Introduction to GPON and XGS-PON Protocols

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Access Network Visibility

Agenda (1 hour)

- Webinar Introduction
- Introduction to the GPON protocol
- Introduction to XG-PON and XGS-PON
- GPON and XGS-PON Comparison
- Questions

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Introduction

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TraceSpan has for over 18 years been in the business of providing non-intrusive access troubleshooting and analysis tools.

For more than ten years Oded Hadass has been the Director of Product Management for TraceSpan's portfolio of GPON, NG-PON, G.fast and xDSL test products.

Oded's vast expertise in access technologies enables him to support both service providers and vendors in solving their own technical challenges.

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Introduction to the GPON Protocol

- GPON Transmission Basics – Downstream and Upstream
- AES Encryption
- ONU Activation Process
- GPON Network Hierarchy – T-CONTs and GEM Ports
- Control Messages

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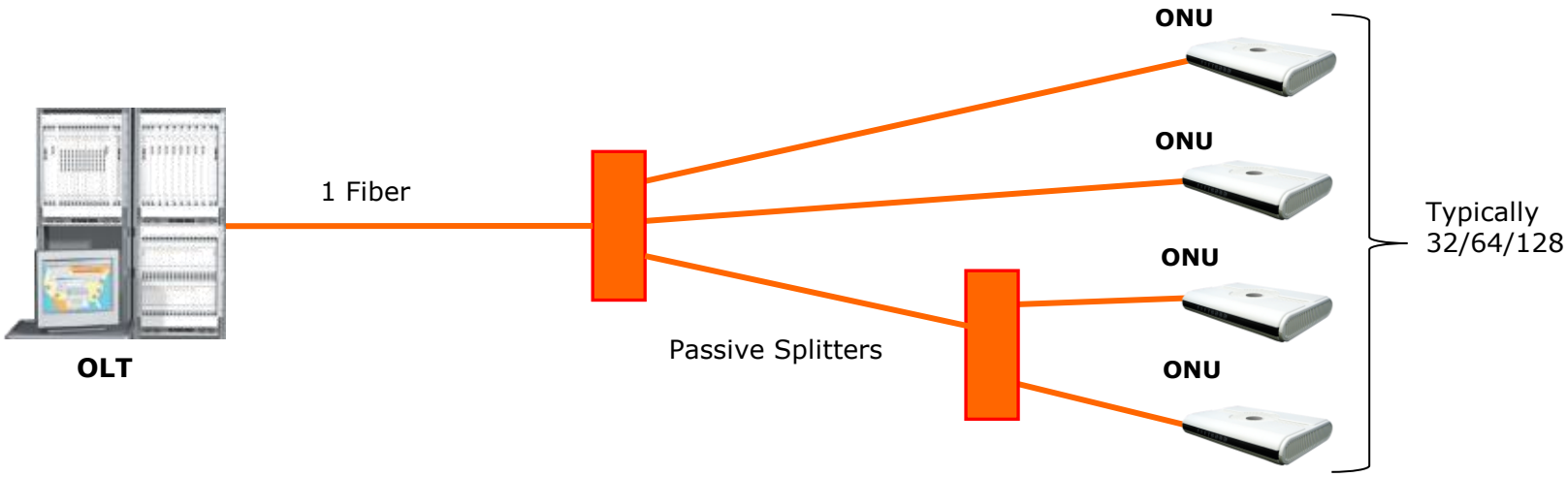
Passive Optical Networks (PON)

- Passive point-to-multipoint infrastructure
  - A single fiber and a single OLT interface to serve multiple ONUs
  - Passive (unpowered) optical splitters



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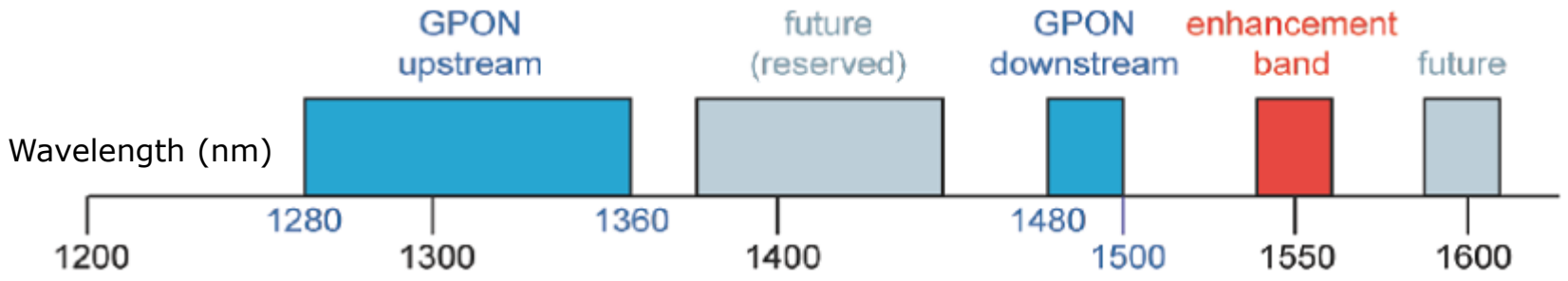
GPON Highlights

- Support for asymmetric line rate operation, 2.488 Gbit/s D/S and 1.244 Gbit/s U/S rates
- Downstream wavelength 1490 nm
- Upstream wavelength 1310 nm
- Option for "RF" Video overlay: wavelength 1550 nm
- Up to 128 ONUs per fiber tree but 32 or 64 is more typical.
- 28 dB optical budget to support 20 km reach and 1:32 split ratio
- First standards published in 2003-2004 by ITU-T, current standards are from 2014



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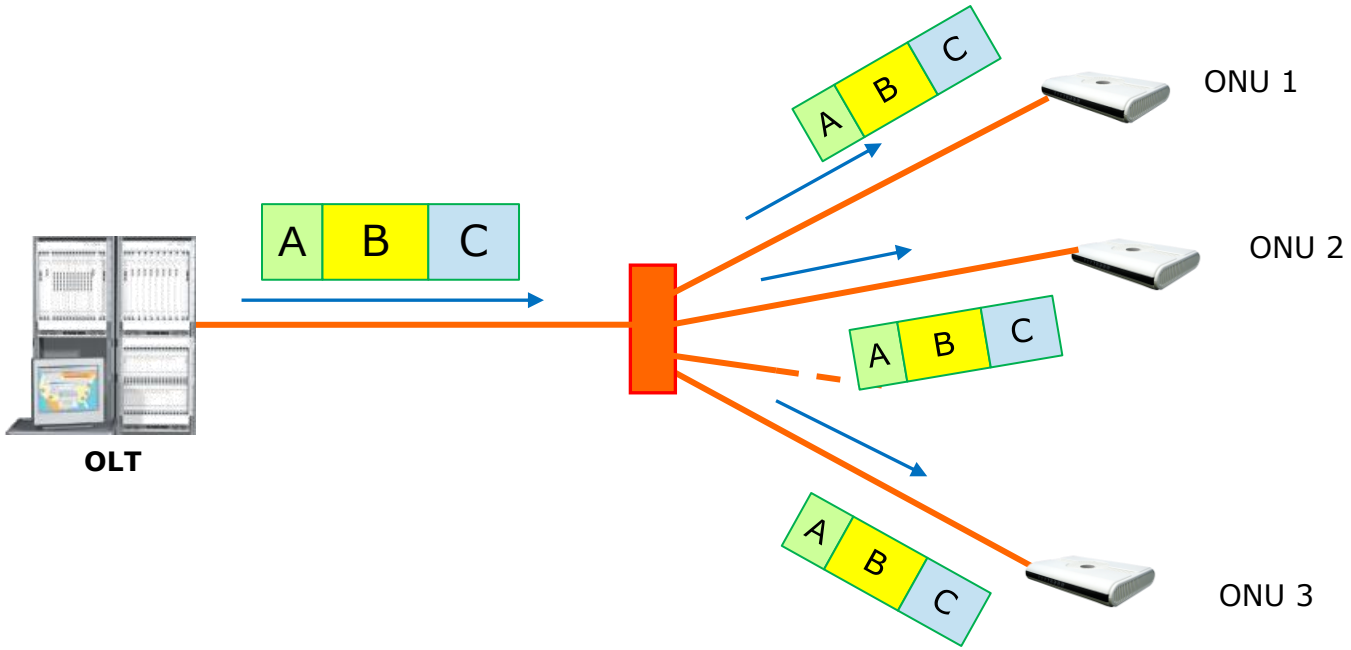
GPON Transmission Basics – Downstream

- Point to Multi-Point
- Every ONU gets **all the transmissions**
- Security addressed by AES (Advanced Encryption Standard, 128-bit key)



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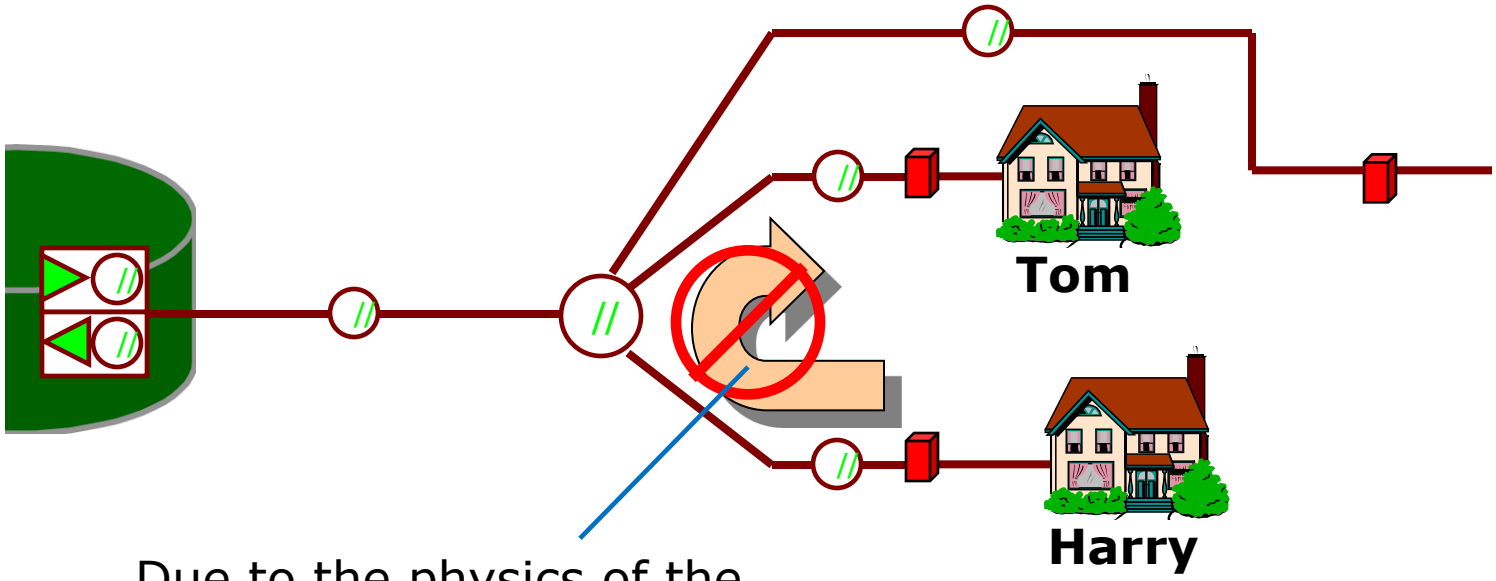
Optical Signal Flow and Isolation



Due to the physics of the network, Harry's data flows upstream but does not come to Tom's box, so Tom cannot see Harry's data

