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Performance Analysis of Digital Modulation for Coherent Detection of OFDM Scheme on Radio over Fiber System

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ABSTRACT

Radio over fiber (RoF) system with the coherent detection offers high linearity for the transparent transport of high-frequency microwave signals, and better receiver sensitivity compared with intensity-modulated direct detection systems. The purpose of this paper is to analyze the performance of digital modulation for coherent detection of orthogonal frequency division multiplexing (OFDM) scheme on RoF system at 10 Gbps up to 100 km fiber length. The results show that coherent detection of OFDM-RoF system with 16 quadrature amplitude modulation (16-QAM) has the value of bit error rate (BER) and the symbol error rate (SER) is very low and its constellation is better compared with other modulation formats (4-QAM, quadrature phase shift keying (QPSK), 8-PSK and 16-PSK), which BER 16-QAM is 0.053 and SER is 15.7%. The results also show that BER value of 4-QAM and QPSK relatively similar to fiber length variations. In general, an increasing value of the BER and SER for each modulation format is almost equal to the fiber length of 60-70 km (Region I and II). However, there is a significant increase in the value of BER in fiber length of 80-100 km (Region III. A and III. B) for the modulation of 4-QAM, QPSK, 8-PSK, and 16-PSK.

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1. INTRODUCTION

The wireless communication system requires increasing capacity and extensive advantage. Radio over fiber (RoF) system is useful to increase the access to capacity with high subcarrier frequency for the wireless system [1]. Radio over fiber (RoF) system is an appropriate combination of a fiber optic link and radio waves. RoF in a wireless network is the next broadband wireless generation with high-speed data transmission, which increases high capacity channel of radio frequency (RF) modulation [1],[2]. The modulation concept of fixed communication and mobile broadband for optical and wireless, it can connect by using OFDM, so that use of it, is appropriate, due to its many applications to increase RF modulation.

The performance of RoF system depends on the optical modulator, optical fiber channel, the power level of laser and RF, non-linear optical power level, bit rate and modulation used. The performance of RoF system is related to the modulation format such as QAM or PSK and mechanism up conversion E/O (electrical to optical) at the transmitter (direct modulator or external modulators), and also the mechanism down conversion O/E (optical to electrical) at the receiver (coherent detection or direct detection). There is previous research used OFDM technique for carrier 1550nm frequency with direct detection. It increases signal RF transmission performance with a 16-QAM constellation in a single mode fiber (SMF) [2] which used quadrature modulator 7.5 GHz and the single optical modulator gave high data rate transmission but limited to short distances. The performance of the coded-OFDM in Multimode fiber (MMF) also shows 16-

QAM, and 16-phase shift keying (16-PSK) technique raise the bit rate for medium-haul transmission along two km [3]. There is facilitation to defend OFDM orthogonal signal in the 4-QAM format for the 7.5 GHz carrier frequency, it uses an optical modulator, LiNb Mach-Zehnder modulator (LiNb-MZM) [1], the OFDM signal can pass through SMF until 60 km with electrical amplification. On the other hand, High-level modulation is a solution to increase the bit rate. High-level modulation as 16-QAM has a better spectral signal efficiency than binary phase shift keying (BPSK), 4-QAM and 8-QAM [4]-[6], although robustness of system decrease with the increasing of symbol data modulation. In addition, the use of MZM as an external modulator shows more robust performance compared with that of the direct modulator when implemented with OFDM modulation technique, while the direct connection between the output of the transmitter gives an error vector magnitude (EVM) of 0.4%, which is almost perfect (an ideal modulator would have 0%, and this value increases to 7.9 % over a 100 km fiber link [7]. In addition, there is also a modeling system about a novel Inter-Carrier Interference (ICI) reduction algorithms cancelation under the various channel environments, to achieve high performance based on the OFDM optical network has already been considered in the literature [8],[9].

