Hybrid Fiber Wireless Access Networks (Fi-Wi)

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Abstract: Elaborated in this paper the concept of hybrid fiber wireless access network is. Need and purpose of such connection is discussed along with the enabling technologies and architectures. The comparison between two enabling technologies shows their advantages and disadvantages in respective parameters. Then optical millimeter wave optical network shows how actually the network is established from central office to BS using optical wireless mechanism. The important point discussed in this report is hybrid fiber wireless in-home networks. Accordingly, type of fiber used for such technology is also discussed. Then network architecture shows how home network can be established by using optical heterodyne and polarization multiplexing. Even if, this architecture is proposed, experimental setup is also discussed. Finally, we can conclude that this technique will play vital role in high speed networks in next few years.

Keywords: radio-over-fiber, optical heterodyne, polarization multiplexing.

1. INTRODUCTION

The use of internet and networks is done to provide access to information when we need it, where we need it & in whatever format we need it in. Both, the wireless and optical technology can be used together to establish better network. Actually, both technologies are complementary to each other. But, the hybrid connection of both technologies overcomes their respective drawbacks. Optical is having distance limitation & wireless is having bandwidth limitation. The hybrid fiber-wireless connection is established, which is popularly known as fi-Wi access network. Passive optical networks (PONs) of optical fiber to the home (FTTH) or close to it (FTTX) networks, where they interface with a number of wireless access technologies.

Here, we have focused on enabling technologies and elaborate on emerging FiWi architectures, free space optical (FSO) & Radio over fiber (RoF) are two technologies for Fi-Wi Networks. RoF networks are attractive since they provide transparency against modulation techniques and are able to support various digital formats and wireless standards in a cost-effective manner. Optical fiber penetrates into the homes of residential and business customers because In recent years, optical fiber is likely to entirely replace copper wires. The final frontier of optical technology is converged with their wireless counterparts. By combining the capacity of optical fiber networks with the mobility of wireless networks, FiWi networks form a powerful platform for the support and creation of emerging as well as future applications.

In this article, Future in-home wireless network is discussed which deliver high speed services with the fiber transmission (1 km) and wireless delivery (1 m) of 61.3-Gbps data at 40-GHz at mm-wave bands. In the aspect of signal processing, multiple input and multiple output orthogonal frequency division multiplexing (MIMO-OFDM) is widely used. In the physical aspect, the higher frequency mm-wave bands are desired due to their large bandwidth. Therefore, the mm-wave MIMO-OFDM is viewed as an interesting solution for future high-speed in-home wireless networks. However, the mm-wave is prone to high atmospheric loss, which thereby, limits its delivery flexibility. Consequently, the hybrid fiber-wireless in-home network is sought after due to the ultra-low loss and the huge bandwidth of optical fibers. In such network, the mm-wave signal is generated at a central station and modulated onto an optical carrier. At a base station (BS), the optical signal is converted to the electrical signal via a photodiode (PD) and then, is boosted to the antennas by cascaded electrical amplifiers (EAs). Supporting MIMO-OFDM services at one wavelength rather than separate wavelengths is highly desired for low cost hybrid fiber-wireless in-home networks. Motivated by the above facts, propose a novel high-speed (61.3 Gbps) hybrid fiber-wireless in-home network system with optical heterodyne (OH) and polarization multiplexing (PolMux). Traditionally, OH systems were proposed with optical phase-locked loop and injection locking to suppress the phase noise. Recently, simplified OH systems are proposed with free running narrow line width (low phase noise) lasers.
and phase noise compensation using digital signal processing (DSP). These systems can support emergent physical protections for fiber links during disasters even the protections in the protocol layer are possible. PolMux can further support MIMO-OFDM services by using two orthogonal polarizations at the same optical wavelength with negligible additional cost. The de-multiplexing of PolMux and MIMO is realized by using DSPs. This system comprises a PolMux-OH scheme with a data rate of 61.3 Gbps. In addition, it also demonstrates the effectiveness of adopting DSP for phase noise compensation and de-multiplexing of PolMux and MIMO. Currently the highest spectral efficiency for the PolMux-OH systems with OFDM signals is 3.41 bit/s/Hz to the best of our knowledge. In our work, the new record-breaking spectrum efficiency (6.82 bit/s/Hz) is achieved.

