International Telecommunication Union

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

G.9803
Amendment 2
(02/2022)

SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Access networks – Optical line systems for local and access networks

Radio over fibre systems
Amendment 2

Recommendation ITU-T G.9803 (2018) – Amendment 2

Recommendation ITU-T G.9803

Radio over fibre systems

Amendment 2

Summary

Recommendation ITU-T G.9803 develops a new type of optical access network based on radio-over-fibre (RoF) technologies.

Recommendation ITU-T G.9803 defines fundamental architecture and requirements for radio over fibre systems and specifies radio over fibre transmission systems suitable for access network and radiolocation applications.

Amendment 2 includes new RoF architectures and related requirements to support International Mobile Telecommunications-2020 (IMT-2020) mobile fronthaul applications.

History

Edition	Recommendation	Approval	Study Group	Unique ID[*]
1.0	ITU-T G.9803	2018-11-29	15	11.1002/1000/13773
1.1	ITU-T G.9803 (2018) Amd. 1	2019-08-29	15	11.1002/1000/14023
1.2	ITU-T G.9803 (2018) Amd. 2	2022-02-13	15	11.1002/1000/14892

Keywords

Radio over fibre.

---

[*] To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11 830-en.

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications, information and communication technologies (ICTs). The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

Compliance with this Recommendation is voluntary. However, the Recommendation may contain certain mandatory provisions (to ensure, e.g., interoperability or applicability) and compliance with the Recommendation is achieved when all of these mandatory provisions are met. The words "shall" or some other obligatory language such as "must" and the negative equivalents are used to express requirements. The use of such words does not suggest that compliance with the Recommendation is required of any party.

INTELLECTUAL PROPERTY RIGHTS

ITU draws attention to the possibility that the practice or implementation of this Recommendation may involve the use of a claimed Intellectual Property Right. ITU takes no position concerning the evidence, validity or applicability of claimed Intellectual Property Rights, whether asserted by ITU members or others outside of the Recommendation development process.

As of the date of approval of this Recommendation, ITU had not received notice of intellectual property, protected by patents/software copyrights, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the appropriate ITU-T databases available via the ITU-T website at http://www.itu.int/ITU-T/ipr/.

Table of Contents

Recommendation ITU-T G.9803

Radio over fibre systems

Amendment 2

Editorial note: This is a complete-text publication. Modifications introduced by this amendment are shown in revision marks relative to Recommendation ITU-T G.9803 (2018) plus its Amendment 1.

1   Scope

This Recommendation develops a new type of optical access network based on radio-over-fibre (RoF) technologies. This Recommendation describes a fundamental architecture and requirements for RoF systems. This Recommendation specifies the system overview, physical layer requirements, system requirements and co-existence with passive optical network (PON) for analogue RoF systems supporting the international mobile telecommunication (IMT) system over optical distribution network (ODN). This Recommendation also describes the system overview and physical layer requirements for analogue RoF systems supporting the foreign object debris (FOD) detection system.

2   References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T G.987]	Recommendation ITU-T G.987 (2012), *10-Gigabit-capable passive optical network (XG-PON) systems: Definitions, abbreviations and acronyms*.
[ITU-T G.989.2]	Recommendation ITU-T G.989.2 (2014), *40-Gigabit-capable passive optical networks (NG-PON2): Physical media dependent (PMD) layer specification*.
[ITU-T G Suppl. 55]	Supplement 55 to ITU-T G-series Recommendations (2015), *Radio-over-fibre (RoF) technologies and their applications*.
[ITU-T J.186]	Recommendation ITU-T J.186 (2008), *Transmission equipment for multi-channel television signals over optical access networks by sub-carrier multiplexing (SCM)*.

3   Definitions

3.1   Terms defined elsewhere

This Recommendation uses the terms defined in clause 3 of [ITU-T G.987] and [ITU G Suppl. 55].

3.2   Terms defined in this Recommendation

None.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

BB   Baseband Block

BBU   Baseband Unit

BEP   Back-End Processor

BS   Base Station

CA   Carrier Aggregation

CAPEX   Capital Expenditure

CD   Chromatic Dispersion

CPE   Customer Premise Equipment

CPRI   Common Public Radio Interface

CWDM   Coarse Wavelength Division Multiplexing

DAS   Distributed Antenna System

DEMUX   Demultiplexer

D-RoF   Digitized Radio over Fibre

E/O   Electrical-to-Optical

ETSI   European Telecommunications Standards Institute

FCAPS   Fault, Configuration, Accounting, Performance, and Security

FCP   Frequency Conversion Processor

FCU   Frequency Conversion Unit

FDM   Frequency Division Multiplexing

FEP   Front-End Processor

FM-CW   Frequency-Modulation Continuous-Wave

FOD   Foreign Object Debris

FSK   Frequency-Shift Keying

FWA   Fixed Wireless Access

GPON   Gigabit-capable Passive Optical Network

IDU   Indoor Unit

IF   Intermediate Frequency

IMT   International Mobile Telecommunication

IoT   Internet of Things

IP   Internet Protocol

IPTV   Internet Protocol TV

LMDS   Local Multipoint Distribution System

LTE   Long Term Evolution

M/dMP   Modulation and deModulation Processor

MEF   Metro Ethernet Forum

MIMO	Multi-Input Multi-Output
MP-to-MP	Multi-Point-to-Multi-Point
MUX	Multiplexer
NG-PON2	40-Gigabit-capable Passive Optical Network
O/E	Optical-to-Electrical
OAM	Operation, Administration and Management
OBSAI	Open Base Station Architecture Initiative
ODN	Optical Distribution Network
ODU	Outdoor Unit
O/E	Optical-to-electrical
OLT	Optical Line Terminal
OMCI	ONU management and control interface
OMI	Optical Modulation Index
ONU	Optical Network Unit
ORI	Open Radio equipment Interface
PDM	Polarization Division Multiplexing
PON	Passive Optical Network
POTS	Plain Old Telephone Service
P-to-MP	Point-to-Multi-Point
R/S	Reference point at the interface of the ONU to the ODN
RAN	Radio Access Network
RE	Radio Equipment
REC	Radio Equipment Control
RF	Radio Frequency
RFB	Radio Frequency Block
RFU	Radio Frequency Unit
RG	Residential Gateways
RoF	Radio over Fibre
RRH	Remote Radio Head
Rx	Receiver
S/R	Reference point at the interface of the OLT to the ODN
SMF	Single Mode Fibre
SNI	Service Node Interface
TDM	Time Division Multiplexing
TRx	Transceiver
Tx	Transmitter
UE	User Equipment

UNI	User Network Interface
VoIP	Voice over IP
VPN	Virtual Private Network
WDD	Wavelength Division Duplexing
WDM	Wavelength Division Multiplexing
XG-PON	10-Gigabit-capable Passive Optical Network
XGS-PON	10-Gigabit-capable Symmetric Passive Optical Network

5   Conventions

See Conventions in [ITU-T J.186].

6   Fundamental architecture

A radio-over-fibre (RoF) system must have the capability to transmit waveform information over an optical fibre network for radiocommunication services, where the optical fibre network may consist of a single optical fibre as the simplest case. The RoF system must also at least have the following functions:

–   electrical interface to put the waveform information into the RoF system;

–   electrical-to-optical (E/O) conversion of the waveform information for generating the RoF signal;

–   optical interface to transmit the RoF signal into an optical fibre;

–   optical interface to receive the RoF signal from an optical fibre;

–   optical-to-electrical (O/E) conversion of the waveform information for detecting the RoF signal;

–   electrical interface to output the waveform information from the RoF system.

In this Recommendation, the waveform information is the essential physical information for radiocommunication services, such as the format of the radio wave and payload. The carrier frequency of the radio signal is not essential here because it does not affect processing the equivalent baseband signal. The RoF signal is an optical signal carrying the waveform information. In this Recommendation, RoF systems should be designed basically with clauses 5 and 6 in [ITU-T G Suppl. 55].

Figure 6-1 shows the fundamental architecture of a typical RoF system for the case of simplex transmission. The RoF system consists of an RoF transmitter (RoF transmitter (Tx)), an optical fibre network, and an RoF receiver (RoF receiver (Rx)), as shown in Figure 6-1-a. Here, iRoF represents points just before and just after the RoF system, and iRoF-o represents points just before and just after the optical fibre network. The RoF Tx must equip the first three of the above functions. If necessary, the RoF Tx may include electrical front-end processor (FEP), optical back-end processor (BEP), and other processors to meet its physical requirements, as shown in Figure 6-1-b. The RoF Rx must equip the last three of the above functions. If necessary, the RoF Rx may include optical FEP, electrical BEP, and other processors to meet its physical requirements, as shown in Figure 6-1-c.
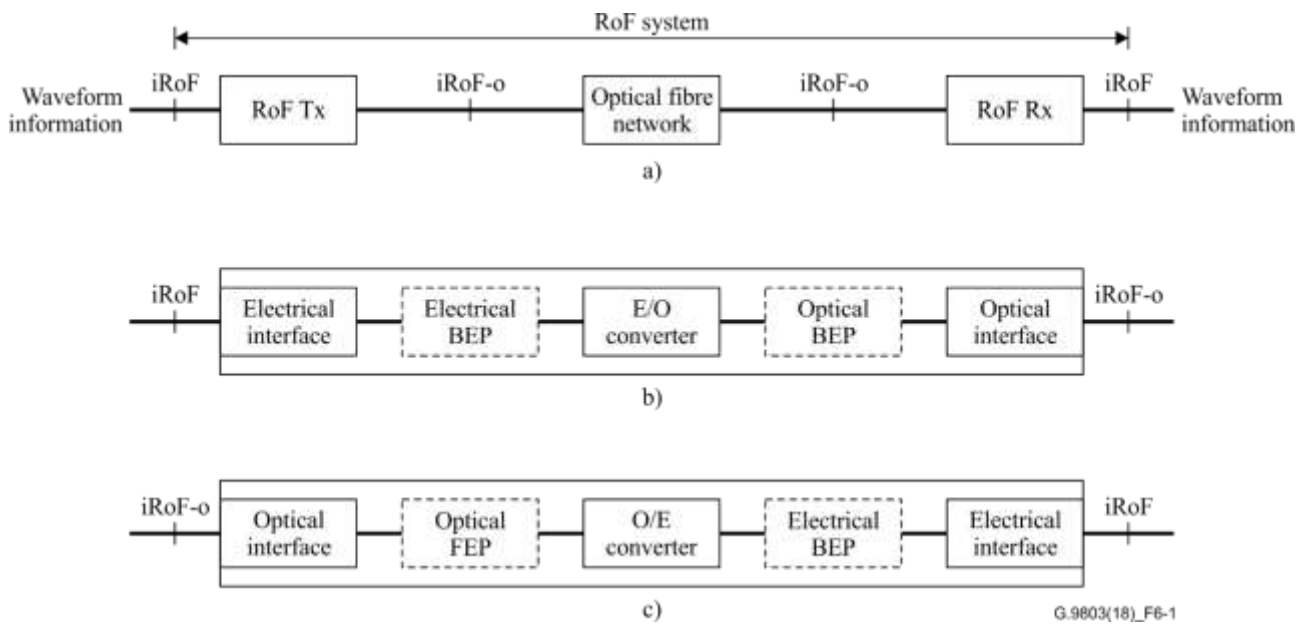
**Figure 6-1 – Fundamental architecture of RoF system (simplex type):
a) typical system configuration; b) typical RoF Tx; and c) typical RoF Rx**

Figure 6-2 shows the fundamental architecture of a typical RoF system for the case of duplex transmission. The RoF system consists of two RoF transceivers (RoF transceiver (TRx)) and an optical fibre network, as shown in Figure 6-2-a. The RoF TRx must equip all the above functions. A typical RoF TRx consists of a pair of RoF Tx and RoF Rx, a pair of electrical divider and combiner, and a pair of optical combiner and divider, as shown in Figure 6-2-b.
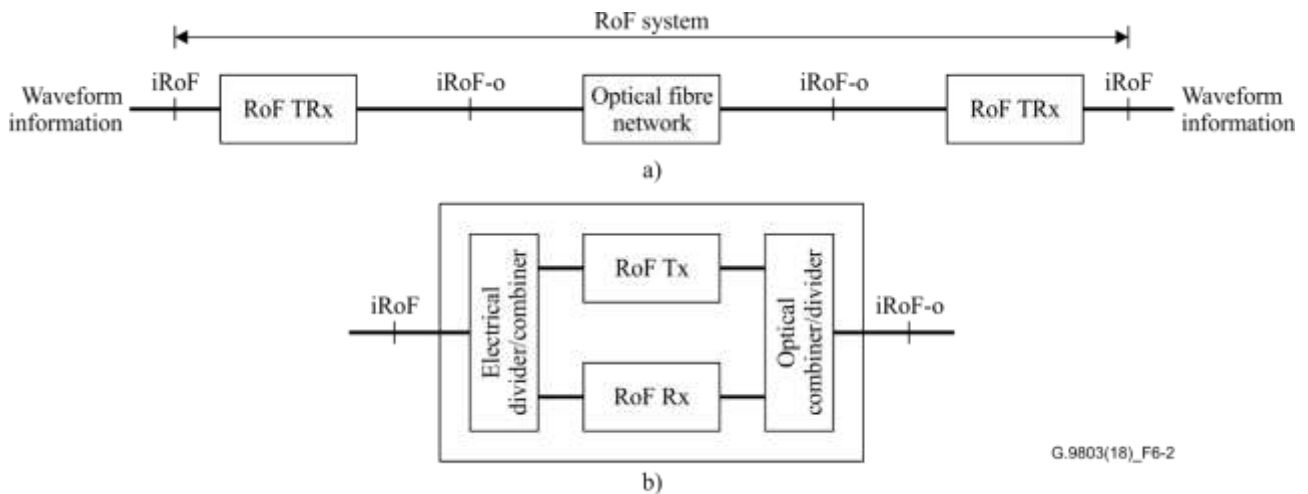
**Figure 6-2 – Fundamental architecture of RoF system (duplex type):
a) typical system configuration; and b) typical RoF TRx**

