Tehnological Aspects of FiWi for Broadband Multimedia Services

Aleksandra Kostić-Ljubisavljević[1], Andreja Samčović[2], Vladanka Aćimović-Raspopović[3]

***Abstract* – Fiber-wireless (FiWi) networks become rapidly mature and give rise to new powerful access network solutions and paradigms. Towards the technical evolution of wireless-optical access networks and the seamless coexistence of both technologies, this paper presents key technical challenges for providing seamless communications in FiWi access networks, and highlights important issues for technologies, architectures, some application areas as well as broadband multimedia services over FiWi networks.**

***Keywords* – Fiber-wireless, technology, architectures, broadband services**

I. INTRODUCTION

In the last decade, wireless and optical communications have experienced rapid growth and commercial success. These great successes in both areas have started fueling the vision of ubiquitous broadband multimedia communications. Building on advances in network infrastructure, low-power integrated circuits, and powerful processing algorithms, the convergence of wireless and optical communications is now underway, paving the way towards widespread acceptance of fiber-wireless (FiWi) access networks in the next decade. FiWi access integrates the high capacity of optical with the flexibility of wireless to enable high-speed communications to mobile users in a transparent and seamless manner.[1] FiWi can be implemented using different architectures. Notable among these, are architectures where optical technologies are used as backhaul network for wireless access points. In particular, architectures which use wireless mesh networks over optical fibers are very attractive, owing to their ease of installation and cost-effectiveness, which allow for wide coverage as well as rapid deployments to support unanticipated needs. Such architecture can yield numerous advantages, such as reduced complexity and flexible resource allocation. Indeed, functions such as modulation/demodulation, up/down-converting, and data multiplexing, can be performed at a central office serving several wireless access points, which in turn reduces operational costs, increases flexibility, and facilitates network scalability. Furthermore, radio resources can be allocated dynamically to wireless sites where they are mostly needed, thus making better usage of the available radio resources, and simplifying mobility handling. Achieving convergence requires the development and evaluation of new architectures and communications techniques that establish the benefits of both technologies while avoiding their shortcomings. In this vein, challenges are involved in all planes, form the network design, planning and dimensioning, to components and business models.

This paper is organized as follows. After the introduction, fiber-wireless networks enabling technologies are presented. Various architectures considering FiWi are given in the next section. The following section is dedicated to radio over fiber application areas. Broadband multimedia services over FiWi conclude this paper.

II. FIWI NETWORKS ENABLING TECHNOLOGIES

Currently, there are two technologies used to implement fiber-wireless (FiWi) networks: free space optical (FSO), also known as optical wireless (OW) and radio over fiber (RoF) [2].

FSO is a type of direct line-of-sight (LOS) optical communications that provides point-to-point connections by modulating visible or infrared (IR) beams. It offers high bandwidth and reliable communications over short distances. The transmission carrier is generated by deploying either a high-power light emitting diode (LED) or a laser diode, while the receiver may deploy a simple photo detector. Current FSO systems operate in full-duplex mode at a transmission rate ranging from 100 Mb/s to 2.5 Gb/s, depending largely on weather conditions. Given a clear LOS between source and destination and enough transmitter power, FSO communications can work over distances of several kilometers. At both source and destination, optical fiber may be used to build high-speed LANs, such as Gigabit Ethernet (GbE).[3]

RoF, on the other hand, allows an analog optical link to transmit a modulated radio frequency (RF) signal. There are different techniques available to realize RoF networks. Typically, an RoF transmitter deploys a Mach-Zehnder intensity modulator in conjunction with an oscillator that generates the required optical carrier frequency, followed by an Erbium doped fiber amplifier (EDFA) in order to increase the transmission range. RoF networks provide both point-to-point and point-to-multipoint connections. Recently, a full-duplex RoF system providing 2.5 Gb/s data transmission over

[1]Aleksandra Kostić-Ljubisavljević is with the Faculty of Transport and Traffic Engineering, Vojvode Stepe 305, 11040 Belgrade, Serbia, E-mail: a.kostic@sf.bg.ac.rs

[2]Andreja Samčović is with the Faculty of Transport and Traffic Engineering, Vojvode Stepe 305, 11040 Belgrade, Serbia, E-mail: andrej@sf.bg.ac.rs

[3]Vladanka Aćimović-Raspopović is with the Faculty of Transport and Traffic Engineering, Vojvode Stepe 305, 11040 Belgrade, Serbia, E-mail: v.acimovic@sf.bg.ac.rs

40 km with less than 2 dB power attenuation was successfully demonstrated using the millimeter-wave band. There are many cost-efficient optical approaches to mixing and upconverting millimeter wave signals.

III. FiWi Architectures

In this section will be presented available architectures for enabling FiWi integration. For instance, the integration of Ethernet passive optical networks (EPON) and WiMAX access networks can be done in several ways; according to [4], the following four architectures can be used.

