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Fifth Generation Fixed Network (F5G); Specification for PON based Industrial Network

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Foreword

This Group Specification (GS) has been produced by ETSI Industry Specification Group (ISG) Fifth Generation Fixed Network (F5G).

Modal verbs terminology

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1 Scope

The present document specifies the network architecture, functional requirements, performance requirements, management and provisioning specifications for PON based industrial networks deployed in typical industrial application scenarios, and satisfies the requirements from industrial services.

2 References

2.1 Normative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

Referenced documents which are not found to be publicly available in the expected location might be found in the ETSI docbox.

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The following referenced documents are necessary for the application of the present document.

[1] ETSI GS F5G 013: "Fifth Generation Fixed Network (F5G); F5G Technology Landscape Release 2".

[2] ETSI GS F5G 024: "Fifth Generation Fixed Network (F5G); F5G Advanced Network Architecture Release 3".

[3] IEC 61158: "Industrial communication networks - Fieldbus specifications".

[4] IEEE 802.3as™-2006: "IEEE Standard for Information technology -- Telecommunications and information exchange between systems -- Local and metropolitan area networks -- Specific requirements Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications".

[5] IEEE 802.1Q™-2018: "IEEE Standard for Local and Metropolitan Area Networks -- Bridges and Bridged Networks".

[6] IEEE 802.1ad™-2005: "IEEE Standard for Local and Metropolitan Area Networks -- Virtual Bridged Local Area Networks -- Amendment 4: Provider Bridges".

[7] Recommendation ITU-T Y.1291 (2004): "An architectural framework for support of Quality of Service in packet networks".

[8] IEEE 802.1D™-2004: "IEEE Standard for Local and metropolitan area networks: Media Access Control (MAC) Bridges".

[9] IETF RFC 7348: "Virtual eXtensible Local Area Network (VXLAN): A Framework for Overlaying Virtualized Layer 2 Networks over Layer 3 Networks".

[10] IEEE 802.3ad™-2000: "IEEE Standard for Information Technology -- Local and Metropolitan Area Networks -- Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications-Aggregation of Multiple Link Segments".

[11] Recommendation ITU-T G.9807.1 Amendment 2 (2020): "10-Gigabit-capable symmetric passive optical network (XGS-PON)".

[12] Recommendation ITU-T G.987.1 (2016): "10-Gigabit-capable passive optical networks (XG-PON): General requirements".

[13] IEEE 802.1Qci™-2017: "IEEE Standard for Local and metropolitan area networks -- Bridges and Bridged Networks -- Amendment 28: Per-Stream Filtering and Policing".

[14] Recommendation ITU-T G.983.5: "A broadband optical access system with enhanced survivability".

[15] IEEE 802.3af™-2003: "IEEE Standard for Information Technology -- Local and Metropolitan Area Networks -- Specific Requirements -- Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications -- Data Terminal Equipment (DTE) Power Via Media Dependent Interface (MDI)".

[16] IEEE 802.3at™-2009: "IEEE Standard for Information technology -- Local and metropolitan area networks -- Specific requirements -- Part 3: CSMA/CD Access Method and Physical Layer Specifications Amendment 3: Data Terminal Equipment (DTE) Power via the Media Dependent Interface (MDI) Enhancements".

[17] IEEE 802.3bt™-2018 IEEE: "Standard for Ethernet Amendment 2: Physical Layer and Management Parameters for Power over Ethernet over 4 pairs".

[18] IEC 60529: "Degrees of protection provided by enclosures (IP Code)".

[19] IEC 61000-4-2:2008: "Electromagnetic compatibility (EMC) - Part 4-2: Testing and measurement techniques - Electrostatic discharge immunity test".

[20] Recommendation ITU-T G.988: "ONU management and control interface (OMCI) specification".

[21] IETF RFC 6241: "Network Configuration Protocol (NETCONF)".

[22] ISO/IEC 20922:2016: "Information technology — Message Queuing Telemetry Transport (MQTT) v3.1.1".

[23] IEEE 802.3™-2018: "IEEE Standard for Ethernet".

[24] IETF RFC 4789 (2006): "Simple network management protocol (SNMP) over IEEE 802 networks".

[25] IEEE 802.1X™-2020: "IEEE Standard for Local and Metropolitan Area Networks -- Port-Based Network Access Control".

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

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The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ETSI GR F5G 001: "Fifth Generation Fixed Network (F5G); F5G Generation Definition Release #1".

[i.2] ETSI GR F5G 007 (V1.1.1): "Fifth Generation Fixed Network (F5G); F5G Industrial PON".

[i.3] ETSI GR F5G 008 (V1.1.1): "Fifth Generation Fixed Network (F5G); F5G Use Cases Release #2".

[i.4] IETF RFC 8040: "RESTCONF Protocol".

[i.5] Recommendation ITU-T G.Sup51 (06/17): "Passive optical network protection considerations".

[i.6] ETSI GR F5G 021: "Fifth Generation Fixed Network (F5G); F5G Advanced Generation Definition".

[i.7] IETF RFC 4241: "A Model of IPv6/IPv4 Dual Stack Internet Access Service".

[i.8] IETF RFC 4213: "Basic Transition Mechanisms for IPv6 Hosts and Routers".

[i.9] IETF RFC 8305: "Happy Eyeballs Version 2: Better Connectivity Using Concurrency".

[i.10] IETF RFC 8200: "Internet Protocol, Version 6 (IPv6) Specification".

[i.11] IETF RFC 2474: "Definition of the Differentiated Services Field (DS Field) in the IPv4 and IPv6 Headers".

[i.12] IETF RFC 9099: "Operational Security Considerations for IPv6 Networks".

[i.13] Recommendation ITU-T G.987.3 (2020): "10-Gigabit-capable passive optical networks (XG-PON): Transmission convergence (TC) layer specification".

[i.14] Recommendation ITU-T G.9804.2 (2021): "Higher speed passive optical networks - Common transmission convergence layer specification".

[i.15] Recommendation ITU-T G.Sup71: "Optical line termination capabilities for supporting cooperative dynamic bandwidth assignment".

[i.16] Recommendation ITU-T G.984.3 (2014): "Gigabit-capable passive optical networks (G-PON): Transmission convergence layer specification".

[i.17] Recommendation ITU-T G.984.1 (2008): "Gigabit-capable passive optical networks (GPON): General characteristics".

[i.18] Recommendation ITU-T G.9804.1 (2019): "Higher speed passive optical networks – Requirements".

[i.19] IEEE 802.1Qbv™-2015: "IEEE Standard for Local and metropolitan area networks -- Bridges and Bridged Networks -- Amendment 25: Enhancements for Scheduled Traffic".

[i.20] IEEE 802.1Qbu™-2016: "IEEE Standard for Local and metropolitan area networks -- Bridges and Bridged Networks -- Amendment 26: Frame Preemption".

[i.21] Recommendation ITU-T E.419 (2006): "Business oriented Key Performance Indicators for management of networks and services".

[i.22] ETSI EN 300 019-1-4: "Environmental Engineering (EE); Environmental conditions and environmental tests for telecommunications equipment; Part 1-4: Classification of environmental conditions; Stationary use at non-weather protected locations".

[i.23] ETSI EN 300 019-2-4: "Environmental Engineering (EE); Environmental conditions and environmental tests for telecommunications equipment; Part 2-4: Specification of environmental tests; Stationary use at non-weather protected locations".

3 Definition of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, the following terms apply:

deterministic networking: network feature primarily in a best-effort packet network, in which the deterministic quality of service is applied to flows designated as being critical to a real-time application

field data network: network transporting factory intra-plant industrial data

NOTE: The industrial PON-based network serves as a connection and convergence network for the machines within the factory because the product line data is carried over the industrial PON-based network.

industrial environment adaptation: capability of a device to adapt to the industrial environments while maintaining an acceptable level of service

industrial protocol adaptation: capability of a device to adapt to the industrial scenarios to interpreting and/or converting a range of industrial communication protocols

network resilience: capability of a network to protect against and maintain an acceptable level of service in the presence of network failure(s)

PON slice: resource allocation and isolation mechanism in Passive Optical Networks (PON), which divides the physical PON network into multiple logically independent networks

NOTE: Each slice is configured to support the specific Service Level Agreements (SLAs), ensuring that various types of traffic are appropriately handled and isolated on a shared physical infrastructure, guaranteeing that the quality of critical applications and services is not affected.

3.2 Symbols

Void.

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

10GE	10 Gbit/s Ethernet
10G-EPON	10 Gbit/s Ethernet Passive Optical Network
40GE	40 Gbit/s Ethernet
50G-PON	50 Gbit/s Passive Optical Network
100GE	100 Gbit/s Ethernet
ACL	Access Control List
AI	Artificial Intelligence
AN	Access Network
ARP	Address Resolution Protocol
BNG	Broadband Network Gateway
CAN	Controller Area Network
CLI	Command-Line Interface
CO DBA	Cooperative Dynamic Bandwidth Allocation
CPU	Central Processing Unit
CPN	Customer Premises Network
CVBS	Composite Video Baseband Signal
DA	Destination Address
DBA	Dynamic Bandwidth Allocation
DHCP	Dynamic Host Configuration Protocol
DHCPv6	Dynamic Host Configuration Protocol for IPv6
DoS	Denial of Service
DSCP	Differentiated Services Code Point
EMC	Electromagnetic Compatibility
ERP	Enterprise Resource Planning
EMS	Element Management System
EPON	Ethernet Passive Optical Network
FE	Fast Ethernet
FEC	Forward Error Correction
FP16	16-bit Floating Point
FP32	32-bit Floating Point
GE	Gigabit Ethernet
GEM	GPON Encapsulation Method
GFLOPS	Giga Floating Point Operations Per Second
GPON	Gigabit Passive Optical Network
GPU	Graphics Processing Unit
GTC	GPON Transmission Convergence
HART	Highway Addressable Remote Transducer Protocol

