SPECTRAL EFFICIENT HYBRID WIRELESS OPTICAL BROADBAND ACCESS NETWORK

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requirements for the award of the degree of
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Specially dedicated to my beloved family and country YEMEN.

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ABSTRACT

Spectral efficient hybrid Wireless Optical Broadband Access Network (WOBAN) is a favourable 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. This thesis proposes the WOBAN in two architecture designs: the WOBAN based on transmission of wireless signal as a BaseBand signal Over Fiber (BBOF), and the spectral efficient hybrid WOBAN based on transmission of wireless Multi-Input Multi-Output Orthogonal Frequency Division Multiplexing (MIMO OFDM) signals over Wavelength Division Multiplexing Passive Optical Network (WDM PON) as a Radio Over Fiber (ROF). Wireless MIMO signals which have the same carrier frequency cannot propagate over a single optical fiber on the same wavelength, so a novel Optical Single-SideBand Frequency-Translation (OSSB-FT) technique is proposed to solve this problem in the second WOBAN architecture. The OSSB-FT technique is an efficient method since it excludes the crosstalk between different broadband wireless MIMO signals with the same carrier Radio Frequency (RF). Besides, it is a cost-effective technique as one optical source is enough to generate the optical carrier which is reused at the Access Point (AP), and multiple wavelengths for carrying several wireless MIMO signals over the same fiber. The physical layer performance is reported in both architecture designs of the WOBAN. In the first design, the WOBAN provides data rate of 2 Gb/s bidirectional optical backhaul for each wavelength channel along 20 km optical fiber link. In the wireless front-end, each Optical Network Unit/Access Point (ONU/AP) propagates data rate of 54 Mb/s along 50 m wireless link. The spectral efficient hybrid WOBAN achieved a data rate of 7.80 Gb/s along the optical backhaul of 20 km. The wireless front-end AP could support data rate up to 240 Mb/s along 100 m outdoor wireless link.

ABSTRAK

Spektrum cekap hibrid Rangkaian Capaian Jalur Lebar Optik Tanpa Wayar (WOBAN) adalah seni bina yang baik untuk akses rangkaian generasi akan datang. Ia adalah gabungan angkut balik optik yang optimum dan bahagian depan tanpa wayar untuk rangkaian akses yang cekap. Tesis ini mencadangkan WOBAN dalam dua reka bentuk seni bina: WOBAN berasaskan penghantaran isyarat tanpa wayar sebagai isyarat jalur asas melalui gentian (BBOF), dan spektrum cekap hibrid WOBAN berasaskan penghantaran isyarat tanpa wayar multi-input multi-output ortogon frekuensi bahagian pemultipleksan (MIMO-OFDM) ke atas pembahagian gelombang multiplexing rangkaian optik pasif (WDM-PON) sebagai radio melalui gentian (ROF). Isyarat MIMO tanpa wayar yang mempunyai frekuensi pembawa yang sama tidak boleh merambat melalui gentian tunggal optik pada panjang gelombang yang sama, jadi teknik terjemahan frekuensi jalur sisi tunggal optik (OSSB-FT) yang novel dicadangkan untuk menyelesaikan masalah ini dalam seni bina WOBAN yang kedua. Teknik OSSB-FT adalah satu kaedah yang cekap kerana ia mengelakkan cakap silang antara isyarat MIMO tanpa wayar yang berbeza jalur dengan frekuensi radio pembawa (RF) yang sama. Ia juga adalah satu teknik yang sangat jimat memandangkan hanya satu sumber optik sudah cukup untuk menjana pembawa optik yang digunakan semula di titik capaian (AP), dan banyak panjang gelombang untuk membawa pelbagai isyarat MIMO tanpa wayar melalui gentian. Prestasi lapisan fizikal dilaporkan dalam kedua-dua reka bentuk seni bina WOBAN. Dalam reka bentuk pertama, WOBAN menyediakan angkut balik optik dua arah pada kadar data sebanyak 2 Gb/s untuk setiap saluran gelombang sepanjang 20 km pautan gentian optik. Di bahagian hadapan tanpa wayar, setiap unit/pusat akses rangkaian optik (ONU/AP) merambat pada kadar data 54 Mb/s sepanjang 50 m pautan tanpa wayar. Reka bentuk kedua dicadangkan bagi mencapai kadar data sehingga 7.80 Gb/s oleh angkut balik optik pada gentian optik di sepanjang 20 km. Bahagian depan AP tanpa wayar menyokong kadar data sehingga 240 Mb/s di sepanjang 100 m pautan luaran tanpa wayar.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

4G	–	Fourth Generation
ADS	–	Advanced Design System
AP	–	Access Point
ATM	–	Asynchronous Transfer Mode
AWG	–	Arrayed–Waveguide–Grating
AWGN	–	Additive White Gaussian Noise
b/s/Hz	–	bit/second/Hertz bandwidth efficiency unit
BBOF	–	Baseband–Over–Fiber
BER	–	Bit Error Rate
BPF	–	Bandpass Filter
BPON	–	Broadband Passive Optical Network
BPSK	–	Binary Phase Shift Keying
BS	–	Base Station
BSS	–	Basic Service Set
CB	–	Conventional Band
CCK	–	Complementary Coded Keying
CDMA	–	Code Division Multiplexing Access
CDMA PON	–	Code Division Multiplexing Access Passive Optical Network
CL	–	Optical Coupler
CO	–	Central Office
CP	–	Cyclic Prefix
CW	–	Continuous Wave