There are also many types of research on the coherent detector system on the radio over fiber, in particular, the use of the local oscillator optical down-conversion receiver. Including the use of millimeter-wave (MMW) on coherent radio-over-fiber (RoF) has been able to be applied to an optical and radio seamless network conversion, the results show 20 Gbaud QPSK has a data rate of 37.2 Gbps, and the transmission distance can be extended up to two km under the operation of 10-Gbaud when a high power amplifier with higher output power of 20 dBm is used [10]. Judging from the effects of chromatic dispersion, radio systems for optical fiber modulated in phase with coherent detection can be an alternative for RF signal transmission to optical fiber for the use of frequency of 100 GHz, the value of the QPSK BER of 10-4 can be achieved with the level of under 16 dB SNR with a maximum value is obtained at 1-Gbps on fiber length of 80 km. While 250 Mbps Binary Phase Shift Keying (BPSK) can transmit without errors at the receiver for 40 and 80 km to the SNR close to zero [11]. The configuration of the coherent detection mechanism [11] consists of analog optical front-end and digital IQ mixer, where the optical front-end consists of an optical 900 hybrid (phase shifter), four balanced photodetectors, and a local laser diode (optical local oscillator). On the other hand, the extraction of exact differential phase noise and the effect of phase noise cancelation are successfully demonstrated for a 10-Gbaud QPSK RoF signal for a digital-signal-processing-assisted optical coherent detection of an uplink radio-over-fiber signal with a local two-tone light, which is insensitive to the laser phase noises [12]. Regarding linearity, Optical phase-modulated (PM) radio-over-fiber (RoF) links have assisted with coherent detection, and digital signal processing (PM-Coh) offers the high linearity for the transparent transport of high-frequency microwave signals, and better receiver sensitivity than with intensity modulated direct detection systems [13].

The purpose of this paper is to analyze the performance of coherent detection of OFDM-RoF system for digital modulation variation at 10 Gbps up to 100 km fiber length. Based on the previous research, the coherent detection of OFDM-RoF system uses a QAM/PSK sequence with two optical modulator and single continuous wave laser (CW-Laser) as optical input at the transmitter like in research [10], and four balanced PIN detector with phase shifter 900 and a local oscillator at receiver as well as the configuration of coherent detection on previous research [11]. OptiSystem 13 and OptiFiber 2 software are used for simulation. Scheme of OFDM-RoF uses a low pass cosine roll-off filter (LPCROF) as a filter at OFDM stage output and LiNb-MZM as an optical modulator. The results of simulation will be discussed and analyzed covered at the OFDM output; RF to optical upconverter (RTO) output, optical loop output, optical link output, coherent detection output, and subsystem receiver, as well as QAM/PSK, received constellation at the receiver. It also includes the value of the BER and SER for each modulation format, 4-QAM, 16-QAM, QPSK, 8-PSK, and 16-PSK.

2. COHERENT DETECTION OF OFDM-ROF SCHEME

Coherent detection of OFDM-RoF scheme consists of five parts that include of RF-OFDM transmitter, RF to optical up-converter (RTO), the optical link, optical to RF down-converter (OTR), and RF OFDM receiver. This OFDM-RoF scheme is presented in Figure 1, RF-OFDM transmitter consists of QAM/PSK sequence generator to generate a bit sequence of OFDM signal and flowed by different frequency from each sub-carrier, in which the digital input source) is generated by the pseudo random bit sequence (PRBS) generator. OFDM modulator is the important part in the transmitter scheme because OFDM is a multi-carrier transmission technique, which divides the available spectrum into many carriers, each one being modulated by a low rate data stream [14]. As shown in Figure 1, the input data can be in different modulation formats, M-QAM, and M-PSK.

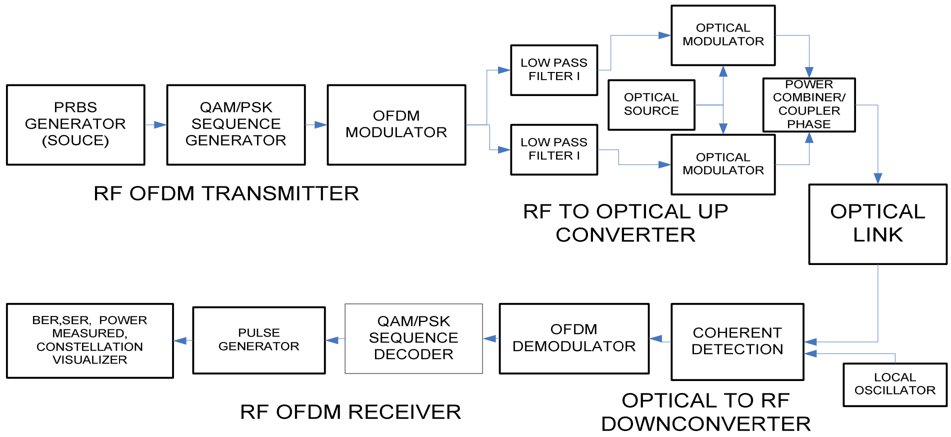


Figure 1. Block Diagram of Digital Modulation for Coherent Detection of OFDM-RoF Scheme

In the baseband, the single carrier modulations are composed of 4-QAM, 16-QAM, QPSK, 8-PSK, and 16-PSK. The baseband signal can be expressed as $\{X(m): m = 0,1,......,N-1\}$, where *m* is the sub-carrier index and *N* is the number of sub-carrier [13]. *X(m)* are then modulated onto orthogonal frequency division multiplexing (OFDM) *S(n)* given by [15]:

$$S(n) = \frac{1}{\sqrt{N}} \sum_{m=0}^{N-1} X(m) e^{j2\pi mn/N} \quad (1)$$

Where $n=0,1,\ldots, N-1$ is the time domain index.