ID	Identifier
IGMP	Internet Group Management Protocol
IPv6	Internet Protocol version 6
IP	Internet Protocol
IPG	Inter-Packet Gap
ITU-T	International Telecommunication Union - Telecommunication Standardization Sector
LAND	Local Area Network Denial Attack
MAC	Media Access Control
MB	Megabyte
MES	Manufacturing Execution System
MLQ	Multicast Listener Query
MQTT	Message Queuing Telemetry Transport
NPU	Neural Processing Unit
NETCONF	Network Configuration Protocol
NNI	Network-to-Network Interface
OLT	Optical Line Terminal
OMCI	Optical Network Terminal Management and Control Interface
ME	Managed Entity
ONU	Optical Network Unit
ONU-ID	Optical Network Unit Identifier
OSI	Open Systems Interconnection
PLOAM	Physical Layer Operations, Administration, and Maintenance
PLC	Power Line Communication
PoE	Power over Ethernet
PPPoE	Point-to-Point Protocol over Ethernet
PRI	Primary Rate Interface
QoS	Quality of Service
RA	Router Advertisement
RESTCONF	RESTful Configuration Protocol
SA	Source Address
SAP	Service Access Point
SLA	Service-Level Agreement
SDN	Software-Defined Networking
SNI	Server Name Indication
SNMP	Simple Network Management Protocol
SPP	Service Processing Point
SSD	Solid State Drive
SYN	Synchronization
TCP	Transmission Control Protocol
T-CONT	Transmission Container
TFLOPS	Tera Floating Point Operations Per Second
TOS	Type of Service
TSN	Time-Sensitive Networking
UDP	User Datagram Protocol
UCL	User Control List
UNI	User-Network Interface
VLAN	Virtual Local Area Network
VNI	VxLAN Network Identifier
VTEP	VxLAN Tunnel End Point
VxLAN	Virtual eXtensible LAN
Wi-Fi™	Wireless Fidelity
XGEM	10 Gigabit GPON Encapsulation Method
XG-PON	10-Gigabit-capable Passive Optical Network
XGS-PON	10-Gigabit-capable Symmetric Passive Optical Network
XGTC	10 Gigabit GPON Transmission Convergence

4 Overview

Industrial networks are designed to connect and control devices, systems, machines, and other assets within the industrial environment. With digital transformation, remote control machinery and sensors are deployed to automate production, monitoring, and management. Industrial networks are incorporate facilities related to the Industrial business including R&D centres, warehouses, administrative offices and customer service branches.

Industrial PON, is inheriting a mature PON technology from the residential access network, and enhancing it to include functions required by the industrial customers. Industrial PON shall support high quality connectivity for communication between sensors, devices, machines, and people within the industrial parks.

NOTE: For more detailed description of PON based industrial network see ETSI GR F5G 001 [i.1], ETSI GS F5G 013 [1], ETSI GR F5G 007 [i.2] and ETSI GR F5G 021 [i.6].

The present document describes the typical industrial PON deployment scenarios, encompassing the architecture, the key industrial functions and the interfaces of the industrial PON system. The PON based industrial network architecture includes the management system, the OLTs, and ONUs used in industrial scenarios. PON based industrial network shall comply with the industrial environmental recommendations.

In the present document, the network architecture, the functional requirements, the performance requirements, the management and provisioning specifications for PON based industrial networks are specified.

5 Industrial scenarios and requirements

5.1 Overview

There are three deployment scenarios for PON based industrial networks, as described in ETSI GR F5G 007 [i.2] (Industrial PON) and in ETSI GR F5G 008 [i.3] (Use Cases Release #2), namely:

1) The field data network which is primarily in the industrial environment.

2) The office network including sales, marketing, finance and managerial staff areas.

3) The surveillance network including internal and external video surveillance and sensors.

PON based industrial networks shall support the above three sub-networks within a single network infrastructure. Network slicing is essential for the isolation of these sub-networks.

Smart network monitoring and management functions based on NETCONF/YANG and telemetry technology are needed for smart operation and rapid service configuration in the PON based industrial networks.

5.2 Field Data Network

The primary application in PON based industrial networks is transport factory intra-plant industrial services. PON serves as a connection and convergence network for the machines within the factory.

There are several industrial field level interfaces and protocols defined in the IEC 61158 series [3]. Therefore, the ONUs in the industrial network need to be equipped with the corresponding physical interfaces and the built-in protocol-related functions, or provide connectivity to existing industrial gateways, to support the communications between the Power Line Communication (PLC), other industrial gateways, and production management systems. Deterministic network transmission and high service availability are required for these field data network scenarios. The PON based industrial network integrated with deterministic networking functions, shall support the configuration of bounded transmission times, and various network protection schemes for the differential network resilience scenarios.

Machine vision applications are being deployed in the production line, which require high bandwidth. High-resolution images/video cameras are installed on the production lines to capture high-definition images or video streams for further AI-based analysis and recognition, which quickly locate malfunctioning production and defective products. These applications require very large upstream network bandwidth, with traffic flows in the order of tens of gigabits per production line. XGS-PON [11] systems support symmetric 10 Gbit/s bandwidth, which satisfy these bandwidth needs, and in future 50G-PON [i.18] will provide up to symmetric 50 Gbit/s bandwidth to further enhance the network capabilities.

5.3 Office Network

PON based industrial network should support the transport of traffic from the office area of a factory for internet/intranet surfing, telephony and Wi-Fi® APs traffic. The applications and services in this scenario are similar to the majority of services carried by PON system in the public access network.

The PON system need to provide Ethernet physical interfaces, and network functions for internet/intranet surfing similar to the ONUs in the residential and business scenarios, and also support configuration and management for rapid service configurations. XGS-PON [11] with 10 Gbit/s bandwidth satisfies the large bandwidth requirements in office network.

5.4 Surveillance Network

Another important industrial network scenarios are the video surveillance networks and the environment sensing networks around the factory.

PON ONUs shall support Power over Ethernet (PoE) functionality to provide both network connectivity and electricity supply for remote video monitoring cameras. Other capabilities like Wi-Fi® Access Point (AP), small cellular cells may also be embedded to the industrial PON ONU to realize the data transmission for several kinds of sensors.

6 Industrial PON system architecture

The industrial PON system is part of the end-to-end F5G network architecture defined in ETSI GS F5G 024 [2], which includes both the Customer Premises Network (CPN) and the Access Network (AN) segments.

NOTE 1: The aggregation network for Industrial PON scenario is for further study.

The industrial PON system provides service connectivity for the users and devices in the industrial area. The most often deployed protocols used in the industrial scenarios shall be supported by the industrial PON system. The industrial ONUs are ONUs specifically used in PON based industrial networks. These ONUs support industrial interfaces/protocols and industrial scenario specific functions. They perform the Service Access Point (SAP) functions and the OLTs performs the Service Processing Point (SPP) functions.

As the industrial PON system is the industrial factory intranet, the factory intranet may be self-contained depending on the network scale, deployment scenario, and security considerations of the customers. The OLT uplink may additionally support aggregation edge functions. The PON based industrial network may be connected to higher level network elements or may operate stand-alone.

NOTE 2: Aggregation edge functions are traditionally Broadband Network Gateway (BNG) type functions and are for further study.

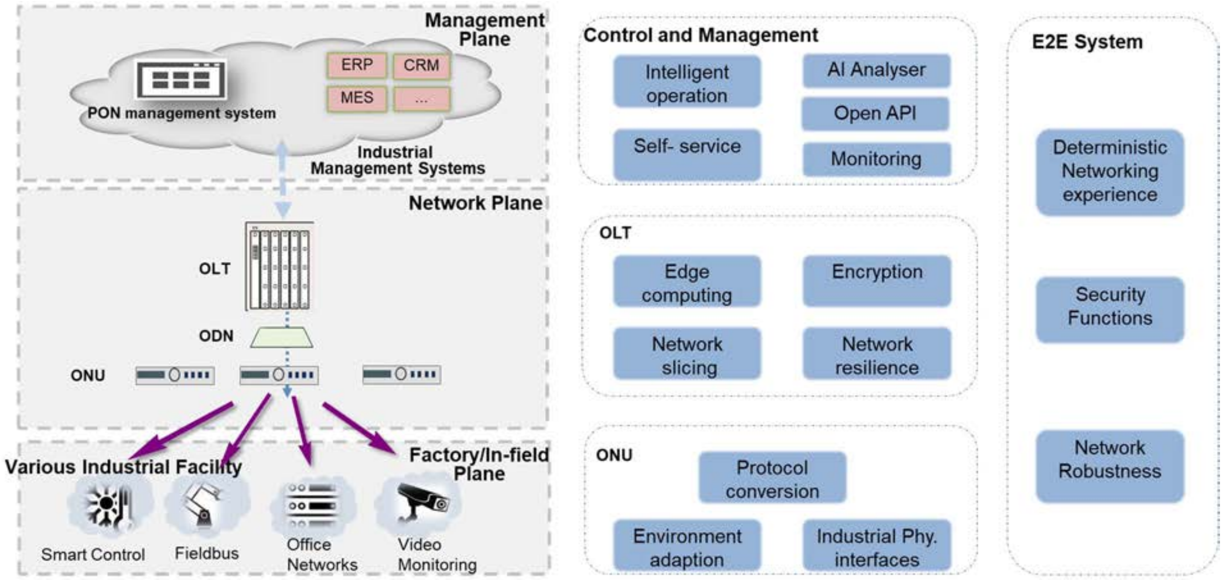

Figure 1: PON based industrial network architecture overview

Figure 1 shows that the network planes that provides the communication between the management and factory/In-field plane.

The Industrial PON system has enhanced capabilities including network slicing, deterministic networking, network resilience, encryption and edge computing to support the industrial services and applications. The OLTs shall support an integrated open compute platform (which consists of general-purpose hardware and operating systems, and can support third-party developed software) that realizes essential edge computing functions. The compute platform shall support the local data processing in the factory, and shall cooperate with higher layer cloud computing functions to provide dedicated cloud and IT services for industrial customers.

The industrial ONUs shall provide the interconnection capability with machines and shall support the various industrial physical interfaces (CAN, RS-232, etc.) and protocol conversion capabilities. Various factory facilities, office and surveillance services shall be supported by the PON based industrial network and form a unified factory network. Certain types of industrial ONUs shall support the operation in harsh environments.

The control and management system for the PON based industrial network, shall support both conventional and SDN-based intelligent operation and management. The industrial PON control and management system shall provide open APIs, to other existing manufacturing management systems within the factory, which lead to IT and OT convergence.

EXAMPLE 1: Conventional control and management system use CLI, SNMP, etc. while SDN-based intelligent control and management system use NETCONF/YANG based management schemes.

EXAMPLE 2: Open APIs include NETCONF [21], RESTCONF [i.4] and MQTT [22].