CWDM	–	Coarse Wavelength Division Multiplexing
DAM	–	Dual Arms Modulator
dB	–	Decibel
dBm	–	Decibel milliwatt
DC	–	Direct Current
DEMUX	–	Demultiplexer
DFB	–	Distributed Feedback Laser Diode
DSP	–	Digital Signal Processing
DSSS	–	Direct Sequence Spread Spectrum
DWDM	–	Dense Wavelength Division Multiplexing
E/O	–	Electrical/Optical Process
EPON	–	Ethernet Passive Optical Network
ESSB–FT	–	Electrical Single Sideband – Frequency Translation
EVM	–	Error Vector Magnitude
FEC	–	Forward Error Correction
FFT	–	Fast Fourier Transform
FiWi	–	Fiber–Wireless
FP-LD	–	Fabry–Prot Laser Diode
FQOM	–	Frequency Quadrupling Optical Millimeter-wave
Gb/s	–	Gigabit per second
GEM	–	Generic Encapsulation Method
GPON	–	Gigabit Passive Optical Network
HOWAN	–	Hybrid Optical Wireless Access Network
HT–LTF	–	High Throughput Long Training Field
HT–MF	–	High Throughput–Mixed Format
Hz	–	Hertz
I–branch	–	Inphase–branch
IEEE	–	Institute of Electrical and Electronics Engineers

IFFT	–	Inverse Fast Fourier Transform
IL	–	WDM Interleaver
IM	–	Optical External Intensity Modulator
ISI	–	Intersymbol Interference
ISM	–	Industrial, Scientific and Medical Radio Band
ITU	–	International Telecommunication Union
LAN	–	Local Area Network
LED	–	Light–Emitting Diode
LLID	–	Logical Link Identifier
LO	–	Local Oscillator
LPF	–	Low Pass Filter
LR	–	Long–Reach
LSSB	–	Lower Single Sideband
LTE	–	Long–Term Evolution
MAC	–	Medium Access Control
MAN	–	Metropolitan Area Network
Mb/s	–	Megabit per second
MCS	–	Modulation and Coding Scheme
MIMO	–	Multiple–Input Multiple–Output
ML	–	Maximum Likelihood
MMF	–	Multi-Mode Fiber
mm–wave	–	millimetre–Wave
MUX	–	Multiplexer
MZM	–	MachZehnder Modulator
NG	–	Next Generation
NLOS	–	Non–Line–of–Sight
NRZ	–	Non Return to Zero
O/E	–	Optical/Electrical Process

OCS	–	Optical Carrier Suppression
OCSS	–	Optical Carrier Suppression and Separation
ODD	–	Optical Distribution Node
ODSB	–	Optical Double Sideband
OFDM	–	Orthogonal Frequency Division Multiplexing
OFDM PON	–	Orthogonal Frequency Division Multiplexing Passive Optical Network
OFDMA	–	Orthogonal Frequency Division Multiplexing Access
OLT	–	Optical Line Terminal
ONU	–	Optical Network Unit
OSNR	–	Optical Signalto–Noise Ratio
OSSB+C	–	Optical Single Sideband with Carrier
OSSB–FT	–	Optical Single Sideband – Frequency Translation
P2MP	–	Point–to–Multipoint
P2P	–	Point–to–Point
PD	–	Photodiode
PHY	–	Physical Layer
PIN	–	P-type Intrinsic N-type photodiode
PMD	–	Polarization Mode Dispersion
PON	–	Passive Optical Network
PS/C	–	Passive Optical Power Splitter/Combiner
QAM	–	Quadrature Amplitude Modulation
Q–branch	–	Quadrature–branch
QPSK	–	Quadrature Phase–Shift Keying
RB	–	Rayleigh Backscattering
RF	–	Radio Frequency
RN	–	Remote Node
ROF	–	Radio over Fiber

RSOA	–	Reflective Semiconductor Optical Amplifier
Rx	–	Receiver
SCM	–	Sub-Carriers Multiplexing
SDM	–	Spatial Division Multiplexing
SISO	–	Single–Input Single–Output
SMF	–	Standard Single Mode Fiber
SNR	–	Signal-to-Noise Ratio
SS	–	Subscriber Station
TDM	–	Time Division Multiplexing
TDM PON	–	Time Division Multiplexing Passive Optical Network
Tx	–	Transmitter
UHF	–	Ultra-High Frequency
U–NII	–	Unlicensed National Information Infrastructure
USSB	–	Upper Single Sideband
WAN	–	Wide Area Network
WDM	–	Wavelength Division Multiplexing
WDM DEMUX	–	Wavelength Division Demultiplexer
WDM MUX	–	Wavelength Division Multiplexer
WDM PON	–	Wavelength Division Multiplexing Passive Optical Network
WEU	–	Wireless End-User
WiFi	–	Wireless Fidelity
WiGEE	–	Wireless Gigabit Ethernet Extension
WiMAX	–	Worldwide Interoperability for Microwave Access
WLAN	–	Wireless Local Area Network
WMAN	–	Wireless Metropolitan Area Network
WMN	–	Wireless Mesh Network
WOBAN	–	Wireless Optical Broadband Access Network
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LIST OF SYMBOLS

