8 — GPON Network Architecture

8.1 Introduction: GPON Network

An Optical Distribution Network (ODN) based on Gigabit Passive Optical Network (GPON) technology consists of two main parts that may be implemented by network equipment that can be categorized as follows:

- Optical Line Termination (OLT):

  This unit provides central processing, switching, and control functions. This equipment is located at the network side of the Optical Distribution Network
- Optical Network Unit (ONU):

  This unit is located at the subscriber premises as distributed end-points of the ODN. This equipment implements the GPON protocol and adapts GPON Protocol Data Units to subscriber service interfaces.

  Note — There is a specific case for ONU equipment that is generally referred to as Optical Network Termination (ONT). This specific term is generally used to designate a single-user subscriber premise equipment.

8.2 Alcatel-Lucent GPON Network Architecture

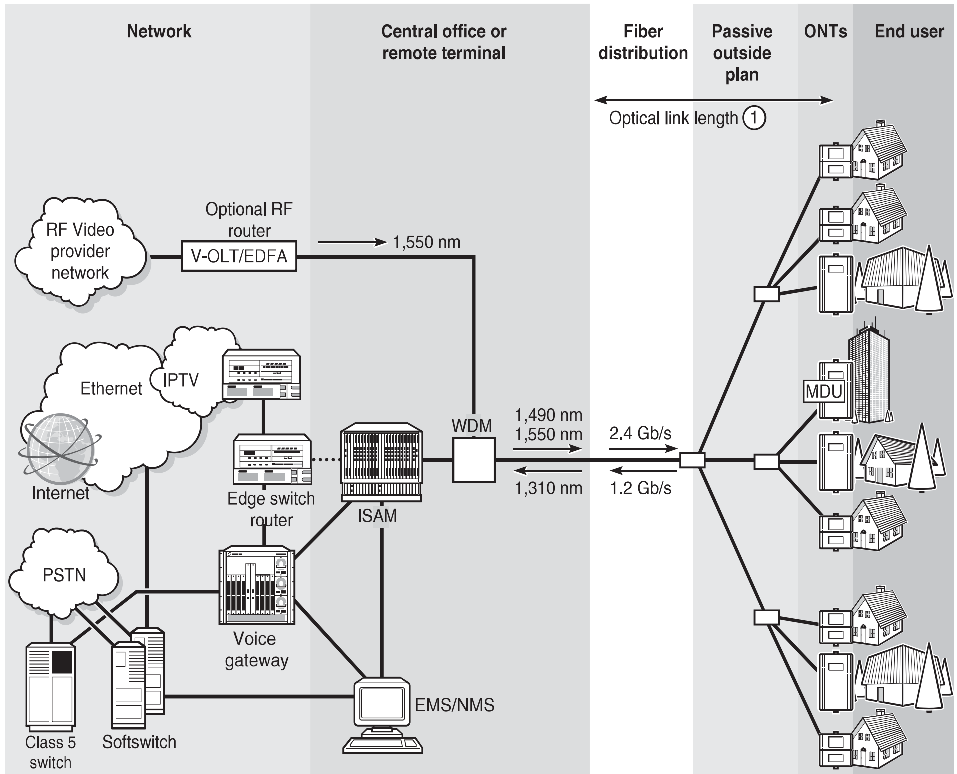
In the Alcatel-Lucent GPON network architecture, the OLT function is provided via three distinct equipment types:

- Packet - Optical Line Termination (P-OLT) unit which corresponds to the ISAM with its NT and GPON LTs.
- Video - Optical Line Termination (V-OLT) unit which distributes Radio Frequency (RF) overlay video signals across the GPON if the network provider chooses this method for providing Video Services. (This optional equipment is provided by a third-party supplier and hence outside of the scope of ISAM)
- Wavelength Division Multiplexer which is only needed in case of V-OLT presence in the network, and which is used to mix and separate the RF Video signal into/from the optical fiber going towards ONUs. (This optional equipment is also outside of the scope of ISAM)

Alcatel-Lucent also provides a wide variety of ONU equipment which works seamlessly together with the ISAM (P-OLT) products to form a fiber access network capable of delivering high quality voice, video, and data services to both single-family or multi-dwelling residential subscribers and business subscribers.

