Performance of RoF-MMW-WDM Backhaul System based on Hybrid Optical OFDM Transportation Enabling 128-QAM Format for B5G Communication Networks

Musaddak M. Abdul Zahra[1,2*] and Laith A. Abdul-Rahaim[1]

[1*]Electrical Engineering Department, College of Engineering, University of Babylon, Babylon, Iraq. musaddaqmahir@mustaqbal-college.edu.iq

[2]Computer Techniques Engineering Department, Al-Mustaqbal University College, Babylon, Iraq.

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Abstract

For growing transmitting capability over fixed bandwidth, there are many potential techniques that had been developed in the recent years. There are several possible methods for increasing transmission capacity over fixed bandwidth. One of the most effective methods that can offer achieving more information is orthogonal frequency division multiplexing (OFDM). We designed a powerful simulation framework for a backhaul RoF-MMW optical transmission system between main base station and remote antenna unit based on multi-carrier OFDM modulation. The powerful simulation of next generation optical MC-OFDM transportation along RoF-MMW long transmission system had been successfully implemented. By using 50 Gb/s default bit rate and 128 QAM modulation format for OFDM-RoF-MMW system along 50 km, the best achievement of overall bit rate obtained (11.2 Tb/s) with accepted BER to get ultra-high-capacity transmission system. Thanks to the python DSP and the losses compensators used in the simulation framework, the PAPR losses and drift in the receiver section had been compensated and many values of OFDM sub-carriers (16 and 32 OFDM sub-carriers) achieved for ultra-high-capacity transmission system.

Keywords: Hybrid Systems, QAM, RoF, OFDM, MMW, B5G.

1 Introduction

Living human styles and communication have led to wireless communications being feasible and flexible [1]. There is a growing need for improved wireless communications systems for quicker data transmission, high quality information, multimedia communication, live video streaming and content share [2-5]. Although wireless systems have overcome various problems from wireless techniques, some elements cause issues to develop an effective wireless communication system [6,7]. The design of an efficient communication system is hampered by two important elements [8].

First, is fading which is a phenomenon that results in changes of the channel strength due to small-scale impacts of the multipath. Second are Huge-scale fluctuations might come from the loss of track caused by attenuation or the shade caused by large barriers. Wireless communication is carried out on the open air in which systems are subjected to various transmission problems that leading to signal loss

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*Corresponding author: Electrical Engineering Department, College of Engineering, University of Babylon, Babylon, Iraq. Computer Techniques Engineering Department, Al-Mustaqbal University College, Babylon, Iraq.

[9]. The primary goal of study is to learn how to overcome these problems so as to improve the efficiency of a communication system.

The characteristics of such wireless communication are [10,11]:

- Cost efficiency: Wired communication networks are cheaper and require no comprehensive maintenance or infrastructure. Time investment for preparation and work is not necessary with wireless communication. Even if wireless communication involves wireless cabling, the cost of wireless communication is quite cheap.
- Flexibility: Wireless communication allows people to stay for sending and receiving messages in a desk or phone booth. Every Wireless Transmitter can accept a number of receivers that are restricted to physical connections of the equipment via the wireless communication System.
- Comfort: Wireless devices like mobile phones are easy to operate. It allows everyone to use the phone regardless of where they are located. Physical interaction is not required to transmit messages. The ongoing contact guarantees that people are able to react promptly to catastrophes.

With its effective qualities, the development of wireless systems has produced various advances.

- Transmission: The distance conveyed using wireless system can be anywhere from a few metres (e.g. remote control) to thousands of kilometres (e.g. radio communication).
- Applications: Include GPS devices, door openers, wireless computer mice, headboards, radio reception, satellite, wireless television and cable telephones. Figure below shows recent application areas of wireless technology [12].

