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PERFORMANCE ANALYSIS OF HYBRID OPTICAL-WIRELESS ACCESS NETWORK PHYSICAL LAYER

REDHWAN Q. SHADDAD[1,2*], ABU BAKAR MOHAMMAD[3], ABDUL AZIZ M. AL-HETAR[4,2], SEVIA M. IDRUS[5]

Abstract The hybrid optical-wireless access network (HOWAN) is a favorable architecture for next generation access network. It is an optimal combination of an optical backhaul and a wireless front-end for an efficient access network. In this paper, the new architecture of the HOWAN is proposed and designed based on both a wavelengths division multiplexing/time division multiplexing passive optical network (WDM/TDM PON) at the optical backhaul and a worldwide interoperability for microwave access (WiMAX) technology at the wireless front-end. It is demonstrated 2 Gb/s for downstream/upstream can be achieved at optical backhaul along 20 km of single mode fiber (SMF) for each wavelength channel with bit error rate (BER) of 10^{-9}, at a data rate of 30 Mb/s per Base Station (BS) along a 5 km outdoor wireless link with BER of 10^{-5} .

Keywords: Hybrid optical-wireless access network (HOWAN); Passive optical network (PON); Wavelength division multiplexing (WDM); Wireless mesh network (WMN); Orthogonal frequency division multiplexing (OFDM)

1.0 INTRODUCTION

In the last decade, the bandwidth demand of end users for broadband services such as quad-play (voice, video, Internet, and wireless) and multimedia applications has increased. For broadband access services, there is strong competition among several technologies, such as optical access technologies and wireless access technologies. Optical access network provides high-bandwidth digital services and long-distance communications but it has limited availability to end-users. Wireless access network is ubiquitous and flexible penetration to end-users but it supports limited bandwidth [1]. Thus, future access technologies must provide flexible deployment, large backbone capacity, upgrade-ability, and

1,3,4&5 Photonic Technology Center, Infocomm Research Alliance, Universiti Teknologi Malaysia, 81310, UTM Johor Bahru, Johor Darul Ta'azim, Malaysia
2 Communication and Computer Engineering Department, Faculty of Engineering and Information Technology, Taiz University, Yemen
* Corresponding author: rqs2006@gmail.com

scalability to user number and demand. Bandwidth demand in access networks will continue to grow rapidly due to the increasing number of technology-smart users. A HOWAN is an optimal combination of an optical backhaul and a wireless front-end for an efficient access network.

In this paper, the optical backhaul of the HOWAN is implemented by using a cost-effective WDM/TDM PON. WDM/TDM PON has been considered as a promising option due to its large throughput and quality of service (QoS) [2]. It supports data rate up to 2 Gb/s symmetrical operation. The wireless front-end is implemented by using WiMAX (IEEE802.16a) technique which has many interesting characteristics such as high data rate, and easy deployment in wireless metropolitan area network (WMAN) [3]. IEEE802.16a supports data rate up to 70 Mb/s at 2.4 GHz frequency band.

The rest of this paper is organized as follows. In Section 2, the WDM/TDM PON-based HOWAN architecture is described and optical backhaul simulation are shown. The optical backhaul is integrated with the wireless front-end by using a WiMAX (IEEE802.16a) technique in Section 3. Section 4 is dedicated to describe the simulation results and discussion. Finally, Section 5 concludes this paper.

2.0 PROPOSED ACCESS NETWORK ARCHITECTURE

The proposed HOWAN architecture is shown in Figure 1. At the backhaul of the network, optical line terminal (OLT) is built in the CO and connected by an optical fiber. Then, a remote node (RN) distributes the data to manifold optical network units (ONUs). In the front-end, a set of wireless routers forms a wireless mesh network (WMN). Mobile and stationery end users are connected to the network through these nodes, whose locations are fixed in the WMN. A selected set of these routers (gateways) are connected to the optical backhaul. Usually, each gateway is attached with one ONU.