Figure 6-3 shows the fundamental architecture of complex type of RoF systems shown in Figures 6-1 and 6-2. As shown in Figure 6-3, the RoF system may be able to support point-to-multi-point (P-to-MP) or multi-point-to-multi-point (MP-to-MP) architecture.
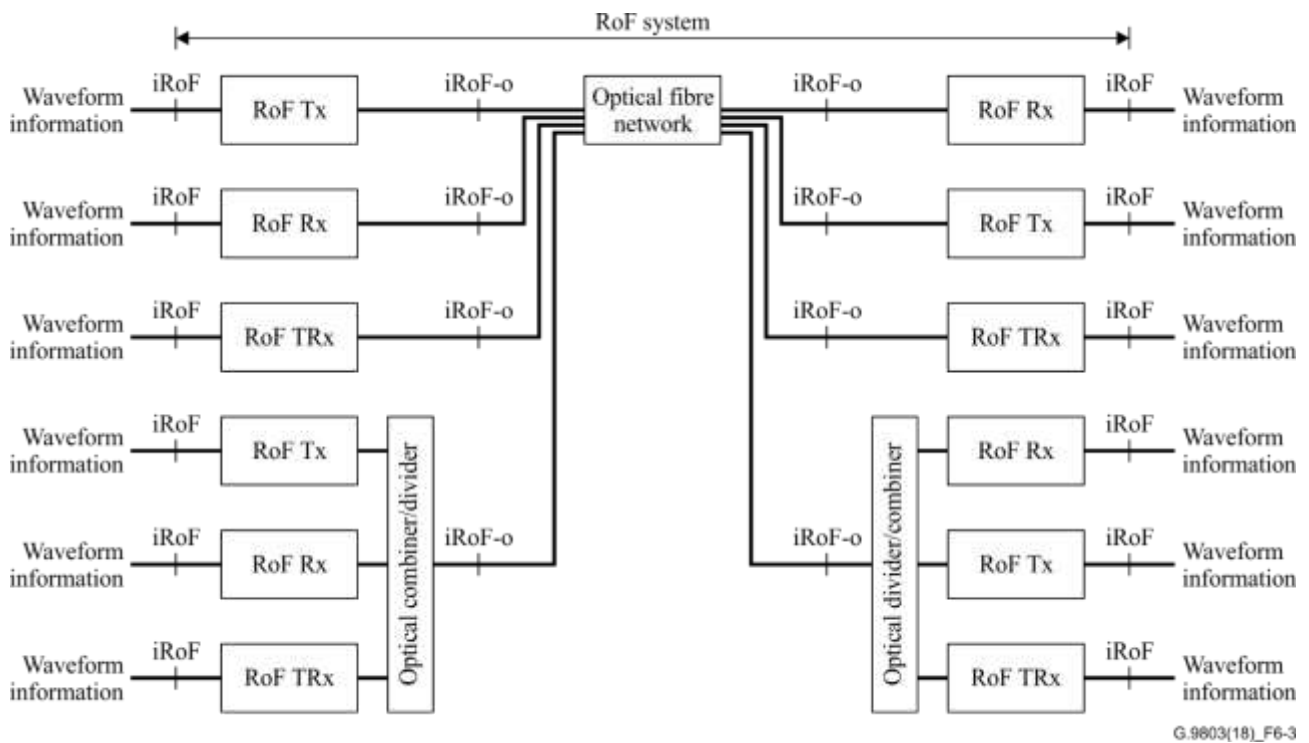
Figure 6-3 – Fundamental architecture of RoF system (complex type)

Major RoF system elements and functions in the above architectures are explained in Appendix I and clause 7 of [ITU-T G Suppl. 55] in detail.

Although the waveform information at the output of the RoF system (hereafter referred to as output waveform information) should basically be the same as the waveform information at the input of the RoF system (hereafter referred to as input waveform information), the output waveform information may become different from the input waveform information by processing the RoF signal within the RoF system. In other words, although the RoF system should basically have the function of a repeater, it may also have a function of signal processing as if it is part of a radio signal processor. Moreover, the input waveform information may be a combination of several waveform information components.

7 Fundamental requirements

7.1 Radio signal quality

Radio signals generated through the RoF system must comply with standardization or recommendations of each radiocommunication service when it is radiated from an antenna. To meet this requirement, noise figures and nonlinearity of RoF systems should be properly designed and managed. To optimize total system performance, in addition, RoF systems should have flexibility to balance trade-offs in radio signal frequency band, total power level of radio signal, the number of radio signals, and optical path loss for various applications, taking the radio signal quality into account.

7.2 Latency

Since most radiocommunication services have requirements related to latency, the RoF system should be designed to satisfy the required latency of each radiocommunication service. Therefore, in general, maximum fibre distance of the optical fibre network in the RoF should be limited to meet the demand.

7.3 Eye safety

All necessary mechanisms must be provided to ensure that no eye damage can be caused to end users unaware of risks associated with a fibre termination inside a customer premise, including labelling and safety locking mechanisms if necessary. The system should meet all applicable requirements for the classification, service group designation, and accessibility to ensure safe operation and servicing of the optical fibre communication system at each node.

Unless otherwise noted, laser sources used in RoF systems should satisfy Class 1 to 3R defined in [b-IEC 60825-1] and [b-IEC 60825-2].

7.4 Interoperability

RoF systems must support interoperability between RoF Tx and RoF Rx and among RoF TRxs. All relevant interfaces to facilitate interoperability may be defined in appropriate standards or recommendations.

Annex A

Analogue RoF system supporting international mobile telecommunication system over optical distribution network

(This annex forms an integral part of this Recommendation.)

A.1 System overview

In this annex, an analogue RoF system supporting an international mobile telecommunication (IMT) system over an ODN is specified.

A.1.1 General requirements

The RoF system requirements include support for:

– fronthaul link in at least one of IMT-Advanced systems and IMT-2020 systems;

– wavelength division duplexing (WDD), in which different wavelengths are allocated for down- and up-links in the optical domain;

– usage of ODN, which is generally used in passive optical network (PON) systems, or point-to-point access systems.

The RoF system may also support:

– capability to coexist with PON systems;

– capability to extend to fronthaul link in IMT-2000 systems;

– capability to extend to fronthaul link for carrier-grade Wi-Fi systems;

– capability to extend to fronthaul link for broadband fixed wireless access (FWA) systems;

– capability to support multiservice of the above systems;

– access schemes using multiplexing such as wavelength division multiplexing (WDM) and polarization division multiplexing (PDM);

– RoF optical line terminal (OLT) should support single service or multiservice.

A.1.2 Reference architecture

Figure A.1 shows a typical IMT system supported by an RoF system. The RoF system mainly consists of the RoF OLT, ODN, and the RoF optical network unit (ONU). The RoF OLT is commonly located in the network site and directly connected to one or more baseband units (BBUs). The basic function of the RoF OLT is to convert radio signals to optical signals and vice versa. Generally, the BBU is the baseband processing unit in a base station (BS) of the IMT system. It is placed in the network site, and connected with the remote radio head (RRH) via the RoF system. In particular, a single RoF OLT is able to accommodate multiple BBUs to make efficient use of the ODN. The BBUs are linked with a service provider's core network to offer various mobile Internet services to users. The ODN is an optical fibre network consisting of optical fibres as a transmission media and optical splitters such as power splitters and/or passive WDM routers to provide connections between the RoF OLT and the RoF ONUs. The RoF ONUs are usually placed in remote sites and linked with one or more RRHs. Similar to the RoF OLT, the RoF ONU is capable of converting optical signals into radio signals and vice versa. The RRH contains the base station's radio-frequency-band (RF-band) circuitry and frequency up/down converter function. Typically, each RRH has plural antennas equipped with high-power amplifiers and low-noise amplifiers for supporting multi-input multi-output (MIMO) configuration. Interface S is the point on the optical fibre just after the RoF OLT (downstream)/RoF ONU (upstream) optical connection point (i.e., optical connector or optical splice). Interface R is the point on the optical fibre just before the RoF ONU (downstream)/ RoF OLT (upstream) optical connection point (i.e., optical connector or optical splice). The RoF ONU has a user network interface (UNI). The RoF OLT has a service node interface (SNI). SNI/UNI depends on the nature of services

offered by the service provider. SNI and UNI are utilized to define the transmitted signal type and allowable signal delay or latency within the whole RoF system.
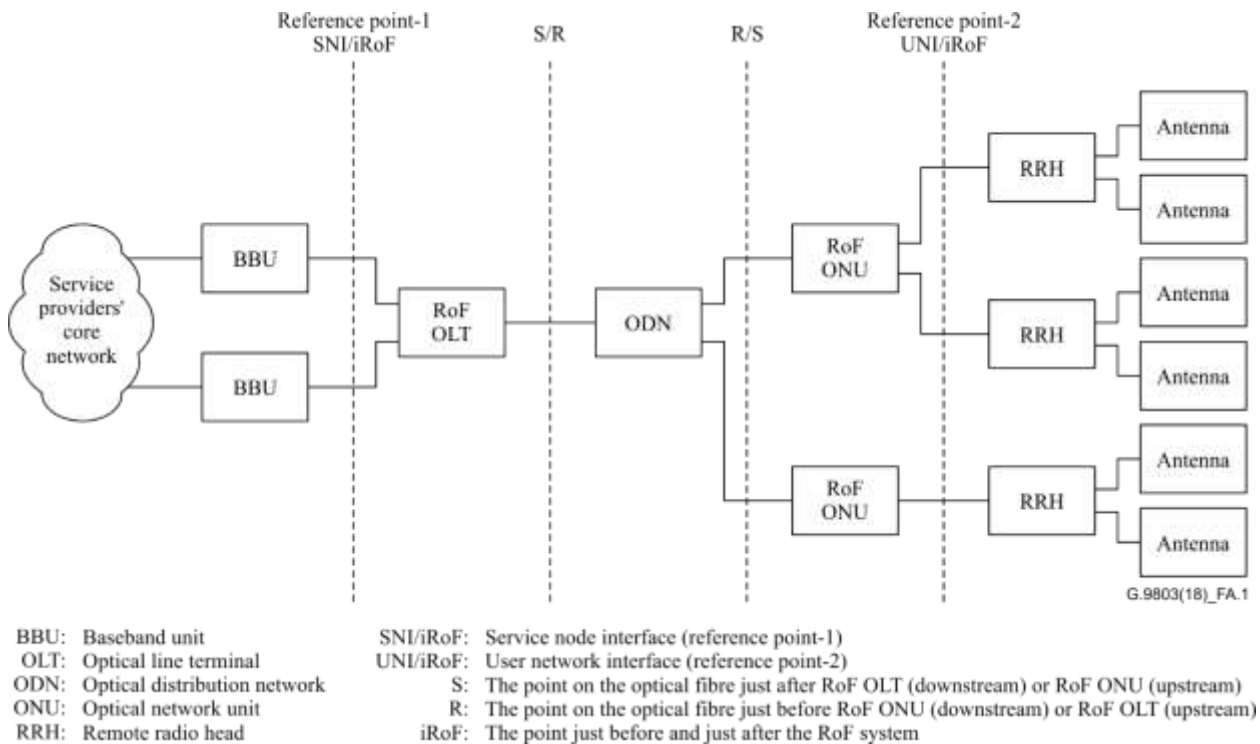
Figure A.1 – Typical IMT system supported by RoF system

Based on the IMT system shown in Figure A.1, a generalized reference architecture of an RoF system supporting IMT systems is illustrated in Figure A.2. Its support of multiservice is shown in Appendix II. The RoF system basically corresponds to Figure A.1. If necessary, the RoF OLT is connected to one or more BBUs via an additive frequency conversion unit (FCU). The RoF OLT consists of one RoF TRx. Note that RoF TRx is described in clause 6. If necessary, the RoF OLT may accommodate multiple BBUs via a multiplexer/demultiplexer (MUX/DEMUX), and the RoF ONU is linked with one or more RRHs via a ~~DEMAX~~DEMUX/MUX. The MUX and DEMUX typically ~~uses~~use frequency division multiplexing (FDM), time division multiplexing (TDM), or packet division multiplexing. The RoF ONU consists of one RoF TRx. Specifications of the BBU, the FCU, the MUX, the DEMUX, and the RRH are outside the scope of this Recommendation. iRoF represents points just before and just after the RoF system. There are some cases where the RoF ONU and RRHs are located separately and a second RoF system may be required between the RoF ONU and RRHs.
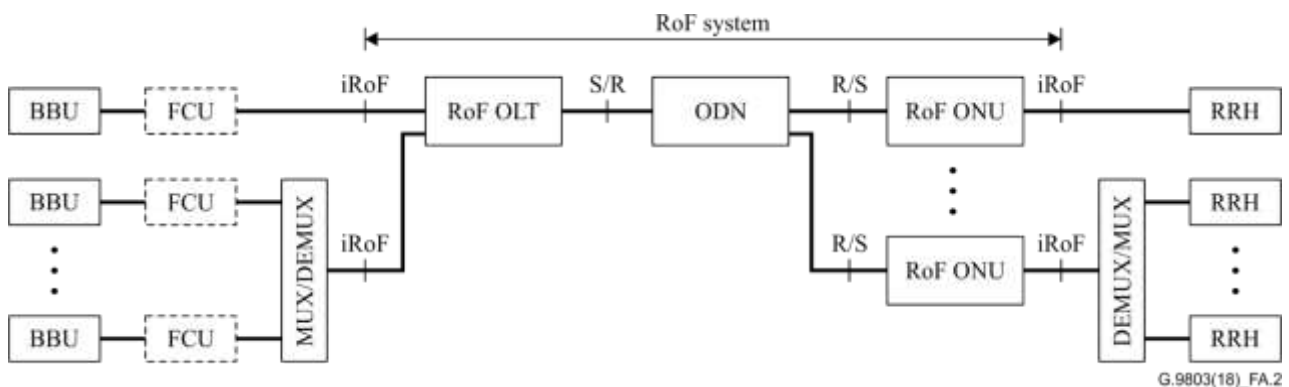
Figure A.2 – Reference architecture of RoF system supporting IMT systems over ODN