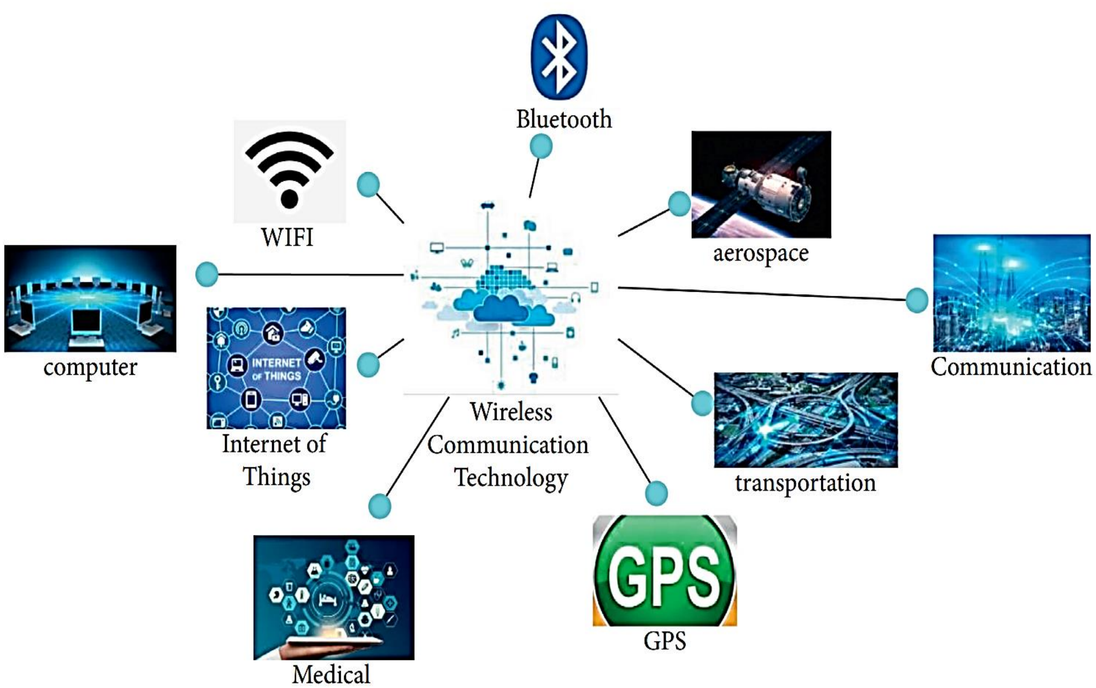

Figure 1: Applications Areas of Wireless Communications Technology [12]

The role of wireless communication in our lives has been identified with radio communication and television broadcasting [13]. Both applications leverage technology to be used with the same channel and several signals [13]. This approach is called frequency division multiplexing (FDM).

FDM was widely utilised to establish voice communication for wireless systems in the first generation [14]. Time division multiplexing (TDM) was employed for the efficient use of the communication channel in second generation systems in which data processing is also enabled [15]. In order to develop third generation systems, data transfer, multimedia traffic and an integrated voice were needed [16]. The ability of the channel is restricted. Fourth generation is the stage of broadband mobile network that supersedes third generation and is the predecessor of fifth generation (5G) [17-19].

5G is described as the next generation mobile network, however, it is not projected as a modest improvement over 4G but as a new network [20].

5G has some challenges that must be overcome [20]. Multiple antennas per device will be common, so the beamforming and steering is very important to enhance the performance, the efficiency and reduce the interferences [21]. Studies talk about employing higher frequencies, in the range of microwaves [22]. Besides, it is very important to improve the efficiency of overall system. Figure (1.2) shows the generations evolution of wireless communication systems.

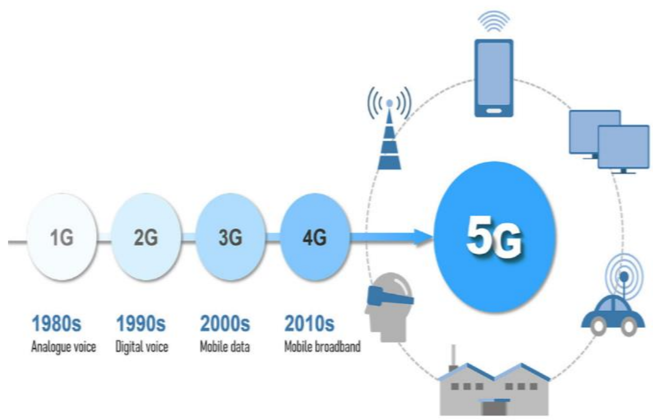

Figure 2: Evolution of Wireless Communication Systems [23]

1.1 Millimetre Wave Technology

There are need for new technologies to provide larger data transmission rates for users at business data centres with higher bandwidth smartphones, thus, the demand is more than before for users of business data centres [34].

There are a large number of technologies available for the delivery of high fibre optic cabling. Millimetre wave technology delivers bandwidth equivalent with fibre optics, but without the logistical and economical disadvantages of applications [35].

