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Fifth Generation Fixed Network (F5G);
F5G Industrial PON

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Foreword

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Modal verbs terminology

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1 Scope

The present document studies the application of PON systems for industrial networks, including various deployment scenarios, industrial PON system descriptions, key functions, performance recommendations, interfaces, management system, ONU with industrial interfaces and industrial environment adaptation recommendations.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

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.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

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 008: "Fifth Generation Fixed Network (F5G); F5G Use Cases Release #2".

[i.3] ETSI GS F5G 003: "Fifth Generation Fixed Network (F5G); F5G Technology Landscape".

[i.4] ETSI GS F5G 004: "Fifth Generation Fixed Network (F5G); F5G Network Architecture".

[i.5] Recommendation ITU-T G.984.1 (2008): "Gigabit-capable passive optical networks (GPON): General characteristics".

[i.6] Recommendation ITU-T G.987 (2012): "10-Gigabit-capable passive optical network (XG-PON) systems: Definitions, abbreviations, and acronyms".

[i.7] Recommendation ITU-T G.987.1 (2016): "10-Gigabit-capable passive optical networks (XG--PON): General requirements".

[i.8] Recommendation ITU-T G. Sup74 (2021): "Network slicing in a passive optical network context".

[i.9] Recommendation E.419 (2006): "Business oriented Key Performance Indicators for management of networks and services".

[i.10] IEC 60529: "Degrees of protection provided by enclosures (IP Code)".

[i.11] 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-weatherprotected locations".

[i.12] 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-weatherprotected locations".

[i.13] IEC 61000-4-2:2008: "Electromagnetic compatibility (EMC) - Part 4-2: Testing and measurement techniques - Electrostatic discharge immunity test".

[i.14] CCSA (China Communications Standards Association) 2018-0172T-YD: "Networking Technology for Industrial Internet-General Technical Requirements for Passive Optical Network (PON)".

[i.15] IEEE 802.3ae™-2002: "IEEE Standard for Information technology - Local and metropolitan area networks - Part 3: CSMA/CD Access Method and Physical Layer Specifications - Media Access Control (MAC) Parameters, Physical Layer, and Management Parameters for 10 Gb/s Operation".

[i.16] IEEE 802.3af™-2003: "IEEEE 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 - Data Terminal Equipment (DTE) Power Via Media Dependent Interface (MDI)".

[i.17] 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".

[i.18] IEEE 802.3bt™-2018: "IEEE Standard for Ethernet Amendment 2: Physical Layer and Management Parameters for Power over Ethernet over 4 pairs".

[i.19] IEEE 802.3bz™-2016: "IEEE Standard for Ethernet Amendment 7: Media Access Control Parameters, Physical Layers, and Management Parameters for 2.5 Gb/s and 5 Gb/s Operation, Types 2.5GBASE-T and 5GBASE-T".

[i.20] IEEE 802.3i™-1990: "IEEE Standard for Local and Metropolitan Area Networks - System Considerations for Multi-segment 10 Mb/S Baseband Networks (Section 13) and Twisted-Pair Medium Attachment Unit (MAU) and Baseband Medium, Type 10BASE-T (Section 14)".

[i.21] IEEE 802.3u™-1995: "IEEE Standards for Local and Metropolitan Area Networks: Supplement - Media Access Control (MAC) Parameters, Physical Layer, Medium Attachment Units, and Repeater for 100Mb/s Operation, Type 100BASE-T (Clauses 21-30)".

[i.22] IEEE 802.11™-2020: "IEEE Standard for Information Technology--Telecommunications and Information Exchange between Systems - Local and Metropolitan Area Networks--Specific Requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications".

[i.23] IEEE 802.11a™-1999: "IEEE Standard for Telecommunications and Information Exchange Between Systems - LAN/MAN Specific Requirements - Part 11: Wireless Medium Access Control (MAC) and physical layer (PHY) specifications: High Speed Physical Layer in the 5 GHz band".

[i.24] IEEE 802.11b™-1999: "IEEE Standard for Information Technology - Telecommunications and information exchange between systems - Local and Metropolitan networks - Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Higher Speed Physical Layer (PHY) Extension in the 2.4 GHz band".