Independent Architecture — In this approach WiMAX base stations serving mobile client nodes are attached to an optical network unit (ONU) just like any other wired subscriber node, whereby an ONU denotes the EPON customer premises equipment. WiMAX and EPON networks are connected via a common standardized interface (e.g., Ethernet) and operate independent of each other.[5]

Hybrid Architecture — This approach introduces an ONU-base station (ONU-BS) that integrates the EPON ONU and WiMAX BS in both hardware and software. The integrated ONU-BS controls the dynamic bandwidth allocation of both the ONU and BS.

Unified Connection-Oriented Architecture — Similar to the hybrid architecture, this approach deploys an integrated ONU-BS. But instead of carrying Ethernet frames, WiMAX media access control MAC protocol data units (PDUs) containing multiple encapsulated Ethernet frames are used. By carrying WiMAX MAC PDUs, the unified architecture can be run like a WiMAX network with the ability to grant bandwidth finely using WiMAX's connection-oriented rather than EPON's queue-oriented bandwidth allocation.

Microwave-over-Fiber Architecture — In this approach the WiMAX signal is modulated on a wireless carrier frequency, and is then multiplexed and modulated together with the baseband EPON signal onto a common optical frequency (wavelength) at the ONU-BS. The central node consists of a conventional EPON optical line terminal (OLT) and a central WiMAX BS, called a macro-BS. The OLT processes the baseband EPON signal, while the macro-BS processes data packets originating from multiple WiMAX BS units.

Besides the aforementioned generic integration approaches of EPON and WiMAX networks, several other FiWi architectures based on WiFi technology have been studied, as described in the following. The network shown in Figure 1. interconnects the central office (CO) with multiple WiFi-based wireless access points (WAPs) by means of an optical unidirectional fiber ring. The CO is responsible for managing the transmission of information between mobile client nodes (MCNs) and their associated WAPs as well as acting as a gateway to other networks. Each WAP provides wireless access to MCNs within its range. All MCNs take part in the topology discovery, whereby each MCN periodically sends the information about the beacon power received from its neighbors to its associated WAP. In doing so, WAPs are able to estimate the distances between MCNs and compute routes. Multihop relaying is used to extend the range. To enhance the reliability of the wireless link, the CO sends information to two different WAPs (path diversity). The proposed implementation can support advanced path diversity techniques that use a combination of transmission via several WAPs and multihop relaying (e.g., cooperative diversity or multihop diversity). Consequently, the CO must be able to assign channels quickly and efficiently by using one or more wavelength channels on the fiber ring to accommodate multiple services such as wireless LAN (WLAN) and cellular radio network.

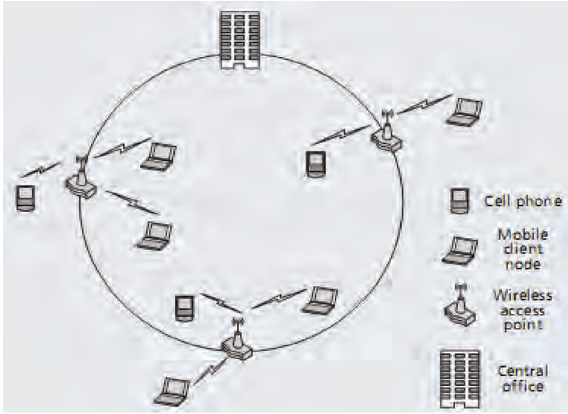

Figure 1. Optical unidirectional fiber ring interconnecting WiFi-based wireless access points [1]

Figure 2 depicts a hybrid FiWi architecture that combines optical star and ring networks. Each fiber ring accommodates several WiFi-based WAPs, and is connected to the CO and two neighboring fiber rings via optical switches. The optical switches have full wavelength conversion capability, and interconnect the WAPs and CO by means of shared point-to-point light-paths. The network is periodically monitored during prespecified intervals.

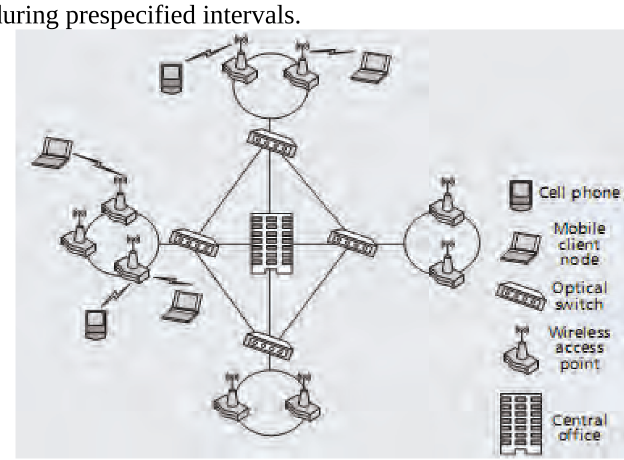

Figure 2 Optical hybrid star-ring network integrated with WiFi-based wireles access points [1]

At the end of each interval, the lightpaths may be dynamically reconfigured in response to varying traffic demands. When traffic increases and the utilization of the established lightpaths is low, the load on the existing lightpaths is increased by means of load balancing. Otherwise, if the established lightpaths are heavily loaded, new lightpaths need to be set up, provided enough capacity is available on the fiber links. In the event of one or more link failures, the affected lightpaths are dynamically reconfigured using the redundant fiber paths of the architecture.