The interface between the OLT and industrial the ONUs, shall support XG-PON or XGS-PON [11], and may support 50G-PON [i.18]. The interface between the OLT and industrial management [12] systems shall support a minimum of 10G Ethernet [23].

Network resilience is provided by various network protection schemes, this architecture may be deployed with a single or dual links between the industrial OLT and the industrial ONU depends on the different protection schemes.

7 Key function specifications

7.1 Basic functions

7.1.1 MAC address learning & Layer 2 forwarding

The OLT and the ONU shall support dynamic MAC addresses learning, the number of ONU UNI MAC addresses learned limitations may be configured by either the local or the management schemes.

The OLT and ONU MAC address aging shall be configurable.
The OLT and ONU shall support layer 2 forwarding for jumbo frame defined in [4] for both upstream and downstream directions.

NOTE: Jumbo frame size is considered to be between 1 500 bytes and 9 000 bytes. Jumbo frames exceeding 1 518 bytes are not in the scope of deterministic networking performance requirements in clause 8 of the present document.

7.1.2 Layer 2 isolation

The OLT shall support layer 2 isolation between each ONU connected, the isolation is enabled by default, and may be disabled by either the local or the remote management schemes.

The ONU shall support layer 2 isolation between each UNI within the ONU, the isolation is enabled by default, and may be disabled by either the local or the remote management schemes.

7.1.3 Frame filtering

The OLT shall support Ethernet frame filtering based on the source MAC address, the destination MAC address, the source IP address, the destination IP address and either the TCP port ID or the UDP port ID.

The ONU shall support Ethernet frame filtering based on the physical ONU UNI port, the Ethernet frame encapsulation protocols, the source MAC address, the destination MAC address, the Ethernet priority identification (P-bit).

The ONU may optionally support Ethernet frame filtering based on the source IP address, the destination IP address, and either the TCP port ID or UDP port ID.

The OLT and the ONU shall support filtering of specific frames including DHCP OFFER/ACK/NAK frames, IP multicast stream and IGMP query frame based on configuration.

The OLT and ONU shall support filtering of specific frames with protocols defined in the IEC 61158 series [3] based on configuration.

The OLT and ONU shall support frame suppression with configurable bandwidth limitation for layer 2 multicast/broadcast frames.

7.1.4 Loop detection

The OLT shall support a loop detection functions between different ONU UNI ports within a single OLT PON port, and different ONU ports between different OLT PON ports.

The OLT shall disable the corresponding ONU ports if a loop is detected, and shall send an alarm indication to the PON management system.

The ONU shall support loop detection between UNI ports, and shall disable the corresponding UNI ports if a loop is detected, and shall send alarm indication to the PON management system via the OLT.

7.1.5 VLAN functions

The OLT and the ONU shall support VLAN functions as defined in [5]. Different VLAN IDs may be configured based on the OLT PON port, and the ONU UNI ports.

The OLT shall support VLAN stacking as defined in [6].

If the OLT supports different sub-networks with different services within the PON based industrial network, each sub-network shall be assigned different VLAN ID values, in order to realize service isolation among the sub-networks.

7.1.6 OLT NNI link aggregation

The OLT shall support link aggregation as defined in [6], if it is deployed with multiple Ethernet ports on the NNI side.

7.1.7 Multi-service QoS mechanism

7.1.7.1 General requirement

The PON based industrial network shall support QoS mechanisms as defined in [7], including traffic classification, marking, queuing and scheduling, traffic policing, congestion avoidance and buffer management. It may support traffic shaping.

7.1.7.2 Parameter configuration for Service-Level Agreement (SLA)

The PON based industrial network shall support Service-Level Agreement (SLA) configuration based on the user-level or the service-level. The SLA parameters includes fixed bandwidth, assured bandwidth, maximum bandwidth.

The SLA configuration may be setup independently for the upstream and the downstream directions.

7.1.7.3 Priority tagging

The PON based industrial network shall support priority tagging for the user data packet in the upstream direction, with the user priority tags as defined in [6], the IP layer priority tags including IP TOS (IPv4), Traffic Class (IPv6) and DSCP.

The industrial ONU's priority tagging function may be configured by either the local or the remote management system.

7.1.7.4 Flow classification

The OLT shall support flow classification based on packet frame parameters listed below.

The ONU shall support flow classification based on the physical UNI ports and the packet frame parameters listed below.

The packet frame parameters shall include the GEM port number, the destination MAC address (MAC DA), the source MAC address (MAC SA), the VLAN ID, the User Priority defined in [5], the EtherTypes, the destination IPv4/v6 address, the source IPv4/v6 address, the destination IPv6 address prefix, the source IPv6 address prefix, the IP protocol version, the IP protocol types, the IP priority (IPv4 TOS, IPv6 Traffic Class, DSCP).

7.2 Optional IP/Ethernet functions

7.2.1 IPv6 functions

The Industrial PON OLT and the ONUs may optionally support IPv6 functions, including IPv4/IPv6 dual stacking [i.7], [i.8], [i.9], IPv6-based traffic classification [i.10], priority marking [i.11], and security related functions [i.12]. For the IPv4/IPv6 dual stacking, the OLT and the ONU should support IPv4 and IPv6 dual protocol stack simultaneously, and should support configuration enabling/disabling of the IPv4 and IPv6 protocol stacks.

For IPv6-based traffic classification, the OLT and the ONU should recognize IPv6 packets and should support setting up different Ethernet priorities for IPv4 and IPv6 packets to differentiate between IPv4 and IPv6 services. The OLT and the ONUs should support classifying upstream traffic flows based on various combinations of parameters including the IPv6 source address, the IPv6 destination address, the TCP/UDP source port, the TCP/UDP destination port, the IPv6 Traffic Class field, and the IPv6 Flow Label field.

For priority marking, the OLT and the ONU should support mapping the IPv6 flow classification to IPv6 service priorities for the upstream flows. They should support the use of the IEEE 802.1Q [5] PRI field as a priority identifier and may optionally support using the DSCP field of the IPv6 Traffic Class field as a priority identifier. The OLT may optionally support modifying the priority field (IPv6 Traffic Class) of the upstream and downstream IPv6 flows.

For security related functions, the followings should be supported:

- IPv6 Packet Filtering.

  The OLT should support filtering the upstream and downstream data frames based on various combinations of parameters including the IPv6 source address, the IPv6 destination address, the TCP/UDP source port, the TCP/UDP destination port.

  The OLT should support filtering the upstream Dynamic Host Configuration Protocol for IPv6 (DHCPv6) the Advertise, the Reply, the Reconfigure and the Relay-reply messages from the user ports.

  The OLT should support filtering the upstream Multicast Listener Query (MLQ) messages and the IPv6 multicast data packets from the user ports.

  The OLT should support filtering the downstream Multicast Listener Report (MLR) messages from the network side.

- Denial of Service (DoS) Attack Prevention.

  The OLT should prevent DoS attacks including the Ping of Death, the Synchronization packets Flood (SYN Flood), the Local Area Network Denial attack (LAND), and IP spoofing that target the device, in order to prevent excessive CPU usage.

- The IPv6 Address and Prefix Anti-Spoofing.

  The OLT should prevent IPv6 address spoofing and should discard frames with unallocated IPv6 addresses.

  The OLT IP anti-spoofing mapping table should support aging, where the aging time of the table entries should be obtained from the lifetime information in the Router Advertisement (RA) messages and the DHCPv6 messages. It should also support static configuration through the management interface.

7.2.2 VxLAN functions

VxLAN technology encapsulates Layer 2 packets using Layer 4 protocol, and the encapsulated data packets are transmitted over the UDP transport layer.

Industrial PON devices should support the VxLAN packet encapsulation formats specified in [9], including IPv4 and IPv6 packet formats.

Specific requirements for the OLT device functionality include:

- The OLT should support VxLAN functionality and the VxLAN Tunnel End Point (VTEP) starting point should be on the OLT NNI.
- The OLT VxLAN tunnel endpoints should support enabling or disabling of the specific VxLAN Network Identifier (VNI) through configuration.
- The OLT should support isolation between VxLAN tunnels.
- In scenarios where VxLAN and VLAN services coexist on the same upstream port, the OLT should support the coexistence of VxLAN and traditional VLAN services without affecting each other.
- When enabling VxLAN, the OLT should support forwarding or discarding of ARP, PPPoE protocol packets, DHCP, and other packets for each VxLAN tunnels.

The OLT should support real-time performance monitoring for each VxLAN tunnel. The collected metrics should at least include packet received count, packet sent count, packet loss count and error packet count.

7.3 Network slicing

7.3.1 General requirements

The PON based industrial network slicing architecture and slicing granularities are described in [i.2]. The OLT should support dynamic creation, configuration, modification, and deletion of network slices, and these slice operations shall not affect other network slices within the OLT.

7.3.2 Ethernet related functions

PON based industrial network slices, should support Ethernet related functions including MAC address learning, layer 2 forwarding, layer 2 aggregation, loop detection, and link aggregation functions.

For MAC address learning, the OLT should provide independent forwarding for each slice, supporting dynamic and independent MAC address learning. The MAC address tables for different network slices should be isolated from each other, and the MAC address learning slice processes should not affect each other.

For layer 2 forwarding, the network slices should support layer 2 forwarding for Ethernet services, ensuring line-speed forwarding for both upstream and downstream traffics.

For layer 2 aggregation, the network slices should support upstream flow aggregation from multiple PON interfaces.

For layer 2 isolation, the network slices should support layer 2 isolation between the ONUs within the same slice.

For loop detection, the network slices should support loop detection between different ONU UNI ports within the same PON port, and different ONU UNI ports within the same slice. When a loop is detected, the network slice should disable the targeting ONU UNI ports and raise an alarm.

For the link aggregation function, when the network slice's network side has multiple Ethernet interfaces, it should support link aggregation as specified in [10], and should support link aggregation within the same linecard and between linecards.

7.3.3 VLAN functions

The VLAN resources for each network slice should be independent. The VLAN IDs for the different network slices may overlap. The VLAN function should support isolation of the broadcast domain between network slices for the same VLAN IDs.

7.3.4 QoS functions

Industrial network slices should provide QoS mechanisms to ensure the QoS functions for various priority services based on the SLA agreements in both upstream and downstream directions.

