Chapter

Optical Inhouse Networks

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Abstract

Optical fiber networks are currently the standard for delivering high bandwidth to customers. Various access technologies to business networks with a very high bandwidth up to access networks for buildings and individual consumers have emerged. In the area of business networks, bandwidths of 10 Gb/s have become established, while in the area of customer bandwidths of 100 Mb/s to 1 Gb/s are used. This chapter will focus on the optical network connections inside buildings. The use of optical glass fibers or/and polymeric optical fibers in different network topologies in connection to high-speed actual WIFI- technologies will be discussed.

Keywords: optical fiber, distributed network structure, optical polymeric fibers, local area networks, open building reference model

1. Introduction

Depending on how far the glass fiber extends into the access network, one speaks of "Fiber to the Curb" (FTTC), "Fiber to the Building" (FTTB), "Fiber to the Home" (FTTH), "Fiber to the Desk" (FTTD). As an alternative, DSL technology, outdoor DSLAMs and VDSL with vectoring, contribute data transmission rates of up to 200 Mbit/s for broadband distribution to the subscriber, whereby these copper-based connection technologies have reached now their capacity limits [1].

As shown in **Figure 1**, the international optical network is essentially divided into three levels. Based on the international level of the global area network with

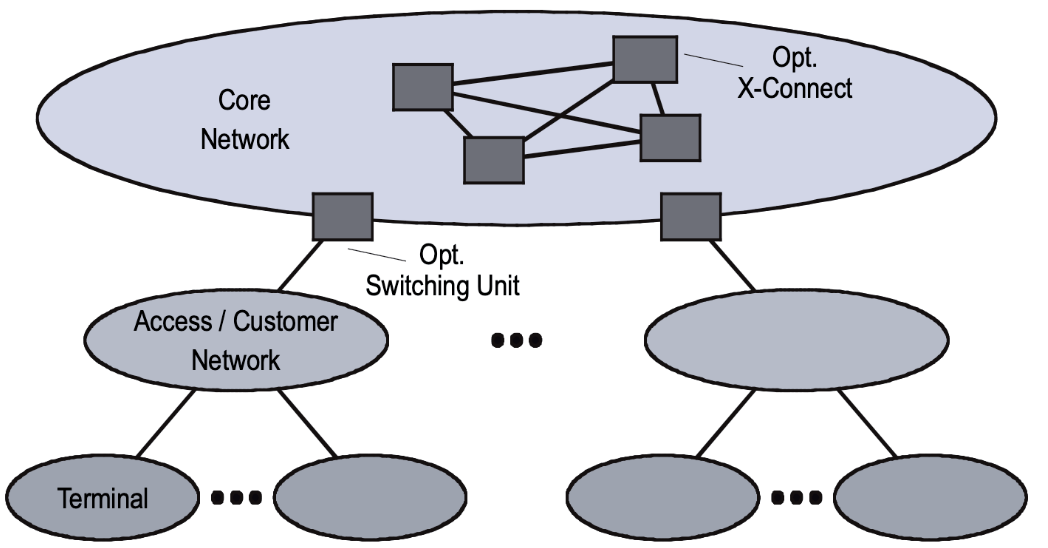

Figure 1.
Worldwide optical network structure.

very high data rates of 10–100 Gb/s, branches go to the level of regional networks with data rates of 1–10 Gb/s and from there to the third level of the customer network. There we speak of data rates of 100 Mb/s to 10 Gb/s. Based on this core network, the wireless networks (4G, 5G) to supply the mobile devices in the area with up to 1Gb/s are realized [2].

The mobile networks with LTE or 5G and the cable television networks also use this term for the part of their networks that includes the subscriber connections and offers access to higher network levels. However, radio technology can only be seen as an alternative to fiber optic infrastructure in rural areas, as little cabling needs to be installed. Unfortunately, the bandwidth of these radio networks decreases quadratic by the distance to the radio base station, so that the effectively transferable data rate will fall down strictly in rural areas. The cable television networks are currently based on DOCSYS 3.1 and already use fiber optic connections as FTTB variants and are therefore to be seen as fiber optic technology despite different software and hardware configurations. Currently, most of the optical fiber optic connections are made in the FTTB area [3, 4].

At a connection point in the basement of the building, the fiber optic cable coming from the outside is connected to a router or switch. Starting from there, the data is transferred to the different areas and floors of the office building or the apartment block either via fiber optics, polymer fibers or electrical Ethernet cables (e.g. CAT 7). This is referred as network levels 3 and 4, before branching from the different floors to the individual offices or apartments via switches. The other cabling in the apartments and offices is called network level 5. Here, in turn, there are appropriate routers for the apartments or switches for the offices in order to distribute the data in the individual rooms. Levels 3–5 are nowadays mainly connected via optical cables and will be analyzed in this chapter in a differentiated manner and discussed with examples. This also includes the use of additional technologies such as WiFi, Zigbee, Bluetooth or dLAN/powerline [5] in the home and office [6–8].

2. Distributed network structures

Computer networks in apartments, small buildings and office environments (Small Office/Home Office - SoHo) are typical fields of application for Ethernet-based communication networks [9]. Local services such as network printers or file shares are implemented on these network structures, or DSL and cable providers offer their customers IP-based services such as Internet access, IP-TV or VoIP (Voice over IP).

For the implementation of Ethernet/POF-based SoHo networks, different areas must be conceptually considered (e.g. laying cables, selection and structuring of electronic components), implemented and connected to the Internet using suitable devices and processes [10–13].

Based on the sub-areas to be implemented for the realization of a network in the desired SoHo target market, the protocols and standards to be considered are so diverse that the existing orientations as well as the derived test methods and devices appear unsuitable.

