

Photonic in-building networks : architectures and advanced techniques

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Photonic In-Building Networks – Architectures and Advanced Techniques

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Abstract

In-building networks delivering broadband wired and wireless services can be realized cost-effectively with duplex plastic optical fibre, particularly when sharing ducts of electrical power cabling. Point-to-point architectures are well-suited for residential buildings, and bus or star-bus ones for larger buildings.

1. Introduction

Fibre to the Home access networks are being installed in increasing volumes in many countries, and are offering large access capacities of 100Mbit/s or even up to 1Gbit/s [1]. However, this capacity only reaches up to the doorstep of the user's home; reaching the user himself is hampered by the shortcomings of today's in-building networks. Moreover, trends such as high-definition video streaming and fast exchange of huge data files to and from centralized terabyte-capacity servers may require that the capacity of an in-building network even exceeds the one of the access network connection. In-building networks today mostly consist of a mixture of networks which each are laid out for a particular set of services: coaxial cable networks for TV and radio broadcasting, twisted pair cables for telephony, Cat-5 cables and wireless LAN for data communication between desktop and laptop PC-s, servers, printers, etc. The variety of networks complicates maintenance, upgrading of services, and the introduction of new services. Combining the delivery of all services, wired and wireless, in a single converged in-building network can offer many improvements. Optical fibre is a powerful medium for this, thanks to its transparency for any signal format and its large bandwidth. Suitable candidates are bend-insensitive silica single-mode fibre (SMF), silica multimode fibre (MMF), and large-core plastic optical fibre (POF). Next to the technical advantages, the cost aspects of the fibre solutions are of major importance.

In this paper, we will discuss the architectural solutions for a fibre-based in-building network, its economical aspects, and a number of techniques for maximizing its capacity.

2. In-building network architectures

The wired backbone network can be laid out in a number of basic architectures [2]: a point-to-point (P2P) architecture (Fig. 1.a) with individual cables running from the residential gateway (RG; connects the in-building network to the access network) to each room;

a bus architecture (Fig. 1.b) with a cable to each floor which by means of a hub is tapped off to each room; and a tree architecture (Fig. 1.c) with a cable to each floor from where via a switch a cable runs to each room. The maximum link length depends on the cable type and the data speed; for Cat-5E it is 100 metres for Fast Ethernet and Gigabit Ethernet, for MMF 550 metres, and for PMMA POF typically 70 metres for Fast Ethernet and up to 50 metres for Gigabit Ethernet (still in the research phase). With SMF, the maximum link length achievable exceeds any realistic building size. Given the limited reach of POF and Cat-5E links, a larger building is covered by putting the RG at a more centralized position, such as in the hybrid star-tree architecture (Fig. 1.d) or variants thereof (star-P2P, star-bus).

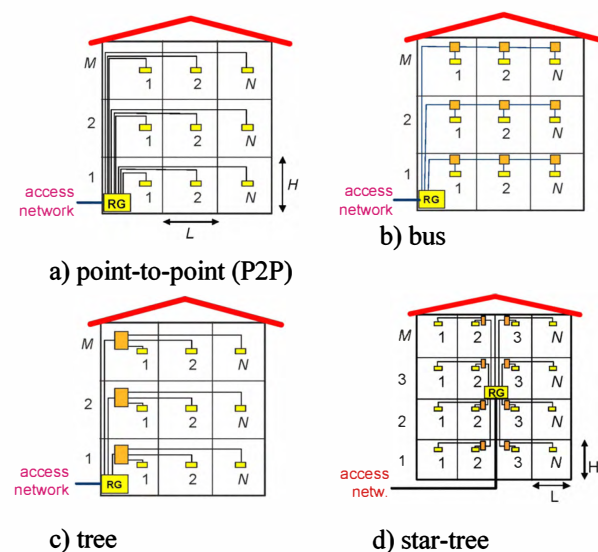


Fig. 1 In-building network architectures

Various building scenarios may be considered; we restricted our studies to three typical ones: residential home, office building, and multi-dwelling building. The building dimensions assumed are given in Table 1.

Table 1 Building dimensions

	No. of floors M	No. of rooms per floor N	Distance between floors H (in m)	Distance between wall outlets L (in m)
Residential home	3	4	3.3	8
Office building	10	50	3.8	10
Multi-dwelling bldg.	10	16	4	14

In the following, we assumed that the nodes in the network (the hubs in the bus architecture, and the switches in the tree architecture) perform their routing functions in the electronic domain; hence there is opto-electronic conversion at their inlets and outlets. Typically, they can handle IP-based signals but no non-IP signals (such as analog video), and thus the network becomes opaque. A fully transparent network, able to handle any signal format, is achieved in a P2P fibre-based architecture, and in all-optical bus or tree architectures where passive optical power splitters or passive wavelength routers are used in the nodes. As these passive optical devices are readily available for SMF but not commercially available (yet) for MMF and POF, a transparent network requires SMF.