A.1.3 Reference configuration

Figure A.3 shows reference configurations of an RoF system. The basic configuration, shown in Figure A.3-a, is composed of an RoF OLT, an RoF ONU, and an ODN connecting them together. This basic setup is the point-to-point configuration. Figure A.3-b shows another point-to-multi point configuration, in which an RoF OLT accommodates multiple RoF ONUs via a single ODN. Figures A.4-a and A.4-b describe reference configurations of cascaded RoF systems. The cascaded RoF systems were configured by connecting the point-to-point and/or point-to-multi-point RoF systems described in Figures A.3 a) and A.3 b) in series.
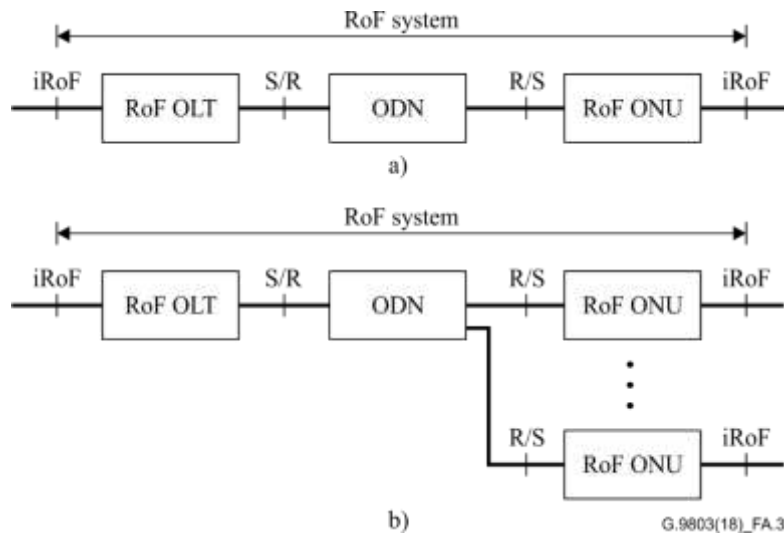
Figure A.3 – Reference configurations of RoF system:
a) point-to-point configuration; and b) point-to-multi-point configuration
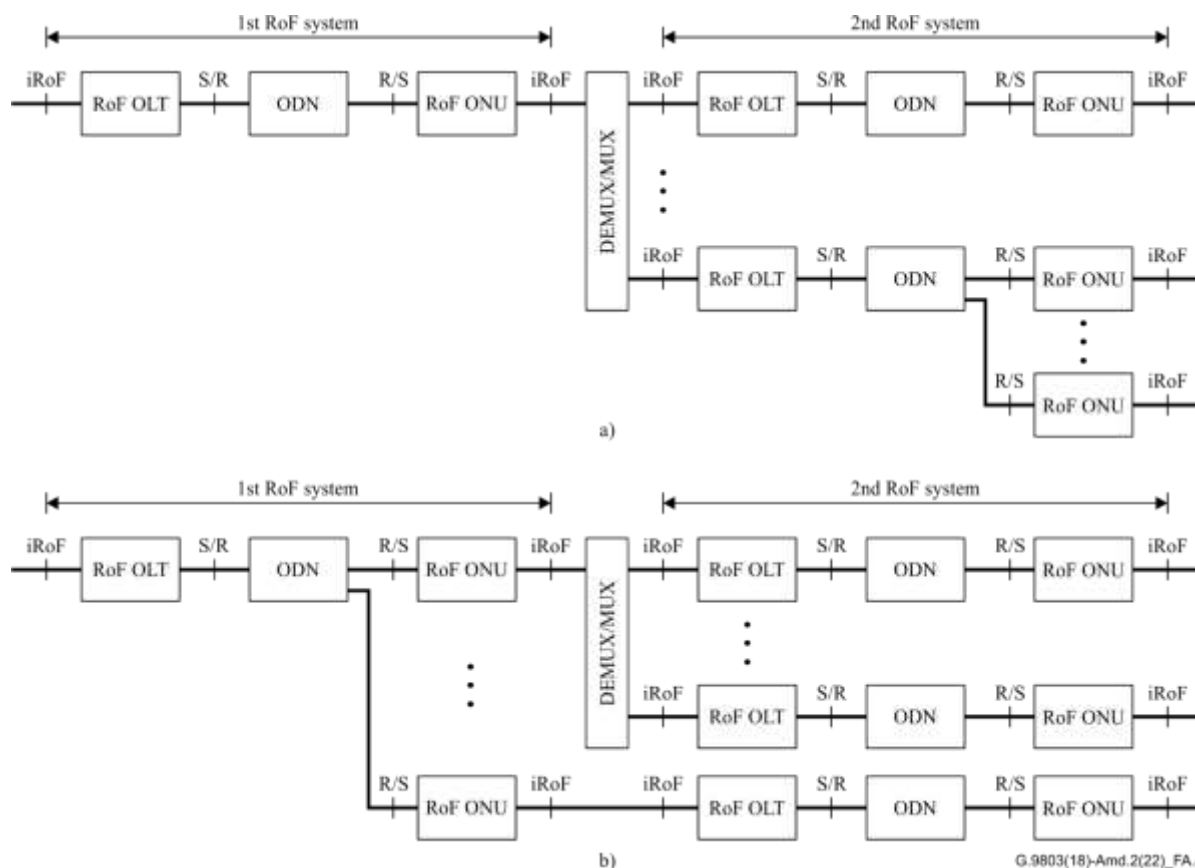
**Figure A.4 – Reference configurations of cascaded RoF system:
a) based on point-to-point ODN; and b) based on point-to-multi-point ODN**

A.1.4 Service node interfaces

An SNI is defined as the interface that includes the following conditions:

– interconnection between BBU and the RoF-based access network;

– described by a well-known standard;

– includes a physical layer aspect.

Examples of SNIs, physical interfaces, and services that they provide are shown in Table A.1.

Table A.1 – Examples of SNI and services supported by RoF systems

SNI (Note 1)	**Physical interface** (Note 2)	**Service** (Note 3)
1GigE/10GigE/40GigE/100GigE [b-IEEE 802.3]	1000BASE/10GBASE/40GBASE/100BASE	Ethernet
[b-ITU-T G.8261], [b-ITU-T G.8262]	–	Synchronous Ethernet
Common public radio interface (CPRI)/(open base station architecture initiative(OBSAI)/ open radio Interface (ORI)	–	IMT-2000, IMT-Advanced and IMT-2020
[b-ITU-R M.1457], [b-ITU-R M.2012]	[b-IEC 60169] based Analogue IF and RF interface	IMT-2000, IMT-Advanced, and IMT-2020
NOTE 1 – There are many other services accommodated in RoF systems, but those services do not have specified SNIs. NOTE 2 – Each item in column "Physical interface" is illustrated by the corresponding entry in column "SNI". NOTE 3 – Column "Service" shows services supported by the physical interface.		

A.1.5 User network interfaces

A UNI is defined as the interface that includes the following conditions:

– interconnection between the RoF-based access network and the RRH;

– described by a well-known standard;

– includes a physical layer aspect.

Some UNIs are provided via an adaptation function, so it is not mandatory for the RoF ONU to support those interfaces. Examples of UNIs, physical interfaces, and services are shown in Table A.2.

Table A.2 – Examples of UNI and services supported by RoF systems

UNI (Note 1)	Physical interface (Note 2)	Service (Note 3)
100 Mbit/s/1 Gbit/s Ethernet [b-IEEE 802.3]	100/1000BASE	Ethernet
[b-ITU-T G.8261], [b-ITU-T G.8262]	–	Synchronous Ethernet
CPRI/OBSAI/ORI	–	IMT-2000, IMT-Advanced and IMT-2020
[b-ITU-R M.1457], [b-ITU-R M.2012]	[b-IEC 60169] based Analogue IF and RF interface	IMT-2000, IMT-Advanced and IMT-2020
NOTE 1 – There are many other services accommodated in RoF systems, but those services do not have specified UNIs.		
NOTE 2 – Each item in column "Physical interface" is illustrated by the corresponding entry in column "UNI".		
NOTE 3 – Column "Service" shows services supported by the physical interface.		

A.2 Physical layer requirements

A.2.1 Transmission medium

This Recommendation is based on the fibre described in [ITU-T G.989.2].

A.2.2 Frequency band

NOTE – For IMT applications, see "Input carrier frequency" and "Output carrier frequency" in Appendix VII for frequency band.

A.2.3 Optical link loss

NOTE – For IMT applications, see "Optical Link Loss" in Appendix VII for optical link loss.

A.2.4 Transmitted/received signal quality

This Recommendation is based on the parameters and specifications described in [b-3GPP TS 36.104] for IMT-advanced services and [b-3GPP TS 38.104] for IMT-2020 services.

A.2.5 Transmitted/received unwanted/spurious emissions

This Recommendation is based on the parameters and specifications described in [b-3GPP TS 36.104] for IMT-advanced services and [b-3GPP TS 38.104] for IMT-2020 services.

A.2.6 Transmitted/received intermodulation characteristics

This Recommendation is based on the parameters and specifications described in [b-3GPP TS 36.104] for IMT-advanced services and [b-3GPP TS 38.104] for IMT-2020 services.

A.3 System requirements

A.3.1 Operation, administration and management function

The RoF ONUs must be remotely manageable and support configuration functions. The RoF system must provide full fault, configuration, accounting, performance, and security (FCAPS) management capability for the RoF ONUs.

In traditional optical access systems, ONU management and control based on ONU management and control interface (OMCI) defined in [b-ITU-T G.988] may be used in the RoF system for RoF ONU management. Appendix VII describes the operation, administration and management (OAM) channel frequency information and its implementation in the frequency domain for the RoF system.

A.3.2 Provisioning

Provisioning refers to the processes involved in the initialization of the attributes and resources on users and network components to provide proper services to a user. The term provisioning, in this Recommendation, refers to the process of configuration and readiness for the management of RoF OLT and RoF ONU. Configuration is generally specified as the process of defining and transporting the provisioning data to the network elements (e.g., RoF OLT and RoF ONU).

A.3.3 Environmental requirements

For indoor use, the RoF system should operate in the operating temperature range defined in [b-IEC 62149-10].

For outdoor use, RoF ONUs should operate in the outdoor temperature range defined in [b-ATIS-0600010.01.2008], [b-Telcordia GR-487], or [b-ETSI ETS 300 019-1-4]. Optionally, the RoF OLT may be able to operate over the extended outside temperature range.

A.3.4 Eye safety

Taking coexistence with other PON systems into account, the total optical power at the point S just after the RoF OLT and RoF ONU should satisfy Class 1M and Class 1 shown in [b-IEC 60825-2], respectively.

A.4 Coexistence with PON

Possible PONs coexisting with RoF are:

– Gigabit-capable passive optical network (GPON);

– 10-Gigabit-capable (symmetric) passive optical network (XG(S)-PON);

– 40-Gigabit-capable passive optical network (NG-PON2).);

– 50-Gigabit-capable passive optical networks (50G-PON).

WDM would be a reasonable method to support the coexistence. If WDM coexistence is selected, the RoF system wavelength plan can be further investigated.

A.4.1 Optical wavelength

The RoF system should support mobile services defined in ITU-R recommendations on IMT-2000 and IMT-Advanced. It should also support fixed network services to provide compatibility with existing PON systems. The RoF system must provide efficient traffic sharing among residential, business, and other customers; and should offer an upgrade to greater bandwidths without foreseeable technology roadblocks or bottlenecks.

An additional factor for determining the RoF system operating wavelength is the wavelength dependent characteristics of commercialized semiconductor optoelectronic devices. It is necessary to consider operating wavelength drift on the laser diode temperature and wavelength dependent responsivity of a photodetector.

Wavelength plans of standardized optical access network systems are shown in Appendix IV. Wavelength plan of the RoF system should be carefully designed by taking into account coexistence requirements with the deployed access networks. It would be possible to use the unoccupied wavelength region as the RoF system operating wavelength. It is also desirable to use a coarse wavelength division multiplexing (CWDM)-based wavelength plan described in [b-ITU-T G.695] for cost-effective deployment and operation of the RoF system.

Annex B

RoF system supporting foreign object debris detection system

(This annex forms an integral part of this Recommendation.)

B.1 System overview

B.1.1 General requirements

RoF system requirements include support for:

– fronthaul link of radar signal transmitter;

– point-to-multi-point topology.

B.1.2 Reference architecture

Figure B.1 illustrates a typical foreign object debris (FOD) detection system supported by an RoF system. To detect several-inch-class debris, it is assumed to use a millimetre-wave-band frequency-modulation continuous-wave (FM-CW) signal for the FOD detection as a radar signal. This system alerts a following airplane immediately after detecting an FOD via an airport traffic control tower. This Annex focuses on an RoF system for distributing the FM-CW signal.
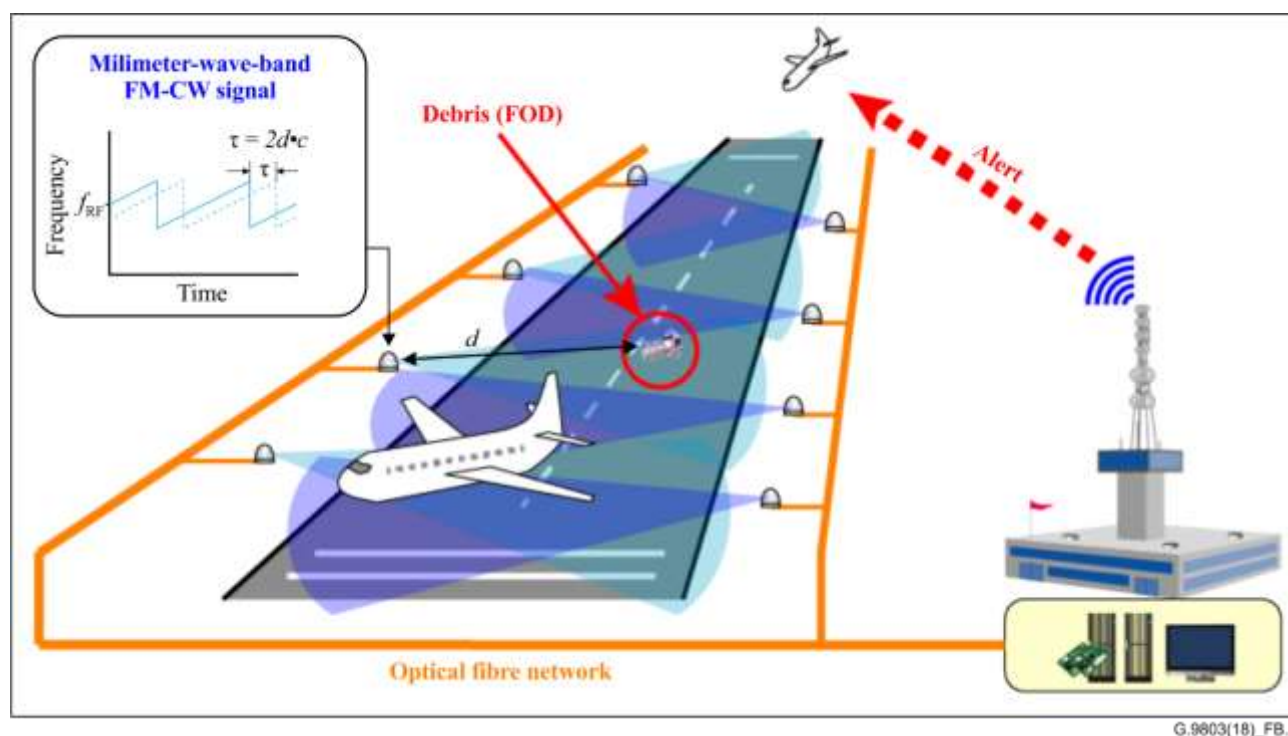
Figure B.1 – A typical FOD detection system supported by an RoF system

A reference architecture of an RoF system is shown in Figure B.2.
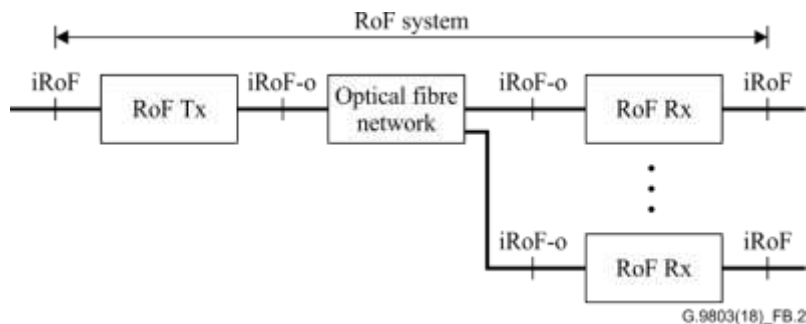
Figure B.2 – Reference architecture of RoF system supporting an FOD detection system

B.2 Physical layer requirements

B.2.1 Functional specifications

For an FOD detection system generating an FM-CW signal with a sweeping range of 92 to 100 GHz, its supporting RoF system specifications are shown in Table VIII.1 of Appendix VIII.

Appendix I

Relationship between fronthaul link and RoF systems

(This appendix does not form an integral part of this Recommendation.)

