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Access, Terminals, Transmission and Multiplexing (ATTM);
Plastic Optical Fibres;
Part 1: Plastic Optical Fibre System Specifications for 100 Mbit/s and 1 Gbit/s;
Sub-part 1: Application requirements for physical layer specifications for high-speed operations over Plastic Optical Fibres

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Contents

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Foreword

This Technical Specification (TS) has been produced by ETSI Technical Committee Access, Terminals, Transmission and Multiplexing (ATTM).

The present document is part 1, sub-part 1 of a multi-part deliverable covering Plastic Optical fibre, as identified below:

Part 1: " Plastic Optical Fibre System Specifications for100 Mbit/s and 1 Gbit/s";

Sub-part 1: "Application requirements for physical layer specifications for high-speed operations over Plastic Optical Fibres";

Sub-part 2: "1 Gbit/s and 199 Mbit/s physical later for Plastic Optical Fibres".

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1 Scope

The present document provides a compendium of application requirements for full-duplex 100 Mbit/s and 1 Gbit/s Ethernet based home networking infrastructures based on Plastic Optical Fibre (POF) transmission media. The description of applications covers different network topologies as well as different field particularities.

2 References

2.1 Normative references

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

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

[1] ETSI TS 105 175-1 (V2.0.0): "Access, Terminals, Transmission and Multiplexing (ATTM); Plastic Optical Fibre System Specifications for 100 Mbit/s and 1 Gbit/s".

[2] IEC 60793-2:2011: "Optical fibres - Part 2: Product specifications - General".

[3] IEC 60793-2-40: "Optical fibres - Part 2-40: Product specifications - Sectional specification for category A4 multimode fibres".

[4] IEC 60794-2-40: "Optical fibre cables - Part 2-40: Indoor optical fibre cables - Family specification for A4 fibre cables".

[5] ETSI TS 105 175-1-2: "Access, Terminals, Transmission and Multiplexing (ATTM); Plastic Optical Fibres; Part 1: Plastic Optical Fibre System Specifications for 100 Mbit/s and 1 Gbit/s; Sub-part 2: 1 Gbit/s and 100 Mbit/s physical layer for Plastic Optical Fibres".

[6] CENELEC EN 50173-1:2011: "Information technology - Generic cabling systems - Part 1: General requirements".

[7] CENELEC EN 50173-4:2007: "Information technology - Generic cabling systems - Part 4: Homes".

[8] IETF RFC 2544: "Benchmarking Methodology for Network Interconnect Devices".

[9] IEEE™ 802.3: "IEEE™ Standard for Ethernet".

[10] Recommendation ITU-T Y.1564: "Ethernet service activation test methodology".

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] Recommendation ITU-T G.9960: "Unified high-speed wire-line based home networking transceivers - System architecture and physical layer specification".

[i.2] IEEE™ 802.3z: "Media Access Control Parameters, Physical Layers, Repeater and Management Parameters for 1,000 Mb/s Operation, Supplement to Information Technology - Local and Metropolitan Area Networks - Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications".

[i.3] IEEE™ 802.3u: "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.4] IEEE™ 802.1Q: "IEEE™ Standard for Local and Metropolitan Area Networks - Virtual Bridged Local Area Networks".

[i.5] IEEE™ 802.1p: "IEEE™ Standard for Local and Metropolitan Area Networks - Supplement to Media Access Control (MAC) Bridges: Traffic Class Expediting and Dynamic Multicast Filtering".

[i.6] IEEE™ 802.1D: "IEEE™ Standard for Local and metropolitan area networks: Media Access Control (MAC) Bridges".

[i.7] IEEE™ 802.11a -1999: "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications. High-speed Physical Layer in the 5 GHz Band".

[i.8] European Council Document 12608: "The potential dangers of electromagnetic fields and their effect on the environment".

[i.9] Broadband Forum TR-069 Amendment 4: "CPE WAN Management Protocol".

[i.10] IETF RFC from 3410 to 3418: "Internet Management Protocol. SNMPv3".

[i.11] Broadband Forum TR-143: "Enabling Network Throughput Performance Tests and Statistical Monitoring".

[i.12] ICT ALPHA [PUBLIC] D1.1p: "Architectures for flexible Photonic Home and Access Networks' - "End user future services in access, mobile and in building networks".

[i.13] ANSI/TIA/EIA-568: "Commercial Building Telecommunications Cabling Standards".

[i.14] ISO/IEC 9314-3:1990: "Information processing systems -- Fibre distributed Data Interface (FDDI) -- Part 3: Physical Layer Medium Dependent (PMD)".

3 Abbreviations

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

B2B	Business-to-Business
BER	Bit Error Rate
BW	Bandwidth
CAT	Category
CPE	Customer Premises Equipment
DECT	Digital Enhanced Cordless Telecommunications
DVB-X	Digital Video Broadcasting technology
ECG	Electro Cardio Gram
EHC	Electronic Health Care
EHG	Electro Hystero Gram
EMC	Electro Magnetic Compatibility
EMI	Electro Magnetic Immunity
EU	European Union
FDDI	Fibre Distributed Data Interface
FEC	Forward Error Correction
FER	Frame Error Rate
FTTH	Fibre To The Home
GOF	Glass Optical Fibre
HD	High Definition

HDTV	High Definition Television
ICT	Information and Communication Technologies
IEC	International Electrotechnical Commission
IP	Internet Protocol
IPTV	IP Television
IT	Information Technology
ITU	International Telecommunication Union
ITU-T	ITU Telecommunication Standardization Sector
LC	Lucent Connector
MAC	Media Access Control
MDI	Medium Dependent Interface
MDU	Multi Dwelling Units
MIC	Media Interface Connector
MMOG	Massively Multiplayers Online Games
MTRJ	Mechanical Transfer Registered Jack
MTTFPA	Mean Time To False Packet Acceptance
MTU	Maximum Transfer Unit
NA	Not Applicable
NDIM	Neighbouring Domain Interference Mitigation
NIR	Near Infra Red
NRZ	Non Return to Zero
NRZI	Non Return to Zero Inverted
OFDM	Orthogonal Frequency De-multiplexing
PAM	Pulse Amplitude Modulation
PCS	Physical Coding Sublayer
PDA	Personal Digital Assistant
PHY	Physical
PLC	Power Line Communications
PMA	Physical Medium Attachment
PMD	Physical Medium Dependent
POF	Plastic Optical Fibre
RFC	Request for Comments (RFC) is a publication of the Internet Engineering Task Force
RJ	Registered Jack
RX	Reception
SC	Subscriber Connector
SI-POF	Step Index Plastic Optical Fibre
ST	Straight Tip connector
STB	Set Top Box
STB/TV	Set Top Box / Television
TC	Technical Committee
TV	Television
TX	Transmission
UHDTV	Ultra High Definition TV
UPA	Universal Powerline Association
US	United States of America
VDE	VDE, the Association for Electrical, Electronic &Information Technologies
VLAN	Virtual Local Area Network
VPN	Virtual Private Network
xDSL	Generic Digital Subscriber Line technology

4 New home networking application requirements

4.1 Introduction

In the past, POF has been used in the networking market with limited success. The main reasons for that are:

- xDSL was bringing up to 20 Mbit/s to the home.
- PLC and Wi-Fi™ already fulfilled the requirement for the home networking.