[i.25] IEEE 802.11n™-2009: "IEEE Standard for Information technology-- Local and metropolitan area networks-- Specific requirements-- Part 11: Wireless LAN Medium Access Control (MAC)and Physical Layer (PHY) Specifications Amendment 5: Enhancements for Higher Throughput".

[i.26] IEEE 802.11ac™-2013: "IEEE Standard for Information technology - Telecommunications and information exchange between systems-Local and metropolitan area networks - Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications - Amendment 4: Enhancements for Very High Throughput for Operation in Bands below 6 GHz".

[i.27] IEEE 802.11ax™-2021: "IEEE Standard for Information Technology - Telecommunications and Information Exchange between Systems Local and Metropolitan Area Networks - Specific Requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 1: Enhancements for High-Efficiency WLAN".

[i.28] NIST SP 800-57 Part 1 Rev. 5: "Recommendation for Key Management: Part 1 - General".

[i.29] IEC 61158: "Industrial communication networks - Fieldbus specifications".

[i.30] Recommendation ITU-T G.987.3 (2014): "10-Gigabit-capable passive optical networks (XG-PON): Transmission convergence (TC) layer specification".

[i.31] Recommendation ITU-T G.9804.1 (2019): "Higher speed passive optical networks - Requirements".

[i.32] Recommendation ITU-T G.9804.2 (2021): "Higher speed passive optical networks - Common transmission convergence layer specification".

[i.33] Recommendation ITU-T G.9804.3 (2021): "50-Gigabit-capable passive optical networks (50G-PON): Physical media dependent (PMD) layer specification".

[i.34] IEEE 802.1Qbv™-2015: "IEEE Standard for Local and metropolitan area networks -- Bridges and Bridged Networks - Amendment 25: Enhancements for Scheduled Traffic".

[i.35] IEEE 802.1Qch™-2017: "IEEE Standard for Local and metropolitan area networks--Bridges and Bridged Networks--Amendment 29: Cyclic Queuing and Forwarding".

[i.36] IEEE 802.11g™-2003:"IEEE Standard for Information technology-- Local and metropolitan area networks-- Specific requirements-- Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Further Higher Data Rate Extension in the 2.4 GHz Band".

[i.37] IEEE 802.1Qbu™-2016: "IEEE Standard for Local and metropolitan area networks -- Bridges and Bridged Networks -- Amendment 26: Frame Preemption".

[i.38] IEEE 802.3br™-2016: "IEEE Standard for Ethernet Amendment 5: Specification and Management Parameters for Interspersing Express Traffic".

3 Definition of terms, symbols and abbreviations

3.1 Terms

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

industrial environment adaptation: capability of maintaining acceptable level of service within industrial environments

industrial protocol adaptation: capability to interpret and/or convert 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: group of one or more flows associated with one or more ONUs that are treated as a single entity by a hierarchical traffic scheduler

NOTE: Defined in ITU-T G. Sup74 (2021) [i.8], clause 3.2.3.

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 PON
AES Advanced Encryption Standard

AGV	Automated Guided Vehicles
AI	Artificial Intelligence
AN	Access Network
AP	Access Point
API	Application Programming Interface
AR	Augmented Reality
ASIC	Application Specific Integrated Circuit
BASE-T	Baseband Twisted pair cable
BE	Best Effort
BNG	Border Network Gateway
CAN	Controller Area Network
CCD	Charge Coupled Device
CMOS	Complementary Metal Oxide Semiconductor
CO	Cooperative
CPN	Customer Premise Network
CPU	Central Processing Unit
CQF	Cyclic Queing and Forwarding
CX	short-haul Copper
DBA	Dynamic Bandwidth Allocation
DC	Data Centre
DevOp	Development and Operation
DHCP	Dynamic Host Configuration Protocol
DI/DO	Digital Input/Digital Output
DSP	Digital Signal Processing
DU	Distributed Unit
E2E	End to End
EC	Edge Computing
EMC	ElectroMagnetic Compatibility
EMI	Electro-Magnetic Interference
EMS	Electro-Magnetic Susceptibility
EPON	Ethernet PON
ER	Extended Range
ERP	Enterprise Resource Planning
ETH	Ethernet
F5G	Fifth Generation Fixed Network
FE	Fast Ethernet
FEC	Forward Error Correction
FOCAS	Flight Operations, Compliance and Safety
FPGA	Field Programmable Gate Array
FTTx	Fiber To The x
FTTX	Fibre To The X
GE	Gigabit Ethernet
GPON	Gigabit PON
GPU	Graphical Processing Unit
GTC	Gigabit-capable passive optical network Transmission Convergence
HD	High Definition
HMEE	Hardware-Mediated Execution Enclave
HSP	Higher Speed PON
HTTP	HyperText Transfer Protocol
IaaS	Infrastructure as a Service
ID	Identification
IEEE	Institute of Electrical and Electronic Engineers
IIoT	Industrial IoT
IoT	Internet of Things
IP	Internet Protocol
IT	Information Technology
LAG	Link Aggregation
LLS-FH	Low-Layer Split mobile Fronthaul
LOSi	Loss Of Signal for ONUi
LR	Long Range
LRM	Long Reach Multimode
LX	Long-haul fibre