Figure I.1 shows the fundamental block diagrams of a typical radio transceiver in a BS. The radio transceiver basically consists of a baseband modulation and demodulation processor (M/dMP), frequency conversion processor(s) (FCP(s)), and a radio-frequency-band (RF-band) BEP/FEP. The RF-band BEP/FEP is assumed to be mainly an air-interface function, such as a radio antenna, which may include general functions for signal distortion compensation, such as amplifications, bandpass filtering, equalizations, signal monitoring, etc. As shown in Figure I-1, there are two frequency conversion schemes in the radio transceiver: one is the direct frequency conversion between baseband signal and RF signal (Figure I.1-a), and the other is the multistage frequency conversion between baseband signal and RF signal (Figure I.1-b). In both schemes, there are four major reference points from (A) to (D) shown in Figure I.1, at which the radio transceiver can be functionally separated. Here, it is noted that for general purpose, there is no restriction on either digital or analogue not only for the processors but also for the interfaces at the reference points. Other reference points may be possible if there is a modified configuration of radio transceiver.
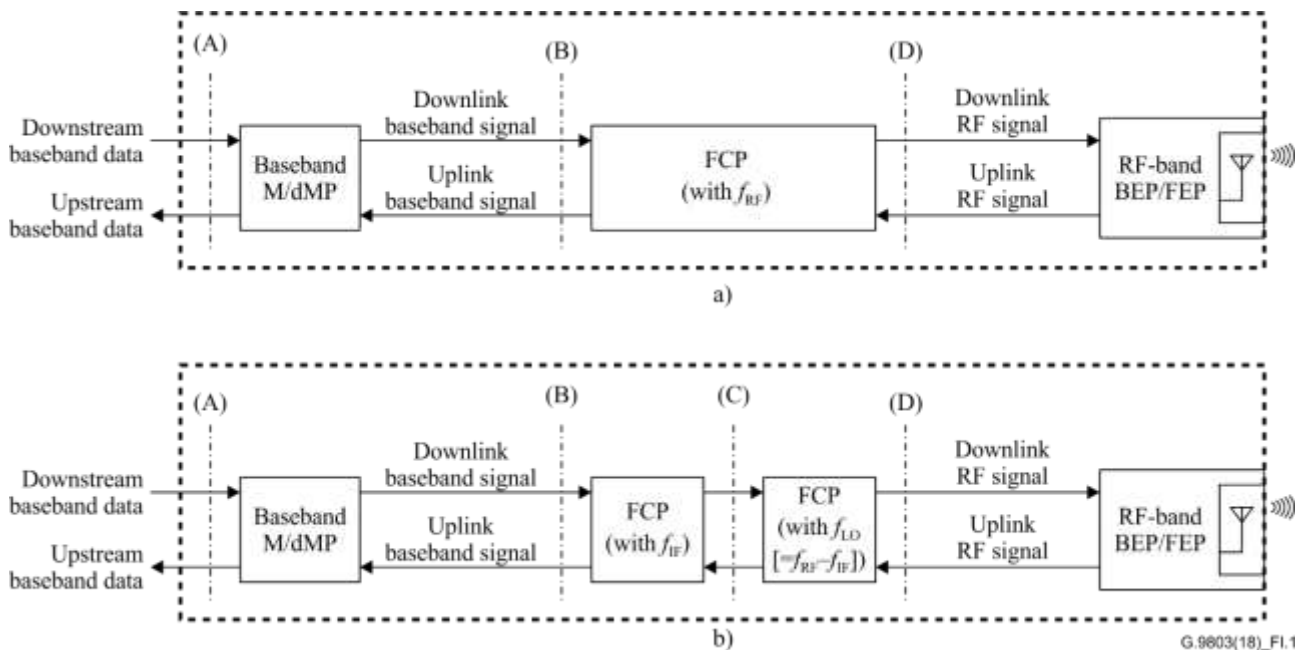
Figure I.1 – Fundamental block diagrams of typical radio transceiver in a BS:
a) direct frequency conversion scheme; b) multistage frequency conversion scheme

(A)   Radio transceiver entrance interface:

   No separation of the radio transceiver is substantively carried out. Therefore, this reference point is a candidate point for making a conventional mobile backhaul link.

   In view of the present situation, it will be natural that this interface is digital.

(B)   Baseband interface:

   This reference point is a candidate of separable points inside of a radio transceiver. In this case, only the baseband M/dMP is located in the network side, and other functions, such as the RF-band FCP (f_{RF}) and the RF-band BEP/FEP, are located in the antenna side.

   When the interface is analogue, the system architecture corresponds to "equivalent low-pass (equivalent baseband) signal(s) transmission". When the interface is digital, on the other

hand, it becomes an equivalent baseband digitized RoF (D-RoF) and corresponds to the system architecture assumed in the existing standards, such as [ITU-T G.989.1], European Telecommunications Standards Institute (ETSI), ORI, CPRI, and OBSAI. The correspondence relationship with these existing standards is summarized in Table I.1.

Table I.1 – Correspondence relationship with existing standards

This Recommendation (in Figure I.1)	Baseband M/dMP	A set of FCP and RF-band BEP/FEP
[b-ITU-T G.989.1]	Baseband unit (BBU)	Remote radio unit (RRU)
ETSI ORI	Baseband unit (BBU)	Radio frequency unit (RFU) or Remote radio head (RRH)
ETSI ORI, CPRI	Radio equipment control (REC)	Radio equipment (RE)
OBSAI	Baseband block (BB)	Radio frequency block (RFB)

(C)   Intermediate frequency band interface:

This reference point is a candidate of separable points inside of a radio transceiver. In this case, the baseband M/dMP and the intermediate-frequency-band (IF-band) FCP (f_{IF}) is located in the network side, and the RF-band FCP (f_{LO} [$= f_{RF}-f_{IF}$]) and the RF-band BEP/FEP are located in the antenna side.

When the interface is analogue, the system architecture corresponds to an IF-band "subcarrier signal(s) transmission". When the interface is digital, on the other hand, it becomes an IF-band D-RoF.

(D)   Radio frequency band interface:

This reference point is a candidate of separable points inside of a radio transceiver. In this case, almost all functions, such as the baseband M/dMP and the RF-band FCP (f_{RF}), are located in the network side, and only the RF-band BEP/FEP is located in the antenna side. Therefore, it is expected that the configuration in the antenna side becomes the simplest.

When the interface is analogue, the system architecture corresponds to an RF-band "subcarrier signal(s) transmission". When the interface is digital, on the other hand, it becomes an RF-band D-RoF.

From the above, not only point (B) but also points (C) and (D) are candidates of separable points inside of a radio transceiver. Figure I.2 illustrates "fronthaul link" in a typical radio access network (RAN). In this figure, a BBU with a function of M/dMP represents one partial radio TRx located in the network side. A RRH represents the other partial radio TRx located in the antenna side. An FCU with a function of FCP may be optionally equipped within each partial radio TRx (i.e., BBU and RRH). The RoF system in Figure I.2 is a strong candidate for providing the front-haul link.
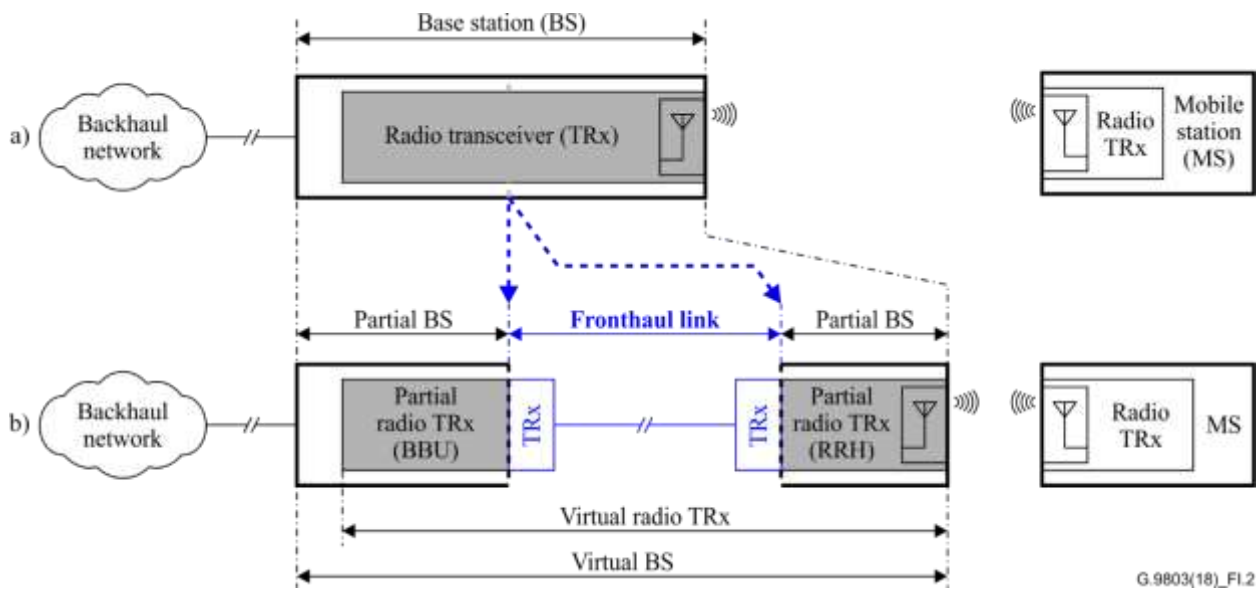
Figure I.2 – Fronthaul link in RAN:
a) conventional architecture; and b) possible architecture with fronthaul link

Appendix II

Use cases

(This appendix does not form an integral part of this Recommendation.)

II.1   Multiservice RoF system

Figure II.1-a shows a multiservice RoF system. This system consists of a multiservice RoF OLT, an ODN, and multiple RoF ONUs. The multiservice RoF OLT is located at the central office with connections to multiple BBUs corresponding to the number of services employed. Multiple BBUs correspond to the service provider's various core networks for different services. RRHs connect RoF ONUs and antennas. Another possible configuration is shown in Figure II.1-b. The system consists of BBUs that are directly connected to their corresponding RoF OLTs before being combined for transmission.

In Figures II.1-a and II.1-b, the functions of ODN and RoF ONUs are the same as those in Figure A.1. In both configurations, the multiservice RRH typically contains circuit board, RF amplifiers and frequency converters, and antennas. Here, different antennas correspond to the number of different services offered by the RoF system.
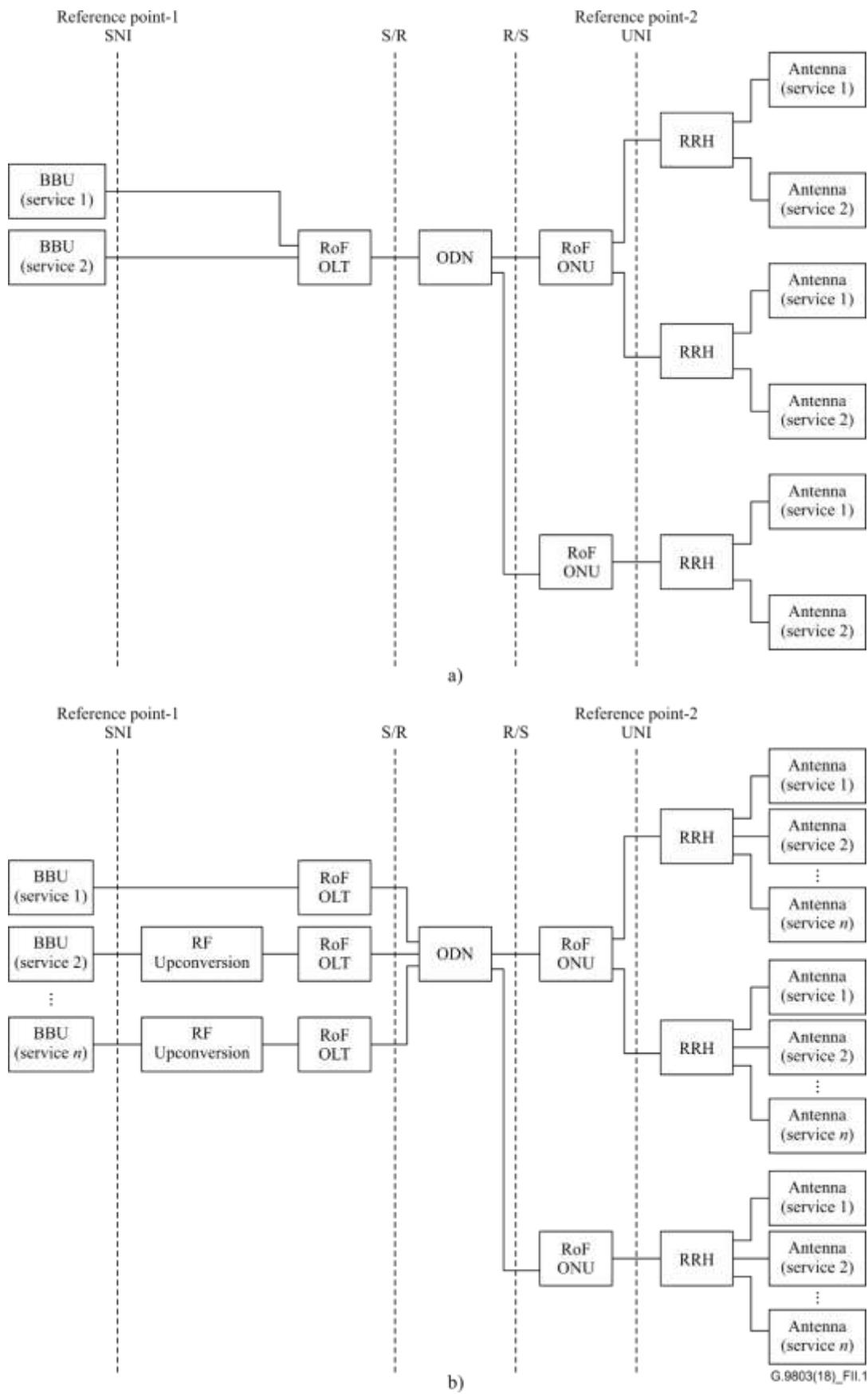
Figure II.1 – Multiservice RoF system architecture in a) single RoF OLT configuration; b) multiple RoF OLT configuration

II.2 Multiservice RoF system for indoor DAS applications

The multiservice RoF system configuration in Figure II.2 includes the conventional RoF system elements as proposed in Figure A.1 and a distribution point for indoor distributed antenna system (DAS) application. In Figure II.2-a, the multiservice RoF OLT is located at the central office with connections to multiple BBUs corresponding to the number of services employed. Multiple BBUs correspond to the service provider's various core networks for different services (e.g., triple-play, long term evolution (LTE), WiFi). Alternatively, Figure II.2-b presents the system with BBUs that are directly connected to their corresponding RoF OLTs before being combined for transmission.

The two configurations shown in Figures II.2-a and II.2-b correspond to two different deployment scenarios for an operator.

–   In Figure II.2-a, a single RoF OLT is shared among different services. This is applicable for an operator that has small amounts of customers in a site, or for an operator that experiences link budget problem and would not be able to introduce additional combiners.