For the design of a general and expandable structure in the SoHo environment, an abstraction model was developed - which is suitable as a basis for orientation for the implementation of network structures, service models and test methods in the SoHo environment.

In the telecommunication networks a special scheme is applied to distribute the data from the source/headend to the customer. The distribution is divided into five levels (see **Table 1** and **Figure 2**):

Network level	Task
1	Content production
2	Operation of the head-end stations that receive and forward the TV and radio signals
3	Street/curb distributors
4	House distributors
5	Between router in the home and telephone/Internet devices

Table 1.
Network levels in the telecommunication network.

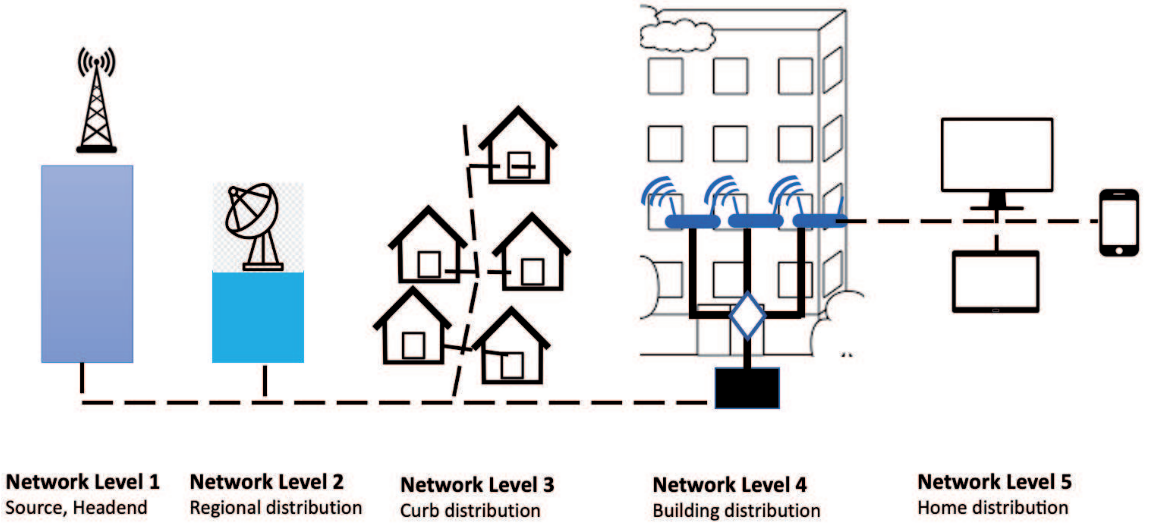

Figure 2.
Distribution of the telecommunications transmission path from the provider via the curb distribution to the building and in the building to the flats.

Level 1: Content/data production.

These include program providers such as Premiere, the public and private broadcasting stations and also Cloud applications.

Level 2: Operation of head-end stations.

The internet data is received via these stations and then passed on. In the case of the TV cable network, one of these head-end stations is always required, as this is where the signals from the satellite are converted and processed for cable reception, among other things. The reception technology in the cable networks has been completely converted to the digital standard since DOCSYS 3.1 [14] and is therefore at the same level as the telecommunications networks. Typical data rates are between 10 Gb/s up to 100Gb/s.

Level 3: Street distributor/curb.

This refers to the network areas that were relocated from the head-end stations to the residential areas (FTTC-fiber to the curb). Typical data rates are between 1 Gb/s up to 10Gb/s.

Level 4: house distributor.

Customers can only be reached via the fourth network level into the houses (FTTB - fiber to the building). Many small operators are exclusively active here, the number of which is estimated at several thousand. In order to offer new products and services, the operator must be able to feed them into the network. This requires an adaptation of several network levels, which, however, often turns out to be very difficult due to the large number of responsible companies at the various levels. Only in the rarest of cases does an operator have several levels, which makes the actual structure difficult to understand for the end user. Typical data rates are between 100 Mb/s up to 10Gb/s.

Level 5: Flat distribution.

The network connection directly with the customer is now being rolled out worldwide via optical fibers, since only these technologies enable a correspondingly high bandwidth. This level is between router and telephone/Internet devices such as smartphones, tablets or IP TV realized. Typical data rates are between 10 Mb/s up to 1Gb/s (FTTH - fiber to the home).

3. Open building interconnection reference model - OBI

Based on the different orientations of the four identified work areas (building blocks) (see **Figure 3**) as well as the multitude of standards and guidelines to be taken into account, which data center operators are familiar with - but not known to house and apartment owners in the targeted SoHo target market - the following situation arises:

A model is required that includes the four identified work areas - defines interfaces and thus offers orientation for further work [15, 16]. All areas relevant for the conception, construction and operation of SoHo networks and in-house communication can be structured, edited and tested in a reproducible manner [17, 18].