With a wavelength of between 1 –10 millimetres, the RF signal spectrum is between 30GHz and 300GHz [36]. The term of the Millimetre Wave mainly relates to a few radar frequency bands that are 38, 60 and, more recently, 70 and 90 GHz wavelengths [36]. Commercial millimetre waves (MMW) Cable-Free links are high performing, reliable, high capabilities, and offer latest-generation wireless networking. As a result of their advantages, Millimetre waves had been used widely in modern wireless systems to enhance system capabilities and performance. Figure below shows the frequency range of cellular and millimetre waves [37].

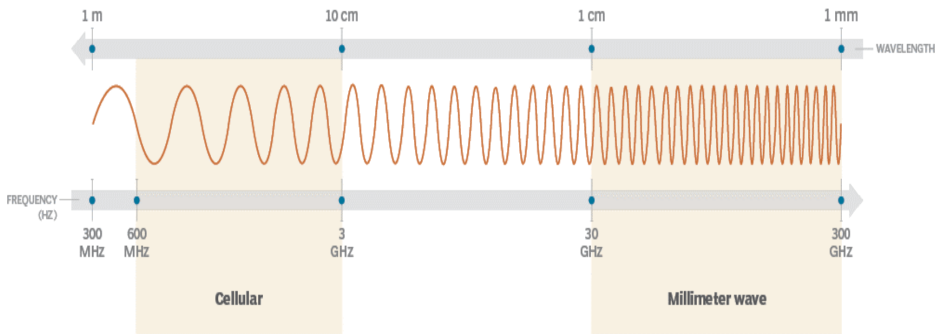

Figure 3: Cellular Wave Vs Millimetre Wave [37]

1.2 Radio over Fiber systems (ROF)

The term "Radio over Fiber" (RoF) refers to a technique that permits radio frequency (RF) signals to be transmitted over an optical fiber link with only a slight loss in performance of RF [38]. Although distributed antenna systems are already using RoF systems, most of them use single mode fiber links powered by distributed feedback laser (DFB) or Fabry-Perot laser diodes [38]. Many studies investigate the feasibility of using a cheap laser diode fibre link to transmit radio frequency (RF) signals, such as those used in ultra-wide bands (UWB) and local area networks (LAN). This contained building a system of RF fiber optic by modeling, characterizing, and simulating the optical link components such as single mode fiber (SMF), laser diode, and PIN photo diode alongside the components of RF [39].

RoF links are comparable to digital fiber optic links, with the exception that they are typically operated at the linear region of the laser diode [39]. Further, the signals that would be responsible for propelling these links would largely be of the small signal variety, consequently, modest signal models would be sufficient to describe these links [39]. Then, links of RoF were began getting applied widely for remoting of antenna for wireless cellular networks and satellite earth stations [38]. These fiber links often used intensity-modulated direct detection (IMDD) technology. Figure (4) explain the general concept of RoF [38].

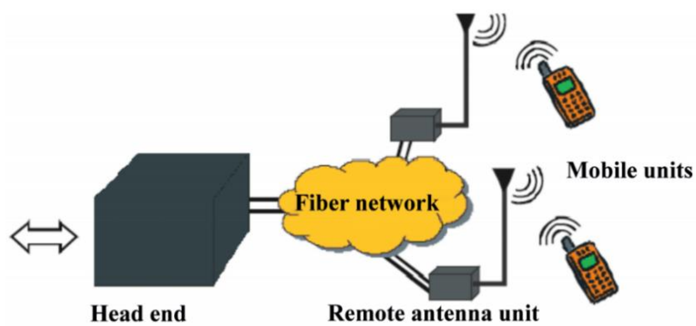

Figure 4: General Concept of RoF

1.3 OFDM Modulation

OFDM is a multi-carrier transport technique for communication system with high data-rate transmission [40]. To ensure the orthogonality of subcontractor’s careful control of the relationship between all the operators is necessary [40]. The initial OFDM is therefore produced by selecting the needed range, depending on the modulation system and the input data [41]. Any carrier's production requires the same transmission dates to be allocated. For the basis of the modulation scheme, the required amplitude and phase are computed [41]. Then the appropriate spectrum is transformed to its time domain signal using an inverse Fourier transformation [42]. Inverse Fast Fourier Transform is used for various applications where efficient transformations are performed and also orthogonal signals are guaranteed. The FFT is the outcome of the identification of equivalent waveforms resulting from a sum of the orthogonal sinusoidal component, A time domain signal converted into its corresponding frequency spectrum. The amplitude and stage of the sinusoidal component act the spectrum of the signal of time domain [43].