M&C	Management & Control
MAC	Media Access Control
MCA	Management, Control & Analytics
MES	Manufacturing Execution System
MITM	Man-In-The-Middle
MQ	Message Queue
MQTT	Message Queue Telemetry Transport
MS	Management System
NAND	Not-And
NBI	Northbound Interface
NMS	Network Management System
O&M	Operation & Management
OAM	Operation Administration and Maintenance
ODN	Optical Distribution Network
OLT	Optical Line Termination
OMCI	ONU Management and Control Interface
ONU	Optical Network Unit
ONUi	Optical Network Unit No. i
OPC UA	Object linking and embedding for Process Control - Unified Architecture
OPC-UA	Open Platform Communications Unified Architecture
OS	Operating System
OT	Operational Technology
P2MP	Point to Multipoint
PaaS	Platform as a Service
PC	Personal Computer
PLC	Programmable Logic Controller
PMD	Physical Media Dependent
PoE	Power over Ethernet
PON	Passive Optical Network
POTS	Plain Old Telephone Service
QBV	802.1Qbv
QoS	Quality of Service
RFID	Radio Frequency Identification
RS	Recommended Standards
RTOS	Real-Time Operating System
RTT	Round-trip Time
SAP	Service Access Point
SCADA	Supervisory Control And Data Acquisition
SDi	Signal Degraded of ONUi
SDN	Software-Defined Network
SFi	Signal Fail of ONUi
SN	Serial Number
SPP	Service Processing Point
SR	Short Range
SR-DBA	Status Reporting DBA
SSD	Solid-State Drive
SX	Short-haul fibre
TC	Transmission Convergence
T-CONT	Transmission Container
TDM	Time-Division-Multiplex
TDMA	Time-Division-Multiple Access
TF	Transmitter Failure
TL1	Transaction Language 1
TM	Traffic Management
TSN	Time Sensitive Network
TTE	Time Triggered Ethernet
UART	Universal Asynchronous Receiver-Transmitter
UE	User Equipment
UNI	User Network Interface
URL	Uniform Resource Locator
VLAN	Virtual Local Area Network
VM	Virtual Machine

VR	Virtual Reality
Wi-Fi®	Wireless Fidelity
XG	10 Gbps
XG-PON	10-Gigabit-capable Passive Optical Network
XGS	10 Gbps Symetrical
XGS-PON	10-Gigabit-capable Symmetric Passive Optical Network
XML	eXtensible Markup Language
YANG	Yet Another Next Generation
ZTP	Zero Touching Provisioning

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 the process of production, monitoring, and management. Industrial networks are extended to include facilities related to the business, such as R&D centres, warehouses, administrative offices, and customer service branches.

Industrial PON, inherited a mature PON technology from residential access network (see [i.5], [i.6] and [i.7]), and enhances it to include functions required by the industrial customers. Industrial PON needs to support high quality connectivity to communicate between sensors, devices machines, and people within the industrial parks, see ETSI GR F5G 001 [i.1] and ETSI GS F5G 003 [i.3].

In the present document, typical industrial PON deployment scenarios, the architecture, the key functions and interfaces of the industrial PON system are described. These include the management system; the ONUs used in industrial scenarios and addresses industrial environmental recommendations.

5 Typical scenarios

5.1 Overview

There are three typical main deployment scenarios for industrial PON, which are illustrated as a complete overview in Figure 1. These scenarios have been included in F5G use cases (see ETSI GR F5G 008 [i.2]), and there follows a brief overview of these scenarios.