2. FIWI NETWORKS ENABLING TECHNOLOGIES

A. Free space optical (FSO) or optical wireless

FSO is a 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. If, a clear LOS between source and destination and enough transmitter power, FSO communications can work over distances of several kilometers [1].

Free-space point-to-point optical links can be implemented using infrared laser light, although low-data-rate communication over short distances is possible using LEDs. Infrared Data Association (IrDA) technology is a very simple form of free-space optical communications. On the communications side the FSO technology is considered as a part of the Optical Wireless Communications applications. The reliability of FSO units has always been a problem for commercial telecommunications. Consistently, studies find too many dropped packets and signal errors over small ranges (400 to 500 meters).

B. Radio over fiber (RoF)
RoF, on the other hand, allows an analog optical link to transmit a modulated radio frequency (RF) signal. Typically, an RoF transmitter deploys a Mach-Zehnder intensity (MZI) 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 P2P and point-to-multipoint connections. Recently, a full-duplex RoF system providing 2.5 Gb/s data transmission over 40 km with less than 2 dB power attenuation was successfully demonstrated using the millimeter-wave band [1].

The simplest scheme for transporting mm-wave wireless signals via an optical fiber feed network is to directly transport the mm-wave wireless signals over fiber (RF-over-fiber) without any need for frequency translation at the remote BS. In this configuration, the mm-wave wireless signal is externally modulated onto the optical carrier resulting in an optical double sideband (ODSB) signal. The two side bands are located at the wireless carrier frequency away from the optical carrier. RF-over-fiber transport has the advantage of realizing simple base-station designs with additional benefits of centralized control, independence of the air interface and also enabling multi wireless band operation. Its major drawback is the requirement for high-speed optical modulation techniques that have the ability to generate mm-wave modulated optical signals and also high-speed photo detection schemes that directly convert the modulated optical signals back to mm-wave signals in the RF domain [2].

**Comparison between two enabling technologies**

<table>
<thead>
<tr>
<th>Features</th>
<th>FSO</th>
<th>RoF</th>
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<tbody>
<tr>
<td>Connectivity</td>
<td>Point-to-point</td>
<td>Point-to-point and point-to-multipoint</td>
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<tr>
<td>Transmission mode</td>
<td>Full duplex</td>
<td>Full duplex</td>
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<tr>
<td>Scalability</td>
<td>High in terms of bandwidth</td>
<td>Low in terms of bandwidth</td>
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<td>Availability</td>
<td>Low in fog</td>
<td>High in fog</td>
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<tr>
<td>Interference</td>
<td>Background sunlight</td>
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<tr>
<td>Spectrum license</td>
<td>Not required</td>
<td>Required</td>
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**3. ARCHITECTURES**

**a. Types of Architectures**

**Independent Architecture -**

In this approach WiMAX base stations serving mobile client nodes are attached to an optical network unit (ONU), whereby an ONU is the EPON customer equipment. WiMAX and EPON networks are connected via a common standardized interface (e.g., Ethernet) and operate independent of each other.

**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 MAC protocol data units (PDUs) containing multiple encapsulated Ethernet frames are used. By carrying WiMAX MAC PDUs, the unified architecture can be run 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. [1]