The OFDM principle is the division and transmission of a high-rate data stream in low-rate streams by several subcarrier. It divides the basic bandwidth into narrow parallel orthogonal sub channels. OFDM signals are generated at the transmitter by IFFT, which yields orthogonal carriers as shown in figure below [43].

Figure (5) shows the idea in the frequency field [44]. Due to its rectangular form of pulse in the temporal area the spectrum of each modulated carrier is $sin(k\ f)/\ f$. Although the spectrum of several modular carriers overlaps, each operator lies in the spectral nulls of all other carriers [44].

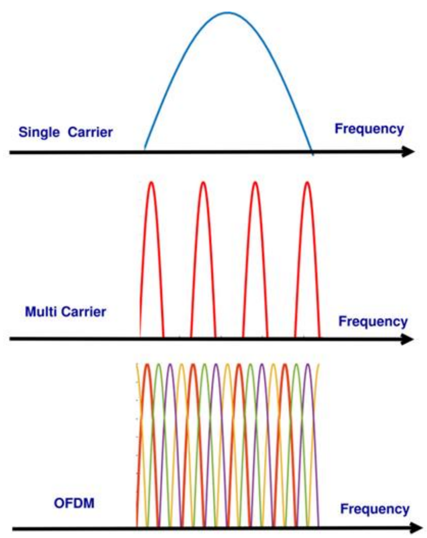

Figure 5: Frequency Spectrum for Different Multicarrier Transmission

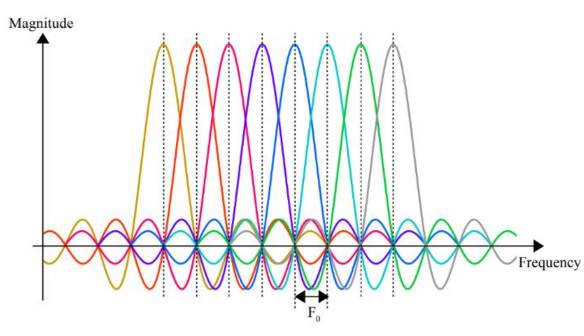

Figure 6: Multi- Carriers OFDM Signal [44]

Therefore, no interference in the data streams for two subcarriers until the recipient makes the proper demodulation.

Where F_0 is frequency space between two subcarriers. Modulation is the method through which a certain parameter of the peripheral waveform may be changed to use this signal to transmit a message. Usually a high-frequency sinusoidal waveform is a carrier signal used. Therefore, the method of modulation is called analogue modulation. The carrier parameter is constantly changing and is called analogue signal.

Upon converting the analogue signal into a digital sample signal, several types of digital modulation techniques can be achieved by distinguishing the carrier signal parameter [45]. The Binary Amplitude Shift keying (BASK) varies by amplitude, and changing phase outcomes are achieved using the Binary (BPSK) [45]. The digital modulation techniques are categorised on the basis of detection or bandwidth compaction properties [46]. Based on the principle of ASK and PSK modulations, quadrature amplitude modulation (QAM) can be obtained [46]. QAM modulation have many advantages among the recent modulation formats so it had been used widely with OFDM applications [46]. As can be observed in Figure 7, the line signal's spectrum is similar to that of N independent signals of QAM, where the signaling rate between N frequencies [47]. One of the complex integers from the initial input is carried by each QAM signal.

Each QAM signal′s spectrum is of the following form $sin(k\ f)/\ f$, as can be seen in Figure (7), the other subcarriers all have central nulls. This guarantees the subcarriers' orthogonally. This approach modulates a binary code for the analogue carrier signal. Digital modulator devices are the interfaces between transmitters and channels. The digital modulation system is characterised according to its capacity for detection or compression of bandwidth. The key criteria for optimum modulation are cost-efficiency, bandwidth, power efficiency, signal to noise ratio (SNR), higher service quality and the BER.

