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HSBASE-P: A standard for Gigabit transmission over Plastic Optical Fibre (POF)

originated by

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The market need

In the past, POF has been used in the networking market with only limited success - even in the home. due to the limited access speeds which, based on xDSL, were bringing up to 20 Mbps to the home. At the same time power line carrier (PLC) and Wi-Fi home networking technologies were already fulfilling the limited demands for bandwidth generated by domestic software applications and services.

However, the situation is changing and the established trends in Japan, South Korea, and US are now being seen across Europe with telecom operators, in a competitive race of bit rates and prices, using different access technologies as marketing slogans. In parallel with this market push effort the bit rate demand is steadily increasing due to new services including HD-IPTV, "cloud" services, VPN, and life/work styles (remote/home working, self-employment, etc.).

This competitive landscape has forced telecom operators to invest on massive FTTH deployment projects as a way of differentiating themselves. As an example, at the end of 2011 there were more than 75 million FTTH subscribers worldwide *(Source: FTTH Council Europe)* and this will increase in coming years. For example, the European Commission Digital Agenda states that by 2020, at least 50 % of EU households should have 100 Mbps. *(Source: European Commission Digital Agenda)*

The bitrate race has started from 20 (xDSL/Cable) to 50 M bps, 100 Mbps and 200 Mbps. Rather than price reduction as a differentiation strategy, telecom operators are offering higher and higher bit-rates to support new services being offered.

A robust, reliable, stable and flexible "home network" topology is needed to reflect this trend, which is able to use the total provided bit-rate from the external network at any point in the home and also providing the extra bandwidth to be used for services such as file sharing and local video streaming.

A hybrid mixture of networking technologies is demanded comprising a reliable, cabled network (to support fixed-location PCs, multimedia hard-drives, IPTV set-top-boxes and routers) along with a, flexible, and ubiquitous mobile network based upon distributed Wi-Fi access points for tablets, laptops and smart-phones.

Such a combination is not only desirable at a practical level. Cabled networks are naturally more "energy efficient" than their wireless counterparts. Energy efficiency is an important topic in society for two reasons: firstly, environmental sustainability arguments are forcing the usage of energy efficient infrastructures; secondly, health concerns may force limitations of transmitted power in wireless networks, limiting high-speed reliable coverage to a single room *(Source: Council of Europe. Document 12608May 6th 2011).*

The easiest, most affordable and fastest way to introduce new cabling either in green (new construction) or brown (already constructed) fields is to re-use or share power supply pathways (ducts or conduits) within a daisy chain/tree topology. In such shared pathways, optical fibre transmission provides a significant benefit in term of electromagnetic immunity.

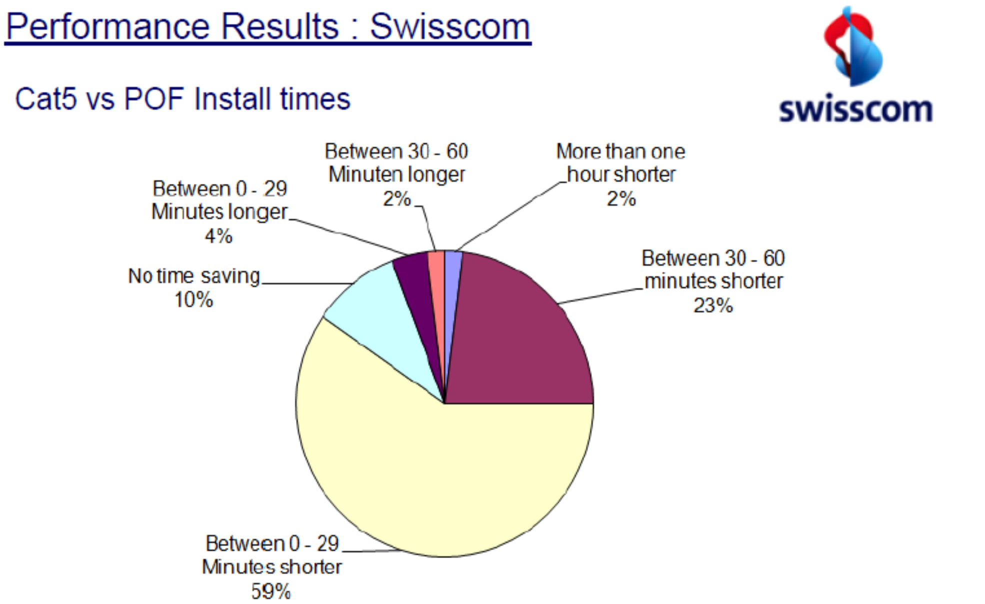
The technology up to now

POF-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 Category 5e as it is easier to install. POF installations do not require any connectorization and can be laid down sharing existing power supply ducts. Several financial studies based on field trials report savings on the order of 15 % to 20 % when comparing with Category 5e alternatives with the savings mainly coming from installation times.