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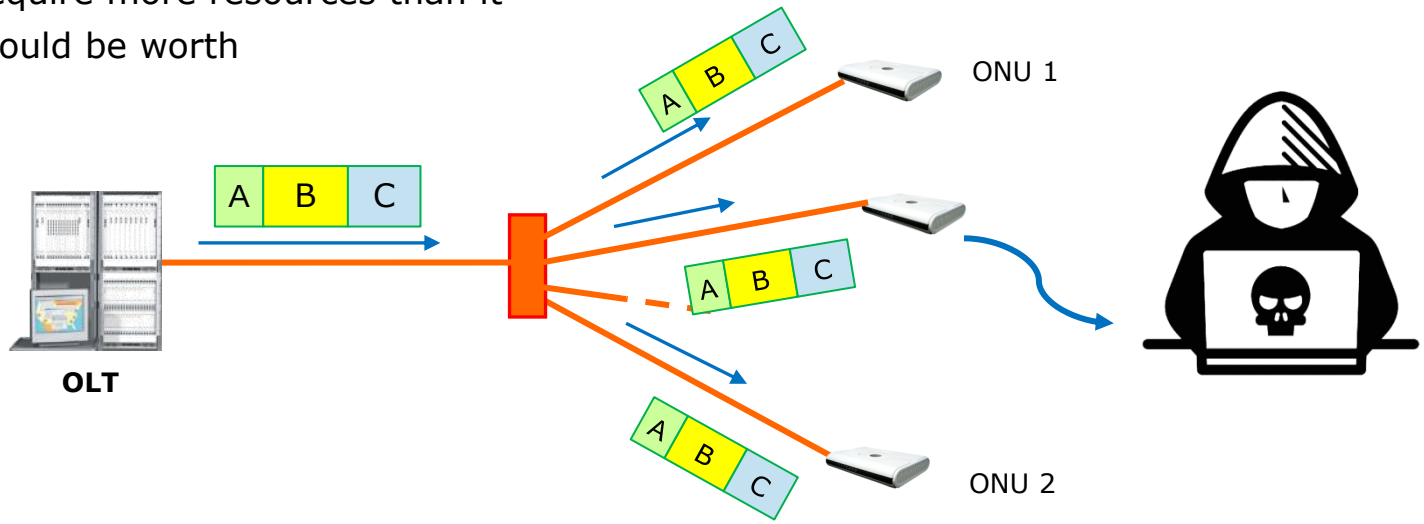
GPON Security Threat Model

- The basic concern in PON is that the downstream data is broadcast to all ONUs attached to the PON – if a malicious user were to re-program his ONU, then the malicious user could listen to all the downstream data of all the users

- Other, more exotic threats are not considered practically important – require more resources than it would be worth



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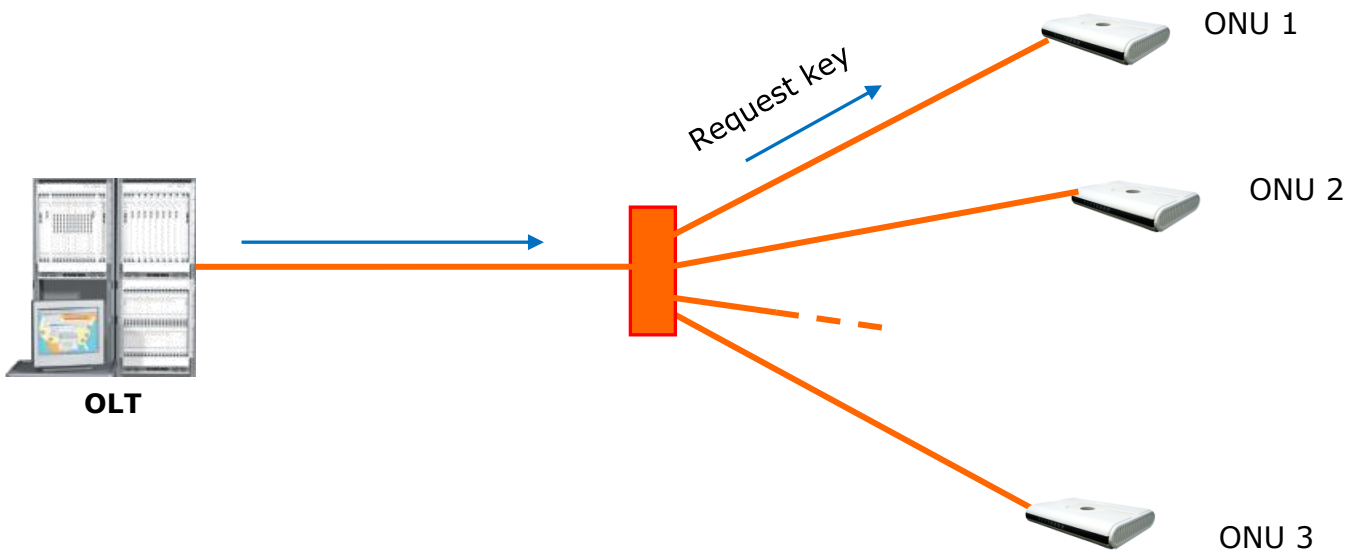
AES Encryption

1. The OLT initiates the process – requests a key from the ONU



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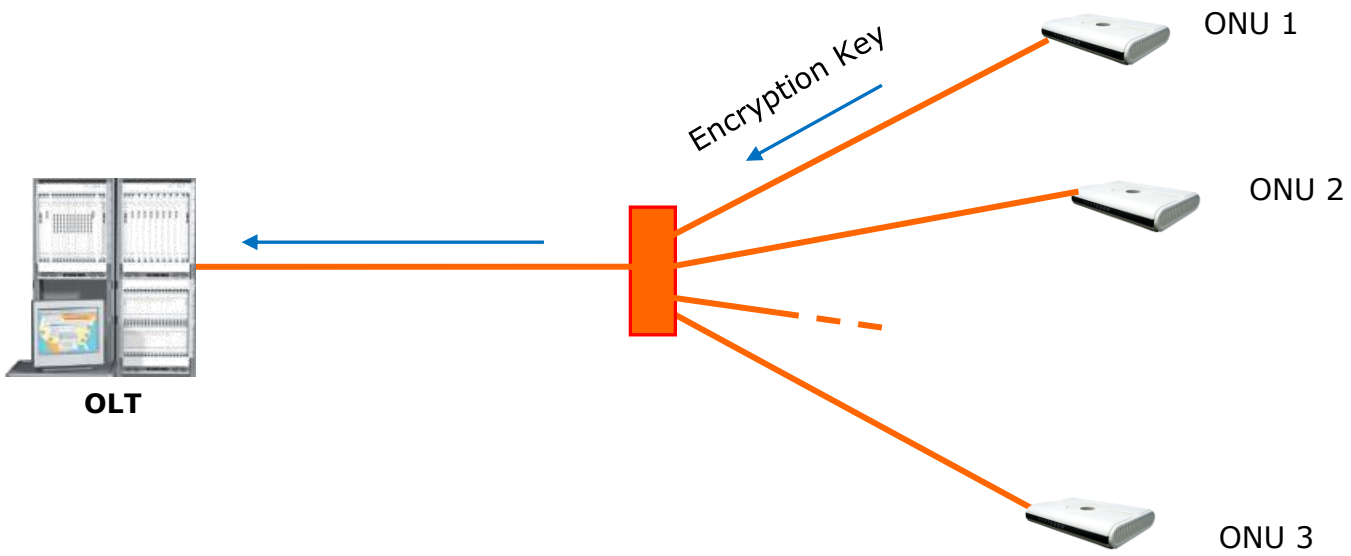
AES Encryption

1. The OLT initiates the process – requests a key from the ONU
2. The ONU generates the key and sends it to the OLT



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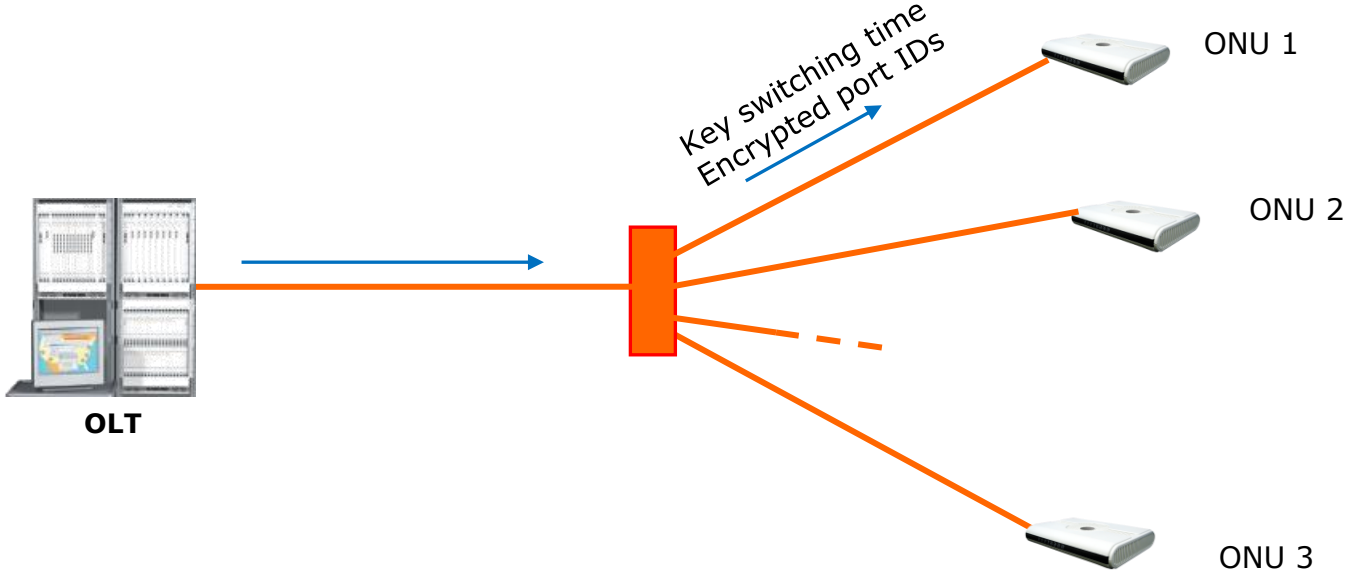
AES Encryption

1. The OLT initiates the process – requests a key from the ONU
2. The ONU generates the key and sends it to the OLT
3. The OLT defines the Key Switching Time and the encrypted ports and notifies the ONU



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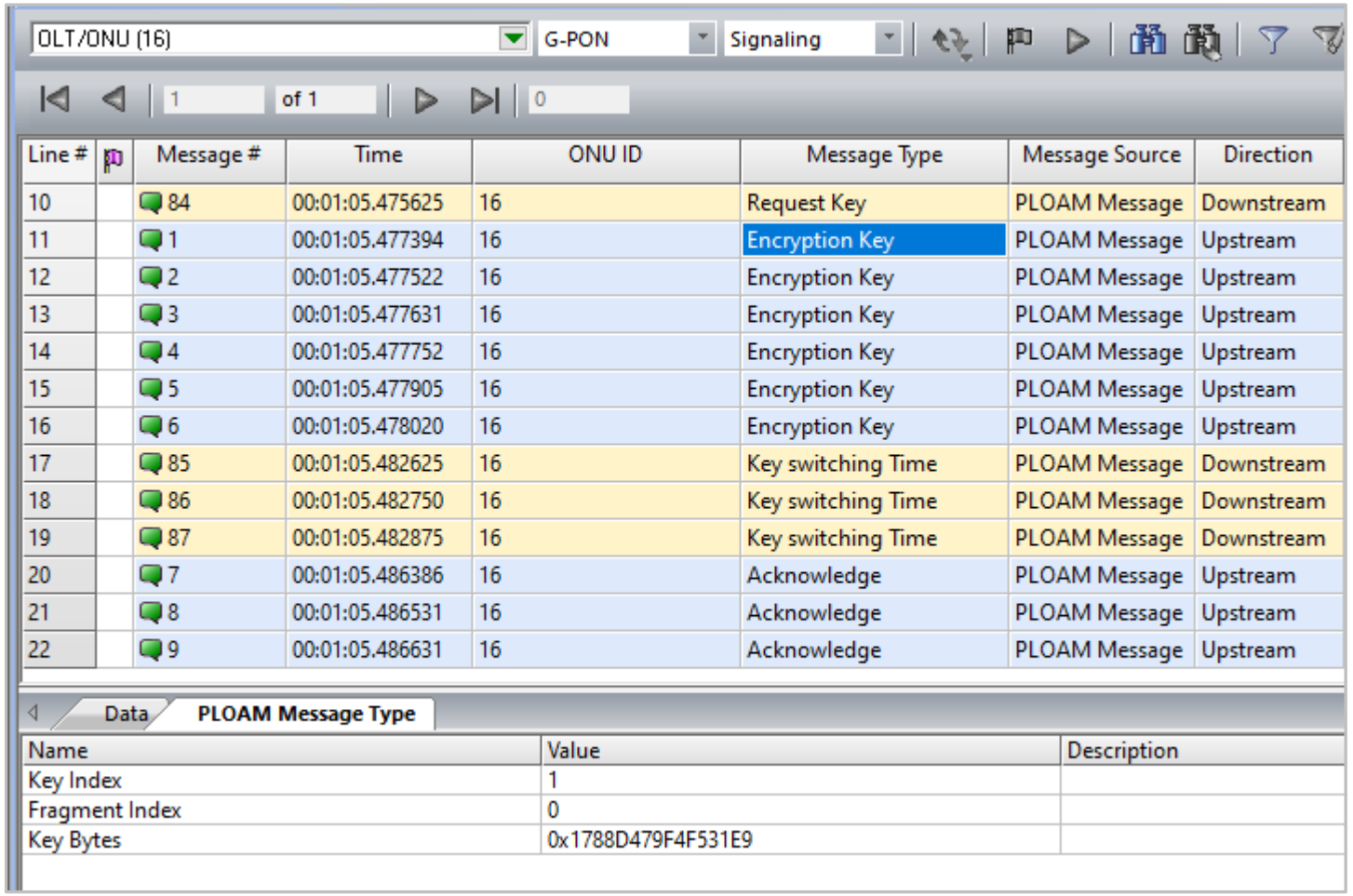
GPON Encryption Messages – Example



