Modeling and Analysis of the Receiver Performance in External OFDM-RoF Network Using QAM Modulation

Dr. Adnan Hussein Ali¹, Suhad Hasan Rhaif²

¹Middle Technical University, Institute of Technology- Baghdad, Iraq
²Middle Technical University, Technical Instructors Training Institute, Baghdad, Iraq

aaddnnaann63@gmail.com

Abstract. The use of optical-OFDM systems is mainly restricted by their limited dynamic range as a result of a high peak to average power ratio (PAPR) and nonlinear distortion (NLD). Radio-over-Fiber (RoF) systems are mainly deployed for light modulation and mm-wave signals transmission over fiber links. This paper evaluated the performance of RoF links with respect to their external modulation in a bid to highlight the challenges attributable to the various optical system components. The Mach-Zehnder Modulator (MZM) have been used in external modulation; it is a tested modulation scheme for quadrature amplitude modulation QAM (a vector modulation format) where signal subcarriers are generated using an OFDM scheme. Simulation results based on Optisystem 13 software exposes that the receiver performance of the optimum system for achieving has a better Bit Error Rate (BER) and three longest distance as 10, 50, 100 km for 16 QAM-OFDM-RoF system are reached by using optimum receiver launch power.

Keywords— OFDM-RoF, External Mach–Zehnder modulator, 16QAM, Constellation Diagram.

1. Introduction

The deployment of analog optical links has experienced a remarkable growth owing to its capabilities for use in several applications, for example RoF, antenna remoting, besides optical signal processing [1]. Studies have recently focused on the improvement of the performance of optoelectronic links, as well as providing the solution to the noted challenges and problems which affects the performance of the major processes in the system [2]. Systems for wireless communication involve enhancement capacity and widespread advantages. The RoF system is one of the systems for improving the access of capacity for wireless systems using high sub-carrier frequency [3]. It is suitable hybridization of a fiber optic link with millimetres waves. Within a wireless network, RoF can be considered a next broadband wireless generation characterized by high capacity, RF modulation and high data transmission speed [4].

The most promising techniques within an optical fiber communication is orthogonal frequency division multiplexing (OFDM) owing to its flexibility in processing digital signals, high-spectral efficiencies, as well as the capability of combating both polarization mode dispersion (PMD) besides chromatic dispersion (CD) [5]. The topical study by [6] proposed a new MZM dual drive-based scheme for hybrid coupler incorporated with double parallel MZM combination on the optical single sideband. Another investigation on external modulation (EM) based QAM showed the ability of the investigated modulations in reducing the stimulated Brillouin scattering SBS besides optimizing the nonlinear compensation for Long Term Evolution LTE-RoF through assorted launch power for power budget enhancement [7].
The lowest attenuation optical wavelengths are 850, 1310, and 1550 nm. Larger theoretical bandwidths of 50THz are supported by the traditional optical fibers as they can combine the 1310 nm and 1550 nm transmitting windows with each other. Normally, the 1550 nm (~193.1 THz) optical wavelength is the preferred wavelength because, when light is propagated through the fiber link, 1550 nm is the smallest power attenuation symbol of the three wavelengths encountered. Efforts are still directed towards improving loss reduction even though it is a challenging task with fiber fabrication techniques [8].

2. OFDM-RoF System Model

2.1 Radio-over-fiber (RoF)

The ROF technologies were developed as a very cost-effective technique for the reduction of the cost of radio systems. This system ensures an enhanced sharing of costly radio equipment sited at the centrally located centers (or switching centers, or else referred to as central stations (CS)) by simplifying the remote antenna sites [9]. Contrarily, Graded Index Polymer Optical Fiber (GIPOF) is developed with a higher capacity compared to copper cables; its installation and maintenance costs are lesser compared to those of ordinary silica fiber.

The link of fiber optic in which a modulation of the optical signals at RF then propagated through an optical fiber is referred to as RoF. RF signal is demodulated at the receiving end and then transmit to an intended wireless operator. With this technique, RoF technology can shift the complexity of the system from the antenna at the remote BS toward a CS [10].