Based on the basic services defined within the OBI model, the conception of test scenarios was started. For this it is necessary to classify the network structure that is likely to be encountered. Starting from a transfer point (e.g. DSL [19], FTTH, DOCSIS [20] that connects to the public wide area data network (WAN) [18], SoHo routers are used that provide services for the internal network that are defined using an operating system (firmware) (LAN) (e.g. switch, WLAN, FXS (Foreign eXchange Station), FITH (Fiber In The Home)). The owner of the SoHo network has no influence on the implementation of the WAN area, apart from the choice of provider and product. The situation is different with the implementation of the LAN structure. Which implementation is used primarily defines the intended use of the LAN. The router already mentioned shows the following structure (**Figure 4**) taking into account its functions (**Figure 5**):

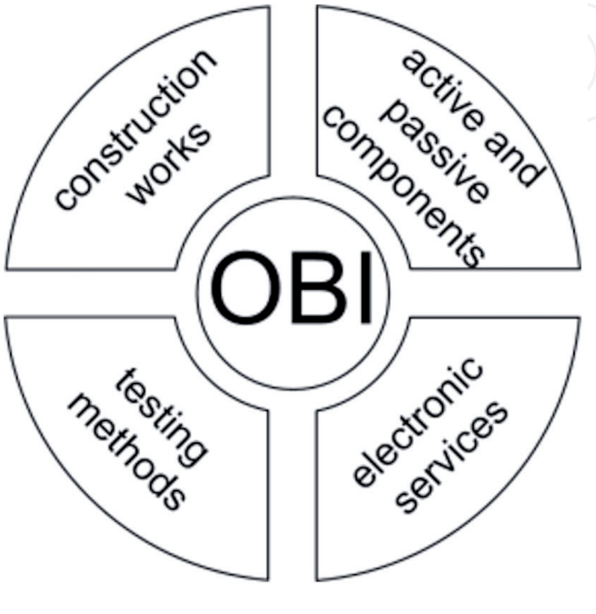

Figure 3.
O B I - open building reference model.

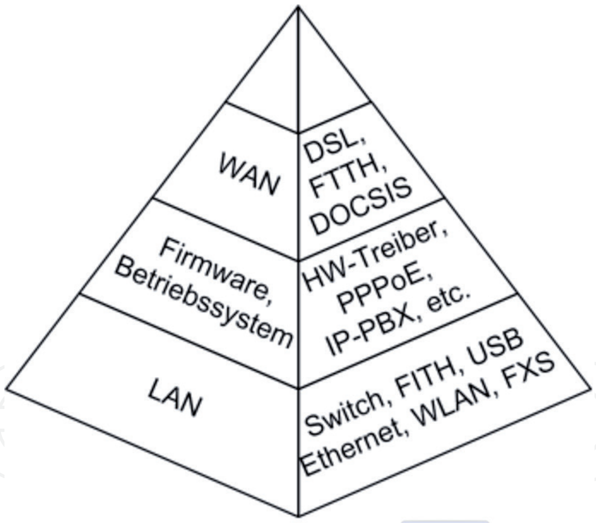

Figure 4.
Functional overview of a SoHo router.

	WAN	Router	LAN
Symbol			
Funktion	DSL, FTTH, DOCSIS	HW-Treiber, PPPoE, IP-PBX, Firewall	Switch, FITH, Ethernet, WLAN, FXS

Figure 5.
Network structure in the SoHo-environment.

Due to the owner's preference, all technical options (e.g., WLAN, fiber optic, POF, Cat [5–7], etc.) as well as the associated active and passive components are available for a structure.

If the SoHo network is viewed from the point of view of the services operated on it, the guarantee of the correct functioning and the quality of service by the provider of the WAN connection ends in the SoHo router which is depicted in **Figure 6**. It is assumed here that the provider of the WAN connection terminates the VoIP traffic on a SIP registrar [21] integrated in the SoHo router. All local end devices contact this SIP registrar, which in turn forwards the VoIP traffic to the telephone server of the WAN provider for termination using a SIP trunk.

The configurations, implementations and functions in the LAN area for mapping the functional correctness and quality of service for the defined basic services (network access, VoIP, WLAN) are part of the current work. For the investigation of the bandwidth-prioritized VoIP, a test scenario specially adapted to SoHo environments was designed.

In order to obtain reproducible results, the dependency on external disturbances (on the WAN side) must be excluded, which is why a local VoIP registrar was configured (codecs: g.711u [22], h264 [23]) and used. The SIP video telephones use - for the VoIP within the LAN - different transmission media, e.g., Cat (5/6/7), POF and WLAN and different combinations and configurations of the active and passive components. The ITU standards for PESQ [24] and the E-model [25] are used for objective assessment of the voice quality of VoIP calls.

Both test methods take into account all parameters involved in the transmission (e.g., noise, SNR, latencies, jitter, echoes, packet losses, etc.) as well as their mutual dependency. For the examination, a defined language file is transmitted (see **Figure 7**- red/

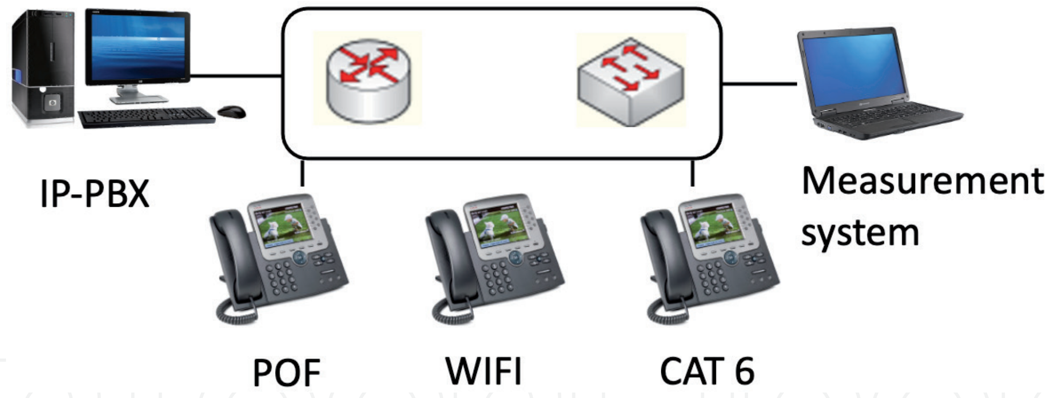

Figure 6.
SoHo - network topology for VoIP test.

