State-of-the-Art of Home Networking

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Abstract *A brief overview is given of the state-of-the-art in home networking services, network architectures, technologies and applications covering both technical as well as techno-economic aspects.*

Introduction

The emergence of Fibre-to-the-Home has solved the challenge of delivering high-capacity services to residential users, at least up to the doorstep of their home. However, the delivery bottleneck has now shifted to the indoor network. Moreover, home-internal applications (e.g. HD video streaming, fast file exchange) may even require higher data rates than in the FttH access link [1].

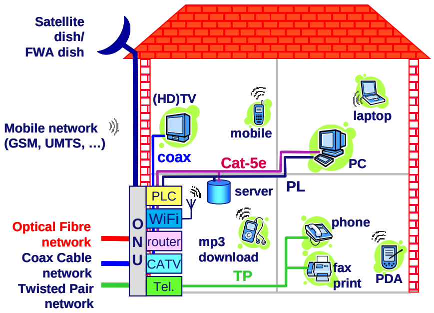


Fig. 1: Mixture of indoor networks

Today's indoor networks are often a blend of different networks, each optimized for a particular kind of services: coaxial cable for video and radio broadcast services, twisted pair for voice telephony, Cat-5E and WiFi for data services, PLC for data over power lines (Fig. 1).

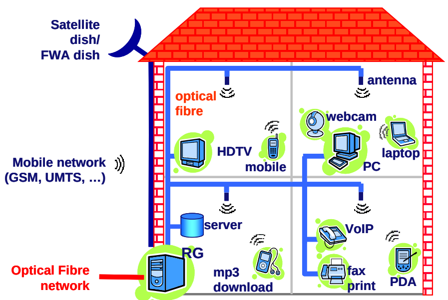


Fig. 2: Converged indoor network

Converging the delivery of the various services into a single wired home network (Fig. 2) may offer a number of advantages: only a single network needs to be installed and maintained, introduction and upgrading of services is facilitated, and flexible interactions between services can be created as only a single platform is involved (the Residential Gateway, RG, which is also the interface with the access network). Optical fibre is attractive as the medium for the converged indoor network; its low loss and large bandwidth provide transparency for any signal format, and its EMI-insensivity allows installation in existing ducts of e.g. the electrical power lines.

In-building service scenarios

There is a large variety of in-building scenarios, which may be categorized in buildings for residential users (single-family homes, multi-dwelling unit buildings a.k.a. apartment buildings) and (semi-)professional buildings (such as office buildings, hospitals, hotels, schools, etc.). The requirements on the in-door network may differ widely, depending on the type of building, and on the services requested. Residential users typically need a mix of services based on video (broadcast and/or video on demand), audio (FM radio, CD player), interactive multimedia (e.g. games), telephony, and data (internet, fast file exchange, …). Increasingly, new services such as remote health services and domotica services are entering the residential domain.

Indoor networks for (semi-)professional buildings are typically more extensive, where the building may have many floors and many rooms per floor. In an office environment, the services required are mostly of a professional nature, mainly based on exchanging data files and internet services, while putting more stringent requirements on reliability and security. In hospitals, there is a mix of health-related services (health monitoring, image files, …) with high reliability demands, and less-demanding entertainment services for the patients. In hotels, the services may vary from hotel administrative data to entertainment services on demand per room.

A (non-exhaustive) list of indoor network service classes is:

- Basic communication (e.g. instant messaging, e-mail, telephony, video conferencing)
- Internet-related services (web browsing, e-shopping, e-banking, etc.)
- Video-related services (video-on-demand, IP-TV)
- Online virtual environments (social network, multimedia gaming)
- Remote technical services (control/survey your home)
- Remote health services (health monitoring)

Concerning the communication parameters for these classes, the requirements for the bitrate, delay, jitter, and allowable packet loss can be quantified. For other aspects such as mobility, traffic priority, security and energy consumption, qualitative targets can be set. The most demanding requirements are put by the video-based services. The highest bitrate demands vary from some 1 Mbit/s for video surveillance, up to 20Mbit/s for HD IP-TV, to some 600 Mbit/s for immersive UHD-TV); low packet loss is required (<1%), and the jitter and delay requirements become tight for immersive videoconferencing (<20ms and <150ms, respectively). For online virtual gaming, bitrates are moderate (<400kbit/s), but jitter requirements are more strict (<10ms).