A radio signal modulates the laser light in a ROF link before propagating it over an optical fiber carrier. Being that the RF carrier signal is analog, the laser modulation is also analog. When using frequency conversion, modulation can take place at either the radio signal frequency or at some intermediate frequencies. Basically, a link of analog fiber optic is comprised of bi-directional interface which hosts either an analog laser transmitter besides a photodiode receiver situated by the side of the BS or pair of remote antenna unit and photodiode receiver and a laser transmitter (analog) situated at the radio processing unit. The remote antenna unit is connected to the CS via one or more optical fibers.

The recent RoF systems are equipped with more radio-system capabilities (such as data modulation, frequency conversion, and signal processing) in addition to mobility and transportation functions [11].

The RoF systems (shown in Figure 1) are mainly used for microwave signals transmission for realizing mobility functions at a control station.

![Figure 1. ROF systems](image)

The input electrical signal required of the multi-functional RoF systems is determined by the intended functionality, as well as on the RoF technology. Such signals may be modulated IF, baseband data, or the existing RF modulation signal that will be propagated [12]. The major use of the electrical signal is for the modulation of the optical source. Then, the corresponding optical signal may be propagated to a remote station through the fiber optics link where the photodetector reconverts the data into electrical form. The electrical signal generated by this process must satisfy the required specifications of the intended wireless application [13].

With the RoF, it is also easy to integrate and upgrade signals since the conversion of electrical signal to optical signal considers the function of a baseband- to- modulated RF format. Although optical fiber may not completely replace the traditional transmission mediums like copper coaxial, fiber is considered the most efficient and practical medium in an application where factors like future upgrades, losing RF
power, in addition to transparency future system can be considered. Despite the substantial prospects of RoF, more studies are still required in this area before it can be widely deployed [14].

2.2. Optical OFDM
The OFDM is equipped with the highest efficiency data spectrum [15]. OFDM can increase system’s capability and can be transmitted through RF and an optical fiber. As a multi-carrier transmission technology, OFDM can transmit high data rate access with transformation for low speed parallel data access. OFDM first appeared in wireless systems as a technology of physical layer by means of effective in reducing inter-symbol interference (ISI) due to wireless access expansion [16]. The transmission of mode between the BS and the antenna is achieved using a single-mode or multimode optical fibers. Currently, the OFDM techniques have been approved into many novel wireless systems, like WiMAX, LTE, in addition to Wi-Fi [17].

The high spectral efficiency of OFDM modulation, coupled with its advantages in the RF domain, have made it applicable in several wireless systems. Optical OFDM has been recently considered a potential technology for future optical communications; hence, the advantages of OFDM will be extended to optical technology [18].

The dual-polarization method is used in a 16-QAM OFDM-RoF system as shown in Figure 2. The OFDM guard symbol is placed on the ISI of the sub-carrier and this is intended for the Polarization Division Multiplexed (PDM) model with no guard band interference of the sub-carrier symbol. Because the OFDM symbol does not make a parallel line due to the signal spread spectrum, the sub-carriers’ orthogonality signals are missing the line for the higher-order modulation. The PDM supports the higher-order modulation format of the CO-OFDM signal.

![Figure 2. OFDM-RoF System using Dual Polarization for 16-QAM](image)

OFDM has major advantages for the recent and upcoming system as specified below [19].
1- OFDM can transmit high-speed data stream which is divided into many numbers of the sub-carrier.
2- The multiple sub-carrier symbols have low data rate carrier which can increase into a high data rate of peak pilot carrier. This symbol enables a lower data rate to support higher data rate carrier. This is a scalable process of the OFDM signal.
3- Achieving of high spectrum efficiencies with OFDM, in which the sub-carrier can be overlapped. This is the main advantage of OFDM signal for Orthogonality of the signal. It increases the capacity of the transmission and receiving signals.
4- It reduces the power consumption to the energy efficient operation that can be implemented by the OFDM system. The efficient energy can be implemented to the particular OFDM sub-carrier that amplifies to the channel bandwidth. Hence the power consumption is applied into selective sub-carrier symbol.
5- The optical OFDM can reduce the Inter-Symbol Interference and Guard Interval of the signal.
6- Optical OFDM provides multi-band OFDM which generates a number of electrical sub-carrier modulates to a large number of the optical carrier. So, the data rate of each sub-carrier significantly increases.
7- Optical OFDM provides signal synthesis mechanism that is to convert efficiently electrical signals into optical.
3. Optical-Wireless Integration