For bidirectional links, duplex POF cables are assumed. Given the higher fibre losses which reduce the link budget, and the issues with coarse wavelength multiplexing, a bi-directional single-POF link is not readily feasible.

3. Economic analysis

We have analyzed the costs to install the various network architectures using different media (SMF, MMF, POF, Cat-5E), for the three building scenarios mentioned. The network items taken into account are: cables, ducts, connectors, media converters (opto-electronic transceivers), hubs, and switches. For the various architectures, the costs of each category were expressed in the building dimensions given in Table 1. Based on prices obtained from various manufacturers, and typical labour costs for mounting and installation, the costs per item assumed in our analysis are given in Table 2.

Table 2 Network cost items

	Cat-5E	POF	SMF	MMF
Installed cable (€/m)	1.8	1.7	1.74	1.95
Max. link length (m)	100	70	1000	550
Mounted connector (€)	13	3	15	14
Media converter (€)	-	30	70	40
Hub/tap (€)	20	20	20	20
Switch (€/port)	10	10	10	10

It should be noted that market prices vary considerably, depending on specific type and volume, and also the labour time involved for e.g. mounting different connector types varies widely. We assumed typical values here; e.g., we assumed 10 minutes labour time per field-mounted optical connector, which typically amounts to 10€. A major advantage of using large-core POF is its easy (do-it-yourself) mounting to devices, mostly not even requiring a connector but just plugging in the bare fibre; hence connection costs of POF can be much lower than those of SMF, MMF, and Cat-5E. Furthermore, as fibre is not sensitive for electromagnetic interference (EMI), the fibre cables may share the ducts of the electrical power cables, thus avoiding the costs of separate ducts. This is not feasible for Cat-5E cables, for EMI and safety reasons.

For a residential home (with $M=3$ floors), the average network installation costs per room versus the number of rooms per floor are given in Fig. 2. These results have been calculated for buried ducts, as in green-field installation. The duct costs are lower for on-the-wall mounted ducts, as in brown-field installation (i.e. upgrading), but the total costs are then only marginally lower. As Fig. 2 shows, the costs are lowest for Cat-5E cabling, but for cabling with duplex POF cable the costs are only marginally higher. For smaller homes (low number of rooms per floor), the costs for the P2P architectures are lower than those for shared architectures (bus, tree). For larger homes, the costs of the shared architectures are lower, in particular for the bus architecture, as the costs of the common network parts are shared by more rooms and the average cable length per room in the P2P architecture gets considerably higher.

When sharing the ducts with the electrical power cabling, in the fibre solutions the duct costs are saved. As shown in Fig. 3, the POF solutions then become quite competitive with the Cat-5E solution.

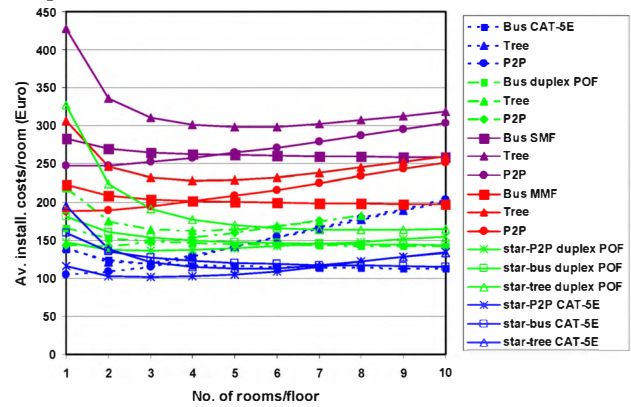


Fig. 2 Network installation costs for residential home

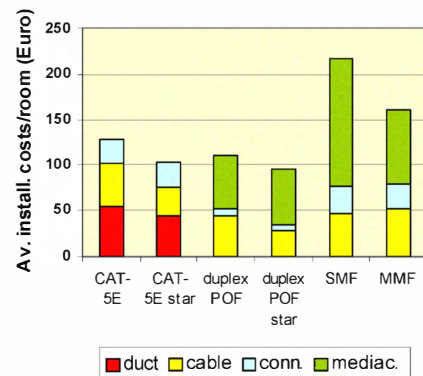


Fig. 3 Residential home with $M=3$ floors and $N=4$ rooms/floor; cost items for P2P architecture (with duct sharing for the fibre solutions)

For larger buildings, the cabling and ducting costs become dominant; hence the bus architecture, which offers the highest sharing factor of the cabling, yields the lowest network installation costs per room. As illustrated in Fig. 4, with duct sharing the POF solutions can

outperform the Cat-5E solutions regarding network installation costs.