Industrial network slices should support QoS mechanisms based on [9], including traffic classification, priority marking, queuing and scheduling, traffic shaping, traffic policing, congestion avoidance, and buffer management.

7.3.5 Network slicing management

PON based industrial network should provide independent operation and management functions for each slice, including configuration management, performance management, fault management, and security management.

The system administrator should be capable of setting up independent management permissions for each slice, and the system administrator of the corresponding slice management account should only have visibility, management and control over the virtual network elements within its own slice.

7.4 Deterministic networking

7.4.1 General introduction

The PON based industrial network system may introduce several technologies to optimize the deterministic networking capabilities of the network, including the latency and packet jitter performance.

These technologies as shown in Table 1 including:

- Cooperation between PON and the industrial devices.
- Single-frame multi-burst (frame-based dense burst allocation) technology.
- Optimization of quiet window opening.
- Other optional technologies including:
  - PON link latency optimization by dual wavelengths.
  - Dual-plane forwarding of the OLT.
  - Cooperative DBA (Dynamic Bandwidth Allocation), as shown in Table 1.

The PON based industrial network system may selectively support these technologies to satisfy the deterministic performance requirements in different industrial scenarios.

Table 1: Standardization status of technologies to optimize the deterministic networking capabilities of the PON based industrial network

Technology name	Standardization status
Cooperation between PON and industrial devices	Need to be standardized in the future
Single-frame multi-burst (frame-based dense burst allocation)	Defined in [i.13], [11], [i.14]
Optimization of quiet window opening	Defined in [i.14]
PON link latency optimization by dual wavelengths	Defined in [i.14]
Dual-plane forwarding of the OLT	Need to be standardized in the future
Cooperative DBA (CO DBA)	Defined in [i.15]

7.4.2 Cooperation between PON and industrial devices

To optimize the deterministic networking capabilities of the industrial PON system, including the latency and packet jitter performance, the upstream time slots of each ONU may be coordinated with the periodic traffic characteristics of other ONU's data flows. These characteristics can be processed by the OLT, to adjust the arrangement of the burst allocations in the upstream transmission accordingly for certain ONUs.

Refer to Annex A of the present document for more details on a feasible implementation.

7.4.3 Single-frame multi-burst

Conventional PON systems, as defined in [i.13], [11], [i.14], [i.16], employ an upstream time slot allocation mechanism based on a fundamental unit of 125 µs. To achieve better deterministic latency and packet jitter performance in PON based industrial network systems, single-frame multi-burst (frame-based dense burst allocation) functionality should be supported on each OLT PON port. This entails increasing the allocated frequency of the upstream timeslots, enabling ONUs to transmit multiple upstream packets within a single 125 µs window, thus optimizing upstream transmission latency and packet jitter.

For PON based industrial network systems based on GPON, the OLT PON ports enabling the single-frame multi-burst functionality, may optionally support flexible configuration of the number of upstream burst allocation series assigned to each ONU within each 125 µs upstream timeslot allocation cycle.

For PON based industrial network systems based on XG-PON, XGS-PON, and 50G-PON, the OLT PON ports which enables single-frame multi-burst functionality, should support flexible configuration of the single-frame multi-burst values allocated to each ONU within each 125 μs upstream time slot allocation cycle.

The OLT PON ports enabling single-frame multi-burst (frame-based dense burst allocation) functionality should support independent configuration of this function at a T-CONT granularity.

It is important to note that enabling single-frame multi-burst functionality would result in increasing the number of burst packets, consequently increasing the number of overheads including preambles. This may lead to a reduction in the overall effective upstream bandwidth of this OLT PON port. During deployment, the optimal number of bursts should be determined based on the specific latency, packet jitter, and available bandwidth requirements of the services being carried.

The detailed relationship between different single-frame multi-burst service configurations and available upstream bandwidth can be found in Annex B.

7.4.4 Quiet window opening management

7.4.4.1 Disabling of quiet window opening

To have better performance for time sensitive services, the PON based industrial network shall support the configuration of independently enabling and disabling the quiet window opening of each OLT PON port through either the PON management platform or the local management interface.

The PON based industrial network may support automatically enabling of the quiet window and registration interactions based on the condition that there are new ONUs are connected, as well as automatically closing the quiet window after all ONUs have been brought online as planned.

The PON based industrial network may support the fast registration function, after all the planned ONUs have completed registrations, for the scenario that new ONUs replacing existing ones or existing ONU devices going offline and are back online again. A fast registration method may be adopted by allocating existing ONU-IDs and equalization delays to these ONUs to complete the registration process, in accordance with relevant provisions as defined in [i.14].

7.4.4.2 Adaptive quiet window opening

PON based industrial network should support, for each OLT PON port, independently configuring the length, and the position within the upstream burst as well as the frequency of the quiet window, based on the actual fibre length and differential fibre distance of all the ONUs within this port.

In typical industrial scenarios, the distance between the OLT and the ONU generally does not exceed several kilometres. Therefore, if the quiet window length is determined by the defined maximum fibre distance of 20 kilometres as per [i.17], [12], [i.18], it will introduce significant fixed latency and packet jitter into the system.

Thus, in PON based industrial network, the quiet window length may be optimized to achieve better deterministic upstream transmission performance [i.13] according to the actual fibre distance range industrial scenarios. This optimization provides an appropriate quiet window to meet the registration authentication requirements for ONUs newly joining and the re-registration needs for already registered ONUs. It reduces the latency and packet jitter in the upstream for ONUs in the operational state (O5 state) as well.

A practical way of optimizing the quiet window length is to select different lengths based on whether there are newly unregistered ONUs within the PON port, thereby achieving optimization of the system's determinism capability. The different conditions for optimizing the ONU quiet window.

1) Condition when there is/are no newly unregistered ONU(s) within the PON port.

    a) The OLT gets the round-trip delay of each registered ONU and determines the maximum value of round-trip delay of the registered ONUs.

b) The OLT sets the quiet window length (as type-1 quiet window length) for registered ONUs based on this maximum round-trip delay, which is applied when the registered ONU reactivates. To set these quiet window lengths for registered ONUs, the OLT adds the maximum round-trip delay to a first pre-set delay to obtain the quiet window length used by the registered ONU in states O2 and O3. The OLT adds the maximum round-trip delay to a second pre-set delay (which is less than the first pre-set delay) to obtain the quiet window length used by the registered ONU in state O4.

c) The OLT sends this type-1 quiet window indication message, which includes the quiet window type identifier to the registered ONU.

2) Condition when there is/are newly unregistered ONU(s) within the PON port.

a) The OLT sets the quiet window length (as type-2 quiet window length) used by the unregistered ONUs according to the standard quiet window length [i.13], [i.14], [i.16], as the maximum suggested quiet window length during serial number acquisition (O2-3 states) is 250 µs. The maximum suggested quiet window length during ranging (O4 state) is 202 µs.

b) The OLT sends the type-1and type-2 quiet window indication messages to all the ONUs. The type-1quiet window indication message includes the quiet window type identifier for registered ONUs, while the type-2 quiet window indication message includes the quiet window type identifier for unregistered ONUs.

c) Each ONU checks its stored authentication information. In the case of being a registered ONU, it responds to the type-1 quiet window indication message. In the case of being an unregistered ONU, it responds to the type-2 quiet window indication message.

7.4.4.3 Dedicated activation wavelength

To prevent the quiet windows from occupying upstream timeslot resources, PON based industrial network may support an upstream wavelength channel dedicated to quiet window opening for ONU discovery, registration and ranging functions. For detailed implementation methods refer to Appendix IX of [i.14].

7.4.5 Other deterministic networking functions

7.4.5.1 TSN Capability Support

The OLT Server Name Indication (SNI) ports and the ONU UNI ports may support the following features:

- Time-gating functionality as defined in [i.19].
- Frame preemption functionality as defined in [i.20].
- Ingress flow policing functionality as defined in [13].

These features aim to optimize latency and packet jitter for both upstream and downstream service packet transmission.

7.4.5.2 Interoperability under Mixed Deployment

The ONUs that are configured with low latency and deterministic latency settings should be able to coexist and function properly with ONUs not utilizing these configurations within the same OLT PON port. The OLT shall have the final decision if low latency and deterministic latency settings between OLT and ONUs are not consistent.

The ONUs that are configured with low latency and deterministic latency settings should operate in the following scenarios:

- Multiple ONUs: each ONU may utilize its own specific low latency and deterministic latency configuration.
- Single ONU with differentiated Traffic Flows: different service flows within the same ONU may be assigned distinct low latency and deterministic latency configurations via different T-CONTs.

7.5 Network resilience

7.5.1 Optical link protection switching requirements

7.5.1.1 General functional requirements for optical link protection switching

The Industrial PON OLT shall support Type C (defined in [13]) dual-transmission and selective receiving technology to achieve zero packet loss in the process of switching and self-healing.

An OLT supporting optical link protection shall support real-time synchronization of ONU registration, ranging and service configuration information on the active and standby PON ports. During protection switching, an OLT shall maintain attributes of each ONU, such as ONU authentication status, FEC configuration and SLA other than changes in ONU protection switching attributes.

In order to improve network reliability and survivability, an industrial PON system shall support optical link protection switching in the following two ways:

a) Automatic switching: triggered by fault discovery or early warning information, including signal loss, signal degradation, hardware failure or abnormal software operation.

b) Forced switching: triggered by administrative events.

NOTE: The architecture of the PON system in the industrial scenario, are currently comprised of chassis and linecards, similar to the conventional PON systems used in public access network, and it is not likely to change in the near future. Thus the network resilience realized by protection switching between linecards can be adapted for the industrial PON system.

7.5.1.2 Optical link protection switching type

An industrial PON system shall support Type C optical link protection defined in [14].

NOTE: Type C protection includes single OLT with dual PON ports/dual OLTs with different PON ports, single ONU with dual PON ports and dual PON MAC chips, and 1:1 redundancy for the trunk fibre, optical splitter and distribution fibre.