(Source: http://www.comoss.com/ref/news/1000-Rollins-ATT.pdf).

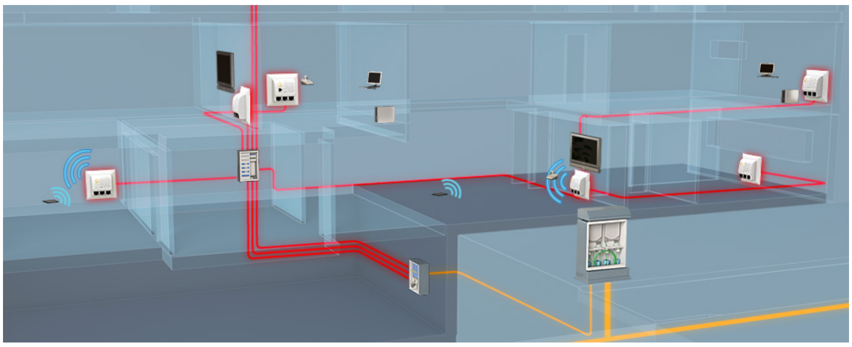
Figure 1 shows some figures on the comparison between Category 5e and POF installation times. Figure 2 shows a typical POF installation described in the studies. It can be seen that in more than 40% of the installations Cat-5e takes 30 minutes more than an equivalent POF installation. This is a substantial time of the total installation which typically takes 2 hours for POF.

Figure 1



Source: Firecomms

Figure 2



Source: Casacom Gmbh

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 among home construction, rehabilitation and office installation professionals. (www.pofto.org, www.quasar-pof.com, www.china-pof.org ,etc.)

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 Mbps for typical home up to 50m. A comparison of different home network technologies is summarized in Table 1.

Table 1

(Source: based on NYCE networks)

ISSUE	POF	Category 5e/6	HomePlug© (PLC)	HomePNA© (Coax+Phon.)	Coax	Wireless
Customer Installable	Yes	Not	Yes	Yes	No	Yes
Network user reconfigurable	Yes	No	No	No	No	N/A
Whole House Coverage	Yes (1)	Not Always	Yes	Not Always	Not Always	Not Always
Immune to Interference	Yes	No	No	No	No	No
Enables Mobility	Yes (1)	No	Available	No	No	Yes
Cost Effective	Yes	Not Always (4)	Not Always (4)	Not Always (4)	Not Always (4)	Not Always (4)
Reliable	Yes	Yes	Not Always	Not Always	Yes	Not Always
Number of Outlets (Typical)	Unlimited (2)	4, 8, 24	40	8, 62, 120	5	N/A
Bandwidth (Mbps)	100, 1000	100, 1000	14, 85, 200	128, 160, 256	270	11, 54, 108, 130, 230
Dedicated QoS links	Yes (3)	Yes (3)	No	Yes	Yes	No

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

HS-BASE-P: Features

In 2009 the German standardization body VDE/DKE established a working group (VDE/DKE WG 412.7.1) to develop and standardise a Gigabit solution for POF i.e a physical layer specification for a communication technology optimized for Plastic Optical Fibers (POF). The optical fibre used is IEC 60793-2:40 A4a.2 currently employed in home network installations and already specified as Category OP1 cabled optical fibre for use in industrial generic cabling in accordance with EN 50173-3 and ISO/IEC 24702. The result is a new Ethernet standard designated HS-BASE-P and entitled "VDE 0885-763-1:*Physical layer parameters and specification for high speed operation over plastic optical fibres type HS-BASE-P*" .

The standard is written and structured following the established IEEE 802.3 conventions. PCS, PMA, PMD and MDI are completely defined to guarantee interoperability between silicon from different manufacturers. It has been conceived from the beginning to be an OPEN standard, as any of the IEEE 802.3PHYs. A summary of the HS-BASE-P main performance highlights is shown in Table 2.