This system uses a component of OFDM OS12, where output I and Q will be flowed to each a low pass-cosine roll-off filter (LP-CROF), where the value of roll off factor r can be arranged from 0 until 1. OFDM modulation results in 512 sub-carriers at M-QAM/PSK position (QAM/PSK Mary position) and 1024 points of FFT. Loss of power can be lost by use an electrical gain before it comes to the optical modulator. Scheme of RF-OFDM transmitter simulation is shown in Figure 2.

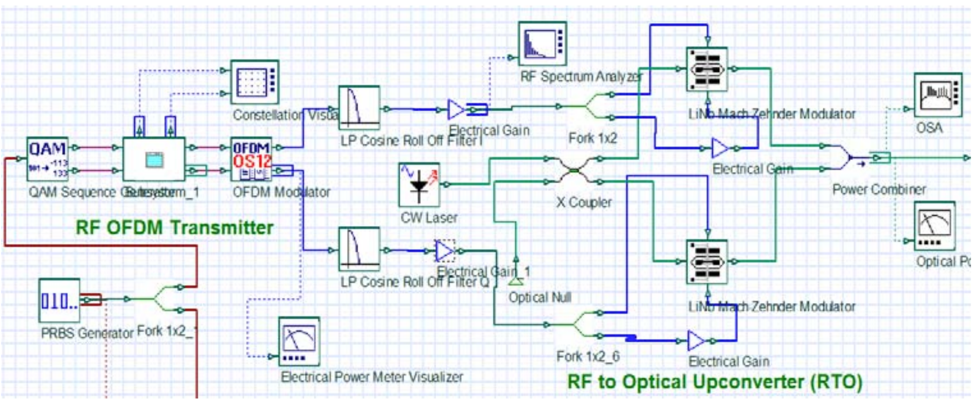


Figure 2. RF OFDM Transmitter and RTO

RTO steps electrical to optical (E/O) conversion, where the optical modulator is used in this system model is LiNb-MZM. This part is presented in Figure 2. In this step, CW laser is used to deliver the signal from continued optical waves. The laser phase noise of CW Laser is modeled using the probability density function:

$$f(\Delta\varphi) = \frac{1}{2\pi\sqrt{\Delta f dt}} . e^{-\frac{\Delta\varphi^2}{4\pi\Delta f dt}} \quad (2)$$

where $\Delta\varphi$ is the phase difference between two successive time instant and *dt* is the time discretization. A Gaussian random variable for the phase difference between two successive time instans with zero mean and a variance equal to $2\pi\sqrt{\Delta f}$ have been assumed, with Δf as the laser linewidth. LiNb-MZM is an external modulator which is an important component of high bit rate lightwave systems is placed between RF and laser [16]. Output formula of optical field LiNb MZM is given by [17]:

$$E_o(t) = \frac{E_{in}(t)}{10^{\left(IL/20\right)}} \cdot \left[\gamma . e^{\left(j\pi v_2(t)/V_{\pi RF} + j\pi v_{bias2}/V_{\pi DC} \right)} + (1-\gamma) . e^{\left(j\pi v_1(t)/V_{\pi RF} + j\pi v_{bias1}/V_{\pi DC} \right)} \right] \quad (3)$$

where $E_{in}(t)$ is the input (optical signal), *IL* is the parameter insertion loss, $v_1(t)$ and $v_2(t)$ are the input electrical voltage for the upper (1) and lower (2) modulator arms, $v_{bias1}(t)$ and $v_{bias2}(t)$ are the setting for bias voltage 1 and bias voltage 2, $V_{\pi RF}$ and $V_{\pi DC}$ are the switching modulation and bias voltage, and γ denoted the power splitting ratio of both Y-Branch waveguide (assumed to be symmetrical), and is given by :

$$\gamma = \left(1 - \frac{1}{\sqrt{\varepsilon_r}} \right) / 2 \qquad \varepsilon_r = 10^{ExtRatio/10} \quad (4)$$

where ExtRatio is linked to the parameter Extinction ratio.