This model is shown in Figure 8-1.

Figure 8-1 ISAM GPON Network Architecture



1 The maximum optical link length depends on the specific equipment and deployment conditions

Standards

The Alcatel-Lucent GPON network is developed based on the following ITU-T standards:

- G.984.1 (GPON Service requirements)
- G.984.2 (GPON PMD layer)
- G.984.2 (GPON PMD layer) amendment 1
- G.984.3 (GPON TC Layer)
- G.984.3 (GPON TC Layer) amendment 1 and 2
- G.984.4 (GPON OMCI)
- G.984.4 (GPON OMCI) amendments 1 and 2

8.3 GPON Implementation of ISAM

ISAM provides the core processing, switching, and control functions and interacts in the upstream direction with the Ethernet switch and voice gateway using the NT cards. The ISAM shelves with their NT and GPON LT boards comprise the conceptual P-OLT system from the GPON Network point of view.

The Alcatel-Lucent ONU products are edge devices that use GPON technology to extend a fiber optic cable from a P-OLT shelf to a subscriber residence, including single-family residences, multi-dwelling residences such as an apartment building, and small office / home office applications.

There are two types of GPON LT boards in ISAM with different GPON capacities:

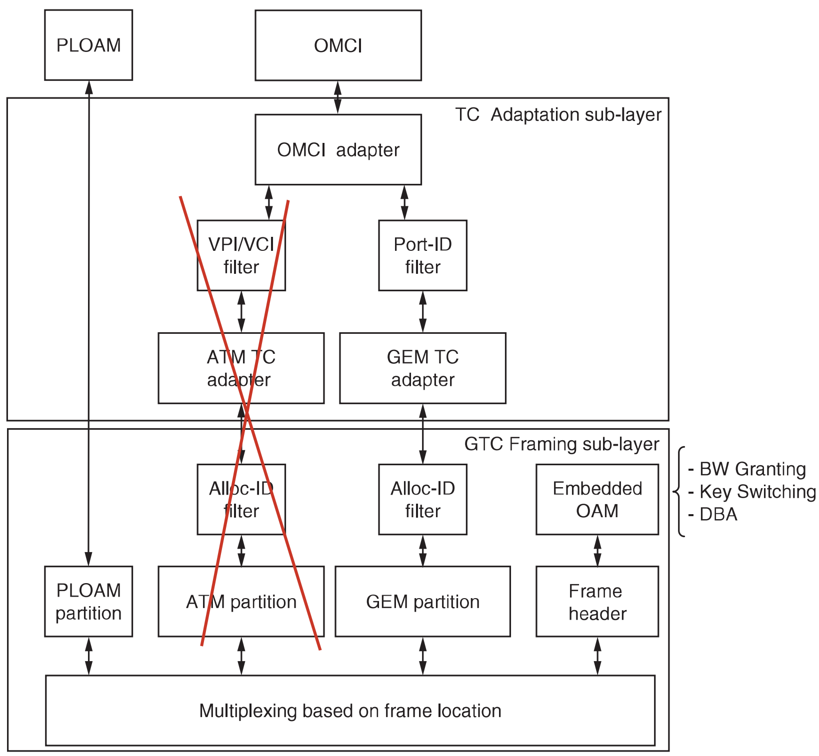
- 2.4Gb/s Downstream / 1.2Gb/s Upstream
- 10Gb/s Downstream / 2.5Gb/s Upstream

Transmission Convergence Layer - Multiplexing Architecture

ITU-T GPON recommendations provide two multiplexing mechanisms: ATM base and GEM base.

ISAM only supports GEM multiplexing. The ATM partition is not supported.

