The Convergence of Wired and Wireless Services Delivery in Access and Home Networks

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Abstract: Radio-over-fiber, backhauling and femtonodes are considered for delivering mobile communication services over access and home networks. The RoF overlay is an attractive alternative for optical access, whereas femtonodes are a justified option for home networks.

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1. Services and their delivery to the end-user

The services that could be envisaged in the network of the future include web-browsing, video streaming, file-sharing, IP telephony, an so on, but also various flavors of television (including 3D) and videoconferencing of a much higher quality than we use today [1]. The access network is usually the "last" segment of the operator network passed by the services before reaching the subscriber. The services are then delivered to the end-device, whether it is a TV, computer, mobile phone or a personal digital assistant. Some of the services are more typical to the mobile communications (such as voice) and some to the data networks/Internet (such as web-browsing), though in general most of the services can be delivered both ways. Therefore, when discussing "wired" and "wireless" services, it is more applicable to speak about the delivery method, than about the wired or wireless nature of the service.

This paper addresses the delivery and transport methods of various services over access and home network domains.

2. What is convergence?

Convergence in telecommunications refers to the combination of multiple services through lines of telecommunication from a single provider [2]. In the context of service delivery, it can also be formulated as the convergence to a single transport platform or infrastructure. Combining the transport of many services over the same infrastructure brings an immediate advantage of sharing the cost of the civil works as well as increased revenues (which are now collected from more types of traffic) for network operators and service providers.

In the context of access and home networks, the convergence is using these networks for delivering both the regular traffic (e.g. from the Internet) and mobile communication signals, such as GSM, UMTS, or LTE/Beyond 3G (B3G).

3. Radio-over-fiber, backhauling and femto-modes

A straightforward method to transport mobile communication signals over an optically transparent access network (like the passive optical network - PON) is to use Radio-over-fiber (RoF), an established technology broadly employed in fiber distributed antenna systems [3]. The joint use of the access network is illustrated in Fig. 1. Other methods, which can be used for both optically transparent and "opaque" access architectures include essentially the encapsulation of digital mobile communication signals as digital data over the network. The digital signals are obtained by e.g. digitizing RoF signals using e.g. the bandpass sampling method [4], following the OBSAI [5] and CPRI [6] digital transmission standards. There are also other backhauling methods using one or another type of encapsulation, e.g., employing the multi-aggregation site gateway [7].

One more solution for the transport of UMTS and potentially LTE signals over the network is based on so called femtonodes [8]. A femtonode is a much simplified base station (BTS or Node B) designed to be installed at the customer premises. It can be a part of an access modem/router or a separate unit connected to the former by means of an Ethernet connection or via the home network as illustrated on the left side of in Fig. 1. Its objective is to provide UMTS (or B3G) wireless indoor coverage primarily for residential users. The femtonode runs over the Internet protocol and, for stable operation together with other applications, requires connections faster than ADSL [8]. In the following sections the specifics of converged transport over the access and home network domain is considered in more detail.

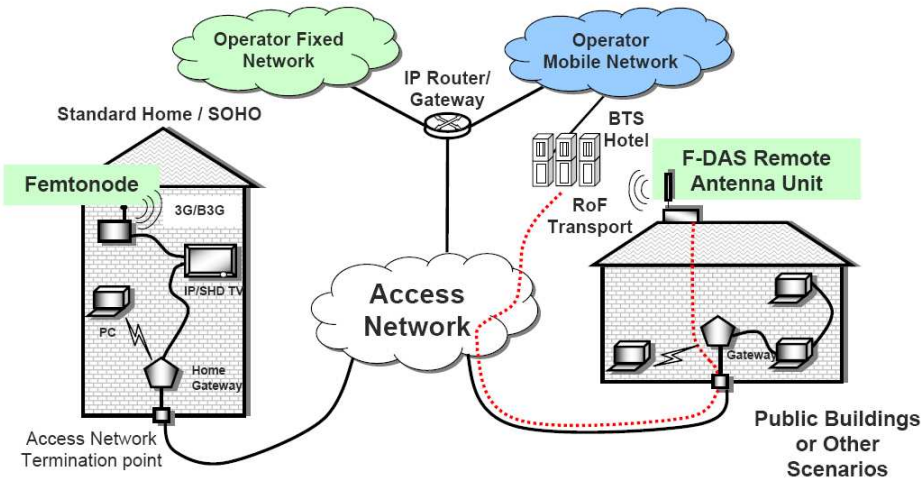

Fig.1. Converged mobile/optical access network using RoF and a femtonode.

4. Access networks

The access network is in general based on various wired (xDSL, cable, or optical fiber) and/or wireless (WiMAX, GSM, UMTS/HSPA) technologies. The optical fiber access network comes in two major flavors: point-to-multipoint passive optical network (PON) with a passive optical splitter as a "distribution element", and point-to-point active optical networks (AON) with an active switch in the field (also known as the Active Ethernet). In some cases, the fiber is deployed to the premises directly from the central office (with no active equipment in the field) which is referred to as the "home run" architecture.