Residential gateway

The RG is a key enabler of converging the various services into a single network. It forms the bridge between the public access network and the private in-home network, where it may translate modulation formats, assure privacy, provide secure access for outside parties to do maintenance and upgrading of the indoor network, and provide QoS control tailored to the indoor terminals. It may also provide home-internal functions such as local data storage and inter-coupling of indoor devices.

Network topologies

A number of topologies for the indoor wired backbone network may be considered (see Fig. 3): point-to-point (P2P), bus, tree, and hybrid forms thereof.

Various choices for the wired media may be considered, based on copper (coaxial cable, Cat-5/6/7, power lines) or fibre (silica single-mode fibre (SMF), silica multimode fibre(MMF), and large-core plastic optical fibre (POF)). The Cat-x cables and power lines need careful signal processing to overcome the bandwidth restrictions at higher data speeds. On the coaxial lines, specific modulation techniques are needed to fit the data in between the video channels. Optical fibre offers typically a large bandwidth, low losses and absence of EMI effects, which reduces the signal processing needs. The reach of Cat-x and POF is limited; hence in larger buildings active regeneration is needed which may be done in the network splitting nodes but also makes them opaque (i.e. limits the signal transparency of the network).

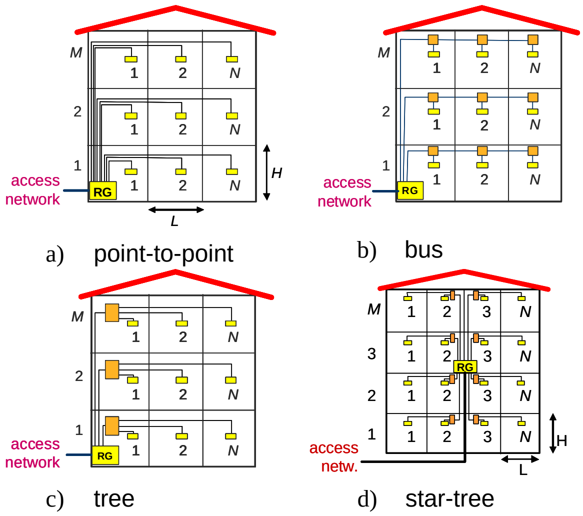
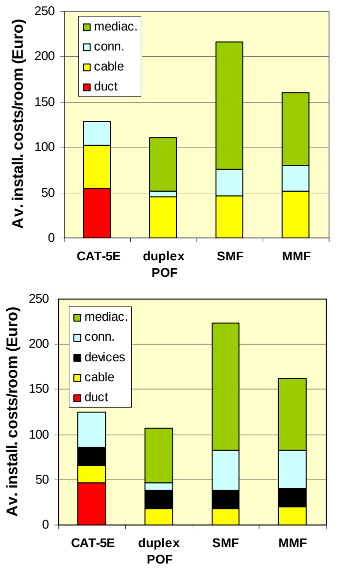


Fig. 3 In-building network architectures

Economic aspects

Analysis of the network installation costs (CapEx – capital expenditure) and of the network operation costs (OpEx – operational expenditure) [2] has shown that for a single-family residential home (typ. 3 floors, 4 rooms/floor) a P2P topology is the most cost-efficient one. For larger buildings, the cabling costs are reduced when a point-to-multipoint (bus or tree) topology is chosen, because of the cable sharing which outweighs the costs of the extra network splitting elements. It has been found that a bus topology yields the lowest CapEx, as it maximizes the cable sharing and minimizes the required duct diameters. Regarding OpEx, the dominating factor is the power consumption in the active network splitting nodes and in the O/E/O transceivers needed for the fibre solutions. Based on typical market prices, the CapEx items per room are shown in Fig. 4 for a residential home and an office building, for various choices of the cable media, where the fibre solutions incur no duct costs when assuming that sharing of existing ducts of the power cabling is applied. For both cases, a duplex POF solution outperforms the Cat-5E, SMF and MMF solutions, notwithstanding the not-yet-maturity of POF solutions.



