

Simulative Performance Investigation of OFDM & f-OFDM for Optical Wireless Communication System

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Internet of Things (IoT) is a fast-growing technology that requires innovative solutions and technologies to realize its vision efficiently. Optical Wireless Communication (OWC) technology is one of the emerging connectivity technologies that could benefit this IoT deployment. Orthogonal Frequency Division Multiplexing (OFDM) is regarded as a technique of encoding data on multiple carriers as it promises high data rates and lays down the foundation for many standards of wireless communication such as 5G network. However, large OOBE (Out-Of-Band Emission) and large Peak to Average Power Ratio (PAPR) in OFDM makes it less potent to meet demand of high data rate. Therefore, Filtered-OFDM (f-OFDM) act as promising candidate for future wireless generation networks. The motivation of this paper is to analyze the applicative aspect of Multicarrier Modulation schemes (OFDM and f-OFDM) in implementation of OWC technology within the IoT. The parameters used for evaluating the robustness of the designed system are namely- Bit error Rate (BER), Signal to noise ratio (SNR) Peak to average power ratio (PAPR) and Power Spectral Density (PSD). The investigation reveals an increment of 25% SNR and decrement of 16% occurrences of error during transmission for f-OFDM. Further, Quadrature Amplitude Modulation (QAM) modulation scheme increase this SNR to 30% (approx.), thus promising the designed system as suitable contender for upcoming linked OWC and wireless networks like IoT.

Keywords: Filtered OFDM, Internet of Things, Out-Of-band emission, Peak to average power ratio, Power spectral density

Introduction

There is a rapid increase in the data rate transmission in digital era along with efficient utilisation of spectrum bandwidth, so this area of study has greater importance. The idea of combining parallel data transmission and frequency multiplexing begin in 1960s. Due to recent advances in research and development, implementation of OFDM has been made possible in high-speed communication. Fast Fourier Transform (FFT) used in OFDM eliminates the need of coherent demodulation thus making it a cost-effective technology. It has been adopted in arena of telecommunication as Wi-Fi, DSL internet services, radio broadcasting, WiMAX and many more areas.¹ Orthogonal Frequency Division Multiplexing (OFDM) systems provide resistance to frequency selective fading by dividing the overall channel into various narrowband sub-channels. It makes the spectrum easily accessible by closely spacing the overlapping sub-carriers orthogonally. Channel equalisation is one of the prominent issues with CDMA systems that makes the technique quite

complex as compared to OFDM. Since wireless channel suffers from multipath effects, OFDM has significant impact in wireless market due to its cancellation which makes it ideal for high data applications.² Moreover, receiver in such systems does not require adaptive equaliser as compared to single carrier system. Despite having several advantages, its high PAPR adds disadvantage to this technique. In conventional OFDM, rectangular pulse shape is used (sinc pulse in frequency domain) where side lobe varies inversely with respect to frequency which does not produce localized spectrum thus produce interference. So, a portion of bandwidth is reserved as guard band which ultimately leads to loss of spectral efficiency. Moreover, such systems are highly sensitive to carrier frequency variations in transmitter and receiver. Such frequency errors produced randomly affects the orthogonality of carriers causing Inter Symbol Interference (ISI). Interference created by multipath can be elegantly suppressed using CP (Cyclic Prefix) if its length exceeds delay spread. This provides the criteria for selection of CP duration.

Recently, 5G has gained much more attention from researchers for incorporating new systems in PHY

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(Physical layer) such as waveform designing.³ So, to overcome the issues of OFDM, f-OFDM technique is implemented as spectrally localised waveform and capable of providing efficient MIMO services along with desirable characteristics of OFDM. Suppression of OOB and transmission of data sequence in asynchronous manner makes this technique recommended for fifth-generation (5G) communications. It offers several features like flexibility in integration with antenna transmission, less complex in terms of computations, lesser latency. Also, it offers PAPR reduction techniques⁴ such as PTS (Partial Transmit Sequence), SLM (Selective Mapping). Phase noise generated in the optical transmission majorly affect the stability of local oscillator thus LMS (Least Mean Square) algorithm is used to improve BER without changing the framework of OFDM.⁵ Several digital modulation schemes can be employed in this system namely- 8-PSK, QPSK, BPSK, 16-QAM to analyse the performance in terms of system capacity, data security, speed with quality transmission of information. The various application of PSK is Radio Frequency Identification (RFID), Bluetooth, wireless Local Area Networks (LANs). BPSK makes 0° and 180° phase shift in the respective carriers while QPSK offers 0°, 90°, 180°, 270°.

