Optimisation of In-Building Optical Networks

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Abstract *A single in-building optical fibre network can efficiently deliver wired and wireless services. Point-to-point architectures using POF are attractive for small buildings; for large buildings SMF-based all-optical bus architectures using weighted tap couplers are preferable.*

Introduction

With FTTH techniques being rolled out at increasing pace in access networks, offering unprecedented bandwidths to residential homes, the next challenge is to get these bandwidths into the homes themselves[1,2]. Inside residential homes and (semi-)professional buildings, currently a wide variety of networks is deployed: twisted copper pairs for telephony and fax, coaxial cables for CATV and radio broadcast signals, Cat-5 cables for connecting computers and other IP-based terminals, wireless LAN for laptop computers, PDA-s and gaming consoles, dedicated cables for domotica applications, etc. The maintenance and upgrading issues associated with this jungle of networks could be considerably simplified by replacing all of them by a single integrated multi-services network.

Optical fibre with its huge bandwidth and transparency for all kinds of signal formats is uniquely suited as the transport medium in such an integrated network. Silica single-mode fibre (SMF) offers the ultimate performance, but requires precision tools and skilled personnel for installation. Silica multi-mode fibre (MMF) with its larger core is easier to install; silica graded-index multimode fibre has a high bandwidth and has already been installed widely in office buildings. Large-core polymer optical fibre (POF) with its large ductility is even easier to install; ∅1mm-core PMMA step-index POF is well suited for do-it-yourself installation by residential home owners. Gigabit Ethernet transport using a low-cost LED over 50 metres of 1mm PMMA SI-POF has been demonstrated[3]. Also high-capacity wireless microwave signals can be delivered over multimode fibre by the dispersion-robust optical frequency multiplying technique[4].

In-building optical network architectures

The optical fibre integrated network can basically be laid out in a number of architectures, as shown in Fig. 1. The connection from the access network to the in-building network is made via the Home Communication Controller (HCC), which acts as a gateway and can perform many signal translation and network control functions. In the point-to-point (P2P) architecture, individual fibres run from the HCC to wall outlets in each room. The tree and bus architecture are point-to-multipoint (P2MP) architectures, which can be optically transparent when the splitting nodes do optical power splitting or wavelength routing, or opaque when the nodes internally do O/E/O conversion. The star architecture is multipoint-to-multipoint (MP2MP), and allows direct communication between the wall outlets in different rooms without the intervention of the HCC; this can be done all-optically if the star coupler is a reflective optical coupler.

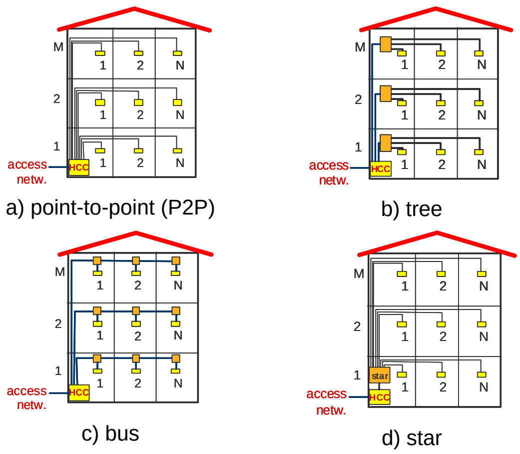

Fig. 1: Network architectures

An assessment has been made of the costs of installing these architectures. When the star coupler is installed next to the HCC, the costs of the star network are similar to those of the P2P network. Fig. 2 shows a comparison of the installation costs of the P2P, the tree and the bus architecture, for a low-rise building (M=3 floors) and a high-rise one (M=10 floors) versus the number of rooms N per floor. The parameters assumed were: room height H=3 metres, room length L=5 metres, fibre cable costs of 3€/metre, costs of installed duct for a single fibre cable 15€/metre (and increasing with the square root of the number of cables in it). The network nodes were assumed to cost €20 for a 1x2 splitter, and €15 per port for a 1xN splitter ($N \geq 3$).

As illustrated by Fig. 2, for small buildings (low-rise, with M=3 floors and $N \leq 3$ rooms/floor), the cost differences between the architectures are relatively small. For larger buildings, in particular for high-rise (M=10) buildings with a large number N of rooms per floor, the bus architecture is clearly more cost-effective than the P2P and tree ones.

