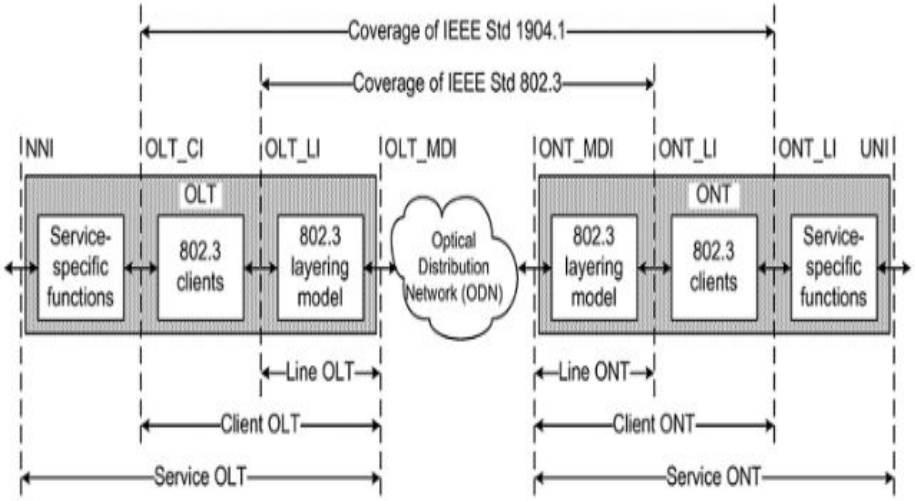
Service Interoperability in Ethernet Passive Optical Networks

- There was a formation of SIEPON working group that focused on the development of a standards-based architecture for EPON devices to provide two purposes:
  - OLT and ONT equipment suppliers' open competition
  - Direct competition for drive innovation and price reductions within the community of EPON.

(contd...)

SIEPON

- The figure shows the level of coverage the IEEE 1904.1-2013 standard supports.



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Planning to Implement the Network

Introduction

- There can be consideration and addressing of the requirements, design, and implementation stages of the project during the planning process for the design and implementation of the network.
- There will be understanding and assurance of the success of the network in the planning process.

(contd...)

The Planning Requirements

- Technical Goals
  - The services and products are provided to allow high-bandwidth connectivity.
  - FTTx made it possible to deploy new types of services.
- Business Goals
  - The aging telecommunications infrastructure has been replaced with newer fiber-based facilities and leased facilities can be migrated to the owned facilities.

(contd...)

The Planning Requirements

- The state-of-the-art and future-proofed telecommunications infrastructure has been provided.
- The competitive position has been improved relative to other telecommunications providers.
- The operating expenses has been reduced as compared to existing non-optical fiber plants.
- The operation of the new network has been integrated into the organization's existing business structure and the network is leveraged for the organization's core utility services.

(contd...)

The Planning Requirements

- Access Goals
  - The wider residential telecommunications connectivity has been provided for underserved constituents of the community.
  - The network operators are allowed to introduce future-proofed technologies into the telecommunications market in the local served community or serving area.

(contd...)

The Planning Requirements

- Top-level requirements mapping to technical requirements
  - Inside plant
  - General networking
  - Services deployment
  - Management systems
  - Outside plant

(contd...)

Technical Requirements

- Inside plant requirements
  - FTTx Equipment
    - Includes the optical line terminal (OLT) and optical network terminal (ONT) device requirements.
    - Also includes ancillary customer premises equipment (CPE) devices which connect to the ONT for:
      - Data services
      - Video services

(contd...)