λ	–	Wavelength
λ_d	–	Downlink wavelength
λ_u	–	Uplink wavelength
f	–	Frequency
ω	–	Angular frequency
$\Delta\lambda$	–	Channel spacing (wavelength interleave)
Δf	–	Channel spacing
B	–	Bandwidth
α	–	Attenuation factor
β	–	Propagation constant
L	–	Optical fiber length
P_T	–	Transmitted power
$\mathcal{R}_{sen}$	–	Receiver sensitivity
$\mathcal{IL}_{AWG}$	–	Insertion loss of AWG router
$\mathcal{IL}_{IL}$	–	Insertion loss of optical interleaver
$\mathcal{IL}_{DAM}$	–	Insertion loss of DAM
$\mathcal{IL}_{IM}$	–	Insertion loss of IM
$\mathcal{IL}_{CL}$	–	Insertion loss of coupler
$\mathcal{IL}_{Cir.}$	–	Insertion loss of circulator
$\mathcal{S}$	–	Splitter ratio of PS/C
G_{EDFA}	–	Gain of optical amplifier EDFA
V_π	–	Half-wave voltage of DAM

$E_{in}(t)$	–	Input optical signal
$E_{out}(t)$	–	Output optical signal
$v(t)$	–	RF modulating electrical voltage
V_b	–	DC bias voltage
$V_{\pi RF}$	–	Switching RF voltage
$V_{\pi dc}$	–	Switching bias voltage
Ω	–	Insertion loss
γ	–	Power splinting (combining) ratio of arm two for the input (output) Y-branch waveguide in DAM
$J_n(q)$	–	n-order Bessel function of the complex parameter q
t_d	–	Time delay
EVM	–	Error vector magnitude
BER	–	Bit error rate
EVM_{rms}	–	Root square mean value of EVM
	–	

CHAPTER 1

INTRODUCTION

1.1 Introduction

In the last decade, the bandwidth demand of end users has increased for broadband services such as quad-play (voice, video, Internet, and wireless) and multimedia applications. For broadband access services, there is strong competition among several technologies, such as optical access technologies and wireless access technologies. Next generation (NG) access networks are proposed to provide high data rate, broadband multiple services, scalable bandwidth, and flexible communication for manifold wireless end-users (WEUs). The optical fiber access networks provide high-bandwidth digital services and long-distance communication, but less ubiquitous. The wireless access networks provide flexible and ubiquitous communication with a low deployment cost. However, its deployment scalability is limited by the spectrum and range limitations [1–3]. The wireless optical broadband access network (WOBAN) is a powerful combination of optical backhaul and wireless front-end. This integrated architecture contributes a good scalability, cost effective, and flexible communication system. Figure 1.1 shows the general architecture of the wireless optical access network. The optical backhaul is a tree network connecting the central office (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 access points (APs). The wireless front-end consists of widespread APs to penetrate numerous WEUs.

In the optical access technologies, the dominant broadband access network is a point-to-multipoint (P2MP) optical network, which is called a passive optical