The FiWi network shown in Figure 3 consists of an optical wavelenght division multiplex (WDM) backhaul ring with multiple single-channel or multichannel PONs attached to it.

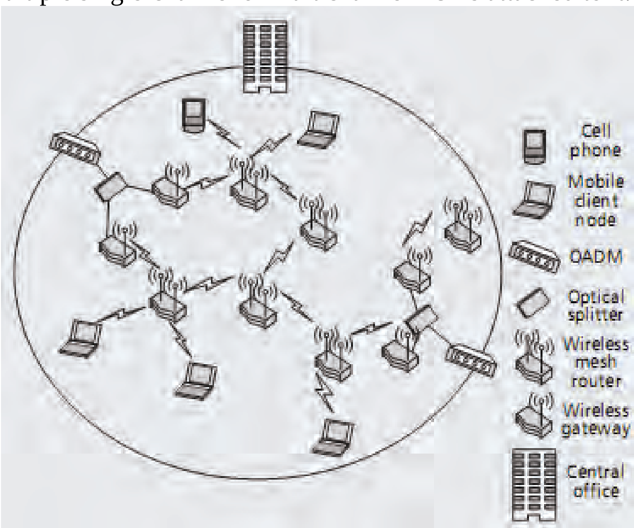

Figure 3 Optical unidirectional WDM ring integrated with a WiFi-based wireless mesh network [1]

More precisely, an optical add-drop multiplexer (OADM) is used to connect the OLT of each PON to the WDM ring. Wireless gateways are used to bridge PONs and WMNs. In the downstream direction, data packets are routed from the CO to the wireless gateways through the optical backhaul and then forwarded to the MCNs by wireless mesh routers. In the upstream direction, wireless mesh routers forward data packets to one of the wireless gateways, where they are then transmitted to the CO on one of the wavelength channels of the optical backhaul WDM ring, as each PON operates on a separate dynamically allocated wavelength channel. Since the optical backhaul and WMN use different technologies, an interface is defined between each ONU and the corresponding wireless gateway in order to monitor the WMN and perform route computation taking the state of wireless links and average traffic rates into account. When the traffic demands surpass the available PON capacity, some of the TDM PONs may be upgraded to WDM PONs. If some PONs are heavily loaded and othershave less traffic, some heavily loaded ONUs may be assigned to a lightly loaded PON by tuning their optical transceivers to the wavelength assigned to the lightly loaded PON. This architecture provides cost effectiveness, bandwidth efficiency, wide coverage, high flexibility, and scalability. In addition, the reconfigurable TDM/WDM optical backhaul helps reduce network congestion and average packet latency by means of load balancing. Moreover, the dynamic allocation of radio resources enables cost-effective and simple handovers.

IV. Radio-Over-Fiber Application Areas

To fully consider the application of RoF technology one must look at the radio technologies that are to be transported over this network. From the perspective of most radio air-interface designers the inclusion of an optical fiber link into the link budget of the interface is an additional challenge. The already tight noise and distortion budgets offer little flexibility and therefore often require high performance from the optical link. In effect, the RoF link designer is being asked to provide a virtually transparent pipe through which a radio signal can be transported.

In this section will be given a brief review of some of the radio standards that have been considered for RoF systems.

Cellular radio systems (GSM and UMTS) have been extensively investigated with commercial offering having been available for some time. Research has typically concentrated on multiple channel operation or considering the extreme performance limits of the systems. For example simulation studies have considered the interaction of second-generation (GSM) and third-generation (W-CDMA) wireless systems orW-CDMA and (WLAN). In these systems distortion due to the linearity of the optical components is a major consideration as discussed previously with solutions such as predistortion being proposed.

As new radio standards appear, different issues arise although most are based on the radio formats' susceptibility to distortion. For example, ultra-wideband (UWB), an impulse radio standard that uses low power and a very wideband bandwidth (typically >500MHz), has been developed for short reach systems. This bandwidth is significantly greater than other radio standards and introduces a number of new challenges relating to linearity and induced distortion, with investigations considering a number of aspects including its co-existence with WLAN. Additionally, optical techniques have also been investigated for the generation of the short pulses that form these signals.