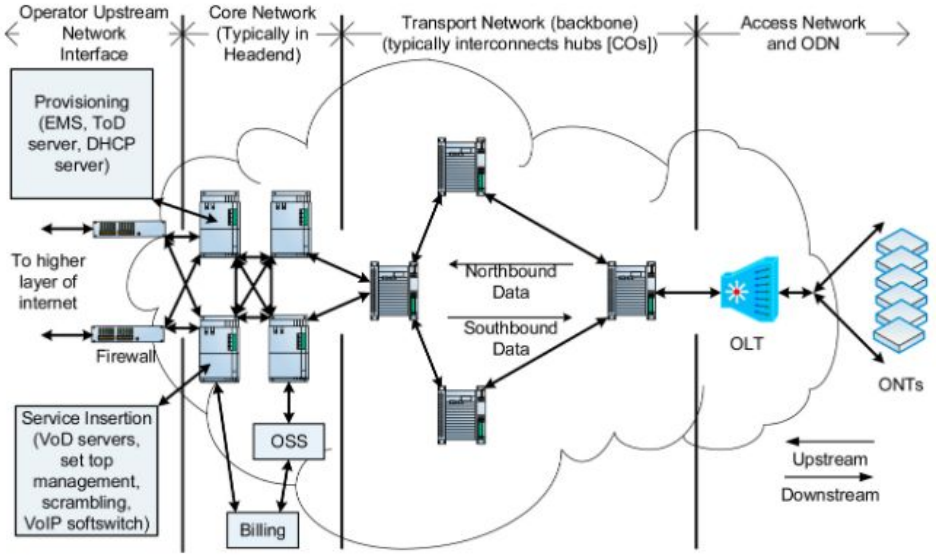
Technical Requirements

- Voice-over-Internet-Protocol (VoIP) services
- General networking requirements
  - Network Partitioning
    - The form of multilayer switching and routing devices is taken by the equipment in this area with high capability for packet processing and a large amount of connected equipment.

(contd...)

Technical Requirements

- The partitions of the overall network implementation is shown in the figure.
  - Upstream network interface partition
  - Core network partition
  - Transport network partition
  - Access network partition



(contd...)

Technical Requirements

- Services deployment requirements
  - The requirements related to the insertion, network support, and premise distribution of individual service types are considered in the services deployment category.
  - There is a break down of every FTTx network implementation into the deployment of the triple-play services (data, video and voice).
  - The services may not be deployed at the same time, with the implementation of one or two services first and other services later.

(contd...)

Technical Requirements

- Management systems requirements
  - There are three categories for the development of sets of requirements for network management:
    - Provisioning systems
    - Business support systems
    - Operational support systems

(contd...)

Technical Requirements

- Outside plant requirements
  - The requirements related to the creation of a well-designed and maintainable ODN are the outside plant (OSP) requirements.
  - The skills are required for locating fiber cabinets, passive splitters and test points in the optical plant such as fiber trenching, fiber cable and duct burial, aerial fiber rigging, optical enclosure and cabinet deployment, and fiber splicing.

(contd...)

Technical Requirements

- A contracting agency implements the OSP which are skilled at the methodologies used for ODN implementation.
- The OSP contracting agency can help with the choices available to the operator and current best practices in ODN deployment.

(contd...)

Open Access Networks

- There are a number of service providers in an open access network which sell retail services over the same access network infrastructure simultaneously and the subscribers are allowed to decide from which service provider they will purchase their services.
- In many regions of the world, the open access networks are becoming increasingly popular.
- An open access model is provided by the special requirements for the FTTx network.

(contd...)

Open Access Networks

- All services are applicable with the open access model.
- IPTV provides the video services for an open access model.
- An open access network transfers all of the service data to and from outside the network operator's domain.

(contd...)

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Outside Plant

Introduction

- The part of the network between the headend and the ONT on or in the homes of the subscribers is the OSP.

(contd...)

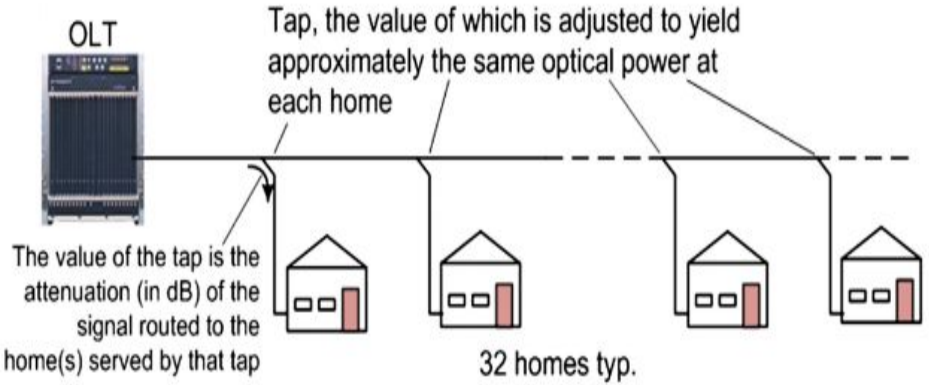
Homerun Fibers

- Each home is served with its own fiber in the home-run configuration from the headend.
- Homerun fiber is also known as point-to-point, P2P, and active Ethernet (AE).
- The highest ultimate bandwidth is offered by the homerun fibers, since no fiber shares bandwidth between any two users but this is not applicable at the headend.