Combination of both phase and amplitude modulation named as QAM transmit data by varying both amplitude and phase of carrier wave thus it is more bandwidth efficient but requires complex algorithms for demodulation. It is extensively used for 802.11 Wi-Fi standards, satellite communication.⁶ IEEE 802.11 standard lays down the specifications of Wireless LAN having 2.4 GHz band of operation. It has the capacity of achieving data rate up to 2 Mbps and uses frequency hopping spread spectrum, Direct sequence spread spectrum techniques. Considering the requirements for 5G, f-OFDM improves the spectral efficiency by providing both forward and backward compatibility. The main advantages of this technique are: (1) Easy channel equalisation, (2) Efficient bandwidth utilization, (3) Less computational complexity, (4) Less OOB, (5) Flexibility in integration with antenna transmission, (6) Minimum usage of guard bands.

Literature Review and Gap Analysis

This section discusses a comprehensive analysis of existing techniques used in Radio Frequency spectrum for reliable data transmission. Furthermore, pros and cons of current methods are discussed along

with the research gap findings. The scope and latest research work in Optical domain is outlined here, which ensure security as well. OFDM system is known to meet the requirement of Long-Term Evolution (LTE) network as well as provides cost effective solution with higher data rates. Therefore, it is one of the most popular techniques in wireless communication. Jadav⁷ surveyed the effect of different types of interference possible in OFDM systems like ISI, ICI (Inter Carrier Interference) and CCI (co-channel interference on BER along with application of wavelet transform and channel coding. The paper does not focus on advanced channel coding which is efficient for 5G and B5G networks. The study examines five PAPR reduction strategies⁸ in general and concludes that peak insertion is the most successful. Nevertheless, no particular method of PAPR reduction for the OFDM system is provided. In order to choose the best PAPR technique, the study takes into account a number of factors, including data rate loss, transmit signal power increase, BER rise, and computational complexity. It simulates the system only for Single Input Single Output (SISO). System can be extended to MIMO OFDM for development of more reliable system. Bharti⁹ discussed the solution for primary drawback of OFDM that is PAPR. To reduce PAPR, a number of strategies are employed, including SLM, companding, and clipping. An algorithm was presented in the paper and compared with PAPR suppression techniques that were already available. The suggested approach makes use of the conventional partial transmit sequence and the idea of interleaving once the symbols in the OFDM sub-block are separated. According to investigations, the suggested algorithm reduced the PAPR by about 2 dB with regard to Complementary Cumulative Distribution Function (CCDF), outperforming the conventional PAPR reduction techniques. The unresolved problem for this strategy is to combine hybrid precoding with PAPR reduction. Pandey *et al.*¹⁰ performed the comparative analysis of BER in terms of different M values (4,16,32,64,128 and 256-QAM) and observe that M-QAM modulation scheme for OFDM system is more noise immune as compared to other schemes. Comparison with f-OFDM system could provide more insights on parameters like Spectral efficiency and PAPR. Directional Modulation (DM) could be added as another feature in Physical Layer (PHL) of wireless network by varying the radiation pattern in a particular direction thus

suppressing the side lobes. This overcomes the issue associated with power dissipation in side lobes in OFDM. In 2019, Ding *et al.*¹¹ proposed the architecture of OFDM transmitter using time modulated array for more secure transmission and results are validated through simulations. By proper designing, they are able to develop OFDM-DM system having narrow BER of main lobe and able to suppress side lobes thus enhancing the secrecy of information at low cost. The research discussed above, assume only free space dynamics but for maintaining the security of transmission predefined knowledge of real time radiation's direction could be included.