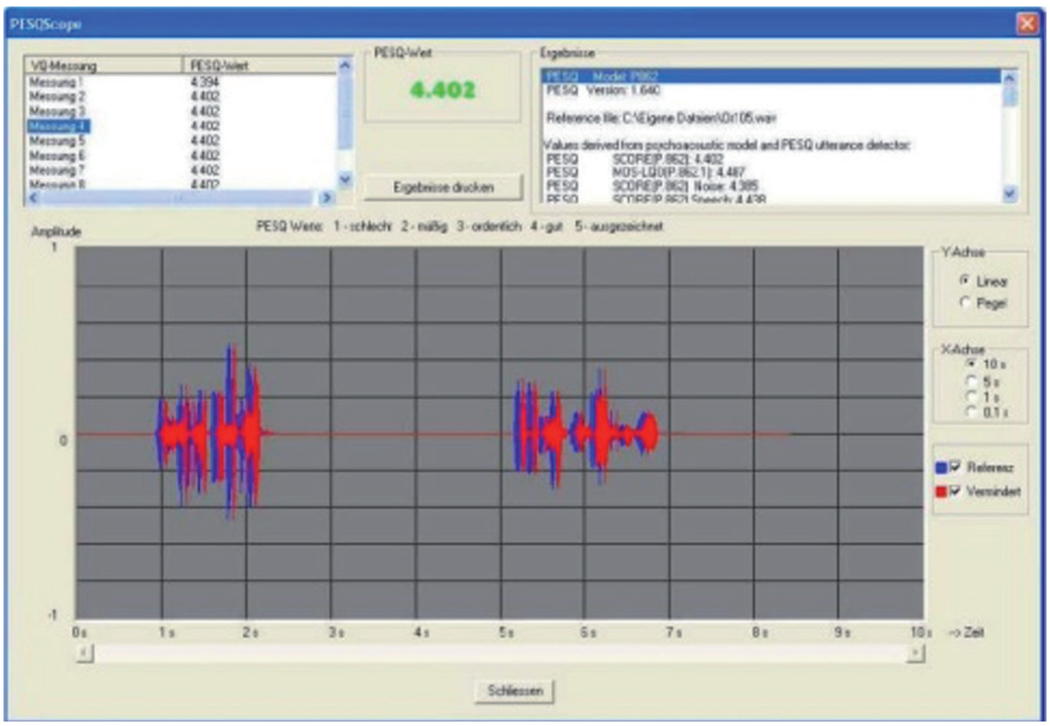

Figure 7.
PESQ-measurement in SoHo network topology.

reduced) and compared with the original file (see **Figure 7**- blue/reference). The result is a numerical score value (PESQ-MOS factor for PESQ, R factor for E-model) for the comparison tables.

After calibration of the individual transmission links and selection of suitable test parameters and routines, the configurable parameters of the active components (e.g., QoS, VLAN, IPv6) can be examined in the context of "Influence on the quality of VoIP transmissions in SoHo environments". Statements can also be made about the influence of the codecs used (e.g., H264, G711, G722 [26]) or the number of maximum SIP connections in the context of the bandwidth limit of the existing network topology. By using the VoIP registrar function in commercially available SoHo routers that are already available on the market (today already with all major Internet providers), the test routines can be run through - without measurement setups and configurations - and thus provide comparable results. By using the OBI model, communication and network structures in SoHo environments, especially for technology-supported care assistance systems [27] with the personal data that arise there, can be referenced and verified.

4. Network types in the building

4.1 Glass fibers vs. polymeric fibers vs. CAT

Optical waveguides are made of optical glasses or assembled, partially assembled, provided with plug connections cables and lines for the transmission of light in the visible as well as ultraviolet or infrared range. Fiber optic cables form flexible connections for the transmission of optical signals. Depending on the application, the fiber optic cables consist of Quartz glass, e.g. pure silicon dioxide (SiO2) or organic glass Polymeric fibers consist of acrylic glass [28]. From a physical point of view, both optical waveguides are dielectric waveguides.

Today, fiber optic cables [29] are mainly used as a transmission medium for wired telecommunication processes. In addition, there are diverse applications: fiber optic cables for laser radiation for material processing [30, 31], in medicine for lighting and imaging purposes: microscope lighting [32], endoscopes [33], decoration lighting [34], for contact-free sensors [35], in measurement technology, e.g. in infrared thermometers and spectrometers [36].

Today, fiber optic cables are increasingly used for information transmission, in telecommunications and also in the area of computer networking. The term optical fiber is standardized in DIN 47002 and VDE 0888 and means that it is a conductor in which modulated light is transmitted. The fiber optic cable can be made of fiberglass or plastic. With plastic fiber-optic cables, the so-called POF, high transmission rates can be achieved, which can be up to several million bit/s. Furthermore, POF are insensitive to electromagnetic interference, largely secure against eavesdropping and have very low attenuation values compared to copper conductors.

A comparison of different fiber optical waveguides in glass and in polymeric materials are depicted in **Figure 8**. There are multimode fibers (MMF) available in two sizes, 62.5 or 50 microns, and four classifications: OM1 (62.5/125 μm), OM2, OM3, OM4 (50/125 μm) [37]. The GOF fiber type for SoHo applications is the multimode GOF with a diameter 50 μm core and 125 μm cladding. The bandwidth of this device is typically 1–10 GBit/s over 100–500 m. The POF has a very limited bandwidth of 1 Gbit/s over 100 m link length in Ethernet networks.