Line #	Message #	Time	ONU ID	Message Type	Message Source	Direction
10	84	00:01:05.475625	16	Request Key	PLOAM Message	Downstream
11	1	00:01:05.477394	16	Encryption Key	PLOAM Message	Upstream
12	2	00:01:05.477522	16	Encryption Key	PLOAM Message	Upstream
13	3	00:01:05.477631	16	Encryption Key	PLOAM Message	Upstream
14	4	00:01:05.477752	16	Encryption Key	PLOAM Message	Upstream
15	5	00:01:05.477905	16	Encryption Key	PLOAM Message	Upstream
16	6	00:01:05.478020	16	Encryption Key	PLOAM Message	Upstream
17	85	00:01:05.482625	16	Key switching Time	PLOAM Message	Downstream
18	86	00:01:05.482750	16	Key switching Time	PLOAM Message	Downstream
19	87	00:01:05.482875	16	Key switching Time	PLOAM Message	Downstream
20	7	00:01:05.486386	16	Acknowledge	PLOAM Message	Upstream
21	8	00:01:05.486531	16	Acknowledge	PLOAM Message	Upstream
22	9	00:01:05.486631	16	Acknowledge	PLOAM Message	Upstream

Data | **PLOAM Message Type**

Name	Value	Description
Key Index	1	
Fragment Index	0	
Key Bytes	0x1788D479F4F531E9	

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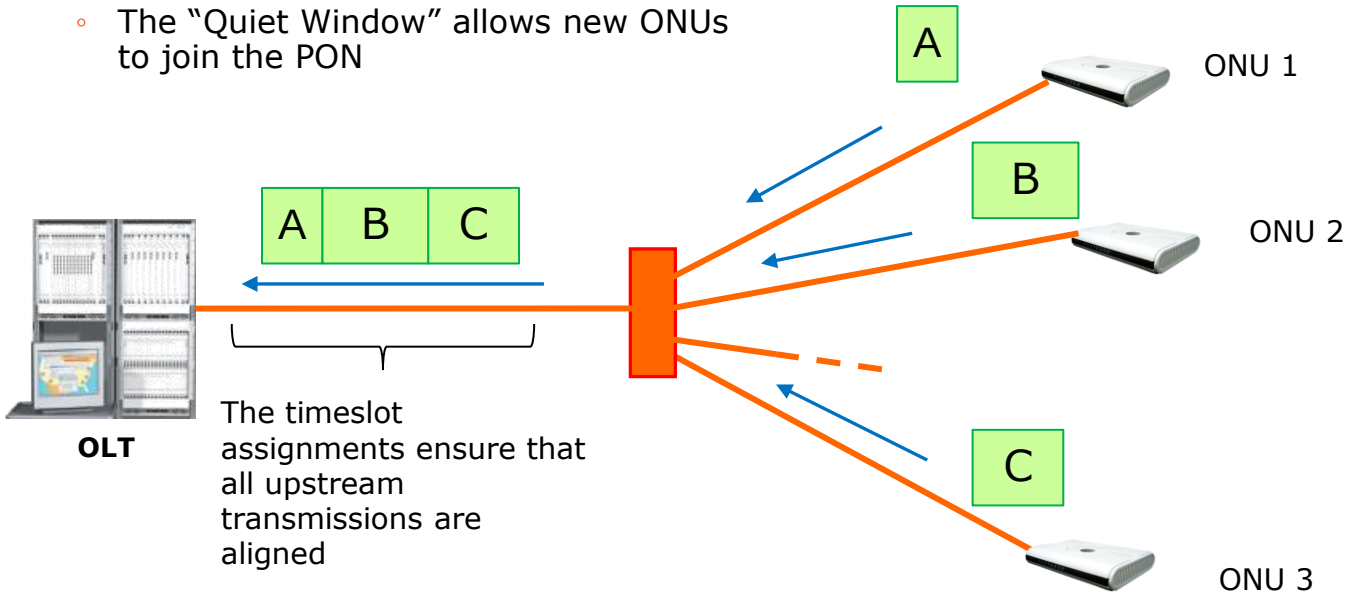
GPON Transmission Basics - Upstream

- TDMA (Time Division Multiple Access) mechanism:
  - The OLT assigns timeslots (BWmaps) for every ONU to transmit its upstream transmissions to ensure collision-free transmission
  - During the ONU activation process, the OLT assigns an Equalization Delay to each ONU to compensate for different distances from the OLT, meaning different delays
  - The "Quiet Window" allows new ONUs to join the PON



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ONU Activation Process

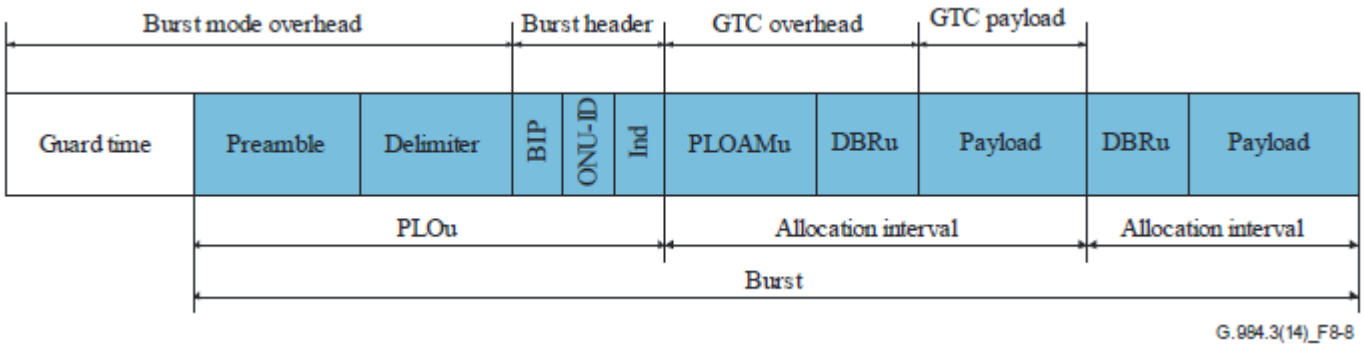
- Defined in G.984.3, clause A.6 and Figure A.5
- Defines a state machine with 5 states:
  - Initial state (O1)
  - Standby state (O2)
  - Serial Number state (O3)
  - Ranging state (O4)
  - Operation state (O5)

Notes:

1. The **ONU Bring-up** process includes the ONU activation process, followed by some OMCI message exchange. It is described in G.988 and will be covered separately later on.
2. There are two additional states that the ONU can transition to, but are not part of the activation – POPUP state (O6) and Emergency Stop State (O7)

Important Terms

- PSync
  - Physical Synchronization – a fixed 32-bit pattern (0xB6AB31E0) that begins every downstream frame
  - The ONU uses this pattern to find the beginning of the frame
- Preamble and Delimiter
  - Each upstream burst begins with the upstream physical layer overhead (PLOu) section which is composed of preamble, delimiter and the 3-byte burst header
  - The preamble is used to identify the start of the upstream burst at the physical layer, the delimiter identifies the start of the frame at the GTC (MAC) layer



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ONU Activation Process – Full Activation Process Flow Diagram

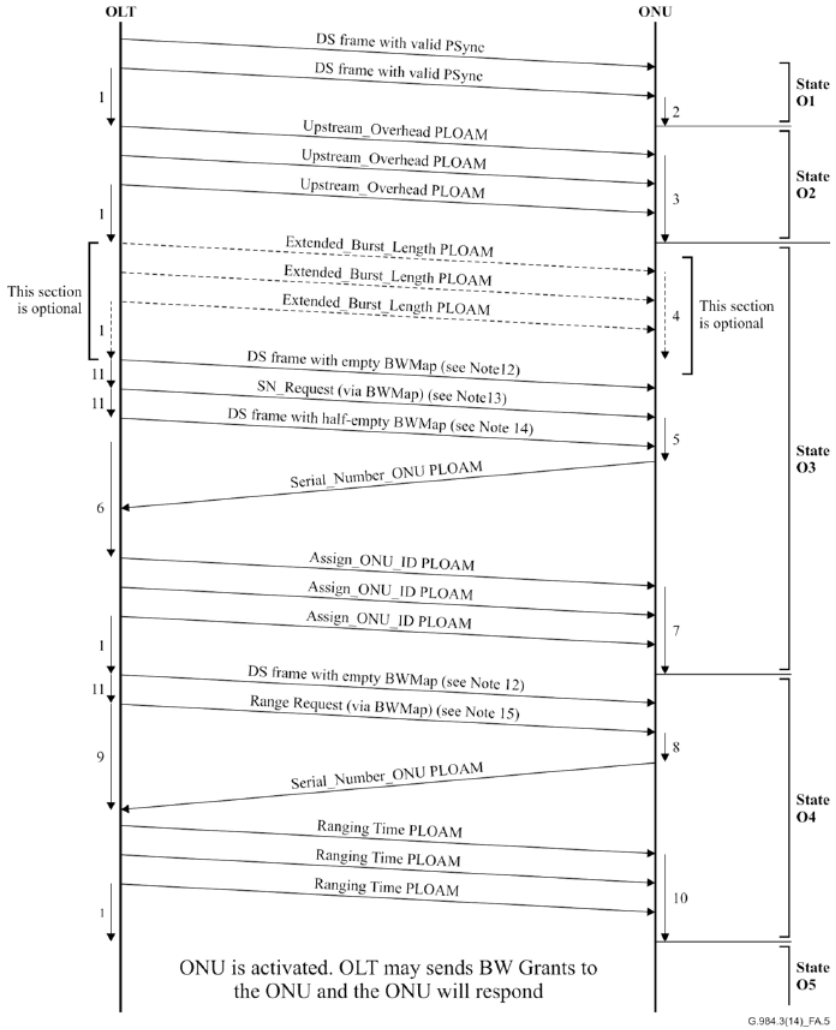

Figure A.5 – Activation process flow

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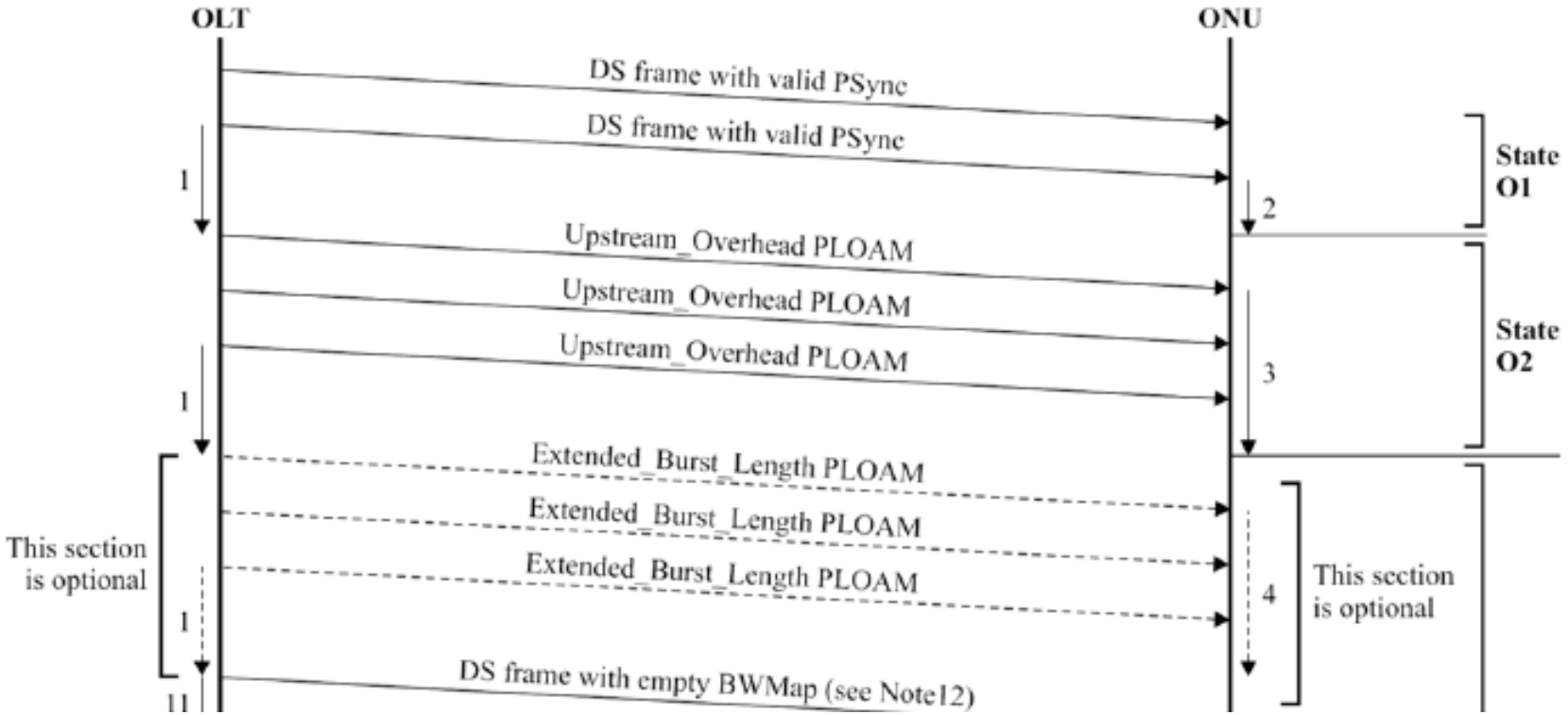
ONU Activation Process – States O1, O2