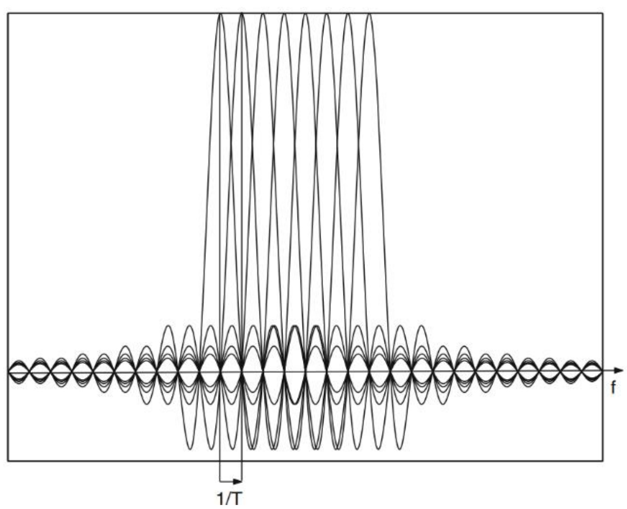

Figure 7: Spectrum of OFDM for Every Signal of QAM

In accordance with this methodology, each modulation scheme is evaluated for its performance by measuring its chance of error, named additive white Gaussian noise (AWGN). The modulation approaches, which can send more bits/symbol, are immune to noise-induced mistakes and channel interferences. Delay distortion may be a significant parameter for the determination of any modulation scheme for digital radio [47].

2 Proposed System

In the proposed system, an OFDM signals can be modulated using Mack Zehnder Modulator with the millimeter wave carrier in the central station and transferred into an optical signal and after that they had been transmitted to the main base station by PON-WDM using RoF technology. The designed systems implemented using Virtual PI photonics software tool.

In order to analyze the ability of the designed backhaul hybrid system, the availability of an OFDM over RoF based on MMW-WDM-PON transmission link will be designed and implemented under the exists of many impairments from both electrical and optical domain including nonlinearity of fiber, fading of wireless networks, and other noise effects such as photodetector (PD) noise, amplifier noise, and clipping noise. Signal-Error-Rate (SER) of the designed system will be analyzed with many parameters in system like modulation index to give design information for system performance. The following figure shows the design of hybrid OFDM transmission along MMW-WDM-RoF -PON link.

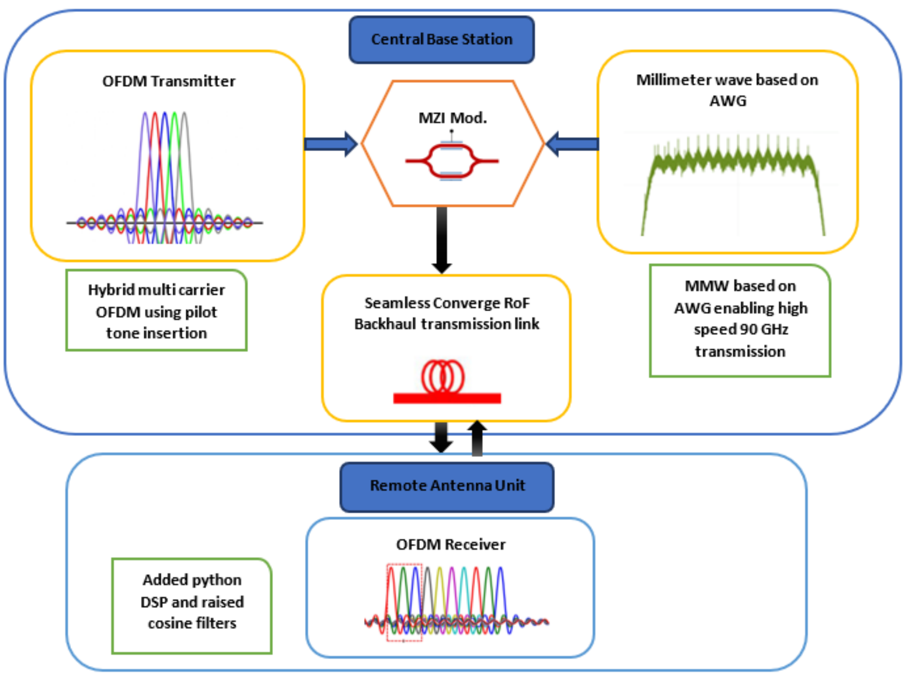

Figure 8: OFDM-RoF-MMW-WDM/PON Proposed System

Considering the requirement of a backhaul connection in terms of capacity, we investigate the WDM-PON with different wavelengths for higher data rates. Also, the wavelength's number is enough for system to test all the cases of wavelength combination induced by FWM effect such as nondegenerate and degenerate parameters. In the central station, based on the given modulation format, for example using M-QAM, orthogonal frequency division modulator maps the input information onto symbols which is complex and transferred by each sub-carrier. The positive and real time domain signal is required because the optical modulator is depending on the intensity modulation technique. By using orthogonal frequency division modulator, every OFDM signal is modulated on MMW-RF sub-carrier. By using Subcarrier-Intensity Modulation (SIM) technique, in Mach-Zehnder-modulator (MZM), a modulated MMW-RF carrier is obtained to drive the optical carrier's intensity (for each wavelength).