Figure 8-2 GPON Functional Blocks



- In downstream direction, the GEM frames are carried in the GEM partition, and arrive at all the ONUs. The ONU framing sublayer extracts the frames, and the GEM TC adapter filters the GEM fragment based on their 12-bit port ID. Only frames with the appropriate port IDs are allowed through to the GEM client function at the ONU.
- In upstream direction, the GEM traffic is carried over one or more Transmission Containers (T-CONTs). The OLT receives the transmission associated with the T-CONT, and the frames are forwarded to the GEM TC adapter, and then to the GEM client function at the OLT.

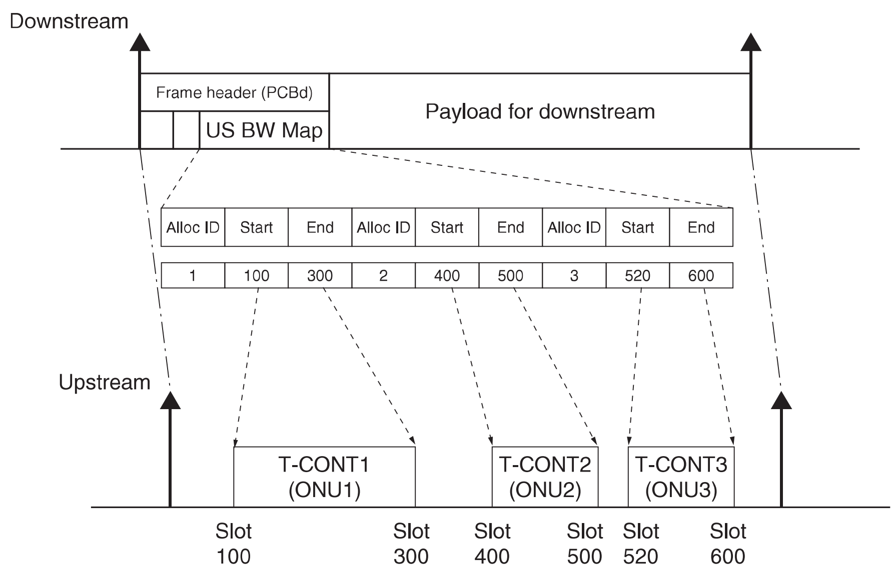
One ONU can be served by one or several T-CONTs, but a given T-CONT can only be used by a single ONU. Also, a given T-CONT can transport traffic from several GEM ports, but traffic from a given GEM port can only be carried by a single T-CONT.

ISAM GPON-LTs support 2.048 GEM clients (also called GEM ports) and 1.024 T-CONTs per GPON interface. Both GEM ports and T-CONTs are internal GPON protocol constructs/abstractions that are not directly exposed to the operator for convenience and ease of management.

Transmission Convergence Layer - GPON Media Access Control

The Transmission Convergence layer in ISAM provides media access control for upstream traffic.

Figure 8-3 PON media access control concept



In the basic concept, downstream frames indicate permitted locations for upstream traffic and upstream frames synchronized with downstream frames as outlined in Figure 8-3.

The ISAM sends pointers in the frame header Physical Control Block downstream (PCBd). The pointers indicate the time at which each ONU must begin and end its upstream transmission. In this way, only one ONU can access the GPON at any time, and there is no contention in normal operation. The pointers are 2 bytes long and given in units of bytes, allowing the OLT to control the GPON at an effective static bandwidth granularity of 64 kb/s. The size of the GTC frame is 125 µs. The downstream payload contains GEM packets that are uniquely destined to some specific T-CONT/ONUs. The ONUs examine the GEM header and only process the GEM packets which port IDs match its own.

Transmission Convergence Layer - Upstream and Downstream Frames

Figure 8-4 shows the PON downstream frame format.