In Europe, since 2009, and much earlier in Japan, South Korea and US, the situation has changed. Telecom operators are in a competitive race of bit rates and prices and are using different access technologies as marketing slogans. In parallel with this market push effort, bit rate demand is steadily increasing due to new services like HD-IPTV, Clouding, VPN, and life/work styles (Remote jobs, self-employment, etc.).

This competitive landscape has forced telecom operators to invest on massive FTTH deployment projects.

- At the end of 2011 > 75 million FTTH subscribers worldwide. At 2020, up to 50 % of EU households should have 100 Mbit/s.

The bitrate race has started from 20 Mbit/s (xDSL/Cable) to 50 Mbit/s, 100 Mbit/s and 200 Mbit/s. Rather than price reduction as a strategy, telecom operators are offering more and more bit-rates supporting new services.

To fulfil this trend, a robust, reliable, stable and flexible network topology is needed within the house. The customer needs to be able to use the total provided bit-rate in any point of the house as well as have a remaining extra bandwidth to be used for services like file sharing and local video streaming.

A hybrid mixture of networking technologies, offering Fixed-Wired-Reliable network and a Wi-Fi Flexible-Mobility-Ubiquity, is demanded. Tablets, Laptops and smart-phones require a Mobile network. Fixed PCs, Multimedia hard-drives, IPTV set-top-boxes and routers are normally wire connected.

New wire installations may reuse mains conduits within a daisy chain/tree topology. This is the easiest, less expensive and fastest way to introduce a new wiring either in green (new construction) or brown (already constructed) fields. Moreover, wired networks are naturally more "Energy Efficient" than wireless. Energy efficiency is an important topic in the society for two reasons: environmental care arguments are forcing the use of an Energy Efficient infrastructure. Secondly, health reasons are starting to force the limitation in transmitted power in the Wi-Fi network, limiting the high-speed coverage to a single room (see Council of Europe. Document 12608 [i.8] May 6th 2011).

4.2 FTTH deployment

Even when Asia-Pacific countries are leading the FTTH deployment, North America is following with a big growth rate. Europe is following the tendency.

This deployment multiplies by 2, 4 or even 10 times the available bitrates in the home. New services are offered in parallel to just the Internet connection. This increase of the services is seen by the Internet Providers as a fundamental requirement in todays competitive market. The Internet Provider offers the bit rate and the services. That is why the quality of the access network, as well as the quality of the home network is a major requirement of this deployment.

Home networking has to accommodate to the required performance, robustness, and feasibility of the offered services. The Internet providers are the main supporters of a high quality home networking.

4.3 Internet based services

To the traditional World Wide Web surfing and e-mail services, other services have been added to the public Internet offer:

- **Voice over IP:** Traditional analogue phone lines are being replaced more and more with VoIP digital technology. Nevertheless, the requirements of this service are more related with signal jitter and latency than with bit rates. A low packet error rate is required to avoid artefacts in the sound.

- **Video over IP, or IPTV:** Consists on providing video services over IP networks, within a local network, or via the Internet. Currently the IPTV business is growing and competing with Satellite, Cable and Terrestrial TV. The biggest added value of IPTV over its competitors is the Pay-Per-View service. IPTV requires high bandwidths up to 16 Mbit/s for a very high quality HD compressed video. Multi room IPTV (several TVs in a home) is now becoming a popular service offered in most of the provider portfolio. Jitter is typically an important metric for this type of service, whereas latency is not. There is an increase in demand for HDTV as well as more than one HDTV terminal per household. Each HDTV service requires around 4 Mbit/s to 20 Mbit/s depending on the quality issued and programme type (news, sports, etc.).

- **Telework:** Home-based Businesses and Remote employment opportunities. Remote access to office networks requires bitrates in the order of 1 Mbit/s to 10 Mbit/s. But home workers will appreciate speeds as fast as possible, even 100 Mbit/s, to have the same work experience as in the office. Telework is growing in US and Europe as a consequence of the economic downturn and the increasing cost of transportation. Work-life balance is also playing an important role in Telework growth.

- **Telehealth:** Access to Healthcare Professionals and "multiplication of specialists". Consists mainly in video traffic, requiring low latency and 2 Mbit/s speed.

- **Tele-education:** Specialized courses, retention of impacted workers and enhancement of classroom training. Typical requirements are around 1 Mbit/s to 2 Mbit/s speed.

- **E-Government:** Access to forms and applications, communication to representatives, citizen involvement, intelligent first-responders.

- **File storing in the "cloud":** The requirement is "as fast as possible". Pictures and videos represents multi gigabyte source of information in a house nowadays. Moving all this information may take forever if speed is not high enough.

- **Online gaming:** Requirements of 1 Mbit/s and low latency is needed for this service.

- **Sustainability:** Energy management systems within the home and the future Smart Grid deployment will also add to the demand for higher bandwidth at home.

In table 1 a summary of the main needs of current Internet services is shown (see ICT Alpha [i.12]).

Table 1: Needs of Internet services

Service	Bit rate	Delay	Jitter	Packet loss	Mobility	Traffic Priority	Security
Internet	1 Mbit/s to 100 Mbit/s	Relaxed specification	< 10 ms	None (BER < 10^{-8})	Yes	Low	No
Music	5 kbit/s to 128 kbit/s	Buffer dependent	Buffer dependent	< 1 %	Yes	High	No
File sharing (peer-to-peer)	1 Mbit/s to 100 Mbit/s	Relaxed specification	< 10 ms	None (BER < 10^{-8})	Yes	Low	No
Web3D	10 Mbit/s to 1 Gbit/s	Relaxed specification	< 10 ms	None (BER < 10^{-8})	Yes	Low	No

4.4 Current in-home networking services

The communication networks essentially allow an exchange of information between persons, between persons and equipment (e.g. a video server), and between equipment (e.g. a sensor and an actuator). Based on the type of the information exchange and the inherent service requirements, the following groups/classes of services can be identified (see ICT Alpha [i.12]):

- Basic communication such as telephony, e-mail, and instant messaging.

- Internet-related services such as general browsing, e-banking, e-shopping and similar; including file sharing.

- Video-related services such as Video on Demand, IPTV, video conferencing and similar.

- Online Virtual Environments such as social network or gaming.

- Remote Technical services such as the ability to remotely control/survey your home.

- Remote Health services such as remote health monitoring.

From the above classification, video-related services are among the most bandwidth demanding services with presence today at the home. A few examples follow:

- IPTV.

- Video on Demand, multimedia content production and delivery.
- Video conferencing and video telephony.
- Video streaming/Home Theatre.
- TV Broadcast (DVB-X).

Table 2 summarizing the demands for these applications follows (see ICT Alpha [i.12]).