In our proposed system, the Mack Zender modulator is used to modulate the optical carriers with OFDM signals for better performance and simplifying the transmitter. Optical carriers are demonstrated at wavelength demultiplexer named as Wave Guide Grating (AWG) to get the required number of carriers. Then multiplexed using Wavelength Division Multiplexing (WDM) before being modulated with MZM then transmitted through a fiber.

Table 1: The Proposed System Parameters

Name	Symbol	Value
Number of OFDM Modulation index	m	16,32
Coefficient of Fiber nonlinear	γ	1.3 $(W.km)^{-1}$
coefficient of Fiber attenuation	α	0.2 dB/km
Optical channel 1 frequency	$\upsilon 1$	193.1 THz
Dark current	I_d	0.1 nA
Channel spacing	$\Delta\upsilon$	200GHz
Thermal noise power spectrum density	S_T	$10^{-12}\, A/_{Hz}{}^{-0.5}$
Bit rate	Rb	10Gb/s-50Gb/s
M -ary	M	6
Wireless distance	d	10-100 Km
MMW frequency	fmm	90 GHz
Tx gain	G_{Tx}	35 dB
Rx gain	G_{Rx}	30 dB

An EDFA is presented in the transmitter to increase the gain in PON and mitigate optical power's budget. Erbium-doped fiber amplifier (EDFA) is an active-element, so it is usually given at the central unit for signal channel amplification to the level wanted for transmitting into the link of fiber. In RAU, all optical signals are directly transferred to electrical signals by using a photodetector (PD). Millimeter signal is filtered by photo diode, then amplified, and transferred to the antenna. In the RRH, a low noise amplifier (LNA) used to amplify the received signal. Then, the OFDM demodulator used to reconstruct the data.

3 Numerical Results

Figure (9) presents the results of MC-OFDM-MMW-RoF system using 128-QAM format. Highest achievable 128 format can be obtained with nearly acceptable BER for this system to be the best choice of obtaining ultra-high-capacity transmission system among all designed systems.

The highest overall transmission system achieved by using 32-OFDM system with 128-QAM format. Figure (10) presents the results of MC-OFDM-MMW-RoF system using 128-QAM format.

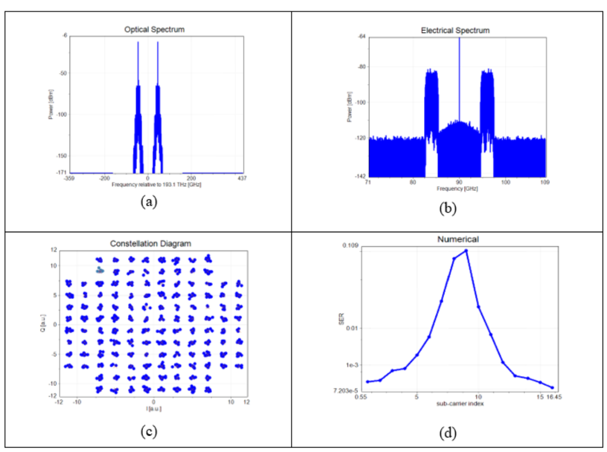

Figure 9: 16 Sub-carrier OFDM-RoF-MMW System: (a): Optical Spectrum of OFDM on MMW, (b): Electrical Spectrum for 16 OFDM Signals (c): Received Constellation Diagram at 128 QAM Format, (d): SER for Each Sub-carrier

