TECHNICAL REPORT

TR-352

Multi-wavelength PON Inter-Channel-Termination Protocol (ICTP) Specification

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Executive Summary

NG-PON2, specified in ITU-T Recommendation series G.989, is a multi-wavelength PON system which includes in its scope an additional interoperability dimension in comparison with the earlier PON systems: one that applies between the OLT channel terminations (CTs) within a single NG-PON2 system. The NG-PON2 CTs must exchange information related, among other functionalities, to channel profile configuration and status sharing, ONU activation, ONU tuning, rogue ONU mitigation. OLT channel termination interoperability allows diversification of suppliers of the TWDM and PTP WDM NG-PON2 subsystem, as well as the suppliers of the TWDM CTs for business and residential applications. OLT channel termination interoperability is also instrumental in the case of co-operative multi-operator environments, where different operators share the same ODN each using only a subset of available NG-PON2 wavelength channel pairs. This technical report defines the requirements of the Inter-Channel-Termination Protocol (ICTP), which is used to exchange such information between CTs, enabling inter-vendor NG-PON2 interoperability.

ICTP can also be used by single wavelength channel pair PON systems, such as XGS-PON, specified in ITU-T Recommendation G.9807.1, for exchange of information for protection purposes.

1 Purpose and Scope

1.1 Purpose

The purpose of this Working Text is to specify a protocol that is executed between the OLT Channel Terminations and, based on the multiple wavelength channel architecture and functional descriptions outlined in ITU-T Recommendation G.989.3, enables wavelength channel management and protection management within an NG-PON2 system. To the extent of protection management, the protocol specified herein is also applicable to single wavelength channel PON systems, such as XGS-PON specified in ITU-Recommendation G.9807.1.

1.2 Scope

This Technical Report provides:

- the specification of ICTP message formats, state machines, and data structures which serve to implement the channel management functional primitives employed by the high level channel management functions.
- the description of the channel termination synchronization issues;
- the description of the ICTP defects and failures;
- the overview of the ICTP transport options;
- ICTP use cases.

2 References and Terminology

2.1 Conventions

In this Technical Report, several words are used to signify the requirements of the specification. These words are always capitalized. More information can be found be in RFC 2119 [3].

MUST	This word, or the term "REQUIRED", means that the definition is an absolute requirement of the specification.
MUST NOT	This phrase means that the definition is an absolute prohibition of the specification.
SHOULD	This word, or the term "RECOMMENDED", means that there could exist valid reasons in particular circumstances to ignore this item, but the full implications need to be understood and carefully weighed before choosing a different course.
SHOULD NOT	This phrase, or the phrase "NOT RECOMMENDED" means that there could exist valid reasons in particular circumstances when the particular behavior is acceptable or even useful, but the full implications need to be understood and the case carefully weighed before implementing any behavior described with this label.
MAY	This word, or the term "OPTIONAL", means that this item is one of an allowed set of alternatives. An implementation that does not include this option MUST be prepared to inter-operate with another implementation that does include the option.

2.2 References

The following references are of relevance to this Technical Report. At the time of publication, the editions indicated were valid. All references are subject to revision; users of this Technical Report are therefore encouraged to investigate the possibility of applying the most recent edition of the references listed below.
A list of currently valid Broadband Forum Technical Reports is published at www.broadband-forum.org.

Document		Title	Source	Year
[1]	G.989	*NG-PON2: Definitions, abbreviations and acronyms*	ITU-T	2015
[2]	G.989.3	*NG-PON2 : Transmission Convergence Layer Specification*	ITU-T	2015
[3]	RFC 2119	*Key words for use in RFCs to Indicate Requirement Levels*	IETF	1997

[4]	TR-101 Issue 2	*Migration to Ethernet-Based Broadband Aggregation*	BBF	2011
[5]	TR-156 Issue 3	*Using GPON Access in the context of TR-101*	BBF	2012
[6]	G.9807.1	*10-Gigabit-capable symmetric passive optical network (XGS-PON)*	ITU-T	2016

2.3 Definitions

The following terminology derived from ITU-T G.989 [1] is used throughout this Technical Report.

Channel Group	A set of channel pairs carried over a common fiber.
Channel Pair	A set of one downstream wavelength channel and one upstream wavelength channel that provides connectivity between an OLT and one or more ONUs
Channel Partition	Any of operator-specified non-overlapping subsets of TWDM or PtP WDM channels in an NG-PON2 system.
Channel Termination	A logical function that resides at the OLT network element and that terminates a single TWDM channel or a PtP WDM channel in a NG-PON2 system In the XGS-PON context, the term channel termination refers to a logical function associated with an OLT port that terminates an XGS-PON.
ICTP Primitive	A ICTP primitive refers to an internal event caused by the receipt of an ICTP message or state transition driven exclusively by the ICTP message exchange.
Optical Distribution Network	A point-to-multipoint optical fibre infrastructure. A *simple* ODN is entirely passive and is represented by a single-rooted point-to-multipoint tree of optical fibres with splitters, combiners, filters, and possibly other passive optical components. A *composite* ODN consists of two or more passive *segments* interconnected by active devices, each of the segments being either an optical trunk line segment or an optical distribution segment. A Passive optical distribution segment is a simple ODN itself. Two ODNs with distinct roots can share a common subtree.
Optical Line Termination	A network element in an ODN-based optical access network that terminates the root of at least one ODN and provides an OAN SNI.
Optical Network Unit	A network element in an ODN-based optical access network that terminates a leaf of the ODN and provides an OAN UNI.
PtP WDM Channel	In an NG-PON2 system, PtP WDM channel refers to the pair of one downstream wavelength channel and one upstream wavelength channel providing point-to-point connectivity.

PtP WDM PON	A multiple wavelength PON system that enables point-to-point connectivity using a dedicated wavelength channel per ONU for the downstream direction and a dedicated wavelength channel per ONU for the upstream direction
Service Profile	The exhaustive information needed to provide service to an authenticated ONT according to a particular service contract.
TWDM Channel	In an NG-PON2 system, TWDM channel refers to the pair of one downstream wavelength channel and one upstream wavelength channel providing point-to-multipoint connectivity by using, respectively, time division multiplexing and multiple access mechanisms.
TWDM PON	A multiple wavelength PON system in which each wavelength channel may be shared among multiple ONUs by employing time division multiplexing and multiple access mechanisms
Type B Protection	Type B protection configuration involves a single channel group where each individual channel pair has two OLT channel terminations.
Type WL Protection	Type WL refers to a PON protection architecture that is exclusive to multi-wavelength PON systems, is dependent on availability of at least two OLT CTs operating on different downstream and upstream wavelength channels while being attached to one and the same ODN, and allows to protect against the failure of one OLT CT and/or of the segment of fiber specific to that OLT CT by retuning the affected ONUs to the downstream and upstream wavelength channels associated with another OLT CT.
Wavelength channel	A unidirectional (downstream or upstream) optical communications channel characterized by a single unique central frequency or a set of unique central frequencies mapped to one WM tributary port

2.4 Abbreviations

This Technical Report uses the following abbreviations:

CG	Channel Group
CP	Channel Pair
CT	Channel Termination
DWLCH	Downstream Wavelength Channel
ICTP	Inter-Channel-Termination Protocol
ILODS	Intermittent Loss of Downstream Synchronization (ONU state)
LOB	Loss of Burst
NE	Network Element
OAN	Optical Access Network
OAM	Operation and Maintenance
ODN	Optical Distribution Network

OLT	Optical Line Terminal
ONU	Optical Network Unit
OSS	Operation Support System
PLOAM	Physical layer OAM
PON	Passive Optical Network
PtP WDM	Point-to-Point Wavelength Division Multiplexing
R/S	Receive/Send reference point of ODN interface at the ONU
RBN	Regional Broadband Network
RG	Residential Gateway
SN	Serial Number
SNI	Service Node Interface
S/R	Send/Receive reference point of ODN interface at the CT
TR	Technical Report
TWDM	Time & Wavelength Division Multiplexing
UNI	User-Network Interface
UWLCH	Upstream Wavelength Channel
VPN	Virtual Private Network
WA	Work Area
WM	Wavelength Multiplexer
WMM	Wavelength Mobility Manager

3 Technical Report Impact

3.1 Energy Efficiency

The Inter-Channel-Termination Protocol specified in TR-352 supports OLT power saving by consolidation of the active ONUs on few selected TWDM channels, thus allowing to free and turn off the other TWDM channels in a TWDM PON system. Such consolidation may become feasible on a timescale of diurnal or seasonal variations in customer activity, or in the course of service terminations and activations. Therefore, TR-352 has a direct impact on energy efficiency.

3.2 IPv6

TR-352 has no impact on IPv6.

3.3 Security

The Inter-Channel-Termination Protocol specified in TR-352 improves security of multi-wavelength passive optical network systems by providing means to detect and mitigate certain types of rogue and malicious behavioral patterns on the part of the PON clients and by supporting multi-operator environments.

3.4 Privacy

Any issues regarding privacy are not affected by TR-352.

4 ICTP Architecture

4.1 Reference Architecture

The reference architecture of an NG-PON2 system with the ICTP-related elements is shown in Figure 4-1.

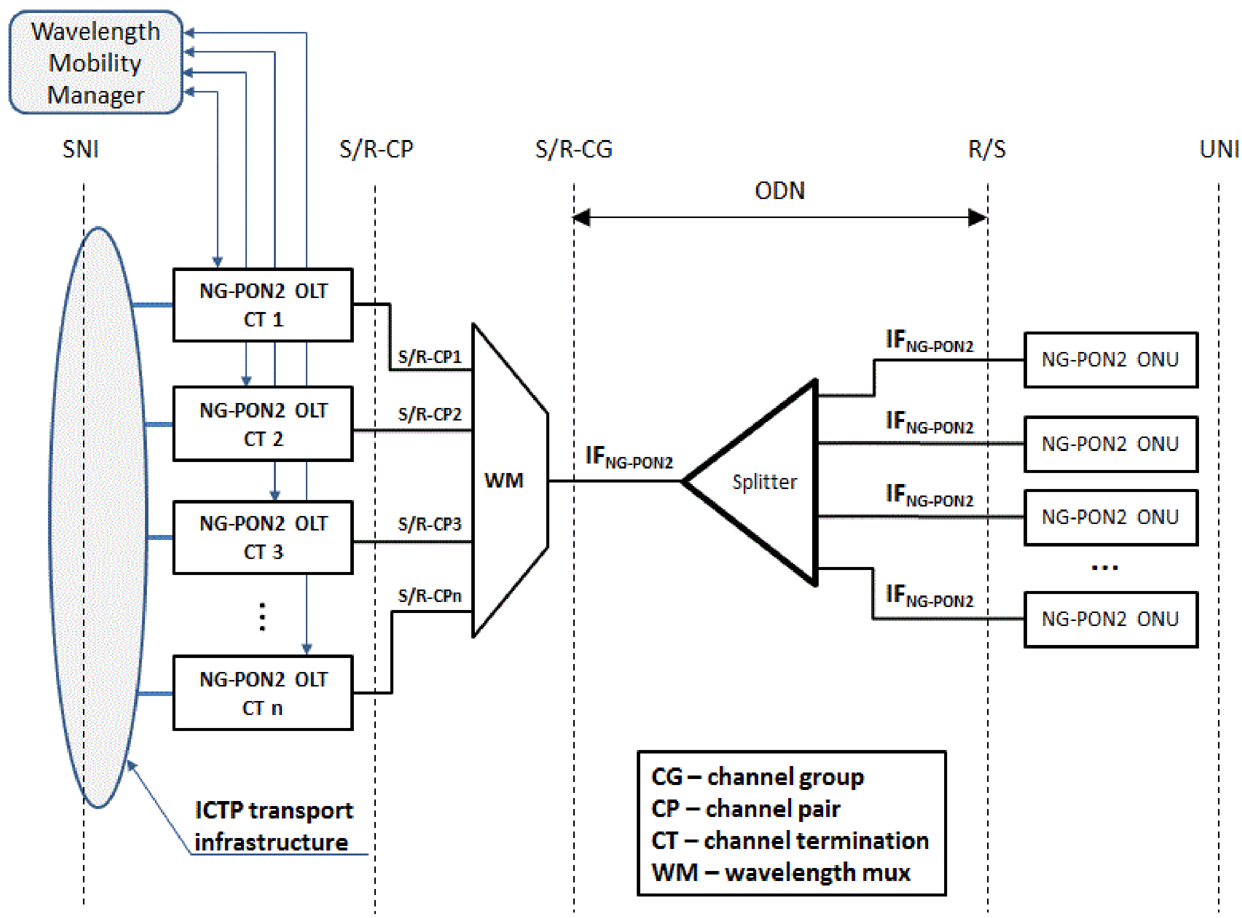


Figure 4-1 – Reference architecture of an NG-PON2 system

A point-to-multipoint passive optical distribution network (ODN) provides physical connectivity to a set of NG-PON2 optical network units (ONUs) attached to the ODN leaves at the R/S reference point. A set of NG-PON2 optical line terminal (OLT) channel terminations (CTs) are aggregated via wavelength multiplexer (WM) and connected to the root of the ODN at the S/R-CG (channel group) reference point. The interface between each OLT CT and the WM corresponds to the S/R-CP (channel pair) reference point.

Each OLT CT terminates a TWDM channel or a Point-to-Point (PtP) WDM channel, that is, a pair of one downstream wavelength channel and one upstream wavelength channel providing logical point-to-multipoint or point-to-point connectivity, respectively, using appropriate shared or dedicated mechanisms. A single TWDM or PtP WDM channel is present at the S/R-CP reference point. Multiple TWDM or PtP WDM channels are present at the S/R-CG reference point and the R/S reference points.

An NG-PON2 ONU is equipped with a tunable transceiver which is able to tune to a subset of available TWDM and PtP WDM channels. The Physical Media Dependent (PMD) layer specification (ITU-T G.989.2) provides the TWDM OLT CT and ONU parameters that allow for nominal line rates per channel of 9.95328 Gbit/s and 2.48832 Gbit/s in either direction, as well as line-rate agile PtP WDM OLT CT and ONU parameters. The NG-PON2 Transmission Convergence (TC) layer specification (ITU-T G.989.3) describes the procedural and formatting aspects of data framing, service and PHY adaptation, as well as the protocol functions of ONU activation and configuration management, performance management, security management, wavelength channel management, protection, ONU power management, and rogue ONU mitigation.

To coordinate ONU operation on an NG-PON2 system and to effectively support the NG-PON2 protocol functions mentioned above, the OLT CTs which form an NG-PON2 system interact with each other over a back-office transport infrastructure using the Inter-Channel-Termination protocol, which is specified in the present document.

The primary purpose of ICTP is to deal with interactions between CTs, so that an ONU can switch from one wavelength channel to another wavelength channel while guaranteeing continuity of the TC layer. For its operation, ICTP relies on the assumption that the information on the channel pair to be used by each ONU provisioned on the given NG-PON2 system either is available to all CTs in that system, or is available to at least one CT and can be shared by that CT with any other CT on the system. This assumption is applicable to both a single operator case and in a cooperative multi-operator environment. This document does not cover the decision process selecting the operating wavelength channels for a specific ONU. These decisions, which are based on the operator-specified prioritized, multi-level policies (such as those concerned with load balancing, OLT power saving, administrative handover, service protection, etc.) are implemented either manually by the operator, or by an abstract functional entity called Wavelength Mobility Manager (WMM) which is functionally located outside the OLT(s). Conceptually, the WMM resides within the upper level management functions. The actual realization of the WMM is up to implementation.

Figure 4-2 illustrates the placement of NG-PON2 within the TR-156 reference architecture.

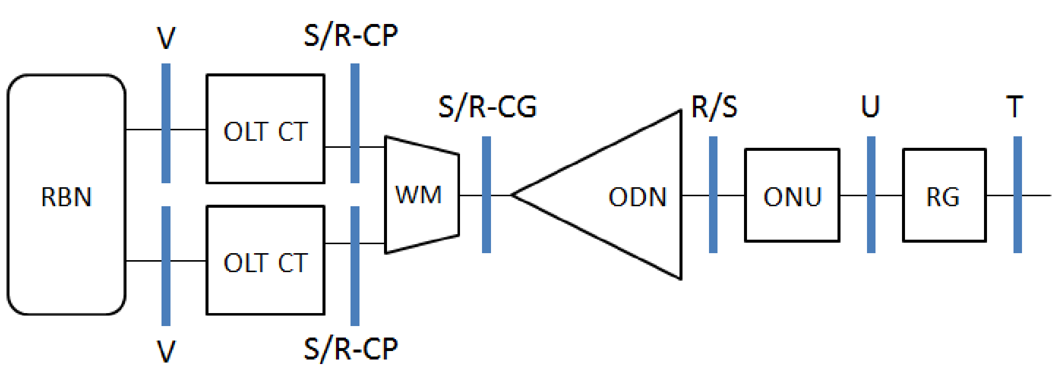


Figure 4-2 – NG-PON2 Mapping into TR-156 Reference Architecture.

4.2 Protection Architecture

The ICTP specification is applicable to the following G.989.3 protection architectures.

- 1:1 Type B Protection (G.989.3 Clause 18): The 1:1 Type B protection configuration involves a single channel group where each individual channel pair has two OLT channel terminations. Figure 4-3 shows a dual-parented Type B protection configuration, where the OLT CTs terminating a protected channel pair are housed in different OLT chassis. The only difference between the dual-parented configuration shown in G.989.3 Figure 18-1 and the single-parented configuration, is that the two OLT channel terminations associated with a channel pair in the latter configuration belong to the same OLT chassis and have the possibility to share the same SNI. The two OLT CTs terminating the same protected channel pair are mutually known as Type B peers.

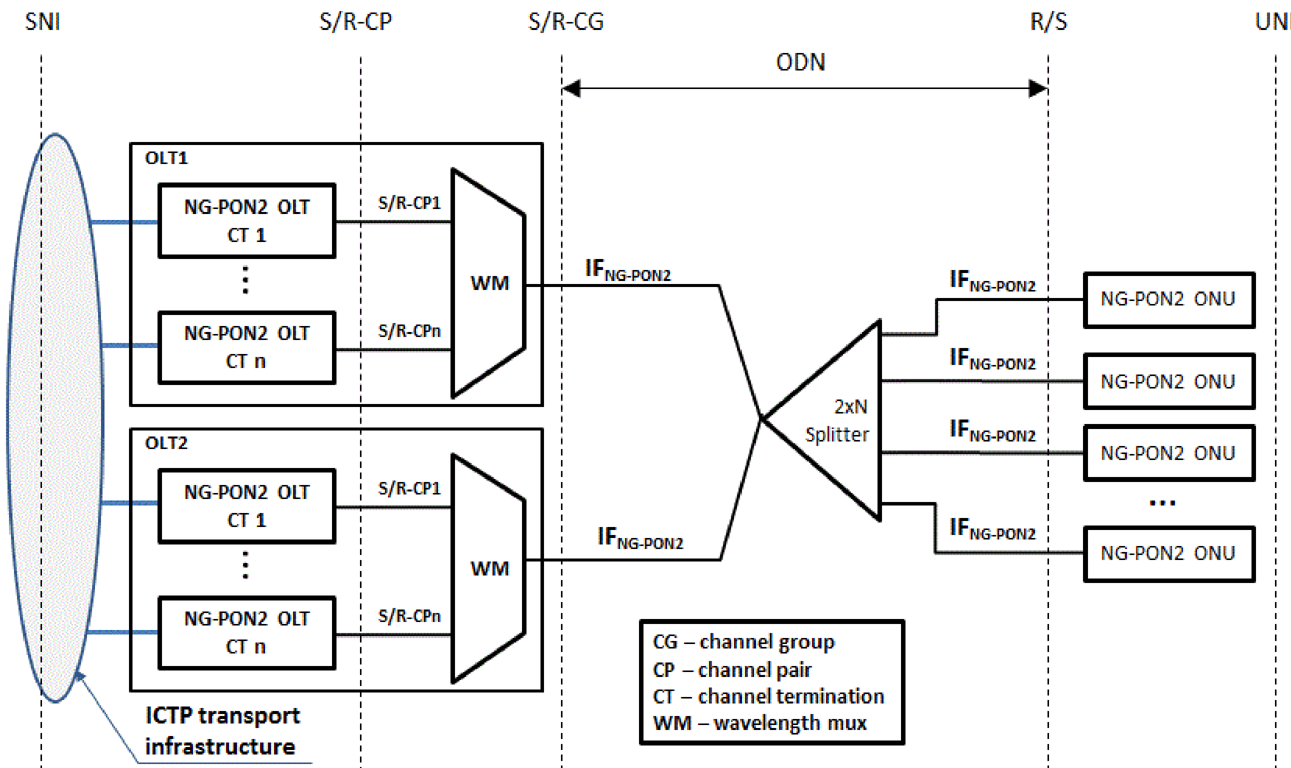


Figure 4-3 – 1:1 Type B Protection

- Type WL Protection: Type WL refers to a PON protection architecture that is exclusive to multi-wavelength PON systems, is dependent on availability of at least two OLT CTs operating on different downstream and upstream wavelength channels while being attached to one and the same ODN, and allows to protect against the failure of one OLT CT and/or of the segment of fiber specific to that OLT CT by retuning the affected ONUs to the downstream and upstream wavelength channels associated with another OLT CT.