As depicted in **Figure 9** the single mode GOF (SMF) offers the highest bandwidths of over 10 Gbit/s, which go well beyond the bandwidths required in the

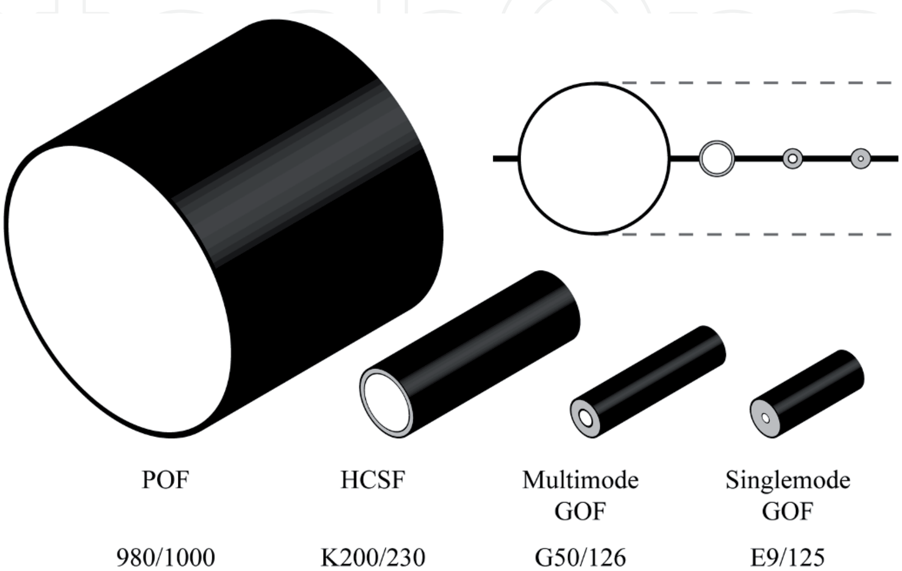

Figure 8.
Dimensions of GOF and POF fiber types.

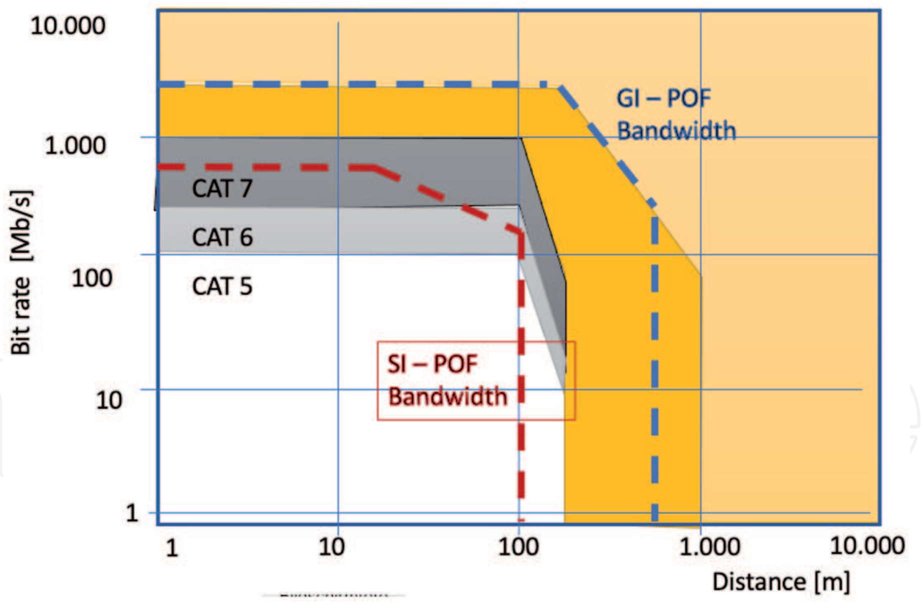

Figure 9.
Transmission speeds of single mode and multimode GOF, POF and CAT for inhouse applications.

SoHo area. This is why the SMF still plays a subordinate role in the short-term computing area in buildings. On the other hand, the multimode GOF (MMF) with bandwidths of 1 Gbit/s has significantly higher application potential, since the connectors and other active components such as transmitters and receivers are significantly cheaper than those of SMF components. The POF has significantly expanded its bandwidth potential in recent years and with gradient index POF (GI-POF) can also allow up to 10 Gbit/s over 50 m transmission distance, but has only been investigated in research studies to date. The step index POF (SI-PF), which can be used commercially with a maximum of 1 Gbit/s, is significantly worse in terms of transmission bandwidth. On the other hand, experimental studies show, that Wavelength Division Multiplex (WDM) techniques [38] applied in the POF spectrum of 400 nm to 780 nm can overcome the bandwidth restrictions and can realize more than 15 Gb/s via 4 chromatic transmission channels [39]. Additional WDM sources can extend the overall bandwidth to more than 40 Gb/s [40].

The copper technology of the CAT cables currently also achieves gigabit transmission speeds, but is very susceptible to installation errors such as bending radii that are too small. However, the CAT cable connection has the advantage of passive networking without further active transmitter/receiver elements.

4.2 POF fibers for inhouse applications

For signal transmission over short to medium distances of up to approx. 100 m, optical waveguides made of acrylic glass (polymethyl methacrylate or PMMA), so-called POF, are used.

Polymer fiber technology for optical data transmission has developed very dynamically over the past 10 years [41]. Starting with simple transmission options for the consumer sector such as digital links between DVD players and preamplifiers in the home multimedia sector (TOSLINK [42] system) with data rates of a few Mb/s, the technology has now established itself in the automotive sector with the use of MOST bus [43]. Here, POF is used in the visible wavelength range, since the components at this level of application must be manufactured as cost-effectively as possible for the end user. Mobile multimedia applications are of particular importance in the automotive sector, where over 50 vehicle types (approx. 15 million vehicles) have been equipped with POF bus systems since its introduction in 2001.