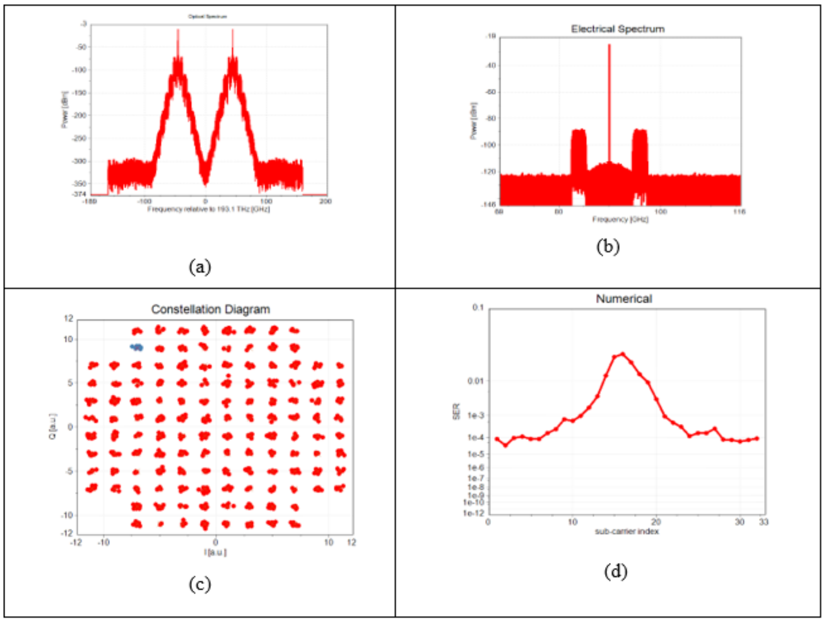

Figure 10: 32 Sub-carrier OFDM-RoF-MMW System: (a): Optical Spectrum After AWG, (b): Electrical Spectrum for 32 OFDM Signals (c): Received Constellation Diagram at 128 QAM Format, (d): SER for Each Sub-carrier

Figure (11) presents the performance of BER vs SNR for hybrid RoF-MMW system with MC OFDM at 128QAM. We can notice that even for high setting of SNR the value of BER still not favorable due to the susceptibility of 128 QAM to losses.

Figure (12) shows the performance of BER vs fiber length for hybrid RoF-MMW system with MC OFDM at 128QAM. Minimum acceptable BER and maximum distance of 80 km achieved for 16-OFDM system and minimum acceptable BER at maximum distance of 50 km achieved.

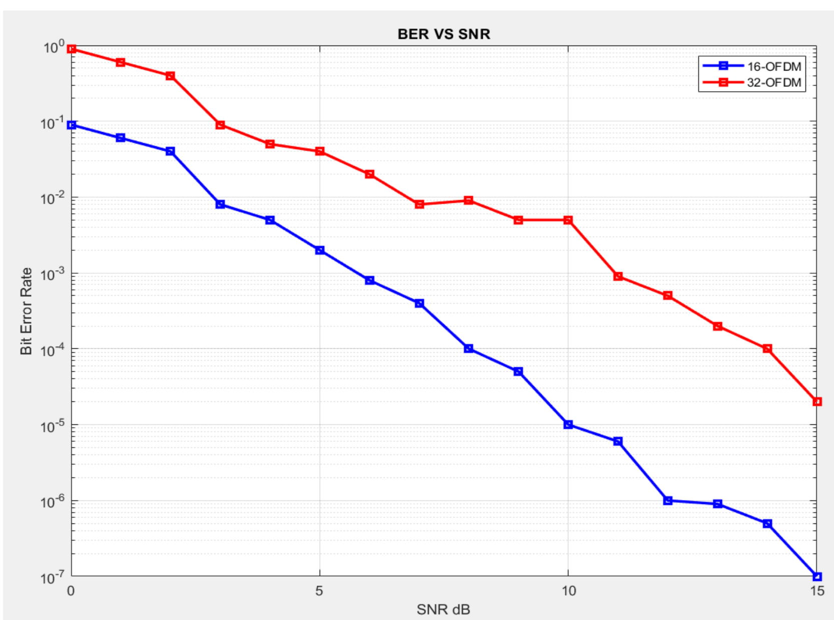

Figure 11: Performance of BER vs SNR for Hybrid RoF-MMW System with MC OFDM at 128QAM