–   In Figure II.2-b, multiple RoF OLTs are used according to the services being transmitted, where Triple-play could be connected via service 1, LTE via service 2, and WiFi via service 3. This scenario is applicable when a large number of users are connecting to the system within a site, where dedicated RoF OLTs are required. Alternatively, this scenario is applicable for an operator capable of sustaining the link budget incurred from the additional combiner in the ODN.

In certain scenarios, there are frequency up/down converters within the RRH unit.
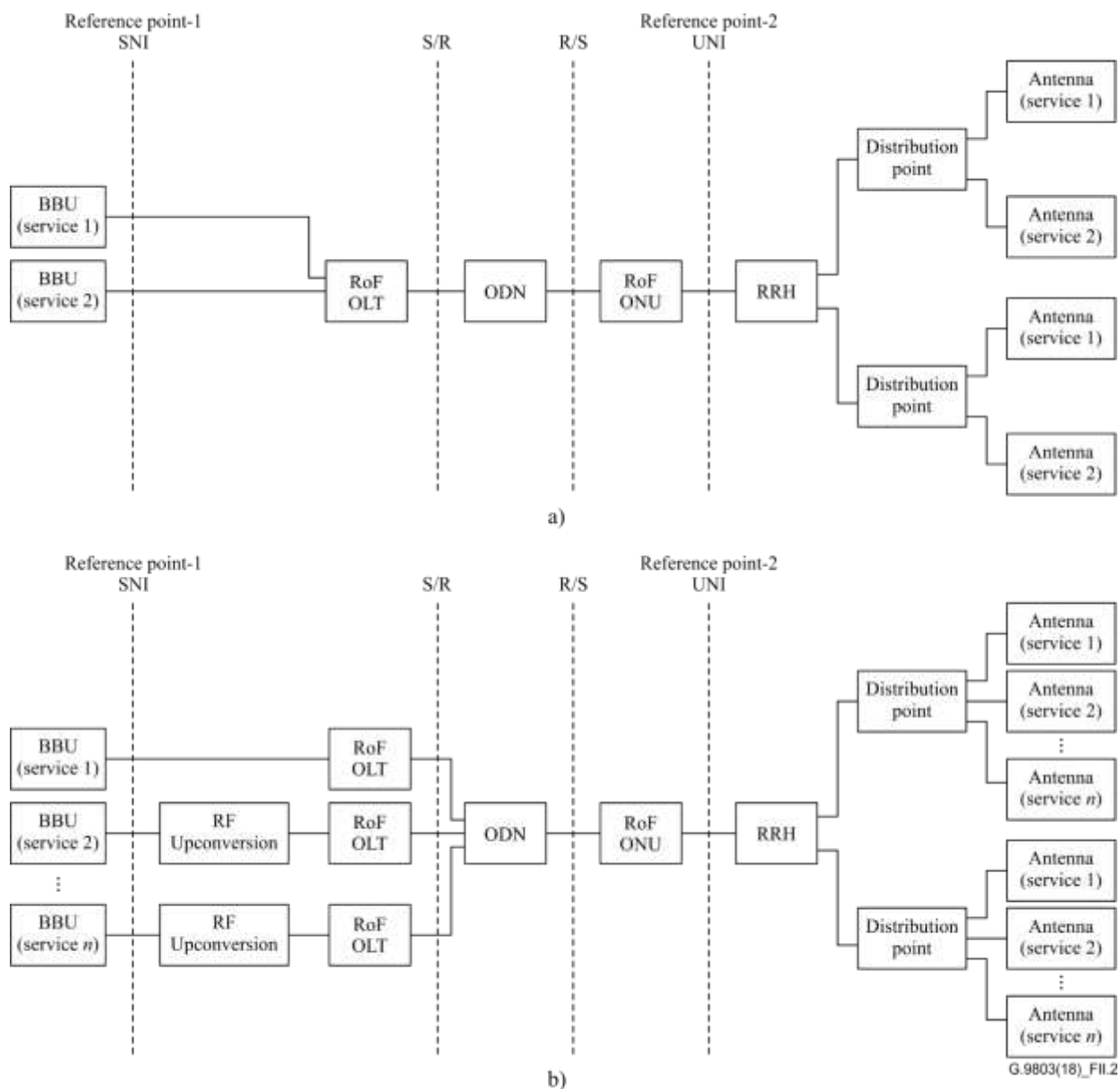
Figure II.2 – Multiservice RoF system architecture for Indoor DAS, where a) is single multiservice RoF OLT configuration; and b) is multiple RoF OLT configuration

In Figures II.3-a and II.3-b, the systems are reconfigured after the RRH. The last-mile wireless connectivity between RRH and outdoor unit (ODU)-indoor unit (IDU) at customers' premise, is established to allow wireless link transmission, for the optical fibre deployment is not practical or requires extremely high capital expenditure (CAPEX). The distribution point shown in Figure II.2 is renamed as ODU/IDU in Figure II.3, as it becomes more complex than a simple distribution point. Examples of possible bands are shown in Appendix VI.2.

Figure II.3 – Use cases for a) single multiservice RoF OLT configuration; and b) multiple RoF OLT configuration

After the UNI, the ODU-IDU is connected to the user equipment (UE)/residential gateways (RG) wirelessly. Since the frequencies for the individual services received from RRH is at high frequency, the ODU-IDU adaptively converts the frequencies according to an operator's licenced spectrums for indoor distribution. Furthermore, with ODU-IDU, the need for multiple customer premise equipment (CPE) is eliminated, thus results in easy installation and operation. Frequency band of the indoor wireless links between the ODU-IDU and the UE/RG is shown in Appendix VI.2.

II.3 RoF system architecture including head-end and remote units for indoor DAS applications

The RoF system architecture for indoor DAS applications is shown in Figure II.4. It includes the conventional RoF system elements as described in Figure A.1. For indoor DAS application, the head-end (host) units, the remote units, and the distribution points are added to the general RoF system architecture. In Figure II.4, the RoF OLT is located at the central office with connections to multiple BBUs corresponding to the number of services employed. The BBUs correspond to service provider's various core networks applied for different services (IMT-2000, IMT-Advanced, IMT-2020, etc.).

The RoF OLT is connected to the RoF ONU via the ODN. The RoF ONU is usually placed near the RRH. To alleviate the shadowing effect of radio signals in the indoor environment, the head-end (host) units, distribution points, and the remote units are positioned in the indoor area. Table II.5 summarizes the purpose and the function of the head-end unit and remote unit. The head-end unit receives mobile data signals from the RRH and distributes them to a number of remote units through a distribution point. Proper signal reshaping procedure is also required for the purpose of signal distribution in the head-end unit. The distribution points are composed of optical/RF splitters or optical/RF combiners. They split or combine the mobile signals between two or more signal paths. The remote unit feeds mobile data signals to each antenna. The remote unit delivers the wireless signal with predetermined RF carrier to the antenna depending on the typical service types.
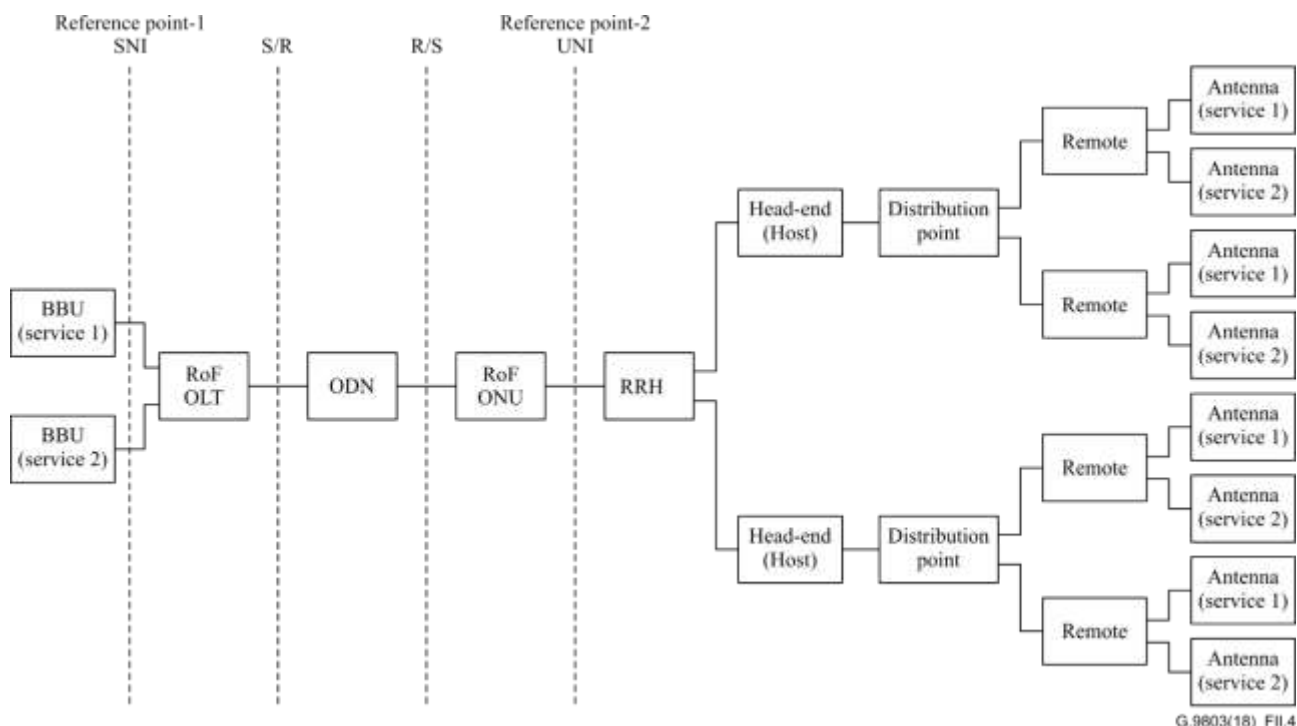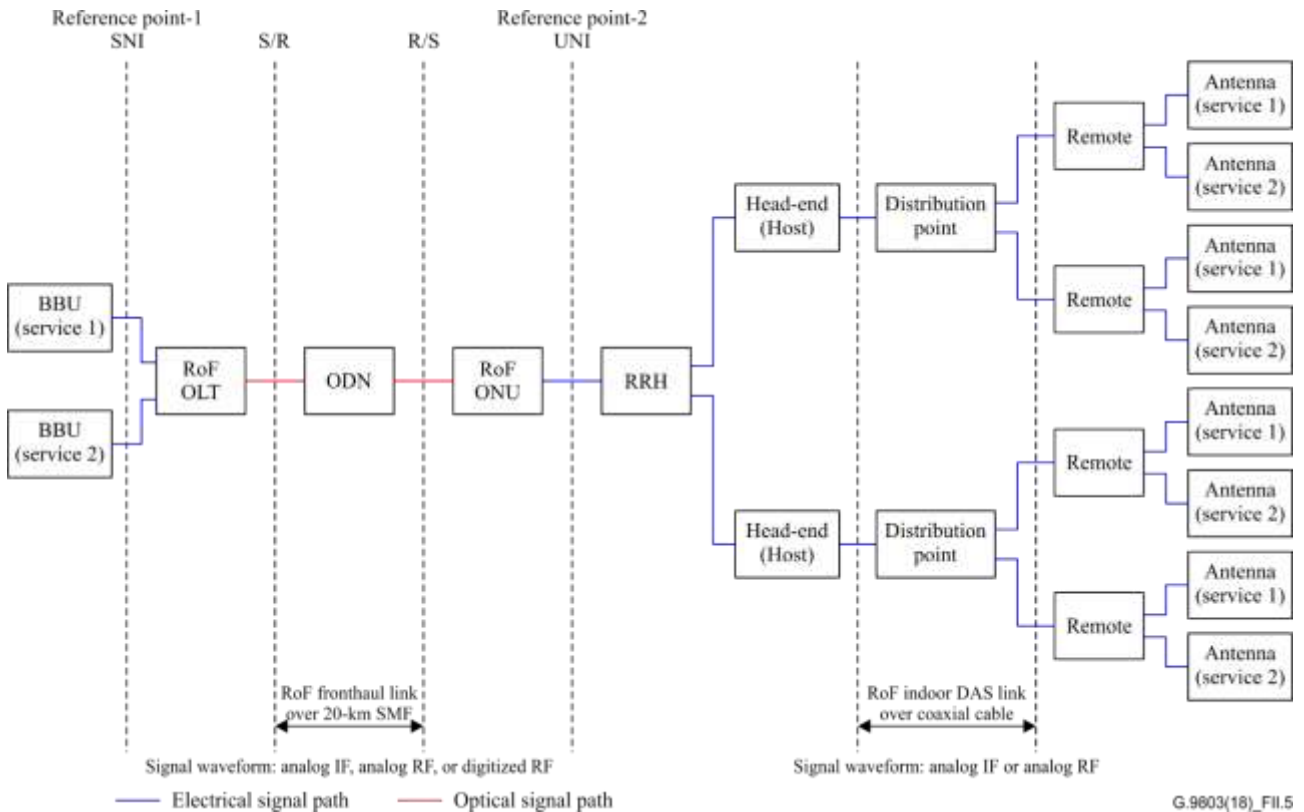

**Figure II.4 – RoF system architecture including head-end and remote units
for indoor DAS applications**

Table II.5 – The purpose and the function of the head-end unit and remote unit

	Head-end unit	Remote unit
Purpose	– physical link interface between RRH and antenna via remote unit – signal reshaping to consider distribution point – distribution of timing and frequency synchronization signal – delay correction caused by each antenna position with different distances from head-end	– physical link interface between head-end unit and antenna – high power amplification for downlink and proper signal reshaping for uplink – reception of timing and frequency synchronization signal
Function	– electrical to optical conversion or vice versa (when employing optical fibre as transmission media) – RF (licensed carrier) to IF (unlicensed carrier for optical transmission) conversion or vice versa (when employing optical fibre as transmission media) – Remote unit and antenna management	– optical to electrical conversion or vice versa (when employing optical fibre as transmission media) – IF (unlicensed carrier for optical transmission) to RF (licensed carrier) conversion or vice versa (when employing optical fibre as transmission media) – dedicated antenna management

In general, mobile signals could be transmitted over coaxial cable or optical fibre between the RRH and the antenna in an indoor environment, as shown in Figure II.5. In Figure II.5, the optical signal path and electrical signal path are illustrated separately. Even though it is possible to deliver mobile signals via copper cable in a small office or residential area, it is difficult to transmit mobile signals with licensed carrier through a coaxial cable in large buildings, long tunnels or large stadiums because of relatively longer transmission distances. In addition, the received signal power at the antenna is relatively low due to the existence of distribution point such as RF power splitter. As a result, the service provider cannot offer appropriate quality of service to many users. For indoor DAS applications, it is required to manage delay caused by path length difference between antenna positions. To prevent the above-mentioned problems, it is necessary to employ the head-end units and remote units for indoor DAS applications.

Figure II.5 – RoF system architecture for indoor DAS applications using coaxial cable in the indoor DAS environment

Optical transmission should also be carefully considered for indoor DAS applications. When optical fibre is deployed for configuring an indoor DAS link, the revised RoF system architecture is shown in Figure II.6. In Figure II.6, two RoF systems are connected in series. The functions of RoF OLT and head-end unit are quite different. Table II.6 summarizes these functional differences.