Table 2

Bitrate	1 Gbps, MAC Layer compatible with other 1 Gbps full duplex standards in IEEE 802.3.
Adaptive Bit Rate	Optional, it may be supported to guarantee connectivity under extreme conditions.
Jitter / Latency	.. driven by the application. The new standard requires more restrictive values for jitter and latency than previous ETSI technical specifications like TS 105 175-1.
Frame Error Rate, Bit Error Rate	Even though TS 105 175-1 requires a BER less than 10^{-12}, the new standard defines a maximum BER of 10^{-10}. The chosen BER level is suitable for compatibility with 1000-BaseT installations and can be reasonably verified.
RFC 2544 compliance	The new standard complies with the standard validation tests required in 1 Gbps connections.
Backwards Compatibility	The new standard warrantees backwards compatibility with already deployed 802.3 100BASE-X devices with PCS and PMA specified under clause 24.
Environmental requirements	Temperature, EMI and Safety levels are driven by the application. The new standard complies with ETSI TS 105 175-1 where typical levels are stated.
Topologies	Several options are supported by the new standard - mainly "star", the topology of choice for green fields and "daisy chain" ideally suited for brown field deployments (allowing the reuse of the mains ducts) with additional "tree" topologies to support branches.
Energy Efficient Ethernet	Low power modes are described as optional in the new standard opening the door for Energy Efficient Ethernet implementations.

HS-BASE-P: Standard structure and performance

It is structured around several annexes defining several speeds and functionalities:

- 1000BASE-P: Fixed bit-rate, full duplex Gigabit link;
- 100BASE-P: Fixed bit-rate, full duplex 100Mbps link. (Optional);
- xGBASE-P: Variable bit-rate, full duplex Gigabit link. (Optional);
- xFBASE-P: Variable bit-rate, full duplex 100 Mbps link. (Optional).

1000BASE-P PHY defines a normative full duplex, fixed bit-rate of 1 Gbps link. As opto-electronics improves the achievable performance is expected to be 50 m and 70 m of Category OP1 cabled optical fibre in worst-case and typical scenarios respectively – although the "worst, worst case" channel length using current opto-electroincs limits the performance to 25m with 50 m to be expected under typical operating conditions.

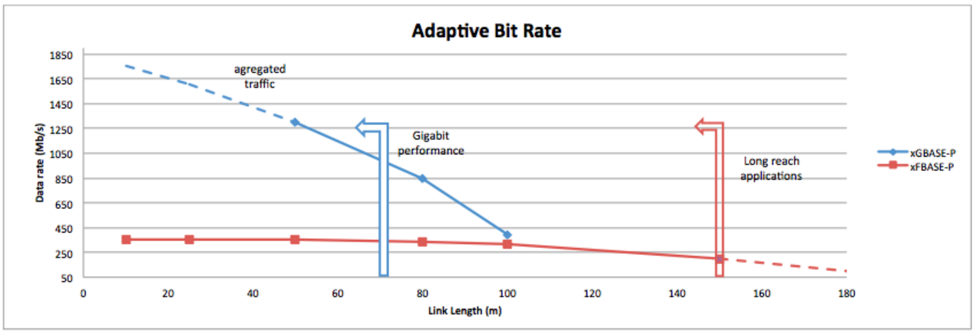
The **100BASE-P** PHY is an optional annex for a full duplex fixed bit-rate link of 100 Mbps. The achievable performance of this annex is 100 m and 150 m of Category OP1 cabled optical fibre in worst-case and typical scenarios respectively. The Table 3 summarizes the main parameters of these two annexes.

Table 3

	1000BASE-P	100BASE-P
Coding and Modulation	312,5 Mbaud, 16-PAM, 3.3145 bits/s/Hz/dim	62,5 Mbaud, 4-PAM, 1,8145 bits/s/Hz/dim
Delay constrain	<25us	<90us
BER	$<10^{-10}$	
MTTFPA	$>10^{40}$ years	
Worst case max link	50 m	100 m
Typical max link	70 m	150 m

Finally, the **xGBASE-P** and **xFBASE-P** PHYs are the optional annexes describing the Adaptive Bit Rate (ABR) versions of the 1 Gbps and 100 Mbps annexes. The Adaptive bit rate functionality is based on the quality of the received signal.

The ABR modes are very cost effective solutions especially suited to extend the coverage with bit rates between 100 Mbps and 1 Gbps, ensuring link robustness in distances up to 200 m. A comparison of bit-rates vs. POF lengths under the ABR behaviour is shown in figure 3.