The design of this system uses loop control for high variation of fiber optic with wavelength/time 200. Optical frequency filter used to anticipate losses that caused by noise fiber scattering and signal dispersion when it through on fiber. The length of optical fiber link being simulated is 10 to 100 km with attenuation 0.2 dB/km. Scheme of the optical link can be shown in Figure 3. SMF 28 used in the optical fiber, where the characteristics imported from OptiFiber 2 software as shown in Figure 4.

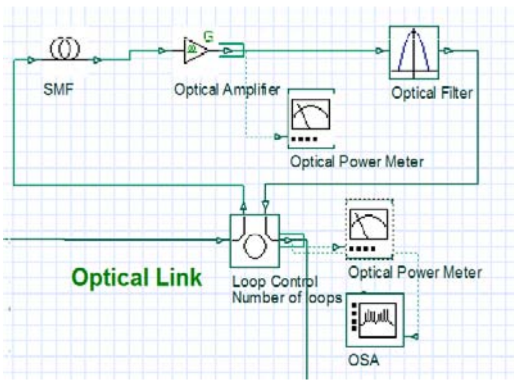


Figure 3. Optical Link

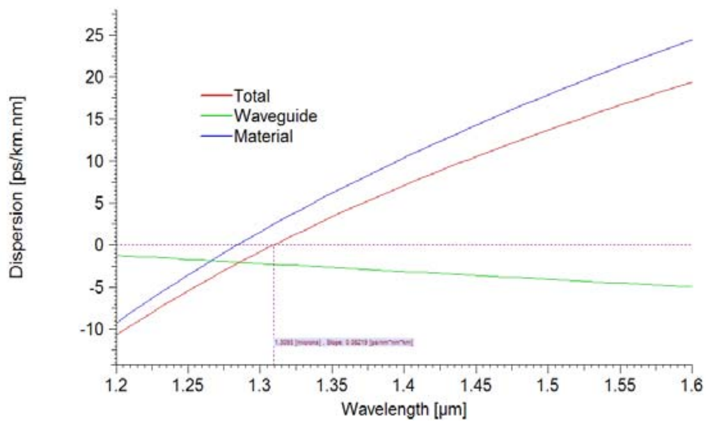


Figure 4. Dispersion Characteristic of SMF 28 (OptiFiber 2)

Optical to RF down-converter (OTR) is known as an optical detector. It consists of four of photo-detector PIN with an external source where it is produced by a local oscillator as shown in Figure 5. In this step, CW laser is used as the local oscillator. The PIN photodiode component is used to convert an optical signal into an electrical current based on the device's responsivity. The incoming optical signal and noise bins are filtered by an ideal rectangular filter to reduce the number of samples in the electrical signal. The new sample rate is defined by the parameter sample rate. We can define the center frequency and calculate it automatically by centering the filter at the optical channel with maximum power. Moreover, the RF-OFDM receiver is inverse from a process in RF-OFDM transmitter which consists of OFDM demodulator and QAM decoder. Carrier frequency signal as a result of conversion O/E received will be de-multiplexing to get an output signal. All output will be shown as points on the diagram signal constellation form before coming on the QAM sequence decoder. Scheme of RF-OFDM transmitter simulation is presented in Figure 5. Visualization of simulation results uses RF and optical spectrum analyzer, electrical and optical power meter, and constellation visualizer. Moreover, the general parameters of the simulation can be seen in Table 1.