Table II.6 – Functional differences between RoF OLT and head-end unit

	RoF OLT	Head-end unit
Function	– electrical to optical conversion or vice versa – delivering optical mobile data to RoF ONU via ODN which includes single mode optical fibre and optical splitter – physical link interface between BBU and ODN (the output of BBU is analogue IF, analogue RF or digitized RF signal) – all of the control and management function is dedicated to BBU so the RoF OLT has no control and management function	– electrical to optical conversion or vice versa (if transmission media is optical fibre) – there is no optical/electrical conversion (if transmission media is coaxial cable) – signal reshaping (compensating the link loss caused by distribution point) – deliver mobile data signal to remote unit via distribution point which comprised of RF power splitter or optical power splitter – physical link interface between RRH and antenna via remote unit (the output of RRH is normally analogue RF signal, so frequency up/down conversion function should be needed) – delay correction caused by each remote unit position with different distances from head-end – Remote unit and antenna management
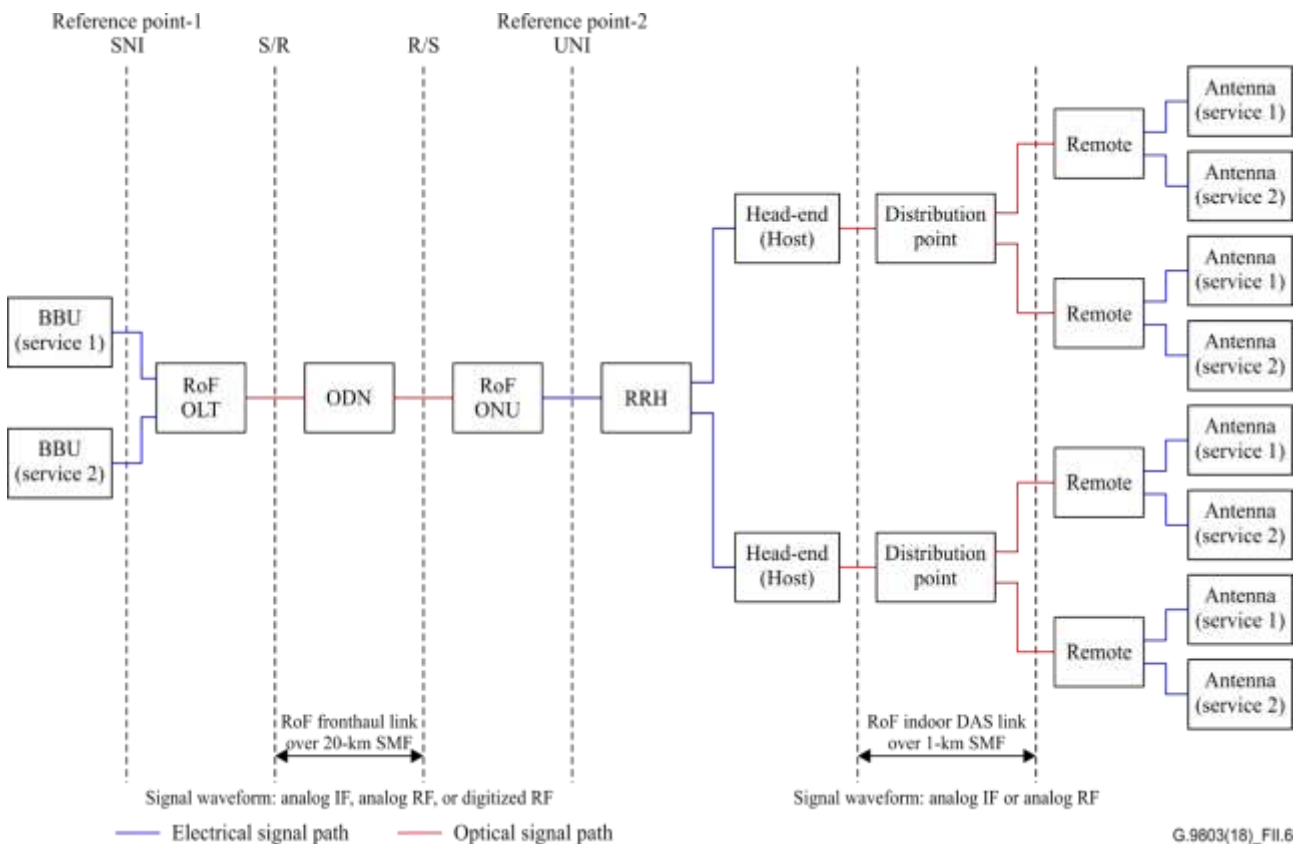
Figure II.6 – RoF system architecture for indoor DAS applications using optical fibre in an indoor DAS environment

In order to remove the shadow areas of radio signals in large buildings, long tunnels and big stadiums and to provide a high-quality of service to each user, it is essential to utilize optical fibre as a transmission medium in indoor DAS environment. However, as shown in Figure II.6, the transmission distance of the RoF fronthaul link and the RoF indoor DAS link is quite different. In addition, the elements and interfaces of each link and the types of signals that can be accommodated are different.
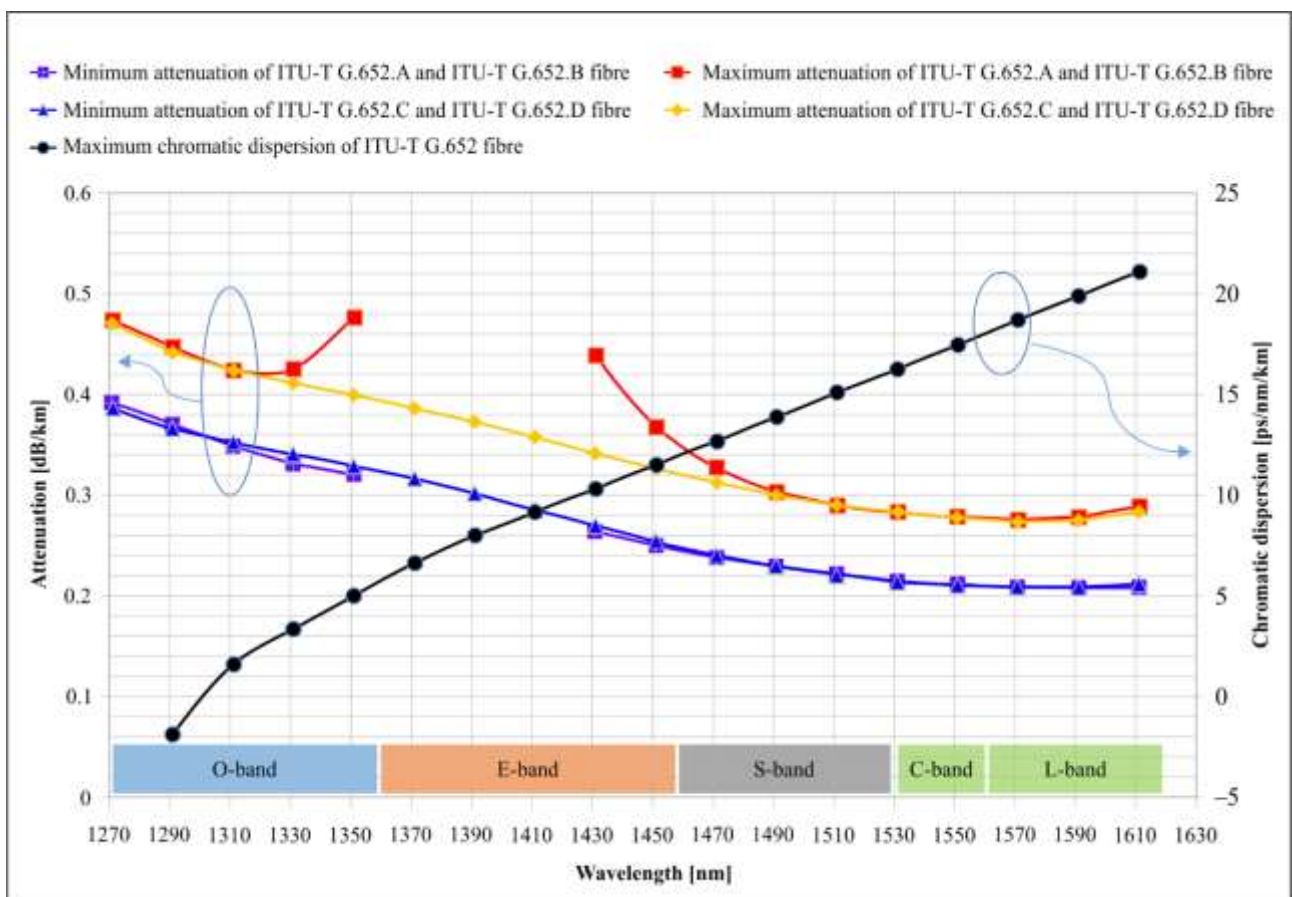
Appendix III

Fibre characteristics

(This appendix does not form an integral part of this Recommendation.)

Figure III.1 shows the attenuation and the chromatic dispersion (CD) of [b-ITU-T G.652] single mode fibre (SMF) over the defined ITU-T bands. Attenuation is the reduction in the optical power of light having traversed the fibre. It is expressed as a ratio in decibel units per kilometre fibre distance. As shown in Figure III.1, the attenuation of an optical signal is wavelength dependent and is lowest in the C-band and lower L-band. CD is a physical phenomenon comprising the dependence of the phase or group velocity of a light wave in the fibre, on its propagation characteristics such as optical wavelength. CD will limit the RoF system reach as signal line rate or carrier frequency increases. As shown in Figure III.1, CD is wavelength dependent, and it is has a zero value at less than about 1310 nm for SMF. When the RoF system employs directly modulated laser diode as a light source, its performances are seriously degraded by the nonlinear distortions due to the interplay between the chirp of laser diode and CD of SMF. The value of CD is raised as the wavelength increases. In order to design the link budget and select the operating wavelength of the RoF system, it is necessary to carefully consider the fibre characteristics of attenuation and CD.

See also clause 8.4 in [b-ITU-T G.989.1].

Figure III.1 – Attenuation and chromatic dispersion of single mode fibre

Appendix IV

Wavelength plan of conventional optical access network systems

(This appendix does not form an integral part of this Recommendation.)

Wavelength plans of conventional PON systems are illustrated in Figure IV.1.
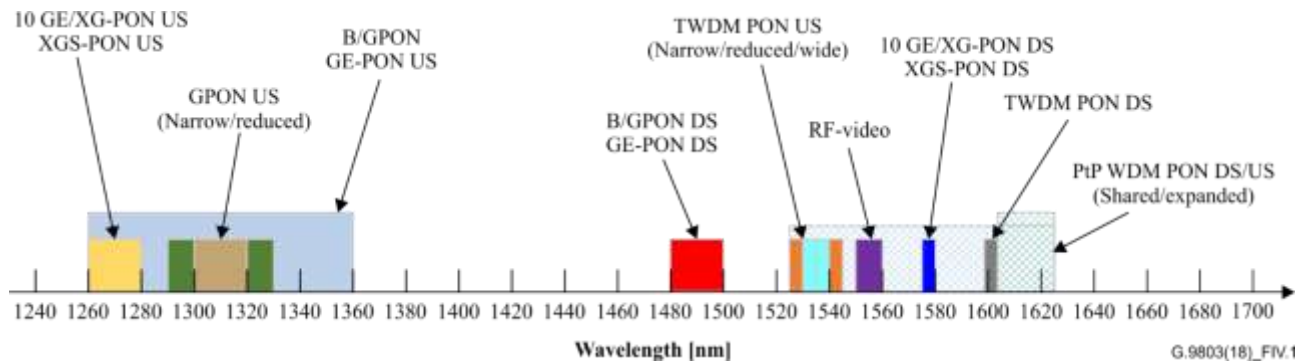
See also Appendix I in [ITU-T G.989.2].

Figure IV.1 – Wavelength plans of optical access network systems

Appendix V

Possible services supported by RoF systems

(This appendix does not form an integral part of this Recommendation.)

RoF systems have the potential to support various services for mobile users, residential subscribers, business customers, mobile and fixed backhauling, and other applications. Mobile services defined in ITU-R recommendations on IMT-2000 and IMT-Advanced are basically supported by RoF systems. Table V.1 summarizes examples of current and future mobile services supported by RoF systems.

Table V.1 – Examples of current and future mobile services supported by RoF systems

No.	Service	Remarks
1	Messaging	Messaging services (e.g., SMS, MMS, e-mail) exchange messages between user terminals. Video messaging service is comparable to voicemail with a video accompanying the voice message.
2	Voice telephony	Voice communication involving two or more parties that includes features such as call waiting, conference calling, voicemail, message waiting indication, caller ID and calling name ID. Voice over IP (VoIP) is a form of voice telephony service. See [b-ITU-T H.323].
3	High-quality video telephony	High-quality video telephony is full-duplex, realtime audiovisual communication between or among end users. It may be provided as a complement of traditional voice telephony service. See [b-ITU-T H.100], [b-ITU-T F.703], [b-ITU-T F.724].
4	Video conference	Video conference is full-duplex, realtime audiovisual communication between or among end users. See [b-ITU-T H.140], [b-ITU-T F.702], [b-ITU-T F.733].
5	Internet browsing	Internet browsing is accessing Internet pages to get information. It mainly involves communication between UE and an information server/content provider.
6	Interactive gaming	Interactive gaming services mainly involve data transferred between multiple users that are connected to a server, or directly between the equipment of multiple users. Realtime communication with low delay and low jitter may be required for interactive gaming.
7	File transfer/download	File transfer/download is the act of transferring a file electronically from one network element to another.
8	Multimedia	Multimedia is media that uses multiple forms of information content and information processing (e.g., text, audio, graphics, animation, video, interactivity) to inform or entertain the audience (user). Multimedia communication is an essential element of various application services described in this section which are to be supported by IMT. See [b-ITU-T F.700], [b-ITU-T F.701], [b-ITU-T F.741].
9	Mobile broadcasting/multicasting	Mobile broadcasting is one to many transmission of multimedia content (e.g., text, audio and video) over the mobile networks. This includes mobile instant and interactive content/TV is the ability to interact with an audio/video programme by exchanging multimedia information.

Table V.1 – Examples of current and future mobile services supported by RoF systems

No.	Service	Remarks
10	IoT (Internet of Things)	Every object is being and will be connected through wired or wireless internet technologies. These connected "things" can be smart phones, sensors, actuators, cameras, vehicles, etc., ranging from low-complexity devices to highly complex and advanced devices. A significant number of connected devices are expected to use IMT systems. Smart energy distribution grid system, agriculture, healthcare, vehicle-to-vehicle and vehicle-to-road infrastructure communication are generally viewed as potential fields for further growth of the IoT.
11	Mobile commerce	Mobile commerce is buying and selling of goods and services through wireless handheld devices, such as cellular telephone and personal digital assistants. It mainly involves data transferred between UE and financial servers connected with secured databases. This service also enables the realtime sharing and management of information on products, inventory, availability, etc. This service requires a high level of reliability.
12	Public alerting	Public alerting enables emergency management officers to quickly notify all residents and emergency response teams, within a defined area of hazardous situations, such as chemical spills, power outages, weather warnings and other potential life-threatening events. Location, device screen characteristics and a feedback mechanism may be required as an enhanced public alerting service.
13	Priority service	Priority service provides qualified users with priority access to radio resources and network resources to help increase call completion rates, especially during periods of congestion or emergency.
14	Location-based services	Location-based services, which depend on the present location of a user, enable users to find other people, vehicles, resources, services or machines.