(contd...)

Distributed splitting

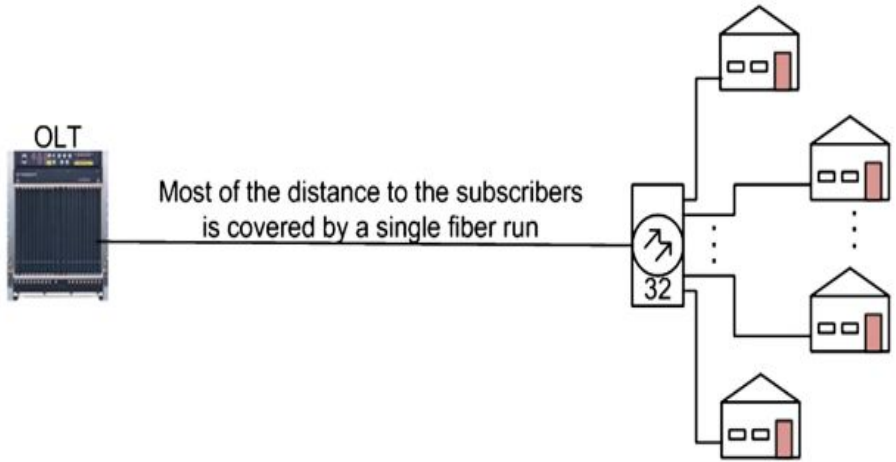
- EPON and GPON systems use distributed splitting
- Figure shows the architecture of distributed splitting used by HFC plant.



(contd...)

Centralized splitting

- The centralized splitting architecture is shown in the figure.



(contd...)

Cable Color Codes

- The buffer tubes are used to place the fiber strands into cables and to handle the fiber more efficiently multiple buffer tubes are contained.
- The cable's total strand count depends on the application.
- A color coding system is used to identify the fiber strands within the buffer tube such that each fiber is surrounded with the protective sheath.
- TIA-598 defines the colors.

(contd...)

Cable Color Codes

- The identification system for individual fibers, fiber buffer tubes/units, and groups of fiber buffer tubes/units within a cable structure are defined by this standard.
- In order to locate specific fibers for connection, termination, or testing, the identification methods may be used.

(contd...)

Aerial Plant

- The cost of aerial plant installation is lower as there are a lot of variables
- The highest position is occupied by the telephone company when the same pole has been shared between telephone, cable television, and electric lines.
- Due to safety reasons, the highest part of the pole is occupied by the power.

(contd...)

Aerial Plant

- The position on the pole is assigned by the owner of the pole during the attachment application process.
- There must be a minimum distance of cable from the ground so that high vehicles could not damage it and minimum safety clearances can be made from the other cable attachments.

(contd...)

Aerial Plant

- If no room is available on the pole to meet spacing rules, the one has to pay so that other cables on the pole can be rearranged which is known as make ready.
- The make-ready cost is beared by the last company to be attached to the pole in order to achieve proper clearance.
- Rent has been paid to the owner if the pole is not owned by the individual.

(contd...)

Underground Plant

- Due to esthetic reasons, utilities are required to be underground in most newer areas and some older areas.
- The initial construction cost is more than aerial construction but superior reliability has been attained by this plant as it is more safe from human-induced problems as well as nature-induced problems.
- The splitter cabinets are the only aboveground elements.
- The splices are held through hand-holds at grade level

(contd...)

Fusion Splicing

- Fusion splicing is the process of fusing or welding two fibers together by using an electric arc.
- This process provides the lowest potential forward and the best return signal loss.
- The splice is made by using a special machine which can be operated by skilled team only.

(contd...)

Fusion Splicing

- In fusion splicing, the two fibers are cut at right angles which are to be joined, the protective coatings are removed, and the two ends aligned in a very precise butt joint.
- Then heat the fibers until they melt and fuse together.
- A metal sleeve is installed over the splice after completing the splice in order to protect it.

(contd...)

Pre-terminated Drop Cables

- Pre-terminated drop cable is used by some installers.
- The drop cable can be bought in certain increments of length and the correct length pre-terminated cable can be grabbed while installing a drop.
- The significant cost of field termination can be saved by these drops when qualified splicers are not available.

(contd...)

Bend Radius

- If a conventional fiber is bent tightly, some photons may enter the cladding at an angle and will not reflect back to the center of the fiber.
- Hence, they will be lost and increase the fiber loss.
- So, bend radius defines how tightly the fiber can be bent during installation or for a long-term after pulling it.