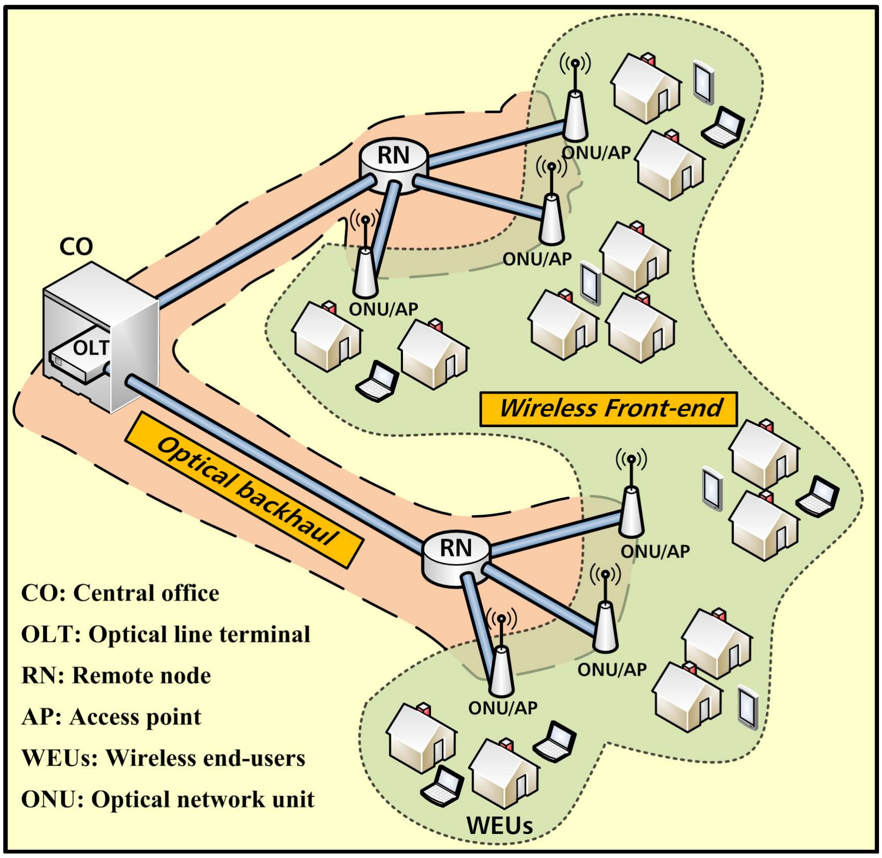

Figure 1.1: The architecture of wireless optical access network.

network (PON). In the PON, an OLT at the CO is connected to multiple optical network units (ONUs) by using one downlink wavelength in the downstream direction and another uplink wavelength in the upstream direction [4]. The time division multiplexing PONs (TDM PONs) have the simplest architecture. The existing TDM PON architectures are economically feasible, but limited-bandwidth [5]. The wavelength division multiplexed PON (WDM PON) is used to solve the bandwidth problem in TDM PON. A WDM PON solution supports multiple wavelengths over the same fiber infrastructure, and creates a point-to-point (P2P) optical network. A separate wavelength channel is assigned for each link between the OLT and each ONU in both upstream and downstream directions [6, 7]. A code-division multiple-access PON (CDMA PON) is proposed as an optical access network to satisfy the subscribers increasing data traffic and considered as a low cost solution [8]. In CDMA PON, many subscribers can access to the optical channel asynchronously and securely [9]. To avoid the dispersion effects on the optical signal in the TDM PON and WDM PON, the bandwidth-efficient optical orthogonal frequency division multiplexing PON (OFDM PON) is proposed [10, 11].

Among the various emerging optical and wireless access technologies, the OFDM-based technologies are the most promising technologies because they provide the highest transmission capacity, the highest spectral efficiency, the most flexible dynamic bandwidth allocation, and has a robust dispersion tolerance in both the optical and wireless links [10, 12–15]. In the optical access network, it is possible to use hybrid approaches. The combination of TDM and WDM in a hybrid PON network could be the most cost effective way of introducing scalable cost-effective WDM/TDM PON into the access network [16]. A novel lightwave centralized hybrid bidirectional access network for integration of WDM/OFDM PON with radio–over–fiber (ROF) systems is proposed in [20] by employing multi-wavelength generation and the carrier-reuse technique. The proposed PON reduces Rayleigh backscattering (RB) in the bidirectional transmission. In this system, both 11.29 Gb/s OFDM-16 Quadrature amplitude modulation (QAM) downlink and 5.65 Gb/s OFDM quadrature phase-shift keying (QPSK) uplink are investigated along 25 km SMF.

There are three major techniques that have been employed for wireless broadband access networks: worldwide wireless fidelity (WiFi), worldwide interoperability for microwave access (WiMAX), and long-term evolution (LTE). Most wireless broadband access technolgies are implemented by using OFDM technique. WiMAX (IEEE 802.16) is a recently adopted IEEE standard that was designed for fixed and mobile access networks [14]. It has a useful range of about 5 km at a data rate of 75 Mb/s. WiFi (IEEE 802.11) is more mature than WiMAX, but it has a limited range of 100 – 200 m and a data rate of 11–54 Mb/s (IEEE 802.11 a/b/g). The new standard IEEE 802.11n supports data rate up to 600 Mb/s. High data rates are achieved by using the multiple-input multiple-output (MIMO) concept and by increasing the channel bandwidth [17]. The LTE represents the fourth generation (4G) mobile communications systems and cellular radio access networks. LTE-Advanced offers a data rate up to 1 Gb/s with larger bandwidth [2]. In this thesis, the WiFi technology is used at the wireless front-end of the proposed WOBAN. The WiFi technique provides broadband multiple services with high data rate especially the standard IEEE 802.11n. The WiFi technology provides high spectral efficiency up to 15 b/s/Hz. In spite of the range limitation, the WiFi technique is more extensively used than WiMAX technique for recent wireless access network because of its maturity [18]. In addtion, the WiFi technique is more suitable for dense urban area [19].

The optical backhaul of the WOBAN is a tree network connecting the CO and wireless front-end. The wireless front-end consists of gateway routers which is known as APs and wireless mesh routers are widespread to penetrate an end-user's neighbourhood. To transmit the wireless signal over the optical fiber, two main schemes are proposed [20–22]: (1) baseband-over-fiber (BBOF) transmission scheme, (2) ROF transmission scheme. In the BBOF transmission scheme, the received bit stream at the ONU/AP is modulated by radio frequency (RF) transmitter and then sent to the WEU. In the ROF transmission scheme, the wireless signal is upconverted over fiber using optical carrier with specified wavelength. The AP downconverts the received optical signal to the suitable wireless signal. The AP amplifies and then propagates this wireless signal directly to the WEU through the wireless channel .

