FiWi Access Network: Performance Analysis of the Physical Layer

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Abstract

The fiber-wireless (FiWi) access network is a prestigious architecture for next generation (NG) access network. NG access networks are proposed to provide high data rate, broadband multiple services, scalable bandwidth, and flexible communication for manifold wireless end-users (WEUs). In this paper, the FiWi access network is designed based on a wavelengths division multiplexing/time division multiplexing passive optical network (WDM/TDM PON) at the optical backhaul with data rate of 2.5 Gb/s and wireless fidelity-worldwide interoperability for microwave access (WiFi-WiMAX) technologies at the wireless front-end along a 50 m- 5 km wireless links with data rate of 54 Mb/s- 30 Mb/s respectively. The performance of the optical backhaul and the wireless front-end, in the proposed FiWi access network, has been evaluated. The scalability of the optical backhaul based on maximum split ratio of 1/32 for each wavelength channel and a fiber length of 24 km from the central office (CO) to the access point (AP) is analyzed with bit error rate (BER) of 10⁻⁹.

Keywords: FiWi access network; WDM/TDM PON; WiFi; WiMAX.

1 Introduction

The main purpose of the communication networks generally is to provide access to information when we need it, where we need it, and in whatever format we need it in. Access network is a part of communication network which delivers different data from the central office (CO) to manifold end-users. The hierarchical organization of the modern communication network comprises from many levels: local area networks (LANs), access networks, metropolitan area networks (MANS), and wide area networks (WANs).
Fig. 1 shows the hierarchical organization of the modern communication network and illustrates the typical range and data rates for each part in this network. Next generation (NG) access network is proposed to provide high data rate, broadband multiple services, scalable bandwidth, and flexible communication for manifold wireless end-users (WEUs) [1].

Optical and wireless access networks are two promising broadband access technologies for high-capacity access networks and provide different levels of bandwidth, which shows a good match in capacity scales [2–4]. Bandwidth demand in access networks continues to grow rapidly due to the increasing number of technology-smart WEUs. A FiWi access network is an optimal combination of an optical backhaul and a wireless front-end for an efficient NG access network [5].

The FiWi access network supports high data rates and throughput with minimal time delay [3, 6–8]. The FiWi access network sometimes is called hybrid optical wireless access network (HOWAN) [2, 9, 10] or wireless-optical broadband access network (WOBAN) [4, 5, 11]. Fig. 2 shows the general architecture of the FiWi access network. The optical backhaul is a tree network connecting the CO and wireless front-end. The optical backhaul comprises of an optical line terminal (OLT) at the CO, a standard single mode fiber (SMF), a remote node (RN), and multiple optical network unit/access points (ONU/APs). The wireless front-end consists of widespread APs to penetrate numerous WEUs. The ONU/AP can be called mostly AP.

![Hierarchical organization of the modern communication network](image-url)

**Fig. 1.** Hierarchical organization of the modern communication network.

In this paper, the optical backhaul of the FiWi access network is implemented by using a cost-effective wavelength division multiplexing/ time division multiplexing passive optical access network (WDM/TDM PON) as a promising option due to its large throughput [12], and its great...
scalability since it can support different wavelengths over a single fiber optic [5]. The proposed PON supports a data rate of 2.5 Gb/s in symmetrical bidirectional operation. The wireless front-end is implemented by using wireless fidelity (WiFi) or worldwide interoperability for microwave access (WiMAX) technique [12]. WiFi technologies are widely exploited in commercial products due to their low cost, high data rate, and easy deployment in wireless local area networks (WLANs) [6, 12]. WiFi supports data rate up to 54 Mb/s along a 50 m wireless link. WiMAX provides point-to-multipoint wireless connections with a transmission rate of 30 Mb/s and can be used for longer distances. So WiMAX is particularly suitable for wireless metropolitan-area networks (WMANs) [5].

Most of the existing works, based on performance evaluation of the FiWi access network are concerned on network layer aspects [2, 5, 11, 13]. In this paper, the FiWi access network is designed based on the baseband-over-fiber (BBOF) transmission scheme. In this scheme, the received bit stream at the ONU/AP from the optical fiber is modulated by radio frequency (RF) transmitter as wireless signal and then sent to the WEU [14]. OptiSystem 12.0 and Advanced Design System (ADS) 2010 software tools are used together to simulate the proposed network.

The remaining paper is organized as follows: the architecture of FiWi access network is presented in Section 2. The simulation design of the proposed access network is viewed in Section 3. The performance evaluation and the scalability analysis of the PHY layer are discussed in Sections 4 and 5 respectively. Section 6 concludes the paper.

Fig. 2. Architecture of WiFi access network.