Millimeter-wave fiber-wireless network

New emerging wireless standards will further enhance existing wireless transmission speeds and throughputs; however, they still operate within the lower microwave regions (2–4 GHz). This places a heavy burden on the already congested wireless spectrum in the microwave region. This leads to the use of the large unused bandwidths of sub-millimeter or millimeter-wave (mm-wave) frequency regions for the provision of future broadband wireless services. One particular band of interest is the unlicensed 60 GHz frequency band (57–64 GHz) which is targeted towards short range in-building high-speed applications, has gained significant popularity in the last few years. With the inherent high propagation loss characteristics of wireless signals at these frequencies, pico or microcellular architectures are essential to provide efficient geographical coverage which necessitates a large deployment of antenna base-stations (BSs). With the dramatic increase of the throughput of each BS in such systems, the use of an optical fiber backbone is required to provide broadband interconnections between the central office (CO) and the entire antenna BSs. This leads to the integration of the optical and wireless broadband infrastructures via a common backhaul network that in turn offers significant advantages while supporting both wired and wireless connectivity. In this hybrid network layout, significant reduction of the antenna BS complexity can be achieved by moving the routing, switching and processing functionalities to the CO. This strategy also enables the cost and equipment to be shared among the entire antenna BSs. Although the optical-wireless integration is able to simplify the backhaul infrastructure and offers significant benefits to future service providers, the implementation of the hybrid fiber wireless network is not straightforward and issues regarding wireless signal transport, signal impairments, spectrum allocation, performance optimization and integration with existing infrastructure have to be considered[2].

Figure 3. Millimeter-wave fiber-wireless network
b. Network Architecture

![Network Architecture](image)

The proposed in-home hybrid fiber-wireless network architecture is shown in Fig 4. The baseband data of users are delivered from the central offices to the gateway (GW) of a dense population region (e.g. central business district or dense residential district). At the GW, the baseband DSP (e.g. OFDM (de)-modulation) for users data, and the protocol processes are performed. The processed baseband electrical signals are then modulated onto different wavelengths assigned for the respective destinations (e.g. residential or commercial buildings). All functions except for frequency up conversion are located at the GW. Since the equipment for such functions is centralized in the GW, the capital expenditures and operational expenditure can be significantly reduced. A star topology can be adopted between the GW and the buildings with dedicated fiber connections due to the short distances (1-km). Depending on the capacity demand, a set of wavelengths (λ-set) can be allocated to the home communication controllers (HCCs) of different houses. As shown in Fig., inside the HCC, the set of arrived wavelengths (λ-3, λ-4) pass through an optical circulator (Cir1) and coupled with the optical local oscillator (OLO) signals (λ-3b, λ-4b) via an optical coupler (OC). λ-3b, λ-4b are generated from two tunable lasers. The coupled optical signal pairs (λ-3/3b, λ-4/4b) travel toward the second optical circulator (Cir2). Both Cir1 and Cir2 are used to separate the forward and reflected signals for bi-directional operations. Finally, the optical signal pairs are delivered to different destination rooms via a WDM-tree fiber network using a wavelength de-multiplexer. In principle, a point-to-point or even a dynamic network can be employed to provide more capacity. This architecture is scalable and all wavelengths can be used since there are dedicated optical fiber connections from each HCC to the GW. As shown in Fig 5., the sets of λ-3/3b and λ-4/4b are then conveyed to room-a/b, and room-c/d, respectively. The up conversion of the baseband signal carried on λ-3/4 can be realized through the beatings be- tween λ-3 and λ-3b, or between λ-4 and λ-4b. By tuning the wavelengths of λ-3b and λ-4b, the frequency of the generated mm-wave can be flexibly adjusted to satisfy the dynamic spec- tral allocations. In principle, the optical local oscillators can be located in the GW. Here we place them in the HCC since they can be integrated with polarization beam splitters and PDs in a single chip. The signaling for protocol control between the GW and the HCC can be distributed by using the low frequency detection methods. [2]

**Experimental setup**

![Experimental Setup](image)
Fig. 5 shows the experimental setup for the proposed hybrid fiber-wireless in-home network system with OH and Pol-Mux. At the optical transmitter, the 14.5-dBm optical carrier at 1557.04 nm, is emitted from an external cavity laser (ECL). It is modulated by an in-/quadrature- phase (IQ) modulator driven by I and Q branches of a baseband electrical OFDM signal. Such signal is generated by an arbitrary waveform generator (AWG) which acts as a digital to analog converter (DAC). Its sample rate is set to 11.5 GSaps.