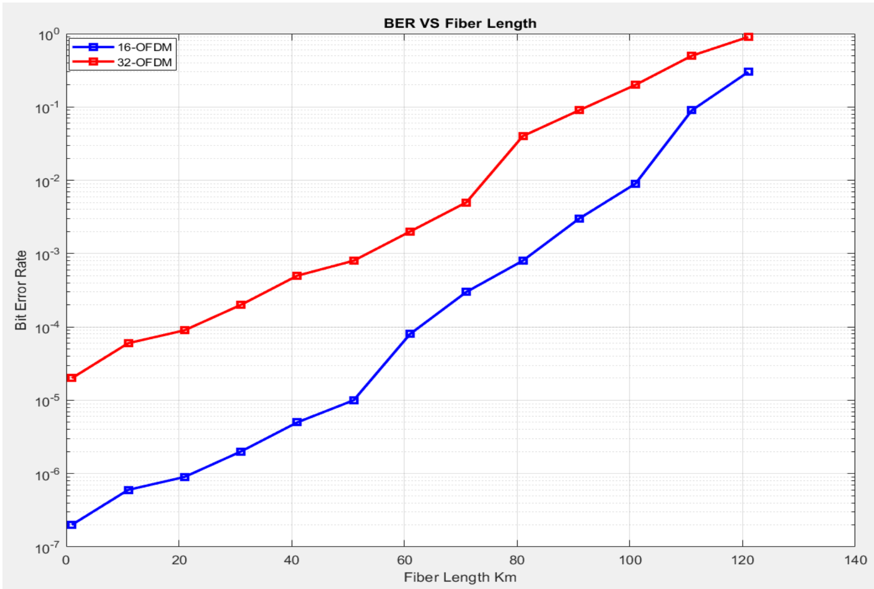

Figure 12: Performance of BER vs Fiber Length for Hybrid RoF-MMW System with MC OFDM at 128QAM

Figure (13) shows the electrical spectrum of OFDM carriers by using a carrier frequency of (6GHz) in 128-QAM system. The use of (6GHz) achieved best system performance and supports the transmission range of B5G networks to be the best carrier frequency value for our designed systems.

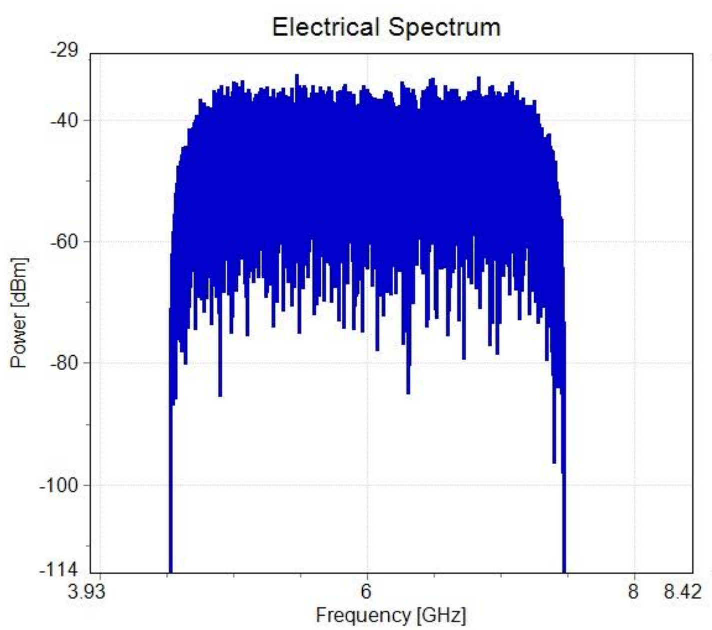

Figure 13: Electrical Spectrum of OFDM Carriers by Using a Carrier Frequency of (6GHz) at 128QAM Format

The designed systems show a very promising performance to be involved in the next generation networks. By using default bit rate of 50 GHz, the best achieved results of OFDM-RoF-MMW system can be summarized using 32 subcarrier-OFDM system with 128 QAM format to obtain overall ultra-high-capacity system of nearly 11.2 THz (32-OFDM*7 bits/symbol*50GHz).

4 Conclusion

In this paper, an OFDM-RoF-based MMW-WDM PON system for hybrid wireless and optical networks had been designed. The powerful simulation of next generation optical MC-OFDM transportation along RoF-MMW transmission system had been implemented.

Thanks to the python DSP and the losses compensators used in the simulation framework, the PAPR losses and drift in the receiver section had been compensated and many values of OFDM carriers (8, 16, and 32 OFDM carriers) achieved for ultra-high-capacity transmission system. Also, a successful long transmission of up to 100 km obtained for RoF-MMW system under different bit rates and modulation formats.

By using 50 Gb/s default bit rate and 128 QAM modulation format, the best achievement of overall bit rate obtained with accepted BER to get 11.2 Tb/s ultra-high-capacity transmission system.

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