In this work, the baseband-over-fiber scheme is used to transport the radio frequency (RF) wireless signals as a baseband signal over fiber. The system then upconverts detected data to the specified radio frequency at the antenna gateway BS. So ONUs are equipped with functions of both traditional ONUs in PON and gateways in WMN to implement the integration of the optical backhaul and the wireless front-end. Figure 2 shows the integrated optical-wireless system architecture. The downstream optical signals are created by the OLT and propagated along the optical fiber to the integrated ONU/BS. The ONU/BS in the HOWAN converted the downstream optical signals received from the RN into downlink wireless signals that will be sent to the WMN. At the upstream direction, the uplink wireless signals are received by the ONU/BS and converted to the upstream optical signals that will be sent to the CO. This scheme has the advantage of using mature digital and electronic circuitry for signal processing at the BS. Further, it also enables low-speed optoelectronic devices to be used within the BS [5]. The OptiSystem 8.0 and Advanced Design System (ADS) 2008 software tools are used to accomplish design and simulate the performance of the HOWAN. To accomplish the integration between these tools, there are many components to save and load the files which are contain time-domain waveform data for defining the signals associated with certain sources in the two software tools.

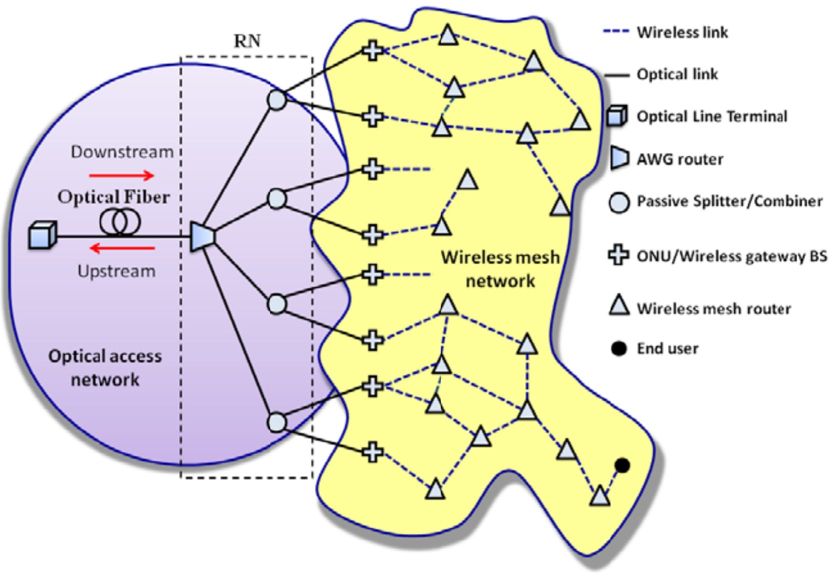

Figure 1 HOWAN architecture

Table 1 Allocated wavelengths WDM/TDM PON (downlink, uplink)

Downlink wavelengths		**Uplink wavelengths**	
Wavelength (nm)	**frequency (THz)**	**Wavelength (nm)**	**frequency (THz)**
1548.5100	193.6000	1549.3200	193.5000
1550.1200	193.4000	1550.9200	193.3000
1551.7200	193.2000	1552.5200	193.1000
1553.3000	193.0000	1554.1300	192.9000
1554.9400	192.8000	1555.7500	192.7000
1556.5600	192.6000	1557.3600	192.5000
1558.1700	192.4000	1558.9800	192.3000
1559.7900	192.2000	1560.6100	192.1000

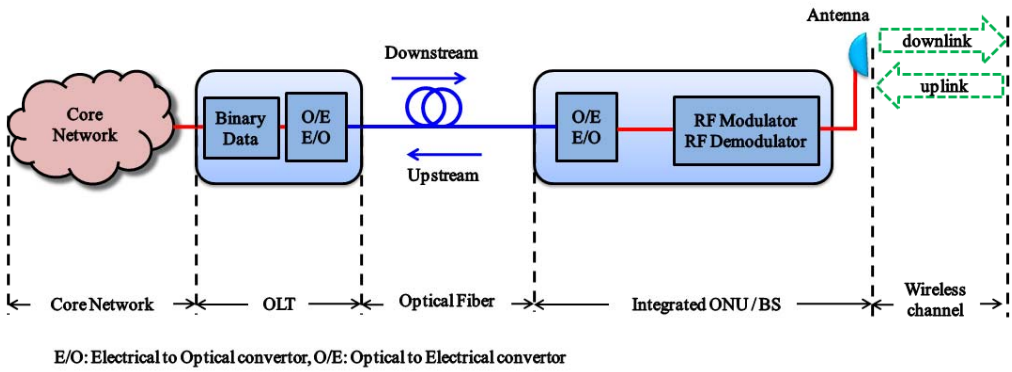

Figure 2 Integrated optical-wireless system architecture

3.0 SIMULATION DESIGN

HOWAN design comprises of multiple users connected to a CO represented by an OLT connected to multiple ONUs through 20 km of SMF. The system uses WDM/TDM PON with wavelength assignment and bandwidth allocation done at the OLT. Each ONU is integrated with an BS. The HOWAN is designed to operate at 2 Gb/s symmetrical for each wavelength at bit error rate (BER) of 10^{-9}. The wireless access used is the WiMAX (IEEE802.16a) technology with a data rate of 30 Mb/s.