2 Architecture of FiWi access network

The architecture of FiWi access network is shown in Fig. 2. At the optical backhaul, OLT is built in the CO and connected by an SMF which propagates the data to an RN. The RN then
distributes the data to manifold ONUs. The FiWi access network should be able to be deployed on large coverage area, provides high data rate, and supports broadband services to the WEUs. The wireless mesh network (WMN) offers a promising architecture to achieve these requirements. The WMN employs multihope communication system effectively. So WMNs extend the coverage of WiFi islands to provide a flexible high-bandwidth wireless network. The WMNs can operate in either of WiFi or WiMAX techniques [15]. In the front-end, a set of wireless mesh routers (WMRs) forms a WMN. WEUs are connected to the network through these nodes, whose locations are fixed in the WMN. Some mesh routers are gathered with the ONUs in the optical backhaul to produce Access Points (APs).

The downstream are created by the OLT as a baseband optical signal and propagated along the optical fiber to the APs. The AP receives the baseband optical signal from the optical fiber and then upconverts it into downlink wireless signal at defined RF frequency that will be sent to the WMN. In the upstream direction, the uplink wireless signal is received by the AP as RF signal and converted to the upstream baseband optical signal that will be sent to the CO.

3 Simulation design

FiWi access network design comprises of two bidirectional segments: (1) optical fiber link which connects the CO with the APs, and (2) wireless links which connect the APs with the WEUs. The proposed FiWi access network uses the BBOF transmission scheme as shown in Fig. 3. In this scheme, the transmitted downstream data is upconverted by optical modulator and propagates as a baseband signal over optical fiber. A laser diode (LD) is used for optical modulation at specific wavelength ($\lambda_c$). AP receives the baseband optical signal which is
directly detected and decoded by a photodiode (PD), a low pass filter (LPF), and decoder. The decoded bit downstream is then modulated by the RF modem at the carrier frequency $f_{RF}$. In the upstream direction, the RF modem receives the uplink wireless signal at the AP, and then decodes it to a bit upstream which is send back to the CO as a baseband signal over fiber. The FiWi access network is designed to operate at 2.5 Gb/s symmetrical for each wavelength at bit error rate (BER) of $10^{-9}$. The wireless access used is the WiFi or WiMAX technology with a data rate of 54 Mb/s or 30 Mb/s respectively.

The optical backhaul is implemented using WDM/TDM PON as shown in Fig. 4. The wavelength assignment and bandwidth allocation is accomplished at the OLT. An eight ($N = 8$) downlink wavelengths are assigned to transmit the downstream which propagates along 24 km SMF with attenuation 0.2 dB/km. The downstream is demultiplexed according to their downlink wavelengths by an arrayed-waveguide-grating (AWG) router. Each downstream with a specific downlink wavelength is then split to M optical signals by a passive optical splitter/combiner (PS/C). This optical backhaul is provides 2.5 Gb/s downstream/upstream for each wavelength channel.

At the wireless front-end, the AP uses 5.2 GHz and 2.35 GHz RF carrier frequencies for each WiFi and WiMAX transceivers respectively. The orthogonal frequency division multiplexing (OFDM) technique is used in these transceivers. Each of the OFDM based IEEE 802.11a (WiFi) or IEEE 802.16a (WiMAX) transceiver in AP consists of two main parts: WLAN digital signal processor (WLAN DSP) subsystem and RF modulator/demodulator (RF modem). The general specifications of the wireless front-ends are summarized in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>WiMAX</th>
<th>WiFi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitter Power</td>
<td>-10 dBm</td>
<td>-16 dBm</td>
</tr>
<tr>
<td>Carrier frequency</td>
<td>2.35 GHz</td>
<td>5.2 GHz</td>
</tr>
<tr>
<td>Channel bandwidth</td>
<td>10 MHz</td>
<td>20 MHz</td>
</tr>
<tr>
<td>Data rate</td>
<td>30 Mb/s</td>
<td>54 Mb/s</td>
</tr>
<tr>
<td>Link Range</td>
<td>5 km</td>
<td>50 m</td>
</tr>
<tr>
<td>Radio technology</td>
<td>OFDM</td>
<td>OFDM</td>
</tr>
<tr>
<td>Modulation</td>
<td>64-QAM</td>
<td>64-QAM</td>
</tr>
</tbody>
</table>

Fig. 5. BER performance of the downlink/uplink in the optical backhaul.
4 Performance evaluation

BER performance is carried out at both ONU and OLT receivers for the downlink/uplink wavelengths using bi-directional transmissions. Fig. 5 shows the BER performance in the downstream/upstream direction for the downlink/uplink channels versus the received optical power at receiver side of ONU and OLT respectively. The power penalty at a BER of $10^{-9}$ is only $\approx 0.7$ dB after the transmission over a 24 km SMF. This power penalty is slight difference to get a good quality communication system.