4.3 ICTP Transportation Options

The ICTP specification is applicable to a wide range of NG-PON2 system deployment scenarios which include a variety of ICTP transportation options:

1. The OLT CTs within the same NG-PON2 line card communicating over internal shared memory or message-passing channel.
2. The OLT CTs on the distinct line cards installed within the same OLT network element (NE), or chassis, communicating over a secure backplane communication channel.
3. The OLT CTs on distinct line cards installed within distinct OLT NEs of the same central office communicating over secure LAN infrastructure.
4. The OLT CTs on distinct line cards installed within distinct OLT NEs at geographically distinct locations communicating over a virtual private network (VPN).
5. The OLT CTs on distinct line cards installed within distinct OLT NEs at geographically distinct locations communicating over an open public infrastructure where IPSEC VPN is used to secure ICTP communications.

The distinct OLT NEs in options 3, 4, and 5 can be owned by the same operator or by different operators.

In an NG-PON2 system encompassing multiple OLT CTs, a given OLT CT may employ different transportation options to communicate with other OLT CTs of the system.

4.4 ICTP Functional Primitive Abstraction

An ICTP access reference point is defined to demarcate the CT and the ICTP transport infrastructure (see Figure 4-4). An ICTP implementation is agnostic to its deployment scenarios and ICTP transportation options it may be required to support. ICTP packets are transported over the ICTP transport infrastructure to the ICTP access reference point(s). An implementation may then abstract the informational dataset carried over the ICTP packets into ICTP primitives as defined in G.989.3 Table VI-3 and G.9807.1 Table VI-3 ICTP primitives table. ICTP packet format and state machine is defined in clause 6. The establishment of an ICTP transportation channel is specified for options 3, 4, and 5 only [see clause 4.2] and is left to implementer discretion for options 1 and 2.

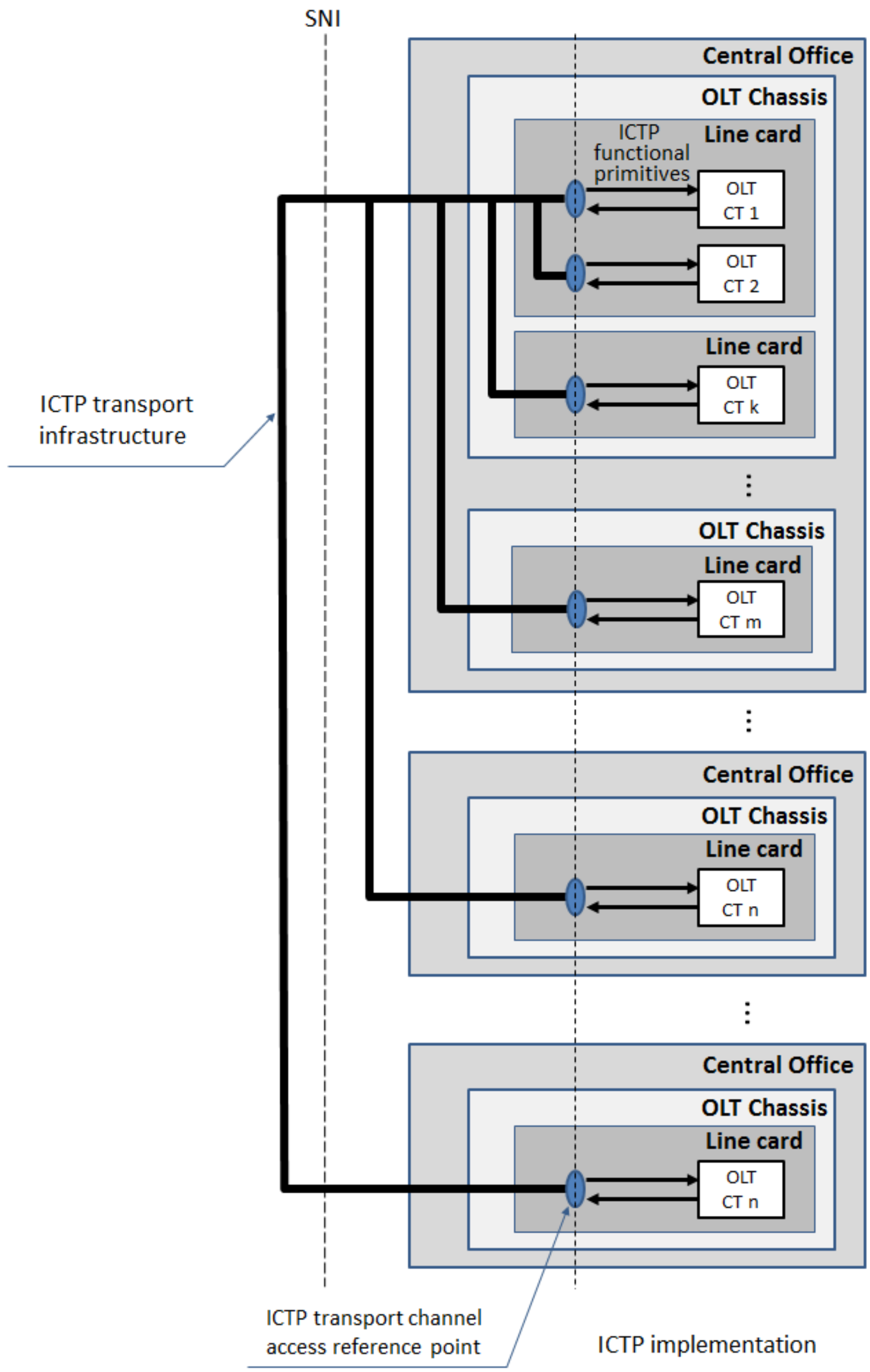


Figure 4-4 – ICTP Access Reference Point

4.5 ICTP Message Transport

4.5.1 Protocol stack

The ICTP protocol stack is shown in Figure 4-5. The lower four layers correspond to the ICTP transport infrastructure. As the network layer protocol, the OLT NE shall support IPv4 and may support IPv6. The IP layer only supports point-to-point transmission for delivering the ICTP messages. As the transport layer protocol, the OLT NE shall support TCP. The specific TCP port number, assigned to the ICTP application by IANA, is 7202.

The data link and physical link entities of the transportation infrastructure protocol suite are link-specific, and are not discussed further.

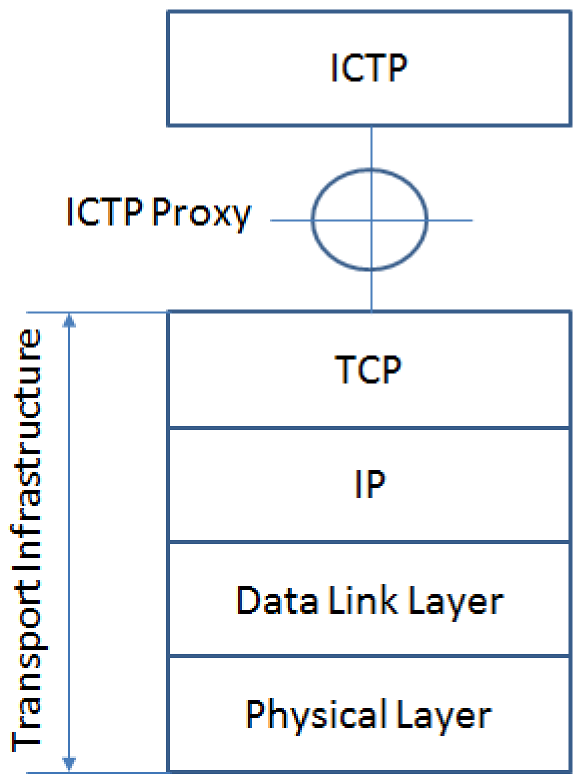


Figure 4-5 – ICTP protocol stack

4.5.2 ICTP Proxy

ICTP proxy provides an interface between the ICTP layer and the ICTP transport infrastructure protocol suite. One ICTP proxy hosts one or more CTs within an OLT NE. The CTs hosted by an ICTP proxy may belong to the same NG-PON2 system or to different NG-PON2 systems. An OLT NE may have one or more ICTP proxy instances.

Each ICTP proxy has a unique IP address.

While this document does not mandate the details of IP address management, the implementation may take into account the following considerations:

- Whenever possible, a single subnet is preferred over a routed network (maintaining a single subnet may not be possible in case of multiple operators and/or distinct geographical locations of interacting OLT network elements).
- Whether a single subnet or a routed network is used may be reflected in the ICTP state machine timers, allowing larger latency for the routed case.
- The ICTP proxy address may or may not be equal to the management address of the OLT NE. In some scenarios, security considerations may require separation of the management and ICTP proxy addresses.

The ICTP proxy performs the following functions.

1. For each hosted CT, the ICTP proxy maintains the identity of the NG-PON2 system the CT belongs to.
2. If the ICTP proxy hosts at least one CT of an NG-PON2 system, the ICTP proxy maintains a configuration table for that NG-PON2 system. The configuration table comprises:
    a. The identities of all the CTs forming the NG-PON2 system, including any Type-B protection primary and secondary CTs. .
    b. The channel partition association for each CT.
    c. The characterization of each CT as either TWDM CT or PtP WDM CT.
    d. An indication whether each CT is hosted locally by the same ICTP proxy or by a peer ICTP proxy elsewhere.
    e. The forwarding information to reach remote CTs that are managed by other ICTP proxies.
3. The ICTP proxy maintains a point-to-point TCP connection with each peer ICTP proxy hosting a CT which is included into any of the configuration tables maintained by this ICTP proxy. The TCP socket associated with each such connection represents the forwarding information for the peer ICTP proxy in a configuration table.
4. Upon receiving an ICTP message from a locally hosted CT, the ICTP proxy analyzes the ICTP message header, looks up the NG-PON2 system configuration, and forwards one or more copies of the ICTP message to the recipient CTs, which can be hosted either locally or elsewhere.
5. Upon receiving an ICTP message over a TCP connection from a CT hosted elsewhere, the ICTP proxy analyzes the ICTP message header, looks up the NG-PON2 system configuration, and forwards one or more copies of the ICTP message to the locally hosted recipient CTs.

Note that the nature of the communication between the ICTP proxy and the locally hosted CTs (for example, shared memory, or message passing over a communication link), as well as the representation form of the local forwarding information, is left to the implementation.

A number of the use cases defined in this document are also applicable to PtP WDM subsystem of NG-PON2 systems. The use of ICTP for PtP WDM is for further study. A subset of the use cases defined in this document, in particular, those related to Type B protection, are applicable to a single-channel PON systems, such as XGS PON.

5 ICTP Data Elements and Use Cases

Network service providers are always in pursuit of ways in which to minimize the cost of operating their networks, and, to this end, secure, reliable mechanisms that enable for the remote administration, maintenance and provisioning functions are prerequisite to the introduction of any new network technology. Within NG-PON2 access systems, where the logical functionality of optical line termination is distributed between multiple OLT channel terminations (CTs), and the CTs of an individual NG-PON2 system may span more than one service provider administrative domain, many of these mechanisms will need to be realized through a properly-defined ICTP. In this section, the key use cases that serve to define these requirements for ICTP are presented. These use cases include NG-PON2 system creation and consistency verification; ONU activation, authentication and service provisioning; and ONU wavelength channel mobility management.

5.1 Data Elements

The data elements used in developing the use cases in this section are outlined in the following table (with ITU-T G.989.3 references included):

Table 5-1 –Data Elements

Data Element	G.989.3 reference	Description
NG2SYS ID	6.5.2	NG-PON2 system identifier (NG2SYS ID) is a 20-bit number that identifies a specific NG-PON2 system within an administrative domain.
PON-ID	6.5.3	PON-ID is a 32-bit structured number that uniquely identifies a TWDM or PtP WDM channel termination (CT) entity within an administrative domain.
DWLCH ID	6.5.4	TWDM downstream wavelength channel ID (DWLCH ID) is a 4-bit number that identifies a downstream wavelength channel and is equal to the ordinal number of the channel in a specific table in G.989.3.
UWLCH ID	6.5.5	TWDM upstream channel ID (UWLCH ID) is a 4-bit number that identifies an upstream wavelength channel within an upstream TWDM operating band.
ONU-ID	6.5.7	The ONU-ID is a 10-bit number assigned by OLT CT that uniquely identifies an activated ONU in an NG-PON2 system.
Alloc-ID	6.5.8	The allocation identifier (Alloc-ID) is a 14-bit number assigned by OLT CT that uniquely identifies an ONU traffic-bearing entity as a recipient of upstream bandwidth allocations in a NG-PON2 system.
XGEM Port-ID	6.5.9	The XGEM port identifier, or XGEM Port-ID, is a 16-bit number assigned by the OLT CT that uniquely identifies an individual upstream or downstream logical connection in an NG-PON2 system.

Data Element	G.989.3 reference	Description
PON-TAG	11.3.3.1	PON-TAG is an 8-byte value that is chosen by the operator and that serves as a static identity of the OLT CT for security context binding purposes.
SN	11.3.4.1	Serial number is an 8-byte value composed of 4-charater vendor ID and a 4-byte integer vendor-specific serial number (VSSN) that provides a globally unique static identifier of an ONU.
REG-ID	11.3.4.2	Registration ID is a 36-byte string that serves as a dynamic identifier of an ONU for basic authentication purposes.
Teqd	13.1	Upstream PHY frame offset, or zero-distance equalization delay, is the elapsed time between the start of the downstream PHY frame carrying a specific BWmap and the upstream PHY frame implementing that BWmap.
MSK	15.3.2	The master session key (MSK) is a 128-bit value that is shared between the OLT CT and the given ONU as a result of an authentication procedure and which serves as a starting point for the derivation of all of the other secret keys used in subsequent secure communications.
Data Encryption Keys	15.5.1	A set of four (two pairs for unicast and two pairs for broadcast) 128-bit numbers shared between the OLT CT and the ONU and used to encrypt the data traffic between them.

5.2 ICTP Use Cases

Table 5-2 lists and describes the essential uses cases that must be supported by ICTP.

Table 5-2 –ICTP Use Case Description

G.989.3 Table VI.1 Number	Use Case	Description
1	CT Profile Sharing	A CT periodically sends a broadcast ICTP message containing its channel profile to other CTs of the NGPON2 system.
2	Silent Start and CT Initialization	When a new CT is initialized on a NG-PON2 system, it employs ICTP to verify its configuration consistency with the system configuration and to avoid accidental interference.

G.989.3 Table VI.1 Number	Use Case	Description
3	Initial Zero-Distance Equalization Delay	1. A CT transmits an ICTP message containing its selected local Zero-distance EqD to the next CT in the pre-defined total order ring. 2. Upon receipt of an ICTP message containing a Zero-distance EqD message, the CT adjusts its local Zero-distance EqD to the larger of the two values, and transmits a message containing its new local Zero-distance EqD to the next CT in the pre-defined total order ring.
4	Initial ONU Validation upon Activation	When a CT receives Serial Number ONU PLOAM message from an activating ONU, • The CT verifies the reported PON-ID, and validates whether the SN is allowed on the NGPON2 system. • If the reported PON-ID is different from CT's own, the CT uses ICTP to query the owner of the reported PON-ID providing the SN of the stray ONU, the UWLCH ID where it has been detected, and an indication whether the SN is valid.
5	SN and Assigned ONU-ID Consistency Verification	For the ONU which pass the initial validation, the OLT CT sends a broadcast ICTP message to confirm the SN uniqueness (no ONU-ID have been assigned to that SN) and the consistency of the proposed ONU-ID assignment (no SN has been assigned that ONU-ID).
6	ONU Discovery Resolution	If the OLT CT receives the SN which is valid on the NG-PON2 system, but cannot associate the reported Reg-ID with a valid service profile, it sends a broadcast ICTP message to ask the peer CTs if anyone recognizes the ONU, prior to handing the ONU over to the interested bidder.
7	Alloc-ID Assignment Consistency Verification	Whenever an OLT CT assigns a non-default Alloc-ID to an ONU, it verifies with an ICTP interaction that the proposed Alloc-ID has not been assigned to any other ONU-ID in the NG-PON2 system.
8 & 9	ONU Handover	In case of a planned ONU handover from one (DWLCH ID, UWLCH ID) pair, or source, to another (DWLCH ID, UWLCH ID) pair, or target, an ICTP transaction guaranteeing state consistency of the involved CTs is executed. If the source and target CTs share a security association, the transaction may include exchange of the MSK and active data encryption keys. Upon completion of planned ONU handover or recovery from

G.989.3 Table VI.1 Number	Use Case	Description
		ILODS which involves a change of the operating (DWLCH ID, UWLCH ID) pair, an ICTP transaction guaranteeing state consistency of the involved CTs is executed.
10	ONU LOB Mitigation	When an OLT CT fails to receive an expected transmission from a particular ONU, it uses a broadcast ICTP alert to notify the peer CTs of the NG-PON2 PON system of the loss of communication with the ONU.
11		This use case has been obsoleted
12	Rogue ONU Mitigation	This use case covers various techniques of rogue ONU isolation (such as attendance report) and mitigation including a broadcast or directed request to peer CTs in a NG-PON2 system to stop a particular ONU from transmitting upstream.
13	Wavelength Protection CT Initialization	The peer CTs on an NG-PON2 system use ICTP to communicate TC layer configuration and service while configuring the ONU, and to exchange the notifications between OLT CTs when protection is triggered.
14		This use case has been obsoleted
15	Synchronization of ONU Dynamic TC Data	The peer CTs on an NG-PON2 system use ICTP to communicate dynamic TC layer data
16	Synchronization of ONU Dynamic Service Data	The peer CTs on an NG-PON2 system use ICTP and IPFIX to communicate dynamic service layer data

5.3 Multi-Operator Environment

This section highlights which use cases are applicable between operators in multi-operator environment, whereas each operator controls one or more TWDM or PtP WDM channels. The applicability of the use cases specified in section 5.2 partially depends on whether the operators have an agreement for an automatic handover in case of customer churn between operators. So the use cases have been divided in 3 categories (Table 5-3):

1. Use cases that are applicable

2. Use cases that are applicable only in case of agreement of automatic ONU handover between operators
3. Use cases that are not applicable between operators in multi-operator environment

Table 5-3 – Applicability of Use Cases in Multi-Operator Environment

Applicable		Conditional Applicable		Not Applicable	
1	CT Profile Sharing	3	Initial Zero-Distance Equalization Delay		
2	Silent Start and CT Initialization	8&9	ONU Handover	13	Wavelength Protection CT Initialization
4	Initial ONU Validation upon Activation			15	Synchronization of ONU Dynamic TC Data
5	SN and Assigned ONU-ID Consistency Verification			16	Synchronization of ONU Dynamic Service Data
6	ONU Discovery Resolution				
7	Alloc-ID Assignment Consistency Verification				
10	ONU LOB Mitigation				
12	Rogue ONU Mitigation				

6 ICTP Messages

6.1 ICTP message format

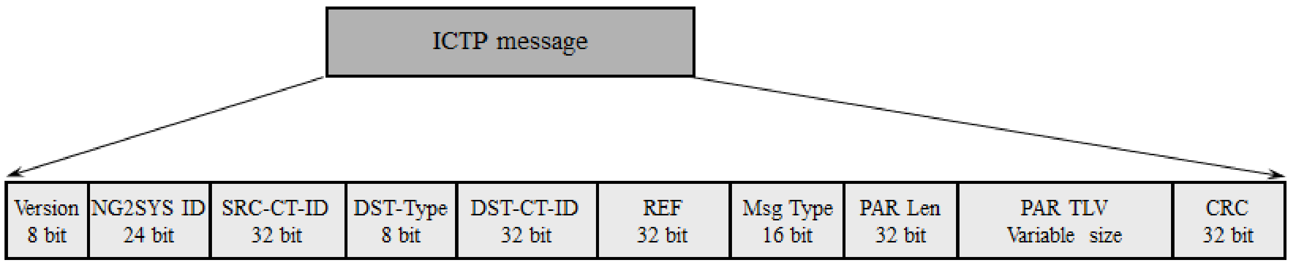


Figure 6-1 – ICTP message format

The format of an ICTP message is shown in Figure 6-1 and consists of the following fields:

- **Version (8 bits)**: ICTP protocol version number. An ICTP implementation must support version 0x01. Unrecognized versions MUST be silently ignored.

- **NG2SYS ID (24 bits)**: NGPON2 system identifier of the sender. The 20-bit value, as defined in Clause 6.1.5.2 of ITU-T G.989.3 [2], occupies the 20 LSB bits of the field; padded with zeros. NG2SYS ID is not applicable to XGS-PON and therefore must be set to all ones when not used. A receiver receiving a value of all ones will ignore the field.
- **SRC-CT-ID (32 bits):** The identifier of the individual CT issuing the ICTP message, represented by the TC layer PON-ID of the sender CT. For PON-ID definition, see Clause 6.1.5.3 of ITU-T G.989 [2] and Clause C.6.1.5.3 of G.9807.1 [6].
- **DST-Type (8 bits):** The qualifier for the DST-CT-ID field below.

  The octet has the form: 0000 0PSU.
  The five MSBs are reserved for future use and set to zero.
  The three LSBs contain the three control flags.