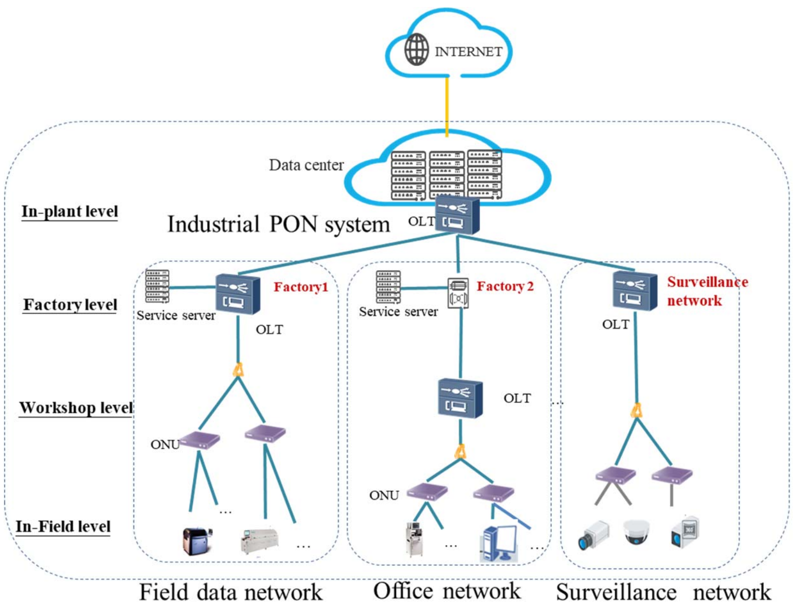

Figure 1: Overview of the industrial PON with typical connectivity scenarios within the factory

The industrial PON system is comprised of three main area (see ETSI GR F5G 008 [i.2]):

1) The field data network which is primarily the industrial environment, described in clause 5.2.

2) The office network including sales, marketing, finance and managerial staff areas, described in clause 5.3.

3) The surveillance network including internal and external video surveillance, alarms sensors and machine monitoring, described in clause 5.4.

5.2 Field Data Network

One major application in industrial PON is the transport of factory intra-plant industrial field level services. Industrial PON serves as a connection and convergence network for the machines within the factory, because the field data from the product line process is carried by the industrial PON.

There are several industrial field level interfaces and protocols defined in the IEC 61158 series [i.29]. Therefore, the industrial PON ONUs need to support the corresponding physical interfaces and the built-in protocol-related functions, or provide connectivity to existing industrial gateways, to support the communications among PLCs, other gateways, production management systems, etc.

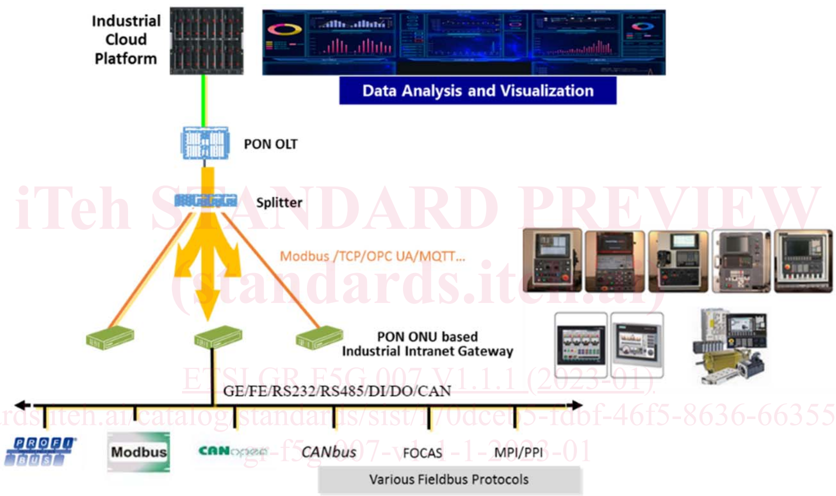

Figure 2: Fieldbus connection and converge network overview

5.3 Office network

The Industrial network supports the transport of traffic from the office area of a factory as internet/intranet surfing, telephony and Wi-Fi® APs traffic, etc. As the PON system is one of the dominant solutions for the fixed network in the public access network, it is an ideal candidate to transport these office network services in the factory.