Table 2: New application demands

Service	Bit rate	Delay	Jitter	Packet loss	Mobility	Traffic Priority	Security
IPTV	2 Mbit/s to 20 Mbit/s (for HD)	< 400 ms; 200 ms recommended	< 50 ms	< 1 %; < 0,1 % recommended	Yes	High	No
VoD	2 Mbit/s to 1 Gbit/s	< 400 ms; 200 ms recommended	< 50 ms	< 1 %; < 0,1 % recommended	Yes	High	No
Videoconference	128 kbit/s to 4 Mbit/s	< 400 ms; 200 ms recommended	< 50 ms	< 1 %; < 0,1 % recommended	Yes	High	No
Video Streaming (uncompressed)	128 kbit/s to 10 Gbit/s	< 400 ms; 200 ms recommended	< 50 ms	< 1 %; < 0,1 % recommended	No	High	No
TV Broadcast (DVB-IP)	96 kbit/s to 45 Mbit/s (HD)	< 400 ms	< 20 ms	None (or use FEC)	Yes	High	No
TV Broadcast (DVB-x, non IP based)	N/A rather BW occupied up to 8 MHz	< 400 ms	< 20 ms	None (or use FEC)	Yes	High	No
Immersive TV (e.g. UHDTV)	24 Gbit/s uncompressed; < 640 Mbit/s compressed	< 400 ms; < 150 ms recommended	< 20 ms	< 0,4 %	No	High	No
Immersive Videoconference using UHDTV	< 640 Mbit/s compressed	< 400 ms; < 150 ms recommended	< 20 ms	< 0,2 %	No	High	No
Stereoscopic TV	62,5 Mbit/s to 320 Mbit/s	< 400 ms; < 150 ms recommended	< 20 ms	< 0,4 %	No	High	No
Free Viewpoint TV	937,5 Mbit/s	< 400 ms; < 150 ms recommended	< 20 ms	< 0,4 %	No	High	No

4.5 Current home networking technologies

4.5.1 Introduction

The main classification criteria for home networking technologies is the one based on wired versus no wired home networks. The flexibility provided by no wired networks has to be well balanced with other advantages provided by the wired technologies. These advantages are summarized in the following paragraph:

- Wired networks are more stable and dependable than wireless and channel interference in wired network from other devices is non-existent (or other access points operating in the same channel).
- Wired networks are faster than their wireless counterparts with, multi-media, voice, video, network games and other real time applications performing better in a wired network.
- Wired networks are more secure despite the existence of encryption in wireless networks. It is still possible for a determined hacker to access the network with the right tools or awareness of vulnerabilities in the network but wired networks can only be connected from within the home thus making it difficult for the hacker to access.

4.5.2 Ethernet CAT-5e/CAT-6 100 Mbit/s / 1 000 Mbit/s

This is the main solution to connect ONTs or Modems to routers and/or IPTV set-top-boxes when distances are higher than a few meters. Is based on the IEEE™ 802.3z [i.2] (1000BASE-T) and IEEE™ 802.3u [i.3] (100BASE-T) standard for the physical layer and the cable is based on ANSI/TIA/EIA-568 [i.13]. The main drawback of this technology is the thickness of CAT-5e or CAT-6 cable. It is difficult for the customer to carry out an invisible installation. Technical support and installation is needed due to the need of cable connectorization and termination.

4.5.3 Wi-Fi 802. 11 a/b/g/n/ac

Wi-Fi (IEEE™ 802.11 [i.7]) is the technology of choice for mobile devices like Laptops, Tablets and Smart-Phones. It normally offers a good QoS within a single room range. Nevertheless, Wi-Fi performance degrades very fast with the number of walls to be crossed and neighbours sharing the same channels. It is a known fact that 2,4 GHz channels are already saturated in big cities. The use of 5 GHz channels provides a new future to the Wi-Fi technology. 5 GHz is currently being adopted in Europe and US. On the other hand there is a growing trend from the European Commission to warn on potential health issue from microwave radiation. Recommendations on Wi-Fi banning and power limitation on schools, libraries, etc. where children and young people are present, have been recently issued (see European Council Document 12608 [i.8]).

4.5.4 Power Line Communications (PLC)

PLC has been used for the last 10 years. Several standards are available without interoperability (HomePlug™, UPA, HomeGrid, etc.). G.hn is expected to solve this multi-standard situation that is jeopardizing the market growth. PLC is typically deployed to avoid the installation of CAT-5e links between distant places within the same home. Devices are connected to the PLC modems using either CAT-5e cables or Wi-Fi. PLC cannot guarantee either bitrate or quality in terms of packet loss (unless packet repetition technology is enabled with a big hit on jitter and latency). Several Internet Providers have discontinued PLC offering in their portfolios due to a 5 % to 20 % complain ratios from customers due to unacceptable QoS. PLC is a shared media and always needs to fight external disturbances from home appliances and neighbours in condominiums.

4.5.5 G.hn

G.hn (Recommendation ITU-T G.9960 [i.1]) is the big strategic move of the home networking industry trying to join together all the cable technologies in the home, Coaxial, Phone line and Power line, guaranteeing interoperability. The bit rates provided by G.hn go up to several hundreds of Mbit/s. G.hn will be used in most of the houses where the existing cabling provides enough coverage. QoS is stable during operation time for all types of wires. G.hn provides both prioritized and parameterized QoS und solves the PLC problem of shared media by a Neighbouring Domain Interference Mitigation (NDIM) function. There are also some issues in some EU countries with the radiated power of these technologies. Further G.hn advantages are information privacy by end-to-end encryption, and profiles adapted to complexity of CPE, e.g. residential gateways with high data rate and home automation devices with low data rate.

Usage of star topology and passive optical splitters in simplex POF networks offers P2MP and MP2MP communication possibilities.

4.5.6 POF (100 Mbit/s)

Plastic Optical Fibre based home networks have been deployed for the last few years. POF has a clear value proposition when compared to other "new wires" installations like CAT-5e/CAT-6 as it is easier to install. POF installations do not require any connectorization and can be laid down sharing the existing main ducts. Several financial studies based on field trials report savings on the order of 15 % to 20 % mainly coming from installation time. Figure 1 shows a typical POF installation. A more detailed POF topology description is provided in clause 5.3.

A well-established market of device OEMs and installation companies exists in Europe and North America. China is rapidly adopting POF as a cheap and easy way to deploy broadband home networks. Continental associations are already promoting POF within the home construction, rehabilitation and Office installation professionals (POF association, POF Chinese Association, etc.).

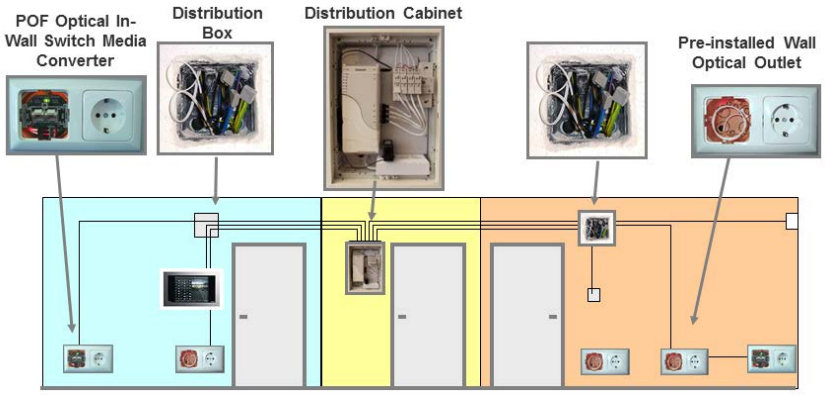

Figure 1: Typical POF based home network

All the POF networking equipment so far in the market is using simple NRZ modulation techniques inherited from the Glass Optical Fibre world thus limiting the performance to 100 Mbit/s for typical home links on the order of 10 m to 20 m.