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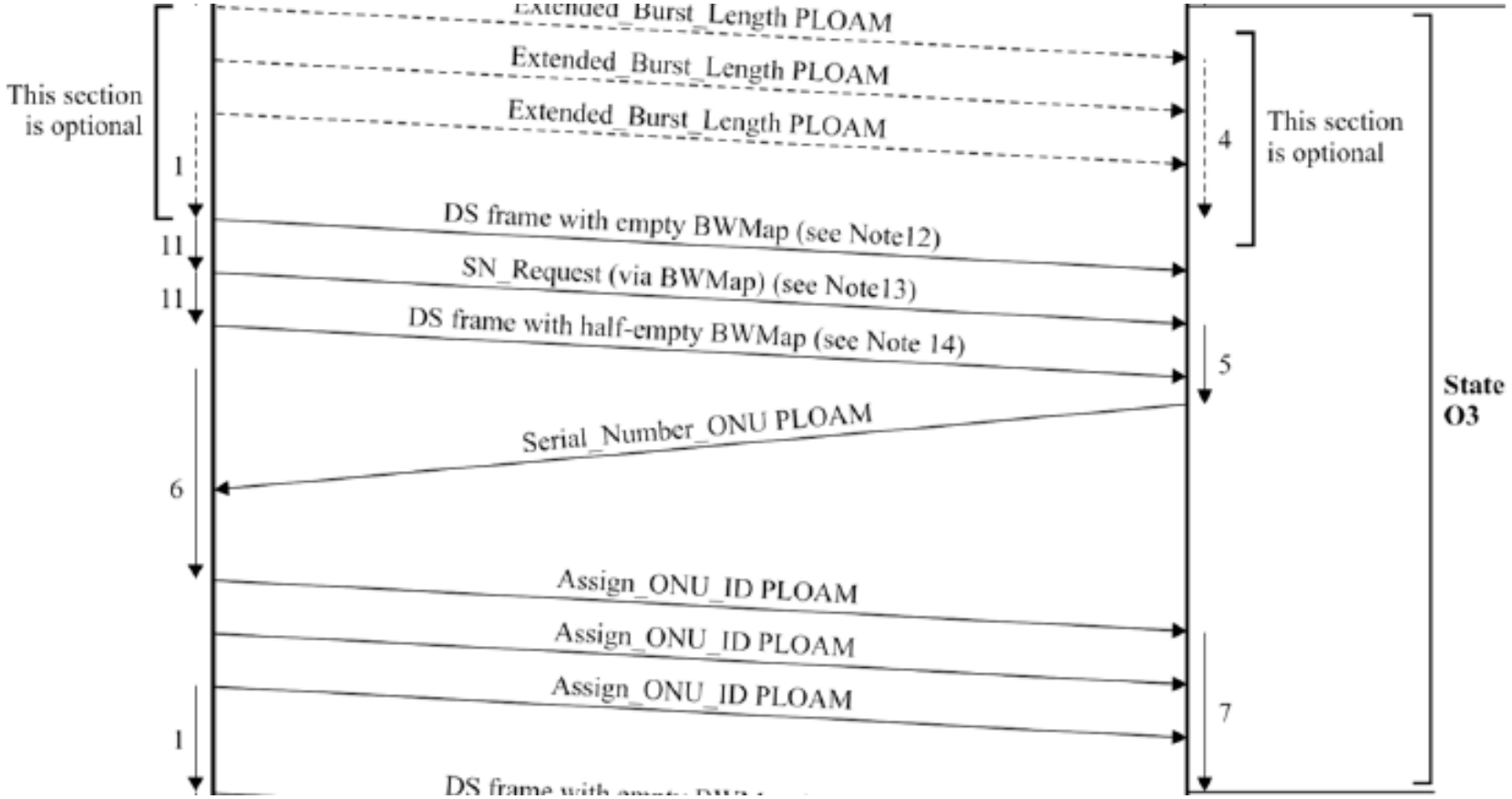
ONU Activation Process – State O3



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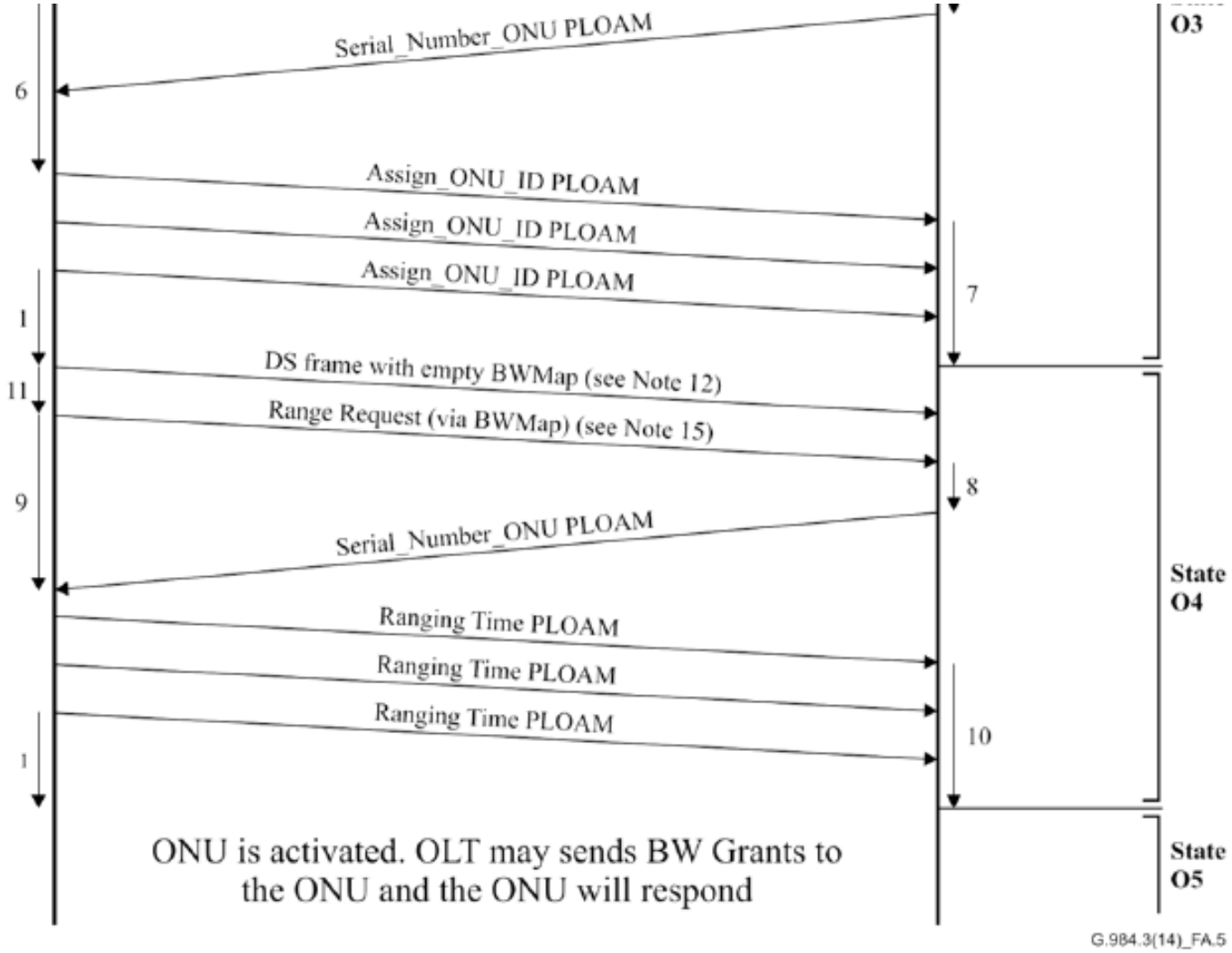
ONU Activation Process – States O3, O4, O5



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ONU Activation Process – Example

OLT | G-PON | Signaling

1 of 1 | 0

Line #	Message #	Time	ONU ID	Message Type	Message Source	Direction
56	50	00:00:30.731000	Broadcast Message	Upstream Overhead	PLOAM Message	Downstream
57	51	00:00:30.731125	Broadcast Message	Upstream Overhead	PLOAM Message	Downstream
58	52	00:00:30.731250	Broadcast Message	Upstream Overhead	PLOAM Message	Downstream
59	53	00:00:30.880750	Broadcast Message	Extended Burst Length	PLOAM Message	Downstream
60	54	00:00:30.880875	Broadcast Message	Extended Burst Length	PLOAM Message	Downstream
61	55	00:00:30.881000	Broadcast Message	Extended Burst Length	PLOAM Message	Downstream
62	56	00:00:31.021500	ONU Activation ID	Serial Number Request	BWmap Event	Downstream
63	1	00:00:31.021555	Unassigned ONU ID	Serial number ONU	PLOAM Message	Upstream
64	57	00:00:31.221750	ONU Activation ID	Serial Number Request	BWmap Event	Downstream
65	2	00:00:31.221805	Unassigned ONU ID	Serial number ONU	PLOAM Message	Upstream
66	58	00:00:31.421500	ONU Activation ID	Serial Number Request	BWmap Event	Downstream
67	3	00:00:31.421555	Unassigned ONU ID	Serial number ONU	PLOAM Message	Upstream
68	59	00:00:31.621625	Broadcast Message	Assign ONU-ID	PLOAM Message	Downstream
69	60	00:00:31.621750	Broadcast Message	Assign ONU-ID	PLOAM Message	Downstream
70	61	00:00:31.621875	Broadcast Message	Assign ONU-ID	PLOAM Message	Downstream
71	62	00:00:31.821750	8	Ranging Request	BWmap Event	Downstream
72	1	00:00:31.821786	8	Serial number ONU	PLOAM Message	Upstream
73	63	00:00:31.822875	8	Ranging Time	PLOAM Message	Downstream
74	64	00:00:31.823000	8	Ranging Time	PLOAM Message	Downstream
75	65	00:00:31.823125	8	Ranging Time	PLOAM Message	Downstream

Data | PLOAM Message Type

Name	Value	Description
Path EqD Descriptor	Main Path EqD	
Delay	309660	

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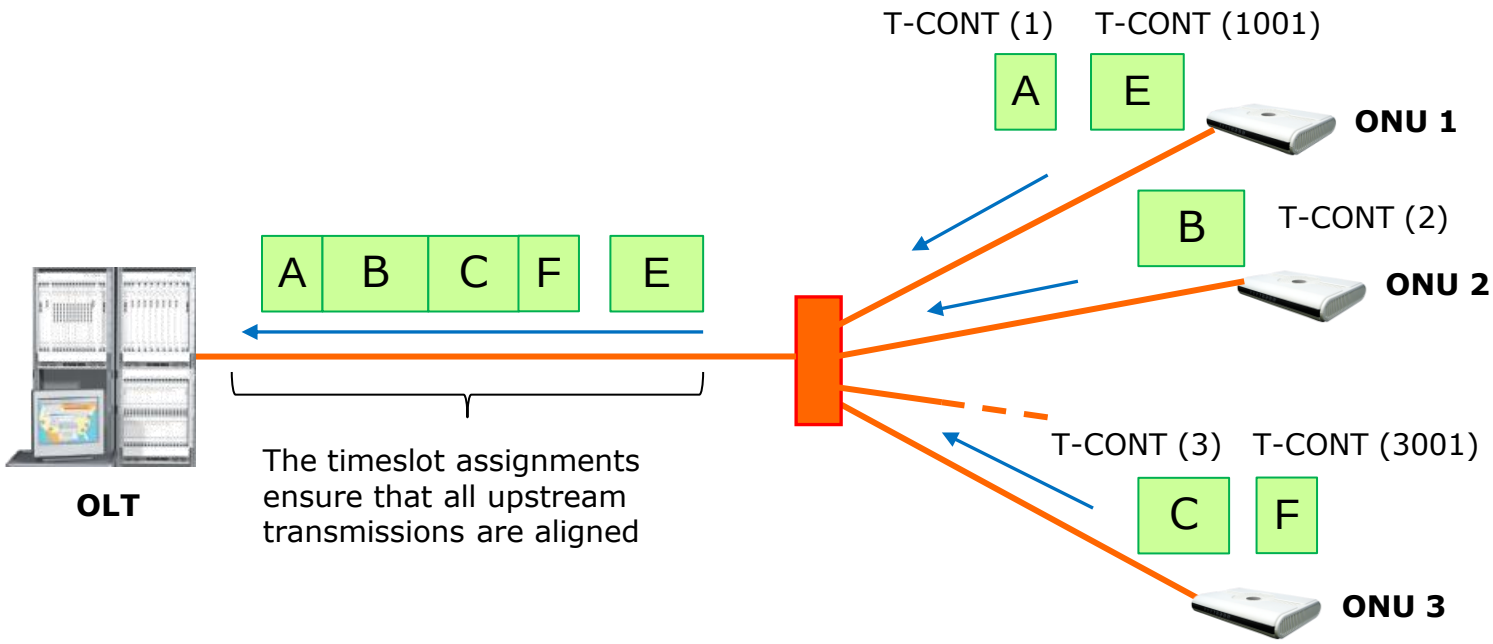
Traffic Containers (T-CONT)