The most straightforward way to provide the GSM/UMTS/B3G signal transport in PON is to use the RoF technology at an overlay wavelength. Indeed, both approaches, RoF and FTTx, use the optical fibre, most often single-mode, to deliver the mobile communication and Internet data, respectively, to the end-user. Such a RoF-over-PON architecture has been elaborated in e.g. [9], where an analog RoF from multiple basestations has been adapted to run at overlay wavelengths over a PON with the 1:64 split. A techno-economic analysis of the solution has shown that the required changes in the RoF system will increase its cost by about 10%, whereas the costs of building a dedicated fibre infrastructure for running the same RoF system would be substantially higher.

The overlay RoF can also be adapted with minimal changes for the point-to-point "home run" and WDM PON access solutions. On the other hand, there is no optical transparency in the active Ethernet architecture and the digital transport is the only choice. Here we note that the bit-rates specified for OBSAI and CPRI range from about 600 Mb/s to 3 Gbit/s, and the digitized emulated WiMAX signal (6 MSymbols/s 16 QAM at 2.475 GHz) has a bit-rate of 1 Gb/s [4]. The direct transport of such fast digital signals will occupy a large portion (if not all) of the GPON downstream capacity (2.5 Gb/s downstream, 1.25 Gb/s upstream) with little or nothing left for the other traffic. The AON solutions use typically Fast (100 Mb/s) and Gigabit Ethernet links and must be therefore upgraded to 10 GbE just to provide the backhauling. Furthermore, the Ethernet-based solution might also require traffic prioritization (or even more advanced traffic engineering) in order to ensure the timely delivery of time-critical mobile communication signals.

The 10G access networks (WDM and WDM-TDM PONs as well as AON) or proprietary access solutions specifically tailored for mobile backhaul will be more suited for tackling the problem. However, as for today, the analog RoF overlay looks as a simpler, more flexible and also cost-effective option, in particular, because it does not occupy the existing bandwidth of the system and allows for a multi-basestation/multi-operator environment using wavelength division multiplexing.

5. Home networks

Home networking is a relatively new research area. Essentially, the home network is a small network in an apartment or private house. The home network is *not* shared with the other users in the building and the associated costs are covered by the end-user. This is a principal difference of the home network from the *in-building* network which serves a group of user with the shared costs as a consequence.

In a simplest case, the home network consists of modem (cable, DSL or fiber) plus an Ethernet switch and/or wireless access point. Computers and other devices in the home are connected via this network. The purpose of the home network is to distribute data services originating from the outside (access network) or from the inside (e.g.

from a media server). The aggregate amount of traffic inside home can exceed that of the access line capacity, in some cases up to two orders of magnitude. The physical layer (PHY) solutions for the home network include wireless radio (mostly WiFi, but also proprietary), wireless optics, Cat-5/6 cables, coaxial cables, power line communication (PLC) and optical fibers. The Cat5, coax and PLC solutions together with WiFi are the most typical home networking solutions today, whereas plastic optical fiber (POF) is an emerging solution [10].

The "do-it-yourself" capability and acceptable performance of POF (1 Gb/s over 50 meters for the step-index 1-mm core POF [11]) makes it perfect for "retrofit"/"brown field" installations, whereas the single-mode fiber (SMF) can be used for future-proof "green field" installations. The POF is essentially used instead of Cat-5 links, whereas the SMF can be used for all-optical point-to-multi-point or multi-point-to-multi-point architectures using passive optical splitters allowing for more flexibility [10]. In particular an NxN passive splitter can be used to organize LAN-like (using one wavelength) or broadcast & select (using WDM) solutions. These solutions allow for a much greater flexibility, in principle enabling the set up of multiple multi-Gb/s networks over the same infrastructure using multiple wavelengths [12].

Today, of all optical fiber solutions, only POF appears to have hardware costs comparable to that of its major competitor – Cat5. The situation for SMF and silica multi-mode fiber (MMF) solutions, especially with the flexibility enabled at the optical layer (which might in principle include splitters, wavelength selective elements, and optical switches), including the use of RoF, is more complex despite obvious advantages. The hardware, installation and maintenance costs look yet prohibitive for a mass deployment. Note that the above statement generally does not apply to in-building networks.

In opaque architectures using POF (and also Cat5 or PLC), the only way to transport the mobile communication signals is to encapsulate them into electrical packets, usually IP packets. This is implemented by femto-nodes which communicate to the operator mobile network using the IP protocol. Traffic engineering on the protocol levels must also be used here to guarantee on-time delivery of the time-critical voice traffic over the best-effort IP network. For completeness, it should be noted that the femto-nodes can in principle be used for providing wireless access to its users, which will be in this case a multi-layer encapsulation of wired and wireless delivery methods.

Last but not least, the story of convergence will not be complete without mentioning the IP Multimedia Subsystem (IMS), which is an architectural framework for delivering the IP multimedia applications to the mobile users. IMS exploits the wireless infrastructure and protocols (GPRS, WLAN, CDMA2000 etc) and acts as a foundation to transport IP-based multimedia services over these infrastructures.

7. Summary

Radio-over-fibre and encapsulation of digital/digitized radio signals into data traffic can be used to provide the transport of GSM/UMTS/B3G signals in existing access and home networks. The bit-rate constraints may limit the direct backhauling of this traffic in today's GPON and AON access solutions making the RoF overlay solution an attractive alternative. On the other hand, backhauling using femtonodes is justified for home networks since economical aspects limit the use of single-mode fibre in the home networks.

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