The NG wireless broadband access technologies are using the MIMO technique with high spectral efficiency, so the hybrid WOBAN must provide this requirement. This study will contribute this types of WOBANs. The transmission of wireless MIMO signals in the hybrid WOBAN can accomplish using one of the two transmission schemes BBOF and ROF to transport the wireless signal over fiber. In the BBOF transmission scheme , the received bit stream from the optical backhaul is processed by a MIMO transmitter at the wireless AP. In the ROF transmission scheme , the wireless MIMO signals, with the same carrier RF, can't be transmitted directly over fiber. When the wireless MIMO signals are transmitted directly over a single fiber, the MIMO signals overlap together and the AP then can't arrange them to multiple transmit antennas. In this study, a novel optical single-sideband frequency translation (OSSB-FT) technique will be used to solve the challenge of transmission of MIMO OFDM signals over one SMF.

1.2 Motivation

Bandwidth demand in access networks will continue to grow rapidly due to the increasing number of technology-smart users. There are many emerging optical and wireless access technologies proposed for this requirement [13, 23, 24]. A WOBAN is an optimal combination of an optical backhaul and a wireless front-end for an efficient access network. The hybrid WOBAN supports high data rates and throughput with minimal time delay [1, 4, 21, 25, 26]. The WOBAN sometimes is called hybrid optical wireless access network (HOWAN) [2, 25, 27–29] or fiber wireless (FiWi) access network [1, 30, 31]. Most of the existing works, based on performance evaluation of the WOBAN are concerned on network layer aspects [4, 25, 32, 33]. In this project, the WOBAN is designed based on the two main schemes for transmission of wireless signal over fiber: BBOF and ROF transmission schemes. The physical layer performance of the WOBAN is analyzed and characterized. For the first transmission scheme BBOF, the WOBAN architecture is implemented by a WDM/TDM PON at the optical backhaul and a WiFi technology at the wireless front-end [3, 28]. The physical layer performance of the WOBAN is evaluated in terms of the bit error rate (BER), eye diagram, and signal-to-noise ratio (SNR). The scalability of the optical backhaul of the WOBAN in terms of the number of supported AP and link reach range are also analyzed [3].

For wireless broadband transmission, the MIMO radio system has been developed [15] and implemented using multiple transmit/receive antennas. MIMO system is distinguished by improved transmission range/reliability, and delivering higher data transmission rates over the single–input single–output (SISO) system. One of the main problems of wireless links is channel fading, especially in the multipath channels. The throughput improvement and path diversity proposed by MIMO technique [34] with the OFDM immunity to dispersive fading of channel is considered as a favourable combination for the broadband wireless access network [35–38].

Most of the proposed WOBANs have been analayzed, designed, and implemented based on transmission of wireless SISO signal over fiber by using either of the aforementioned transmission schemes BBOF or ROF [1, 4, 25, 28, 32, 33, 39]. To carry out a spectral efficient WOBAN, the wireless MIMO OFDM technique will be implemented in this project. By using ROF technique, a spectral efficient hybrid WOBAN is proposed and designed based on transmission of wireless MIMO OFDM signals over WDM PON [40–42]. The spectral efficient WOBAN based on MIMO OFDM transmission by using the OSSB-FT technique. This novel technique can generate multiple wavelengths from one optical source which are used to upconvert the MIMO wireless signal at the optical modulators. whereas MIMO technique support high data rate and reliable system, OFDM technique provides an effective solution to eliminate intersymbol interference (ISI) caused by dispersive channels [43]. The new model for transporting MIMO OFDM signals based WiFi (IEEE 802.11n) over fiber is designed and analysed. A 7.80 Gb/s data rate will be achieved by the optical backhaul along optical fiber length of 20 km. The wireless front-end AP supports data rate up to 240 Mb/s along an outdoor wireless link. Each AP is implemented by using two spatial streams at a channel bandwidth of 40 MHz. The physical layer performance of the proposed WOBAN is analyzed in terms of the BER, error vector magnitude (EVM), SNR, and optical signal-to-noise ratio (OSNR).

1.3 Problem Statement

By using ROF technique, the optical fiber is widely accommodated to carry multiple wireless signals having different carrier frequencies. It is a known fact that multiple wireless signals having the same carrier frequency, such as MIMO signals specified in the IEEE 802.11n standard, cannot propagate over a single optical fiber on the same wavelength. This problem starts once multiple MIMO signals are merged and then upconverted by a single optical carrier. Individual MIMO signals could not be separated and recovered thereafter with regular electrical filtering. A traditional solution for this problem was proposed using WDM or sub-carriers multiplexing (SCM) techniques. These techniques are not cost-effective, since multiple optical sources and photodetectors are required. In this study, a novel OSSB-FT technique is designed and simulated to solve this problem. One optical source is enough to transport several MIMO signals over the optical fiber by using the OSSB-FT technique. A spectral efficient hybrid WOBAN is proposed based on transmission of wireless MIMO OFDM signals over optical fiber using the novel approach.