The optical backhaul is accomplished by using WDM/TDM PON as shown in Figure 3. The OLT assigns N = 8 wavelengths to transmit the downstream which propagates along 20 km standard SMF with attenuation 0.2 dB/km. The downstream is demultiplexed according to their wavelengths by the arrayed-waveguide-grating (AWG) router. Then it splits at passive splitter/combiner (PS/C) to M optical signals. The upstream data is transmitted in the reverse way from each ONU to OLT. Figure 4 shows the allocated wavelengths of the downlink/uplink channels which are selected from conventional band (CB) with 200 GHz channel spacing for each link. Also the uplink channels are separated by 100 GHz downlink channels. Table 1 gives the allocated wavelengths WDM/TDM PON (downlink, uplink). This optical backhaul is provides 2 Gb/s downstream/upstream for each wavelength channel. The common specifications of the optical backhaul components are summarized in Table 2. The insertion loss of AWG is assumed to be 4 dB, which is a typical value in standard AWGs [10]. According to the availability of commercial optical components, it is applicable to use up to 16 wavelengths for the downstream and upstream, respectively [2]. In addition, the maximum split ratio for this access network is 1/32 by study its power budget [11].

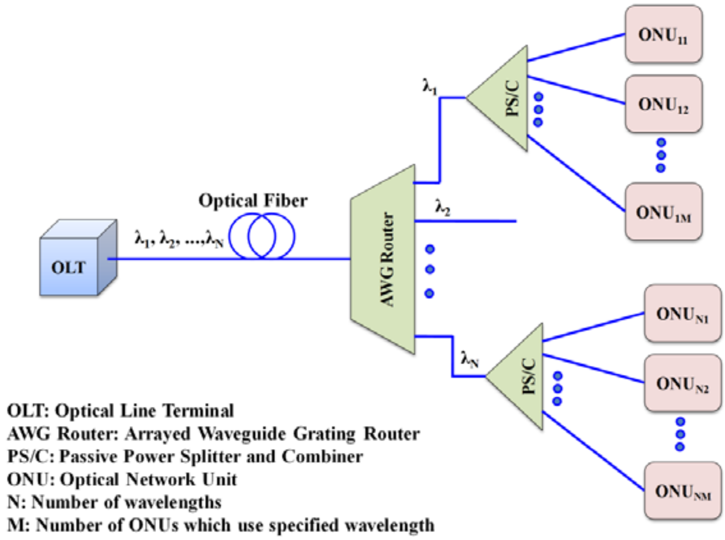

Figure 3 Optical backhaul architecture

Table 2 Common specifications of optical backhaul components

Description	Value	Unit
Transmission power	0	dBm
Receiver sensitivity	-30	dBm
Insertion loss: AWG	4	dB
Port size of AWG	4 – 16	none
Attenuation	0.2	dB/km
Fiber length	23	km
Splicing and aging loss on the link	2	dB
Splitter ratio of PS/C	4 – 32	None

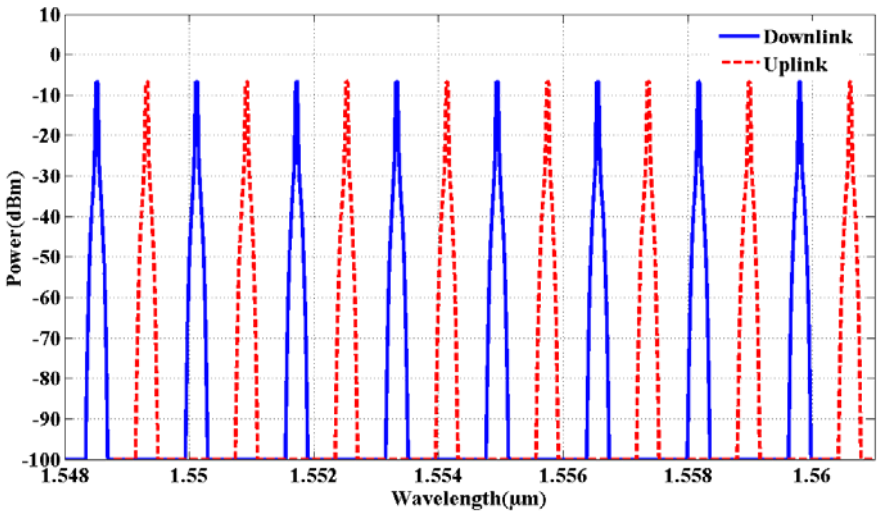

Figure 4 Allocated wavelengths of the downlink/uplink channels for the optical backhaul