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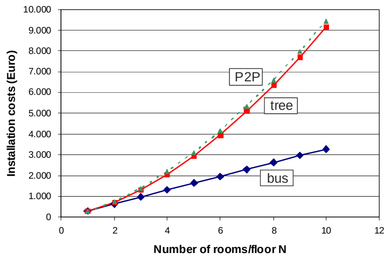
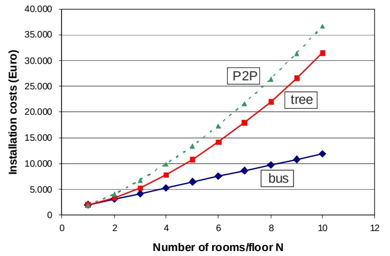
Regarding the fibre type, multimode (silica or polymer) fibre is much less suited than single-mode fibre for P2MP and MP2MP architectures, as power splitters and wavelength routers are hard to realize with multimode fibre (bulk-optics solutions may be devised, carefully trying to avoid mode-selective processes which generate modal noise).

Regarding service upgrading, and regarding the simultaneous support of high-capacity wired services as well as wireless services (by radio-over-fibre techniques), all-optical networks are preferred above opaque ones as they provide end-to-end signal format transparency and thus easily allow modifications in the transported signals.



a) M=3 floors



b) M=10 floors

Fig. 2: Comparison of installation costs

Architecture selection

From the above, one may conclude that for smaller buildings (e.g. residential homes) a P2P architecture using do-it-yourself POF techno-economically is the best choice. It obviously provides signal transparency from the HCC to every wall outlet. Scaling to more wall outlets can be achieved all-optically by installing extra POF-s, or opaquely by adding O/E/O network splitting nodes interconnected with POF.

For larger buildings, P2MP architectures are techno-economically more attractive, in particular a bus architecture. An all-optical P2MP architecture using SMF offers the best prospects for upgrading and for support for both wired and wireless services.

All-optical bus topology with weighted couplers

When using identical optical tap couplers, a bus architecture requires a large dynamic range of the receivers in the user terminals as the optical power available at the first terminal differs considerably from that at the last terminal. Reversely, when the transmitters in the terminals emit at the same power level, the burst mode receiver at the HCC needs to have a wide dynamic range. These power level differences between the terminals can be significantly reduced when all tap couplers do not have the same tap ratio. As shown in Fig. 3, the power tap ratio p_i of the i^{th} coupler should be adjusted such that the tapped power P_0 is equal at all nodes.

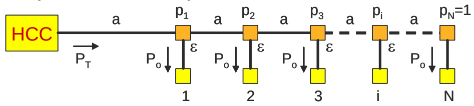


Fig. 3: Weighted tap couplers in a bus

When assuming that the fibre links between the couplers all have a power loss fraction a, and each tap coupler has an excess loss ε, this tap ratio p_i is

$$p_i = 1 - \left(1 + a^{N-i}\varepsilon^{N-1-i}\prod_{j=i+1}^{N-1}(1-p_j)\right)^{-1}$$

with i = 1 .. (N-2) and p_N=1, p_{N-1}=1-1/(1+a). E.g., for a bus with N=10 taps, the optimized tap ratio per coupler is shown in Fig. 4. For nearly lossless fibre links ($a \cong 1$) and lossless couplers ($\varepsilon \cong 1$), we find $p_i \cong 1/(N-i+1)$ and $p_1 \cong 1/N$, so $P_0 \cong P_T / N$. Hence in the lossless approximation the weighted-taps bus performs as efficient as a lossless 1:N power splitter. Thus, when using weighted tap couplers, the bus architecture does not put higher requirements on the dynamic range of the terminal equipment than the star and tree architectures do, and simultaneously saves on costs for fibre cabling and duct space.

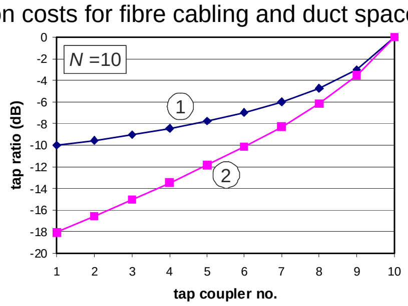


Fig. 4: Optimum tap ratio per coupler (① for loss-free couplers and fibre links; ② for a = -1dB and ε = -0.5dB)

Conclusions

Taking the economics and the potential for upgrading and for integrated delivery of services into account, POF-based P2P architectures are optimum for smaller (residential) buildings, whereas SMF-based bus architectures are the best choice for larger (professional) buildings. By using weighted tap couplers in the bus line, the required dynamic range of the terminals can considerably be reduced.

Acknowledgement

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