3.1. Optical Source (Laser)

‘Laser’ is an Amplification of Light by Stimulated Emission of Radiation. Stimulated emission is the keyword as it is the event that allows the production of intense high-powered light beams containing one or more distinct frequencies. For this type of application, there are 3 major types of laser to be considered [20]:

i. Vertical Cavity Surface Emitting Laser (VCSEL): These are majorly multi (transverse) mode lasers which operate at 850 nm. As they are produced in high volume, their cost is usually low for data communication systems.

ii. Fabry Perot Laser (FP): These lasers mainly operate at the wavelength of 1310 or 1550 nm. They are edge emitters with multiple longitudinal modes. The cost of FP lasers are between those of DFBs and VCSELS.

iii. Distributed Feedback Laser (DFB): These are edge-emitters which operates mainly with a single longitudinal mode at the wavelength range of 1310 to 1550 nm. Their cost is more than that of VCSEL or FP.

3.2. Optical Modulation

Data transmission across an optical fiber require precoding or modulation of the information onto the laser signal. Among the analog modulation techniques are frequency modulation (FM), amplitude modulation (AM), in addition to phase modulation (PM), while the digital modulation systems comprise frequency shift keying (FSK), amplitude shift keying (ASK), besides phase-shift keying (PSK). Among all modulation methods, the preferred digital modulation technique is the binary ASK which also named on-off keying (OOK)) owing to simplicity. In the binary ASK, the power signal may be transferred between two levels [21], where the lower one characterizes a 0 bit whereas 1 bit represents a higher level.

3.3. Optical receiver

The components of an optical receiver include a photodetector, an amplifier, and circuitry for signal processing [22]. The first function the receiver performs when it receives an optical signal then convert it to an electrical one. Upon the completion of the conversion, the amplification of the signal to the best level is carried out so that the next process can be executed. In order to design a receiver, systems’ performance must be determined and predicted using the mathematical models of several receiver stages.

More so, when a receiver is being designed, it is important to take into consideration the distortions and noises that emanate from components at every stage. Furthermore, the receiver must be able to detect signals like weak or distorted, make a choice regarding the signal type to be received and to reshape the distorted signal. This is one of the reasons why receiver considers more complex in comparison with a transmitter designing process. One of the most important criteria used to measure the RoF system is bit error rate, other criteria include the opening of the eye diagram and Q factor [23].

The degree to which the signal is distorted is indicated by the eye diagram opening heights. The upper level of eye diagram designates binary ‘1’ while a bottom level signifies binary ‘0’. The height of eye-opening is required as higher, so that for indicating all of binary ‘1’ as well as ‘0’ to be notable well. There is often a correspondence between the height of eye-opening within a given period of time and the noise margin that has been achieved. A receiver must have a device which is capable of interpreting the optical signal data information. A photodetector can be described as an instrument that have a capability of converting an inbound photonic stream to stream of electrons. After the optical signals have gone through the optical fiber, they get to the receiver in a distorted and weakened state. Therefore, it is important for a photodetector to stand sensitive for an emission wavelength's range of the optically fiber sources that are utilizing. Photodetectors can also contribute to the noise of the system; hence, it must respond rapidly to handle the target data rate.

The semiconductor photodetector which is regarded as the most useful is the PIN photodiode. Here, electron-hole pairs are formed as a result of the absorption of light. Then, the drift of hole and electron
in the reverse direction, a flow of current is producing. Additional current may be flows by way of light possess inflowing the photodetector, thereby resulting in the number of electron-hole pairs.

3.4. Electro-optic Modulation System

In telecommunication systems, light modulation can be performed using two primary methods - direct and external modulation methods. Regarding direct modulation (DM), it is the process of creating pulses by modulating the source via turning a laser on and off. On the other hand, external modulation (EM) involves the modulation of light using a separate device. EM is one of the common light modulation methods for high-speed long-haul telecommunication systems [24].

It can be implemented using different architectures and materials even though the permittivity of electro-optic materials can be affected by the existence of electric fields. Numerous electro-optic materials are birefringent [25]. Being that the permittivity of the materials has a direct influence on the refraction index of the material, it is possible to alter the phase velocities of the light of such materials by introducing electric fields. Optical modulation can be achieved by exploiting these changes in different ways.