The wireless gateway BS is considered as the main part, which is integrated with ONU. The carrier frequency is set to 2.35 GHz for each WiMAX transceivers with 10 MHz channel bandwidth. The orthogonal frequency division multiplexing (OFDM) technique is used in these transceivers. Each of the OFDM based IEEE 802.16a (WiMAX) transceiver in BS consists of two main parts: WMAN digital signal processing (DSP) system and radio frequency (RF) modulator/demodulator. The common specifications of the wireless front-ends are summarized in Table 3.

4.0 SIMULATION RESULTS AND DISCUSSION

The eye diagram and BER were considered to evaluate the performance of the proposed system. BER performance is carried out at both ONU and OLT receivers for the downlink/uplink wavelengths using bi-directional transmissions. The 1×32 PS/Cs were set to analyze BER versus the received optical power at the receiver side.

Figure 5 shows the BER performance in the downstream direction for the eight downlink channels against the received optical power at receiver side of ONUs. The difference margin between the eight analyzed channels is about 0.5 dB at BER of 10^{-9}. In addition, Figure 6 shows the BER performance in the upstream direction for the eight uplink channels against the received optical power at receiver side of OLT. The difference margin between the eight analyzed channels is about 0.8 dB at BER of 10^{-9}. The difference margins are due to the propagation characteristics of the different wavelengths along the optical fiber and the slightly difference of power loss in the passive optical components used in the design. The simulated eye diagrams for the downlink and uplink of the optical backhaul are shown in Figure 7. The eye diagram shows a good quality system at BER of 10^{-9} in each link.

Table 3 Common specifications of wireless front-end

Description	Value	Unit
Transmitter Power	-10	dBm
Carrier frequency	2.35	GHz
Channel bandwidth	10	MHz
Data rate	30 – 70	Mb/s
Link Range	5	km
Radio technology	OFDM (256-Channels)	None
Modulation	BPSK, 64-QAM, 256-QAM	None