A comparison of different home network technologies is summarized in table 3.

Table 3: Comparison between home network technologies

ISSUE	POF (simplex)	POF (duplex)	CAT-5e/6	HomePlug™ (PLC)	HomePNA™ (Coax+Phon.)	Coax	Wireless
Customer Installable	Yes	Yes	Not	Yes	Yes	No	Not Always
Network user reconfigurable	Yes	Yes	No	No	No	No	N/A
Whole House Coverage	Yes (note 1)	Yes (note 1)	Not Always	Yes	Not Always	Not Always	Not Always
Immune to Interference	Yes	Yes	No	No	No	No	No
Enables Mobility	Yes (note 1)	Yes (note 1)	No	Available	No	No	Yes
Cost Effective	Yes	Yes	Not Always (note 4)	Not Always (note 4)	Not Always (note 4)	Not Always (note 4)	Not Always (note 4)
Reliable	Yes	Yes	Yes	Yes	Yes	Yes	Not Always
Number of Outlets (Typical)	N/A	Unlimited (note 2)	4, 8, 24	40	8, 62, 120	3	N/A
Half /Full duplex	Half	Full	Full	Half	Half	Half	Half
Bandwidth (Mbit/s)	*[No Data]*	100, 1 000	100, 1 000	14, 85, 200	128, 160, 256	270	11, 54, 108, 130
Dedicated QoS links	Yes (note 3)	Yes (note 3)	Yes (note 3)	No	Yes	No	No

NOTE 1: Customer can move retrofit devices within home.
NOTE 2: End-point devices can be explicitly "daisy-chained" to extend coverage.
NOTE 3: True multi-drop 100 Mbit/s links with high (QoS) for HD-IPTV can be realized for MDU installations.
NOTE 4: On a connection-point comparison, beyond single connectivity these systems have significant cost increases.

4.6 Current home networking topologies

The home networking topologies depend mostly in the technology supporting the network. Each technology has a "way" of working which conditions its natural topology.

Nevertheless, the interconnection between the modem, the router or the STB is, nowadays, done with a CAT-5e/CAT-6 Ethernet link. The reason for this choice is to guarantee the quality of the link in these critical parts of the network.

- **Ethernet:** When using CAT-5e to interconnect all the home devices the natural topology to follow is a "star". A central point like the router or a switch is typically used to provide connection to all the rooms on the house. This topology increases cabling complexity due to the fact that the place where the router or switch is located requires wide conduits in order to accommodate the CAT-5e outgoing bundle.

- **Wi-Fi:** There are normally one or two Wi-Fi points per house. The main one is normally located by the router, and the second is optional and typically located in the opposite side of the home. The interconnection between these two points is usually done either with CAT-5e, Wi-Fi repeaters or PLC (G.hn) technology. Being Wi-Fi a shared access media, devices with poor reception quality degrade the total performance of the Wi-Fi network. Even if it is not accurate to talk about network topology on Wi-Fi networks, it is useful to regard Wi-Fi as a common "wire" that shares its capacity among all the connected devices.

- **PLC:** As described above, PLC is normally used to extend Wi-Fi coverage or to avoid the installation of long CAT-5e cables. The added value of PLC is the reuse of the mains ducts. Typical mains networks have a tree topology originating in the power meter. From the point of view of the PLC network, the mains line is seen as a single "wire" interconnecting all the devices in a communication shared media.

- **G.hn:** G.hn would be a usual PLC network if there were no use of the Coax or Phone lines. The use of Coax or phone can be seen as an increase of the capillarity in a shared media communication system.

- **POF:** As said before POF uses the existing mains ducts on brown fields. This generates tree topologies where several branches born at the power meter and the different rooms might hang from the same branch depending on the proximity and floor level. Green fields typically lay down specific communication network ducts, which follow a star topology (see figure 2 for an example).

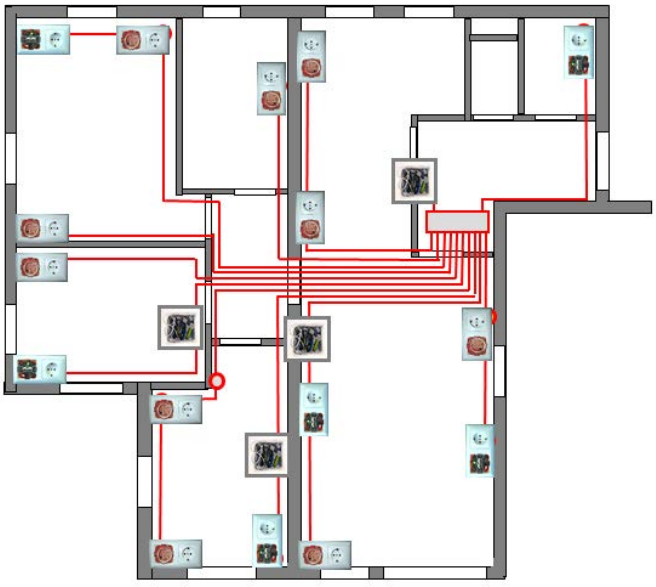

Figure 2: POF star topology example

4.7 New application requirements

Besides the above mentioned existing home applications like video, internet based or home security, new applications and existing applications upgrades are already being offered and in the future more applications will expand the portfolio of service and telecom operators. A list of these services along with its requirements is provided in table 4 (see ICT Alpha [i.12]).

Existing applications upgrades:

Table 4: Future applications requirements

Service	Bit rate	Delay	Jitter	Packet loss	Mobility	Traffic Priority	Security
Immersive TV (e.g. UHDTV)	24 Gbit/s uncompressed; < 640 Mbit/s compressed	< 400 ms; < 150 ms recommended	< 20 ms	< 0,4 %	No	High	No
Immersive Videoconference using UHDTV	< 640 Mbit/s compressed	< 400 ms; < 150 ms recommended	< 20 ms	< 0,2 %	No	High	No
Stereoscopic TV	62,5 Mbit/s to 320 Mbit/s	< 400 ms; < 150 ms recommended	< 20 ms	< 0,4 %	No	High	No
Free Viewpoint TV	937,5 Mbit/s	< 400 ms; < 150 ms recommended	< 20 ms	< 0,4 %	No	High	No

New applications include inter alia:

- Online virtual environments: MMOGs (Massively Multiplayers Online Games), Online Distributed Virtual Environments and interactive games for mobile terminals (see table 5).

Table 5: Virtual Environments requirements

Service	Bit rate	Delay	Jitter	Packet loss	Mobility	Traffic Priority	Security
MMOG	56 kbit/s (relaxed)	< 100 ms (best quality); up to 1 s	< 10 ms	Highly dependent on the engine from 3 % to 35 %	No	High	No
Online Distributed Environments	up to 400 kbit/s	< 100 ms (best quality); up to 1 s	< 10 ms	Highly dependent on the engine from 3 % to 35 %	Yes	High	No
Interactive games (mobile)	1 kbit/s	250 ms	< 10 ms	None	Yes	Low	No

- Remote technical services: Remote residential backup, Remote home monitoring, network watchdog (TR-069 [i.9]), thin client application (remote computer), Robotic assistant, Location based services and grid computing (see table 6).