Figure 8-4 PON Downstream Frame format

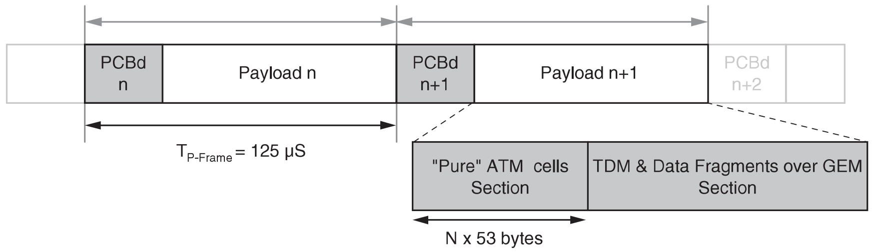
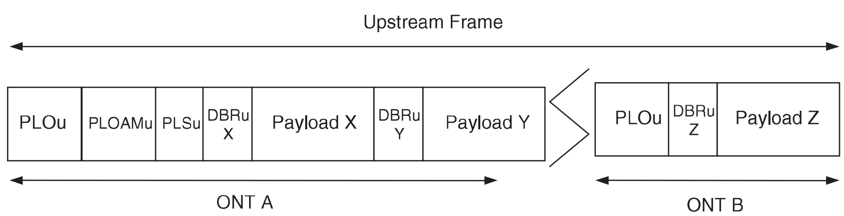


Figure 8-5 shows the PON upstream frame format.

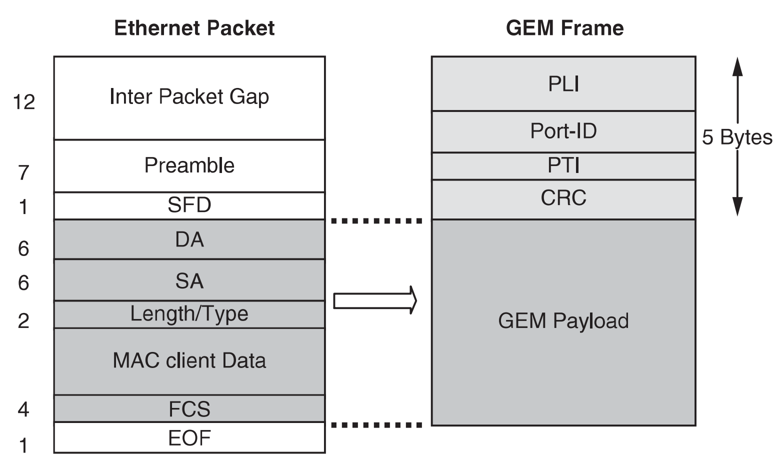
Figure 8-5 PON Upstream Frame Format



Transmission Convergence Layer - GEM Encapsulation of Ethernet Packets

Ethernet packets are encapsulated by ISAM and ONUs into GEM as shown in Figure 8-6. Each packet is mapped into the GEM frame. The *Preamble* and *SFD* bytes are not included in the GEM frame.

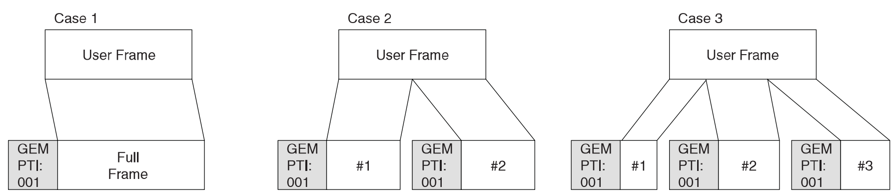
Figure 8-6 Ethernet encapsulation over GEM



Each produced GEM fragment is transmitted contiguously. A fragment cannot straddle a frame boundary. Therefore, the fragmentation process must be aware of the amount of time remaining in the current partition or payload, and must fragment its user data frames appropriately.

Figure 8-7 shows different possibilities of user frames fragmentation.

Figure 8-7 Fragmentation Examples



Dynamic Bandwidth Assignment

Dynamic Bandwidth Assignment (DBA) is the process by which ONUs and their associated T-CONTs dynamically request upstream bandwidth.

ISAM processes the implicit bandwidth requests from ONU via idle cell monitoring and reassigns upstream bandwidth accordingly.

In the idle cell monitoring implementation, ISAM bandwidth reassignment is applied to the distribution of the non-guaranteed or un-assured portion of the service traffic in order not to disturb the guaranteed traffic contracts.