  U: 0 – unicast to PON-ID specified in DST-CT-ID.
  1 – multicast to a group specified by the flags P, S.
  P: 0 – members of CT's own channel partition
  1 – members of all channel partitions within the NG-PON2 system
  S: 0 – members of CT's own TWDM or PtP WDM channel set
  1 – members of both TWDM channels set and PtP WDM channel set.

- **DST-CT-ID (32 bits):** The identifier of ICTP message destination. Format depends on the DST-Type field:

- In the case where DST-Type is 0x00 (Unicast), the DST-CT-ID is the identifier of the individual CT receiving the ICTP message represented by the TC layer PON-ID of recipient CT. For PON-ID definition, see Clause 6.1.5.3 of ITU-T G.989 [2] and Clause C.6.1.5.3 of G.9807.1 [6].
- In the case where DST-Type is multicast (0x0000 xxx1), the DST-CT-ID must be set to all ones. The receiver should always ignore the value received in this field when DST-Type indicate a multicast value.

- **REF (32 bits):** Message reference number. See Section 6.2 for more details.
- **MSG Type (16 bits):** ICTP message type. See Section 6.3 for the definition of the ICTP message types.
- **PAR Length (32 bits):** The length of the Parameter TLV list, represented as an unsigned integer indicating the total length in octets of the PAR TLV section.
- **PAR TLV (variable size):** A concatenated list of message parameters, each described with a {Type, Length, Value} triplet, where:

  Type (16 bits) is a parameter type; see section 6.4 for the list of TLV types.

  Length (16 bits) is an unsigned integer indicating the length of the "Value" field in octets, If the content of the field is not a multiple of 8 bits, the content is aligned at the LSB bits of a field padded with zeros. Value (variable size, multiple of 8 bits) is a parameter value.
- **CRC (32 bits):** The error detection code computed using the CCITT-CRC32 algorithm.

6.2 Use of ICTP message reference numbers

Each ICTP message must contain a REF number determined by the issuing OLT CT, at its own discretion. This number can be used as TLV parameter in a subsequent ICTP message issued by another CT to indicate that the two messages are correlated, (e.g. an ICTP message and its related acknowledge). It is the issuing CT responsibility to select a REF value which it is not already using in a still pending ICTP interaction. Figure 6-2 illustrates the use of REF values in a congested/busy NGPON2 system.

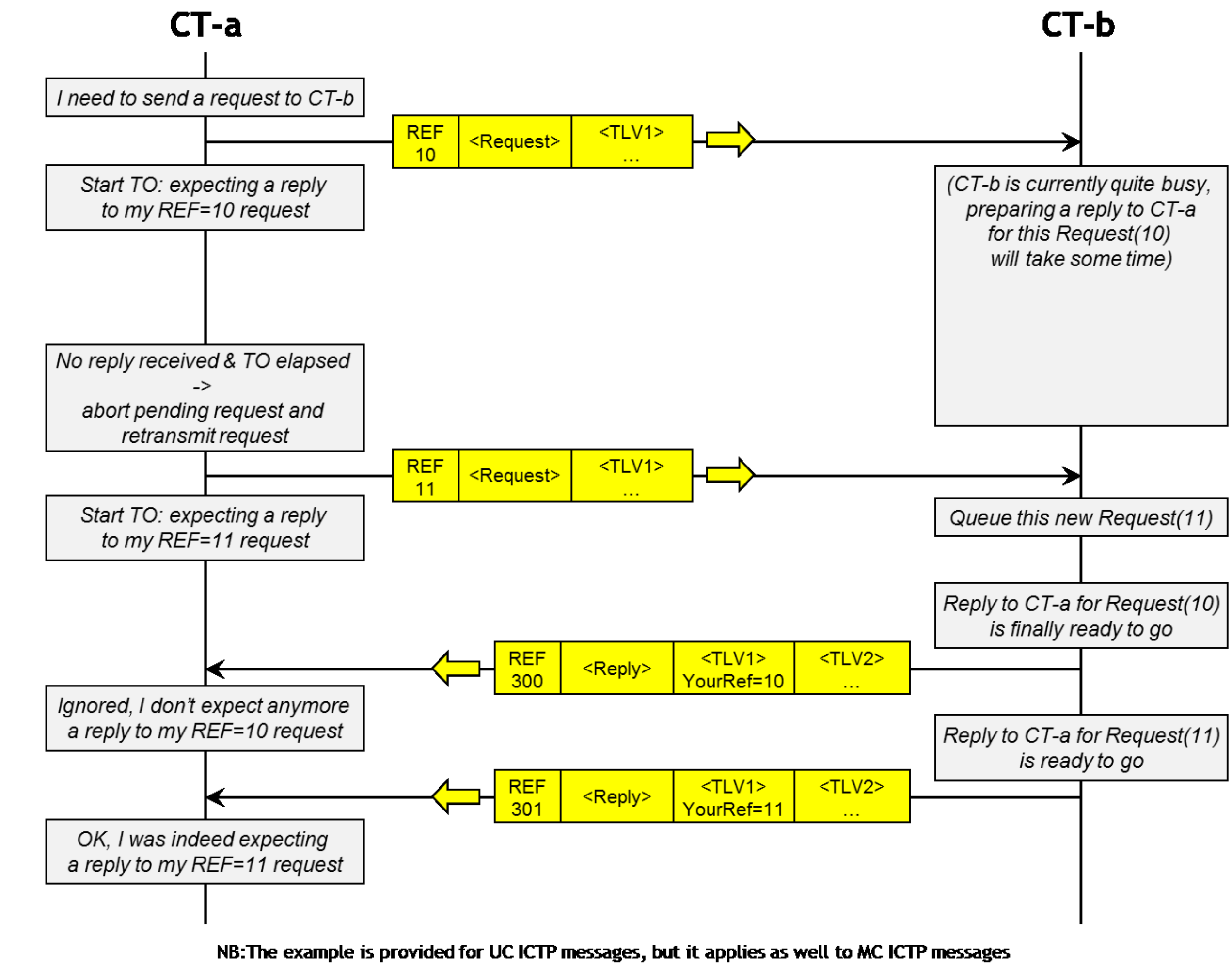


Figure 6-2 – REF Usage Example

6.3 ICTP message types

The following ICTP message types are defined:

Table 6-1 – ICTP message types, associated primitives, and available TLVs

Name	Definition	Associated Primitive	Number	Available TLVs
General ICTP Messages				
Rsvd	Reserved		0x0000	
Ack	A unicast ICTP Generic-Positive Acknowledged		0x0001	
Nack	A unicast ICTP Generic-Negative		0x0002	ErrCode

Name	Definition	Associated Primitive	Number	Available TLVs
	Acknowledged			
ONU authentication request	A broadcast message by an OLT CT that has discovered an ONU but lacks the service profile for the ONU, inquiring if any of CTs in the NG-PON2 system can confirm authenticity and has the service profile for the discovered ONU, which is identified either by the serial number only or by the serial number and the registration ID.	onuAuthen()	0x0003	SN ONU-ID REG-ID
ONU service claim	A unicast message from the CT that has ONU's service profile can confirm its authenticity to the CT that has discovered the ONU and has ascertained that it should provide service to the ONU.	onuClaim()	0x0006	SN ONU-ID
ONU service notification	A message that an OLT CT having the service profile for the ONU and serving the ONU periodically broadcasts within the NG-PON2 system or channel partition.	onuNotify()	0x0014	SN ONU-ID
WL-protection ICTP Messages				
onuWLProtectionInquiry	A unicast message from an OLT CT inquiring whether to adopt the protection role for a specific ONU.	N/A	0x0004	SN ONU-ID
onuWLProtectionStandby	A unicast message affirming the OLT CT role resulting from the negotiation of two CTs involved in protection. The OLT CT affirms its recipient standby role for a specific ONU.	WL-Standby()	0x0005	SN ONU-ID
onuWLProtectionActive	A unicast message affirming the OLT CT role resulting from the negotiation of two CTs involved in protection. The OLT CT affirms its recipient active role for a specific ONU.	WL-Active()	0x0017	SN ONU-ID
Handover Messages				
onuHandoverRequest	A unicast message from ONU hosting CT requesting an ONU handover.	N/A	0x0007	SN ONU-ID

Name	Definition	Associated Primitive	Number	Available TLVs
onuHandoverConsent	A unicast message from ONU hosting CT consenting to an ONU handover	TuneOut()	0x0022	SN ONU-ID
onuHandoverBegin	A unicast message from ONU hosting CT indicating the start of the ONU handover.	TuneIn()	0x0023	SN ONU-ID
onuHandoverConfirmation Indication	A confirmation unicast indication sent by the target CT to the source CT that the ONU is successfully arrived at the target CT	ConfirmOut()	0x0008	SN ONU-ID
onuHandoverConfirmationAcknowledgement	A unicast message sent by the source CT to acknowledge the target CT the reception of "onuHandoverConfirmation Indication" message	ConfirmIn()	0x0013	SN ONU-ID
onuHandoverAbortIndication	An unicast message from the Source OLT CT to the Target OLT CT indicating the failure of the handover procedure (the Source OLT CT has received either TuningResp (NACK) or TuningResp (Rollback) from the ONU-ID).	handoverAbort()	0x000F	SN ONU-ID
Data Integrity and Resolution				
onuDataSyncCompleted	A unicast message affirming the full completion of data synchronization. For example, in the case of WL Protection upon receiving this message, the recipient CT will start sending PLOAM tuning control grants to the ONU to allow ONU to retune after WL Protection event.		0x0009	SN ONU-ID
onuTcDataOffer	A unicast message containing PON TC data for a specific ONU for synchronization between CTs		0x000A	SN ONU-ID REG-ID Alloc-ID XGEM
Service Data Sync Start	A unicast message affirming the start of service data synchronization between CTs.	datasyncstart()	0x000B	SN ONU-ID

Name	Definition	Associated Primitive	Number	Available TLVs
	This message is used for data set outside transport TC data (e.g., IGMP, statistics, DHCP, etc.).			
Service Data Sync End	A unicast message affirming the completion of service Data sync.	datasyncend()	0x000C	SN ONU-ID
Parameter notification	A unicast or broadcast message from the specific CT notifying the other specific CT or all CTs of the local parameter values.	prmNotify()	0x0010	SN ONU-ID Alloc-ID XGEM Teqd CT-Profile ONU-ID Range Alloc-ID Range XGEM Range
Parameter Inquiry	A unicast message from the specific CT requesting parameter value.	prmInquiry()	0x0011	SN ONU-ID Alloc-ID XGEM CT-Profile ONU-ID Range Alloc-ID Range XGEM Range
Parameter Conflict	A unicast message from the specific CT noticing a parameter conflict.	prmConflict()	0x0012	SN ONU-ID Alloc-ID XGEM CT-Profile ONU-ID Range Alloc-ID Range XGEM Range
Failure Handling				
LOBi Alert	A broadcast ICTP alert of an ONU being lost on a given TWDM channel.	lobiAlert()	0x000D	SN ONU-ID Alert-ID
ONU Alert	A broadcast ICTP alert by the given OLT CT to all other OLT CTs in the NG-PON2 system, to indicate an unspecified failure of the tuning procedure and requesting that the ONU with the specified ONU-ID be directed	onuAlert()	0x000E	SN ONU-ID Alert-ID

Name	Definition	Associated Primitive	Number	Available TLVs
	towards specified pair of downstream and upstream wavelength channels.			
Rogue interference alert	A unicast or broadcast message indicating that the specific OLT CT has detected an unexpected rogue interference from identified or unidentified ONU.	rogueAlert()	0x0015	SN ONU-ID UWLCH ID ALERT-ID
Rogue ~~ONU Alert~~ interference Clear	A unicast or broadcast message by the given OLT CT to all other OLT CTs in the TWDM system, to indicate the rogue interference has been cleared.	rogueClear()	0x0024	ALERT-ID
Rogue Mitigation Confirmation	A unicast message by the given OLT CT confirming that rogue mitigation procedures have been applied to the identified rogue ONU.	rogueActionTaken( )	0x0025	ALERT-ID
Type B protection Messages				
TypeB peering	A unicast message sent by one Type B protection peer OLT CT to another Type B protection peer OLT CT, inviting the recipient to perform handshake resolving the Type B protection roles, and to respond with either Type B Handshake Active, TypeB Handshake Standby LOS, or TypeB Handshake Standby Clear.	N/A	0x0018	
TypeB Handshake Active	A unicast message completing the ICTP role handshake between Type B protection peer OLT CTs, which assigns the Active role to the recipient OLT CT.	TypeB-Active()	0x0019	
TypeB Handshake Standby LOS	A unicast message completing the ICTP role handshake between Type B protection peer OLT CTs, which assigns the Standby role to the recipient OLT CT, while warning the recipient to abstain from executing protection switching based solely on timer	TypeB-Standby-LOS()	0x0020	

Name	Definition	Associated Primitive	Number	Available TLVs
	expiration as no upstream transmission is expected.			
TypeB Handshake Standby Clear	A unicast message completing the ICTP role handshake between Type B protection peer OLT CTs, which assigns the Standby role to the recipient OLT CT, while informing the recipient that the Active Type B peer successfully transmits downstream and receives upstream transmissions.	TypeB-Standby-Clear()	0x0021	
TypeB unprotected notification	The OLT CT receiving an ICTP:Unprotected() indication from a failed Type B peer sets the initial value of the Tpfail timer to infinity and continues the regular state machine execution.	Unprotected()	0x0016	

Note: Each ICTP message which is the consequence of a previously received ICTP message should also include in its list of TLV(s) the "REF" TLV containing the REF value used in the header of this received message.

6.4 ICTP message TLV parameters

The following TLV parameter types are defined:

Table 6-2 – ICTP message TLV parameters

ICTP Parameter Type Number	Short Name	Expanded Meaning	Length (Octets)	Type	Definition
0x0000	Rsvd	Reserved			
0x0001	REF	Reference of requesting message	4	Unsigned integer	Section 6.1 Message Reference number
0x0002	ErrCode	Error Code	4	Unsigned integer	See Table 6-3 for error codes
0x0003	SN	ONU Serial Number	8	string	G.989.3 Clause 11.2.6.1 ONU

ICTP Parameter Type Number	Short Name	Expanded Meaning	Length (Octets)	Type	Definition
					Serial Number. It is comprised of: Vendor-ID (4 bytes) and the VSSN (4-byte unsigned integer)
0x0004	ONU-ID	ONU Identifier	2	Unsigned integer	G.989.3 Clause 6.1.5.6 defines the ONU-ID as a 10-bit identifier
0x0005	Alloc-ID	Allocation Identifier	2	Unsigned integer	G.989.3 Clause 6.1.5.7 defines the ONU-ID as a 14-bit identifier
0x0006	XGEM	XGEM Port-ID	2	Unsigned integer	G.989.3 Clause 6.1.5.8 defines the XGEM Port-ID as a 16-bit integer
0x0007	Teqd	Zero distance Equalization delay	4	Unsigned integer	G.989.3 Table 11-6 expresses Equalization delay as integer bit periods with respect to the nominal upstream line rate of 2.48832 Gbit/s, regardless of the actual upstream line rate of the ONU.
0x0008	REG-ID	Registration-ID	36	string	G.989.3 Table 11-24 defines Registration ID as a 36 octet string.
0x0009	CT-Profile	Channel Termination Profile	36	Hexadecimal	G.989.3 Table 11-17 defines the channel profile ploam message. ICTP will carry a shortened 36 byte channel profile PLOAM message (octets 5 through

ICTP Parameter Type Number	Short Name	Expanded Meaning	Length (Octets)	Type	Definition
					40).
0x0010	ONU-ID Range	ONU Identifier Supported Range	4	Unsigned integer	The TLV represents a range of values where the first two bytes are the start of the range and the last two bytes are the end of the range. It may be possible that ranges are discontinuous (where multiple TLVs may exist) or a range of 1 element is available (where the start and end values are the same).
0x0011	Alloc-ID Range	Allocation Identifier Supported Range	4	Unsigned integer	The TLV represents a range of values where the first two bytes are the start of the range and the last two bytes are the end of the range. It may be possible that ranges are discontinuous (where multiple TLVs may exist) or a range of 1 element is available (where the start and end values are the same).
0x0012	XGEM Range	XGEM Port-ID Supported Range	4	Unsigned integer	The TLV represents a range of values where the first two bytes are the start of the range and the last two bytes are

ICTP Parameter Type Number	Short Name	Expanded Meaning	Length (Octets)	Type	Definition
					the end of the range. It may be possible that ranges are discontinuous (where multiple TLVs may exist) or a range of 1 element is available (where the start and end values are the same).
0x0013	ALERT-ID	Correlation identifier of the alert condition	2	Unsigned integer	A value generated by the originator of the alert
0x0014	UWLCH ID	Upstream wavelength channel ID.	1	A 4-bit integer	The identity of the intended upstream wavelength channel as represented by the ONU, placed in the LSB nibble and padded with zeros.

Table 6-3 –Error codes

ErrCode Value	Description
0x00000000	Reserved
0x00000100	Generic error detected at ICTP Proxy
0x00000101	CRC - failed to correct all errors
0x00000102	NG2SYS-ID unknown to the proxy
0x00000103	SRC-CT-ID does not belong to NG2SYS-ID
0x00000104	DST-CT-ID does not belong to NG2SYS-ID
0x00000105	Inconsistent SRC-CT-ID proxy binding
0x00000106	Unknown DST-CT-ID
0x00000107	S-bit DST-Type Mismatch for DST-CT-ID
0x00000108	Service profile not shared (inter-operator working)

ErrCode Value	Description
0x00000200	Generic error related to ICTP Proxy TLV Parameter Mismatch
0x00000201	Unspecified error
0x00000202	Missing TLV
0x00000203	Unknown reference TLV received
0x00000204	Unknown SN
0x00000205	WL Protection mismatch between ICTP message and local configuration
0x00000206	TypeB protection mismatch between ICTP message and local configuration
0x00000300	Generic error detected by the OLT CT.
0x00000301	SRC-CT aborts handover because the ONU has NACK'ed the handover request.
0x00000302	Unsuccessful Service data sync
0x00000303	Unsuccessful TC data sync
0x00000304	Incompatible CT configuration as per WMM configuration
0x00000305	Mismatch of UWLCH-ID/DWLCH-ID for this CT
0x00000306	CT not available
0x00000307	DWLCH out of range for the given ONU-ID
0x00000308	UWLCH out of range for the given ONU-ID
0x00000309	Ttarget expired (TuningResp (NACK))
0x0000030A	Tsource expired and ONU-ID still present

7 ICTP State Machines

7.1 OLT CT silent start state machine

The OLT CT specific state machine that handles the OLT CT silent start behavior and controls the OLT CT role in Type B protection configuration is specified in Clause 18 of ITU-T Recommendation G.989.3.

7.2 Top level ONU-specific state machine

This section specifies the state machine that complements the wavelength handover state machine of Clause 17/G.989.3.

7.2.1 OLT CT Serving state machine

The OLT CT instantiates a Serving state machine for each ONU it becomes aware of. The state of a Serving SM instance associated with a particular ONU is generally independent of the state of other Serving SM instances maintained by the OLT CT.

7.2.1.1 States, timers, inputs, and outputs

Table 7-1 – OLT CT serving states

State	Semantics
Stem	Default state for all ONU-IDs that are disassociated with the given OLT CT. The data structures pertaining to the ONU-ID are invalidated and may be de-allocated. These ONU-specific data structures are instantiated upon one of the following events: - Local ONU discovery - Request to authenticate an ONU from a peer OLT CT - Acquisition of a Service profile for an ONU

Table 7-1 – OLT CT serving states

State	Semantics
Provisioned	The OLT CT has a service profile for the ONU identified by the Serial Number and/or Registration ID. ONU-ID has not been assigned. As a part of the ONU's service profile, the OLT CT is assigned the role of either "Preferred_OLT_CT" or "Protection _OLT_CT" for this ONU and may be provisioned with the identity of a peer OLT CT which is known to also carry a service profile for the ONU, playing the role of "Protection_OLT_CT" or " Preferred_OLT_CT", respectively.
Protecting	The OLT CT has a service profile for the ONU identified by the ONU-ID in addition to Serial Number and/or Registration ID. The ONU is hosted by another OLT CT. Timer Tpres is started and reset each time an onuNotify () is received. Upon Protection switching event, the OLT CT starts service immediately, notifying the Preferred OLT CT (if any) and Protecting OLT CT (if any).
Serving	The OLT CT has a service profile for the ONU, hosts and provides service the ONU. The OLT CT periodically broadcasts onuNotify (). If LOBi condition is declared, the Tlobi timer is started.
Observing	The OLT CT has no service profile for the ONU, but is aware that the ONU is being hosted by a peer OLT CT in the NG-PON2 system. Timer Tpres is started and reset each time an onuNotify () is received.
Discovering	The OLT CT is hosting the ONU, but has no service profile for it. The OLT CT is seeking an adopter for the ONU by periodically broadcasting onuAuthent (). If LOBi condition is declared, the Tlobi timer is started.