In 2009, Similar to DM concept Daly *et al.*¹² have demonstrated phased array by shifting of each element for transmission of data in multiple direction independently. They developed an algorithm using driven elements for communication in multi direction using BER parameter. Various studies have been carried out on f-OFDM related to diversified expectations of upcoming 5G. Zhang *et al.*¹³ discussed the design parameters by framing the outline of f-OFDM in terms of filter design and arrangement of guard band, thus illustrating its advantages. In addition to this, simulation results through extensive comparison of the scheme show that f-OFDM attractively provides 46% throughput gain as compared to OFDM in four distinct services (Pedestrian, Urban, Highway and V2V). Abdoli *et al.*¹⁴ proposed f-OFDM scheme for QPSK which removes overhead of time-synchronization by placing filter at each transmitter for spectrum shaping. This prevents side lobe leakage and a series filter at each receiver is placed for ISI elimination. Implementation of scheme with down sampling and short Fast Fourier Transform (FFT) is performed and its performance is evaluated. The work could be extended by implementation of other modulation techniques also. Application of OFDM in optical fiber communication is immense therefore, Zhang *et al.*¹⁵ discussed the techniques of improving system performance for limiting multi-path and dispersion with the help of forward error correction method. The system is restricted to outdoor scenarios but the future concept of Indoor application including e-Healthcare, smart hospitals etc could extend the scope of this work. Most of the recent work has been concentrated upon comparison between OFDM and f-OFDM scheme but limited work has been done with implementation of different digital modulation techniques in these schemes.

Also, IoT networks are predominantly based on RF communication technologies and the development of IoT data-centric applications is steadily increasing the demand for higher data rate communication links. Research is still underway to evaluate new OWC (Optical Wireless Communication) modulation schemes and compare them with existing ones.¹⁶ This survey provides in-depth knowledge and provided valuable ideas for carrying further research into this particular domain.

Materials and Methods

Interlinking of Optical Wireless Communication and IoT

The Internet of Things (IoT) is a network of interconnected computing systems that have unique identifiers and can communicate with each other without the need for human-to-computer or human-to-human interaction. It includes a vast ecosystem of smart systems with web-enabled applications. These devices are equipped with built-in sensors that collect information and send it to the cloud for analysis and further processing.

The beauty of IoT is that it can operate without human intervention, although humans can interact with these devices to install them, issue commands, or access data. The electromagnetic spectrum consisting of different frequency ranges available for different wireless technologies is displayed in Fig. 1. The selection of an appropriate carrier frequency is based on the needs of the application. Low carrier frequencies offer several benefits, such as the ability to penetrate walls and windows, diffract over obstacles, and propagate over long distances due to low signal attenuation.

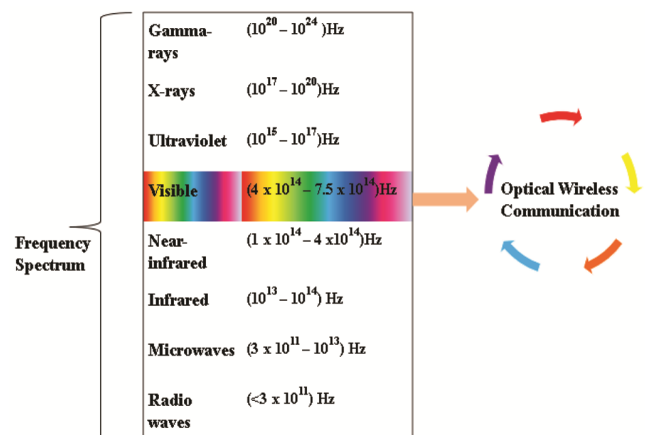


Fig. 1 — Electromagnetic (EM) spectrum displaying Radio frequency (RF) and Optical wireless communication (OWC)

Design and Analysis of OFDM System

OFDM is characterized as digital modulation scheme where large numbers of closely placed sub-carriers (following orthogonality) are used to carry data sequence. Orthogonality of carriers is achieved by placing the sub carriers at null position in frequency spectrum. The data is divided into multiple channel streams. Schematic diagram of OFDM transmitter and receiver is shown in Fig. 2.

OFDM Transmitter: The serial input data contains the information being transmitted which is converted into N parallel paths using S/P converter. After this, data sequence is modulated using different digital modulated schemes as BPSK, QPSK, 8-PSK and 16-QAM and forwarded to IFFT block which produces digital time domain signal as output.¹⁷ After using parallel to serial data cyclic prefix is inserted for elimination of ISI. Finally, data is converted into real time signal using analog converter.