By replacing existing copper-wire based network with fibre, higher access bandwidth can be available, and a single fibre can transport all the network services within the office. In addition, by using an industrial PON solution, the conventional copper cables can be replaced, the duct resources within the buildings are freed up and the duct space is available for future network expansion or network scaling.

By achieving a single converged PON network solution for both the factory workshop and office area, the services configurations and managements can be unified, and faster troubleshooting can be achieved.

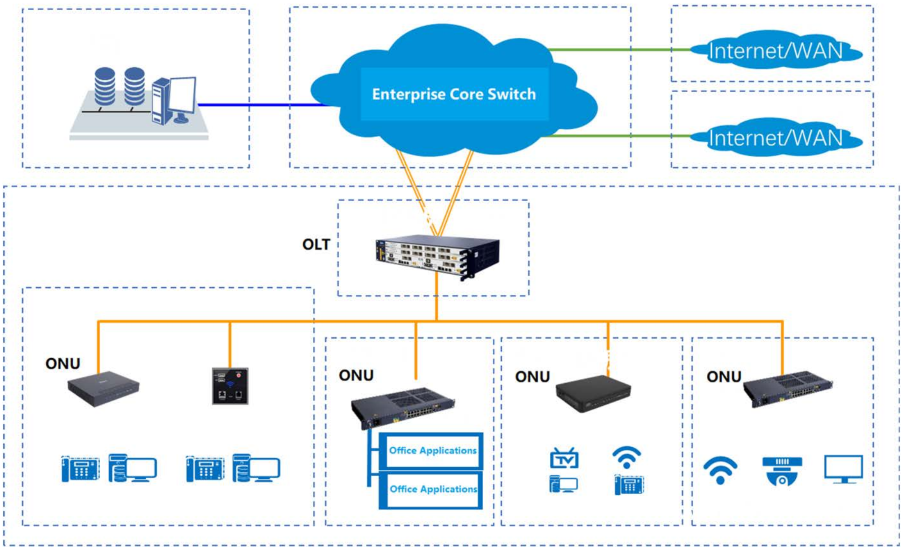

Figure 3: Office network connection via Industrial PON overview

5.4 Surveillance network

Beside the field level network and the office network, other major industrial network scenarios are the video surveillance networks and environment sensing networks around the factory. The industrial PON can fully support sensing services. A PON ONU needs to be capable of supporting Power over Ethernet (PoE) functionality when necessary to provide both network connectivity and electricity supply for remote video monitoring cameras. Other capabilities like Wi-Fi® AP, small cellular cells can also be embedded to the industrial PON ONU to realize the data transmission for several kinds of sensors.

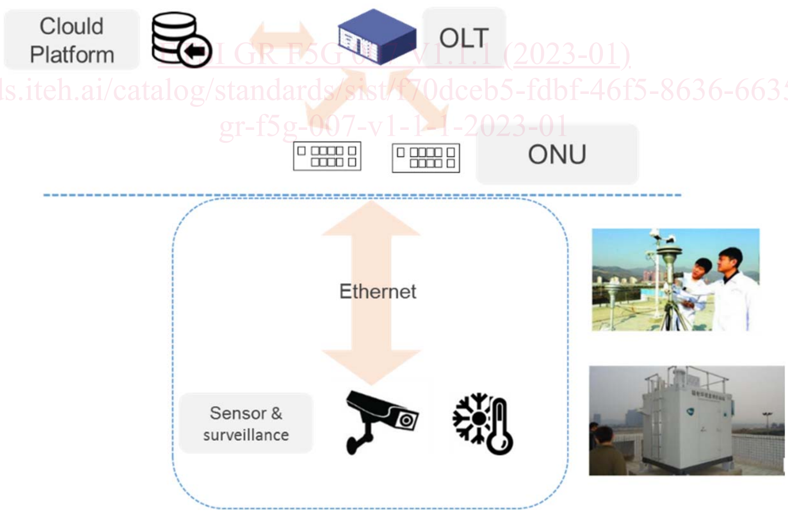

Figure 4: Industrial PON for sensor & surveillance network overview

In the intelligent factory, there are more and more machine vision applications being deployed. High-resolution image/video cameras are installed on the production lines to capture high-definition images or video streams for further AI-based analysis and recognitions, which can quickly locate defective production and products.

Such applications need very large upstream bandwidth on the network, as the traffic could be in the order of tens of gigabits per production line. 10G industrial PON systems, such as 10G-EPON and XGS-PON can be used to satisfy these bandwidth needs and future 50G PON system can further provide 5 times more bandwidth.