Table 7-2 – OLT CT timers

Timer	Full name	State	Semantics and initial value
Tpres	ONU presence timer	Observing, Protecting	The timer prevents the SM from being trapped in the Observing or Protecting states for an inactive ONU. The timer is started upon entry into either of these two states, controlling the transition into the Stem and Provisioned states, respectively. It is reset each time an onuNotify() is received from the currently serving OLT CT and stopped upon exit from the state.
Tlobi	LOBi condition timer	Discovery, Serving	The timer prevents the SM from being trapped in the Discovery or Serving state on the LOBi condition. The timer is started upon declaration of the LOBi condition, controlling the transition into the Stem or Protecting states, respectively. It is reset once LOBi is cleared and stopped upon exit from the state.

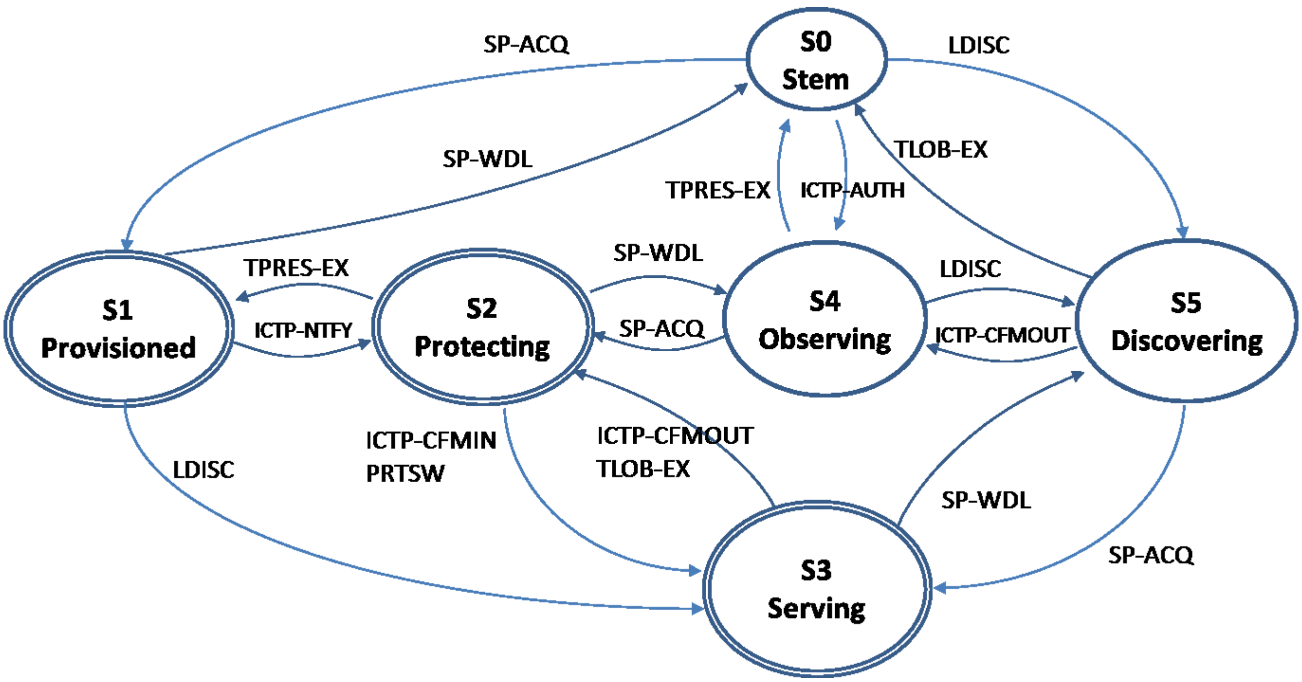
Table 7-3 – OLT Serving state machine inputs

Input	Applicable states	Semantics
ICTP primitives		
onuAuthent ( )	Stem, Provisioned, Protecting, Observing	Request from an OLT CT in an NG-PON2 system to the peer OLT CT in an NG-PON2 system to authenticate the ONU for which the sender OLT CT lacks the service profile.
onuClaim ( )	Serving, Discovery	Declaration by an OLT CT of availability of the service profile for the ONU.
onuNotify ()	Provisioned, Protecting, Observing	Notification by the OLT CT which has service profile for the ONU that the ONU is being hosted and served.
ConfirmOut()	Serving, Discovery	Commit indication of a handover closure transaction associated with a receipt of unicast message from the original Target CT to the Source CT confirming successful handover of the ONU identified by ONU-ID.

Table 7-3 – OLT Serving state machine inputs

Input	Applicable states	Semantics
ConfirmIn()	Protecting	Commit indication of a handover closure transaction associated with a receipt of unicast message from the original Source CT to the Target CT acknowledging the receipt of the ONU handover confirmation.
TC events		
Local ONU discovery	All states	An ONU responding to a serial number grant and providing its authentication credentials. In the Serving and Discovery states, the Local ONU discovery event corresponds to the ONU reactivation without retuning.
Protection switching	Protecting	An ONU responding to a directed PLOAM grant periodically offered for protection.
Timer events		
Tpres expires	Protecting, Observing	Timer expiration
Tlob expires	Serving, Discovering	Timer expiration
EMS events		
Service profile acquisition	Stem, Observing, Discovering	
Service profile withdrawal	Provisioned, Protecting Serving	

7.2.1.2 OLT CT Serving SM state diagram



Acronym Legend

Local events:	
LDISC	Local ONU discovery
PRTSW	Protection switching
SP-ACQ	Service profile - acquisition
SP-WDL	Service profile - withdrawal
TLOBI-EX	Expiration of the LOBi condition timer, Tlobi
TPRES-EX	Expiration of the ONU presence timer, Tpres.
ICTP primitives:	
ICTP-NTFY	ONU service notification, onuNotify()
ICTP-AUTH	ONU authentication request, onuAuthen()
ICTP-CFMOUT	Handover confirmation indication, ConfirmIn()
ICTP-CFMIN	Handover confirmation acknowledgment, ConfirmOut()

Note: Self-transitions are not shown (see Table 7-4).

Figure 7-1 – OLT Serving state transition diagram

In Figure 7-1, the slash (/) is used to distinguish the input event that triggers the state transition from the output action associated with the state transition (Mealy notation). For the input events that trigger transitions, see the state transitions table.

7.2.1.3 OLT CT Serving SM state transition table

Table 7-4 – OLT CT Serving SM state transition table

	Stem (S0)	**Provisioned (S1)**	**Protecting (S2)**	**Serving (S3)**	**Observing (S4)**	**Discovery (S5)**
Local ONU discovery (LDISC)	→ (S5)	→ (S3)	→ (S3)	→ (S3)*	→ (S5)	→ (S5)*
Protection switching (PRTSW)	N/A	N/A	→ (S3)	N/A	N/A	N/A
Tpres expires (TPRES-EX)	N/A	N/A	→ (S1)	N/A	→ (S0)	N/A
Tlobi expires (TLOBI-EX)	N/A	N/A	N/A	→ (S2)	N/A	→ (S0)
onuAuthen() (ICTP-AUTH)	→ (S4)	→ (S2); If Selected, Respond with onuClaim()	→ (S2)* If Selected, Respond with onuClaim()	→ (S3)* Negotiate with sender, possibly start handover	→ (S4)*	→ (S5)* Consistency verification may be needed
onuClaim() (ICTP-CLM)	N/A	→ (S1)*	→ (S2)*	→ (S3)* If **not** Selected, Proceed with handover.	→ (S4)*	→ (S5)* Proceed with handover.
onuNotify() (ICTP-NTFY)	(S4)	→ (S2);	Reset Tpres; → (S2)*	→ (S3)* Negotiate with sender, possibly start handover	Reset Tpres; → (S4)*	→ (S5)* Consistency verification may be needed
ConfirmIn() (ICTP-CFMIN)	N/A	N/A	→ (S3)	N/A	N/A	N/A
ConfirmOut() (ICTP-CFMOUT)	N/A	N/A	N/A	→ (S2)	N/A	→ (S4)

Table 7-4 – OLT CT Serving SM state transition table

	Stem (S0)	Provisioned (S1)	Protecting (S2)	Serving (S3)	Observing (S4)	Discovery (S5)
Service profile acquisition (SP-ACQ)	→ (S1)	→ (S1)*	→ (S2)*	→ (S3)*	→ (S2)	→ (S3)
Service profile withdrawal. (SP-WDL)	N/A	→ (S0)	→ (S4)	→ (S5)	N/A	N/A

Note:

(1) Grey shading indicates that an event is not applicable in the given state. Yellow shading indicates either PLOAM or ICTP protocol violation. An asterisk "*" means that the state machine stays in the same state.

(2) "Selected" refers to the OLT CT which serves the role of the Active CT, that is, Preferred OLT CT that can provide service OR the Protection CT that can provide service after the Preferred OLT CT has notified it cannot provide service.

7.2.2 OLT CT Tuning state machine

The following is a formal specification of the OLT CT tuning state machine, change marked against the content of clause 17.3.3./G.989.3. The new/modified text is in orange. The tuning state machine is instantiated as a part of the OLT's ONU-specific state once the OLT transitions out of the Stem state of the Serving state machine.

7.2.2.1 States, timers, inputs, and outputs

Table 7-5 – OLT CT tuning state machine states

State	Semantics
Away	An instance of the OLT CT's tuning state machine associated with the specific Serial Number has been created, but the ONU has not yet activated or is tuned to a different TWDM channel. The OLT CT does not provide any allocations to the ONU.

Table 7-5 – OLT CT tuning state machine states

State	Semantics
Expecting	The OLT CT either expects a handover of an ONU from another TWDM channel, or is designated to provide TWDM protection to the ONU. Target OLT CT wait timer T_{target} is started upon entry to the state and stopped upon exiting the state. The initial value of T_{target} is finite in case of pending handover and infinite in case of TWDM protection. The OLT CT provides PLOAM-only allocations to the given ONU-ID on a regular basis, but does not react adversely to the missed allocations. The OLT CT may use increased guard times around the expected burst from the given ONU-ID to compensate for the equalization delay uncertainty.
Hosting	The ONU-ID is associated with the OLT CT, and is subject to at least, regular PLOAM allocations.
Redirecting	The OLT CT instructs the ONU to schedule the start of the tuning procedure at a specified moment in the future. The ONU-ID is associated with the source OLT CT, and is subject to at least regular PLOAM allocations Source OLT CT wait timer T_{source} is started upon entry to the state.
Seeing-Off	The OLT CT hands over an ONU to another TWDM channel. The OLT CT provides at least PLOAM allocations to the given ONU-ID on a regular basis, (and may provide data allocation to drain any possibly fragmented SDUs prior to scheduled start of the tuning procedure) but does not react adversely to the missed allocations.
LOB	The OLT CT provides allocations to the ONU, but due to lack of the response declares LOBi condition. The OLT CT periodically transmits broadcast ICTP:LOBi Alert for the ONU.

Table 7-6 – OLT CT tuning state machine timers

Timer	Full name	State	Semantics and initial value
T_{source}	Source OLT wavelength handover wait timer	Redirecting, Seeing-Off	Timer T_{source} limits the duration of OLT CT's wait for the ONU to complete tuning after the Tune-Out handover transaction has been committed. This timer should be longer than T_{target}.

Table 7-6 – OLT CT tuning state machine timers

Timer	Full name	State	Semantics and initial value
T_{target}	Target OLT wavelength handover wait timer	Expecting	Timer T_{target} limits the duration of OLT CT's wait for the ONU arrival after the Tune-In handover transaction has been committed. In case of TWDM protection, the $T_{target,}$ is not used, that is, set to infinity and, therefore, never expires.

Table 7-7 – OLT CT tuning state machine inputs

Input	Applicable states	Semantics
ICTP primitives		
Tune-In (ONU-ID, Source DS PON-ID, Source US PON-ID)	Away	Commit indication of a transaction affirming a scheduled handover of an ONU identified by ONU-ID into the specified pair of downstream and upstream wavelength channels.
Tune-Out (ONU-ID, Target DS PON-ID, Target US PON-ID)	Hosting	Commit indication of a transaction affirming a scheduled handover of an ONU identified by ONU-ID out of the specified pair of downstream and upstream wavelength channels.
ConfirmOut (ONU-ID)	Seeing-Off	Commit indication of a handover closure transaction associated with a receipt of unicast message from the original Target CT to the Source CT confirming successful handover of the ONU identified by ONU-ID.
handoverAbort (ONU-ID)	Expecting	An ICTP message from the Source OLT CT to the Target OLT CT indicating the failure of the handover procedure (the Source OLT CT has received either TuningResp (NACK) or TuningResp (Rollback) from the ONU-ID). The target OLT CT which receives Handover Abort Indication (ONU-ID) stops its timer *T*target associated to the given ONU-ID.
onuNotify (ONU-ID)	LOB	An ICTP message from an OLT CT notifying the previous host of ONU's appearance on a different TWDM channel.
PLOAM events		
TuningResp (<opcode>, ONU-ID)	Away, Expecting, Hosting, Redirecting, Seeing-Off	Tuning_Response PLOAM message with the specified operation code received from ONU-ID. The operation code (<opcode>) can be either ACK, NACK, Complete_u, or Rollback.

Table 7-7 – OLT CT tuning state machine inputs

Input	Applicable states	Semantics
Serial_Number_ONU (Serial_Number)	Away LOB	An ONU activation/re-activation attempt in response to a serial number grant.
Timer events		
T_{source} expires	Seeing-Off	Timer expiration indicating a tuning procedure failure.
T_{target} expires	Expecting	Timer expiration indicating a tuning procedure failure.
Upstream transmission events		
LOBi detected	Hosting	See G.989.3 Table 14-2 and G.9807.1 Table 14-2.
LOBi cleared	LOB	See G.989.3 Table 14-2 and G.9807.1 Table 14-2.

Table 7-8 – OLT CT tuning state machine outputs

Output	Semantics
ICTP messages	
Handover Conform Indication (ONU-ID)	A unicast message from the Target OLT CT to the Source OLT CT initiating a transaction to confirm the successful arrival of the ONU identified by ONU-ID to the Target TWDM channel.
ONU Alert (ONU-ID, Source DS PON-ID, Source US PON-ID)	A broadcast ICTP alert by the given OLT CT to all other OLT CTs in the TWDM system, to indicate an unspecified failure of the tuning procedure and requesting that the ONU with the specified ONU-ID be directed towards specified pair of downstream and upstream wavelength channels. In all failure cases, it is the Source OLT CT that should retain custody of the ONU, because the ONU is known to be able to work with the Source OLT CT, which is not the case for the Target OLT CT. In all cases when this output is used, the WMM is notified as well.
Handover Abort Indication (ONU-ID)	An ICTP message from the Source OLT CT to the Target OLT CT indicating the failure of the handover procedure (the Source OLT CT has received either TuningResp (ACK) or TuningResp (Rollback) from the ONU-ID). The target OLT CT which receives Handover Abort Indication (ONU-ID) stops its timer *T*target associated to the given ONU-ID.
LOBi Alert (ONU-ID)	A broadcast ICTP alert of an ONU being lost on a given TWDM channel.

Table 7-8 – OLT CT tuning state machine outputs

Output	Semantics
PLOAM events	
TuningCtrl (<opcode>, ONU-ID, Target US PON-ID, Target DS PON-ID)	Tuning_Control PLOAM message with the specified operation code transmitted to ONU-ID. The operation code (<opcode>) can be either Request or Complete_d.

Table 7-7 and Table 7-8 list the input and output events using the complete format with the associated parameters. In the OLT state diagram (G.989.3 clause 17.3.3.2) and OLT state transition table below (G.989.3 clause 17.3.3.3) for ONU wavelength channel handover, the specific ONU-ID and the specific pair of source and target wavelength channels associated with input and output events are omitted for clarity; only the relevant operation codes are shown.

7.2.2.2 OLT CT Tuning SM state diagram

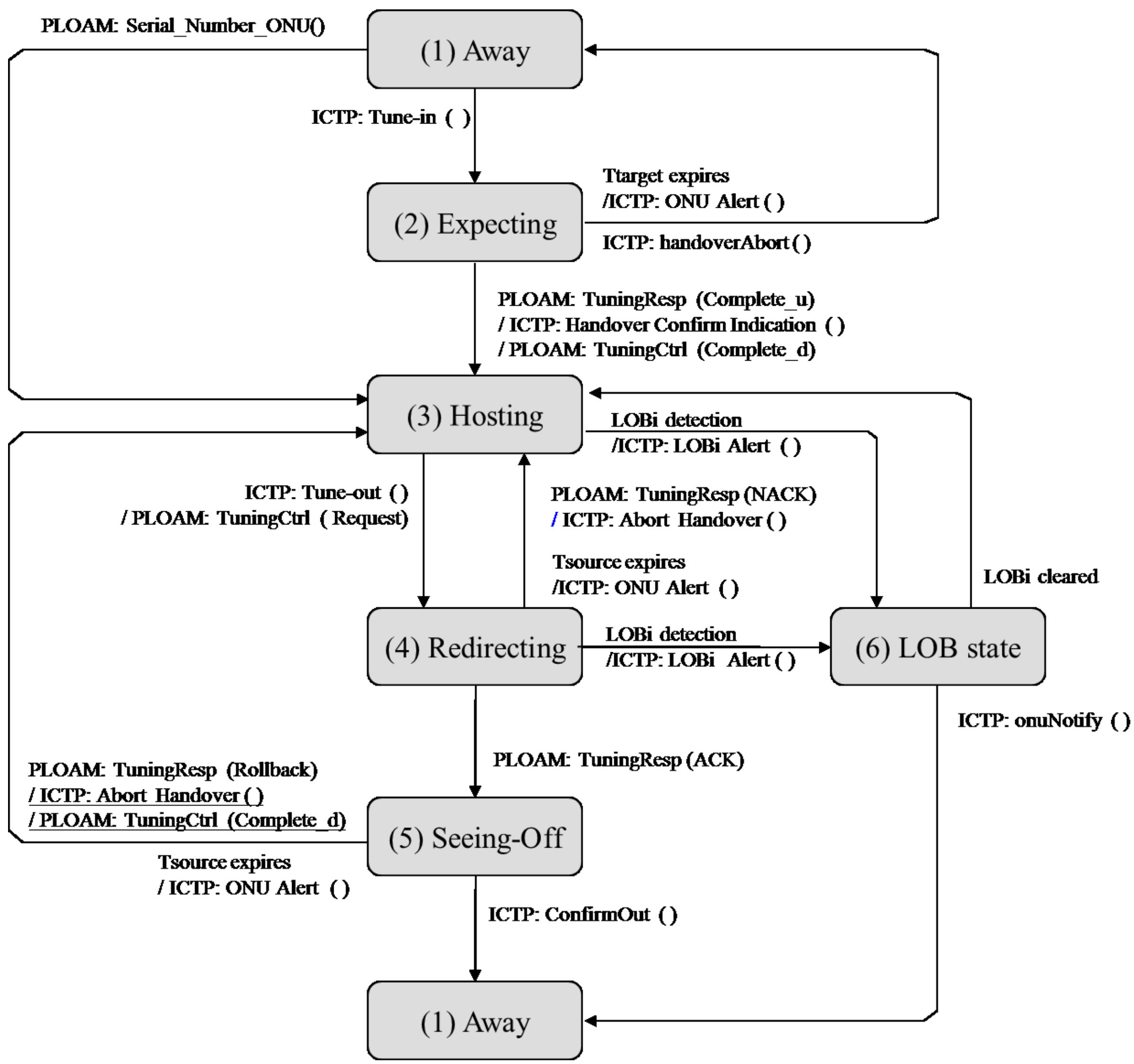


Figure 7-2 – OLT CT tuning state transition diagram

In Figure 7-2, the slash (/) is used to distinguish the input event that triggers the state transition from the output action associated with the state transition (Mealy notation).

7.2.2.3 OLT CT tuning SM state transition table

Table 7-9 – OLT CT tuning state transition table

	(1) Away	(2) Expecting	(3) Hosting	(4) Redirecting	(5) Seeing-Off	(6) LOB
PLOAM: Serial_Number_ONU()	→ (3)	This event is recognized in Away state only				
ICTP: Tune-In ( )	Start T_{target} → (2)	Tune-in is a transaction and, therefore, should be rejected within the ICTP protocol. No input for the wavelength handover SM is generated.				Rejected within the ICTP protocol
ICTP: Tune-Out ( )		Rejected within the ICTP protocol	Start T_{source} TuningCtrl (Request) → (4)	Rejected within the ICTP protocol	Rejected within the ICTP protocol	ICTP: handover Abort()
ICTP: ConfirmOut ( )		ICTP violation	ICTP violation	ICTP violation Stop T_{source} → (1)	Stop T_{source} → (1)	(1)
ICTP: handoverAbort()		Stop T_{target} → (1)	ICTP violation	ICTP violation	ICTP violation	*
ICTP: onuNotify()		*	ICTP violation	ICTP violation	Stop T_{source} → (1)	→ (1)
TuningResp (ACK)		PLOAM violation → (1)	PLOAM violation *	→ (5)	*	

Table 7-9 – OLT CT tuning state transition table

	(1) Away	(2) Expecting	(3) Hosting	(4) Redirecting	(5) Seeing-Off	(6) LOB
TuningResp (NACK)		PLOAM violation → (1)	*	Stop T_{source} ICTP: handover Abort() → (3)	PLOAM violation Stop T_{source} ICTP message: ONU Alert → (3)	
TuningResp (Rollback)		PLOAM violation → (1)	PLOAM violation *	PLOAM violation Stop T_{source} → (3)	Stop T_{source} ICTP: handover Abort() TuningCtrl (Complete_d) → (3)	
TuningResp (Complete_u)		Stop T_{target} ICTP Message: Handover Confirm Indication ( ); TuningCtrl (Complete_ d) → (3)	*	PLOAM violation Stop T_{source} ICTP Message: ONU Alert → (3)	PLOAM violation Stop T_{source} ICTP Message: ONU Alert TuningCtrl (Complete_d) → (3)	
T_{target} expires		ICTP message: ONU Alert → (1)				

Table 7-9 – OLT CT tuning state transition table

	(1) Away	(2) Expecting	(3) Hosting	(4) Redirecting	(5) Seeing-Off	(6) LOB
T_{source} expires				ICTP Message: ONU Alert → (3)	ICTP Message: ONU Alert → (3)	
LOBi detected			→ (6)	Stop T_{source} ICTP:handover Abort() → (6)		
LOBi cleared						→ (3)

Note: Grey shading indicates that an event is not applicable in the given state. Yellow shading indicates either PLOAM or ICTP protocol violation. An asterisk "*" means that the state machine stays in the same state.