T-CONTs are used for the management of upstream bandwidth allocation in the GPON section of the Transmission Convergence layer. As such, T-CONTs are primarily used to improve the upstream bandwidth use on the GPON.

Forward Error Correction

Forward Error Correction (FEC) is used by the transport layer of ISAM and it is based on transmitting the data in an encoded format. The encoding allows the decoder to detect and correct the transmission errors. For example, for input BER of 10^{-4}, the BER at the FEC decoder's output may drop to 10^{-15}. By using the FEC technique, data transmission with low error rates can be achieved, and retransmissions are avoided.

FEC results in an increased link budget. Therefore, higher bit rate and longer distance from the ISAM to the ONUs can be supported. Alternatively, by using this process a higher number of splits per single GPON tree can be achieved over an equivalent distance.

The FEC encoding and decoding of ISAM is based on Reed-Solomon (block based FEC).

Reed-Solomon (RS) is a block-based code, which takes a data block of constant size and adds extra “redundant” bits at the end, thus creating a code word. Using those extra bits, the FEC decoder processes the data stream, discovers errors, corrects errors, and recovers the original data. Reed-Solomon code is specified in CMTT recommendation CCIR 723.

When using a block-based FEC, original data is preserved. Therefore, by ignoring the parity bits, even if the other side does not support FEC, the original data can be processed.

However, block-based FEC error correction is not efficient for very high BER levels (for example, for 10^{-3} BER, a decoding error will be generated).

Delay Tolerance

For the upstream GPON transmission, ISAM provides a configurable Delay Tolerance parameter to realize optimal latency and delay variation characteristics on the GPON link.

Security

ISAM uses Advanced Encryption Standard (AES) for security. Internally AES is enabled/disabled by ISAM for individual port IDs in conformance with the GPON protocol standards. However, management model granularity is provided on a per-ONU basis.

Advanced Encryption Standard is a block cipher that operates on 16 byte (128 bit) blocks of data. It accepts 128, 192, and 256 bit keys. This algorithm is described in documents published by the National Institute of Standards and Technology (NIST) in the USA.

There are several modes of operation for this standard. However, only the “Counter” (CTR) mode is used by ISAM. In this mode, the cipher generates a stream of 16-byte pseudorandom cipher blocks which are exclusive-ORed with the input clear-text to produce the output of cipher-text. The cipher-text is exclusive-ORed with the same pseudorandom cipher blocks to regenerate the clear-text. The key length is fixed at 128 bits.

ONU Ranging and Discovery

When ISAM is ranging new ONUs, working ONUs must temporarily stop transmissions. This is done by opening a ranging window to discover new ONUs.

Two activation/ranging methods supported by ISAM

- Configured-S/N:

  The serial number of the ONU is registered in advance at the OLT and used for authentication of the matching ONT.
- Discovered-S/N:

  The serial number of the ONU is not registered at the OLT. It requires an automatic detection mechanism of the serial number of the ONU based on the operator-assigned ONU Registration ID that is provisioned locally at the ONU and at the ISAM for a match. In case a new ONU is detected, an ONU ID is assigned and the ONU is activated.
  - Operator-assigned ONU Registration ID can take two forms: a simple Subscriber Location IDentifier (SLID) or a LOgical IDentifier (LOID, which consists of a logical subscriber location designation and an associated password).
  - The use of SLID vs. LOID based authentication is provisionable on a per-PON basis.

Concurrent Use of Activation/Ranging Methods:

ISAM also allows a special per-PON configuration in order to support ONUs conforming to either Configured-S/N or LOID-based Discovered-S/N authentication methods to be mixed on the same PON. In this case LOID-based Discovered-S/N has precedence over Configured-S/N mode in processing each ONT.

SLID/LOID-Serial_Number Bundling and Anti Snooping Function:

SLID or LOID (G.988) association with a S/N may to be locked after a user defined time period (for example, 4h/24h) following the first ranging of the ONT with a certain Serial Number. This will allow for changing of ONT during installation. In this case, after the defined period of time, the installed ONT hence its Serial Number shall be considered as final per operator's intentions and the SLID/LOID association to this Serial Number shall be frozen.