- T-CONT: A grouping of logical connections for the purpose of upstream bandwidth assignment
  - Definition from TR-156: A traffic-bearing object within an ONU that represents a group of logical connections, is managed via the ONU Management and Control Channel (OMCC), and **is treated as a single entity for the purpose of upstream bandwidth assignment on the PON**

- 5 T-CONT types are defined in ITU-T G.984.3
  - Type 1 = Fixed bandwidth
  - Type 2 = Assured bandwidth
  - Type 3 = Assured & Non-Assured bandwidth
  - Type 4 = Best effort
  - Type 5 = Fixed, Assured and Non-Assured

Bandwidth Assignments for T-CONTs

- TDMA (Time Division Multiple Access) mechanism:
  - The OLT assigns timeslots (BWmaps) for every ONU to transmit its upstream transmissions,
  - Every BWmap assigment includes the T-CONT ID (Alloc-ID)



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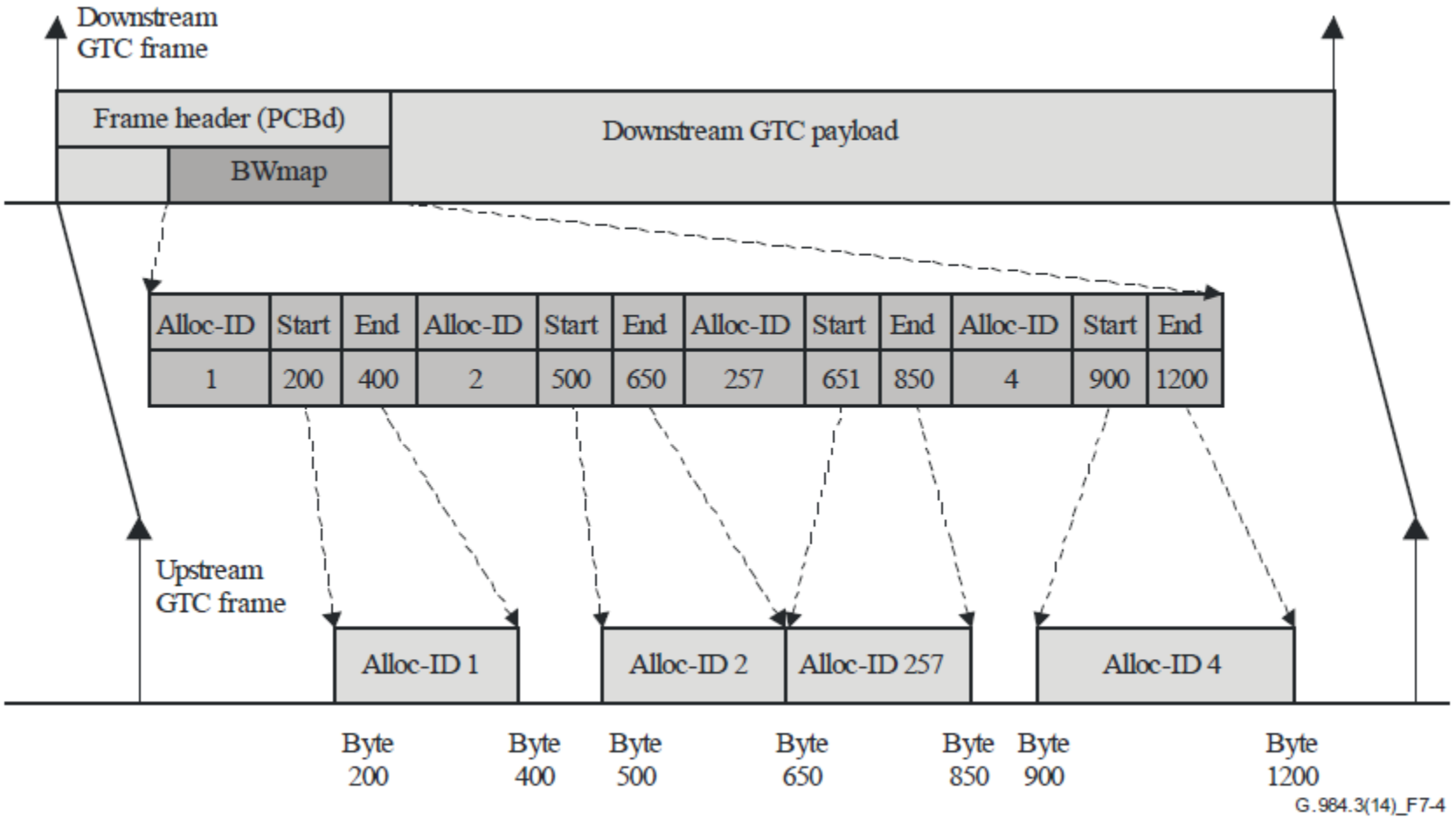
Downstream BWmaps and Upstream Frames



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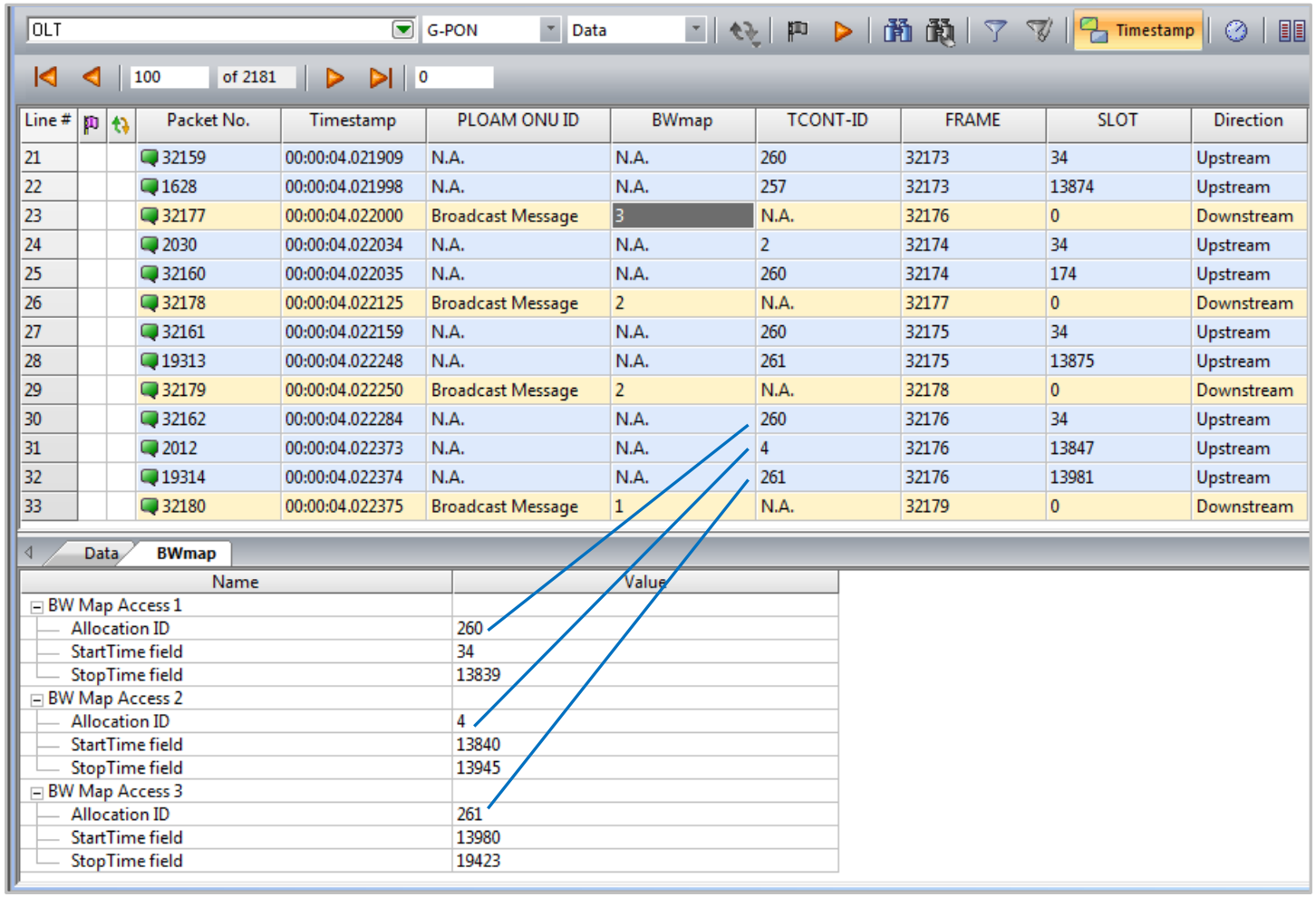
BWmaps and Corresponding Upstream Transmissions



Line #	Packet No.	Timestamp	PLOAM ONU ID	BWmap	TCONT-ID	FRAME	SLOT	Direction
21	32159	00:00:04.021909	N.A.	N.A.	260	32173	34	Upstream
22	1628	00:00:04.021998	N.A.	N.A.	257	32173	13874	Upstream
23	32177	00:00:04.022000	Broadcast Message	3	N.A.	32176	0	Downstream
24	2030	00:00:04.022034	N.A.	N.A.	2	32174	34	Upstream
25	32160	00:00:04.022035	N.A.	N.A.	260	32174	174	Upstream
26	32178	00:00:04.022125	Broadcast Message	2	N.A.	32177	0	Downstream
27	32161	00:00:04.022159	N.A.	N.A.	260	32175	34	Upstream
28	19313	00:00:04.022248	N.A.	N.A.	261	32175	13875	Upstream
29	32179	00:00:04.022250	Broadcast Message	2	N.A.	32178	0	Downstream
30	32162	00:00:04.022284	N.A.	N.A.	260	32176	34	Upstream
31	2012	00:00:04.022373	N.A.	N.A.	4	32176	13847	Upstream
32	19314	00:00:04.022374	N.A.	N.A.	261	32176	13981	Upstream
33	32180	00:00:04.022375	Broadcast Message	1	N.A.	32179	0	Downstream

Data | BWmap

Name	Value
BW Map Access 1	
Allocation ID	260
StartTime field	34
StopTime field	13839
BW Map Access 2	
Allocation ID	4
StartTime field	13840
StopTime field	13945
BW Map Access 3	
Allocation ID	261
StartTime field	13980
StopTime field	19423