In addition to the higher data rate and the resulting improved integration of multimedia applications in busses or automobiles, considerable weight reductions in the cable of 30% are also achieved [44, 45].

For these reasons, optical data transmission is increasingly being used in close proximity, e.g. in office and house communication, in production facilities, in medical technology or in bus systems for cars, trains and planes.

In the following, the optical basics of fibers, called POF (polymer optical fibers) for short, their active and passive components for network technology and their fields of application in the in-house area are presented.

4.3 Optical properties and advantages of POF

Optical fibers consist of a highly transparent core, a cladding and a protective coating and/or buffer. The light-guiding core is used to transmit the signal. The cladding has a lower optical refractive index (density) than the core. As a result, the cladding causes total reflection at the boundary layer and thus guiding the radiation in the core of the optical waveguide. However, light can also get into the cladding through bending or coupling at the beginning of the route. This is usually undesirable and the jacket and protective coating are therefore designed in such a way that this light is strongly attenuated.

The outer protective coating helps against mechanical damage and protects the fiber from environmental influences. The POF consists of PMMA (acrylic glass), has a core diameter of approx. 1 mm (**Figures 10** and **11**) and has a bandwidth of

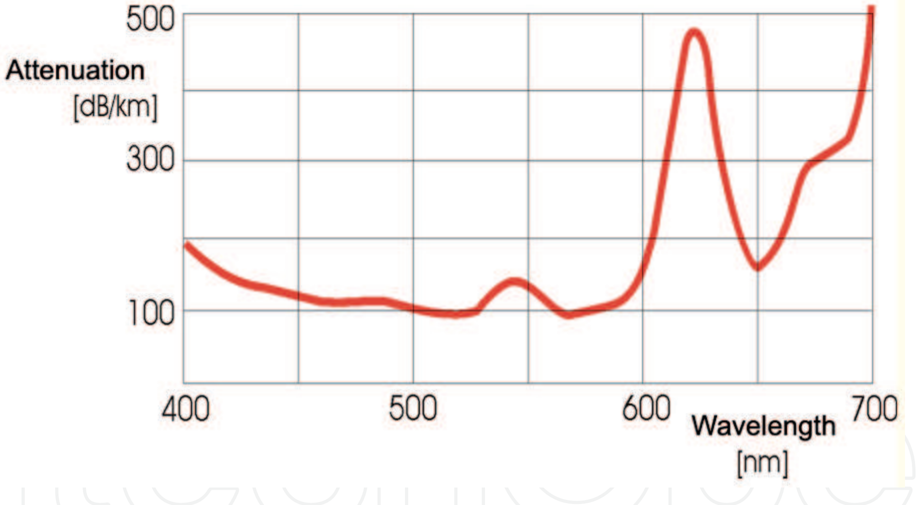

Figure 10.
Attenuation diagram of POF in the visible regime.

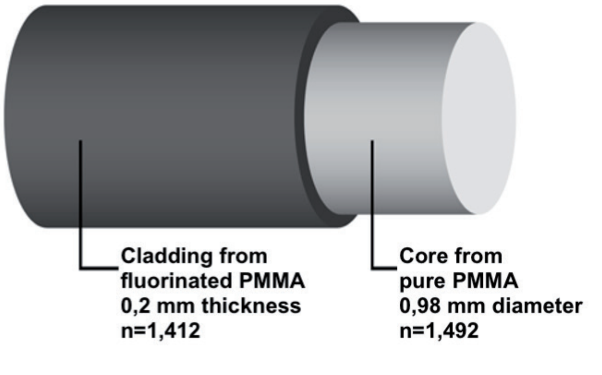

Figure 11.
Schematic draw of a polymeric fib.

	POF	GOF	CAT
EMV	++	++	—
Galvanic isolation	++	++	—
Bug security	+	+	—
Risk in explosive environments	++	++	+
Low weight	++	+	—
Small bending radius	+	—	—
Flexibility	+	—	+
Low cost	++	—	+
Bandwidth	+	++	+
Attenuation/m	—	++	—
Cable and connector assembly costs	++	—	+
++ *very good,* + *good,* – *unsatisfactory.*			

Table 2.
Comparison of GF, CAT and POF transmission connections in SoHo environment [46].

100 Mb/s over 100 m, which can be expanded to 1000 Mb/s with special modulation techniques and laser transmitters. The advantages of POF in laying technology are obvious in several areas compared to WiFi, powerline/dLAN or CAT solutions (see **Table 2**, [46]):

1. Practical aspects

    - Very inexpensive, easy to work with
    - Low weight, very small diameter: 1/10 of copper cables
    - More flexible and cheaper than glass fiber optic cables
    - Easy handling
    - EMC insensitivity

2. Security aspects

    - Better insurability
    - Security against eavesdropping
    - Short-circuit protection, free of hum loops

3. Technical aspects

    - Data rates can be expanded in a future-proof manner (investment security)
    - Several signals can be transmitted on one fiber
    - Significantly cheaper and easier to lay than glass fibers

The 1 mm fiber type is the cheapest to manufacture and is therefore used in 95% of all commercial applications. The refractive index is constant over the entire core cross-section (SI-POF). With other fiber types, for example gradient index fibers (GI) or multi-level index fibers (MSI), significantly higher bandwidths (currently 2.3GHz/100m) can be achieved in the laboratory, but these do not play a role in the consumer market segment. The advantages of the standard SI-POF lie in the wide availability, the very low price, the favorable attenuation behavior (**Figure 10**) a very high numerical aperture, which enables a simple and effective coupling and extraction of light.