After this defined transition period any detected mismatch results in an alarm.

The function of bundling or un-bundling between SLID/LOID with SN is configurable per ONT.

There are three triggers for initiating the activation of an ONU:

- The network operator enables the activation process to start when it is known that a new ONU has been connected.
- The OLT automatically initiates the activation process, when one or more of the previously working ONUs are 'missing', to see if those ONUs can return to service. The frequency of polling is programmable.
- The OLT periodically initiates the activation process, testing to see if any new ONUs have been connected. The frequency of polling is programmable.

Delayed SW Activation Method

Operators may want to avoid interrupting end-user service continuity during the ONT SW upgrade procedure. ISAM provides a special "delayed activation" method to cover such cases. In this mode of operation the desired ONT SW version is downloaded to the passive SW bank of the ONT, however the activation of the SW load is delayed until a naturally occurring interruption such as an ONT Power-Off or PON Plug-Out , or, after clearance of certain fault conditions impacting the ONT ranging such as a PON or LT failure.

This feature is available in the same manner via both individual ONT SW configuration and bulk configuration by means of ONT SW Control Table.

ONU Activation

The activation process is performed under the control of ISAM.

The activation procedure is performed by the exchange of upstream and downstream flags and Physical Layer Operations Administration and Maintenance (PLOAM) standard messages defined for GPON, as follows:

1 ONU receives the requested GPON operating parameters from ISAM.

2 ONU adjusts it parameters accordingly.

3 ISAM discovers the Serial Number of a new connected ONU.

4 ISAM assigns an ONU-ID to the ONU.

5 ISAM measures the round-trip delay of the ONU transmission.

6 ISAM notifies the ONU of the equalization delay.

7 ONU adjusts the transmission phase to the notified value.

In the normal operating state, all the transmissions can be used for monitoring the phase of the arriving transmission. Based on the monitoring transmission phase information, the equalization delay can be updated.

ISAM broadcasts the Serial-Number requests to all ONUs in the Serial-Number state. Consequently, more than one Serial-Number transmission can simultaneously arrive at the OLT causing a collision. The Random Delay Method is used to resolve this problem.

Based on the Random Delay Method, each Serial-Number transmission is delayed by a random number of delay units generated by each ONU. The delay units are 32 bytes long for all bit rates. The random delay must be an integral number of delay units. Following each response to a Serial-Number request, the ONU generates a new random number, thus collisions are easily and efficiently prevented.

OMCI

The ONT Management and Control Interface (OMCI) is the ITU-T G984.4-based open interface definition that provides the management model for provisioning and surveillance related functions between ISAM and ONUs.

Transmission Convergence Layer Performance Monitoring

ISAM provides on-demand counters to monitor GPON TC layer traffic and performance. The related counters are collected internally on a GEM-port basis from both ends of the GPON section, and are presented to the operator on a per-ONU and per-UNI basis. In addition, the same set of counters is also supported for the shared Multicast GEM port of the PON.

Rogue ONT Detection and Defense Mechanism

The Rogue ONT Diagnostic feature of the ISAM provides a means of monitoring ONT behavior on the PON and identifying rogue ONT(s) through the problematic symptoms of other ONTs on the optical network. Alarm notifications are generated upon detection of Rogue ONTs.

There are four Rogue ONT detection methods:

- The on-demand ON/OFF test which is a service-affecting test whether or not a rogue ONT is detected.
- The on-demand pattern test which is a non-service affecting test unless a rogue ONT is present on the PON.
- The background pattern test which is run in background mode on the ONTs at regular intervals or on a given ONT when it ranges. This test is disabled by default.
- The background ON/OFF test which is triggered by PON LOS to run a test on each ONT.

On Demand ON/OFF Test

This test is also called the manual stuck laser test or the manual on/off test.

This test is service affecting as all ONTs on the PON are disabled during the test.