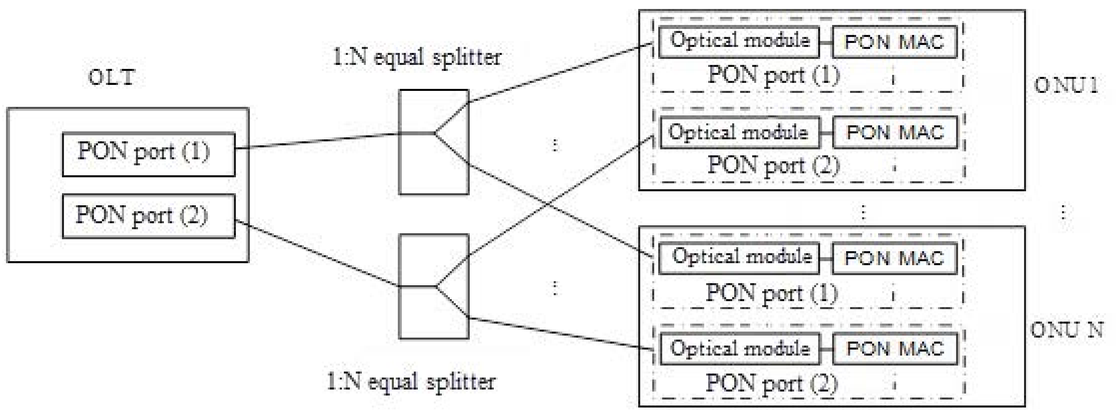

Figure 2: Example of a single OLT Type C optical link protection switching

Figures 2 shows an example of single OLT Type C optical link protection switching, in which one a single PON MAC chip in one a single PON card (when one PON MAC chip supports multiple PON ports), or between different PON MAC chips in one a single PON card.

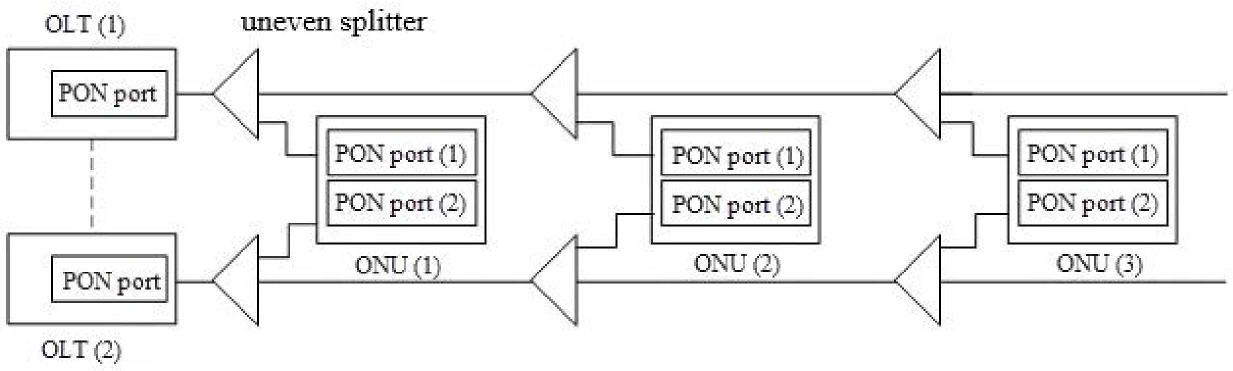

Figure 3: Example of a dual OLTs Type C hand-in-hand protection switching

Figure 3 shows an example of dual OLTs Type C hand-in-hand protection switching between two PON service cards on two OLTs.

The requirements for OLTs, optical splitters and ONUs are as follows:

a) OLT: The PON ports of the active and standby OLTs are both in working mode. The OLT shall back up the active PON port service information synchronously to the standby PON port, so that the standby PON port maintains the service attributes of ONUs during protection switching.

b) Optical splitters: Two 1:N optical splitters shall be used.

c) ONU: An ONU has two independent PON ports (each including a PON MAC chip and an optical module) and registered to the PON ports of the active and standby OLTs respectively. Two PON ports of the ONU work in active-standby state (hot backup). The ONU shall back up the active PON port service information synchronously to the standby PON port.

7.5.1.3 Switchback mechanisms

All protection switching mechanisms of an industrial PON system shall support manual switchback of protected services.

7.5.2 Device protection switching requirements

7.5.2.1 OLT core switch card 1+1 redundancy

An OLT shall support a working and protect switch and support 1+1 protection switching. When the active core switch card detects software exceptions, hardware failures, card removal, or forced switching commands issued by the industrial PON management system, automatic switching occurs, and all services are switched to the standby card. After switching, the necessary information including switching events and switching trigger conditions shall be reported to the PON management system, and the original "standby card" becomes the new "active card".

An OLT shall support real-time synchronization of configuration information between the active and standby core switch cards (to avoid reconfiguring VLANs and other attributes for the standby card in protection switching, so as to increase the switching speed of the service layer). Enabling link aggregation shall not affect the protection switching time of the core switch cards.

7.5.2.2 OLT uplink port dual-homing protection

An OLT shall support dual-homing protection for uplink cards, that is, two OLT uplinks are connected to two different uplink network devices respectively. The OLT actively switches services to the protection uplink after detecting a defect of the working uplink.

The OLT uplink port dual-homing protection shall support manual switchback of protected services.

In the OLT uplink port dual-home protection, the service interruption time during protection switching shall be no greater than 50 ms. For further information see [i.5].

NOTE: Service interruption time consisted of protective switching time and service restoring time for the industrial scenarios.

7.5.2.3 Configuration restoration

An industrial PON system shall support configuration restoration. An OLT shall store configuration information for the ONUs. After abnormal events such as power-off and card replacement, services on the OLT shall be restored automatically. After the ONU has been replaced or powered-off and on again, the OLT shall automatically restore the ONU configurations.

7.5.2.4 OLT power redundancy

An OLT shall support power redundancy. When the active power supply fails (hardware failures, manual card removal) or a switching command is issued by the PON management system, automatic or forced switching occurs. The services of the system shall not be affected in the case that the power module switches from the active one to standby module. After such handover between the power modules, the system shall report the detailed information of the events and trigger conditions to the PON management system.

EXAMPLE: An example of a service not being affect include that no packet loss occurred.

7.6 Security functions

7.6.1 Access security

7.6.1.1 ONU access authentication

Network intrusion is one of the major risks threatening industrial PON systems. An attacker may connect a malicious ONU to the industrial PON system and attack the OLT and the overall industrial network elements.

The industrial OLT shall verify the identity of the ONU before establishing the data transmission connection.

NOTE: Recommendation ITU-T G.988 [20] provides OMCI-based security mechanism to allow mutual authentication of the OLT and ONU and subsequent secure communication of encryption keys before establishing the data transmission connection.

7.6.1.2 Authentication and authorization in management plane

The management system of the industrial OLTs and ONUs provides the functions for the administrator to configure and monitor the devices. The management system is responsible for guaranteeing that the network's operations are secure and reliable. The management system is vulnerable to unauthorized access and privilege abuse.

The industrial OLT and ONU shall verify the identity of the administrator and the associated privileges before allowing the administrator to login and configure the device.

NOTE: It is best practice to assign minimized and need-to-have privileges to administrator accounts according to their security level.

The industrial OLT/ONU shall detect and defend against brute force attack.

EXAMPLE: The defence methods include but are not limited to blocking the IP or MAC address of the attack source machine, or requesting a verification code.

7.6.2 Data security

7.6.2.1 Data encryption

Data transmission in an industrial PON network shall be protected from eavesdropping and tampering.

The industrial OLT and ONU shall support upstream and downstream payload encryption with best practice cryptography. The payload encryption shall be enabled by default.

7.6.2.2 Data isolation

Industrial PON provides services to the office, the surveillance and the manufacturing networks with different security levels. The attacker may perform horizontal movement between the three different service networks once one of them has been compromised.

The industrial network shall be isolated according to the service data security and the QoS levels.

EXAMPLE: The network can be isolated physically by independent network device, like switches, or virtually by different VLAN or PON slicing.

7.7 Edge computing

7.7.1 OLT-side infrastructure capabilities to support edge computing

General-purpose computing hardware can enhance the computing capabilities of the industrial PON OLT. There are two types of computing hardware. The first one is the standalone type, which is a common computing server, connected to the OLT via network connections, and this standalone type is out of the scope of the present document. The second one is the integrated type, in which the general-purpose computing hardware is a computing card that fits into a linecard slot of the OLT chassis, and the requirements of this type are defined in the present document.

The general-purpose computing hardware on the OLT of the industrial PON system can be used to implement edge computing functions. These include running specific enterprise production systems implementing a firewall, network traffic analysis, and other layer 3 network functions, as well as collecting, processing, and storing industrial production data.

For the integrated industrial PON OLT edge computing general-purpose hardware (computing card that fits into a linecard slot of the OLT chassis), the storage and network capabilities are as follows:

- The computing card shall be inserted into the OLT chassis, occupying 1 or more slots, and support coexisting with other OLT cards.
- The computing cards that fit into a linecard slot of the OLT chassis consist of CPUs, memory, hard drives, network cards, and Ethernet switching modules, providing general computing, storage, and network connectivity functions. The CPU performs general computing functions, while memory and hard drives handle storage and caching. Network cards and Ethernet switching modules facilitate data forwarding and exchange between the cards and external applications, and the Ethernet switching module connects to the OLT backplane, providing network connectivity between the edge computing card that fits into a linecard slot of the OLT chassis and other cards in the OLT chassis. The physical dimensions, power consumption requirements, environmental requirements, and installation requirements of the computing cards that fits into a linecard slot of the OLT chassis should meet the requirements of the chosen OLT chassis specifications.

The general-purpose computing hardware should run a widely used and general purpose operating systems supporting the installation and operation of third-party developed software.

The computing capacity and storage capacity of general computing hardware are specified in clause 8.

NOTE: For the computing hardware, the widely used and general purpose processor architectures are used. The optional support for computational processing units based on Graphics Processing Units (GPUs) is advantageous, especially for AI related scenarios.

7.7.2 ONU-side integrated industrial data collection capability requirements

Industrial data collection is the function of collecting data from industrial field devices by the external industrial management systems such as Enterprise Resource Planning (ERP) and Manufacturing Execution System (MES).

The ONUs of an industrial PON system should support data collection functions for the industrial field devices as needed by running functional modules for industrial data collection on an ONU-side open platform. As the terminating side of the industrial PON network, the ONU should integrate edge computing hardware processing capabilities and open programmable operating systems. Based on the architectures including microservices, the ONU has the capability to deploy third-party applications under container technology, allowing the loading of third-party applications based on specific service requirements, including industrial protocol conversion apps.