(contd...)

Ribbon Fibers

- Ribbon fibers are the fiber cables in which the fibers are lying parallel to each other.
- These are mass terminated by using machines that can improve the efficiency of splicing or connectorization.
- The splicing process can reduce the errors.
- With ribbon fiber, if the operator lines up the two fibers with the colors in the same sequence, all of the splices will then be correct.

(contd...)

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Data Services Architecture

Introduction

- The basic underpinning transportation mechanism of the overall system is represented by the data services architecture for the PON access network.
- There is a flow of all the information over the network as data services in some form in large part.
- There can be an access to other additional information such as network management, provisioning, performance management, monitoring, and network control traffic along with the services such as voice, data, and IPTV.

(contd...)

Network Engineering for Access Networks

- Service model architectures
- Transport models
- Network services support
- Data service integration
- Network scalability
- Network resiliency
- Management integration
- Assessment of vendor systems

(contd...)

Assessment of Vendor Systems

- The protocol and feature support must be ensured by the network design and operation teams so that other functionalities can be added in the future if needed.
- The system assessment areas are:
  - Networking support—Switching
  - Networking support—Routing
  - QoS support—Data path
  - QoS support—Controls

(contd...)

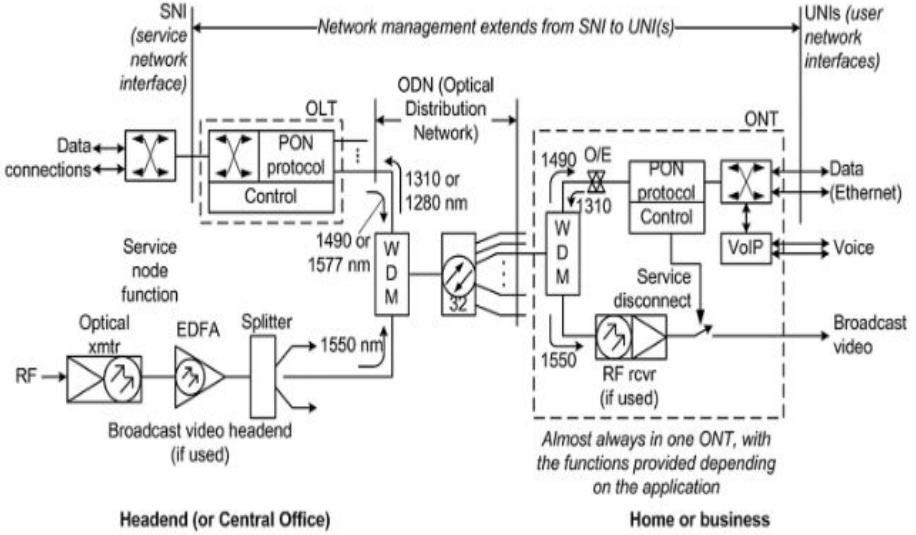
Assessment of Vendor Systems

- QoS support—Provisioning
- Resiliency
- Scalability
- Management system integration
- Provisioning system integration
- ONT integrated service end point—integration
- ONT integrated service end point—provisioning

(contd...)

PON Access Network Model

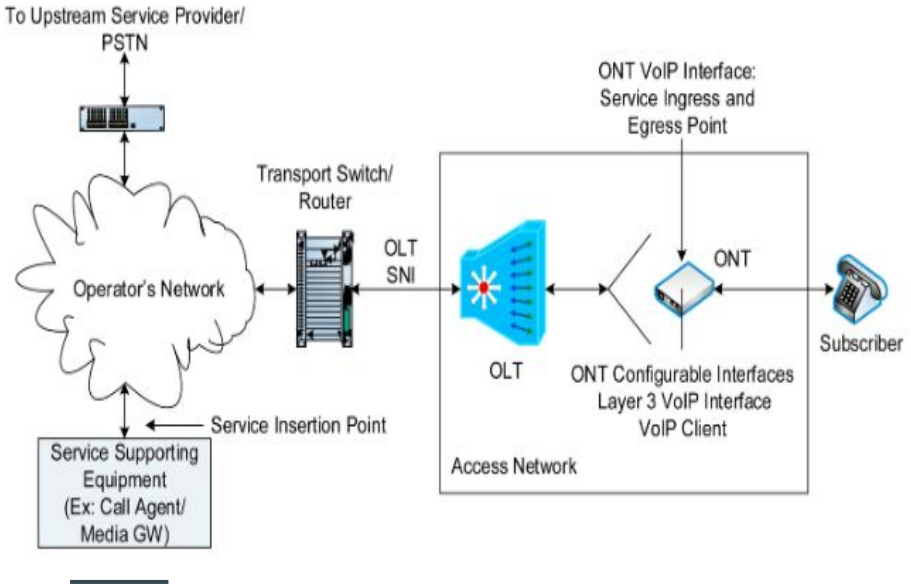
- A unified PON system model is represented in the figure.