Channel: Channel model can help to provide the type of noise and multipath propagation prevalent in the system.¹⁸ Generally, AWGN channel is used.

OFDM Receiver: In order to obtain the time domain signal at receiver demodulator is used with FFT followed by demapper circuit.

Orthogonality: Any two periodic signals can be said orthogonal if integration of their product over one cycle of time period is zero.

$$\int_0 X_1(t)X_2(t)dt = 0 \quad \dots (1)$$

OFDM system utilizes sub carriers which can be represented as sinusoid waveform having frequency being integral multiple of fundamental frequency. It can also be represented as Fourier series.

$$f(t) = \cos (2\pi f_c t + \phi) \quad \dots (2)$$

where, f_c is carrier frequency

Cyclic Prefix: Benefit of using cyclic prefix as guard interval (as shown in Fig. 3) is that it not only removes

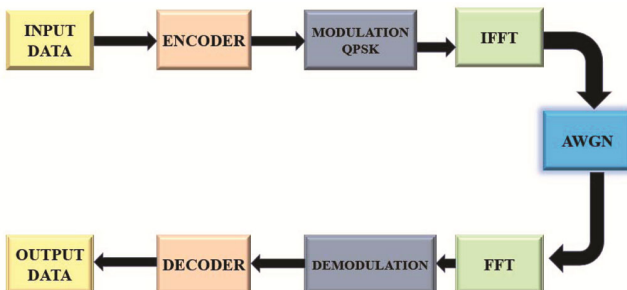


Fig. 2 — OFDM system with AWGN channel

ISI but also behaves as repetition of symbol at the end of OFDM signal to model linear convolution as circular, thus converting it to frequency domain.

For analyzing the performance of OFDM, following parameters are chosen for detailed performance evaluation-PAPR, BER and SNR. PAPR is defined as ratio of the maximum power in transmitted sample to the average power of overall OFDM signal. It is usually measured in dB (decibels). MATLAB (R2023a) toolbox has been used for simulating the design of OFDM system.¹⁹ Large value of PAPR degrades the efficiency of overall system, so its smaller value is preferred for proper operation. PAPR ratio observed for various modulation schemes shows that in case of OFDM, BPSK has highest PAPR of 9.7 dB and significantly less PAPR is observed in 16 QAM. BER and SNR are the two important parameters that quantify the transmission and determines the quality of designed system. BER determines the number of bit errors occurring during transmission per unit time interval. Lower value of BER is required for successful transmission of signal. SNR is expressed as ratio of power contained in signal carrying useful information to the noise power. Higher value of SNR indicates better quality of signal thus less chances of occurrence of errors. SNR and BER calculation observed for various modulation schemes shows 21.8 dB SNR and -0.87 dB BER for 8 PSK, 20.2 dB SNR and -0.7 dB BER for QPSK, 19.3 dB SNR and -5.7 dB BER for 16 QAM, 18.4 dB SNR and -4.1 dB BER for BPSK.

Design and Analysis of f-OFDM

In case of f-OFDM, a filter is designed to improve OOB of the sub carriers. Meanwhile orthogonality of carriers needs to be maintained in complex domain. Considering the necessary criteria, a filter with rectangular response satisfies the conditions and for making it causal, low pass filter with window is realized. Following conditions are required to design the filter-

- i. Sub carriers having flat pass band in sub band
- ii. Sufficient stop-band attenuation

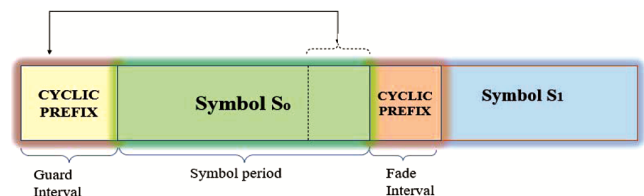


Fig. 3 — Block diagram of cyclic prefix Performance Evaluation of OFDM

iii. For minimal use of guard band, sharp transition required

f-OFDM Transmitter: In the transmitter section, signal after passing through IFFT & CP is fed into a designed filter having certain characteristics. In this, length of the filter exceeds CP length and has bandwidth like that of signal. Thus, by using filter with soft truncation windowing ISI is minimized (Fig. 4a).

f-OFDM Receiver: Signal received from channel is fed into matched filter and then CP is removed from it in order to get the final data at output (Fig.4b).