In Table 7-9, the actions listed for the cells marked PLOAM violation or ICTP violation are mere suggestions based on the likely underlying events. The complete mitigation action is at the OLT CT discretion, as controlled by the WMM. The OLT CT takes into account additional factors such as the LOS_i condition (current and intermittent), PLOAM sequence number value, and state of the security association with the sender, and checks the observed violation for possible signs of the ONU cloning attack. The OLT CT should make a record of the violation, incrementing an appropriate event counter, and may either leave it inconsequential, or take proactive steps including, but not limited to, raising an alarm to OSS, alerting other OLT CTs in the system about a run-away/duplicate ONU, re-authenticating, deactivating or disabling the ONU, or executing a rogue ONU diagnostic procedure. As an example, on receipt of 'ICTP Primitive:Confirm' while in the Redirecting state for a given ONU-ID, the OLT CT may check whether the ONU is in LOS_i, and if so, presumes a loss of Tuning ACK, increments the $LOPC_i$ counter, stops the T_{source} timer and transitions into the Away state.

7.3 Consistency Checking

According to ITU-T G.989.3, the following parameter assignments must be unique across the ODN in an NG-PON2 system:

- ONU-ID assignment to an ONU;
- Alloc-ID assignment to an ONU;
- XGEM Port-ID assignment to a logical connection.

Since in an NG-PON2 system, multiple OLT CTs can assign those parameters, the consistency of the parameter assignments has to be maintained.

Each OLT CT is expected to draw a free identifier value from pools of assignable ONU-IDs, Alloc-IDs, and XGEM Port-IDs each time the PON protocols require a parameter assignment. The primary responsibility to distribute and maintain the conflict-free pools of assignable identifiers rests with an upper layer management entity (OSS/EMS or WMM). The ICTP incorporates the means to provide the secondary tool for consistency verification of the assignable parameters.

Two ICTP message types are involved in consistency verification:

- prmNotify ICTP message: A unicast or multicast ICTP message providing notification to one or more CTs of the local values an ONU-ID, Alloc-ID orXGEM Port-ID;
- prmConflict ICTP message: A unicast ICTP message providing an indication of a conflict of that ONU-ID, Alloc-ID or XGEM Port-ID among OLT CTs.

The ICTP-based parameter consistency verification works as follows:

- each OLT CT proactively advertise its currently assigned identifiers to other OLT CTs with a **prmNotify** ICTP message. If another OLT CT detects a conflict it replies with a **prmConflict** ICTP message. When applied, this procedure is intended as a background process. Refer to use case 5 in Appendix A for further actions if a conflict is detected.
- each OLT CT proactively broadcast its current assignable parameter pools to other OLT CTs with a **prmNotify** ICTP message. If another OLT CT detects a conflict it replies with a **prmConflict** ICTP message. When applied, this procedure is intended as a background process. Refer to use case 5 in Appendix A for further actions if a conflict is detected.

It should be emphasized that the above ICTP procedures are indeed *verification* procedures; they are in principle not strictly mandatory for proper operation of the NGPON2 system under the stated assumptions.

Once an OLT CT receives an indication of a parameter conflict, or it exhausts a pool of assignable parameters for either ONU-ID, Alloc-ID, or XGEM Port-ID, it is expected to report the event to the upper layer management entity. The details are out of the ICTP specification's scope.

7.4 Bulk Service Data Transfer

ONU services (e.g., HSIA, multicast, etc) use learning protocols to establish ONU services. For example, an OLT may snoop upstream control protocol (e.g., IGMP, DHCP, ARP, PPPoE, etc) and learn MAC addresses of the subtending devices. Learnt control protocol information associated with IGMP, etc needs to be synchronized between the peer PON ports (otherwise there will be traffic disruption when a switch/handover is completed). To synchronize peer CTs, service data (e.g., DHCP, IGMP) is pushed using IPFIX protocol across CTs whenever new data needs to be synchronized (e.g., new additions, deletions) or to periodically refresh the data (e.g., as part of an audit).

Additionally, ICTP has the capability to explicitly trigger service data transfer via IPFIX by means of start and end of service data transfer ICTP messages.

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Appendix E contains IPFIX template format.

8 Appendix A: Sequence Analysis of ICTP Use Cases

This section details generic sequences of ICTP interactions which can be used as functional building blocks in various high-level ONU Mobility use cases. To this end, for each such ICTP use case, the following aspects are identified:

(1) Function provided by the sequence;
(2) Interacting Entities (i.e., CPs, ONU);
(3) Preconditions/Assumptions before the sequence has initiated;
(4) Sequence of Atomic ICTP Interactions;
(5) Post-conditions; i.e., the state of the interacting entities after the sequence has completed.

Use Case 1: CT Profile Sharing

(1) Function: Sharing of the CT-specific information to support the profile announcement by the CTs of the NG-PON2 system;
(2) Interacting Entities: SrcCT, DestCTs;
(3) Preconditions/Assumptions:
    - SrcCT is operational with or without any attached ONUs
    - SrcCT has acquired all the profile information pertaining to its own DS and US wavelength channels
    - Each DestCT is operational with or without any attached ONUs;
(4) Sequence of Atomic ICTP Interactions: shown in Figure 8-1;
(5) Post-condition: Each DestCT acquires the profile information pertaining to SrcCT and includes this information into Channel_Profile PLOAM message for the SrcCT.

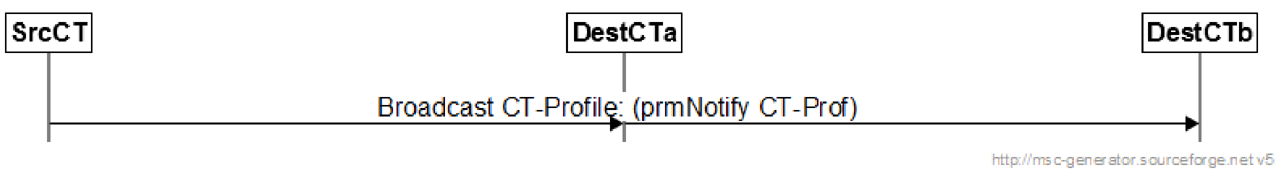


Figure 8-1 – Profile Sharing

Use Case 1b: CT Profile Inquiry

(1) Function: obtaining the profile of a specific CT on request, without waiting for the regular profile announcement;
(2) Interacting Entities: SrcCT, DestCT;
(3) Preconditions/Assumptions:
    - SrcCT is operational with or without any attached ONUs
    - Each DestCT is operational with or without any attached ONUs
    - DestCT has acquired all the profile information pertaining to its own DS and US wavelength channels
    - SrcCT needs to refresh DestCT's profile information;

(4) Sequence of Atomic ICTP Interactions: shown in Figure 8-2;
(5) Postcondition: SrcCT has refreshed its copy of the DestCT's profile information.

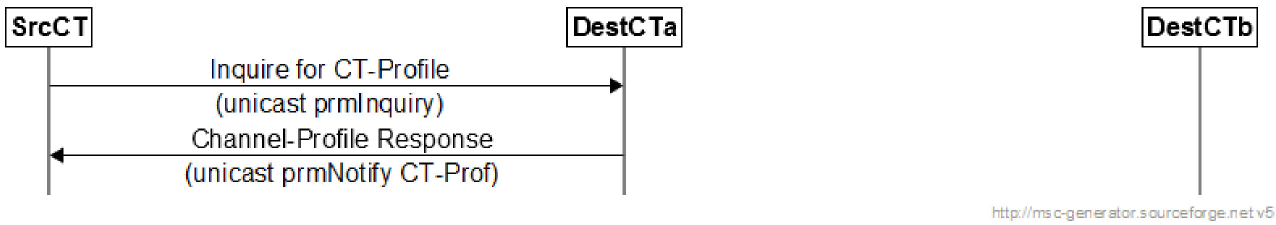


Figure 8-2 – Profile Inquiry

<u>Use Case 2</u>: Silent Start and CT Initialization

(1) Function: Harmless provisioning/activation of an Initiating_CT;
(2) Interacting Entities: CT already active on the administrative domain;
(3) Preconditions/Assumptions:
  - 'ICTP Address' of all CTs within the administrative domain are provisioned via OSS;
  - CT's role as main or protection backup per ONU is provisioned via OSS;
  - Initiating_CT broadcasts its information within its administrative domain;
(4) Scenario of atomic ICTP interactions: shown in Figure 8-3;
(5) Postcondition: Initiating_CT turns to Initiated_CT, and follows the G.989.3 defined behavior according to events observed on its ODN interface.

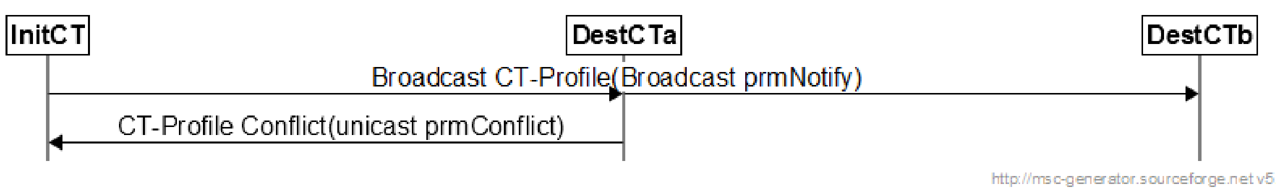


Figure 8-3 – Silent Start and CT Initialization

<u>Use Case 3</u>: Initial Zero-Distance Equalization Delay

(1) Function: To agree on the initial value of the zero-distance equalization delay, which is the preliminary step of the consistent equalization delay procedure;
(2) Interacting Entities: SrcCT, PrevCT, NextCT;
(3) Preconditions/Assumptions:
  - All CTs are operational with no attached ONUs;

- In preparation for execution of the consistent equalization delay procedure, a CT initiates the Teqd agreement procedure by transmitting its selected Teqd along the pre-defined ring order;
- The SrcCT receives the Teqd transmission from the PrevCT in the order, modifies the value, if necessary, and forwards the message to the NextCT;

(4) Sequence of Atomic ICTP Interactions: shown in Figure 8-4;
(5) Postcondition: All operation CTs in the system agree on the common Teqd value.

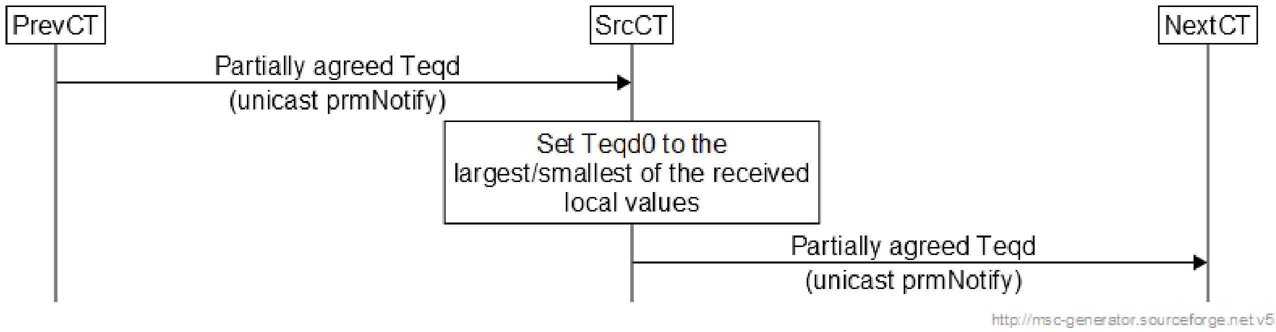


Figure 8-4 – Initial Zero-Distance Equalization Delay

Use Case 4: Initial ONU Validation upon Activation

(1) Function: Mitigation of a stray ONU condition whereby an ONUx that listens to TxCT transmits toward RxCT;
(2) Preconditions/Assumptions: RxCT receives a unsolicited SN_ONU message with PON-ID of the TxCT and some UWLCH ID, which is not equal to the UWLCH ID of the RxCT.
(3) Sequence of Atomic ICTP Interactions: shown in Figure 8-5;
(4) Postcondition: RxCT issues an Adjust_Tx_WL message to the ONUx in order to align its transmission wavelength at the target upstream wavelength channel.

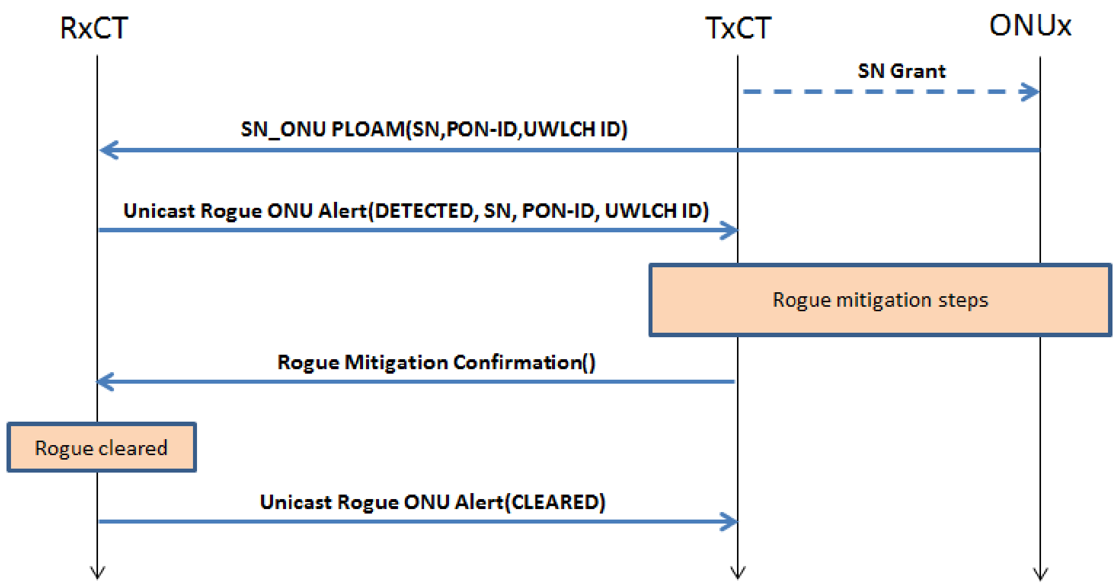


Figure 8-5 – Initial ONU Validation upon Activation

Use Case 5: SN and Assigned ONU-ID Consistency Verification

(1) Function: Inform peer CTs of the ONU-ID assignment to the SN and mitigate associated inconsistencies.
- If multiple ONU-ID are assigned to one and the same SN, all prior assignments are invalidated and Deactivate_ONU-ID PLOAM are issued against them;
- If multiple SNs are assigned one and the same ONU-ID, the HostCT is notified for further action (e.g., Deactivate_ONU-ID and reassign another ONU-ID, or notify EMS/OSS);

(2) Preconditions/Assumptions:
- Each OLT CT is aware of it own pool of assignable ONU-IDs;
- HostCT discovers an ONU by its SN, assigns an ONU-ID to it, and completes ranging;

(3) Sequence of Atomic ICTP Interactions: Please refer to Section 7.3

(4) Postconditions:
- Each DestCT deactivates any prior ONU-ID assignments to that SN, records the new association between the SN and ONU-ID, informs the HostCT of an error condition if the ONU-ID has been previously assigned to a different SN.
- HostCT is informed of any ONU-ID assignment conflicts.

Use Case 6: ONU Discovery Resolution

(1) Function: DiscoverCT inquires to where to move ONUx;
(2) Interacting Entities: ServiceCT, ProtectionCT (optional), DiscoverCT
(3) Preconditions/Assumptions:

- Downstream and Upstream on same CT;
- DiscoverCT has TC-discovered ONUx but is not supposed to provide service to ONUx;
- Two cases are possible:
  - (i) the SN is identified as foreign (ONU-ID not assigned);
  - (ii) the SN is okay, but Reg-ID is foreign (ONU-ID is assigned, EqD may be assigned);
- ServiceCT is aware of ONUx configuration and knows it should provide service to ONUx;
- If configured, ProtectionCT is aware of ONUx configuration and knows it protects ServiceCT for ONUx;

(4) Sequence of Atomic ICTP Interactions: (4) Sequence of Atomic ICTP Interactions: Please refer to Appendix B Examples 1 through 6.

(5) Postcondition: The CT which has discovered the ONU is aware of which CT should provide service to the ONU."

Use Case 7: Alloc-ID Assignment Consistency Verification

(1) Function: Inform peer CTs of the Alloc-ID assignment to the ONU-ID and mitigate associated inconsistencies;
- If multiple ONU-IDs are assigned one and the same Alloc-ID, the HostCT is notified for further action (e.g., cancel Alloc-ID assignment, and reassign another Alloc-ID, or notify EMS/OSS);
- Note that assigning multiple Alloc-IDs to one and the same ONU-ID is valid;

(2) Preconditions/Assumptions:
- Each OLT CT is aware of its own pool of assignable Alloc-IDs;
- HostCT assigns a non-default Alloc_ID (Alloc-IDs) to an ONU-ID;

(3) Sequence of Atomic ICTP Interactions: Please refer to Section 7.3;

(4) Postcondition: Each DestCT records the new association between the ONU-ID and Alloc-ID(s), informs the HostCT of any conflicting prior Alloc-ID assignments
- HostCT is informed of any Alloc-ID assignment conflicts.

Use Cases 8 & 9: ONU Handover

(1) Function: SourceCT which is serving an ONU moves this ONU to TargetCT;

(2) Interacting Entities: SourceCT, TargetCT, ONUx (the one to move);

(3) Preconditions/Assumptions:
- Downstream and Upstream on same CT;
- SourceCT is currently providing service to ONUx (at least provides TC connectivity);
- SourceCT knows that ONUx should move to the TargetCT;
- TargetCT is UP and aware of ONUx configuration data;
- SourceCT has completed the synchronization of dynamic ONUx-data to the TargetCT;

(4) Sequence of Atomic ICTP Interactions: Please refer to Appendix B Examples 1 through 7.
(5) Postcondition: TargetCT is providing service to ONUx.

Use Case 10: ONU LOB Mitigation

(1) Function: To notify the peer CTs of an unexpected disappearance of an ONU;
  - This is an optional tool which an implementation may choose to use;
  - LOBi may be related to a rogue event elsewhere in the system, but may also be confined to a given host CT;
(2) Preconditions/Assumptions: Host CT declares LOBi against an ONU;
(3) Sequence of Atomic ICTP Interactions: shown in Figure 8-6;
(4) Postcondition: Each DestCT may correlate the rogue events it may observe with disappearance of ONUx at its Host CT.

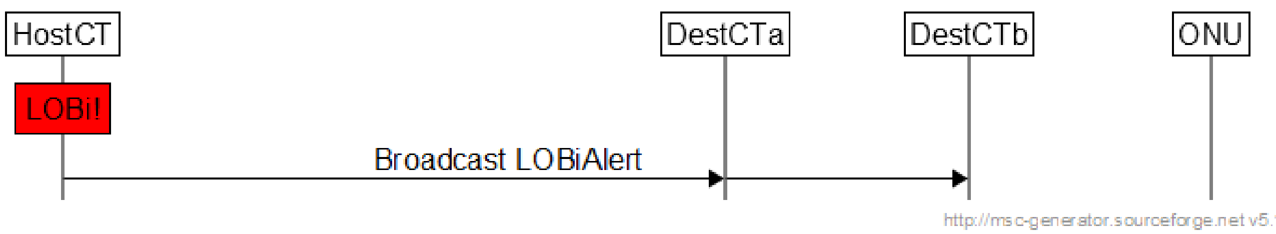


Figure 8-6 – LOBi Mitigation

Use Case 11: This usecase has been deprecated
Use Case 12 (A): Rogue ONU Mitigation (Unidentified Rogue Interference)

(1) Function: AffectedCT, which has detected rogue interference but is unable to identify the source, notifies other OLT CTs on the system for possible multichannel mitigation measures. .;
(2) Interacting Entities: AffectedCT(s), PeerCT(s);
(3) Preconditions/Assumptions:
  - Affected CT and PeerCTs share the same ODN;
  - AffectedCT detects indiscernible rogue interference in its associated upstream channel.
(4) Sequence of Atomic ICTP Interactions: shown in Figure 8-7;
  - AffectedCT notifies PeerCTs of rogue event;
  - PeerCTs take rogue mitigation steps, if such steps are available.
  - AffectedCT detects clearing of the rogue interference condition
  - AffectedCT notifies PeerCTs that rogue condition is cleared;
(5) Postcondition: Normal operation of the PON is restored.