The *Disable Serial Number PLOAM* message is used for testing. This PLOAM is sent to each ONT in turn. G984.3 states that on receiving this message the ONT should go to *Emergency Stop State* and disable the TX optics.

A broadcast option has been added to the *Disable Serial Number PLOAM* message to allow the disabling of ONTs which have been added to the PON but are not yet provisioned at the time of the test. This enhancement is not defined in G984.3.

On-Demand Pattern Test

An ONT which is exhibiting rogue behavior by transmitting outside its assigned time slot should impact other ONTs on the PON. The on-demand pattern test uses the *Diagnostic PLOAM* message to trigger a test mode on an individual ONT while monitoring for adverse impacts on the other ONTs. The impacts may include a change in alarms or an ONT moving to *INACT* state.

The pattern test enabled on one ONT generally does not have an impact on other subscribers unless the ONT being tested is rogue. However, in case of RF overlay, and depending on specific channel line up frequencies, a small amount of transitory interference might be observed on the video signal. If a rogue ONT is found, other subscribers would be impacted for a few seconds on the first check.

This test is implemented via an *ONT Diagnostic Vendor Specific PLOAM* message not detailed in G984.3.

Background Pattern Tests

The background pattern test utilizes the same algorithm as the on-demand Pattern Test and is disabled by default.

When enabled, the diagnostics will trigger a test under two conditions:

- An ONT ranges
- The background timer expires.

Execution of the background test is by default scheduled at an interval of 12 hours. This interval can be configured.

Background On/Off Test

This test is also called the background stuck laser test or Background On/Off test.

The test algorithm is the same as the manual on/off test. The test is disabled by default and is service affecting.

The trigger for this test is a PON LOS event where the RX laser is detected to be on, corresponding to an ONT continuously transmitting irrespective of its allowed window

Automatic RF Service Shutdown

ISAM supports the management capability to provision the automatic RF Video service shutdown function. This capability consists in provisioning a configurable setting for ONTs supporting the underlying function to use in order to determine the period of time to assure continued video service for, in case of communication loss between the OLT and the ONT. RF video service in such ONTs is only restored after a successful re-range with the OLT.

8.4 V-OLT GPON Functions

V-OLT is an optional network equipment that is used to distribute Radio Frequency (RF) video signal from service providers to the ONUs. This equipment is not part of ISAM. The following description of the V-OLT function is provided for informational purposes.

Note however that occasionally, when fiber and equipment in the GPON network are shared, a so-called Raman Effect can occur where signals cross over from downstream digital signals in the lower spectrum and cause visible lines on overlaid broadcast RF video signals. The effect is usually more prominent in the low end video channels that are in the 1550 to 1560 nm range.

The ISAM GPON LTs provide a Raman crosstalk reduction feature that can be enabled if distortion, caused by downstream digital data signals on the GPON network, is visible on the lower spectrum video channels.

Radio Frequency Video Signal Distribution

The V-OLT uses Erbium Doped Fiber Amplifiers (EDFA). The distribution requires a Wavelength Division Multiplexer (WDM) to be overlaid into the fiber path.

The distribution of the optical video signal is described as follows:

- The V-OLT receives an incoming wavelength optical signal with embedded video channels through a fiber path from the cable TV head-end equipment.
- The V-OLT amplifies and splits the optical signal into multiple optical feeds to the video coupler.
- The video coupler merges the video signal over the fiber paths.
- The fiber paths carry the optical signals between the P-OLT and the ONUs.

RF Video Services

The V-OLT supports the full cable television (CATV) spectrum from 47 MHz to 862 MHz.

Access to video services may require a Set-Top Box (STB) between the video output of the ONU equipment and other Customer Premises Equipment (CPE).

The V-OLT requires a separate Element Management System (EMS) to control video output signals from the V-OLT equipment.

8.5 Protection

ISAM supports Type-B protection per ITU-T specification G984.1. Refer to section “Subscriber interface redundancy” in chapter “Failure protection and redundancy provisions in ISAM” for further information.

8.6 ONU Functions

ONU functions are described in chapter “ISAM Support for the GPON ONU”.