(contd...)

VoIP Telephony Service Model

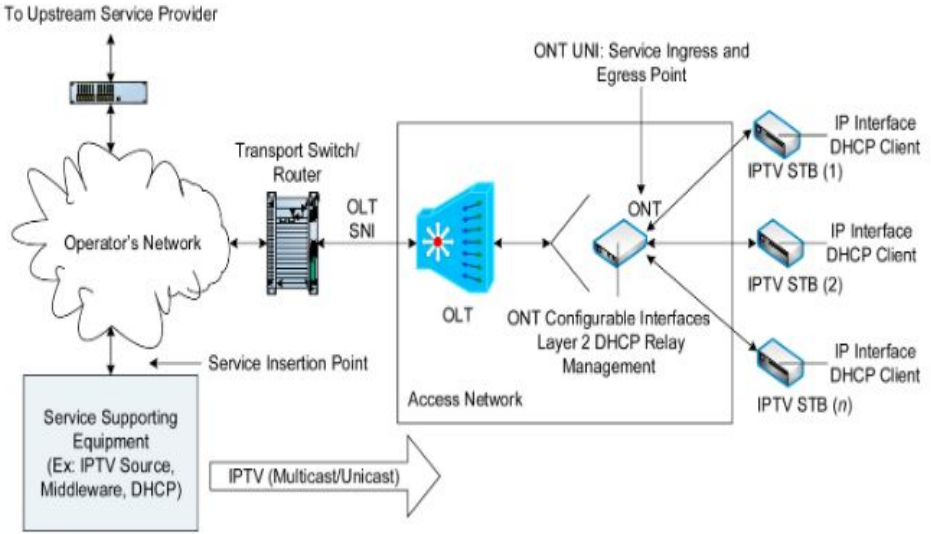
- The integration of ONT device into a VoIP service model framework is shown in the figure.



(contd...)

IPTV Service Model

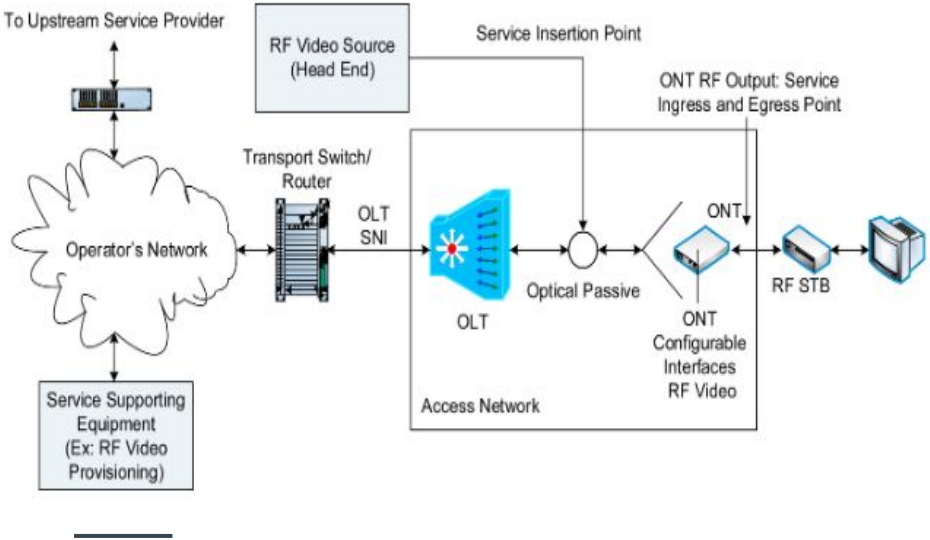
- An overall architectural view of an IPTV service model integrated with the PON access network is shown in the figure.



(contd...)

RF Video Service Model

- The figure shows the ONT integrated into the RF service model.



(contd...)