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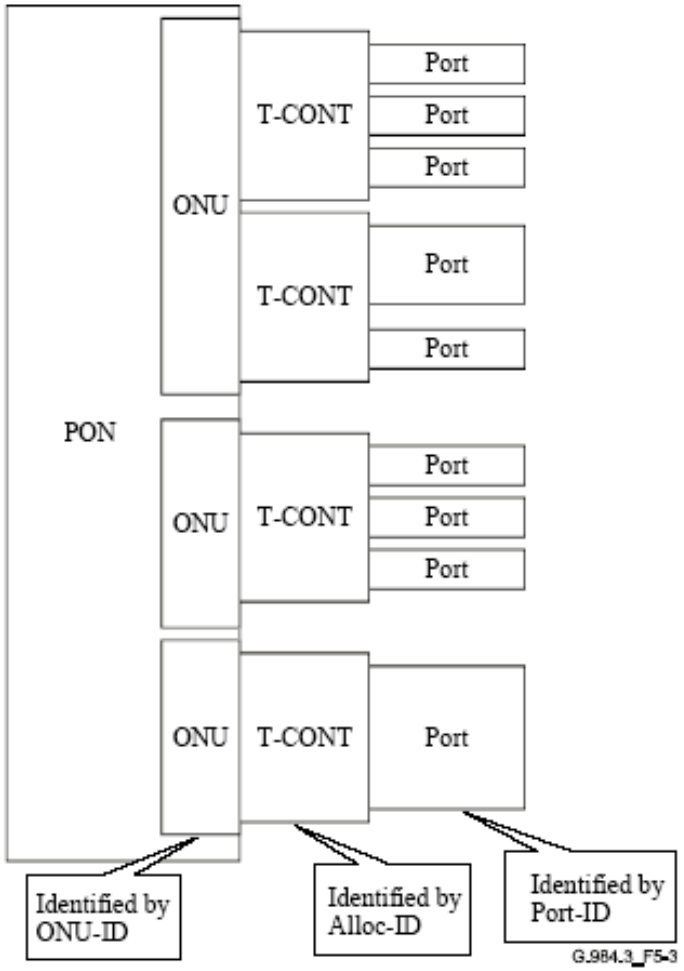
Dynamic Bandwidth Allocation (DBA)

- Not all users and all services need all their peak bandwidth all the time
  - Fixed bandwidth allocations are inefficient
- Dynamic bandwidth allocation is needed to optimize bandwidth usage of the shared medium
  - With DBA, the OLT assesses the bandwidth needs of all ONTs and allocates available bandwidth dynamically
- Allows service providers to define flexible service options, oversubscription levels and Service Level Agreements

GPON Encapsulation Method (GEM) and Multiplexing Model

- GEM is a method for encapsulating user frame data for transport over the GPON
- "GEM ports" represent a logical connection associated with a specific traffic flow



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Control Messages

- Physical layer OAM (PLOAM) messaging channel
  - Supports the PON TC layer management functions, including **ONU activation/deactivation, OMCI channel establishment, encryption configuration and key management**
  - Transported in the 13-byte PLOAM message field within the overhead section of the downstream GTC frame and default Alloc-ID of the upstream GTC burst
  - Specified in ITU-T G.984.3
- ONU management and control interface (OMCI)
  - OMCI messages are transported over a dedicated GEM channel. The OMCI transport mechanism is described in ITU-T G.984.3 clause 14
  - The syntax of the OMCI is specified in ITU-T G.988

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Introduction to XG-PON and XGS-PON

- History and Market Drivers
- Technology and Protocol Highlights
- Burst Profiles and Dual-Rate Support

Beyond GPON – Main Market Drivers

- Competition
- Business services
- Backhaul for 4G and 5G wireless networks

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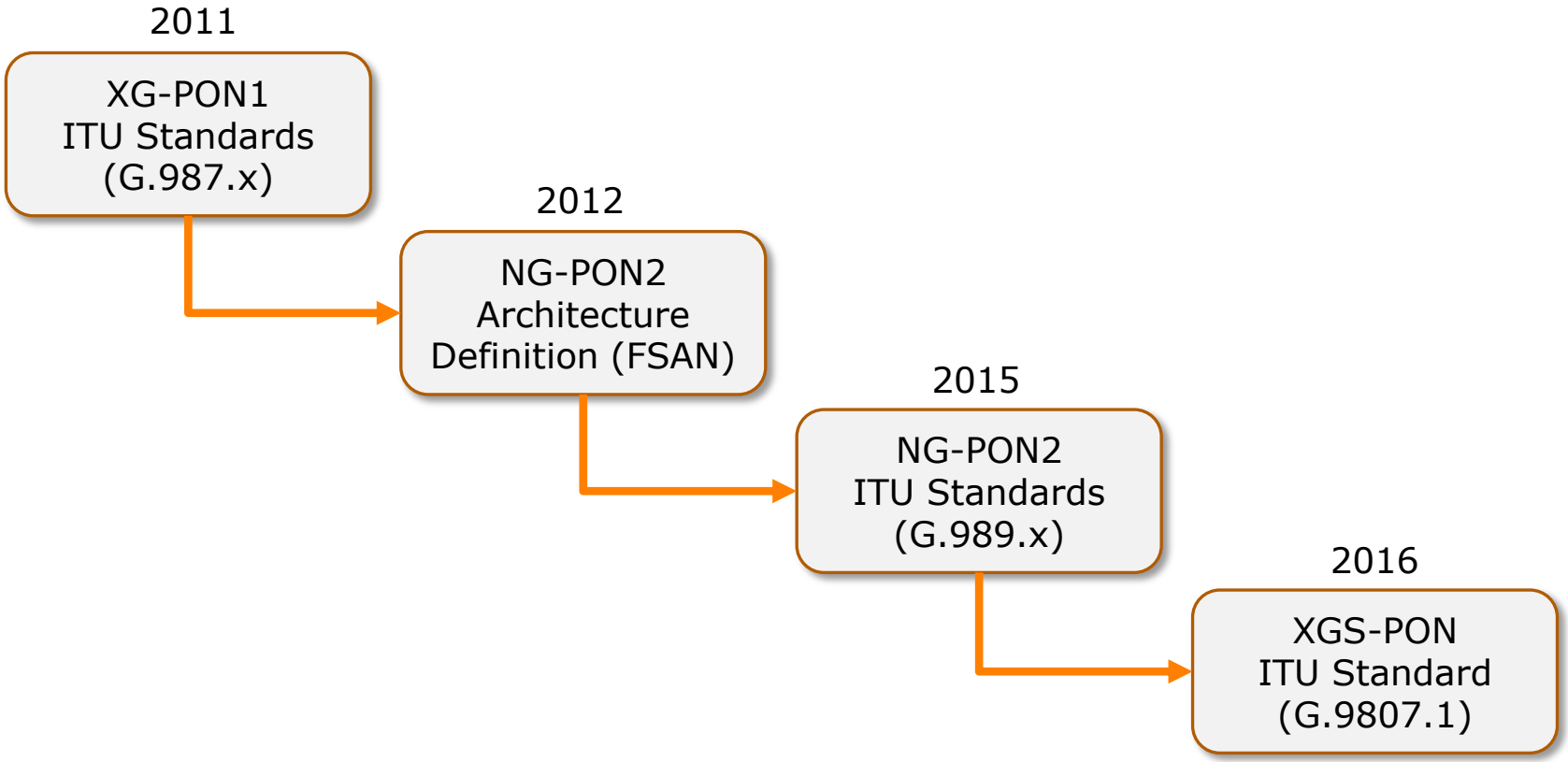
XG-PON1, XGS-PON and NG-PON2 Definitions and Standardization History



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XG-PON1 – Highlights

- Downstream 10 Gb/s (9.95328 Gb/s)
- Upstream 2.5 Gb/s (2.48832 Gb/s)
- Other major enhancements compared to GPON:
  - 29 dB optical budget
  - Split ratio up to 1:256
  - Extended power saving modes
  - Enhanced security

XG-PON1 – Framing and TDMA Control

- Reuse and adaptation of the GPON protocol
- More flexible PLOAM channel
  - Multiple messages in the same frame
  - Extended PLOAM message length – 48 bytes compared to 13 bytes in GPON
- Expansion of fields

Example – Multiple PLOAM Messages in One Frame

PLOAM Message No. 1

PLOAM Message No. 2

Data | BW Maps | PLOAMs

Name	Value
PLOAM Message No. 1 - Burst Profile	
ONU ID	1022
Message ID	Burst Profile
Sequence Number	208
Version	14
Line Rates Applicability	The profile applies to ONUs transmitting at 10G upstream
Profile Index	2
FECInd	0
Delimiter Length	8
Delimiter	0xCE99CE5E5028B41F
Preamble Length	8
Preamble Repeat	32
Preamble	0xCCCCCCCCCCCCCCCC
PON-TAG	0x4D5432204D543220
Downstream PON ID	0x00
PLOAM Message No. 2 - Request Registration	
ONU ID	1
Message ID	Request Registration
Sequence Number	209

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XGS-PON – Highlights

- Downstream 10 Gb/s (9.95328 Gb/s)
- Upstream 10 Gb/s (9.95328 Gb/s) or 2.5 Gb/s (2.48832 Gb/s) – support for two types of ONUs on the same PON
- Protocol and frame structure similar to XG-PON1, but minor differences

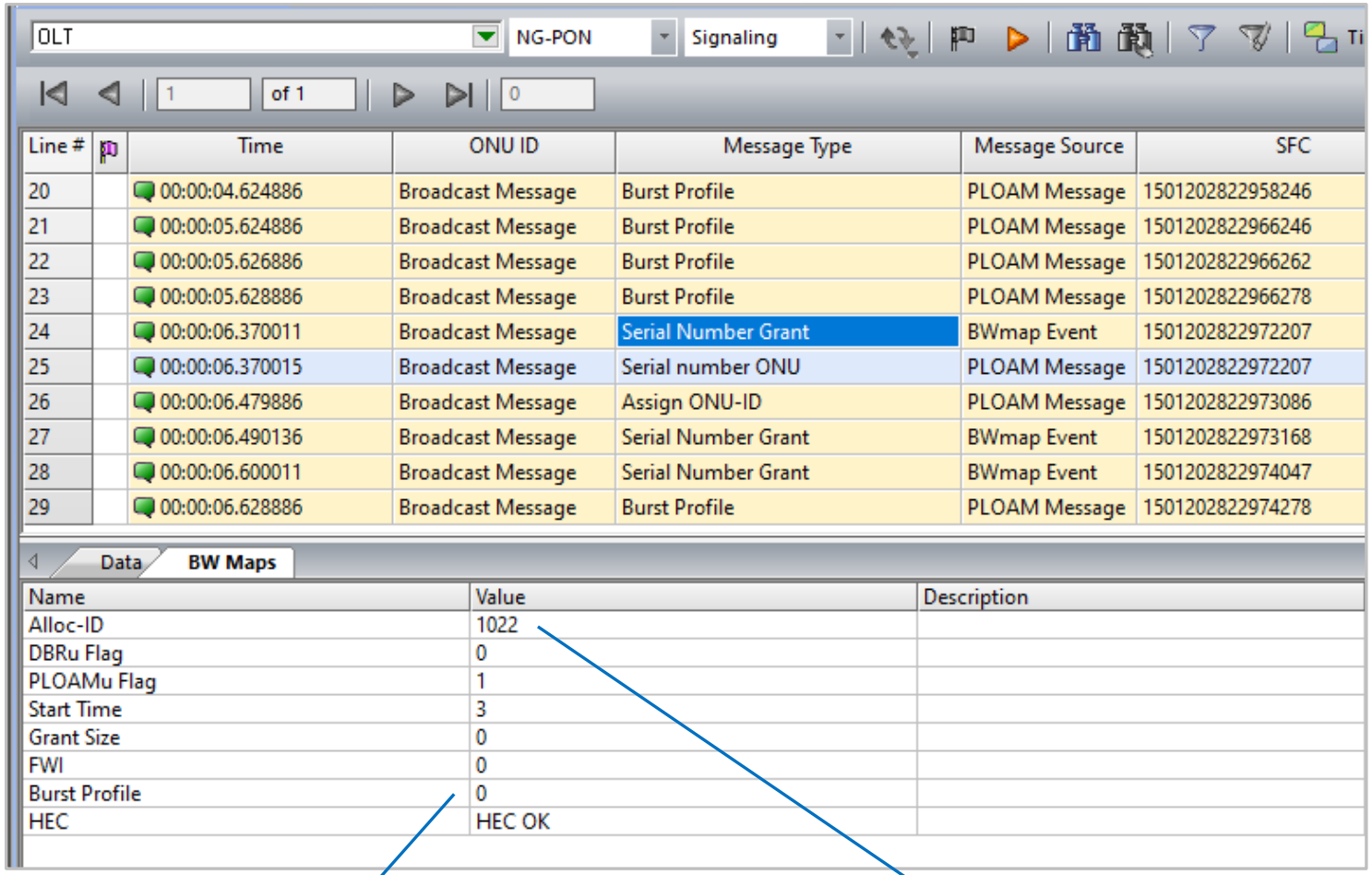
XGS-PON – Profiles and Dual Rate Support

- The Burst Profile PLOAM message specifies parameters for upstream transmission, including:
  - The upstream line rate – 10 Gb/s or 2.5 Gb/s
  - The Preamble and Delimiter
  - If FEC is to be used in the upstream
- There may be several different profiles simultaneously on the PON, each with its own index
- Each BWmap allocation specifies the profile index for the upstream transmission