Lithium Niobate, LiNbO3 has been the commonest material used in various commercial electro-optic modulators. It is an optically transparent and birefringent crystalline material which is mainly used in most of the 10 GHz/channel long-haul telecommunication systems. To develop higher bandwidth systems, several manufacturers are currently offering 40 GHz modulators, and as these products are produced to meet future demands, the emphasis has been placed on higher operating speeds and higher device integration levels [26].

Investigations are ongoing on the use of several electro-optic materials for the development of optoelectronic devices. Different groups are experimenting with nonlinear optical polymers like NLOPs with the aim of creating electro-optic devices such as optical modulators. NLOPs are considered for this purpose owing to their numerous characteristics which may encourage the development of low voltage high-speed electro-optic devices.

For accommodating bit rate demands at data centers, investigations have been focused on higher capacity short-extent optical communication systems [27]. It could be challenging to implement high capacity target optical systems at scenarios with cost-sensitive; however, the current advancement of higher speed DACs and ADCs has made it possible for realizing more than 100 Gb/s data rates per channel with a minimum cost using use intensity modulation with direct detection (IM/DD). Investigations have also been focused on several modulation techniques in a bid to accommodate the targeted data rates at low costs.

The expansion of the current constellations further than a conventional square QAM such as adapting the constellations of the non-square to the noise characteristics of the channels can also improve the systems’ capacity [28]. Although a constellation of square QAM can be mainly applied due to its ease of use, the performance can be improved by ensuring a proper selection of the non-square geometries. The DACs are a vital component of the OFDM systems; hence, extra complexity must not be incurred on transmitter if taking advantage of the arbitrary arrangement of the constellation points in the I/Q plane. The complexity can increase at the receiver owing for the need of 2-D decision unit at searching table rather than a normal QAM slicer [29].

3.5. Electro-Optic Mach Zehnder Modulator

One of the commonest devices for high-speed optical communication systems is the electro-optic Mach-Zehnder modulator which is mainly applied for intensity modulator in the conventional schemes that uses one of the modulation formats; NRZ (non-return-to-zero) or RZ (return-to-zero). These modulators are shown in Fig. 3 have found application as a phase modulator in future systems which uses the differential phase-shift keying (DPSK) format. LiNbO3 is mainly used to develop such modulators as its refractive index is dependent on the electric field (or the applied voltage).

The refractive index of the crystal can then be modulated by the electrical data; hence, the phase of the incoming light wave can be modulated. The conversion of the phase modulation into intensity modulation can be achieved by incorporating the crystal into a Mach-Zehnder interferometer [30].
4. The Model of The Proposed System

The proposed design OFDM-RoF system in this study is presented in Figure 4. In the proposed design, the transmitter and 2 LiNbO3 MZM modulators inject signal SRF(t) generated by a continuous wave (CW) laser. The signal produced from the CW laser is directed to the process via modulation of 16 QAM module in addition to OFDM 12 modulators with 10 Gbps data rate and frequency of 193.1 THz, respectively. The optic signal generated by the modulators is hybridized with the analog signal generated from technique of dithering.

The dithering system is sourced from sinusoidal wave signals of about 200 THz frequency but modulated to the frequency range of 100 GHz. Its selection is based on its capability to generate high frequency in long-span transmission. The Dithering is utilized to regulate high amplitude signal of the frequency modulator FM. At the receiver side, the linewidth effect and power receiver influence at the system was mitigated using local oscillator (LO) power and different linewidths. The proposed scheme was simulated using Optisystem version 13.0.

Figure 4. Receiver of 16-QAM OFDM External modulation.
5. Simulation of the OFDM-RoF Opti-system Model

The Optisystem software is utilized for simulating the optical communication experiments. The use of visualizing tools like constellation visualizer, optical spectrum analyser and an RF spectrum analyser help in visualizing the performances of the OFDM-ROF system. They are mainly used for displaying the output spectrum of the circuit components. Figure 5 showed an external modulation circuit of 16-QAM OFDM with signals that are modulating and recovering. The QAM-OFDM, contain an M-Array sequences having I and Q outputs were produced by feeding the PRBS into the M-QAM generator. Afterward, the QAM symbols were transmitted over parallel overlapped orthogonal subcarriers by feeding the OFDM modulator with I and Q outputs. Then, the electrical inputs of I and Q were modulated with RF carrier of 7.5 GHz using a quadrature modulator.