a) residential home, 3 floors, 4 rooms/floor

b) office building, bus topology (10 floors, 50 rooms/floor)

Fig. 4: Network installation costs per room

Evolution trends

Based on the economic and technical studies done in the FP7 ALPHA project [3], we foresee an evolution roadmap for indoor networks as shown in Fig. 5. After today's status of separate indoor networks, on the short term a first step towards network convergence is expected based on P2P topology and POF for home networks (or MMF/SMF for large buildings). Next, point-to-multipoint topologies are foreseen with opaque (O/E/O converting) network nodes, based on POF/MMF/SMF. In the long term, we foresee point-to-multipoint topologies with passive optical network nodes (power splitters, wavelength routers) where coarse wavelength multiplexing allows overlaying several service delivery networks on a single fibre backbone network (using MMF or SMF). In the far future, the ultimate indoor network performance may be achieved with a point-to-multipoint topology using dense wavelength multiplexing and active optical signal routing in the network nodes, in order to intelligently deliver capacity-on-demand to the various indoor locations, and thus optimize the use of energy and capacity resources of the network [4].

In the converged network scenarios, delivery of wireless services is supported by the indoor backbone network. Initially, radio coverage with a higher density can be provided by smaller radio cells created by installing small radio base stations in every room, fed on IP-basis via the backbone network. In the longer term, network complexity is reduced by radio-over-fibre techniques where the radio signal processing is done in the RG and radio pico-cells (with 60GHz, or UWB technology) are created per room with simple O/E converting antenna sites.

In the far future, optical wireless techniques are foreseen, which can yield a breakthrough regarding the radio capacity bottleneck caused by radio spectrum scarcity and radio interference.

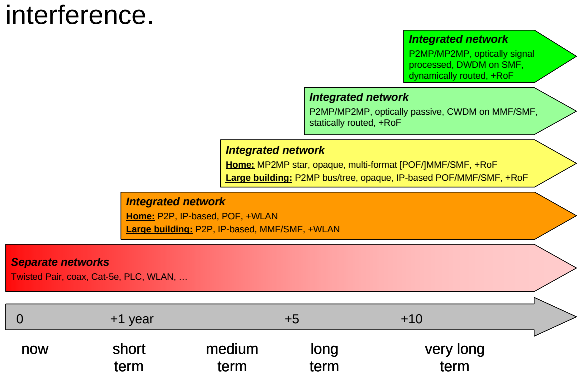


Fig. 5: Roadmap for evolution of indoor networks

Choosing the network medium

When comparing the effective capacity available per user terminal versus the network infrastructure costs, trend lines for the three major categories (fibre, radio, copper) are seen to behave as shown in Fig. 6 . Both for the copper-based (Cat5/6/7 and PLC) and for the radio-based (WiFi, 60GHz, …) solutions the costs grow more than linear with effective capacity; for the fibre-based solutions (POF, MMF, SMF), however, they grow less than linear; this makes fibre technically as well as economically the better choice for high-capacity indoor networks.

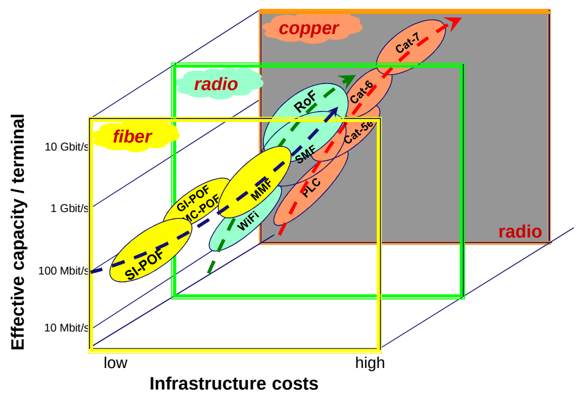


Fig. 6: Trends in network capacity vs. costs

Concluding remarks

In-building networks need to meet booming demands for more capacity and versatility, and optical fibre can both technically and economically offer the most promising solutions.

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