5. Usable connectors for glass fibers and polymeric fibers in the home

The optical polymer fiber POF has particularly good and simple properties for the connection technology between fibers and optical transmitters and receivers [47]. Due to its simple structure, which with a core of 0.98 mm and a cladding of 0.2 mm corresponds exactly to 1 mm outer diameter, the cable can be cut straight with a cutter knife (see illustration) very easily. In contrast to fiber optic connections, the separation and cutting of a plastic fiber is much easier because the fiber optics require very complex mechanics and the dismantling of the fiber optic cables (see YouTube video [48]). A connection of two fibers has particularly low losses, since the large diameter reduces the mechanical boundary conditions for the accuracy of the alignment to + −0.1 mm. This corresponds to a 100 times lower necessary accuracy compared to a fiber optic connector. Because the alignment accuracy between the fiber and the optical element can be measured very generously without generating large losses, the plug-in connections are correspondingly easy to assemble. The **Figure 12** shows an overview of the typical plug connections for POF cables.

A distinction is made between metallic and plastic plugs. The metallic plugs are used in the area of rough environments like car entertainment busses or factory environments for stable connections. The plastic plugs were used in the area of in-house networks without large load peaks.

No plugs are typically used for use in the home, while the fibers can be simply cut off (see **Figure 14**) and butt-inserted into the receptacle of a media converter. This saves a lot of costs and unnecessary time for the connector assembly, as well

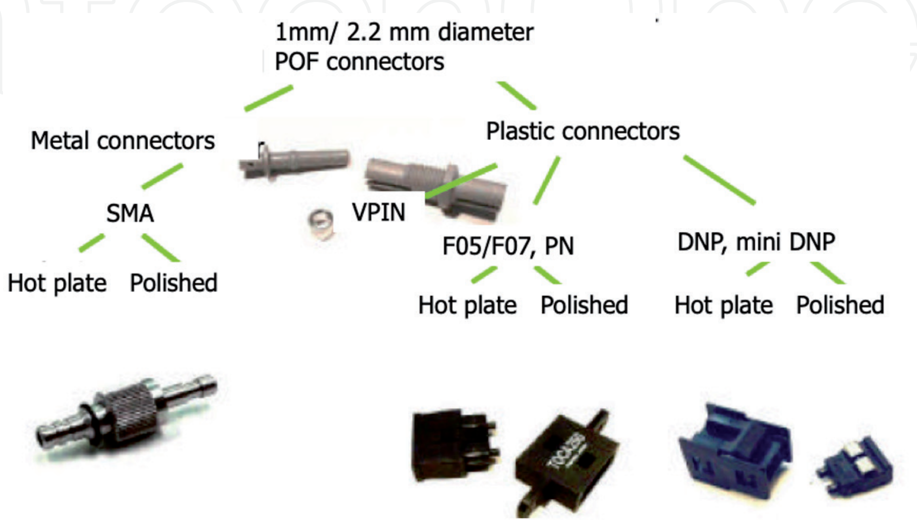

Figure 12.
Typical plugs for POF connections.

as a simple possibility for the non-specialist to lay network cables himself without special knowledge. Typical connectors for butt-inserted connections are shown in **Figure 15**.

Another area for the introduction of POF network technology is the construction and connection technology, e.g. of splicing for POF. This would make it possible to directly couple POF without additional components. This technology is established in fiber optic technology, but in a technology that cannot be used for POF. That is why it would be of crucial importance for the cable laying technology of POF to have such a connection technology with innovative approaches. A splice kit (**Figure 13**) has been implemented at the HarzOptics GmbH Company with industrial partners using injection molding technology, which provides very good conditions for an easy-to-use splice [49]. Very low attenuation of 0.2 dB is typical for this spice method. The basic idea is that the fibers are fit very exact into the splice core of 0.98 mm and the core hoe was filled before with glue. The refractive index of the glue is 1,5 and the hardening of the glue is realized by the use of a UV light lamp, which took only 3 minutes to be hardened (**Figure 15**).

Figure 13.
Optical splice with low attenuation.

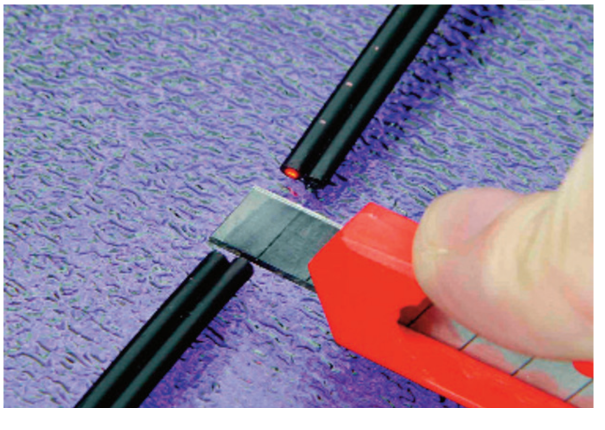

Figure 14.
POF fiber cutting easy with cutter knife.

Figure 15.
POF media convertors, Ethernet switches and 4-port optical POF switch RJ-45 wall outlets with WiFi-Accesspoint (Rutenbeck GmbH).

For the home sector, also known as domotics, an increasing demand for bandwidth is to be expected over the next few years. One reason for this development is the triple play promoted by the leading telecommunications companies, which means a bundled range of services such as IP telephony, IP TV and the Internet (**Figure 16**). Another term used in this context is the "active house". The development of this concept represents the integration of communication and entertainment, as well as the active control of all functional processes in the house (control of the heating, blinds, monitoring systems, etc.), also known as building automation.