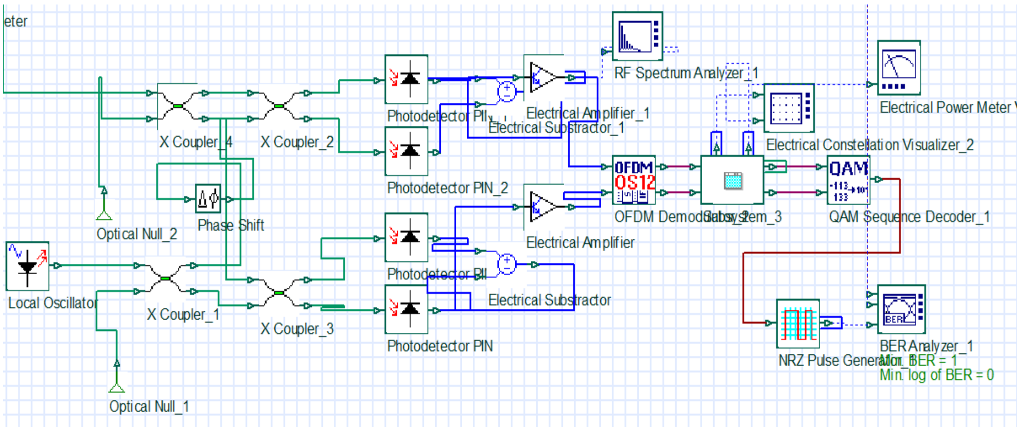


Figure 5. OTR with Coherent Detection and RF OFDM Receiver

Table 1. Parameter of Coherent Detection of OFDM-RoF

Parameter	Value
Bit Rate	10 Gbps
Modulation Format	4-QAM,16-QAM, QPSK, 8-PSK, 16-PSK
Sequence Length	16384
Sample per Bit	8
Sample rate	80 GHz
Frequency CW Laser	193.1 THz
CW Laser Power	-4 dBm
Extinction Ratio	60 dB
Switching Bias and RF Voltage	4 dB
SMF	10-100 km
Attenuation	0.2 dB/km
Local Oscillator Power	-2 dBm
PIN Responsivity	1 A/W

3. SIMULATION RESULTS AND ANALYSIS

Analysis of the performance of each modulation format is viewed from the power output at every step of the OFDM-RoF system and received constellation at the receiver. On the side of the transmitter, the fundamental difference between each modulation format lies in symbol rate and bits per symbol, with 4-QAM and QPSK, which have a symbol rate of ½ of the bit rate of 2 bits per symbol, while 16-QAM and 16-PSK pick symbol rate 1/4 of bit rate with 4 bits per symbol, and 8 PSK with a symbol rate 1/3 of the bit rate with 3 bits per symbol. Theoretically symbol rate 4-QAM and QPSK modulation are greater than the other. The magnitude of the output power of each step can be seen in Table 2.

Table 2. Power Stage Output (dBm) for Different Digital Modulation Format at Fiber Length 10 km

Stage/Modulation Format	4-QAM	16-QAM	QPSK	8-PSK	16-PSK
OFDM	57.049	64.057	54.055	54.316	54.004
RTO	-26.063	-19.427	-29.030	-28.835	-29.031
Optical Loop	-2.379	3.731	-4.766	-4.620	-4.765
Optical Link	6.928	13.574	3.969	4.175	3.985
Coherent Detection	-12.108	-5.424	-15.061	-14.791	-15.089
Subsystem Receiver	100.997	107.558	98.024	97.995	97.975

As shown in Table 2, 16-QAM has the greatest power output of each stage compared to the other modulation. On the OFDM stage output, 16-QAM has a power value output of 10 dB is greater. This significant difference value was also seen at the output of optical link and coherent detection. While the 4-QAM and QPSK relative have the same rated power output of each stage. Different results saw PSK format, the optical output power, and link loop has a very close range, but it has a considerable range when compared to coherent detection and receiver subsystem. Based on the results received the power of 4-QAM and 16-QAM are much better than QPSK, 8-PSK, and 16-PSK. As for the decrease in comparison to the long fiber up to 100 km can be seen in Figure 6. Referring to Figure 6 shows that the reduction in power tends to be linear, in which the 16 QAM received power is the greatest.