6 Industrial PON system description

6.1 System overview

6.1.1 Typical system architecture

The industrial PON system is within the scope of the F5G network architecture defined in ETSI GR F5G 004 [i.4], and it includes both the CPN (Customer Premises Network) and AN (Access Network) segments of the underlay plane.

The industrial PON system provides service connectivity for the users and devices in the industrial area. The major protocols used in the industrial scenarios are supported by the industrial PON system. The ONUs performs the SAP (Service Access Point) functions and the OLTs performs the SPP (Service Processing Point) functions.

As the industrial PON system is the underlying network of the industrial factory intranet, the factory intranet may be self-contained depending on the network scale and security considerations of the customers. The aggregation edge functions such as BNGs are optional for the OLT uplinks. The industrial PON can either be connected to higher level network elements or be stand-alone.

The industrial PON system supports the MCA (Management, Control & Analytics) plane interfaces and related operation and management functions. Conventional network management protocols such as TL1 and SDN based protocols such as NETCONF/YANG are supported by the industrial PON, and advanced functions such as AI analyser can also be deployed in the industrial PON system, see Figure 6.

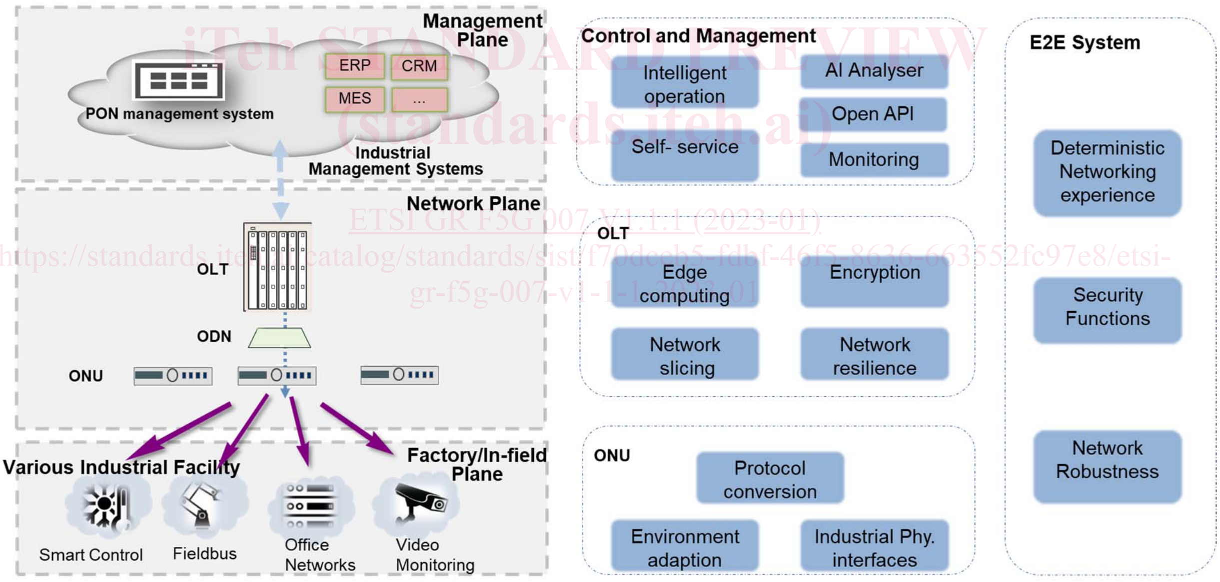

Figure 6: Industrial PON system architecture overview

As shown in Figure 6, the industrial PON system acts as the intra-plant communication hub. The Industrial ONUs provide the interconnection capability and various industrial physical interfaces and protocol conversion capabilities. Various factory facilities, office and surveillance services can easily be connected. The Industrial ONUs are optimized for operations in harsh environments, which may include very high temperature and/or complexelectro-magnetic issues.

The OLT has enhanced capabilities including network slicing, network resilience, encryption and edge computing to fulfil the services for industrial applications. OLTs with built-in open computation platforms can realize essential edge computing functions, to satisfy the local data processing in the factory, and can further cooperate with higher layer cloud computing facilities to provide dedicated cloud and IT services for industrial customers.