Table 6: Remote technical services requirements

Service	Bit rate	Delay	Jitter	Packet loss	Mobility	Traffic Priority	Security
Residential Backup	500 Mbit/s	Relaxed specification	< 10 ms	None (BER < 10^{-8})	Yes	Low	No
Home Monitoring	0,1 Mbit/s to 1 Mbit/s (surveillance video)	< 400 ms	< 50 ms	< 1 %	Yes	Low	Yes
Network Watchdog	20 kbit/s to 100 Mbit/s	Relaxed specification	< 10 ms	< 2 %	Yes	Low	No
Thin Clients	100 kbit/s to 6 Mbit/s	< 150 ms; < 80 ms for video	< 10 ms	None or very small, < 0,1 % recommended	Yes	High	Yes
Robotic Assistant	under study						
Location Based Services	10 kbit/s to 20 kbit/s	< 400 ms	< 50 ms	< 3 %; < 0,1 % recommended	Yes	Low	No
Grid Computing	1 Gbit/s	< 40 ms	< 1 ms	None or very small, < 0,1 % recommended	No	Variable	No

- Health/monitoring services: Electronic Health Care (EHC) systems, Tele-electrocardiogram (ECG), Tele-electrohysterogram (EHG) and medical localization devices (see table 7).

Table 7: Health applications requirements

Service	Bit rate	Delay	Jitter	Packet loss	Mobility	Traffic Priority	Security
TeleEHC	0,5 Mbit/s to 5 Mbit/s (patient); 100 Mbit/s to 1 Gbit/s (hospital/doctor)	80 ms to 100 ms	< 10 ms	None (BER < 10^{-8})	Yes	High	Yes
TeleECG	32 kbit/s (user); 500 kbit/s to 2 Mbit/s (central)	80 ms to 100 ms	< 10 ms	None (BER < 10^{-8})	Yes (patient); No (central)	High	Yes
TeleEHG	32 kbit/s (user); 500 kbit/s to 2 Mbit/s (central)	80 ms to 100 ms	< 10 ms	None (BER < 10^{-8})	Yes, but limited (patient); No (central)	High	Yes
Localization services (medicine)	16 kbit/s (user); 250 kbit/s to 2 Mbit/s (central)	80 ms to 100 ms	< 10 ms	None (BER < 10^{-8})	Yes (patient); No (central)	High	Yes

The main conclusion from this service enumeration/grouping is that the different networks transport services that have an **ever-increasing need for bandwidth and more and more stringent requirements** in terms of delay as services become more and more interactive and video based. As well, it has to be noted that the current trend shows that the services that were once confined to a particular type of network can now be transported by a variety of networks (a user may want to check his emails from its desktop computer but also from its mobile phone or PDA). This implies seamless handovers as well as unified service management requirements.

5 Gigabit POF as a the trunk home networking technology

5.1 Introduction

This clause describes the POF media itself as the trunk or backbone communication media for the home.

It is naive to assume that wireless will always be the answer for home triple-play networking. Although highly desirable to connect a broadband modem or router to IPTV or IP Set-top Box (STB) without the added expense and complication of wiring, it is not always feasible. Each home is unique in structure and layout, and already congested with wireless signals from mobiles, DECT phones, microwaves, wireless PCs, printers and gaming. Telephone companies are now predicting that the necessary quality-of-service (QoS) required for a wireless video link between router and STB/TV cannot be delivered in up to as many as 30 percent of homes. In these cases, a wired alternative solution will be required.

Once the need for a new cabling is established, given the service requirements for the home, POF is a very suitable option described in the present document. The reason for this comes from the installation advantages of POF over other technologies and the possibility of reusing the mains ducts allowing several topologies. The seamless usage of POF as the home backbone along with low power Wi-Fi access points and CAT-5e bridges in each room brings together the best of both worlds: wire and wireless, and makes it an optimum solution.

The present document brings to completion the task to specify a complete, POF based, Gigabit Home networking infrastructure. Other documents from IEC and ETSI standardize the fibre and physical layer as well as the communication requirements respectively.

5.2 POF installation advantages

Table 8 describes the chief advantages of a POF backbone installation versus its closer competitor, CAT-5e/CAT-6, as well versus GOF (Glass Optical Fibre).

Table 8: POF vs CAT6 and GOF

	POF	GOF	CAT6
Cable Diameter	1.5/2.2 mm	3 mm	6.5 mm
Area Occupied	7/15 mm^2 (2x duplex)	28 mm^2	130 mm^2
CO_2 used to manufacture	52 $KgCO_2/km$	---	310 $KgCO_2/km$
Installation Time	30 s	10 min	2 min
Installation Complexity	• Low cost cutter or scissors. • Suitable for consumers or installers. 	• Expensive tools. • Only installers. • Expensive connectors. 	• RJ-45 Crimp tool required. • Requires plug attachment. • Only installers. 
Weight	7.5 g/m	6 g/m	32 g/m
EMI/EMC	• No emissions. • Immune to noise. • Can run alongside power cables.	• No emissions. • Noise immune. • Can run alongside power cables.	• Emits noise. • Susceptible to noise.

POF Cable diameter depends on communication type (i.e. simplex or duplex), and jacket type (1,5 mm or 2,2 mm).

5.3 POF based home networking topologies

As said before, POF is suitable either for Green or Brown fields.

Typically, Green fields provide pre-set installations with Star Topologies. In this case POF will follow the supplied ducts and will evolve the star from the central IT cabinet of the home by means of an optical POF switch. Each room will typically get one access point connecting the POF backbone to the external world either with a Wi-Fi pico-cell or RJ-45 connector. In the future POF native connection will also make sense.

Sometimes, and depending on the specifics of the installation, mostly on Brown fields installations that reuse the main ducts, daisy-chain connections will make sense, either in combination with a star topology giving rise to a tree network or a sort of ring connecting room to room, (see figure 3).

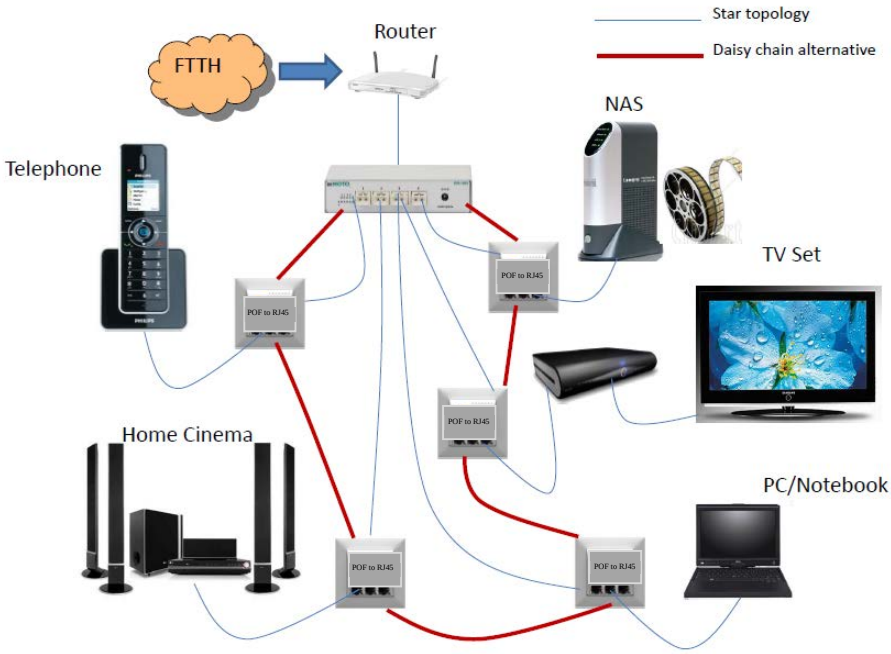

Figure 3: Example of POF home network topology

Another example of a tree POF network is shown in figure 4. Here, a star is deploying the network from a central switch to each room being the most distant rooms connected to the same branch with an outlet that provides this functionality.