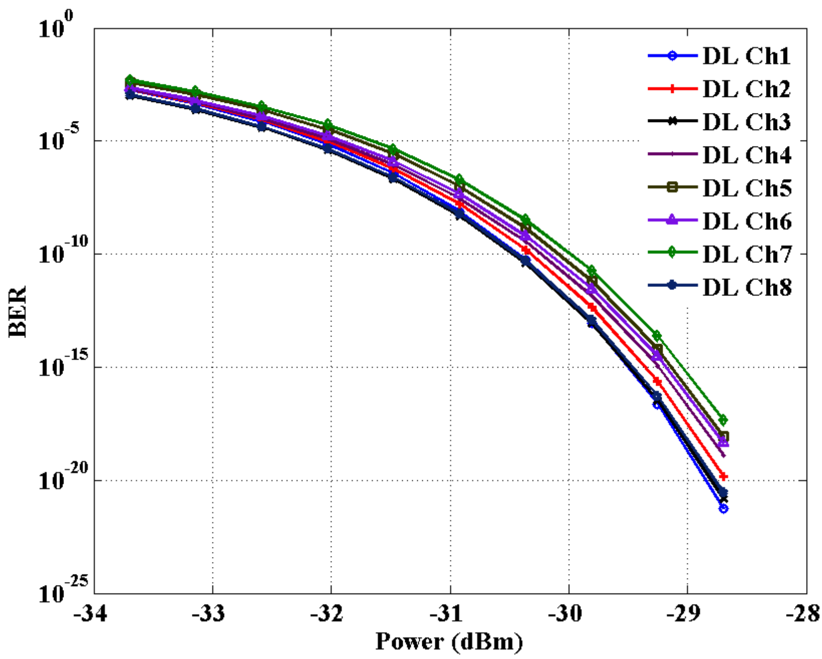

Figure 5 Downlink BER versus received optical power

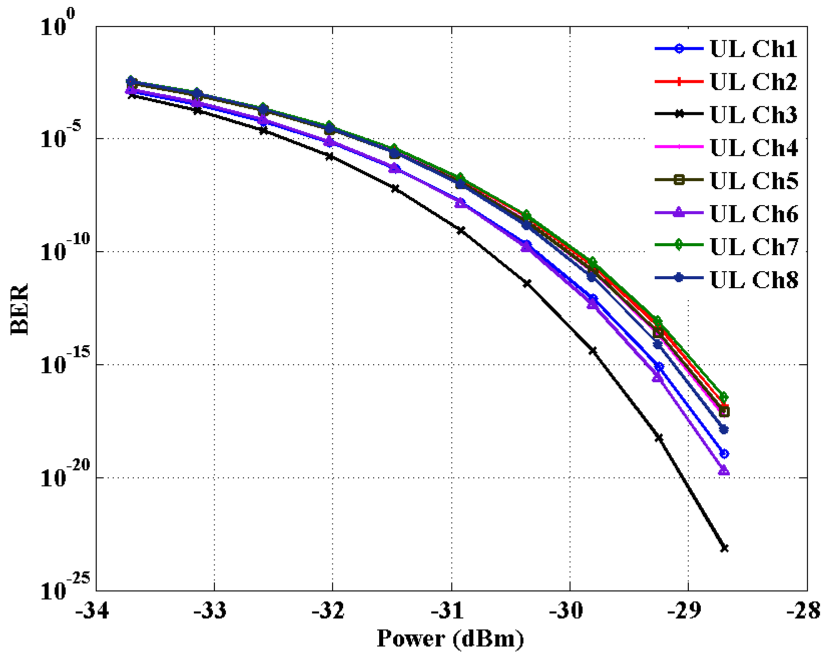

Figure 6 Uplink BER versus received optical power

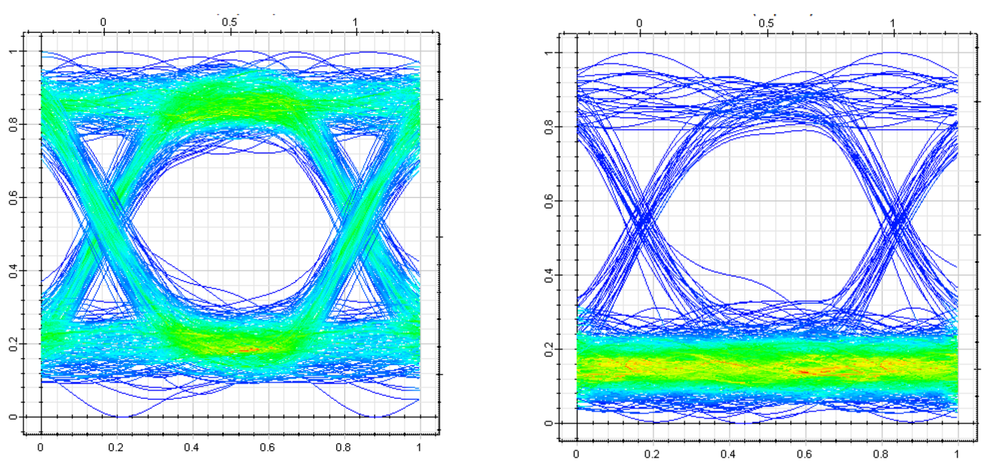

Figure 7 Eye diagrams of the optical backhaul measured at (a) ONU (b) OLT

The electrical signal of the detected data at ONU is amplified, recovered and then inserted to the transmitter of the BS. Each BS supports a data rate up to 30 Mb/s. In the BS transceiver, signaling bits are modulated in one OFDM symbol by using phase shift keying (PSK) technique. On the other hand, the data is modulated in

many OFDM symbols by using 64 Quadrature amplitude modulation (QAM) technique with average transmitter power is 10 dBm. Figure 8 shows the spectrums of the RF transmitted power signal. The WiMAX carrier frequency 2.35 GHz with bandwidth of 10 MHz is investigated. Figure 8 shows the transmitted spectrum mask which is defined by the reference level power which gives the maximal allowed out-of-band radiation power at a given frequency [14].
Figure 9 shows the BER versus signal to noise ratio (SNR) for the received signal at the BS; since the effect of phase noise and frequency offset are considered at the simulation of the BS. The better performance occurs when the SNR is greater than 15 dB in the wireless receiver; at a BER less than 10^{-5}. For 64 QAM modulated OFDM in the wireless receiver, maximum error vector magnitude (EVM) of -31 dB have been estimated. This EVM performance allows perfect symbol detection at the receivers.