1.4 Objectives

The objectives of this research are:

1. to characterize and propose the WOBAN based on transmission of wireless signals over fiber in both BBOF and ROF transmission schemes.
2. to design and model the hybrid WOBAN with high spectral efficiency.
3. to verify and evaluate the physical layer performance of the proposed WOBAN.

1.5 Research Scope

In order to achieve the objective of this research, the following scope of work will be done which comprises of:

- A literature review on related topics such as enabling optical and wireless broadband access technologies, wireless signals transport schemes in hybrid FiWi systems, and key enabling technologies for hybrid optical–wireless access networks. These will include optical millimeter-wave (mm-wave) generation, upconversion, and transmission in a downlink direction, and full-duplex operation based on wavelength reuse.
- Deciding on the specification of elements and subsystems for the design of the WOBAN system.
- Modelling and simulation of the hybrid WOBAN will be done. The wavelengths assignment for the downlink/uplink channels will be implemented at the CO using the optical wavelengths in the C-Band. The wireless access network will be implemented by using WiFi standards operating at 2.4 GHz and 5 GHz.
- The performance analysis of the physical layer will be carried out to get BER less than 10^{-9} at optical backhaul and 10^{-5} at the wireless front-end.
- Comparison will be done with similar work done elsewhere.

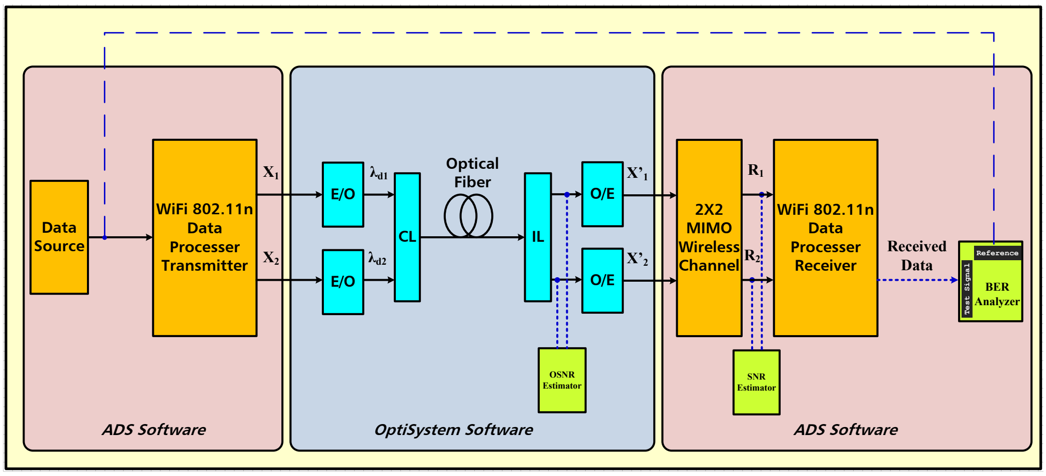

Figure 1.2: Simulation and measurement set-up of the proposed network.

1.6 Simulation Tools

OptiSystem 11.0 software is an innovative optical communication system simulation package that designs, tests, and optimizes virtually any type of optical link in the physical layer of a broad spectrum of optical networks [44]. In addition, Advanced Design System (ADS) 2008 software is a powerful electronic design automation software system. It offers complete design integration to designers of products such as wireless networks [45]. There are many tools already supported to integrate the two simulation software. In the OptiSystem 11.0 software, the components Save ADS File, and Load ADS File are used to save and load files in the '.tim' format respectively. The .tim files are signal data files in Agilent ADS 2008 software. In the ADS 2008 software, the component TimedDataWrite enables the generation of .tim output files, and the component TimedDataRead is considered as a time domain signal generator with file-based data such as .tim file. A simplified diagram to depict one example for the simulation and measurement set-up of the proposed network is shown in Figure 1.2. The electrical digital signal processing and wireless communication systems is simulated by the ADS 2008, while OptiSystem 11.0 simulates the electrical/optical (E/O) processes, the optical/electrical (O/E) processes, and the optical communication systems.

Simulation is performed in discrete time steps. At each time step, the signals generated by all the sources are propagated through the system, and the outputs are evaluated. Thus, the effects of non-linearities and noises in the system can be simulated accurately. This is a useful feature that permits to build an accurate physical model of an actual system. When setting up a BER measurement, three important points were considered: synchronizing test and reference signals, choosing the optimal sampling instant, and scaling test and reference signals appropriately. The simulations in this thesis totally will be implement by integration of the OptiSystem 11.0 software and the ADS 2008 software. MATLAB programming software also will be used for some calculations for example the EVM values and the compatible BERs.

1.7 Research Contributions

This thesis produces two significant contributions to the study and analysis of the hybrid WOBAN. The research contribution are briefly presented in the following subsections.