Depending on the support capability of data collection functional modules, the ONUs of an industrial PON system should support the collection and conversion of industrial data and protocols to PON.

EXAMPLE: Industrial data and protocols include Profibus, Modbus, CAN, LonWorks, HART, Profinet, Ethernet IP and other industrial protocols and standards [1].

The hardware processing capability of the ONUs of an industrial PON system shall meet the real-time requirements of the industrial data collection.

The hardware capabilities required for edge computing functions on industrial PON ONUs are specified in clause 8.

7.8 Interfaces and industrial protocol adaptions

7.8.1 Interfaces on the OLT side

In a PON based industrial network, the OLT provides access, aggregation, switching, and edge computing functionalities. The uplink interface of an OLT typically connects to a datacentre in the factory or in a private cloud.

The uplink cards of OLT should support at least one of these interface types, GE/10GE optical ports, GE/10GE electrical ports, 25GE optical ports, 40GE optical ports, 50GE optical ports or 100GE optical ports, depending on the deploying scenarios. In the case that a GE interface is used, 10M/100M/1000M auto-negotiation function shall be supported.

The PON cards of the OLT should support at least one of these interface types, EPON, symmetric/asymmetric 10G-EPON, combined EPON/10G-EPON, GPON, XG(S)-PON, combined GPON/XG(S)-PON, combined 10G-EPON/50G-PON, combined GPON/50G-PON, combined GPON/XG(S)-PON/50G-PON, depending on the deploying scenarios.

7.8.2 Interfaces on the ONU side

The ONUs, as terminals of the system with imbedded industry gateway functions, connect to the OLT and provide User-Network-Interfaces (UNI) to end users with various user interfaces for different industrial services.

The Network to Network Interface (NNI) types of ONU, should support one of these interface types as EPON, symmetric/asymmetric 10G-EPON, GPON, XG-PON, XGS-PON or 50G-PON.

The UNI types of ONU should support at least one of these interface types, FE electrical interface (100Base-T), GE electrical interface (1000Base-T),10GE electrical interface (10GBase-T), RS-485, RS-232, RS-422, CAN, CVBS, or Wi-Fi, depending on the deploying scenarios.

When the ONU UNI types are FE electrical interface, GE electrical interface, or 10GE electrical interface, optional support for PoE (Power over Ethernet) function should be provided, with the specifications defined in [15], [16] and [17].

7.8.3 Industrial protocol adaptions

Industrial PON ONUs may support the processing of industrial data based on various industrial protocol standards including Profibus, Modbus, CAN, LonWorks, HART, Profinet, EthernetIP.

To achieve the corresponding industrial data acquisition capabilities, the hardware processing capabilities of industrial PON system the ONUs should meet the real-time requirements of industrial data acquisition, specifically according to the carried industrial protocol types and the corresponding requirements in [1].

7.9 Environmental adaption related functions

Industrial PON OLTs are deployed in air-conditioned factory datacentres, the operating conditions are similar to conventional public access networks, and thus there are no additional environmental recommendations for the OLTs.

For the ONUs in the industrial scenarios, ONUs may face very harsh working environmental conditions [i.21].

The detailed requirements for environmental adaption are defined in clause 8.5 of the present document.

8 Performance specifications

8.1 PON and Ethernet related performance

8.1.1 Ethernet-related functions

Industrial PON should comply with the corresponding requirements outlined in references [1], [4]and [5], [6], [7], [8] for the following Ethernet-related functions:

- Basic functions: MAC bridging, Layer 2 switching, frame filtering, Layer 2 isolation, loop detection, flow control, and OLT uplink ports link aggregation.
- Other functions: VLAN functionality, multi-service QoS mechanisms, traffic classification, priority tagging, rate limiting (including upstream/downstream rate limiting for both OLT and ONU), and priority scheduling.

8.1.2 Support on Jumbo Frames

Industrial PON devices should support jumbo frames with lengths ranging from 1 500 to 9 000 bytes.

NOTE: Jumbo frame size is considered to be between 1 500 bytes and 9 000 bytes. Jumbo frames exceeding 1 518 bytes are not in the scope of deterministic networking performance requirements in clause 8 of the present document.

8.1.3 Link Aggregation in the OLT uplink

For link aggregation in the OLT uplink, support for at least 4 link aggregation groups is required. The maximum number of aggregated ports within a link aggregation group should be one of the following:

- 4 for GE ports
- 2 for 10GE ports

The maximum number for higher than 10GE ports is for further study.

Both intra-card (within the same uplink board of the OLT) and inter-card (across different uplink boards of the same OLT), link aggregation should be supported.

Link aggregation functionality should support both load sharing and active-backup modes, configurable by the user.

The link aggregation functionality on the OLT uplink ports should support 1:1 backup protection. The recovery time should be less than 200 ms, with a recommended time of less than 50 ms.

8.1.4 VxLAN Functionality Requirements

The number of VxLAN tunnels supported by an OLT shall be no less than 4 096. The number of VxLAN MAC entries supported shall be no less than 4 096 per port, and no less than 16 384 per device.

Enabling VxLAN functionality [9] should not adversely affect the normal processing of the various protocol packets by the device. With VxLAN enabled, and using a random mix of packet lengths ranging from 64 to 1 518 bytes, the Layer 2 forwarding rate should not be less than 85 % of the forwarding rate achieved with VxLAN disabled.

For VNI Configuration, the OLTs should support a configurable VNI range of 0 to 16 777 215.

For VNI Capacity, the OLTs should support a minimum of 4 096 VNIs, ideally 8 192 VNIs.

8.2 Network slicing performance

8.2.1 General performance requirements

A single OLT should support at least 4 network slices, with a recommended support of 8 network slices.

The OLT should be capable of assigning independent software and hardware resources to each network slice. Dedicated uplink ports should be assigned to a network slice.

8.2.2 MAC Address Learning

The MAC address learning rate for each OLT slice should be no less than 1 000 addresses per second.

The MAC address caching capacity for each PON interface within an OLT slice should be no less than 2 000 entries.

For the OLT slices with a maximum PON port count greater than or equal to 32, the MAC address caching capacity of the aggregation switch should be no less than 64 000 entries, with a recommended capacity of no less than 2 000 entries multiplied by the maximum PON port count.

For the OLTs with a maximum PON port count less than 32, the MAC address caching capacity of the aggregation switch should be no less than 2 000 entries multiplied by the maximum PON port count.

The MAC address aging time for the OLT slices should be independently configurable.

8.2.3 Link Aggregation

The OLT slices should support at least 4 link aggregation groups.

The maximum number of aggregated interfaces for different uplink rates:

- GE interfaces should support aggregation groups with no less than 4 aggregated interfaces.
- 10GE interfaces should support aggregation groups with no less than 2 aggregated interfaces.
- The maximum number for higher than 10GE interfaces is for further study.

Link aggregation functionality should support both load sharing and active-backup modes, configurable by the user.

In active-backup mode, the recovery time should be less than 200 ms, with a recommended time of less than 50 ms.

8.3 Deterministic performance

8.3.1 Requirements for transmission latency

8.3.1.1 North-to-south latency

The north-to-south latency refers to the one-way latency from the OLT SNI interface to the ONU UNI interface, as shown in Figure 4. The fibre transmission delay is not considered, and data packet length is between 64 bytes and 1 518 bytes.

For north-to-south latency, the maximum upstream latency shall not exceed 90 µs, and preferable not exceed 65 µs; the maximum downstream latency should not exceed 40 µs, and preferable not exceed 20 µs.

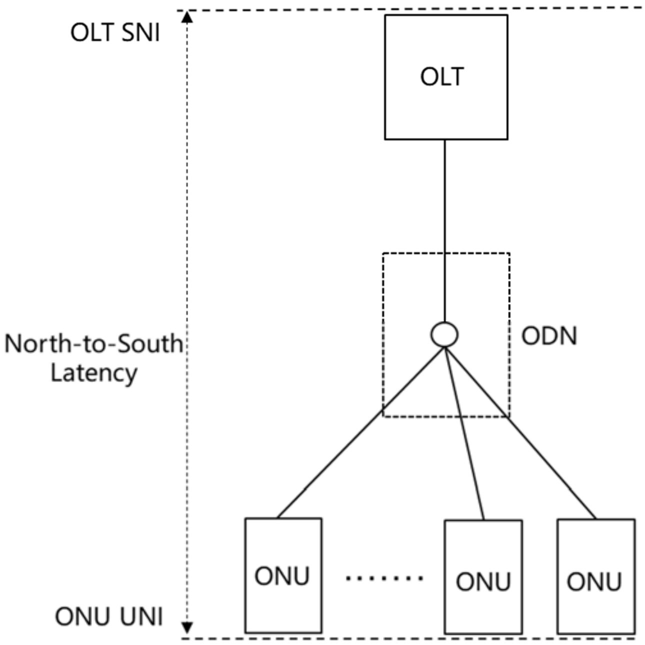

Figure 4: Illustration of north-to-south latency

8.3.1.2 East-to-west latency

The east-to-west latency refers to the one-way latency between UNI interfaces of two different ONUs under the same OLT chassis, as shown in Figure 5. The fibre transmission delay is not considered, and data packet length is between 64 bytes and 1 518 bytes.

For intra-PON port (a PON port belonging to same linecard on the same OLT chassis) and cross-PON port (PON ports belonging to different linecards on the same OLT chassis), the maximum east-to-west latency should not exceed 130 µs, and preferably does not exceed 85 µs.