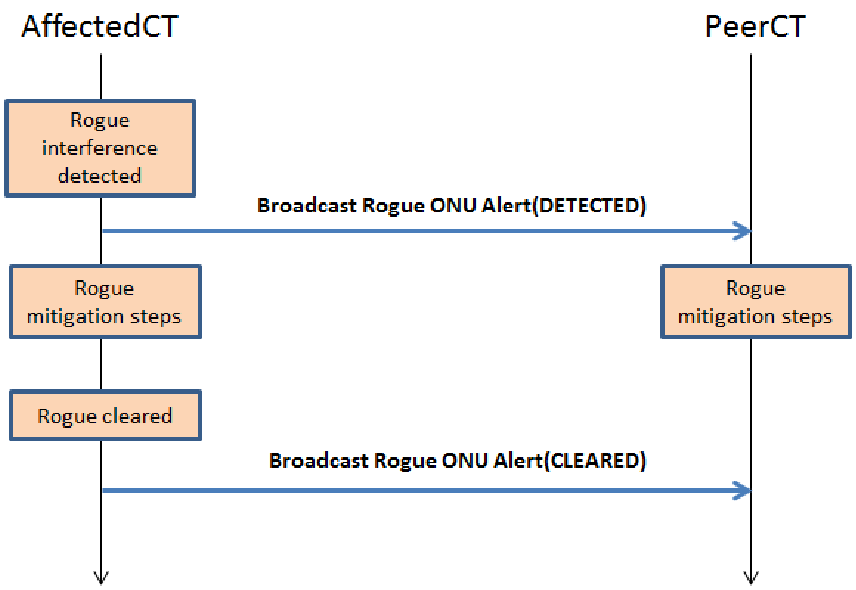


Figure 8-7 – Rogue ONU Mitigation – Unidentified Rogue interference

Note: The specific rogue mitigation steps are out of scope of this document. For a PeerCT having an outstanding LOBi condition, these steps may include, for example, blind placing of the offending ONU into an Emergency Stop state.

Use Case 12 (B): Rogue ONU Mitigation (Rogue Interference from an identified ONU)

(1) Function: AffectedCT, which has detected rogue interference and has identified its source, notifies the HostCT of the offending ONU for mitigation actions.;
(2) Interacting Entities: AffectedCT(s), HostCT, offending ONU;
(3) Preconditions/Assumptions:
  - AffectedCT and PeerCTs share the same ODN;
  - AffectedCT detects a rogue interference in its associated upstream channel;
  - The offending transmission is a well-formed burst;
  - AffectedCT is able to isolate and parse the offending transmission.
  - ;
(4) Sequence of Atomic ICTP Interactions: shown in Figure 8-8;
  - AffectedCT notifes the HostCT of the alleged rogue behavior of the specific ONU;
  - HostCT executes rogue mitigation actions and indicates completion to the AffectedCT;
  - AffectedCT detects clearing of the rogue interference condition
  - AffectedCT notifies HostCT that rogue condition is cleared
(5) Postcondition: Normal operation of the PON is restored.

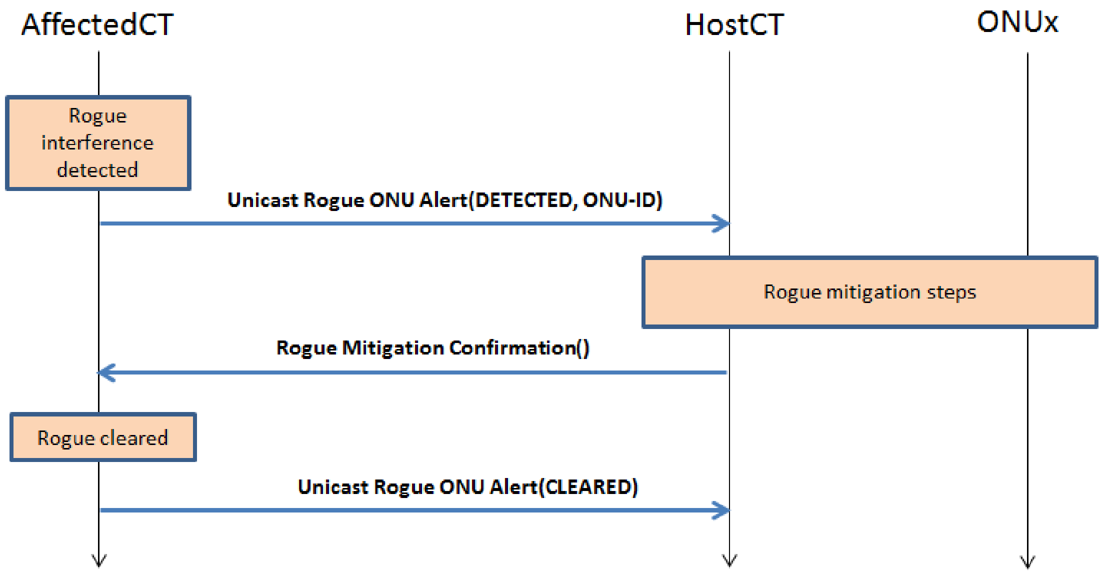


Figure 8-8 – Rogue ONU Mitigation – Rogue Interference from an identified ONU

Note: The specific rogue mitigation steps taken by the HostCT are out of scope of this document. As an example, the HostCT may place the offending ONU into an Emergency Stop state.

Use Case 13: Wavelength Protection CT Initialization

(1) Function: Initialize ProtectionCT for ONUx;
(2) Interacting Entities: ServiceCT, ProtectionCT, ONUx;
(3) Preconditions/Assumptions:
- Downstream and Upstream on same CT;
- ONUx is currently served by ServiceCT;
- ServiceCT is aware that ONUx should be able to take ProtectionCT should ServiceCT fail;
- ProtectionCT is aware of ONUx configuration and knows it can be used by ONUx should ServiceCT fail;
- ProtectionCT is NOT aware yet of any dynamic data concerning ONUx;
- ONUx is not yet aware that it can use ProtectionCT should ServiceCT would fail;

(4) Sequence of Atomic ICTP Interactions: Please refer to Appendix B Examples 1 through 7.
(5) Postconditions:
- ProtectionCT is able to take-over ONUx from ServiceCT from now on, in particular it has up-to-date Dyn-data about ONUx;
- ONUx is aware that it can use ProtectionCT should ServiceCT fail (e.g upon LODS);
- NB: ServiceCT should keep ProtectionCT up to date with regular Incremental Dyn-data Synchronization (i.e. ICTP Sequence of UC 16 for what concerns Dyn-TC-data).

Use Case 14: This usecase has been deprecated.

Use Case 15: Synchronization of ONU Dynamic TC Data

(1) Function: Sync_ingCT does a Dyn-TC-data synchronization to Sync_edCT for ONUx;
(2) Interacting Entities: Sync_ingCT, Sync_edCT;
(3) Preconditions/Assumptions:
- Downstream and Upstream on same CT;
- Sync_ingCT is currently providing service to ONUx (at least provides TC connectivity);
- Sync_ingCT knows it should perform a synchronization of Dyn-TC-data to Syn_edCT;
- Sync_edCT is UP and aware of ONUx configuration data;
- Sync_edCT may or may not have any previous Dyn-TC-data about ONUx;

(4) Sequence of Atomic ICTP Interactions: Please refer to Appendix B Examples 1 through 7.
(5) Postconditions: Sync_edCT has been brought up to date with Dyn-TC-data about ONUx from Sync_ingCT.

Use Case 16: Synchronization of ONU Dynamic Service Data

(1) Function: Sync_ingCT does a Service_DataSync_Start synchronization to Sync_edCT for ONUx, followed by use of IPFIX to transfer service data and then subsequent Service_DataSync_End to conclude transfer of data.
(2) Interacting Entities: Sync_ingCT, Sync_edCT;
(3) Preconditions/Assumptions:
- Downstream and Upstream on same CT;
- Sync_ingCT is currently providing service to ONUx (at least provides TC connectivity);
- Sync_ingCT knows it should perform Service_DataSync_Start synchronization to Syn_edCT;
- Sync_edCT is UP and aware of ONUx configuration data;

(4) Sequence of Atomic ICTP Interactions: shown in Appendix B Example 7
(5) Postcondition: Sync_edCT has been brought up to date with Service-data about ONUx from Sync_ingCT.

9 Appendix B ICTP Message Exchange Examples

This section details generic ICTP message sequences for ONU discovery and handover in an NGPON2 system involved in WL protection. The following use cases are covered:

- Scenario 1: the ONU is discovered on another OLT CT than PreferredCT and ProtectionCT for this ONU and PreferredCT ends-up serving the ONU.
- Scenario 2: the ONU is discovered on another OLT CT than PreferredCT and ProtectionCT for this ONU and ProtectionCT ends-up serving the ONU because PreferredCT cannot serve the ONU.
- Scenario 3: the ONU is discovered on the OLT CT which is PreferredCT for this ONU and PreferredCT ends-up serving the ONU.
- Scenario 4: the ONU is discovered on the OLT CT which is PreferredCT for this ONU and ProtectionCT ends-up serving the ONU because PreferredCT cannot serve the ONU.
- Scenario 5: the ONU is discovered on the OLT CT which is ProtectionCT for this ONU and PreferredCT ends-up serving the ONU.
- Scenario 6: the ONU is discovered on the OLT CT which is ProtectionCT for this ONU and ProtectionCT ends-up serving the ONU because PreferredCT cannot serve the ONU
- Scenario 7: in-service ONU move across OLTs

9.1 Scenario 1: ONU Discovery by CT other than Preferred/Protection CT

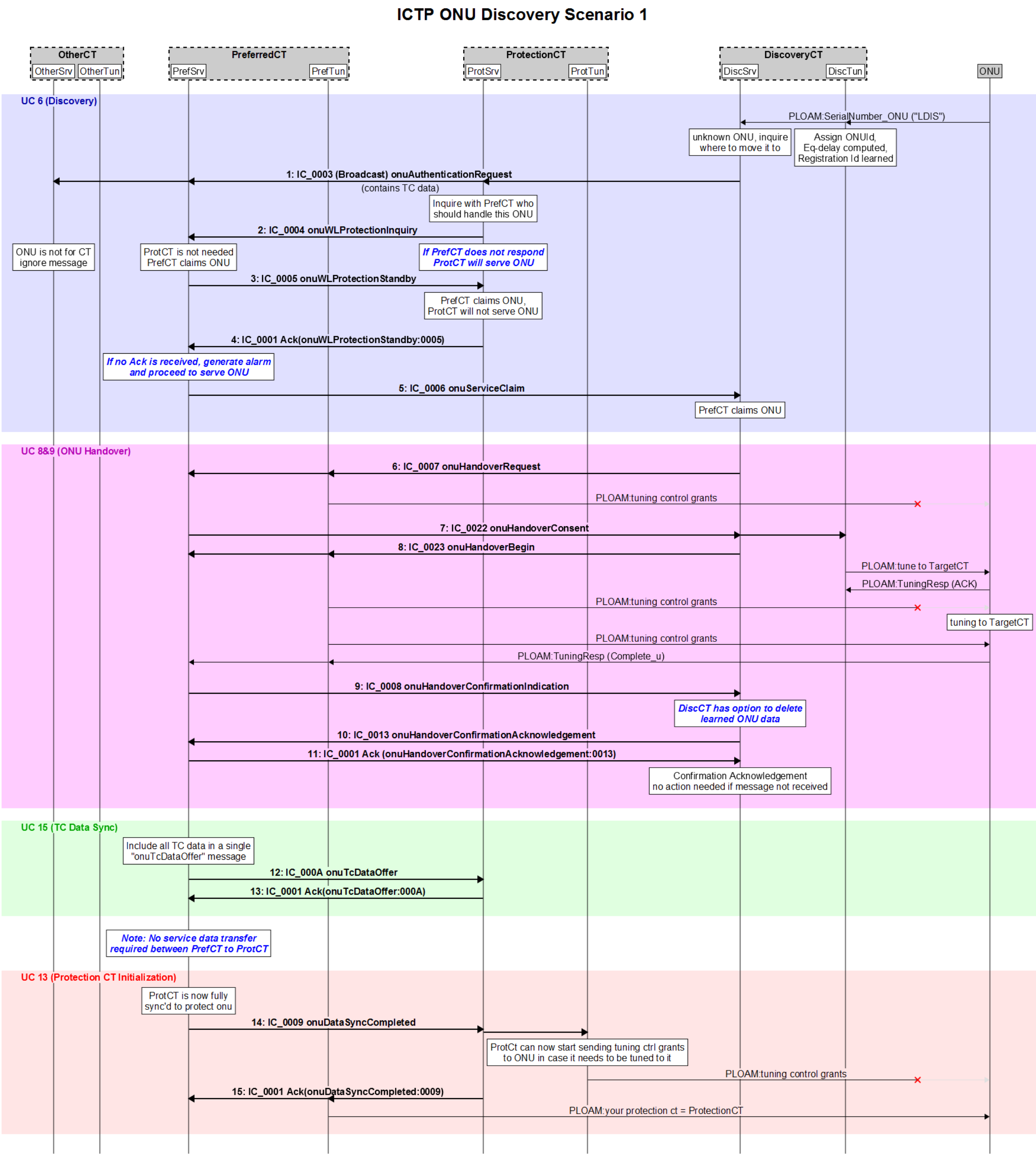


Figure 9-1 – ONU Discovery Resolution (Preferred CT serves ONU)

9.2 Scenario 2: ONU Discovery by CT other than Preferred/Protection CT

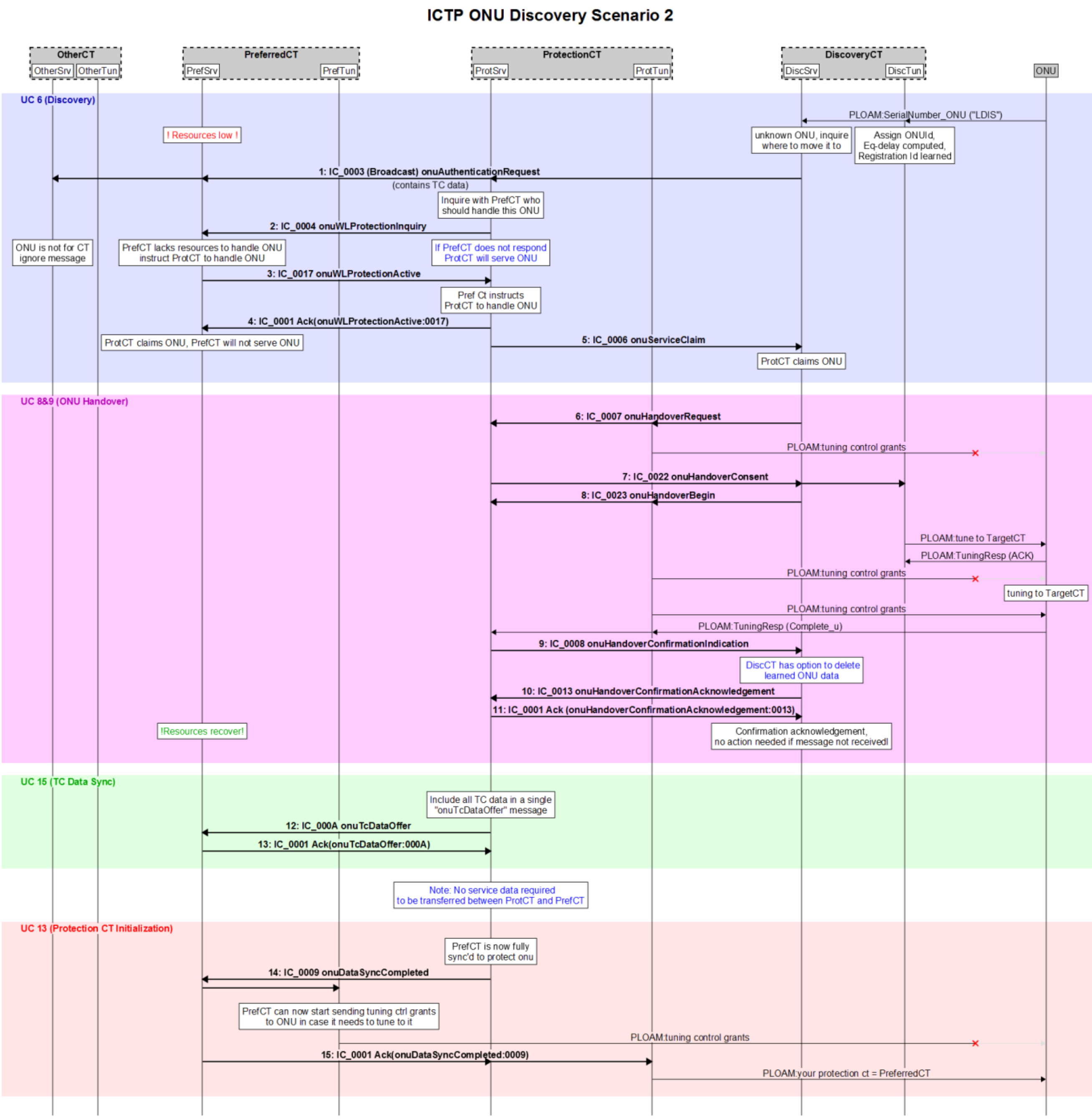


Figure 9-2 – ONU Discovery Resolution (Protection CT serves ONU)

9.3 Scenario 3: ONU Discovery by Preferred CT (servicing by Preferred CT)

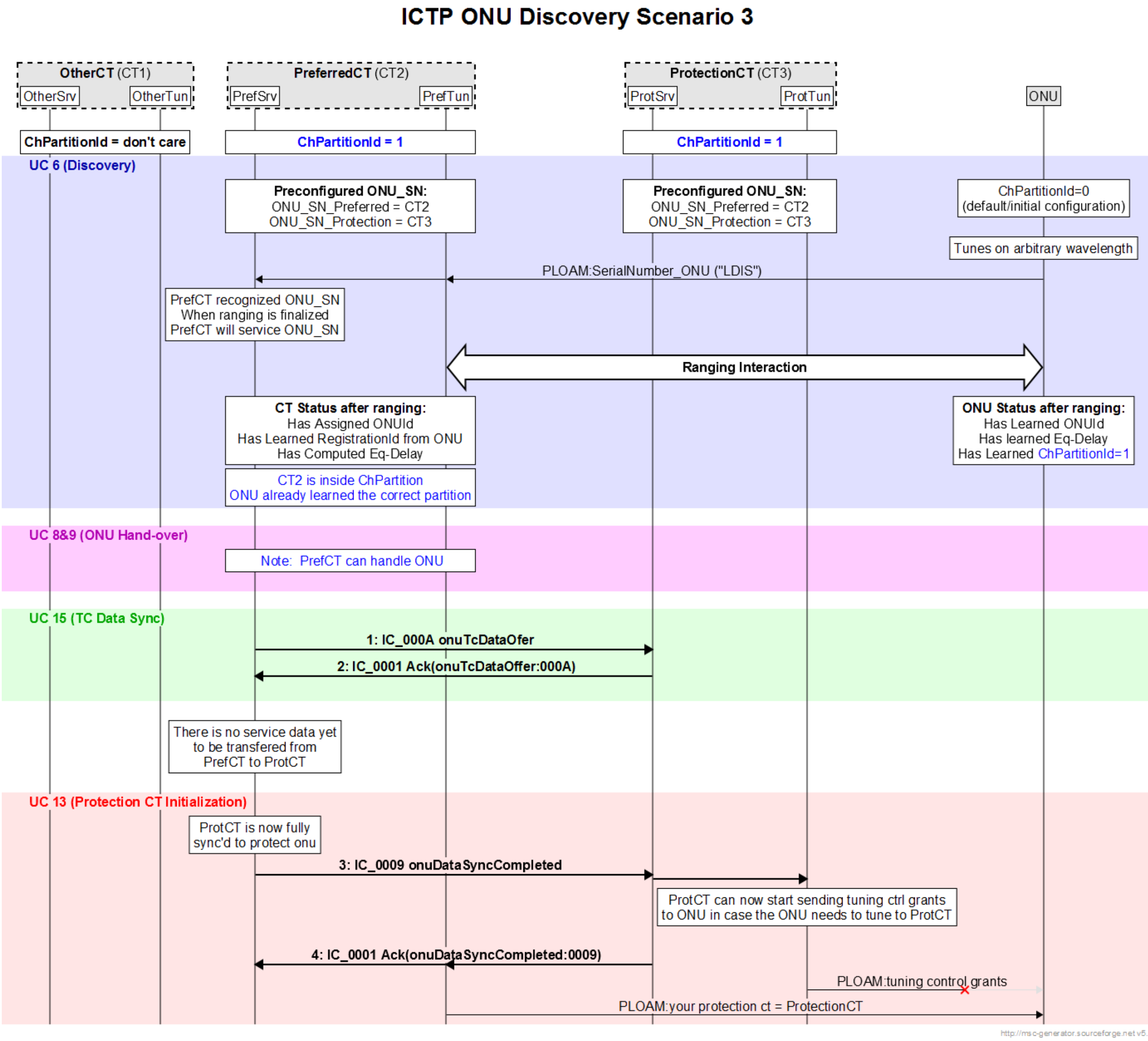


Figure 9-3 – ONU Discovery Resolution (Preferred CT serves ONU)