1.7.1 WOBAN Based on BBOF transmission scheme

Chapter 3 first will introduce an architecture of WOBAN. In this architecture, the BBOF transmission scheme is used to transport RF wireless signals as a baseband signal over fiber. The system modulates the detected baseband signal from optical backhaul to the required radio frequency only at the gateway ONU–AP as shown in Figure 1.3. The WOBAN consists of an optical backhaul supports a wireless mesh network (WMN) in the wireless front-end. In this project, the optical backhaul is carried out by using a cost-effective WDM/TDM PON, and the wireless front-end is executed by WiFi IEEE 802.11a-based WMN. The physical layer performance will be evaluated in terms of the BER, eye diagram, and SNR of the communication system. In addition, the scalability of the optical back-haul in terms of the number of supported

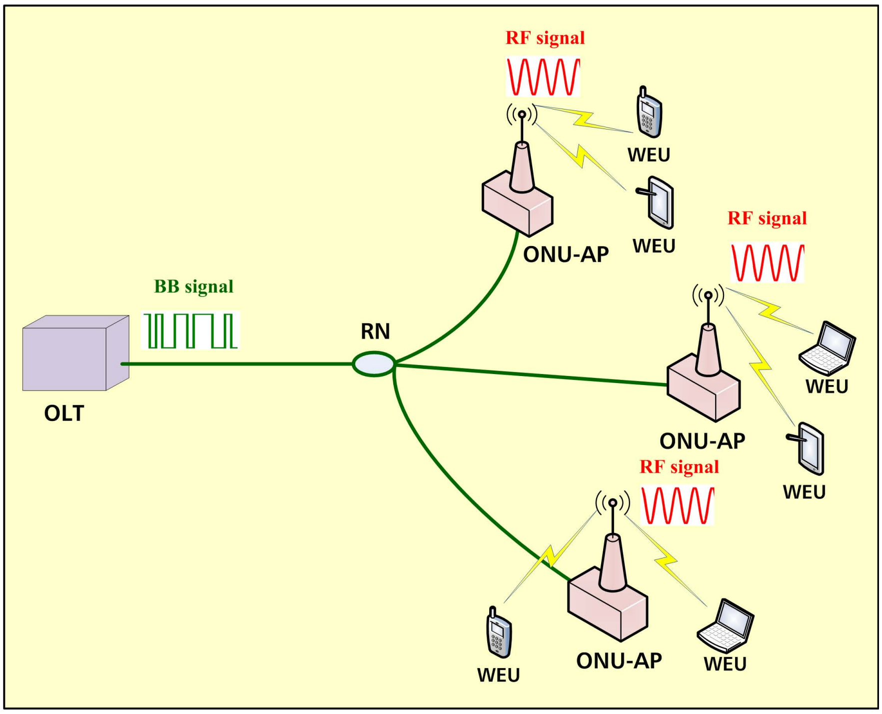

Figure 1.3: WOBAN architecture based on BBOF transmission scheme.

APs and link reach range are analyzed. This contribution has been published and presented in many journals [3,28,29,46] and conferences [23,27,47–49].

1.7.2 WOBAN based on ROF transmission scheme

A simple WOBAN architecture based on ROF transmission scheme for wireless signals is shown in Figure 1.4. The wireless signal is upconverted directly as optical signal at the OLT and then transmitted as ROF signal over fiber. In this scheme, the AP detects directly the received ROF signal, amplifies it and then broadcasts it to the WEU along a wireless channel. Chapters 4 and 5 will propose, demonstrate and investigate a novel OSSB-FT technique for transmission of wireless MIMO signals over fiber, and spectral efficient hybrid WOBAN based on transmission of wireless MIMO OFDM signals over WDM PON respectively. Chapter 5 will introduce a spectral efficient hybrid WOBAN which uses a novel method to solve the challenge of transmission MIMO OFDM signals over one SMF by using OSSB-FT technique.