The industrial PON control and management system support conventional and SDN-based intelligent operation and management. The industrial PON control and management system can provide open API to other existing manufacture management system within the factory, and can lead to IT and OT convergence.

6.1.2 An alternative system architecture

6.1.2.1 Alternative spine-leaf architecture for large-scale industrial park scenarios

For a large industrial plant or a possible expanded industrial park, several OLTs need to be deployed in the factory to transport extensive east-west traffic traversing across the distributed plant.

The conventional architecture and management method mentioned in the previous clause may not be fully suitable for such large scale PON scenarios, as it may lead to issues of high operation and maintenance cost.

To address these issues for large-scale industrial park scenarios, an alternative architecture using a spine-leaf architecture, is shown in Figure 7.

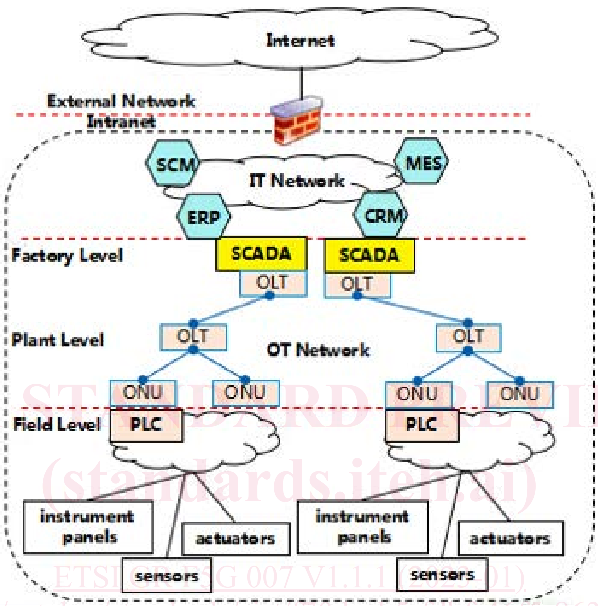

Figure 7: An alternative spine-leaf architecture for industrial PON within the scenario of large-scale industrial park

It is an alternative to the system architecture documented in clause 6.1.1.

6.1.2.2 Overview of the alternative spine-leaf industrial PON Architecture

The detailed architecture of the spine leaf industrial PON OLT extension is illustrated in Figure 8.

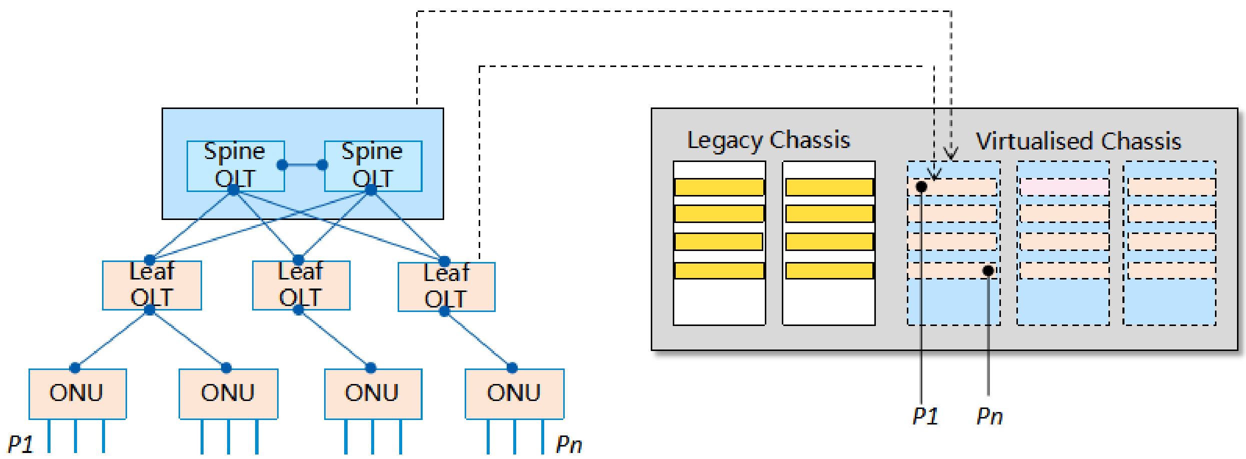

Figure 8: Management of the physical spine leaf Industrial PON OLTs and ONUs Controller