Fig. 6 shows the BER versus signal-to-noise ratio (SNR) for the received signal at the WEU receiver; since the effect of phase noise and frequency offset are considered along the wireless link. The better performance occurs when the SNR is greater than 18 dB and 15 dB in the WEU receiver for WiFi and WiMAX respectively; at a BER less than $10^{-5}$ (standard BER value for wireless communication system). For 64 QAM demodulated OFDM signal in the WEU receiver, maximum error vector magnitude (EVM) of -32 dB and -31 dB have been estimated for the WiFi and WiMAX respectively. This EVM values allows perfect symbol detection at the receivers.

5 Scalability analysis

In this section, the scalability of the optical backhaul in term of the number of supported AP is analyzed. The number of APs is limited by the power budget of the link and available wavelengths. According to the general specifications of optical elements as listed in Table 2, the approximated number of APs can be calculated.

The power budget for the downlink/uplink can be stated as:

$$P_T - 2 \times I_{AWG} - \alpha \times L - I_{SA} - 10 \log_{10} (S) \geq R_{sen}$$  \hspace{1cm} (1)

where $P_T$ is the transmission power, $R_{sen}$ is the receiver sensitivity, $I_{AWG}$ is the insertion loss of AWG router (There are two AWG routers along the optical backhaul in the OLT and the RN to multiplex/demultiplex the downlink/uplink wavelengths), $L$ is the fiber length, $\alpha$ is the fiber attenuation, $I_{SA}$ is the loss of splicing and aging in the link, and $S$ is the splitter ratio of the PS/C for each wavelength channel.
According to Eq. (1), the maximal splitter ratio of the PS/C is then limited by:
\[
10 \log_{10}(S) \leq 15.2 \rightarrow S \leq 33
\]  
(2)

Therefore the maximum number of supported APs is 32 for each up/downlink wavelength.

![Scalability analysis of the proposed network.](image)

Table 2: General specifications of optical elements.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>(P_T)</td>
<td>Transmission power</td>
<td>0</td>
<td>dBm</td>
</tr>
<tr>
<td>(R_{sen})</td>
<td>Receiver sensitivity</td>
<td>-30</td>
<td>dBm</td>
</tr>
<tr>
<td>(I_{AWG})</td>
<td>Insertion loss: AWG</td>
<td>4</td>
<td>dB</td>
</tr>
<tr>
<td>(N)</td>
<td>Port size of AWG</td>
<td>8</td>
<td>none</td>
</tr>
<tr>
<td>(\alpha)</td>
<td>Attenuation</td>
<td>0.2</td>
<td>dB/km</td>
</tr>
<tr>
<td>(L)</td>
<td>Fiber length</td>
<td>25</td>
<td>km</td>
</tr>
<tr>
<td>(L_{SA})</td>
<td>Splicing and aging loss on the link</td>
<td>2</td>
<td>dB</td>
</tr>
<tr>
<td>(S)</td>
<td>Splitter ratio of PS/C</td>
<td>32</td>
<td>none</td>
</tr>
</tbody>
</table>

Moreover, the split ratio of the PS/C (S) and the receiver sensitivity determine the maximum fiber length from OLT to AP. Considering the common specifications of optical components as in Table 2, Eq. (1), the maximum link range \(L_{\text{max}}\) is 24.7 km and 9.7 km for \(S = 32\) and 64 respectively.

Power budgeting for an optical communication system is one of the main parameters to identify how far or big the network architecture can be deployed. Fig. 7 shows the downlink and uplink BER measurement versus length of optical fiber. For \(S = 32\), comparison between BER performance of the downlink and uplink is done and the maximum length of the optical fiber is 24.8 km to provide 2.5 Gbps data rate at BER of \(10^{-9}\). For \(S = 64\), comparison between BER performance of the downlink and uplink is also done and the maximum length of the optical fiber is 10 km. These values of \(L_{\text{max}}\) for both split ratios are close to theoretical calculations.
6 Conclusions

In this paper, the architecture of FiWi access network was proposed and designed as a suitable technique for future access networks. The PHY layer performance of the proposed network has been investigated. The scalability of the optical backhaul, in term of the number of supported APs, was analyzed. In conclusion, the proposed FiWi access network achieved the data rate of 2.5 Gb/s for downlink/uplink over 24 km SMF followed by 50 m or 5 km wireless link with a data rate of 54 Mb/s or 30 Mb/s by using WiFi or WiMAX technology respectively.

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References