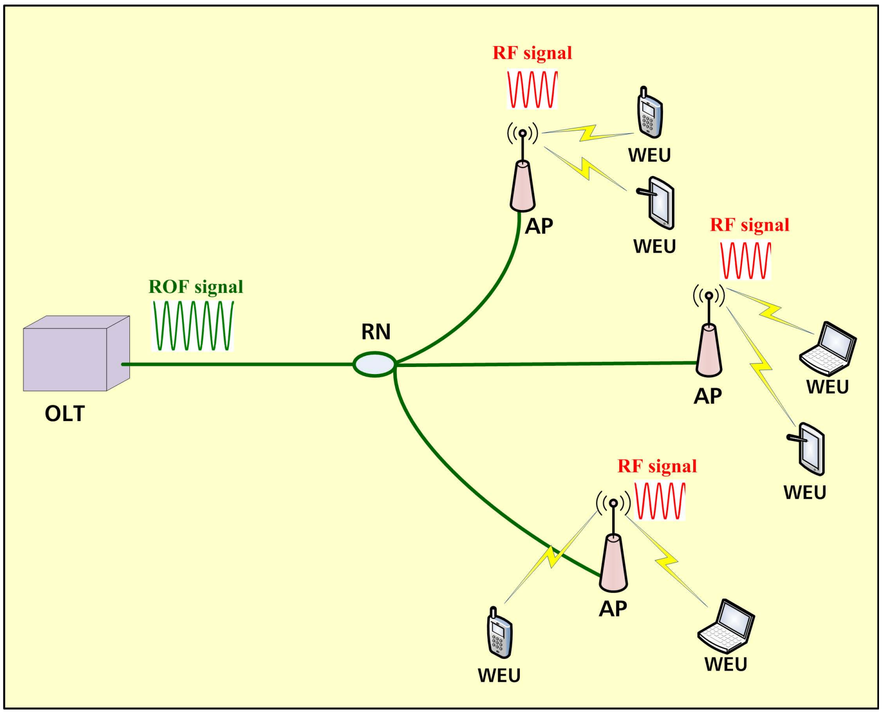

Figure 1.4: WOBAN architecture based on ROF transmission scheme.

The crosstalk between the different MIMO channels with the same frequency is eliminated, since each channel is upconverted on specified wavelength with enough channel spacing between them. The physical layer performance of this architecture will be also analyzed in terms of BER, EVM, SNR, and OSNR. This contribution has been published and presented in many journals [41, 42] and conferences [40, 50].

1.8 Thesis Organization

This thesis is organized into six chapters. Each of the following paragraphs explains the contents of each chapter.

Chapter 1: A general overview of the access networks is demonstrated and the hybrid WOBAN motivation is presented in this chapter. This chapter also introduces the problem formulation of this research, objectives, and research scope. Then the simulation and measurement set-up of the proposed access network is illustrated. Finally, the research contributions and thesis organization are outlined.

Chapter 2: This chapter is a literature review which will define the important concepts of this research. *Key enabling technologies for optical and wireless access networks* are presented and compared in this chapter. Then the advantages and architecture of the WOBAN are proposed. Finally, this chapter also covers the structures and the important findings of previous studies which are most related to this work. This chapter has been published and presented in 31^{st} Progress in Electromagnetics Research Symposium (PIERS), March 2012 [23], and 3^{rd} International Conference on Photonics 2012 (ICP 2012), October 2012 [49].

Chapter 3: In this chapter, the architecture of the *WOBAN based on transmission of wireless signal as BBOF* is proposed and designed as a suitable technique for future access network. In this work, the WOBAN architecture is designed based on a WDM/TDM PON at the optical backhaul and a WiFi technology at the wireless front-end. The WOBAN has been proposed that can provide blanket coverage of broadband and flexible connection for wireless end-users. The proposed WOBAN will achieve data rate of 2 Gb/s for downstream/upstream over 20 km SMF followed by 50 m outdoor wireless link with a data rate of 54 Mb/s. The physical layer performance in terms of the BER, eye diagram, and SNR is reported. Finally, the scalability of the optical backhaul in terms of the number of supported APs and link reach range is analyzed in theory and the simulation. This chapter has been published in many journals: Optoelectronics and Advanced Materials – Rapid Communications (OAM-RC), April 2011 [3], Optics Communications, September 2011 [28], Jurnal Teknologi, May 2011 [29], and Journal of Computer Research : Arabic Language, August 2011 [46], and many conferences: 1^{st} International Conference on Photonics 2010 (ICP 2010), July 2010 [27], 29^{th} Progress in Electromagnetics Research Symposium (PIERS), March 2011 [47], and 7^{th} International Computing Conference In Arabic, June 2011 [48].

Chapter 4: This chapter describes *the novel OSSB-FT technique for transmission of MIMO wireless signals over fiber*. The novel OSSB-FT technique is proposed to solve problem of multiple wireless signals which have the same carrier frequency and cannot propagate over a single optical fiber, such as MIMO signals feeding multiple ONUs or APs in the FiWi system. This chapter will investigate how this technique works and when it is suitable to transmit MIMO wireless signals over fiber. Next, the performance of the new technique is evaluated to transmitted three MIMO signals which have the same RF carrier frequency over fiber. Finally, the performance comparison of OSSB-FT technique with other techniques for transmission of wireless MIMO signals over fiber is discussed. This work has been published in Optics & Laser Technology (JOLT), April 2013 [42] and presented at 3^{rd} International Conference on Photonics 2012 (ICP 2012), October 2012 [50].

Chapter 5: This chapter is dedicated to implement the novel efficient method from Chapter 4 into the WOBAN. *The spectral efficient WOBAN based on transmission of wireless signal as ROF* is proposed using the OSSB-FT technique, where it is designed based on transmission of wireless MIMO OFDM signals over WDM PON as a promising technique for future access network. The WDM PON is design to transport many wireless MIMO OFDM signals over fiber at the optical back–end. The front–end is a WMN with several wireless mesh routers and a few APs. The WMN is established using WiFi technology based on the IEEE 802.11n. The physical layer performance of the proposed access network is analysed and discussed. This work has been published in Optics Communications, September 2012 [41],and presented at 30^{th} Progress in Electromagnetics Research Symposium (PIERS), September 2011 [40].

Chapter 6: This chapter gives *the conclusions and future work* for this thesis. In addtion, the publications list will be viewed in this chapter.

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