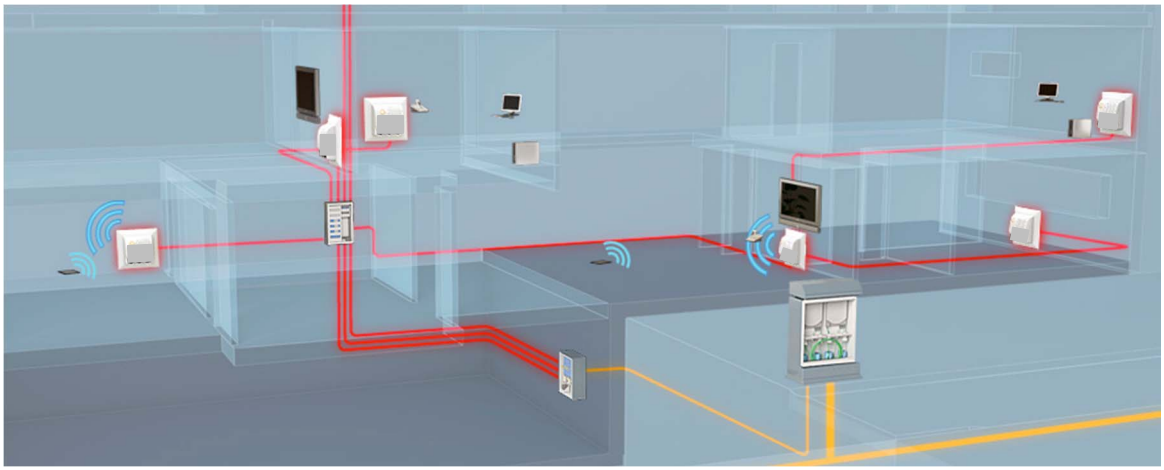

Figure 4: POF star topology example

5.4 Suitability of a POF-WiFi-CAT-5e hybrid network

As said before, there are personal devices like PDAs, Smart Phones, Tablets or portable game consoles that always rely on a wireless connection to deliver the mobility experience to the user. On the other hand, most of the typical home services require a QoS (jitter, latency, priority, etc.) that could only be delivered by dedicated transport media like a wired network. This is the example of HD-IPTV, online Gaming, remote office, etc.

The best solution to be able to fulfil the needs of both types of devices and services is the concept of a POF home backbone or trunk network, running at Gigabit speed with connected access points in each room delivering the Wi-Fi signal in a pico-cell access point or connecting with wired Ethernet devices through RJ-45. See figure 5.

With this solution, a seamless merge of the best of both worlds (mobility and QoS at broadband) is achieved. Legacy support for wireless or wired, Ethernet based, devices is ensured at the same time that new services and devices are easily integrated in the network without the need to upgrade the backbone infrastructure in the mid-term.

There is a wide availability of products in the market that help to build such a network at a reasonable cost.

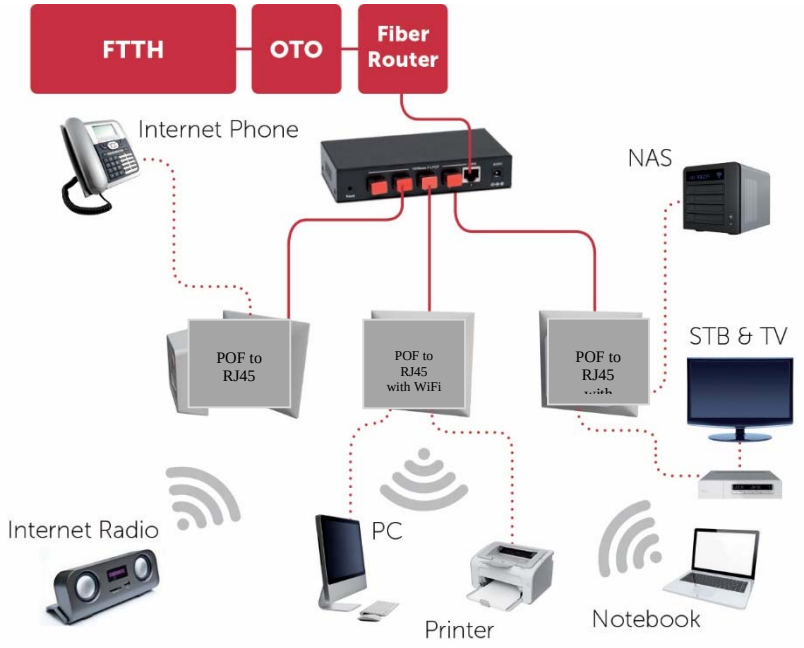

Figure 5: POF products examples

5.5 POF Standards

5.5.1 Introduction

Thanks to the effort of the POF industry and academia, several standards are available. The coverage of these standards is fairly wide from the POF as a physical media to the Gigabit communication protocol. The final objective of each and all the standards is to enable an open and interoperable market that ensures a reliable quality for end users avoiding compatibility issues or unstable performance.

The following clauses provide a brief overview of each document.

5.5.2 Fibre - IEC 60793-2-40 A4a.2 POF

International Standard IEC 60793-2-40 [3] has been prepared by subcommittee 86A: Fibres and cables, of IEC TC 86: Fibre optics.

This is the fourth edition that cancels and replaces the third edition published in 2009 and constitutes a harmonized terminology within the IEC 60793-2 [2] series.

This part of IEC 60793-2 [2] is applicable to category A4 optical multimode fibres and the related sub-categories A4a, A4b, A4c, A4d, A4e, A4f, A4g and A4h. These fibres have a plastic core and plastic cladding and may have step-index, multi-step index, or graded-index profiles. The fibres are used in information transmission equipment and optical fibre cables. In IEC 60794-2-40 [4] the use of these fibres in the indoor applications is specified.

The fibre of choice for POF home network installation is A4a.2. A4a sub-category is a 1 000 μm cladding diameter step-index fibre. Implementation A4a.2 fibre is a higher grade of sub-category A4a fibre in terms of attenuation and bandwidth, to achieve longer distance transmission than implementation A4a.1 fibre.

The standard defines the following attributes:

- Dimensional requirements.
- Mechanical requirements: tensile performance and elongation and tensile load at yield.
- Transmission requirements: attenuation, bandwidth, NA, chromatic dispersion and macro bending loss.
- Environmental requirements: change in attenuation and tensile loads after temperature and humidity cycles.