Performance Evaluation of f-OFDM

PAPR ratio observed for various modulation schemes shows the following results that in case of f-OFDM, BPSK has highest PAPR of 11.37 dB amongst PAPR of 5.35 dB for QPSK, 5.37 dB PAPR for 8PSK and 6 dB PAPR for 16QAM. SNR and BER calculations observed depict 21.8 dB SNR and -1.1 dB BER for 8 PSK, 20.2 dB SNR and -1.1 dB BER for QPSK, 19.3 dB SNR and -7.3 dB BER for 16 QAM, 18.4 dB SNR and -3.7 dB BER for BPSK. Comparison of BER for different modulation techniques shows better performance of 8 PSK in case of f-OFDM but at the cost of BER.

Results and Discussion

In this work, OFDM and f-OFDM system has been designed and their performance is analyzed for optical wireless system. System performance is compared based on three parameters namely- PAPR, BER and SNR by using different modulation schemes such as BPSK, QPSK, 8PSK and 16QAM using MATLAB (R2023a) software.

As mentioned in ‘Performance Evaluation of OFDM’ section, PAPR ratio observed for various modulation schemes is simulated and for 16 QAM technique, PAPR curve is clearly shown in Fig. 5. The curves shown in Fig. 6 demonstrate high SNR (26.5 dB) for 8PSK technique amongst other modulation schemes and thus makes it suitable for transmission in OFDM systems.

The performance parameters BER, SNR and PAPR obtained for OFDM and f-OFDM system respectively are shown in Table 1 having significant value of SNR for f-OFDM (16 QAM). For this particular case PAPR is also very less, thus, making it suitable for further consideration.

After evaluating SNR and BER ratio in OFDM for various Modulation schemes it has been observed that BPSK has 18.4 dB SNR and -4.1 dB BER, QPSK

accounts for 20.2 dB SNR and -0.7 dB BER, 8 PSK has 21.8 dB SNR and -0.87 dB BER and 16 QAM has 19.3 dB SNR and -5.7 dB BER. Similarly, calculation for f-OFDM shows 24 dB SNR and -3.7 dB BER for BPSK, 024 dB SNR and -1.1 dB BER for QPSK, 26.5 dB SNR and -1.1 dB BER for 8 PSK and 25 dB SNR and -7.3 dB BER (better quality of transmitted signal) for 16 QAM.

As discussed in ‘Performance Evaluation of f-OFDM’ section, PAPR ratio observed for various modulation schemes is evaluated and numerical