XGS-PON – Profiles and Dual Rate Support

- The same index may be used for two burst profiles simultaneously, one for 10 Gb/s upstream and the second for 2.5 Gb/s upstream
- The Quiet Window BWmap specifies which type of ONUs should respond using a different broadcast Alloc-ID:
  - Alloc-ID 1022: ONUs transmitting at 10 Gb/s
  - Alloc-ID 1023: ONUs transmitting at 2.5 Gb/s
  - Alloc-ID 1021: Both types of ONUs (shall not be used for the case of XGS-PON interworking with XG-PON1)

XGS-PON Quiet Window BWmap ("Serial Number Grant") Example



Line #	Time	ONU ID	Message Type	Message Source	SFC
20	00:00:04.624886	Broadcast Message	Burst Profile	PLOAM Message	1501202822958246
21	00:00:05.624886	Broadcast Message	Burst Profile	PLOAM Message	1501202822966246
22	00:00:05.626886	Broadcast Message	Burst Profile	PLOAM Message	1501202822966262
23	00:00:05.628886	Broadcast Message	Burst Profile	PLOAM Message	1501202822966278
24	00:00:06.370011	Broadcast Message	Serial Number Grant	BWmap Event	1501202822972207
25	00:00:06.370015	Broadcast Message	Serial number ONU	PLOAM Message	1501202822972207
26	00:00:06.479886	Broadcast Message	Assign ONU-ID	PLOAM Message	1501202822973086
27	00:00:06.490136	Broadcast Message	Serial Number Grant	BWmap Event	1501202822973168
28	00:00:06.600011	Broadcast Message	Serial Number Grant	BWmap Event	1501202822974047
29	00:00:06.628886	Broadcast Message	Burst Profile	PLOAM Message	1501202822974278

Data | BW Maps

Name	Value	Description
Alloc-ID	1022	
DBRu Flag	0	
PLOAMu Flag	1	
Start Time	3	
Grant Size	0	
FWI	0	
Burst Profile	0	
HEC	HEC OK	

Burst Profile Index

Alloc-ID 1022 – for ONUs transmitting at 10Gb/s

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Agenda (1 hour)

- Webinar Introduction
- Introduction to the GPON protocol
- Introduction to XG-PON and XGS-PON
- **GPON and XGS-PON Comparison**
- Questions

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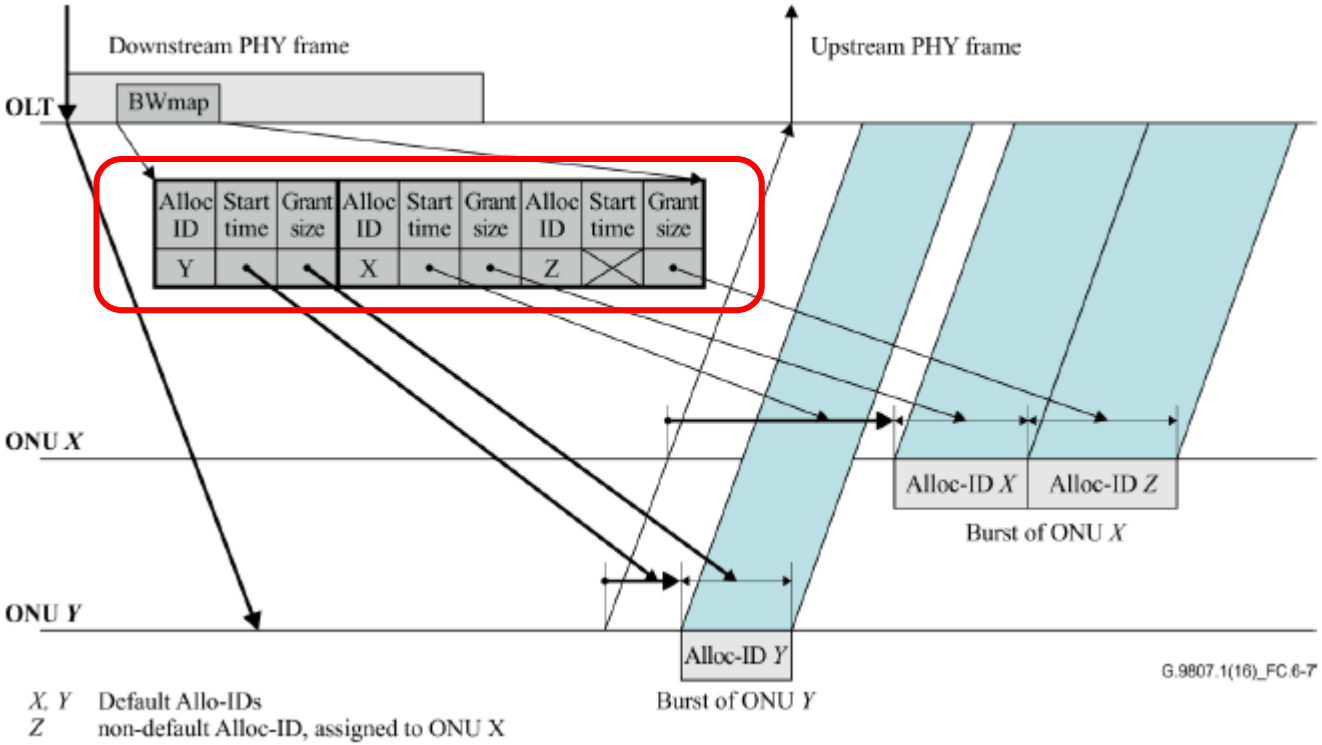
GPON and XGS-PON Comparison

- Frame and BWmap Structure
- Wavelength Assignment
- PON-ID
- ONU-ID, Alloc-ID and Port ID Value Ranges
- Security Threats and Mechanisms

XG-PON1/XGS-PON – BWmap Structure

- In GPON the BWmap specifies the Start Time and Stop Time for the burst, in XG-PON1/XGS-PON – the Start Time and **Grant Size**
- Every XG-PON1/XGS-PON BWmap also specifies the **Burst Profile** as one of its flags, other flags are also slightly different



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Wavelength Assignment

Wavelength (or Range)	Usage
1270 nm	XG-PON1/XGS-PON US
1310 nm	GPON US
1490 nm	GPON DS
1524-1544 nm	NG-PON2 (TWDM) US
1550 nm	Analog (“RF”) Overlay DS
1577 nm	XG-PON1/XGS-PON DS
1596-1603 nm	NG-PON2 (TWDM) DS
1603-1625 nm	NG-PON2 (PtP WDM) Shared Spectrum DS and US

PON-ID

- A typical fiber distribution panel or cabinet has hundreds or even thousands of connections, how can you tell which fiber belongs to which PON?
- **The PON-ID provides a unique identification to every PON**
- Mandatory in XG-PON1/XGS-PON, also added as an amendment to the GPON standard (included in the 2014 version of G.984.3), but defined as optional
- In XG-PON1 and XGS-PON it is part of the downstream frame, in GPON a separate PLOAM message

ONU-ID Values

GPON ONU-ID	XG-PON1 ONU-ID	XGS-PON ONU-ID	Designation	Comment
0..253	0..1022	0..1020	Assignable	Assigned by OLT at ONU activation; used to identify the sender of an upstream burst or a PLOAMu message and the recipient of a PLOAMd message.
254		1021	Reserved	The number shall not be assigned to any ONU, and shall not be used as an ONU-ID.
		1022	Broadcast/reserved	Broadcast address in PLOAMd; not used in PLOAMu. The number shall not be assigned to any ONU, and shall not be used as an ONU-ID.
255	1023	1023	Broadcast/unassigned	Broadcast address in PLOAMd; unassigned ONU in PLOAMu.

Alloc-ID Values

GPON Alloc-ID	XG-PON1 Alloc-ID	XGS-PON Alloc-ID	Designation	Comment
0..253	0..1022	0..1020	Default	Default Alloc-ID, which is implicitly assigned with and is equal to the ONU-ID.
254	1023	1021 1022 1023	Reserved/ Broadcast	Used by OLT in a serial number request allocation structure to indicate that any ONU* executing the serial number acquisition phase of the activation procedure may use this allocation to transmit a serial number response.
255			Unassigned	May be used by the OLT to indicate that a particular allocation structure should not be used by any ONU.
256.. 4095	1024.. 16383	1024.. 16383	Assignable	If more than a single Alloc-ID is needed for an ONU, the OLT assigns additional Alloc-IDs to that ONU by selecting a unique number from this range and communicating it to the ONU using the Assign_Alloc-ID PLOAM message.

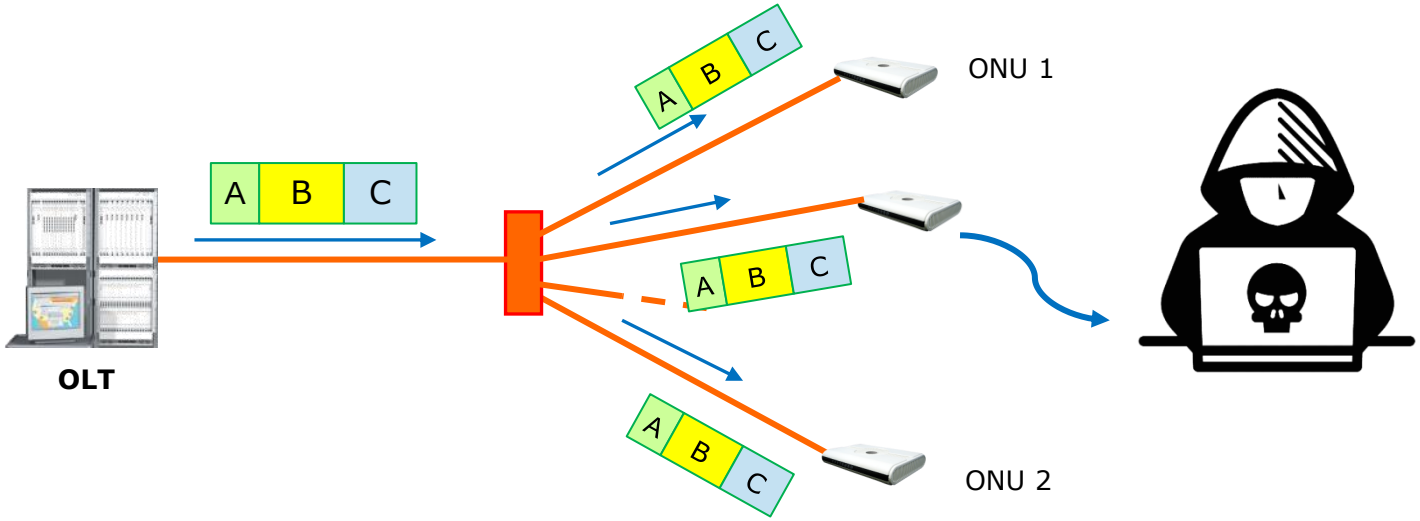
* In XGS-PON different Broadcast Alloc-IDs are used for ONUs transmitting at different upstream rates

Port-ID Values

GPON Port-ID	XG-PON1 Port-ID	XGS-PON Port-ID	Designation	Comment
	0..1022	0..1020	Default	Default XGEM Port-ID, which is implicitly assigned with and is equal to the ONU-ID. It identifies the XGEM port used by the OMCC traffic.
0..4095	1023..65534	1021..65534	Assignable	If more than a single XGEM Port-ID is needed for an ONU, the OLT assigns additional Port-IDs to that ONU by selecting a unique number from this range and communicating it to the ONU using the OMCC. In XGS-PON The values 1021 and 1022 shall not be assigned to XG-PON ONUs.
	65535	65535	Idle	Reserved for Idle XGEM Port-ID.