WiFi (IEEE 802.11a/b/g etc.) systems have been researched widely in part due to he easy availability of access points for experimentation. However, due to the low cost of the access points it is hard to see fiber-based system displacing electronic systems unless it forms part of a wider converged, multi-standard network.

Orthogonal frequency division multiplexing (OFDM), which was introduced to the mainstream of communications by the digital video broadcast (DVB) standard and to data communications by the 802.11g standard, forms the mainstay of most of the next-generation communications standards. To date a number of investigations into the transport of OFDM have been made. Theoretical studies have evaluated the performance of OFDM systems in the presence of non-linear distortion from optical components. A number of experimental investigations have been conducted, although most focus on the transmission of OFDM-based standards.

Yhe transport of radio standards to significant distance using optical fiber is possible, at least at the physical layer. However, other effects can also impact on the system performance. In most experiments a commercial vector signal generator and analyzer setup is used for performance measurements. This offers a controllable signal with high purity to allow repeatable experiments. It does, however, have the drawback of only operating at the physical layer. It must be remembered that the addition of optical fiber into the system can add significant delay into what would normally be the air-interface section of the link. In wide area and centrally controlled architectures, such as GSM or WiMAX, this may not cause significant issues. However, in ad hoc and short-reach architectures, such as 802.11, the addition of 5 μs of delay per kilometer of fiber (10 μs if a round trip is considered) may make a significant contribution to the timeouts of the 802.11 MAC. It is shown that for typical implementations a maximum distance of around 13 km of fiber is permissible before the system fails with complete loss of transmission. It should also be noted that these distances are vendor dependent as the standard only specifies a minimum time-out. The data rate reduces progressively as fiber is added due to the increased delay in the system. One can then see that when the time-out (for either acknowledge of packets in the basic access mechanism or for response to a request to send (RTS) packet in the virtual carrier sense or RTS/CTS mechanism) is exceeded due to the fiber delay, transmission falls sharply. In this section we have reviewed the main, current radio standards and looked at research that has considered their transmission of optical fibers. In general it is seen that transmission is possible, although in some cases linearization either by design in the components or by system techniques is required.

V. MULTIMEDIA SERVICES OVER FIWI

Access networks, services and driving technologies currently undergo changes that have never been seen before.[6] Differences between telecommunications and media delivery domains blur day by day. Integrated multimedia access is the key for revenue generation, customer satisfaction and ultimately for the survival of providers. There is a tradewar in the home access scenario between the traditional voice telecommunication companies and coaxial cable television providers. Both these sectors are now geared to provide bundled multimedia (video, voice and data) services over their networks, to enter the so-called ’triple play’. More and more households have large-screen, high definition televisions (HDTV); large number of HDTV channels are also available. High quality HDTV needs good signal-to-noise ratio (SNR) and high bitrate. As a result both these players need more bandwidth than ever before.Wireless access technologies are also on the transform. Digital video/audio broadcasts (DVB and DAB) over terrestrial or satellite networks are geared to merge with wireless access networks. Wireless cellular network subscribers are no longer satisfied with just voice; they expect different types of data and streaming video. As a result, the demand for multimedia wireless services is also on the rise. There is some interest on Internet Protocol Television (IPTV) because of the promising interactive nature. IPTV delivers video signals using IP technology over a broadband connection. Currently, most operational IPTV networks are deployed on telecommunication network architectures using various technologies to bridge the last mile. Note that despite the IPTV hype, the majority of IPTV services use MPEG-2 compression that has compromised quality. Without the ability to provide HDTV with interactive services (video on demand), DolbyTM quality surround sound audio and some data (such as closed captioning) no media provider can survive. Although, the uncompressed bit rates for big screen HDTV is very high, typically in the Gbps range, good quality HDTV is provided by 19 or 38 Mb/s with complex video and audio compression technologies. Generally, the video signal could be either radio frequency (RF) video or IP (Internet Protocol) video. The IP video is similar to Internet traffic with additional streaming requirement. However, the RF video signal is analog and subcarrier multiplexing is needed to transmit multiple television channels. Furthermore, the RF video is a proven technology that already dominates existing fiber-coaxial networks and has better quality.

VI. CONCLUSION

The ultimate goal of the Internet and communication networks in general is to provide access to information when we need it, where we need it, and in whatever format we need it. To achieve this goal, wireless and optical technologies play a key role. Wireless and optical access networks can be thought of as complementary. Indeed, optical fiber does not go everywhere, but where it does go, it provides a huge amount of available bandwidth.

Wireless access networks, on the other hand, potentially go almost everywhere, but provide a highly bandwidth-constrained transmission channel susceptible to a variety of impairments. Clearly, as providers need to satisfy users with continuously-increasing bandwidth demands, future broadband access networks must leverage on both technologies and converge them seamlessly, giving rise to fiber-wireless (FiWi) access networks.

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