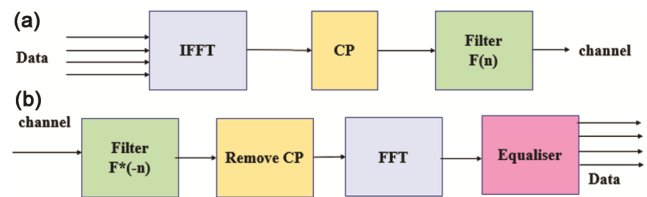


Fig. 4 — Block Diagram of f- OFDM: (a) Transmitter (b) receiver

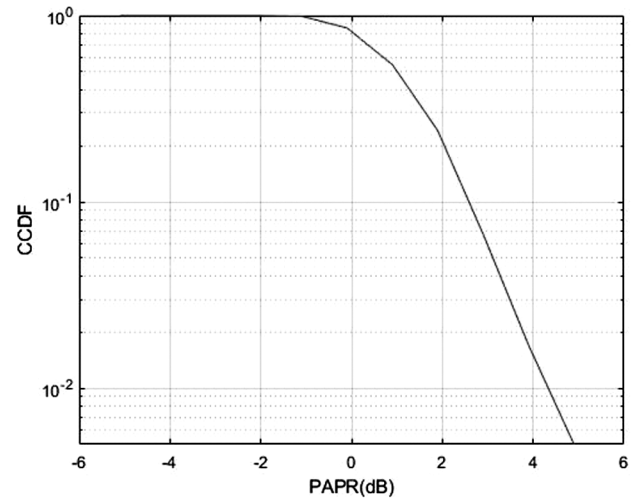


Fig. 5 — PAPR in OFDM for various modulation schemes

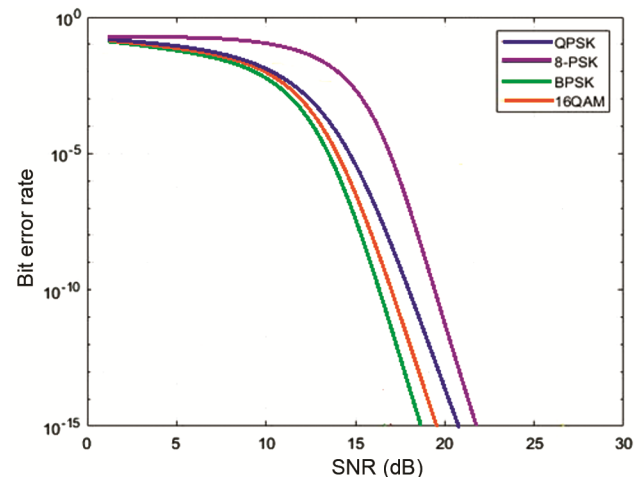


Fig. 6 — BER in OFDM for various modulation schemes

Table 1 — Comparison of BER (dB), SNR (dB) and PAPR (dB) in OFDM & f-OFDM

Modulation Schemes	OFDM			f-OFDM		
	BER (dB)	SNR (dB)	PAPR (dB)	BER (dB)	SNR (dB)	PAPR (dB)
BPSK	-4.1	18.4	9.721	-3.7	24	11.371
QPSK	-0.7	20.2	5.18	-1.1	24	5.35
8 PSK	-0.87	21.8	5.281	-1.1	26.5	5.37
16 QAM	-5.7	19.3	5.297	-7.3	25	6.069

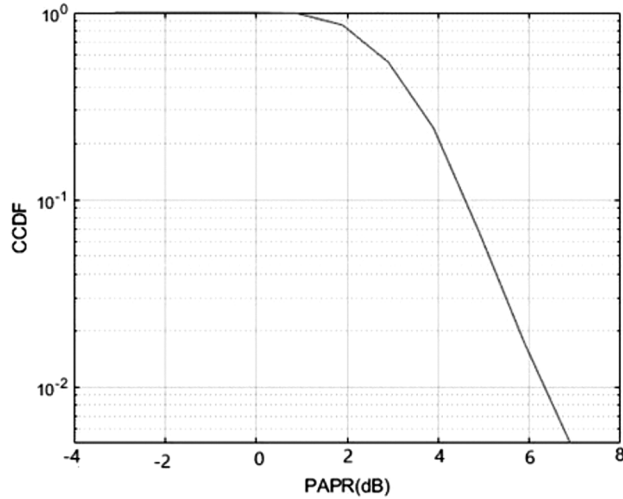


Fig. 7 — PAPR performance in f-OFDM for 16 QAM

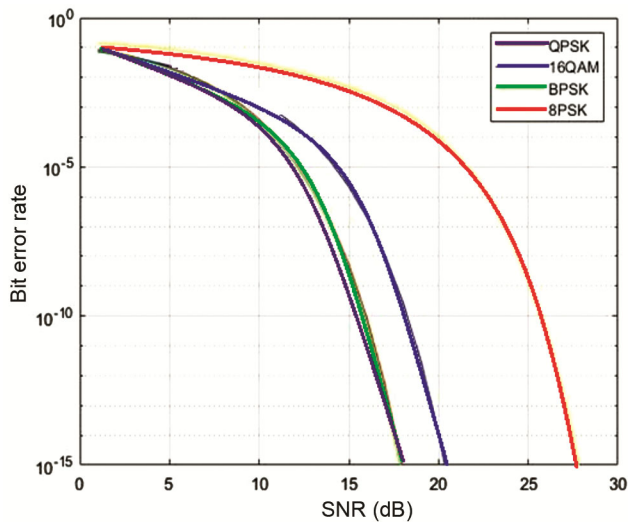


Fig. 8 — BER Vs SNR in f-OFDM for Various Modulation scheme

results shows that 16 QAM provides significant results with lesser PAPR (6 dB) combination with least BER (-7.3 dB) as shown in Fig.7 Comparison of SNR and BER calculations (as depicted in Fig. 8) for modulation schemes shows highest SNR (26.5 dB) for 8 PSK. Through the calculations, a suitable combination of SNR, BER and PAPR values is selected for effective transmission.