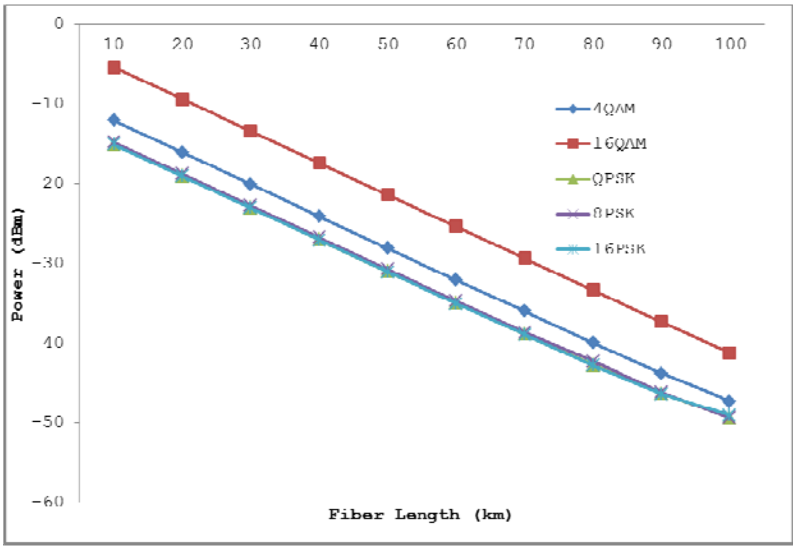


Figure 6. Power Output versus Fiber Length at Coherent Detection Receiver

Evaluation of the power received at the receiver be based on a constellation of forms received by the receiver and the value BER and SER measured. Comparison of BER and SER, each modulation format for the fiber length variation, can be seen in Figures 7 and 8. As for the results of constellation diagrams for fiber length variation can be seen in Figures 9 to13. Based on Figure 7, the characteristic of BER is divided into three regions. In general, an increase in the value of BER for each modulation format is almost equal to the fiber length of 60-70 km (Region I and II). However, there is a significant increase in the number of BER for a fiber length of 80-100 km (Region III. A and III. B) for the modulation of 4 QAM, QPSK, 8 PSK and 16-PSK. It also shows that the 16 QAM has a BER value that is very low compared to other modulation formats, which for the fiber length of 100 km; BER 16-QAM is 0.053. It also shows that the BER value of 4-QAM and QPSK relatively similar to fiber length variations.

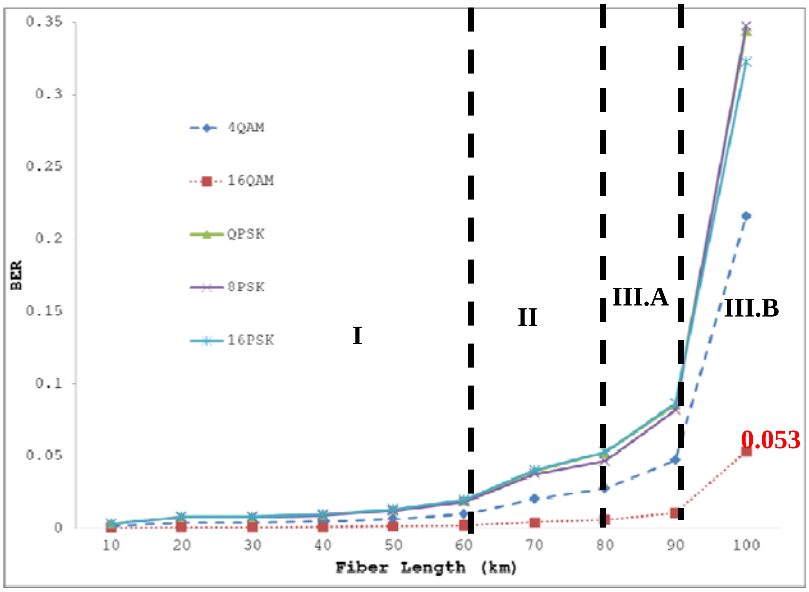


Figure 7. BER versus Fiber Length

Similar to the value of SER, Figure 8 shows that 16 QAM have SER values are very small compared to other modulation formats, which for the fiber length of 100 km, 16-QAM SER for 0.157, or 15.7%. SER value of 4-QAM and QPSK nearly the same relative to fiber length variations. In general, an increase in the value of SER for each modulation format is almost equal to the fiber length of 60-70 km (Region I and II). However, there is a significant increase in the value of SER in fiber length of 80-100 km (Region III. A and III. B) for the modulation of 4 QAM, QPSK, 8 PSK and 16-PSK. Overall use of 16 QAM of coherent detection of the OFDM-RoF system is much better compared to the other modulation.