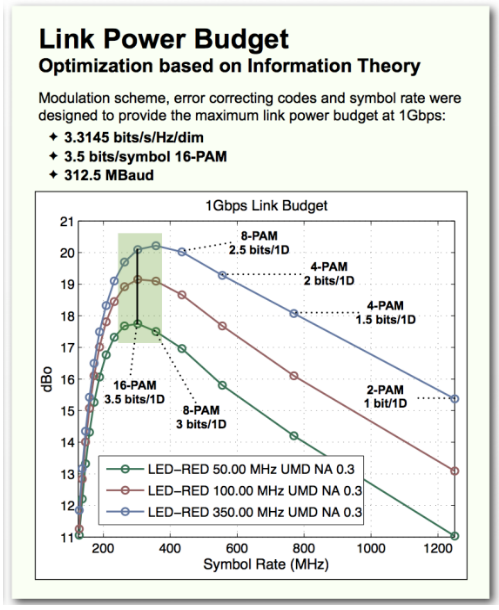
(Source VDE/DKE WG 412.7.1)

Figure 3

HSBASE-P has proven its viability with implementations of real time prototypes. As such, it is already running and providing the expected performance. Independent laboratory testing of prototypes have shown the expected behaviour under fast temperature cycles from -40 ºC to +85 ºC. The system is able to monitor in real time the channel distortions and compensate them to achieve the maximum performance.

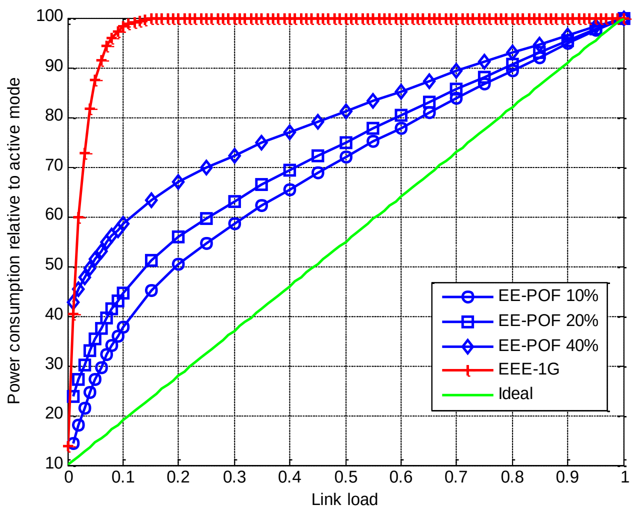
The communication system has been designed from outset with the objective of optimizing the capacity of the communications channel - which comprises not only the optical fibre but the optoelectronics as well. Many transmission modes were evaluated combining different modulation schemes with a plethora of symbol rates. A numerical optimization approach based on Information Theory selected a final winning combination of 312,5 MHz symbol rate with 16-PAM modulation levels. The optimality of this "sweet point" is shown in Figure 4.

The new standard allows an implementation of EEE (Energy Efficient Ethernet).EEE translates into an optimum performance in terms of power consumption of the overall communication system. Figure 5 shows the EEE performance for different transition times from ON to IDLE when compared with 1000BASE-T EEE performance. HS-BASE-P EEE is clearly superior to its 100 BASE-T alternative:



(Source VDE/DKE WG 412.7.1)

Figure 4



(Source VDE/DKE WG 412.7.1)

Figure 5

Summary

The new HS-BASE-P standard is the result of more than two years collaboration between several companies, universities and investigation bodies, with the objective to offer a technological solution for the home networking market that is able to keep pace with the growth of broadband access network speeds. Future home networks based on a mixed of fixed Gigabit POF backbone with WiFi access points will be able to offer the customer the benefit of a reliable, affordable and easy to install POF solution with the mobility and convenience of a wireless ecosystem of home devices. The new HS-BASE-P Gigabit POF standard enables the offer for home networking products to the market ensuring interoperability and superior performance to the end user.