5.5.3 EN 50173-1 and EN 50173-4

CENELEC EN 50173-4 [7] defines channel losses. Different fibres in different scenarios are defined in the document. In concrete POF fibre within indoor applications, and its link budget requirements are described.

Following described standards like ETSI TS 105 175-1 [1] and ETSI TS 105 175-1-2 [5] take in consideration and fully support the CENELEC EN 50173-4 [7] requirements. The present document is linked with CENELEC EN 50173-1 [6].

5.5.4 ETSI TS 105 175-1 (V2.0.0)

The present document from the ATTM technical Committee (Access, Terminals, Transmission and Multiplexing) aims to define a set of relevant Plastic Optical Fibre System Specifications for 100 Mbit/s and 1 Gbit/s.

ETSI TS 105 175-1 [1] (V2.0.0 from October 2011), the latest revision of this document, specifies the POF cabling system 100 Mbit/s and 1 Gbit/s for interoperability among different suppliers. The system comprises the active optical elements, the cables, connectors and wall plugs. A future revision will aim to achieve integration of POF interfaces into end user equipment.

A summary of the main specified items follows:

- **Requirements for 100 Mbit/s and 1 Gbit/s:**
  - Performances:
    - Max. PHY layer data rate.
    - Reachable distance.
    - Macro bend radius and attenuation measurement method.
    - Communication mode (Duplexing).
    - Latency.
    - Temperature range.
    - Eye Safety level.
  - Higher Level:
    - QoS specifications.
    - Interoperability requirements.
    - IP versions compatibility.
    - Plug & Play requirements.

        - Drop in requirements.
        - Remote management and diagnostic requirements.

- **Cabling solutions:**
    - Cable and fibre:
        - Manufacturing requirements.
        - Fibre configuration.
        - Fibre compliance category.
        - Dimensions.
        - Accessibility requirements.
        - Materials safety requirements.
    - Connectors:
        - Typology.
- **Installation:**
    - Bending radius.
    - Bending loss.
    - Bending loss measurement method.
- **Energy Efficiency:**
    - Power consumption in idle or stand by modes.
    - Stand by modes.
    - Transition times.
- **Integrated Wall Plug:**
    - Power supply: Rating, consumption at idle, efficiency.
    - Lifetime.
    - Operating temperature.
    - Interfaces.
        - External sockets:
            - Socket type per country.
            - Ports.
            - Ethernet interfaces and cable autosensing features.
        - Internal sockets:
            - POF interfaces.
            - Optical interface requirements.
            - Installation procedures.
            - Aesthetic requirements.

  - Wall socket plug versions:
    - Socket configuration classes.
    - Ethernet packet management. Switching functionality specification and compliance.
    - Safety classification and requirements.
    - Mechanical and electrical robustness.
    - EMC requirements.
  - Sustainability requirements: materials and energy consumption.
- Annex A (informative): Integrated wall plug form factor.

5.5.5 IEEE™ 802.3 100BASE-FX

Current POF deployments uses IEEE™ 802.3 [9] 100BASE-FX standard as physical layer. This physical layer was designed for glass fibre applications. The suitability for POF applications of this physical layer in 100 Mbit/s bit rate is guaranteed by the band-width limitations of the channel (around 100 MHz) for the typical lengths of fibre in In Home applications. Longer distances and/or higher bit-rates cannot be provided by IEEE™ physical layers due to the bandwidth limitations of the communication channel.

The IEEE™ 802.3 [9] 100BASE-FX standard specifies multimode fibre as the transmission medium. Because 100-FX operates over multimode fibre and reaches distances up to two kilometres, there continues to be widespread use of 100-FX as a cost-effective way to extend Ethernet networks.

100BASE-FX [9] is a version of Fast Ethernet over optical fibre. It uses a 1 300 nm near-infrared (NIR) light wavelength transmitted via two strands of optical fibre, one for reception (RX) and the other for transmission (TX). Maximum length is 400 metres for half-duplex connections (to ensure collisions are detected), and two kilometres for full-duplex over multi-mode optical fibre. 100BASE-FX [9] uses the same 4B5B encoding and NRZI line code that 100BASE-TX does. 100BASE-FX [9] should use SC, ST, LC, MTRJ or MIC connectors with SC being the preferred option. 100BASE-FX [9] is not compatible with 10BASE-FL clause 34 of [9], the 10 Mbit/s version over optical fibre.

100BASE-FX [9] refers to a specific Physical Medium Dependent (PMD) sublayer and baseband medium of specification 802.3. This clause specifies the 100BASE-X PMD (including MDI) and fibre optic medium for multimode fibre, 100BASE-FX [9].

In order to form a complete 100BASE-FX [9] Physical Layer it shall be integrated with the 100BASE-FX [9] PCS and PMA of clause 24 of the same 802.3 specifications. As such, the 100BASE-FX [9] PMD shall comply with the PMD service interface specified in the mentioned clause 24.

The 100BASE-FX [9] PMD (and MDI) is specified by incorporating the FDDI PMD standard, ISO/IEC 9314-3:1990 [i.14], by reference. This standard provides support for two optical fibres. It specifies at MDI level the connectors and Crossover functions.

5.5.6 ETSI TS 105 175-1-2 1 Gbit/s and 100 Mbit/s data rate physical layer for Plastic Optical Fibre

The ETSI TS 105 175-1-2 [5] describes a physical layer for transmitting 1 Gbit/s and 100 Mbit/s over plastic optical fibre. The objectives of ETSI TS 105 175-1-2 [5] are:

- Provide 1 Gbit/s or 100 Mbit/s full duplex data transmission.
- Provide lower speeds than 1 Gbit/s or 100 Mbit/s with adaptive bit rate functionality if communication channel does not provide enough capacity.
- Support operation over Plastic Optical Fibres defined in IEC 60793-2-40 [3] types A4a.2 with the parameters specified in the respective annexes for each PHY.
- Provide a Bit Error Rate (BER) less than or equal to 10^{-12}.
- Provide low power operation mode for power management.

For the purpose of the present document, the data packets used by a PHY based on ETSI TS 105 175-1-2 [5] shall be standard Ethernet frames.

5.5.7 Recommendation ITU-T G.9960 with Annex F for Plastic Optical Fibre

Recommendation ITU-T G.9960 [i.1]) specifies the system architecture and functionality for all components of the physical layer of home network transceivers designed for the transmission of data over premises wiring including inside telephone wiring, coaxial cable, power-line wiring, plastic optical fibres, and combinations of these. These transceivers are intended to be compatible with other devices sharing the in-premises wiring. An overview is given in clause 4.5.5. Annex F of [i.1] specifies parameters for LED-based optical transmission over SI-POF, e.g. centre wavelength of 640 nm to 660 nm, besides OFDM parameters for various bandplans.

6 Requirements for 1 Gbit/s and 100 Mbit/s POF based applications

6.1 Introduction

Most of the requirements of the Gigabit POF based applications are already compatible and defined in ETSI TS 105 175-1 [1].

6.2 Physical layer requirements

The physical layer shall be implemented following ETSI TS 105 175-1-2 [5].