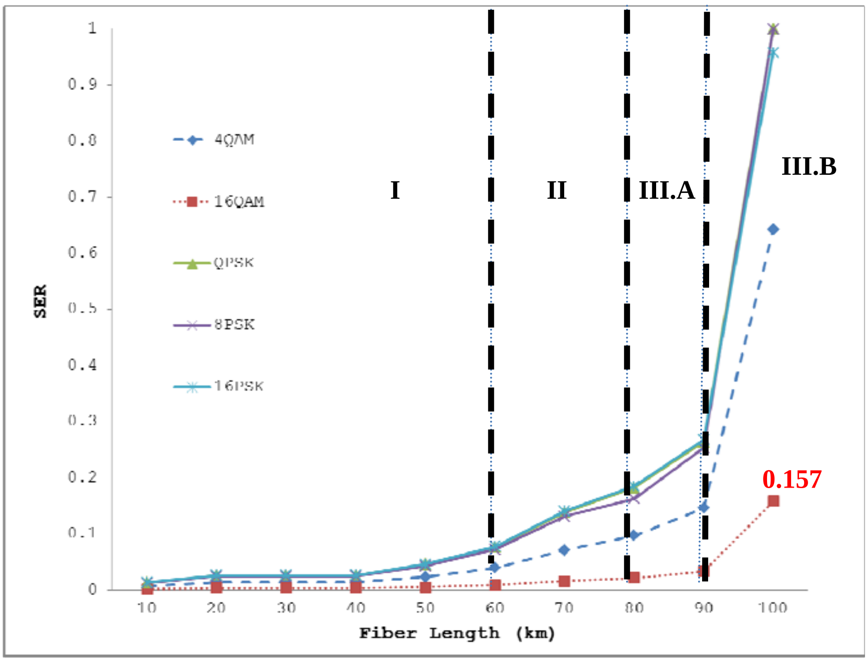
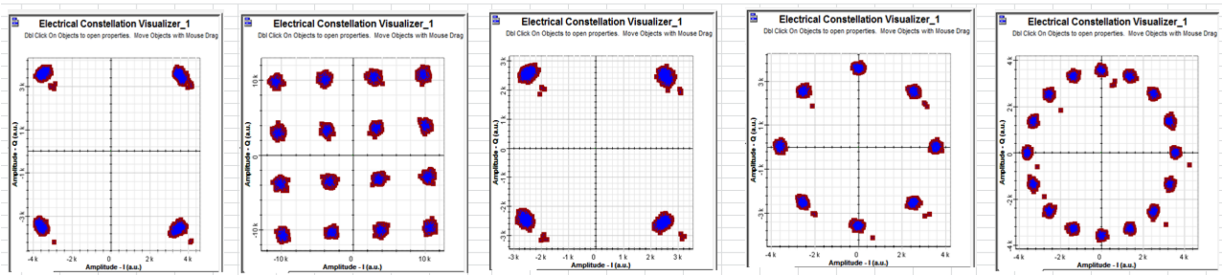


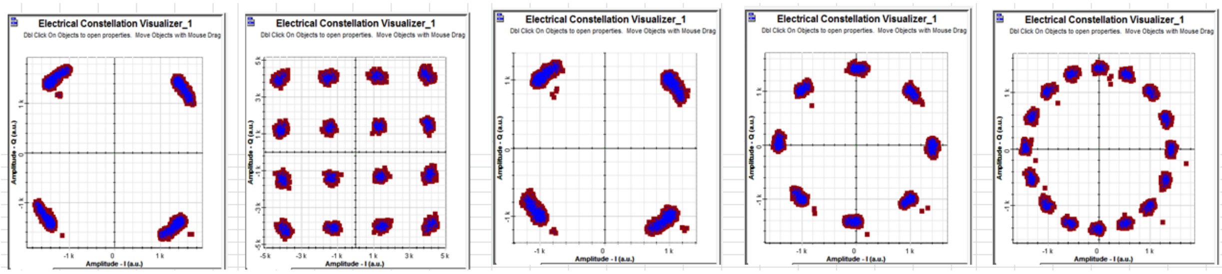
Figure 8. SER versus Fiber length

Impairment power received at the receiver, and the increase in the value of the BER and SER has a significant influence on the constellation diagram at receiver, especially in the receiver subsystem. An amplitude range on the constellation visualizer is influenced by the amount of power received at the receiver. The longer the optical fiber, the greater the reduction in power so that the amplitude of the small constellation. Figures 9 to 13 show a decrease in the power of fiber length variation. By the value of the BER and SER by Figures 7 and 8, it appears that for the length of fiber 10 km to 60 km, the constellation for each modulation format looks very nice. However, to increase fiber length up to 70-80 km, with the figure 12 can be seen that constellation began to deteriorate, the symbol constellation where the distance is getting closer and smaller amplitude, and the greater the noise pulses. BER significantly increased value occurs for 4-QAM, QPSK, 8-PSK and 16-PSK for the fiber length of 90 to 100 km. It can also be seen in the constellation diagram as shown in Figure 13. Instead, BER relatively small increase in value to 16-QAM to 100 km, also seen with the results of constellation diagrams. So for the fiber length of 100 km, 16-QAM has constellation better when compared to other modulation formats with the increase in the value of BER and SER is small anyway. Based on all results, It also shows that this OFDM-RoF scheme with coherent detection is better than previous research [10],[11], where the bit rate can be achieved on 10 Gbps 16 QAM with the small BER and SER values for long transmission up to 100 km SMF.