![Image of Optical-RF Receiver](image)

**Figure 5.** Receiver Optisystem simulation

The Optisystem software was utilized for experiments simulating of the optical communication. In 16 QAM-OFDM-RoF transmitter system, the bit generator can be used in generating the NRZ form signal sequences of 0 and 1 with 16384 bits, and those bits are encoded with 16QAM decoder. At any receiver, a reverse sense is applied for demodulating and recovering the signal. The electrical input signal is duplicated in the quadrate demodulator, it is multiplied by both carriers of sine and cosine, and then an LPF process is applied. The removal of the guard periods is done in the OFDM demodulator, then a process of FFT is applied for each OFDM symbol so that the transmitted spectrum can be regenerated. Finally, the two M-Array inputs are decoded by the QAM decoder into one binary output. The main structural parameters that were used in this simulation are specified as follows: A Bit rate of 10 Gbps, the time window was 1.6 µs, the Sampling rate of 40 GHz, the sequence length was 16384 bits, while the sample per bit is 4 and finally, the number of samples 65536.

Now, when an optical DSB signal is propagated over the optical fiber, relative phase difference is established from the sidebands with the optical carriers due to chromatic dispersion which occurs in the fiber.

At the receiver, two cases can be tested, the first is the optical receiver which consists of photo-detector PD; the optical signal is converted to RF signal as shown in fig. 6-a, and it has a power that is equal -50 dBm with side noise.
The base OFDM signal can be obtained without side noise by using a band pass filter (BPF) so as to achieve a better BER. The signal that is obtained after BPF with a bandwidth of 3 GHz from double sides of the center frequency at 7.5 GHz, is shown in Fig.6(b).

Figure 6. OFDM signal (a) before BPF and (b) after BPF with a bandwidth of 3 GHz

In the second case, the square-law process of the photodetector provides two components shifted in phase relating to the carrier, which results in RF output power losses. The chromatic dispersion impacts may be decreased with removing single optical side spectrum of the DSB. Then, optical filter can be applied for suppressing single sideband so as to reduce the chromatic dispersion effects as shown in fig 7. This single sideband with carrier signal is amplified and filtered many times through a transmission loops at optical fiber, after that it is transferred to the photodetector finally.

Figure 7. single sideband signal with its amplified and filtered signal

Once the clarification of the RF OFDM signal has been achieved through the operation of OFDM demodulator besides demodulation, then an output of demodulator is analyzed so as to achieve the BER desired value. The validation results of demodulator are visualized in the form of a constellation diagram as presented in Figures 8(a, b, and c) according to the fiber optic length (10km, 50km, and 100km). If the fiber length is long past, then it causes a decrease in the received power, whereas constellation noise will be greater.

The results of a constellation visualizer can be achieved by electrical and optical amplifications utilized with 10 Gbps data signals. The use of 16-QAM OFDM-RoF system sequence bit can be employed in achieving the 100 km length of fiber. The fiber length and the power of 16-QAM model integrating with
RoF system considers bigger compared with another model of 4-AM. Thus, the system of an OFDM-RoF model have reliability for using with long haul transmission.

![Electrical Constellation Visualizer_1](a)

![Electrical Constellation Visualizer_1](b)

![Electrical Constellation Visualizer_1](c)

**Figure 8.** Constellation diagram of the received signal for fiber length 10, 50, and 100 km.

6. Conclusions

This study briefly described and explained the central idea of using QAM technique to generate the OFDM symbols, which were also highlighted and discussed. More so, the OFDM-RoF system model and its components, including transmitter, receiver, and optical link, were discussed in this work. This study also presented and compared the external intensity modulations in OFDM-RoF systems. It was observed that better performance was exhibited by the external modulation method, which also demonstrated the ability to yield a symmetric spectrum that is stable. From the obtained values, the external Mach–Zehnder modulator achieved a better modulation performance. The advantages of both OFDM and RoF can be exploited for use in both short and long-haul transmission at high data rates.
The optical OFDM RoF system has been modelled for many applications, but in this study, it is used as a frequency carrier of 7.5 GHz. The data rate of the system is 10 Gbps with modulation type 16QAM with different numbers of subcarriers. The length of the fiber used for the transmission link is 100 Km. The aim of designing and simulating this model is to achieve the best value of BER.