RoF systems also have the potential to support various fixed network services to provide compatibility with existing PON systems such as GPON, 10-Gigabit-capable passive optical network (XG-PON) and NG-PON2. Table V.2 summarizes examples of fixed network services supported by RoF systems.

Table V.2 – Examples of fixed network services supported by RoF systems

No.	Service		Remarks
1	Telephony	VoIP	
2		Plain old telephone service (POTS)	Mean signal transfer delay time between T-V (or (a)-V) should be less than 1.5 ms. If echo cancellation is used in the network, the mean signal transfer delay time between T-V (or (a)-V) on the PON-based system may be longer, provided end-to-end transfer delay requirements are met. 8 kHz reference has to be provided. Signal on the T reference point and V reference point must be continuous. Emulation and/or simulation, as defined in [b-ITU-T Y.2201], is assumed. E.g., packetized voice at ONU.
3	TV (realtime)	Internet protocol TV (IPTV)	To be transported using IP multicast/unicast
		Digital TV broadcasting	Transported using RF-video overlay. See [b-ITU-T G.983.3], [b-ITU-T J.185] and [b-ITU-T J.186].
4	Leased line	T1	Bearer rate is 1.544 Mbit/s. Mean signal transfer delay time between T-V (or (a)-V) should be less than 1.5 ms. Emulation is assumed primarily.
5		E1	Bearer rate is 2.048 Mbit/s. Mean signal transfer delay time between T-V (or (a)-V) should be less than 1.5 ms. Emulation is assumed primarily.
6	High speed Internet access		UNI is typically Gigabit Ethernet. See [b-IEEE 802.3].
7	Mobile backhaul		Accurate frequency/phase/time synchronization should be supported. See [b-ITU-T G.810], [b-ITU-T G.813], [b-ITU-T G.8261], [b-ITU-T G.703], and [b-ITU-T G.8262].
8	L2 virtual private network (VPN) services		Services such as Ethernet services, with latest metro Ethernet forum (MEF) carrier Ethernet 2.0 extension, etc. See [b-MEF 6.1].
9	IP services		Services such as L3 VPN, and VoIP, etc.

Appendix VI

Examples of frequency bands for radiocommunication systems

(This appendix does not form an integral part of this Recommendation.)

VI.1   Frequency bands for IMT systems

VI.1.1   Frequency bands defined in [b-ITU-R M.1036-5]

–   450-470 MHz

–   698-960 MHz

–   1,710-2,025 MHz

–   2,110-2,200 MHz

–   2,300-2,400 MHz

–   2,500-2,690 MHz

–   3,400-3,600 MHz

VI.1.2   Frequency bands defined in 3GPP Release 15 for IMT-2020 service

–   FR-1: 450-6000 MHz

–   FR-2: 24,250-25,600 MHz

VI.2   Frequency bands for IEEE 802.11ac systems

–   5,800 MHz

VI.3   Frequency bands for last-mile wireless connectivity

–   Ku-band:

  –   14-16 GHz

–   Local multipoint distribution system (LMDS) / K-band:

  –   27.5-28.35 GHz

  –   29.1-29.25 GHz

  –   31-31.075 GHz

  –   31.075-31.225 GHz

  –   31.225-31.3 GHz

–   V-band:

  –   57-65 GHz

–   Other millimeter-wave bands:

  –   66-76 GHz

  –   81-86 GHz

VI.4   Frequency bands for radiolocation systems (candidate)

–   92-100 GHz

VI.5   Frequency bands for railway radiocommunication systems (candidate)
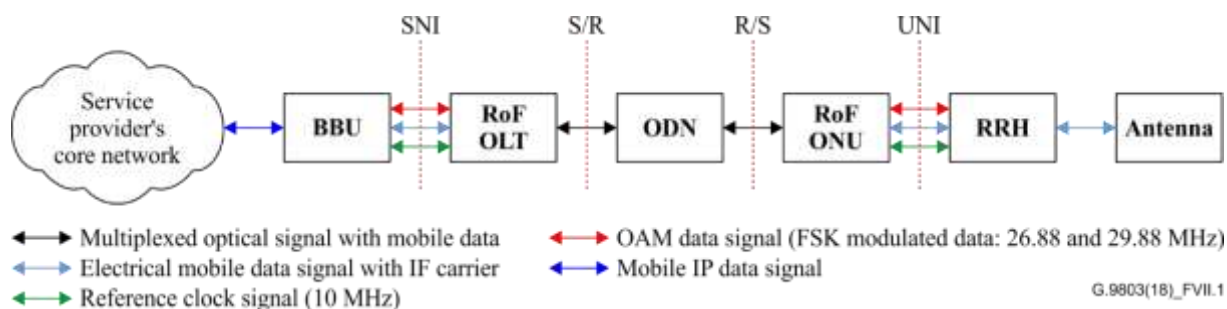
–   92-94 GHz

–   94.1-100 GHz

–   102-109.5 GHz

Appendix VII

Example system interface specifications for Annex A

(This appendix does not form an integral part of this Recommendation.)

Figure VII.1 illustrates the RoF system configuration supporting international mobile telecommunication (IMT) system ODN. This configuration is based on the A.1.2 Reference architecture.

Figure VII.1 – RoF system configuration supporting IMT system over ODN

System interfaces and signal flows inside the RoF system are also depicted in Figure VII.1. At the SNI and UNI interfaces, three types of signals are transmitted. They are the electrical mobile data signal with IF carrier, the reference clock signal (10 MHz), and the OAM data signal. At the S/R and R/S interfaces, wavelength or frequency multiplexed optical signals with mobile data are transmitted over ODN. The physical layer requirements are shown in Table VII.1.

Table VII.1 – Example system interface specification

Items	Specifications	
	Downlink	**Uplink**
Input carrier frequency @ SNI & UNI (intermediate frequency)	150,170,270,290,390,410,510,530,630,650,750,770 MHz (12IF)	
Output carrier frequency @ SNI & UNI (intermediate frequency)	150,170,270,290,390,410,510,530,630,650,750,770 MHz (12IF)	
Each carrier bandwidth @ SNI & UNI	1.4, 3, 5, 10, 20 MHz	
Reference frequency for up/down conversion @ SNI & UNI	10 MHz	
OAM channel frequency @ SNI & UNI	Below 100 MHz (ex: 26.88 MHz downlink frequency-shift keying (FSK), 29.88 MHz uplink FSK)	
System input level (total power) @ SNI & UNI	−10 dBm	−10 dBm
System output level (total power) @ SNI & UNI	−10 dBm	−10 dBm
Gain (from SNI to UNI or vice versa)	0 dB	0 dB
Optical modulation index (OMI) per channel @ S/R or R/S	~ 0.1 (typ.)	

**Table VII.1 – Example system interface specification**

Items		Specifications	
		Downlink	Uplink
Ripple @ SNI & UNI		±1.0 dB Max.	
Optic wavelength @ S/R or R/S (support for multi operator or multi service)	DL0	1550 nm ±7.5 nm	
	DL1	1570 nm ±7.5 nm	
	UL0	1510 nm ±7.5 nm	
	UL1	1530 nm ±7.5 nm	
Optic link loss between S/R and R/S		0 ~ 10 dB	
Operating temp		−20 ~ +60℃	
Gain variation with temp @ SNI & UNI		3 dBp-p@−20~+60℃	
Optical power/channel @ S/R or R/S		+5 dBm ± 1.5dB (Typ)	
TX↔RX isolation @ SNI & UNI		Above 50 dBc/max gain	
Noise floor @ SNI & UNI		−130 dBm/Hz	
Transmission medium		Optical fibre described in [ITU-T G.989.2]	

For better understanding the parameters and specifications shown in Table VII.1, the internal system interfaces of RoF OLT and RoF ONU are shown in Figure VII.2. The RoF OLT and RoF ONU employ dual wavelength up- and downstream transmission system to accommodate multi operators or multi services. This simultaneously offers RoF system provisioning. For frequency up-/down conversion at the RRH, a reference clock signal of 10 MHz is transmitted from the RoF OLT to the RoF ONU. For the purpose of OAM, FSK modems are equipped in an RoF OLT and RoF ONU. IF carrier with OAM data for up- and downlink is set to 26.88 MHz, and 29.88 MHz, respectively.
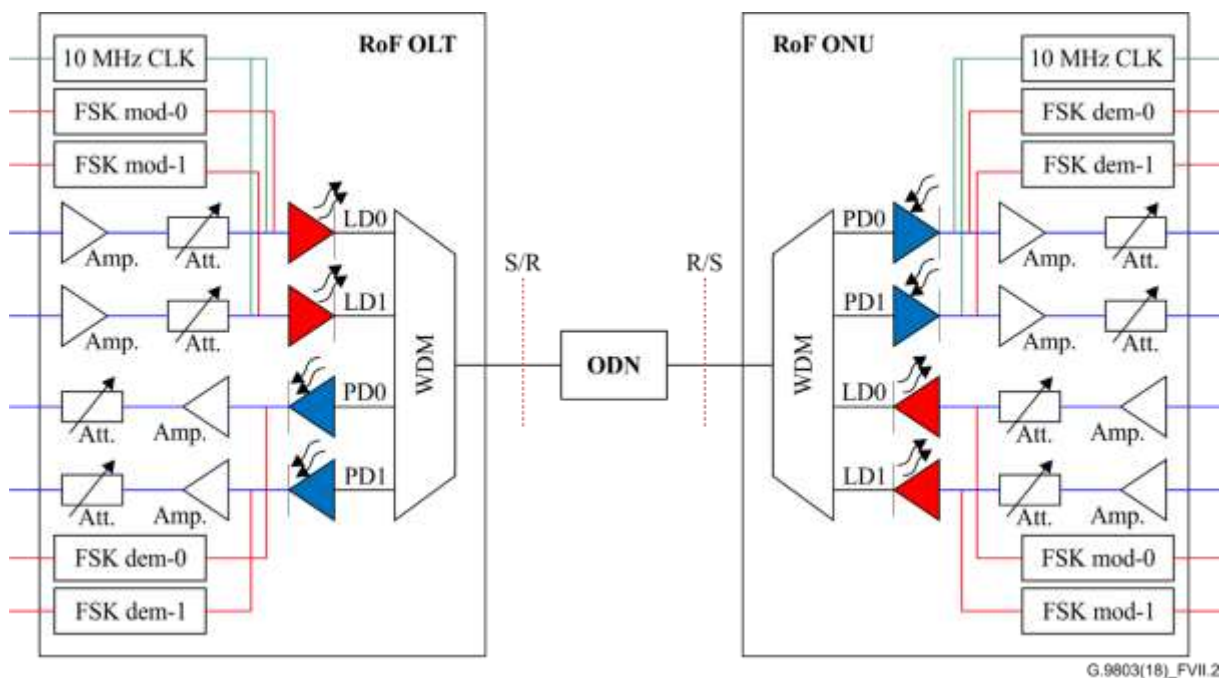
Figure VII.2 – Internal system interface of RoF OLT and RoF ONU

The IF frequency plan is shown in Figure VII.3. The adjacent two IF carriers are employed for supporting two carrier aggregation (CA). Four IF carriers are utilized for the 2x2 MIMO configuration. The three sectors are configured by four IF carriers.
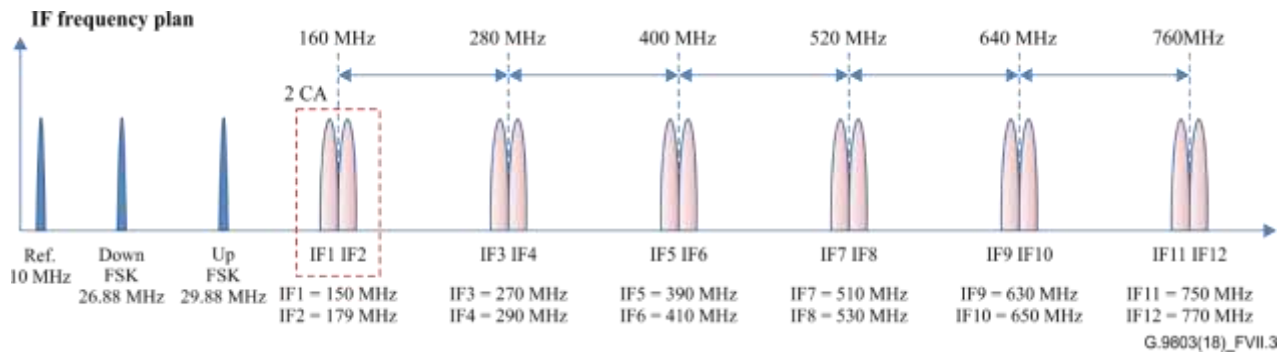
Figure VII.3 – IF frequency plan for specific example of RoF system supporting IMT system over ODN

For physical layer OAM purpose, some OAM parameters, their functions and their appropriate ranges are described in Table VII.2. In order to deploy and operate the RoF system supporting IMT system over ODN, it is proposed to refer these physical OAM parameters, their functions and their appropriate ranges.

**Table VII.2 – OAM parameters, their function descriptions and their ranges
for RoF OLT & RoF ONU**

Physical layer OAM parameters and their appropriate ranges for RoF OLT & RoF ONU				
Parameter	Function	Ranges	Unit	Comment
System input level (total RF power) control	control	0~30	dB	electrical attenuation level
System output level (total RF power) control	control	0~30	dB	electrical attenuation level
System input level (total RF power) monitor	monitor	−30~0	dBm	electrical power monitor
System output level (total RF power) monitor	monitor	−30~0	dBm	electrical power monitor
Optical output power/channel control	control	+3~+7	dBm	optical power control
Optical output power/channel monitor	monitor	−3~+7	dBm	optical power monitor
Optical output power/channel alarm	alarm	<+3	dBm	optical power alarm
Optical input power/channel monitor	monitor	−3~−13	dBm	optical power monitor
Optical input power/channel alarm	alarm	<−5	dBm	optical power alarm
LD enable	control	−	−	enable/disable
PD enable	control	−	−	enable/disable
DC power failure	alarm	−	−	failure alarm
FSK modem enable	control	−	−	enable/disable
FSK modem alarm	alarm	below received signal strength indication (RSSI) threshold value	V	failure alarm

Appendix VIII

Example system configuration and interface specifications for Annex B

(This appendix does not form an integral part of this Recommendation.)