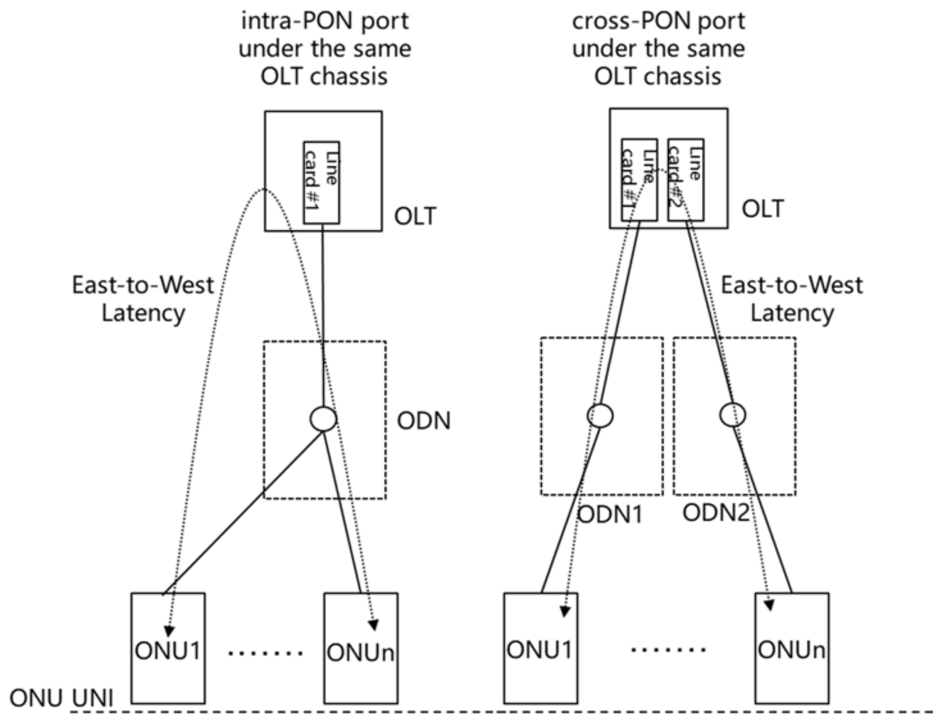

Figure 5: Illustration of east-to-west latency

8.3.2 Requirements for transmission jitter

If packet jitter optimization methods are employed as defined in clause 7.4.2 then collaboration between the PON and industrial devices is required. If TSN Capability Support as described in clause 7.4.5.1 is used then, the maximum jitter in both upstream and downstream directions is preferably no greater than 5 µs.

8.4 Network protection switch performance

The performance requirements for network protection switch shall complied with clause 5 the architecture and requirements for a protected optical access network in [13].

8.5 Environmental adaption

8.5.1 Temperature

For the industrial ONUs, the working temperature range recommendations will differ depending on the detailed scenarios. For the welding scenario, the upper limit as high as 80 °C may be required, while the lower limit may not exceed 0 °C if the factory is in a tropical region. The lower limit as low as -40 °C may be needed if the ONUs operate in the outdoor conditions in the winter in a high latitude region.

There is no universal temperature range for all the ONUs under each working condition. If such ONUs are produced with a universal working temperature range, the electronic devices and the other ONU components would be more complex. These ONUs would have very poor price-quality ratio and may not be acceptable to industrial customers.

A more realistic solution is to define a set of temperature ranges each with different upper and lower limits (see Table 2), and different industrial customers may choose a certain temperature range combination for their environment. Therefore, a compromise between performance and complexity can be achieved.

Table 2 shows different types of temperature ranges for ONUs, an industrial ONU shall conform to one of the types listed.

Table 2: Recommendations for different upper and lower limits in a typical working and store temperature range

Type	Working temperature/°C		Store temperature/°C	
	Lower limit	Upper limit	Lower limit	Upper limit
I	-10	+60	To Be Determined	To Be Determined
II	-20	+70	To Be Determined	To Be Determined
III	-25	+75	-55	+85
IV	-40	+85	-55	+95

The typical test temperature range and verification references can be found in [i.22], [i.23].

8.5.2 Water/dust resistance

The Industrial PON ONUs shall support at least one of the water and dust resistance capabilities listed in Table 3 for different industrial working scenarios.

Several degrees of protection for enclosures are defined in [18], as shown in Table 3.

Table 3: Degrees of protection provided by enclosures (IP Code)

Dust proof level	Waterproof level	Reference
IP4X IP5X IP6X	IPX0 IPX1 IPX2 IPX3 IPX4 IPX5 IPX6 IPX7	IEC 60529 [18]

8.5.3 Humidity

The Industrial PON ONUs shall support the recommended humidity working range in Table 4.

Table 4: A typical recommendation for ONUs humidity working range

Lower limit/%	Upper limit/%
4	95

8.5.4 Electromagnetic Compatibility (EMC)

The Industrial PON ONUs shall support EMC performance requirements in [19].

8.6 Edge computing

8.6.1 OLT side

The specific recommendations for a single edge computing card that fits a linecard slot on the OLT chassis are as follows:

- The CPU should be based on widely used general purpose processor architectures, optionally, the CPU may be equipped with GPU/NPU-based processing units for enhanced computation capabilities.
- The CPU should provide a computing power of no less than 0,4 TFLOPS (FP32 single-precision), and support for virtualization is required.
- The Memory configuration should be flexible and provide a minimum capacity of 32 GB.

- The Hard drive configuration should be flexible and offer a minimum capacity of 256 GB. Hot-swappable hard drives should be supported, and should use the SSD technology.
- The Ethernet module should support a network processing capability of no less than the equivalent of two 10GE interfaces.
- In addition to the functionalities of the general-purpose edging computing card, an optional enhanced type of the computing card may support a GPU or AI acceleration capabilities for enhanced floating-point computing power, providing a minimum of 2 TFLOPS.
- The physical dimensions, electrical requirements, environmental specifications, and installation requirements of the computing card should be compatible with the OLT chassis.
- The computing hardware should run a widely used general-purpose operating system.
- The general-purpose computing hardware should support the installation and execution of software applications on demands from the users.

8.6.2 ONU side

The Industrial PON ONUs that support edge computing functionality should meet the following hardware capability recommendations:

- The CPU should be based on widely used general purpose processor architecture. It may be equipped with GPU/NPU-based processing units for enhanced computational capabilities.
- The CPU computing power should not be lower than 10 GFLOPS (FP16 half precision) or 5 GFLOPS (FP32 single precision).
- Memory Capacity: The memory capacity should be no less than 512 MB.
- Permanent Storage Capacity: The storage capacity should be no less than 4 GB.

NOTE: The compatibility of operating systems and CPU architectures for OLT and ONU, and AI based requirements as virtualization (container, etc.) and co-ordinations need further study.

9 Management and provisioning specifications

9.1 Management protocols

The PON based industrial network should support flexible management of both the OLT and the ONUs, either by direct local interaction or remote centralized control through standard protocols [21], [24].

In local management mode, both the OLT and the ONUs should be accessible for operation and maintenance through either an Ethernet interface or a console port.

In remote management mode of the OLT, the PON management system should support communication either via the Simple Network Management Protocol (SNMP) protocol or the NETCONF/YANG [21].

The remote management of the ONUs should be supported through at least one of the following methods:

- OMCI (ONU Management and Control Interface) as defined in reference [20].
- NETCONF/YANG-based management [21] by a Software-Defined Networking (SDN) controller.
- MQTT based management as defined in [22].

9.2 Local management and provisioning

Both the OLT and the ONUs should provide local management capabilities for operation and maintenance through either an Ethernet interface or a console port.

The local management system should support the following functional aspects:

- Configuration Management
- Fault Management
- Performance Management
- Security Management

The local management system should support either a Command-Line Interface (CLI) or a web-based interface, or both.

9.3 Remote management and provisioning

The remote operation and maintenance management system should provide functionalities for managing both OLT and ONU, specifically in the areas of:

- Configuration Management
- Fault Management
- Performance Management
- Security Management

Multiple approaches may be utilized for remote OLT management. The system should support at least one of the following methods:

- EMS-Based Management: An Element Management System (EMS) should remotely manage the OLT using the SNMP version 2 or version 3. Support for both IPv4 and IPv6-based SNMP communication is required.
- SDN-Based Management: A Software-Defined Networking (SDN) controller system should remotely manage the OLT using the NETCONF/YANG protocol and data modelling language.

Similar to the OLT management, various methods should be employed for remote ONU management. The system should support at least one of the following:

- OMCI-Based Management: The OLT should remotely manage the ONUs using the ONU Management and Control Interface (OMCI) as defined in [20].
- SDN-Based Management: An SDN controller should directly manage the ONUs through the NETCONF/YANG protocol.

9.4 Configuration and delivery

9.4.1 General description

The PON based industrial network management system should, with support from the PON OLT, provide automatic ONU discovery, service provisioning, and support plug & play of the ONUs.

The access controller of PON based industrial network should support interworking of the PON network devices (OLT and ONU) to identify and authenticate of the industrial devices connected. The network controller should also support dynamic configuration of parameters related to user access authorization and service experience parameters including bandwidth and packet delay, based on user device identification. This enables user devices to securely access the network in different physical areas, different campus networks with equivalent service experience.

The PON based industrial network should support automatic identification of industrial devices accessing the network and allocating corresponding VLAN, bandwidth, and packet delay parameters to different industrial devices to support plug & play.

9.4.2 Field Data Network and surveillance network requirements

The PON based industrial network management system should support creating MAC address signature databases for industrial controllers, industrial sensing devices, and video surveillance cameras. The PON based industrial network management system should identify the terminal types based on the signature databases, and match network configuration parameters (VLAN, bandwidth, and delay) to configure accordingly. The PON based industrial network should be associated with the network management system to allocate network parameters to industrial terminals connected to ONUs. This enables plug & play of industrial terminals and simplifies network service configuration.

9.4.3 Office Network Requirements

The network controller should identify and control access of terminals through one of following mechanisms:

- 802.1X [25].
- Portal.
- MAC address authentication.

The PON network devices, in cooperation with the network controller, controls the access authentication of the terminals. To implement per-user QoS, the network controller should also support dynamically delivering service policies to the PON network devices through ACLs and UCLs based on user terminal identification. In this way, parameters related to user access authentication, bandwidth, and packet delay experience may be dynamically configured. Users then may securely access the network in different physical areas and on different campus network devices, with identical service experience.

10 Conclusion

PON has become the dominant access network solution for operators all around the world. PON technology has been widely deployed in public access networks. It has the advantages of large bandwidth, low deploying cost, passive optical distribution network, and smart operation and maintenance capabilities. The ODN technology is neither susceptible to nor generates electromagnetic interferences, which is ideal for the industrial deployments.

The PON technology may support multiple diverse applications, and is suitable for industrial-grade applications with a few extensions. The extensions compared to residential deployments may include deterministic networking, edge computing, the support of different environmental conditions, the support for industrial interfaces and protocol adaptation, supporting different topologies, and higher quality of service performance. The Industrial PON system needs to provide higher performance, higher reliability, and intelligent management to satisfy the service requirements for the various industrial customers.