XG-PON1/XGS-PON – Security (1)

- XGS-PON security is intended to protect against the following threats:
  - Since downstream data is broadcast to all ONUs attached to the OLT, a malicious user capable of replacing or re-programming an ONU would be capable of receiving all downstream data intended for all connected users



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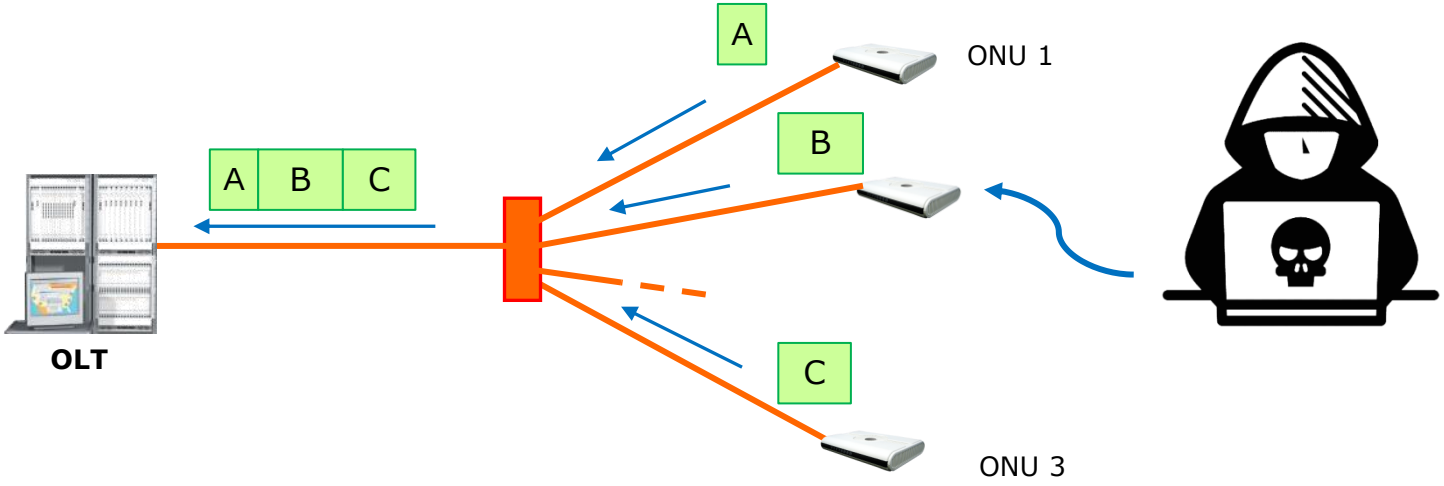
XG-PON1/XGS-PON – Security (2)

- XGS-PON security is intended to protect against the following threats (continued):
  - Since upstream data received by the OLT can originate from any ONU attached to the XGS-PON optical distribution network (ODN), a malicious user capable of replacing or re-programming an ONU could forge packets so as to impersonate a different ONU (i.e., theft of service)



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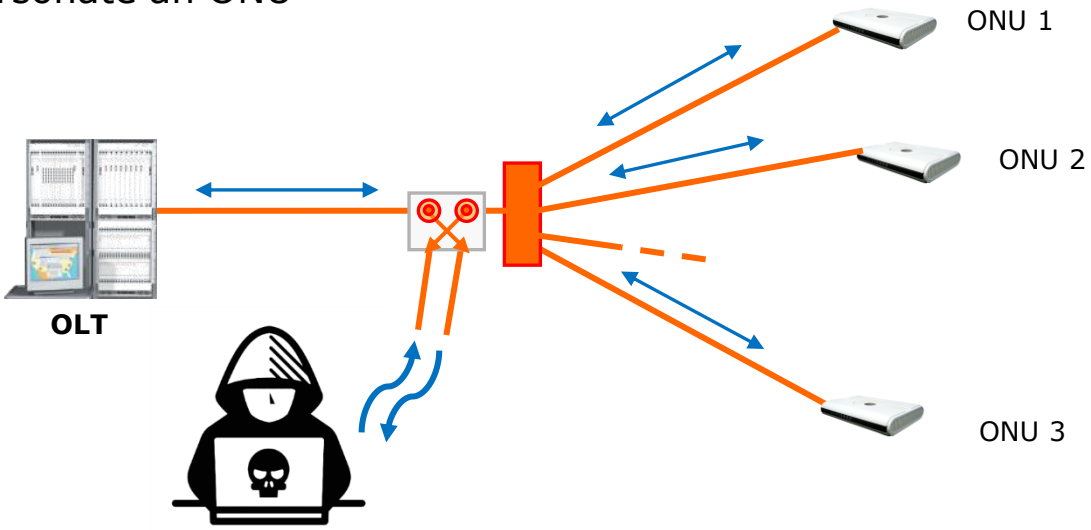
XG-PON1/XGS-PON – Security (3)

- XGS-PON security is intended to protect against the following threats (continued):
  - An attacker could connect a malicious device at various points on the infrastructure (e.g., by tampering with street cabinets, spare ports, or fiber cables). Such a device could intercept and/or generate traffic. Depending on the location of such a device, it could impersonate an OLT or alternatively it could impersonate an ONU



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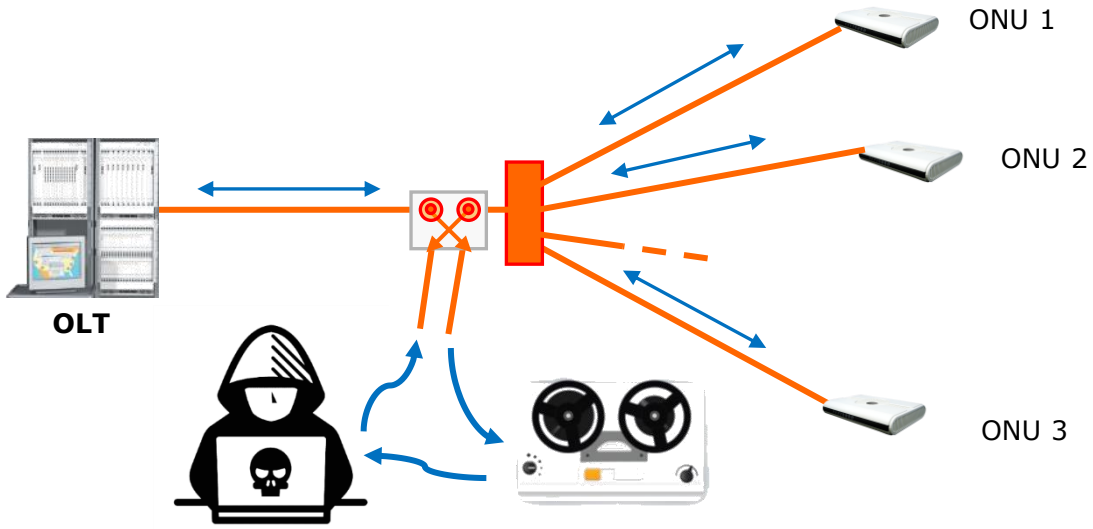
XG-PON1/XGS-PON – Security (4)

- XGS-PON security is intended to protect against the following threats (continued):
  - A malicious user in any of the above scenarios could record packets transmitted on the PON and replay them back onto the PON later, or conduct bit-flipping attacks



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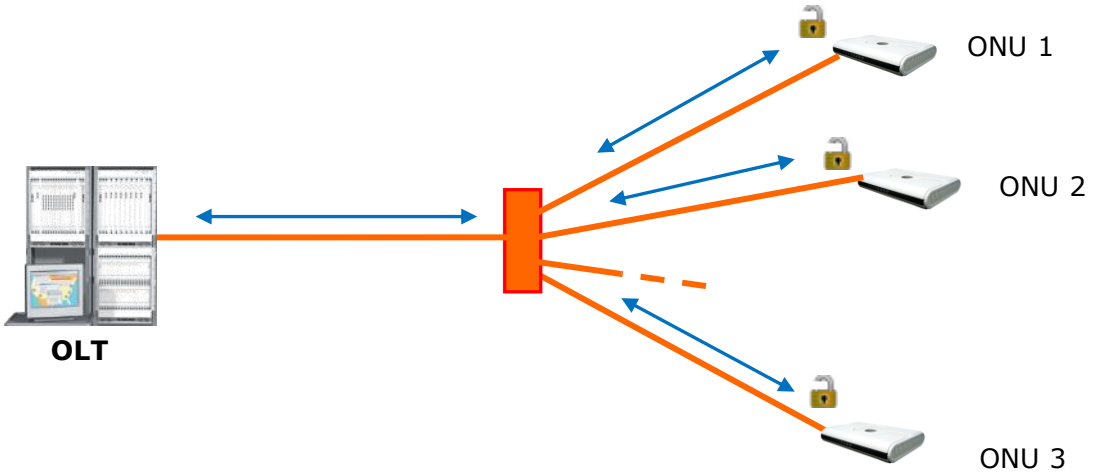
XG-PON1/XGS-PON Security – AES Encryption

- Unlike GPON that supports AES encryption only in the downstream direction, XGS-PON also supports it in the upstream
  - AES encryption is optional
  - In the downstream it is more commonly used than in the upstream
  - XGS-PON supports two keys simultaneously



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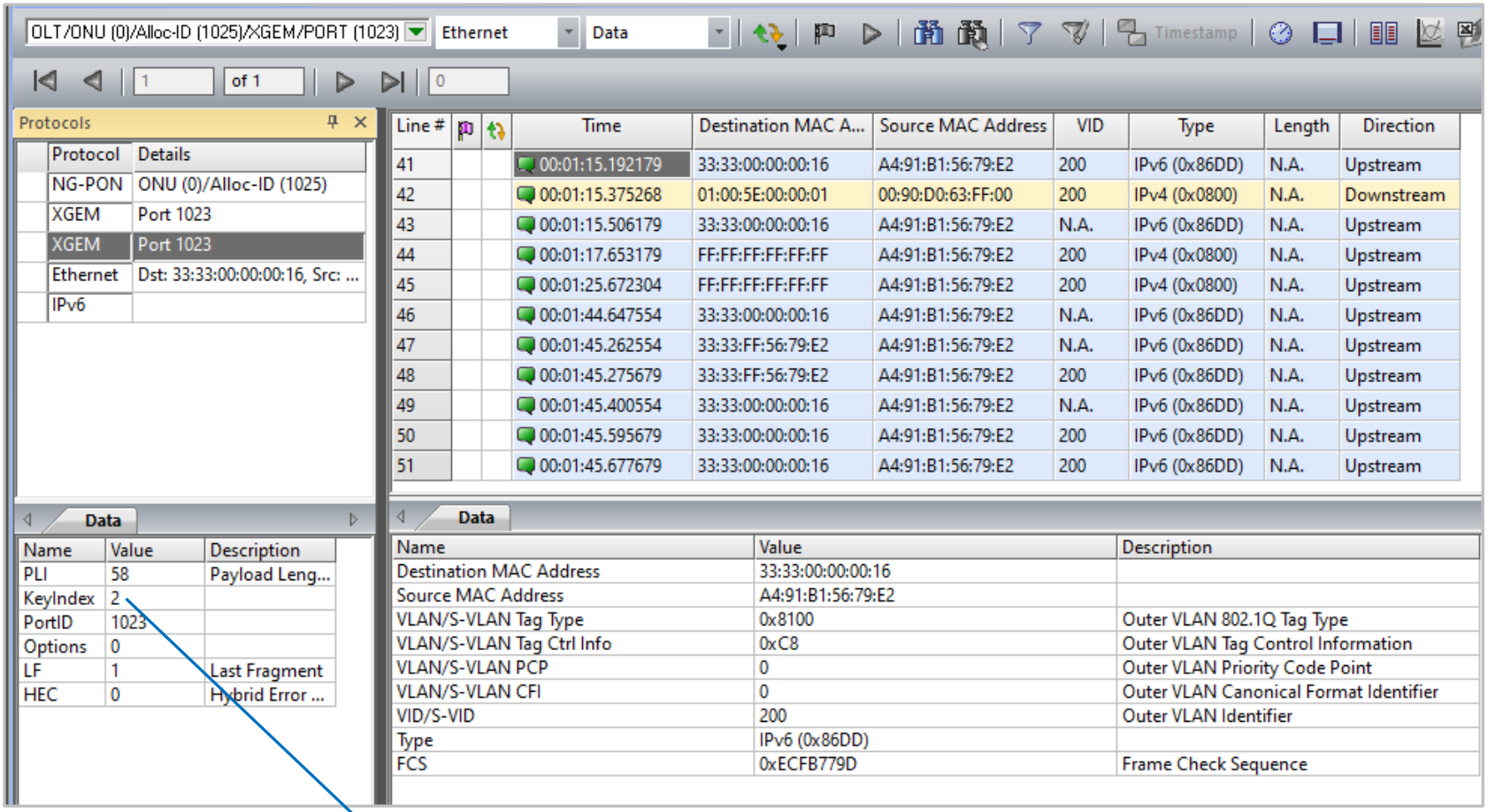
XGS-PON AES Encryption Example



The XGEM Header Key Index indicates which key is used for encryption
Key Index 0 indicates no encryption

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XG-PON1/XGS-PON – Additional Security Mechanisms

- Authentication – the XG-PON1/XGS-PON systems supports three mechanisms for authentication:
  - Registration-based authentication
  - OMCI-based secure mutual authentication
  - IEEE 802.1X-based authentication secure mutual authentication
- MIC – the message integrity check is an 8-byte field that is used to verify the sender's identity and to prevent a forged PLOAM message attack

TraceSpan Products

- Lab
  - NG-PON Xpert™
    - Multi-layer analyzer
    - Multi-ONU Emulator
    - OLT Emulator
  - GPON Xpert™
    - Multi-layer analyzer
    - OLT Emulator
- Field
  - GPON Tracer™

Xpert™ Analyzers and Emulators

GPON Tracer™

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Questions

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Thank you for attending

If you would like additional information about TraceSpan products:

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