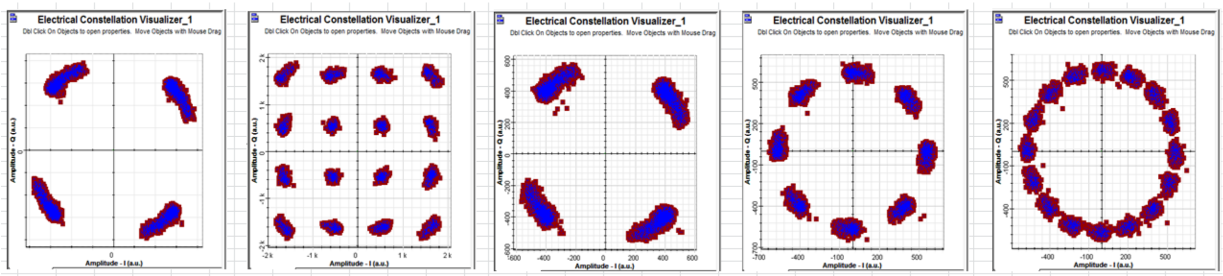
a) 4-QAM b) 16-QAM c) QPSK d) 8-PSK e)16-PSK

Figure 9. Constellation Visualizer for Fiber Length 10 km



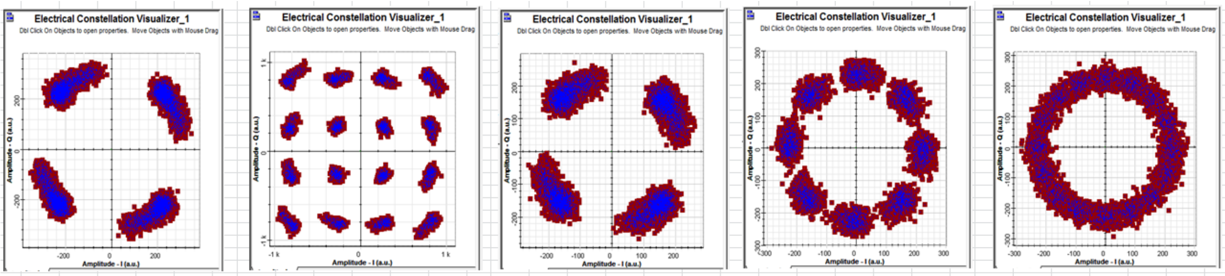
a) 4-QAM b) 16-QAM c) QPSK d) 8-PSK e)16-PSK

Figure 10. Constellation Visualizer for Fiber Length 30 km



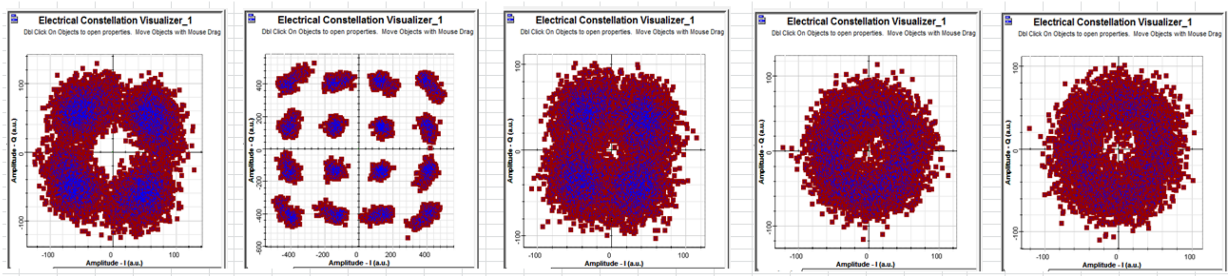
a) 4-QAM b) 16-QAM c) QPSK d) 8-PSK e)16-PSK

Figure 11. Constellation Visualizer for Fiber Length 50 km



a) 4-QAM b) 16-QAM c) QPSK d) 8-PSK e)16-PSK

Figure 12. Constellation Visualizer for Fiber Length 70 km



a) 4-QAM b) 16-QAM c) QPSK d) 8-PSK e)16-PSK

Figure 13. Constellation Visualizer for Fiber Length 100 km

4. CONCLUSION

The results show that coherent detection of the OFDM-RoF system with 16-QAM has the value of the bit error rate (BER) and the symbol error rate (SER) is very small and its constellation better when compared with other modulation formats (4-QAM, QPSK, 8-PSK, and 16-PSK), which BER 16-QAM is 0.053 and SER are 15.7%. The Results also show that the value of BER 4-QAM and QPSK relatively similar to fiber length variations. In general, an increasing value of the BER and SER for each modulation format is almost equal to the fiber length of 60-70 km (Region I and II). However, there is a significant increase in the value of BER in fiber length of 80-100 km (Region III. A and III. B) for the modulation of 4-QAM, QPSK, 8-PSK, and 16-PSK.

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