In this study, the OFDM-RoF system was simulated. The RF signal of the system was sourced through an optical fiber while the simulation was performed in Optisystem simulation software. In this system, the solution was obtained by a successful up-conversion of 10 Gbps OFDM signal on 7.5 GHz carrier frequency over 100 km SMF using the 16QAM modulation format for OFDM systems.

The optical OFDM RoF system was modelled for many applications; in this manuscript, it used frequency carrier 7.5 GHz. The systems’ data rate is 10 Gbps with modulation type 16QAM using different numbers of subcarriers. The length of the fiber for transmission link is 100 Km. The aim of designing and simulating this model is to achieve the best BER value. The outcome of this study showed that the orthogonality of the OFDM signal can be easily maintained in 16QAM format at 10Gbps data bit rate. The developed model using this technique can be used to increase the RF signals’ quality in the existing and future wireless telecommunication systems.

7. References

[1] T. Kanesan, W. Pang, Z. Ghassemlooy, and C. Lu 2014 Investigation of Optical Modulators in Optimized Nonlinear Compensated LTE RoF System Journal of Lightwave Technology, Vol.32, No.23, pp.1944–1950

[2] Y. Wang, J. Yu, X. Li, Y. Xu, N. Chi, and G. K. Chang 2015 Photonic Vector Signal Generation Employing a Single-Drive MZM-Based Optical Carrier Suppression Without Pre- coding Journal of Lightwave Technology, Vol.33, No.24, pp.5235–5241

[3] Al-Raweshidy, H.; Komaki, S. 2010 Radio-over-Fiber Technologies for mobile communication networks, Link design for next generation wireless systems. J. Lightw. Technol, 28, 136–138.

[4] Faris M. Ali, Eman A. Abd Ali, Mayada G. Tarbul 2018 Performance Analysis of Radio over Optical Fiber System with OFDM Using Multiplexing Techniques International Journal of Applied Engineering Research, Vol. 13, no. 12, pp. 10831–10844.

[5] Adnan H. Ali, Hayder J. Alhamdane, Beqared S. Hassen 2019 Design analysis and performance evaluation of the WDM integration with CO-OFDM system for radio over fiber system Indonesian Journal of Electrical Engineering and Computer Science IJECS, Vol. 15, No. 2, pp. 870–878.

[6] Xue Min, Shilong Pan, Yongjiu Zhao October 2014 Optical Single-Sideband Modulation Based on a Dual-Drive MZM and a 120° Hybrid Coupler Journal of Lightwave Technology 32(19):3317–3323

[7] T. Kanesan, W. Pang, Z. Ghassemlooy, and C. Lu March 2013 Impact of Optical Modulators in LTE RoF Systems with Nonlinear Compensator for Enhanced Power Budget Proc. of Optical Fiber Communication Conference California, United States, pp.1-3

[8] Adnan H. Ali,.; Farhood, A.D. 2019 Design and Performance Analysis of the WDM Schemes for Radio over Fiber System With Different Fiber Propagation Losses. Fibers, 7, 19.

[9] J. Armstrong 2009 OFDM for optical communication Journal of Lightwave Technology, vol. 27, no. 3, pp. 189–204

[10] L. Cai, Y. Qi, T. Jiang et al. 2012 Investigation of coherent optical multi-band DFT-S OFDM in long haul transmission IEEE Photonics Technology Letters, vol. 24, no. 19, pp. 1704–1707

[11] Al-Raweshidy, H.; Komaki, S. 2002 Radio over Fiber Technology for the Mobile Communications Networks; Artech House, Inc.: Norwood, MA, USA.