9.4 Scenario 4: ONU Discovery by Preferred CT (Servicing by Protection CT)

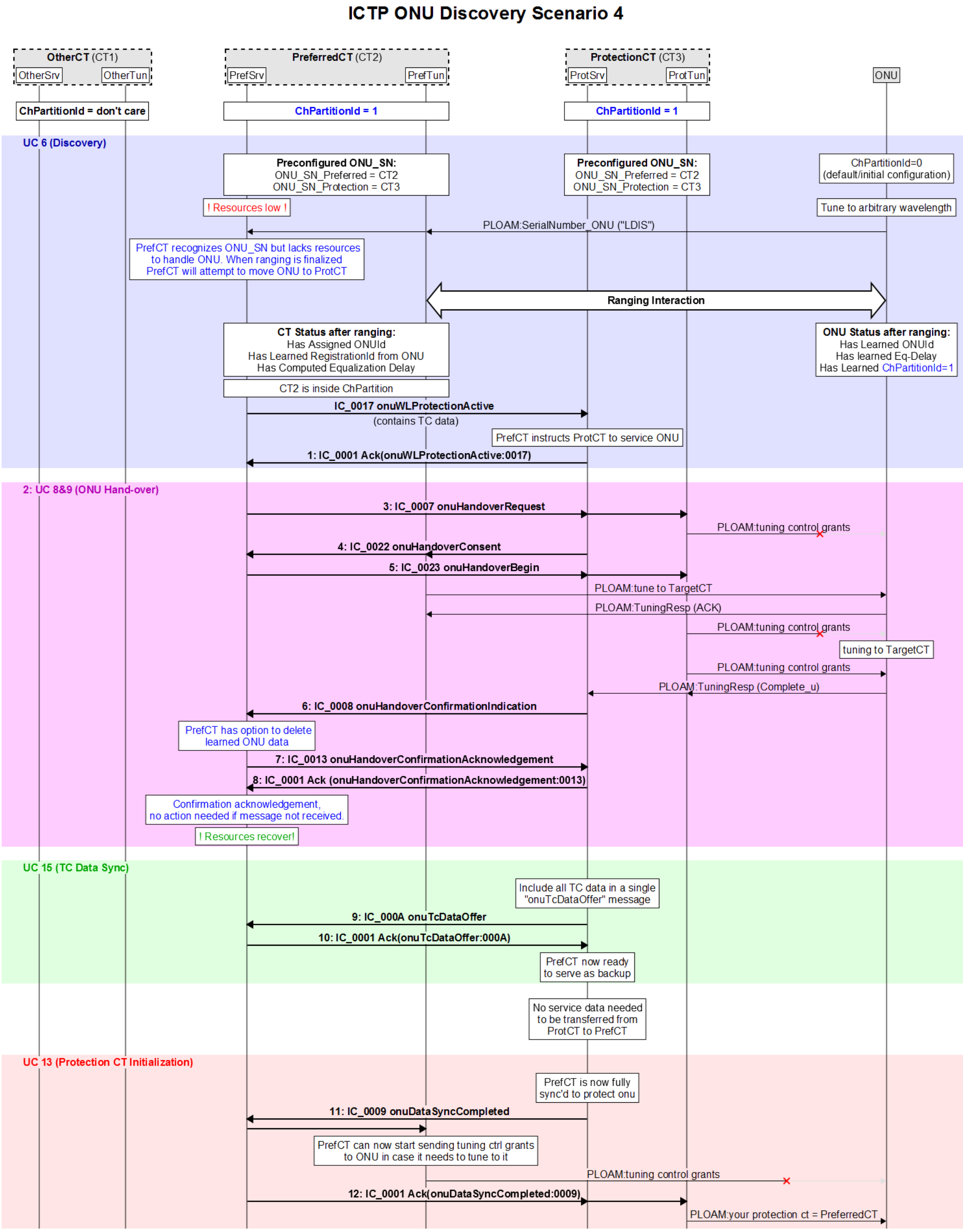


Figure 9-4 – ONU Discovery Resolution (Protection CT serves ONU)

9.5 Scenario 5: ONU Discovery by Protect CT (Servicing by Preferred CT)

ICTP ONU Discovery Scenario 5

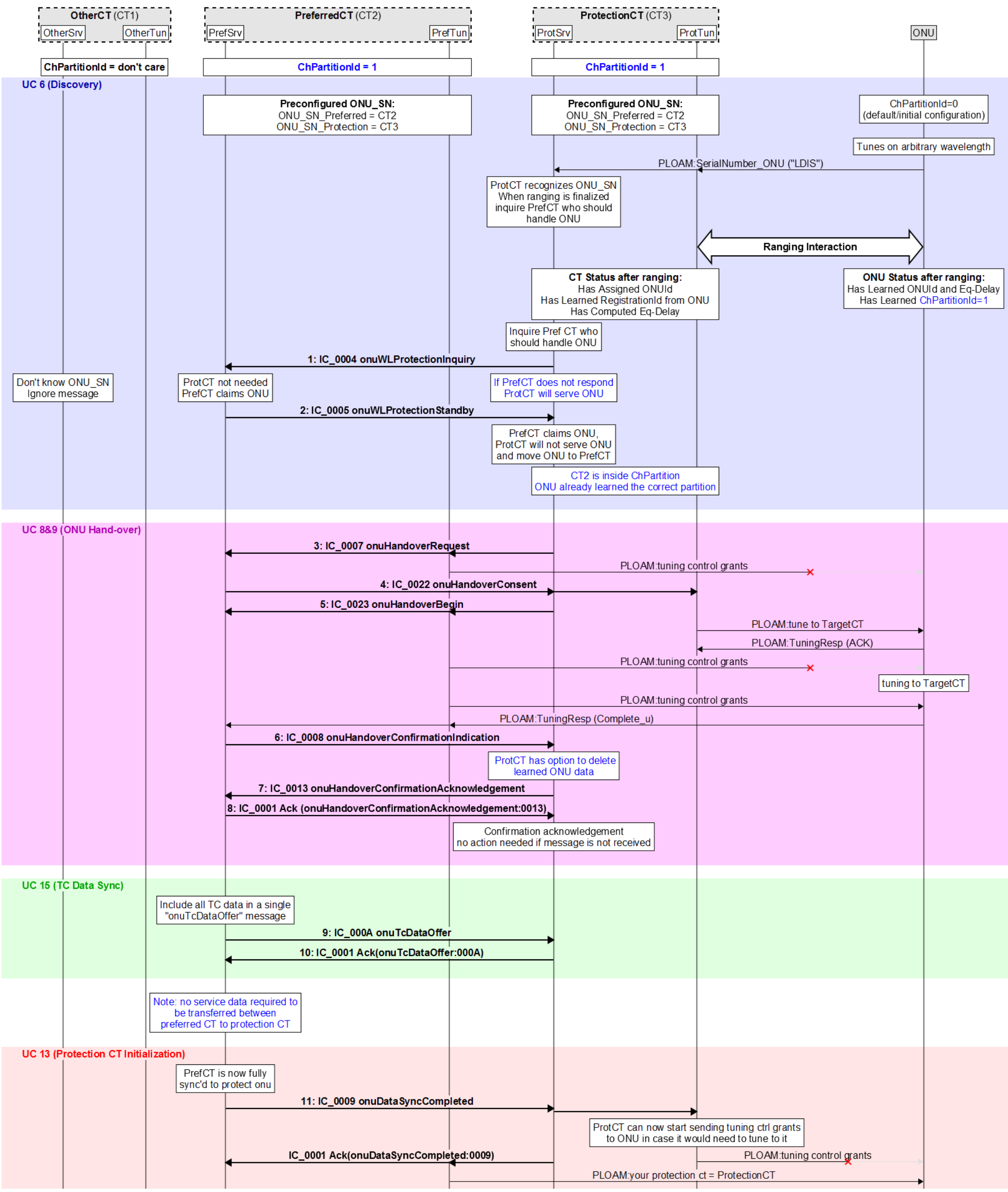


Figure 9-5 – ONU Discovery Resolution (Preferred CT serves ONU)

9.6 Scenario 6: ONU Discovery by Protect CT (Servicing by Protect CT)

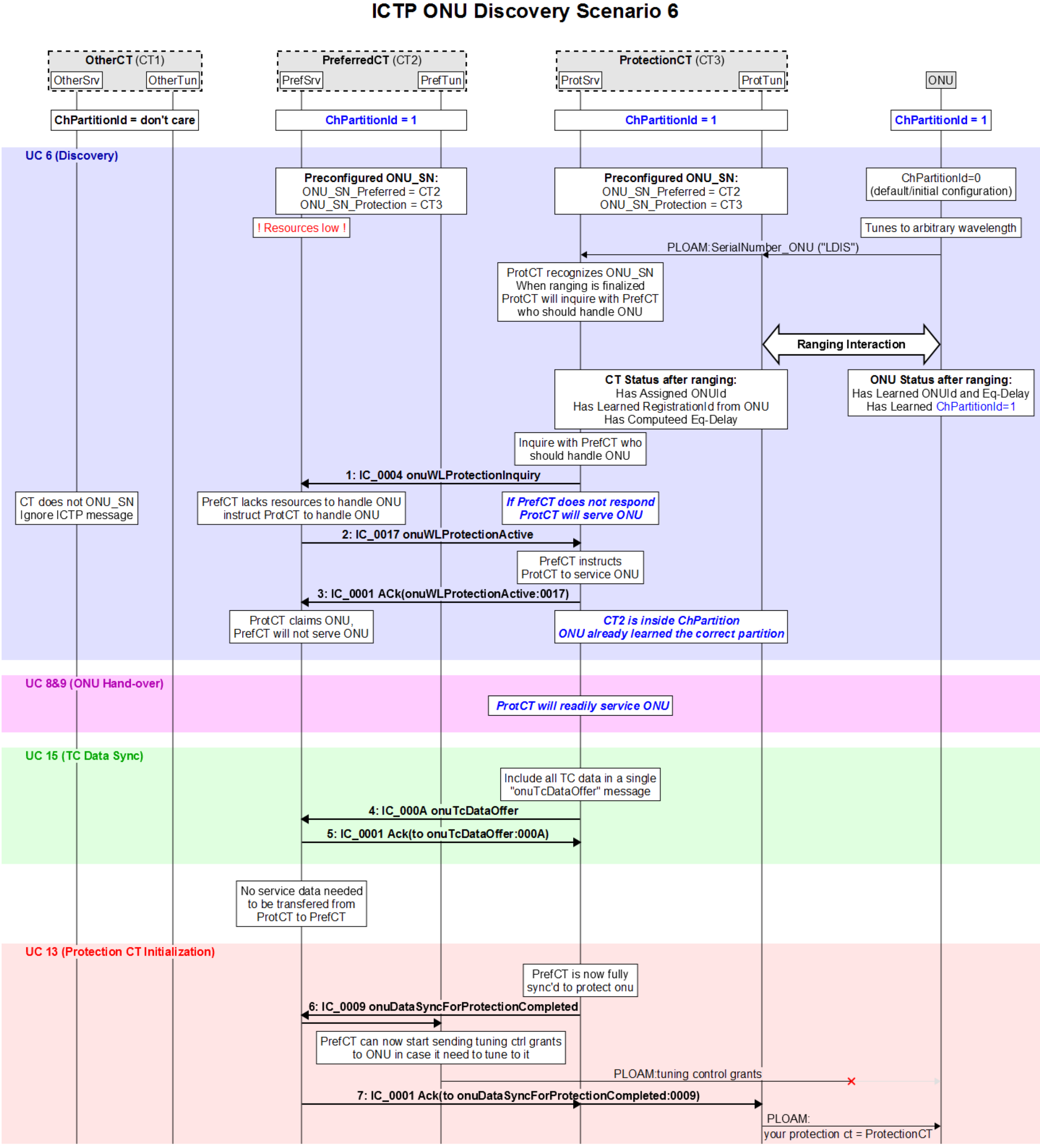
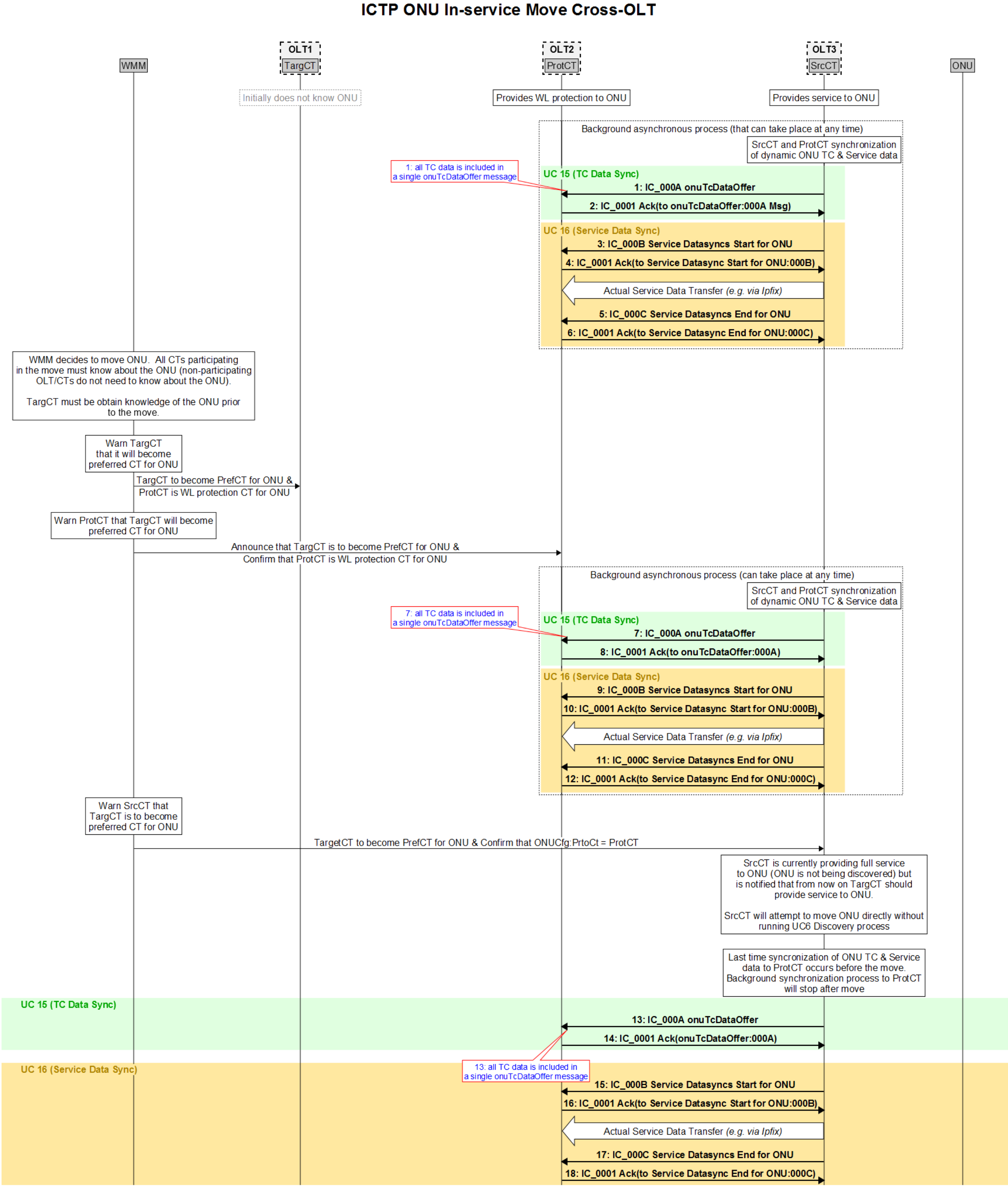


Figure 9-6 – ONU Discovery by Protect CT (Servicing by Preferred CT)

9.7 Scenario 7: In-service ONU move across CTs



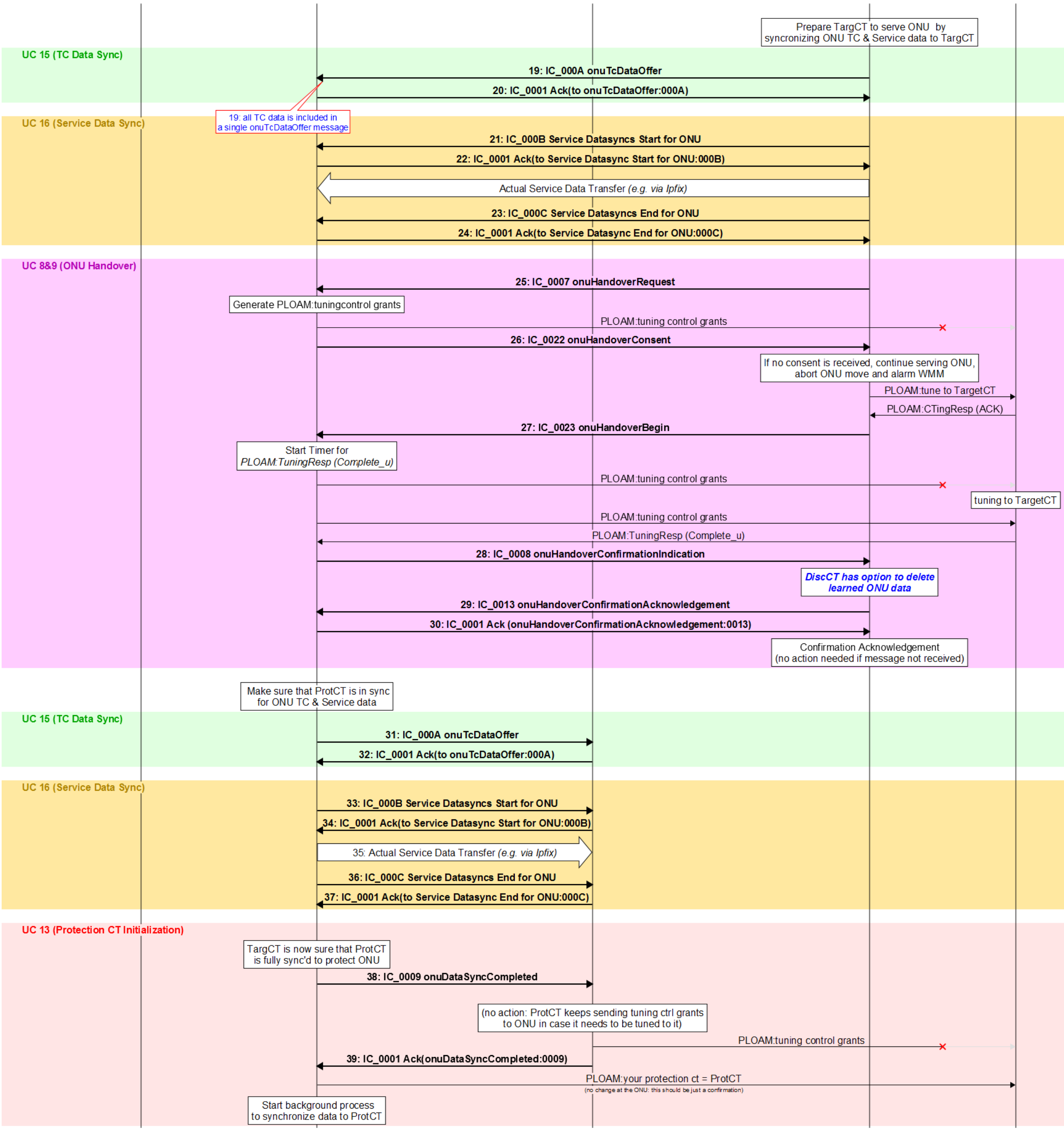


Figure 9-7 – In-service ONU move across CTs

Appendix C

This appendix has been deprecated.