For these areas, active components on the one hand, e.g., media converters for setting up dynamic network structures, and on the other hand, passive optical components such as splitters for the inexpensive construction of such networks are available in sufficient numbers for Ethernet applications up to 1000 Mb/s. There are a variety of applications and simple installation techniques for POF media converters or POF adapters (**Figure 15**) and POF Ethernet switches for installation in flush-mounted switch boxes are available for setting up home networks with polymer fibers [50]. On the user side, one or more ports with RJ-45 interfaces (10/100/1000Base-Tx) are available for connecting the end devices. The polymer fiber is connected on the installation side. The POF is connected to the optical interfaces (1000Base-Fx) using plug-in terminals.

The switch shown also allows the construction of star, bus, tree and ring structures with polymer fiber cables. Some of the ports of POF Ethernet switches even offer Power over Ethernet (PoE) functionality, so that IP telephones, IP cameras or WLAN access points with IEEE 802.11n data rates (up to 240 Mb/s net data rate [51]) can be operated on the POF network without plug-in power supplies.

6. Example of an in-house network with optical POF fibers

A typical example of an application in a single-family home is shown in **Figure 16**. The data which is supplied from outside from the so-called network level 3 via fiber optics or DSL to the house is sent to a router at the house transfer point.

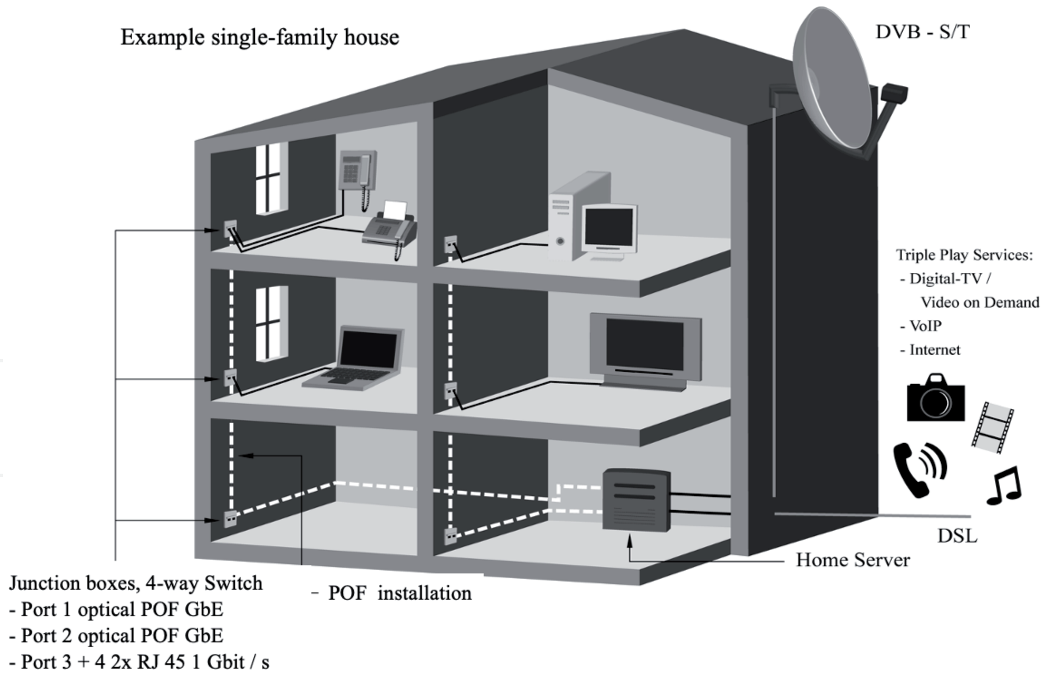

Figure 16.
Optical POF bus in the home network.

From this router, optical POF fiber cables are installed in all rooms in the house with active switches with four ports and connected there. Forwarding via additional switches the data can easily be routed to each room and connected. Furthermore, a corresponding WiFi module can be integrated in these switches, which can illuminate each room individually with small radio energy and is available for mobile devices in this room. By reducing the radio energy, each room can be connected to its own WiFi radio network and thus does not interfere with the transmission quality of the adjoining rooms. The radio energy must be set so low that the radio waves from the individual WiFi areas in the room do not get into the neighboring room and are attenuated enough by the walls.

It is also possible to lay the polymer fiber slightly behind baseboards in existing structures and thus not have to finance complex and expensive construction measures.

7. Conclusions

Optical fiber networks are currently the standard for delivering high bandwidth to customers. It was discussed, that there are various access technologies to local networks with a very high bandwidth up to access individual customers in their homes or flats. The use of optical glass fibers or/and polymeric optical fibers in different network topologies in connection to high speed actual WiFi- technologies have been discussed.

Both, the copper networks with CAT connections, as well as the networking with optical glass fiber and optical were compared and their strengths and weaknesses were shown. The Polymer Optical Fiber exhibits many advantages in comparison to glass fiber and copper as the medium for communication. The mentioned applications show different special sectors to the application of one of the three transmission technologies.

The focus in this work lies on the possibility of conveying high data rates, as well as the simplest possible relocation of network components in the SoHo area. In the area of permanently installed network components, the use of POF fibers proved to be particularly suitable for network bandwidths of up to 1 Gb/s. In addition to the almost relocated optical components, the installation of a wireless network via WiFi is a particularly good addition to make mobile devices easily networkable for the customer. Thus, a recommendation can be issued for both, optical polymer fibers with Ethernet network technology in combination with current WiFi technology. Both system components will experience further expansion stages in the range in the next few years and thus always remain applicable and expandable.

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