[12] Ali, A.H., Abdul-Wahid, S.N. 2012 Analysis of self-homodyne and delayed self-heterodyne detections for tunable laser source linewidth measurements. IOSR J. Eng. 2(10), pp.1–6

[13] Adnan H. Ali, Ali N. Abbas, M. H. Hassan 2013 Performance Evaluation of IEEE 802.11g WLANs Using OPNET Modeler (AJER) Volume-02, Issue-12, pp-09-15.
[14] Van Nee, Richard, and Prasad, Ramjee 2000 *OFDM for Wireless Multimedia Communications* Boston: Artech House.

[15] W. Shieh, H. Bao, and Y. Tang 2008 Coherent optical OFDM: theory and design *Optics Express*, vol. 16, no. 2, pp. 841–859.

[16] Ali A. Abdulrazzaq, Adnan H. Ali 2018 Performance Investigation of Grid Connected Photovoltaic System Modelling Based on MATLAB Simulation, *IJECE* 8 (6).

[17] Adnan H. Ali, 2011, "Simultaneous measurements for tunable laser source linewidth with homodyne detection" - Computer and Information Science, Vol. 4, No. 4; July 2011.

[18] H. Al-Raweshidy and S. Komaki, “Radio-over-Fiber Technologies for mobile communication networks, Link design for next generation wireless systems,” *J. Lightwave. Technology*, vol. 28, pp. 136-138, 2010.

[19] Murtadh M. A. Al-Sammak, Raad S. Fryath, ” Performance Investigation of OFDM-Based Software-Defined Optical Network”, International Journal of Networks and Communications 2018, 8(1): 18-28.

[20] Hussein A M, Adnan H A, "Effect of some security mechanisms on the Qos VoIP application using OPNET", *International Journal of Current Engineering & Technology*, 2013,3 Issue 5.

[21] S. M. A. Satar, et al., “Coherent Optical – OFDM using 64QAM to high data rates 1.60 Tb/s over 4500 km,” *International Journal of Scientific and Research Publications*, vol. 5, Sep 2015.

[22] M. M. Kareem, M. Ismail, M. A. Altahrawi, N. Arsad, M. F. Mansor, and A. H. Ali, ‘Grid Based Clustering Technique in Wireless Sensor Network using Hierarchical Routing Protocol’, in 2018 *IEEE 4th International Symposium on Telecommunication Technologies (ISTT)*, 2018, pp. 1–5.

[23] L. Chen, B. Krongold, and J. Evans, “Theoretical characterization of nonlinear clipping effects in IM/DD optical OFDM systems,” *IEEE Transactions on Communications*, vol. 60, no. 8, pp. 2304–2312, 2012.

[24] Ahmed J. Abid, Fawzi M. Al-Naima, and Adnan H. Ali, "Comprehensive Modeling of PV Array based on Proteus Software", *International Journal of Applied Engineering Research*, Volume 13, Number, pp. 4440-4447, 2018.

[25] B. Barua1, Satya P. Majumder, "BER Performance Analysis of an LDPC Coded OFDM Optical Wireless Communication System with Intensity Modulation and a Direct Detection Receiver", Advances in Wireless Communications and Networks, 2018; 4(2): 43-48.

[26] Abdulrazzaq, A.A.; Abid, A.J.; Ali, A.H. QoS Performances Evaluation for Mobile WIMAX Networks based on OPNET. Int. J. Appl. Eng. Res. 2018, 13, 6545–6550.

[27] Sinan A. Khwandah, John P. Cosmas, Ian A. Glover, Pavlos I. Lazaridis, Neeli R. Prasad, and Zaharias D. Zaharis, "Direct and External Intensity Modulation in OFDM RoF Links", IEEE Photonics Journal, Volume 7, Number 4, August 2015.

[28] AJ Abid, AH Ali, "Smart monitoring of the consumption of home electrical energy", *International Journal of Computer Trends and Technol.*, vol. 47, no. 2, pp. 142–148, 2017.

[29] Ishiwu I. Jude, Yahaya Adamu, Mathew Luka, Alfred Baams, "Optical-OFDM Detection Techniques", *International Journal of Science and Engineering Applications* Volume 7–Issue 03, 23-33, 2018.

[30] Adnan H. Ali, 2015 Performance Evaluation of Wi-Fi Physical Layer Based QoS Systems on Fiber Using OPNET Modeler *International Journal of Soft Computing and Engineering (IJSCE)* vol. 5 Issue-3.