Annex A (informative): Cooperation between PON and industrial devices

A.1 Introduction

In the upstream direction, the PON systems (e.g. GPON, XG(S)-PON) assign upstream burst timeslots unpredictably to each ONU within every 125 µs upstream timeslot defined in the ITU-T PON standards [i.13], [i.14], [i.16]. The randomness of timeslot allocation makes it more difficult to match the performance of the periodic data streams in the industrial scenarios. Thus the PON technology is not optimized for the deterministic transmission requirements of industrial traffic.

On the other hand, there is a strong demand from the industry, for optimization of the upstream latency and packet jitter performance of the PON system. It is important to provide a more appropriate solution for deterministic networking for the industrial customers.

A.2 Typical implementation details

For the industrial network within the workshops of a factory, under normal circumstances, the network topology and network elements (machines, devices for manufacturing products, etc.) connected to the industrial PON system would be very stable, as the number and type network elements would be fixed for most of the time, once the network is deployed and the workshop is running.

Thus, the data transmitted between the industrial network elements and upper layer manufacturing management systems the transmission is periodic with fixed datagram size. These dataflow characteristics may be utilized, to coordinate the upstream timeslots for each ONU based on the periodic characteristics of data flows from underlying network elements, to optimize E2E latency and packet jitter performance, and to achieve better deterministic network performance.

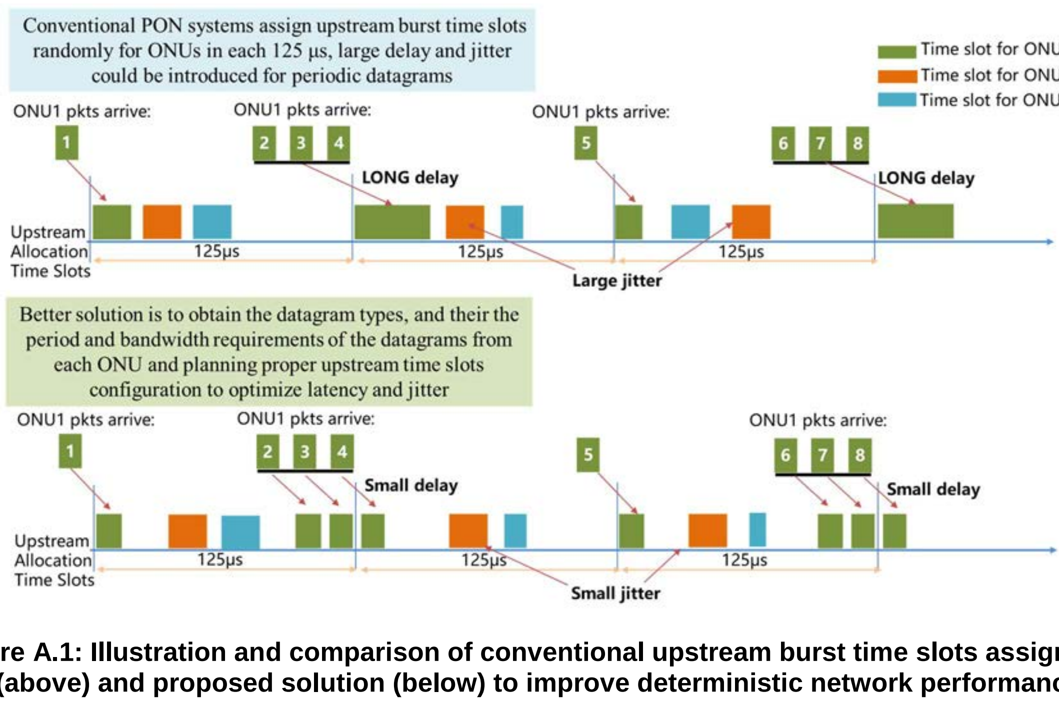

Figure A.1: Illustration and comparison of conventional upstream burst time slots assignment (above) and proposed solution (below) to improve deterministic network performance

With the support of the ONU's localized computing capability, it is feasible to achieve improved latency and packet jitter performance in the industrial PON. The ONU can monitor and analyse the temporal characteristics of the datagrams passing through, while connecting industrial network elements, and report to the OLT utilizing the framing header fields in the upstream transmission using PLOAM [i.13], [i.16] and [11]. The OMCI Managed Entity (ME) [20] is another option to store temporal parameters of the datagrams including cycle, latency, etc.). Such temporal characteristics may be processed by the OLT to adjust the burst allocations in the upstream transmission accordingly for certain ONUs.

According to the PON recommendations [i.13], [i.16], the ONUs' upstream transmission should follow the received arrangement of the burst allocations instructed by the OLT. A typical burst allocation includes the 'StartTime' as defined in [i.13], [i.16], etc., which can be used by the OLT to control the interval between the adjacent burst allocations when arranging the burst allocations.

Hence the deterministic performance of the industrial PON system can be improved by matching the above arrangement to the datagrams and by shortening the waiting time inside the ONU. The optimization process is realized by specific algorithms within the edge computing module in the PON system. It can provide an automatic approach to optimize the deterministic performance without human intervention.

Annex B (informative): Calculating effective upstream throughput from single-frame multi-burst values

B.1 Introduction

When the single-frame multi-burst functionality is enabled, the number of overheads, such as preambles contained in each upstream burst packets, increases proportionally with the number of bursts. This increase in overhead may lead to a decrease in the overall effective upstream bandwidth within the OLT PON port.

Therefore, during deployment, it is crucial to configure an appropriate value for the single-frame multi-bursts based on the specific latency, packet jitter, and available bandwidth requirements of the actual services being carried.

This Annex B provides a comparative analysis of the relationship between different single-frame multi-burst service configuration values and the available effective upstream bandwidth, specifically focusing on GPON and XGS-PON based industrial network.

B.2 GPON scenario

For a GPON system with an upstream rate of 1 244,16 Mbps/2 488,32 Mbps [i.16], the relationship between effective upstream bandwidth and the number of single-frame multi-bursts configured can be approximated using the following formula:

$$BW_{us} = (R_{us} - N_{onu}C_{burst}H_{overhead})\frac{L_{GPON}+20}{L_{GPON}+5}$$

Explanation of variables in the formula above:

- BW_{us}: Effective upstream bandwidth (Mbps).
- R_{us}: The upstream line rate in Mbps, 1 244,16 Mbps/2 488,32 Mbps for ITU-T GPON system.
- N_{onu}: Number of ONUs connected to this OLT PON port.
- C_{burst}: Number of single-frame multi-bursts configured for each ONU.
- $H_{overhead}$: The value of "Single Burst Overhead", calculated based on the GPON GTC layer parameters. Typical values for GTC layer parameters are shown Table B.1.
- L_{GPON}: Packet length (Bytes).
- $L_{GPON} + 20$: The "20 bytes" include the 12-byte Inter-Packet Gap (IPG) and the 8-byte preamble length defined in the Ethernet protocol [23].
- $L_{GPON} + 5$: The "5 bytes" represent the frame header overhead of the GEM frame defined in the GPON series protocols [i.16].

Table B.1: Typical values for GTC layer parameters in GPON system

	Guard band	Preamble	Delimiter	GTC header
Typical values (Byte)	5	36	3	3

$H_{overhead}$ (Single Burst Overhead), calculated based on the parameter values in Table B.1, results in a typical value of: (5 bytes + 36 bytes + 3 bytes + 3 bytes) × 8 × 8 000 (frames) = 3 008 Mbps.

Explanation of the Calculation:

- (5 bytes + 36 bytes + 3 bytes + 3 bytes): This represents the total overhead bytes per burst, derived from the GTC layer parameters. Refer to Table B.1 for the specific meaning of each value (e.g. preamble, delimiter, guard time).
- 8: This converts bytes to bits (8 bits per byte).
- 8 000 (frames): This factor represents the number of frames per second, which is related to the GPON system's clock rate.

Clarification:

- "Effective upstream bandwidth BW_{us}" refers to the effective data rate available for user traffic on the upstream channel after accounting for overheads.
- This calculated effective upstream bandwidth is on the Ethernet frame level (Layer 1 of the OSI model).

B.3 XGS-PON scenario

For an XGS-PON system with an upstream rate of 9 953,28 Mbps [11], the relationship between effective upstream bandwidth and the number of single-frame multi-bursts configured can be approximated using the following formula:

$$BW_{us} = (R_{us} - N_{onu} C_{burst} H_{overhead}) \frac{L_{XGS}+20}{L_{XGS}+8}$$

Explanation of variables in the formula above:

- BW_{us}: Effective upstream bandwidth (Mbps).
- R_{us}: The upstream line rate in Mbps, 9 953,28 Mbps for ITU-T XGS-PON system.
- N_{onu}: Number of ONU within this OLT PON port.
- C_{burst}: Number of single-frame multi-bursts configured for each ONU.
- $H_{overhead}$: The value of "Single Burst Overhead", calculated based on the XGS-PON XGTC layer parameters. Typical values for XGTC layer parameters are shown in Table B.2.
- L_{XGS}: Packet length (bytes).
- $L_{XGS} + 20$: The "20 bytes" include the 12-byte Inter-Frame Gap (IFG) and the 8-byte preamble length defined in the Ethernet protocol.
- $L_{XGS} + 8$: The "8 bytes" represent the frame header overhead of the XGEM frame defined in the XGS-PON series protocols [i.13], [11].

Table B.2: Typical values for XGTC layer parameters in XGS-PON system

	Guard band	Preamble	Delimiter	GTC header
Typical values (Byte)	21 × 8	100 × 8	8	8

$H_{overhead}$ (Single Burst Overhead), calculated based on the parameter values in Table B.2, results in a typical value of: (168 bytes + 800 bytes + 8 bytes + 8 bytes) × 8 × 8 000 (frames) = 63 Mbps.

Explanation of the Calculation:

- (168 bytes + 800 bytes + 8 bytes + 8 bytes): This represents the total overhead in bytes per burst, derived from the XGTC layer parameters. Refer to Table B.2 for the specific meaning of each value (e.g. preamble, delimiter, guard time).
- 8: This converts bytes to bits (8 bits per byte).

- 8 000 (frames): This factor represents the number of frames per second, which is related to the GPON system's clock rate.

Clarification:

- "Effective upstream bandwidth BW_{us}" refers to the effective data rate available for user traffic on the upstream channel after accounting for overheads.
- This calculated effective upstream bandwidth is on the Ethernet frame level (Layer 1 of the OSI model).

History

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