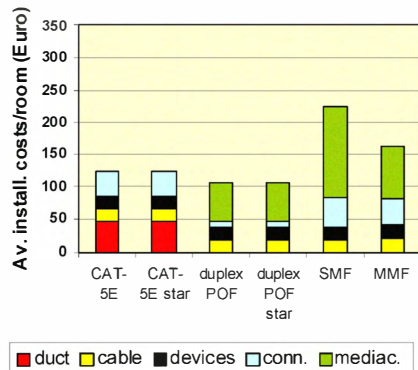


Fig. 4 Office building with $M=10$ floors and $N=50$ rooms/floor; cost items for bus architecture (with duct sharing for the fibre solutions)

4. Broadband transmission over MMF/POF

Large 1mm core step-index PMMA POF offers the advantage of easy installation (even do-it-yourself) and thus is very attractive for residential homes. Graded-index MMF with 50 μ m core diameter has been widely installed in many office buildings, offering the advantage of cheap transceivers and cheaper installation than SMF. However, due to their multimodal light guiding nature, both fibre types offer significantly less bandwidth than SMF. Hence advanced signal modulation techniques are needed to realize high-capacity data transport. We explored comprehensive QAM (quadrature amplitude modulation) techniques which increase the information content per line symbol sent, and thus reduce the line symbol rate needed for a given capacity. We applied these in combination with DMT (discrete multitone) techniques, where multiple carriers are used in parallel, thus reducing the line rate needed per carrier and making the system more robust against the fibre's modal dispersion. Due to the reduced eye opening, more comprehensive QAM formats require a higher signal-to-noise ratio (SNR). In our DMT-QAM schemes, we used power loading and bit loading, thus adapting per carrier the signal power and QAM format to the actual SNR available at that carrier. Using off-line signal processing of the DMT-QAM signals, we achieved a record of 51.8Gbit/s (47.4Gbit/s net) over 100 metres of 50 μ m core perfluorinated GI-POF using a 1.3 μ m DFB laser [3], and 5.3Gbit/s over 50 metres of 1mm core PMMA GI-POF using a 667nm VCSEL and a 400 μ m diameter silicon photodiode [4]. By deploying fast FPGAs, we transmitted 1.25Gbit/s DMT signals in real-time.

Next to high-capacity wired services, we explored advanced techniques to carry wireless services at microwave frequencies over MMF and POF. Using our patented Optical Frequency Multiplying technique [5], we managed to deliver 120Mbit/s 64-QAM wireless signals at a carrier frequency of 17.2GHz over 4.4km 50 μ m core graded-index silica MMF to the antenna site,

and the same signal over 100 metres 50 μ m core perfluorinated GI-POF. We are also applying radio-over-fibre techniques to extend the range of ultra-wideband (UWB) radio signals. UWB radio links operate at very low spectral density and thus can coexist with other radio standards; their wide spectrum according to Shannon's channel capacity law enables a high capacity notwithstanding a low signal-to-noise ratio. They have a short reach; typically some 10 metres only. Operating with a WiMedia multiband-OFDM UWB signal having a spectral width of 512MHz in the third band (4.2-4.7GHz) and using a 667nm VCSEL, we succeeded to deliver 480Mbit/s over 50 metres of 1mm core graded-index PMMA POF to the antenna site. Alternatively, we also deployed Impulse Radio UWB signals, carefully tailored to comply with the FCC spectral mask, and we managed to transport an IR-UWB signal carrying 2 Gbit/s data over 100 metres of 50 μ m core perfluorinated GI-POF [6].

5. Concluding remarks

Even while having not yet achieved the technical maturity and market volume of other cabling solutions such as Cat-5E, optical fibre can already offer cost-competitive solutions to realize a converged in-building network for an integrated delivery of broadband wired and wireless services, in particular when duct sharing with the electrical power cabling is deployed. For smaller (residential) buildings, a P2P architecture using large-core duplex POF is attractive; it allows easy upgrading, and cheap (do-it-yourself) installation. For large (professional) buildings, an opaque star-bus architecture using duplex POF is attractive. On a longer term, an all-optical bus architecture using bend-insensitive SMF and optical power tap couplers may be preferred; it can support any service, is future-proof, and also can perform optical wavelength routing which may improve the network efficiency by allocating capacity-on-demand.

For delivering broadband wired and wireless services over bandwidth-limited silica MMF or POF links, we showed the capabilities of advanced DMT-QAM techniques to carry multi-Gbit/s data streams, and of radio-over-MMF and -POF techniques to generate and transport microwave radio signals by the Optical Frequency Multiplying technique as well as to extend the range of UWB radio signals.

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