The data packets to be used with ETSI TS 105 175-1-2 [5] shall be regular Ethernet frames.

The link budget characteristics of the 1 Gbit/s and 100 Mbit/s are described in figures 6 and 7.

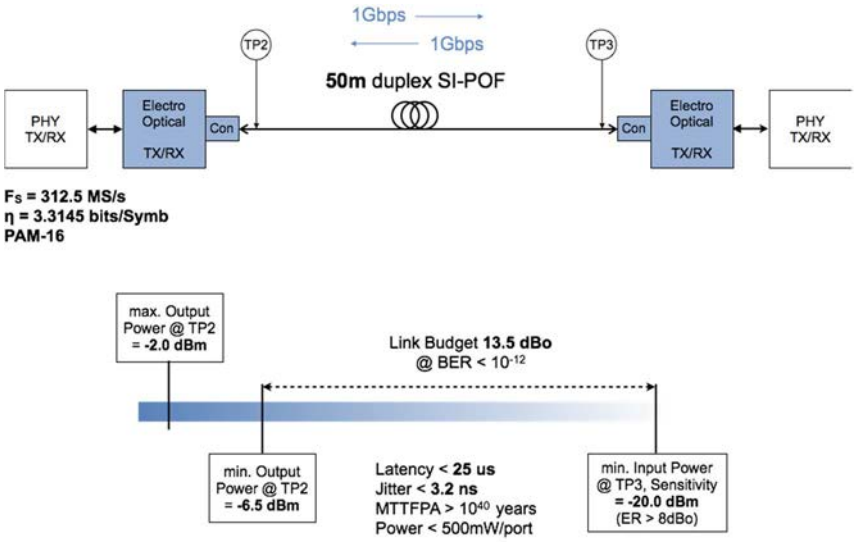

Figure 6: 1 Gbit/s link budget

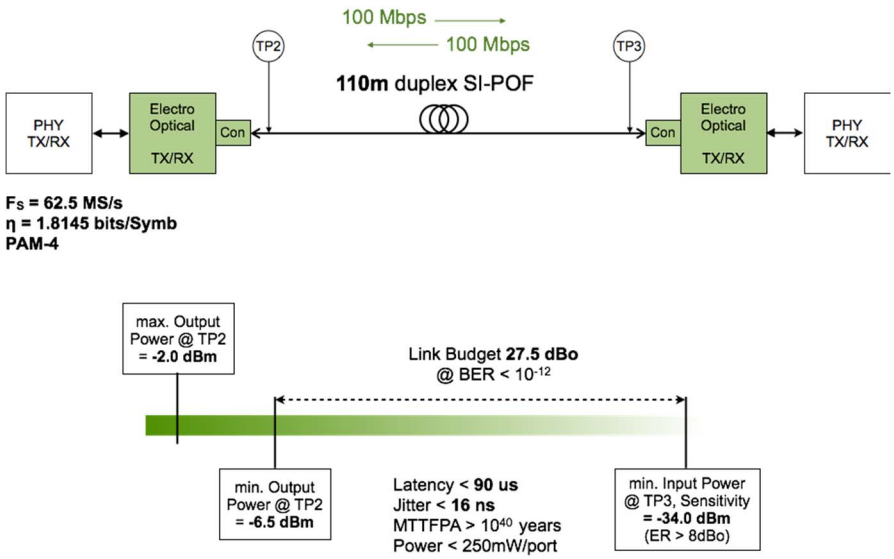

Figure 7: 100 Mbit/S link budget

6.3 Ethernet layer performance

The resulting performance of the implemented Ethernet link should follow:

- Bitrate: shall be exactly 1 Gbit/s or 100 Mbit/s, MAC Layer compatible with other 1 Gbit/s and 100 Mbit/s full duplex standards in IEEE™ 802.3 and [9], clauses 24 and 34, following ETSI TS 105 175-1-2 [5].
- Adaptive Bit Rate is specified as optional in ETSI TS 105 175-1-2 [5] and it may be supported to guarantee connectivity in extreme conditions.
- VLAN: VLAN may be required by applications. Transport layers manage VLAN support, but correct support is required in physical layer considering MTU. Please refer to IEEE™ 802.1Q [i.4].
- Jitter / Latency: is driven by application. Please refer to ETSI TS 105 175-1 [1]. ETSI TS 105 175-1-2 [5] requires more restricting values for jitter and latency than ETSI TS 105 175-1 [1].
- Frame Error Rate, Bit Error Rate: even when ETSI TS 105 175-1 [1] requires BER less than 10^{-12}, ETSI TS 105 175-1-2 [5] defines BER limits less than 10^{-10}. The required BER and FER shall follow ETSI TS 105 175-1-2 [5] requirements. This update in the requirements is needed to make the system compatible with 1000-BaseT installations.
- Validation test required in a 1 Gbit/s and 100 Mbit/s connection according to IETF RFC 2544 [8].
- Validation test of Ethernet services activation might be used following the Recommendation ITU-T Y.1564 [10] test methodology.

6.4 Backwards compatibility

New gigabit over POF implementation shall be backwards compatible with already deployed 802.3 100BASE-FX [9] devices. The 100BASE-FX [9] PCS and PMA are specified in IEEE™ 802.3 [9], clause 24.

6.5 Environmental requirements

- Temperature: is driven by application. Please refer to ETSI TS 105 175-1 [1].
- EMI: please refer to ETSI TS 105 175-1 [1].
- Safety: please refer to ETSI TS 105 175-1 [1].

6.6 Topology requirements

Several topologies shall be supported:

- Star: default topology for green field.
- Daisy/Chain: brown field houses. Reuse mains topology.
- Tree: complementary to Daisy/Chain to support branches.

For the implementation of those topologies bridging and multicast traffic handling shall follow:

- IEEE™ 802.1p [i.5]: Multicast filtering.
- IEEE™ 802.1D [i.6]: MAC Bridges.

For the physical installation of the fibre following requirements shall be followed:

- Bending: please refer to ETSI TS 105 175-1 [1] for bending requirements.
- Lengths: please refer to ETSI TS 105 175-1 [1] for fibre length requirements.
- Link budget: please refer to CENELEC EN 50173-4 [7] and CENELEC EN 50173-1 [6].

6.7 Energy Efficient Ethernet requirements

Low power mode is described as optional in ETSI TS 105 175-1-2 [5]. Consequently, Energy Efficient Ethernet is optional in the present document.

6.8 Network Management requirements

Following network management standards should be supported under the request of B2B demand:

- SNMP v3: please refer to RFC from 3410 to 3418 [i.10] for more details.
- TR-069 Amendment 4 [i.9] and TR-143 [i.11]. CPE-1 profile.

6.9 Diagnostic and monitoring requirements

The system shall provide diagnostic and monitoring requirements. The system shall provide at least the following indicators at both ends of the link for monitoring and diagnostic:

- Received power
- Link margin
- Temperature

The present document does not specify how these indicators shall be implemented.

6.10 Higher Level System requirements

Please refer to ETSI TS 105 175-1 [1].

History

Document history		
V1.1.1	January 2010	Publication as TS 105 175-1
V2.0.0	October 2011	Publication as TS 105 175-1
V1.1.1	October 2015	Publication