VIII.1   Typical system configuration

A typical block diagram of an RoF system implemented in an FOD detection system is shown in Figure VIII.1. The RoF system consists of an RoF transmitter and multiple RoF receivers. They are connected by an optical fibre network including an optical splitter. The RoF transmitter typically consists of a laser diode, an optical modulator, an optical amplifier, and an optical bandpass filter. In the RoF transmitter, a driving signal from a radar signal synthesizer is put into the optical modulator and an FM-CW RoF signal is generated as an output of the optical bandpass filter. The RoF receiver typically consists of a photoreceiver, where a received FM-CW RoF signal is converted to an electrical FM-CW signal, and put into an RF front end. Here, when the RF front end has a frequency multiplier function, the output of RoF receiver may be a frequency-divided FM-CW signal.
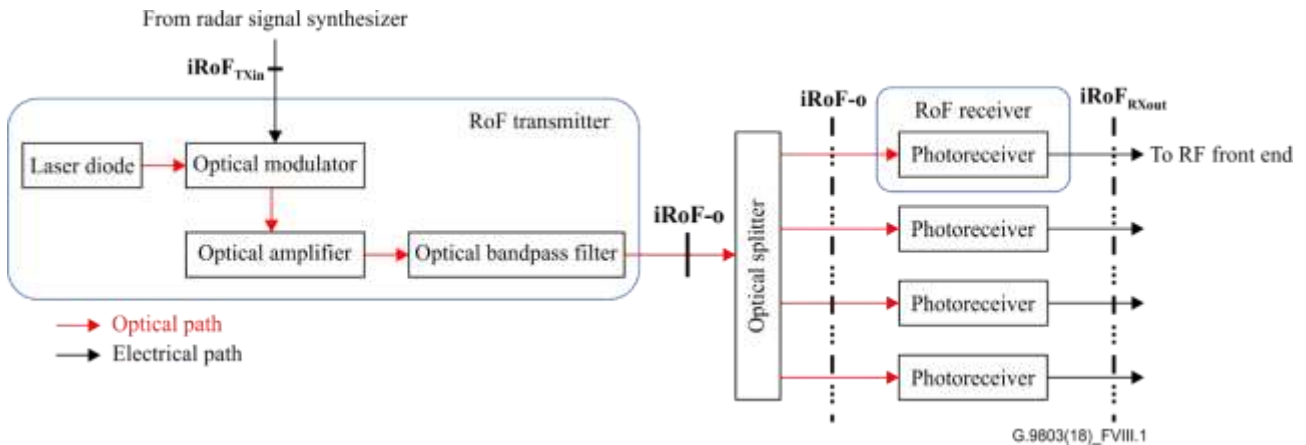

Figure VIII.1 – Typical block diagram of RoF link for FOD detection system

VIII.2   Functional specification

The RoF system supporting the FOD detection system generating the FM-CW signal with a sweeping range of 92 to 100 GHz is specified as a radiolocation service in the ITU Radio Regulations [b-ITU-R RR]. The required functional specifications are summarized in Table VIII.1. m_{ele} and m_{opt} represent the frequency multiplication factor of a frequency multiplier set in the RF front end after iRoF$_{RXout}$ interface and a frequency multiplication factor in an optical domain, respectively. For instance, typical m_{ele} and m_{opt} under a simple double-sideband suppressed-carrier modulation scheme with sidebands of first order modulation components are 3 and 2, respectively.

Table VIII.1 – Functional specification

Parameter	Value			Unit
	Minimum	**Typical**	**Maximum**	**Unit**
Operating wavelength range	1535		1565	nm
Gain from iRoF$_{TXin}$ to iRoF$_{RXout}$	−30	−10	0	dB
Transmitter				
System input level at iRoF$_{TXin}$	10	15	20	dBm
System output level at iRoF-o	−10	3	10	dBm
Input frequency range at iRoF$_{TXin}$	$92/(m_{opt} \times m_{ele})$		$100/(m_{opt} \times m_{ele})$	GHz
Signal bandwidth at iRoF$_{TXin}$			$8/(m_{opt} \times m_{ele})$	GHz
Optical spurious suppression ratio	30			dB
Optical carrier suppression ratio	40			dB
Optical sideband amplitude imbalance		±1		dB
Frequency response		±1		dB
Receiver				
System input level at iRoF-o	−10	−3	0	dBm
System output level at iRoF$_{RXout}$	−20	−10		dBm
Output frequency range at iRoF$_{RXout}$	$92/m_{ele}$		$100/m_{ele}$	GHz

Bibliography

[b-ITU-T F.700]   Recommendation ITU-T F.700 (2000), *Framework Recommendation for multimedia services*.

[b-ITU-T F.701]   Recommendation ITU-T F.701 (2000), *Guideline Recommendation for identifying multimedia service requirements*.

[b-ITU-T F.702]   Recommendation ITU-T F.702 (1996), *Multimedia conference services*.

[b-ITU-T F.703]   Recommendation ITU-T F.703 (2000), *Multimedia conversational services*.

[b-ITU-T F.724]   Recommendation ITU-T F.724 (2005), *Service description and requirements for videotelephony services over IP networks*.

[b-ITU-T F.733]   Recommendation ITU-T F.733 (2005), *Service description and requirements for multimedia conference services over IP networks*.

[b-ITU-T F.741]   Recommendation ITU-T F.741 (2005), *Service description and requirements for audiovisual on-demand services*.

[b-ITU-T G.652]   Recommendation ITU-T G.652 (2016*), Characteristics of a single-mode optical fibre and cable*.

[b-ITU-T G.657]   Recommendation ITU-T G.657 (2016), *Characteristics of a bending-loss insensitive single-mode optical fibre and cable*.

[b-ITU-T G.695]   Recommendation ITU-T G.695 (2018), *Optical interfaces for coarse wavelength division multiplexing applications*.

[b-ITU-T G.703]   Recommendation ITU-T G.703 (2016), *Physical/electrical characteristics of hierarchical digital interfaces*.

[b-ITU-T G.810]   Recommendation ITU-T G.810 (1996), *Definitions and terminology for synchronization networks*.

[b-ITU-T G.813]   Recommendation ITU-T G.813 (2003), *Timing characteristics of SDH equipment slave clocks (SEC)*.

[b-ITU-T G.984.1]   Recommendation ITU-T G.984.1 (2008), *Gigabit-capable passive optical networks (GPON): General characteristics*.

[b-ITU-T G.984.2]   Recommendation ITU-T G.984.2 (2003), *Gigabit-capable Passive Optical Networks (G-PON): Physical Media Dependent (PMD) layer specification*.

[b-ITU-T G.984.3]   Recommendation ITU-T G.984.3 (2014), *Gigabit-capable passive optical networks (G-PON): Transmission convergence layer specification*.

[b-ITU-T G.984.4]   Recommendation ITU-T G.984.4 (2008), *Gigabit-capable passive optical networks (G-PON): ONT management and control interface specification*.

[b-ITU-T G.984.5]   Recommendation ITU-T G.984.5 (2014), *Gigabit-capable passive optical networks (G-PON): Enhancement band*.

[b-ITU-T G.984.6]   Recommendation ITU-T G.984.6 (2008), *Gigabit-capable passive optical networks (GPON): Reach extension*.

[b-ITU-T G.984.7]	Recommendation ITU-T G.984.7 (2010), *Gigabit-capable passive optical networks (GPON): Long reach.*
[b-ITU-T G.988]	Recommendation ITU-T G.988 (2017), *ONU management and control interface (OMCI) specification.*
[b-ITU-T G.989.1]	Recommendation ITU-T G.989.1 (2013), *40-Gigabit-capable passive optical networks (NG-PON2): General requirements.*
[b-ITU-T G.989.3]	Recommendation ITU-T G.989.3 (2015), *40-Gigabit-capable passive optical networks (NG-PON2): Transmission convergence layer specification.*
[b-ITU-T G.8261]	Recommendation ITU-T G.8261/Y.1361 (2013), *Timing and synchronization aspects in packet networks.*
[b-ITU-T G.8262]	Recommendation ITU-T G.8262/Y.1362 (2018), *Timing characteristics of a synchronous Ethernet equipment slave clock.*
[b-ITU-T G.9807.1]	Recommendation ITU-T G.9807.1 (2016), *10-Gigabit-capable symmetric passive optical network (XGS-PON).*
[b-ITU-T G.9807.2]	Recommendation ITU-T G.9807.2 (2017), *10-Gigabit-capable symmetric passive optical network (XGS-PON): Reach extension.*
[b-ITU-T G.suppl.66]	Supplement 66 to ITU-T G-series Recommendations (2018), *5G wireless fronthaul requirements in a PON context.*
[b-ITU-T GSTR-TN5G]	Technical Report ITU-T GSTP-TN5G (2018), *Transport network support of IMT-2020/5G.*
[b-ITU-T H.100]	Recommendation ITU-T H.100 (1988), *Visual telephone systems.*
[b-ITU-T H.140]	Recommendation ITU-T H.323 (1988), *A multipoint international videoconference system.*
[b-ITU-T H.323]	Recommendation ITU-T H.140 (2009), *Packet-based multimedia communications systems.*
[b-ITU-T J.185]	Recommendation ITU-T J.185 (2012), *Transmission equipment for transferring multi-channel television signals over optical access networks by frequency modulation conversion.*
[b-ITU-T Y.2201]	Recommendation ITU-T Y.2201 (2009), *Requirements and capabilities for ITU-T NGN.*
[b-ITU-R M.687]	Recommendation ITU-R M.687-2 (1997), *International Mobile Telecommunications-2000 (IMT-2000).*
[b-ITU-R M.816]	Recommendation ITU-R M.816-1 (1997), *Framework for services supported on International Mobile Telecommunications-2000 (IMT-2000).*
[b-ITU-R M.1036]	Recommendation ITU-R M.1036-5 (2015), *Frequency arrangements for implementation of the terrestrial component of International Mobile Telecommunications (IMT) in the bands identified for IMT in the Radio Regulations.*
[b-ITU-R M.1457]	Recommendation ITU-R M.1457-14 (2019), *Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications-2000 (IMT-2000).*

[b-ITU-R M.1822]	Recommendation ITU-R M.1822-0 (2007), *Framework for services supported by IMT*.
[b-ITU-R M.2012]	Recommendation ITU-R M.2012-3 (2018), *Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications-Advanced (IMT-Advanced)*.
[b-ITU-R M.2083]	Recommendation ITU-R M.2083-0 (2015), *IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond*.
[b-ITU-R M.2133]	Report ITU-R M.2133-0 (2008), *Requirements, evaluation criteria and submission templates for the development of IMT-Advanced*.
[b-ITU-R M.2320]	Report ITU-R M.2320-0 (2014), *Future technology trends of terrestrial IMT systems*.
[b-ITU-R M.2376]	Report ITU-R M.2376-0 (2015), *Technical feasibility of IMT in bands above 6 GHz*.
[b-ITU-R RR]	Radio Regulations: Article (Volume 1) (2016), *Chapter II Frequencies*.
[b-3GPP TS 36.104]	3GPP TS 36.104, *3rd Generation Partnership Project, Technical Specification Group Radio Access Network; LTE; Evolved Universal Radio Access (E-UTRA); Base Station (BS) radio transmission and reception (Release 14)*.
[b-3GPP TS 38.104]	3GPP TS 38.104, *3rd Generation Partnership Project, Technical Specification Group Radio Access Network; NR; Base Station (BS) radio transmission and reception (Release 15)*.
[b-APT/ASTAP/REPT-19]	APT/ASTAP/REPT-19 (2015), *Integration of radio over fiber with WDM PON for seamless access communication system*.
[b-APT/ASTAP/REPT-36]	APT/ASTAP/REPT-36 (201), *Field trial of wireless access WDM-PON deployment based on radio over fiber technology*.
[b-APT/ASTAP/REPT-37]	APT/ASTAP/REPT-37 (2019), *Power over fiber system for radio over fiber network*.
[b-APT/ASTAP/REPT-38]	APT/ASTAP/REPT-38 (2019), *Broadband railway communication systems using radio over fiber technologies*.
[b-APT/ASTAP/REPT-39]	APT/ASTAP/REPT-39 (2019), *Description of radio over fiber technologies for seamless access communication systems*.
[b-ATIS-0600010.01.2008]	ATIS 0600010.0.2008 (2008), *Temperature, humidity, and altitude requirements for network telecommunications equipment utilized in outside plant environments*.
[b-ETSI ETS 300 019-1-4]	ETSI ETS 200 019-1-4 (1992), *Equipment Engineering (EE): Environmental conditions and environmental test for telecommunications equipment; Part 1-4: Classification of environmental conditions Stationary use at non-weatherprotected locations*.
[b-IEEE 802.3]	IEEE Std 802.3-2015 (2015), *IEEE standard for Ethernet*.
[b-IEC 60169]	IEC 60169-1 (1987), *Radio-frequency connectors. Part 1: General requirements and measuring methods*.

[b-IEC 60825-1]	IEC 60825-1 (2014), *Safety of laser products – Part 1: Equipment classification and requirements.*
[b-IEC 60825-2]	IEC 60825-2:2004+Amd1:2006+Amd2:2010 CSV Consolidated version (2010), *Safety of laser products – Part 2: Safety of optical fibre communication systems (OFCS).*
[b-IEC 62149-10]	IEC 62149-10 (2018), *Fibre optic active components and devices – Performance standards – Part 10: Radio-over-fiber (RoF) transceivers for mobile fronthaul.*
[b-MEF 6.1]	MEF Technical Specification (2008), *Ethernet service definitions – Phase 2.*
[b-Telcordia GR-487]	Telcordia GR-487 (2016), *Generic requirements for electronic equipment cabinets.*
[b-WRC-15 236]	WRC-15 Resolution 236 (2015), *Railway radiocommunication systems between train and trackside.*
[b-WRC-15 283]	WRC-15 Resolution 283 (2015), *Studies on frequency-related matters for International Mobile Telecommunications identification including possible additional allocations to the mobile services on a primary basis in portion(s) of the frequency range between 24.25 and 86 GHz for the future development of International Mobile Telecommunications for 2020 and beyond.*

SERIES OF ITU-T RECOMMENDATIONS

Series A	Organization of the work of ITU-T
Series D	Tariff and accounting principles and international telecommunication/ICT economic and policy issues
Series E	Overall network operation, telephone service, service operation and human factors
Series F	Non-telephone telecommunication services
Series G	**Transmission systems and media, digital systems and networks**
Series H	Audiovisual and multimedia systems
Series I	Integrated services digital network
Series J	Cable networks and transmission of television, sound programme and other multimedia signals
Series K	Protection against interference
Series L	Environment and ICTs, climate change, e-waste, energy efficiency; construction, installation and protection of cables and other elements of outside plant
Series M	Telecommunication management, including TMN and network maintenance
Series N	Maintenance: international sound programme and television transmission circuits
Series O	Specifications of measuring equipment
Series P	Telephone transmission quality, telephone installations, local line networks
Series Q	Switching and signalling, and associated measurements and tests
Series R	Telegraph transmission
Series S	Telegraph services terminal equipment
Series T	Terminals for telematic services
Series U	Telegraph switching
Series V	Data communication over the telephone network
Series X	Data networks, open system communications and security
Series Y	Global information infrastructure, Internet protocol aspects, next-generation networks, Internet of Things and smart cities
Series Z	Languages and general software aspects for telecommunication systems