10 Appendix D: ICTP Primitives Transaction examples

ICTP Primitive	Description	Transaction Exchange
Tune-In (ONU-ID, Source DS PON-ID, Source US PON-ID)	Commit indication of a transaction affirming a scheduled handover of an ONU identified by ONU-ID into the specified pair of downstream and upstream wavelength channels.	Figure 10-1 through Figure 10-2
Tune-Out (ONU-ID, Target DS PON-ID, Target US PON-ID)	Commit indication of a transaction affirming a scheduled handover of an ONU identified by ONU-ID out of the specified pair of downstream and upstream wavelength channels.	Figure 10-1 through Figure 10-2
ConfirmOut (ONU-ID)	Commit indication of a handover closure transaction associated with a receipt of unicast message from the original Target CT to the Source CT confirming successful handover of the ONU identified by ONU-ID.	Figure 10-3
ConfirmIn (ONU-ID)	Commit indication of a handover closure transaction associated with a receipt of unicast message from the original Source CT to the Target CT acknowledging the receipt of the ONU handover confirmation.	Figure 10-3

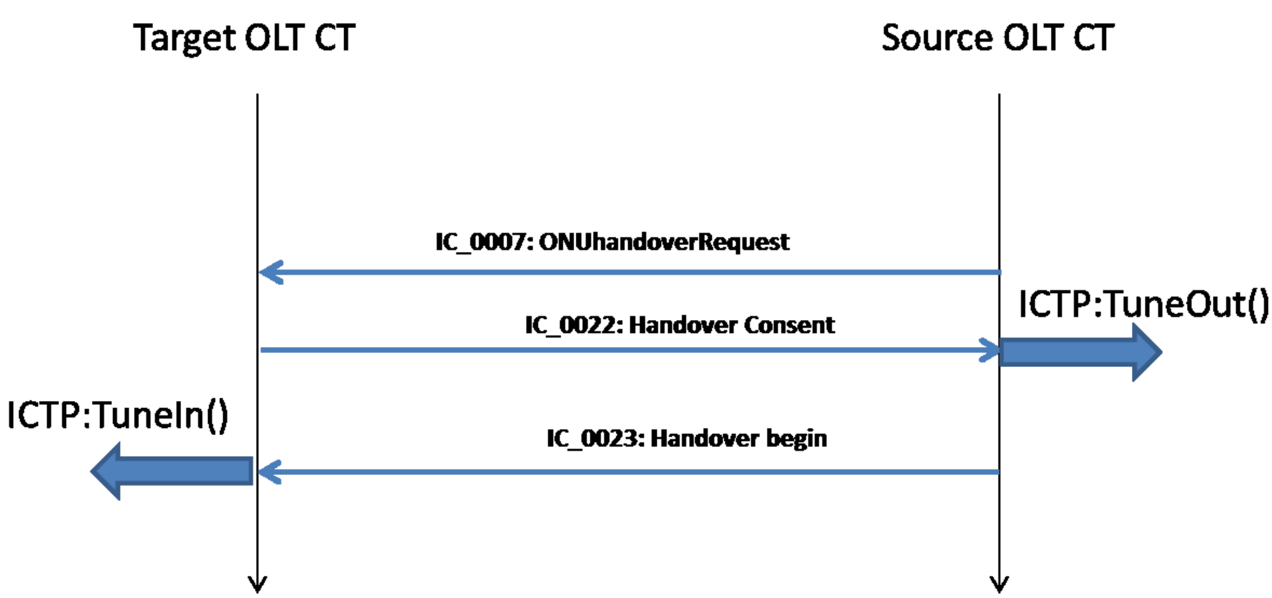


Figure 10-1 – Tune-In/Tune-Out Transaction (Source Initiated)

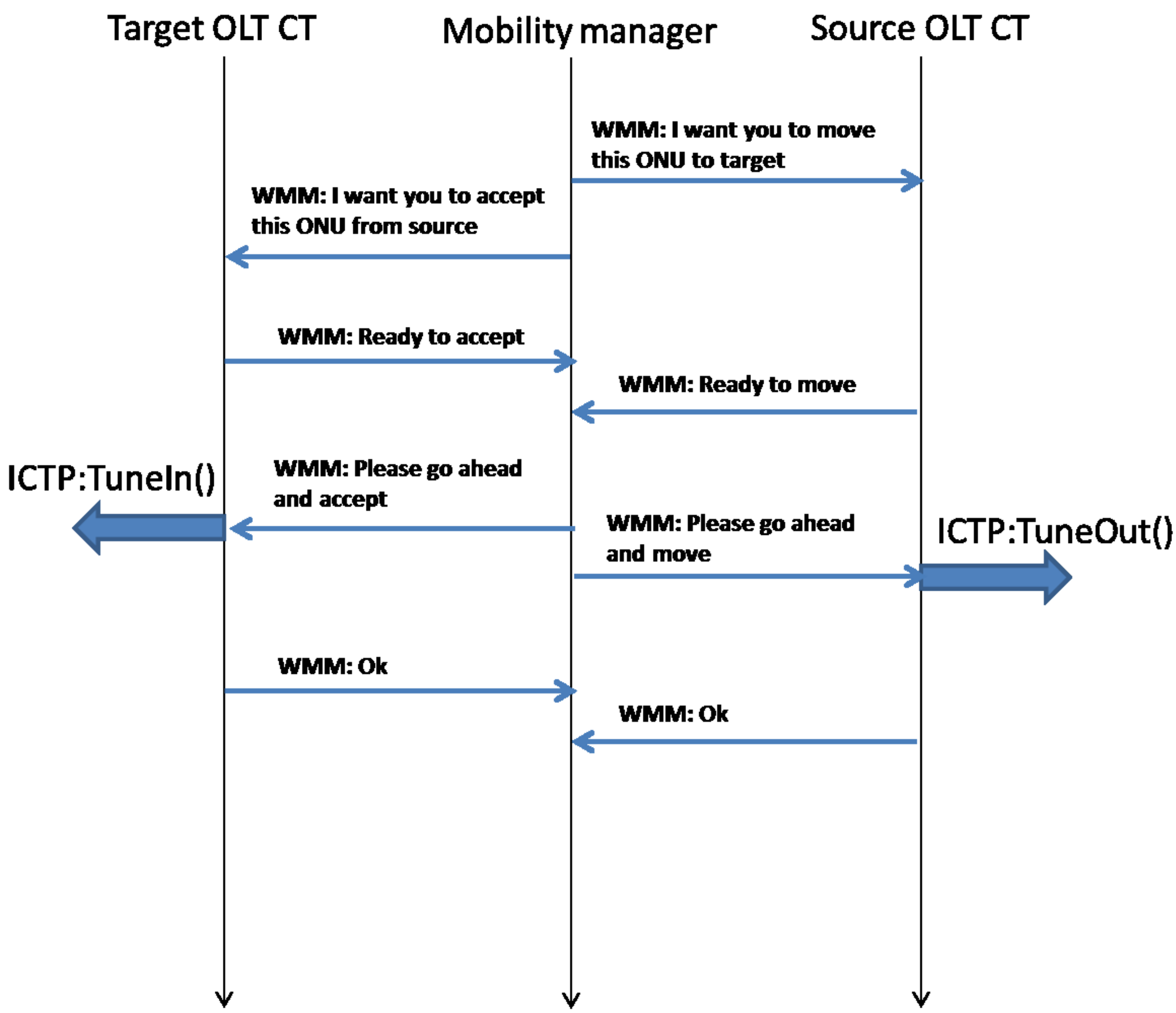


Figure 10-2 – Tune-In/Tune-Out Transaction (with WM Coordination Function)

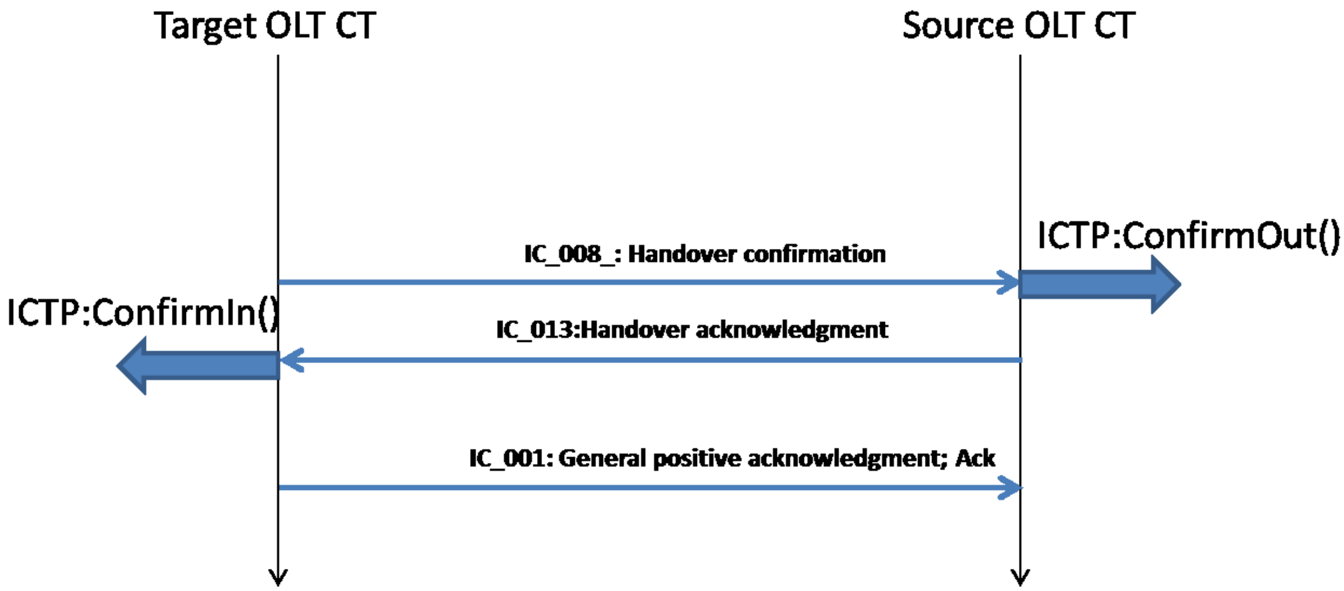


Figure 10-3 – Confirm-In/Out Transaction

11 Appendix E: IPFIX Templates

This appendix defines the IPFIX templates for NGPON2 bulk transfer.

11.1 IPFIX Proxy

Figure 12-1shows a functional view of IPFIX proxy. IPFIX exporter/collector and ICTP proxies can use the same address (and are differentiated by the TCP port being used). When an IPFIX packet is ready to share services data with another CT in its channel partition, the IPFIX exporter on the OLT will package the data and set the observation domain to the Source CT PON-ID. It will use the proxy configuration bindings table (an example is provided in Appendix C) to determine the IPFIX collector address. It will forward the packets to the IPFIX collector which will then extract the services information.

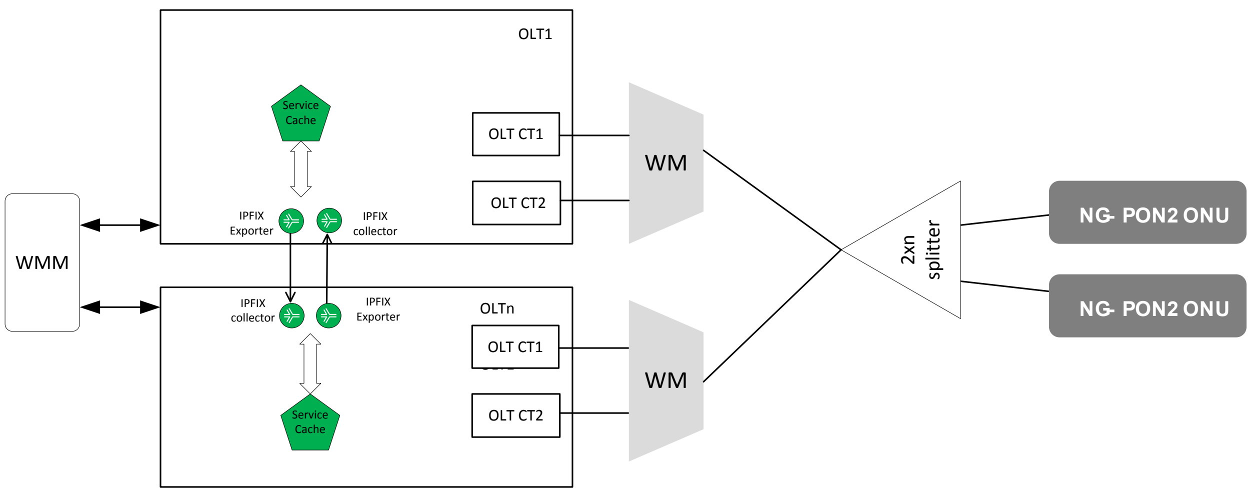


Figure 11-1 – Functional view of IPFIX Proxy (Exporter/Collector)

11.1.1 IPFIX Data Construct

The following services data can be shared across CTs (via IPFIX):

- dhcp leases
- pppoe session information
- Igmp data (e.g., channel, uptime, etc)
- ARP data
- OMCI ME instance (optional)

RFC 7011 defines the IPFIX format. Each IPFIX packet is comprised of a 32-bit observation domain describing the observation point where data was collected. It is recommended that the observation domain be set to the SRC CT PON-ID.


```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|       Version Number          |            Length             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                           Export Time                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                       Sequence Number                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Observation Domain ID                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 11-2 – IPFIX Message Header Format

Below is an example template set for services that could contain IANA assigned Information Element and BBF enterprise-specific Informational Elements.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          Set ID = 2           |          Length               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|      Template ID = 256        |         Field Count = N       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|1| Information Element id. 1.1 |        Field Length 1.1       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Enterprise Number  1.1                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0| Information Element id. 1.2 |        Field Length 1.2       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|             ...               |              ...              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|1| Information Element id. 1.N |        Field Length 1.N       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Enterprise Number  1.N                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|      Template ID = 257        |         Field Count = M       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0| Information Element id. 2.1 |        Field Length 2.1       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|1| Information Element id. 2.2 |        Field Length 2.2       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Enterprise Number  2.2                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|             ...               |              ...              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|1| Information Element id. 2.M |        Field Length 2.M       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Enterprise Number  2.M                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Padding (opt)                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 11-3 – Template Set Example

The following TLVs can be used for IPFIX Service TLVs:

Table 11-1 – NGPON2 Broadband Forum Informational Elements

Templates	ElementID	Name	Data Type	Description
Common IE to all IPFIX Services	1	NG2Sys ID	Unsigned-32	G.989.3 NG2Sys ID (20 bits)
Common IE to all IPFIX Services	2	SRC-CT-ID	Unsigned-32	The identifier of the individual CT issuing the ICTP message, represented by the TC layer PON-ID of the sender CT. For PON-ID definition, see Clause 6.1.5.3 of ITU-T G.989 [2] and Clause C.6.1.5.3 of G.9807.1 [6].
Common IE to all IPFIX Services	3	DST-CT-ID	Unsigned-32	The DST-CT-ID is the identifier of the individual CT receiving the ICTP message represented by the TC layer PON-ID of recipient CT. For PON-ID definition, see Clause 6.1.5.3 of ITU-T G.989 [2] and Clause C.6.1.5.3 of G.9807.1 [6].
Common IE to all IPFIX Services	4	ONU Identifier	Unsigned-16	G.989.3 Clause 6.1.5.6 defines the ONU-ID as a 10-bit identifier
Common IE to all IPFIX Services	5	ONU Serial Number	Unsigned-8	G.989.3 Clause 11.2.6.1 ONU Serial Number. It is comprised of: Vendor-ID (4 bytes) and the VSSN (4-byte unsigned integer)
Common IE to all IPFIX Services	6	XGEM Port-ID	Unsigned-16	G.989.3 Clause 6.1.5.8 defines the XGEM Port-ID as a 16-bit integer

Table 11-2 – Subscriber ARP, MACFF, DHCP Lease Informational Elements

Standard Bodies Forum	ElementID	Name	Data Type	Description	Reference
IANA	243	dot1qVlanId	unsigned16	The value of the 12-bit VLAN Identifier portion of the Tag Control Information field of an Ethernet frame. The structure and semantics within the Tag Control Information field are defined in [IEEE802.1Q	IEEE802.1Q
IANA	245	dot1qCustomerVlanId	unsigned16	The value represents the Customer VLAN identifier in the Customer field as described in IEEE802.1Q].	IEEE802.1Q
IANA	56	sourceMacAddress	macAddress	The IEEE 802 source MAC address field.	IEEE.802-3.2002.
IANA	8	sourceIPv4Address	ipv4Address	The IPv4 source address in the IP packet header.	See [RFC791] for the definition of the IPv4 source address field.
IANA	27	sourceIPv6Address	ipv6Address	The IPv6 source address in the IP packet header.	See [RFC2460] for the definition of the Source

Standard Bodies Forum	ElementID	Name	Data Type	Description	Reference
					Address field in the IPv6 header.
IANA	9	sourceIPv4PrefixLength	unsigned8	The number of contiguous bits that are relevant in the sourceIPv4Prefix Information Element.	
IANA	29	sourceIPv6PrefixLength	unsigned8	The number of contiguous bits that are relevant in the sourceIPv6Prefix Information Element.	See [RFC2460] for the definition of the Destination Address field in the IPv6 header.
BBF	7	IPv4AddressGateway	ipv4Address	The IPv4 Access Router Gateway address.	
BBF	8	IPv6AddressGatewayr	ipv6Address	The IPv6 Access Router Gateway address.	
BBF	9	DHCPv4 Server	ipv4Address	DHCPv4 Server Address	
BBF	10	DHCPv6 Server	ipv6Address	DHCPv6 Server Address	
BBF	11	Expiration	Unsigned32	DHCP Expiry (seconds)	
BBF	12	IS_Static	boolean	Is static address	

Table 11-3 – PPPoE Informational Elements

Standard Bodies Forum	ElementID	Name	Data Type	Description	Reference
BBF	13	PPPoE Session Identifier	unsigned16	RFC 2516 defines the session ID for Discovery packets. The	RFC 2516

Standard Bodies Forum	ElementID	Name	Data Type	Description	Reference
				value is fixed for a given PPP session. The Ethernet Source and Destination Address uniquely identify a PPPoE session.	
IANA	243	dot1qVlanId	unsigned16	The value of the 12-bit VLAN Identifier portion of the Tag Control Information field of an Ethernet frame. The structure and semantics within the Tag Control Information field are defined in [IEEE802.1Q	IEEE802.1Q
IANA	245	dot1qCustomerVlanId	unsigned16	The value represents the Customer VLAN identifier in the Customer field as described in IEEE802.1Q].	IEEE802.1Q
BBF	14	clientMacAddress	macAddress	Subscriber MAC address for this flow	RFC 2516
BBF	15	BRASMacAddress	macAddress	BRAS MAC address for this flow.	RFC 2516
BBF	16	sflag	Unsigned16	Session status flag bitmaps: bit 0: indicates that BNG sent a PPP_MAX_PAYLOAD tag Bit 1: indicates that the inactivity timer is pending Bit 2: indicates that the the IWF timer is pending Bit 3: indicates not to	See TR-101 and RFC 2516

Standard Bodies Forum	ElementID	Name	Data Type	Description	Reference
				send PADT on terminate	
BBF	17	birthtime	dateTimeSeconds	Birth Time for the PPPoE Session	

Table 11-4 – Multicast router Informational Elements

Standard Bodies Forum	ElementID	Name	Data Type	Description	Reference
IANA	243	dot1qVlanId	unsigned16	The value of the 12-bit VLAN Identifier portion of the Tag Control Information field of an Ethernet frame. The structure and semantics within the Tag Control Information field are defined in [IEEE802.1Q	IEEE802.1Q
IANA	245	dot1qCustomerVlanId	unsigned16	The value represents the Customer VLAN identifier in the Customer field as described in IEEE802.1Q].	IEEE802.1Q
BBF	18	queriersourceIPv4Address	ipv4Address	The Querier IPv4 source address	rfc5519
BBF	19	queriersourceIPv6Address	ipv6Address	The Querier IPv6 source address	rfc5519
BBF	20	QuerierUptime	dateTimeSeconds	The time since mgmdRouterInterfaceQuerier was last changed	rfc5519

Table 11-5 – Subscriber Multicast Channel Informational Elements

Standard Bodies Forum	ElementID	Name	Data Type	Description	Reference
IANA	8	sourceIPv4Address	ipv4Address	The IPv4 source address in the IP packet header.	See [RFC791] for the definition of the IPv4 source address field.
IANA	27	sourceIPv6Address	ipv6Address	The IPv6 source address in the IP packet header.	See [RFC2460] for the definition of the Source Address field in the IPv6 header.
BBF	21	HostreporterIPv4Address	ipv4Address	The host reporter IPv4 source address	rfc5519
BBF	22	HostreporterIPv6Address	ipv6Address	The host reporter IPv6 source address	rfc5519
BBF	23	GroupIPv4Address	ipv4Address	The multicast group address	rfc5519
BBF	24	GroupIPv6Address	ipv6Address	The multicast group address	rfc5519

Table 11-6 – ONU MIB Informational Elements

Standard Bodies Forum	ElementID	Name	Data Type	Description	Reference
BBF	25	G.988 EntityClass	Unsigned-16	G.988 Entity Class	bbf2016.700
BBF	26	G.988 EntityInstance	Unsigned-16	G.988 Entity Instance	bbf2016.700
BBF	27	G.988 Attribute Mask	Unsigned-16	G.988 Attribute Mask	bbf2016.700

Standard Bodies Forum	ElementID	Name	Data Type	Description	Reference
BBF	28	G.988 Attribute Values	octetarray	G.988 Attribute Value	bbf2016.700

Table 11-7 – ONU MIB Table Informational Elements

Standard Bodies Forum	ElementID	Name	Data Type	Description	Reference
BBF	29	G.988 EntityClass	Unsigned-16	G.988 Entity Class	bbf2016.700
BBF	30	G.988 EntityInstance	Unsigned-16	G.988 Entity Instance	bbf2016.700
BBF	31	G.988 Attribute Mask	Unsigned-16	G.988 Attribute Mask	bbf2016.700
BBF	32	G.988 Array of Table Rows	octetarray	G.988 Array of Table Rows	bbf2016.700

End of Broadband Forum Technical Report TR-352