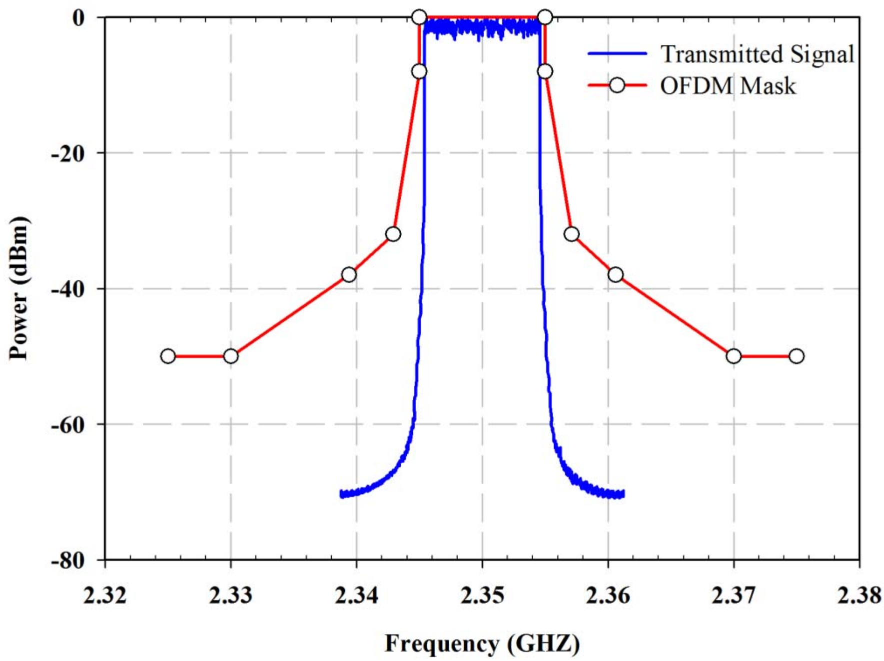

Figure 8 The spectrum of the transmitted RF power signal from WiMAX BS BER

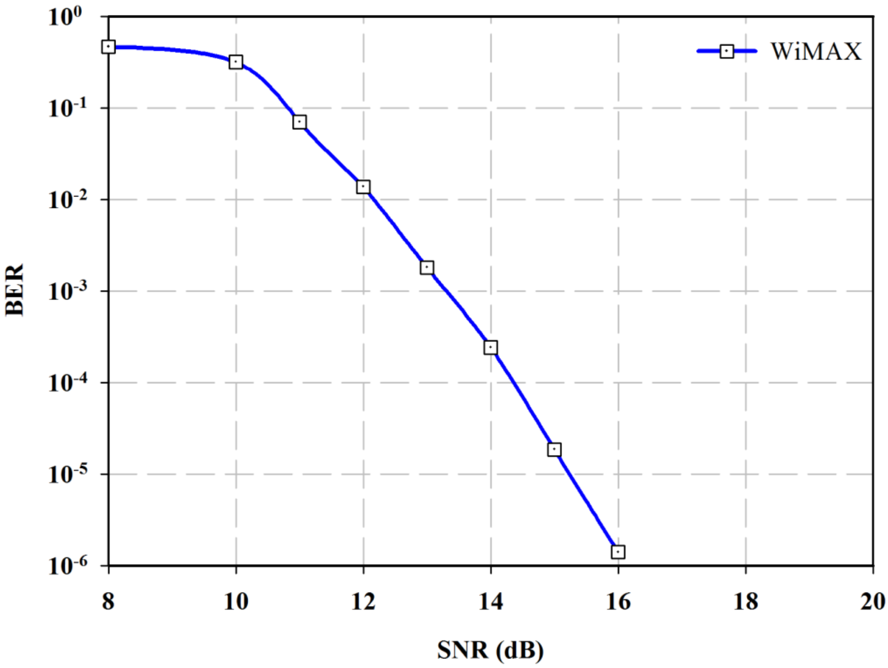

Figure 9 The BER versus SNR at the wireless receiver

5.0 CONCLUSIONS

In this paper, architecture of HOWAN was proposed and designed as a suitable technique for future access networks. The HOWAN has a good performance, a large backbone capacity, and a sufficient power budget margin can make splitting ratio high enough to support large numbers of users. In conclusion, the proposed HOWAN achieved the data rate of 2 Gb/s for downstream/upstream over 20 km fiber length followed by 5 km outdoor wireless link with a data rate of 30 Mb/s.

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