Two types of training sequences (TSs) are added in front of the data OFDM symbols as shown in Fig 5. The first type includes only one TS used for the time synchronization and the frequency synchronization (frequency offset compensation). The other one comprises one TS symbol surrounded by two null symbols in order to construct a pair of time interleaved TSs used for MIMO channel estimations. For the optical OFDM modulation, two Mach-Zehnder modulators of both I and Q branches inside the IQ modulator are biased at the null point of their power transfer curves. The phase difference between the I and Q branches is set to \( \pi/2 \). The PolMux scheme comprises a PBS to separate the modulated optical signal into two branches. An optical delay line (DL) is employed to remove the correlation between the x and y-polarization by providing one symbol delay (25.04ns). An optical attenuator is used to balance the power of the two branches before they are combined via a PBC. The total transmission bit rate is 61.3-Gb/s (11.5GSaps×192/288×2×4) after PolMux. The bandwidth of the OFDM signal is 8.98-GHz (200/256×11.5÷8.98-GHz), and the corresponding spectral efficiency is 6.82 bit/s/Hz. The generated signal is amplified by an Erbium-doped fiber amplifier (EDFA) to compensate for the insertion loss. The amplified signal with 0-dBm optical power is launched into 1-km SMF-28. In the optical up-converter, the wavelength of the OLO is set to 1556.72 nm in order to keep the 40-GHz spectral separation from the received optical signal. Two PBSs and two OCs are applied to realize the polarization diversity for the following OH process. The x and y-polarizations of both the OLO and the received optical signal are separated into two branches via PBSs. For a convenient notation, we define the branch connected to transmitter antenna HA1-T as x-branch and HA2-T as y-branch as shown in Fig 5. Then the x-branch or y-branch) of the OLO and the received optical signal are coupled before being launched into the following PDs. Both branches comprise the optical components from x- and y-polarizations of the modulated MIMO-OFDM signal due to the polarization rotation. Two PDs with 45-GHz 3-dB bandwidth and 7.5-dBm injected optical input are used for the OH process to directly up-convert the arrived baseband MIMO-OFDM signal onto 40-GHz mm-wave carriers at both x- and y-branch. The up-converted signals, amplified by two 40-GHz narrowband EAs are boosted into a 2×2 MIMO wireless link.

**c. Future challenges**

Future broadband access networks will be a combination of first/last mile optical fiber access solutions (i.e., FTTX) and heterogeneous broadband wireless networks providing connectivity to end users. One first challenge is to seamlessly integrate these technologies; while FTTX networks provide TDMA to wired ONU, mobile client nodes in a WMN access the medium through enhanced distributed channel access (EDCA) and multihop routing used to forward their packets to wireless mesh gateways.

Huge bandwidth available in optical access networks for offloading bandwidth-limited wireless networks should be used. The design and evaluation of powerful load balancing and reconfiguration techniques to improve the bandwidth efficiency of future FiWi networks should be studied.

FiWi networks should allow WMN gateways to interconnect with the optical backhaul through multiple points in order to enable multipath routing and improve their survivability with appropriate protection.

Implementation simplicity will be important to the commercial success of FiWi networks. Reduction in the installation and protection costs by means of transferring expensive devices and complex functions to the central office can be achieved.

**d. Conclusion**

This paper concludes that to overcome the drawbacks of respective networks, one hybrid network can be implemented. Such an implementation is easy to implement and robust also. Hybrid FiWi access networks hold great promise to support future and emerging broadband services and applications on the same infrastructure. We have observed that research and development of future FiWi network architectures and protocols have made significant progress, but many open issues mostly related to the design of low-cost components, integrated routing, end-to-end service differentiation to be solved.
Then, by using Optical Heterodyne and Polarization Multiplexing, the high-speed mm-wave MIMO signal can be delivered in a simple hybrid fiber-wireless in-home network with many merits. The proposed system is attractive for future high-speed wireless communications of in-home scenarios.

REFERENCES