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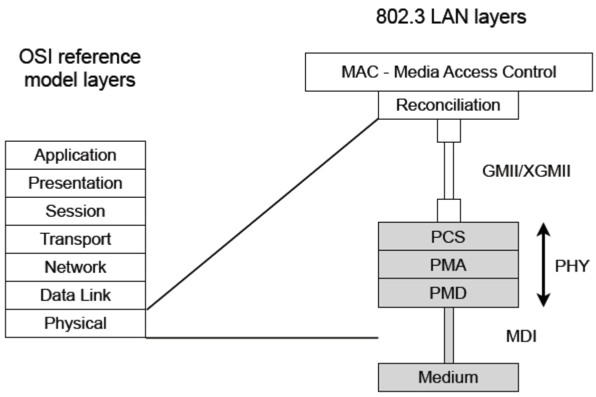
Annex A: Further technical details: HS-BASE-P: Physical layer technology

The new standard follows closely the logical partitioning of IEEE 802.3sub-clauses which warranties interoperability among multi-provider systems:

- Physical Coding Sub layer;
- Physical Medium Attachment;
- Physical Medium Dependent;
- Medium Dependent Interface;
- Service primitives and interfaces.

The standard is a physical layer developed with the aim to approach Shannon's limit of SISO communication channels like POF. The goal of the new standard is to specify communication systems optimized for limited bandwidth non-linear optical communication media. The standard allows affordable silicon implementation thereby reducing the risk to the implementers. The implementers of this physical layer will find it to be competitive in price and power consumption against current 802.3 1000Base-T physical layers.

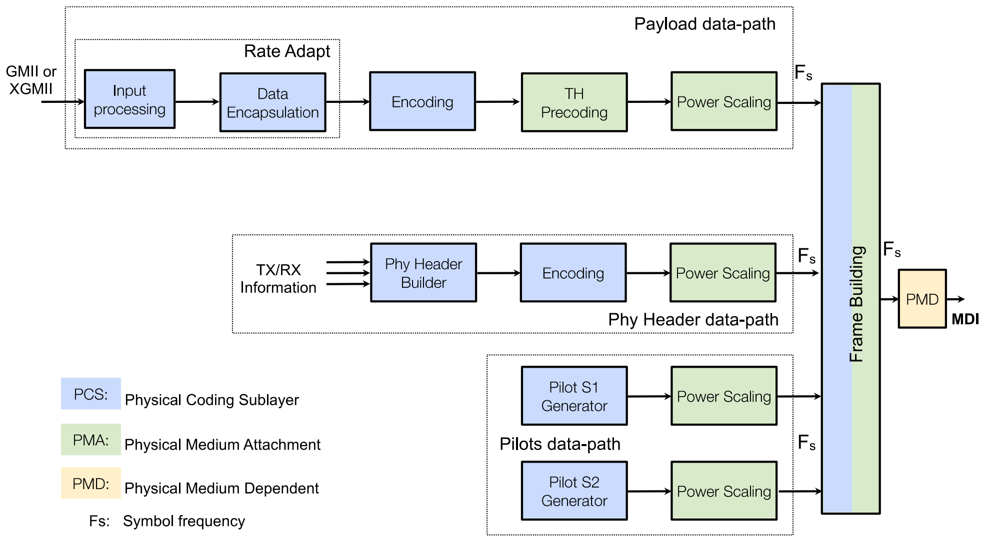


The communication system is structured around the following items:

- channel equalization following the Tomlinson-Harashima Precoding;
- channel coding based on Multilevel Coset Coding (MLCC)[i]

  Based on low cost binary component codes MLCC provides a high coding gain FEC scheme with low complexity HW implememtation for mid- and high spectral efficiencies - the MLCC configurable spectral efficiency property preserves constant coding gain
- frame structure for continuous adaptation and tracking. It allows a low cost implementation of receivers with timing recovery, non-linear channel estimation & equalization -the designed frame enables very fast and robust link start up;
- Energy Efficient Ethernet based on low power modes.

The following transmission block diagram summarizes the technology architecture. The PCS / PMA and PMD parts are coded in different colours. Three data paths, Payload, Headers and pilots, are needed for frame building and also shown in the block diagram of Figure A1.



(Source VDE 0885-763-1)

Figure A1

As already mentioned, the new standard uses a coding technique called Multi-Level Cosset Coding (MLCC). MLCC splits the traffic in three streams. Subsequent encoding takes only part on two of the three streams allowing an optimal coding performance. MLCC reduces the cost and power consumption of the alternative encoding of the full data stream at high data bit rates such as 1 Gbps.

[i] *G. D. Forney et al., "Sphere-bound achieving coset codes and multilevel coset codes", IEEE Trans. on Information Theory, vol. 46, no. 3, May 2000, pp. 820-850*