Overall Service Model Planning

- Define where the service will enter the core and transport networks..
- Define what access network specific features are required.
- Ensure that the provisioning support for each of the trusted interfaces and networking support in the OLT and ONT provides a scalable solution.
- Ensure that for each trusted interface the method of delivery of the provisioning data is secure and scalable via automation.
- Ensure that the service ingress and egress of the OLT and ONT system to the upstream and premises networks are well understood for tagging modes, prioritization marking, and rate limiting of the services.

(contd...)

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Identifying Network Threats and Security Vulnerabilities

Introduction

- There are various issues that are faced by the operator such as IPTV pixelation or voice quality issues or the random Internet point-of-presence failure.
- These issues may be resolved quickly and services can be restored within an acceptable time-frame.

(contd...)

Denial of Service (DoS) Attack

- A DoS can be defined as someone preventing your network from operating at the expected service level.
- The impact of this service outage may be on a single subscriber from making a phone call or watching TV or on a complete service offering.
- A DoS attack on the network of an operator is NOT a condition that can impact the resources outside the operational boundary thereby subscribers service quality can be reduced.

(contd...)

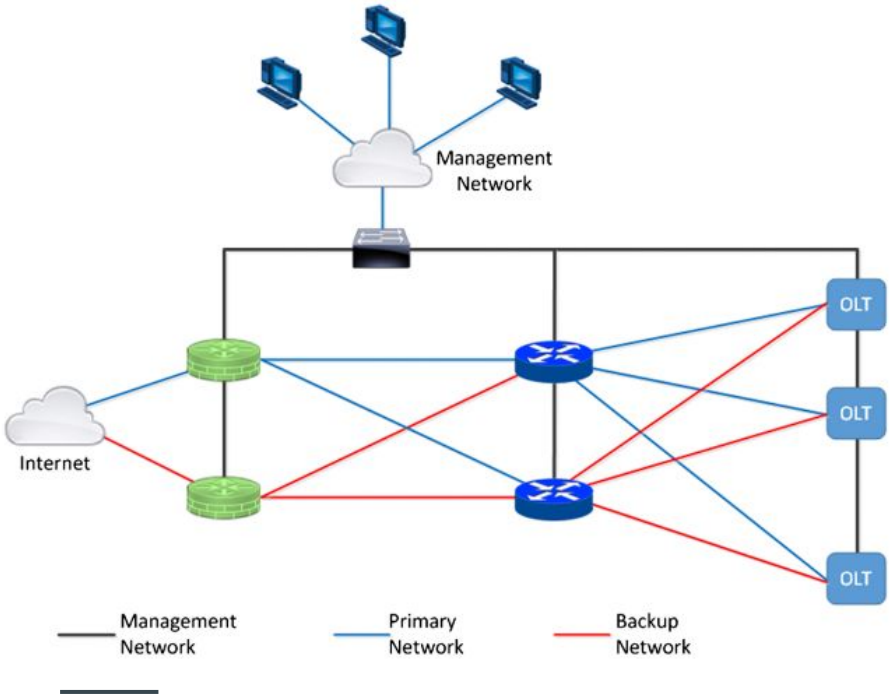
Management Network Security

- Before activating the first services on a network, the ability to control and manage the equipment that will provide services to the subscribers under all conditions is absolutely critical.
- A well-protected and stable management network is required throughout the network architecture.
- In order to minimize construction of network and connectivity costs, the same interface is used to connect the management network through which subscriber services are provided in many cases.

(contd...)

Management Network Security

- The figure shows the management network with dedicated interfaces.



(contd...)

Network Routing Security

- There should be a treatment of the scale and dynamic behavior of network routing security with the highest level of consideration.
- The networking services are impacted by the external influences which include domain name services (DNS), routing protocols such as OSPF and their respective route tables due to which various forms of networking irregularities such as temporary routing loops and unnecessary network failovers are caused.

(contd...)

Network Routing Security

- The defensive techniques such as access control lists are used to control the types of traffic allowed on the network.
- The overall stability of the architecture of the core network will be increased by the disabling services such as ICMP and Ping.
- The guidance on how to protect a network can be provided by a large number of organizations and forums.
- The updates on current threats which are detected throughout the globe are provided by some other organizations also.

(contd...)

Network Routing Security

- An operator must be engaged with the various organizations so that a stable services model can be obtained.
- The impacts of these services are changing continually and there is an identification of new threats daily.
- So, a completely secure network is not obtained at any cost.

(contd...)

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