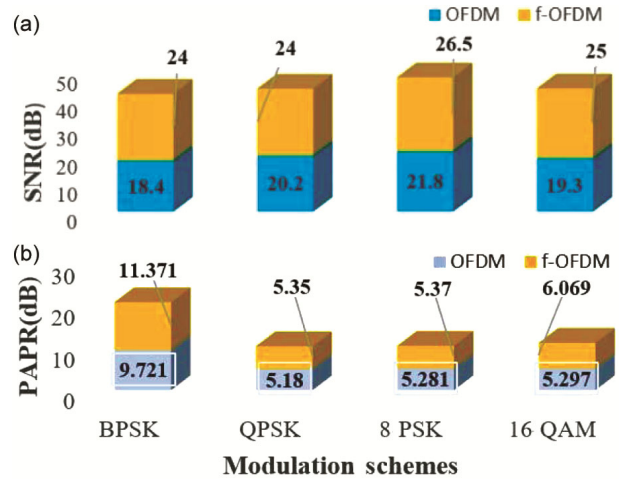


Fig. 9 — (a) SNR for OFDM & f-OFDM for Various Modulation scheme; (b) PAPR for OFDM & f-OFDM for Various Modulation scheme

Graphical analysis of Fig. 9(a), shows 16 QAM and 8 PSK techniques are best suited for selection because of offering high SNR value, but BER value observed for 16 QAM is lesser as compared to later. So, in this case, PAPR value becomes the deciding factor (scheme offering lesser PAPR is ultimately selected).Evaluating the PAPR ratio for various digital modulation schemes from Fig. 9(b) it has been observed that BPSK accounts for 9.7 dB PAPR ratio (highest as compared to other schemes taken into consideration). There is slight variation in this parameter for remaining schemes and has PAPR value around 5.2 dB. It can be observed that by using BPSK modulation scheme quality of the signal would enhance, thus it is unfit for OFDM system in wireless application. There are many techniques used for PAPR reduction such as amplitude clipping, selective mapping and partial transmit sequence. Simulation results shows that by using f-OFDM scheme, an increase of 24.84% is observed in SNR, whereas QAM modulation scheme offers greater SNR of about 29.5% in case of f-OFDM which means more useful information is transmitted over the channel rather than unwanted data.

Data statistics clearly shows that f-OFDM offers 16% less error as compared to OFDM (less probability of

occurrences of error). Along with f-OFDM by using QAM modulation scheme, 28% errors are reduced while sending the information. Thus, f-OFDM scheme offers more advantages as compared to traditional system. There are various applications found for advanced modulation schemes in healthcare systems, Military field and optical communication as shown by researchers.²⁰⁻²²

Comparison with Existing Literature

The Proposed Optical system with f-OFDM technique is compared with the existing framework as mentioned by Mahmud.²³ It can be clearly seen in Table 2 that proposed system has enhanced performance in terms of signal to noise ratio. Since 16QAM is preferred with f-OFDM, so the comparison yields 56% increment in SNR as compared to already established system. This

is ensuring that optical based OFDM system can ensure security of data transmission with significant SNR.

Another parameter that has been improved in the designed framework is PAPR ratio that needed to be reduced value. For this aim, Table 2 depicts that PAPR is reduced significantly considering various modulation schemes, purposely QAM. Thus, the implementation of novel system in optical domain can widened new horizon of research. Optical spectrum can complement the available radio spectrum in the future very well.

Power spectral density for both designed system is presented in Fig. 10 which suggest that f-OFDM leads in power driving applications. The curves demonstrate the possibility of generating an OFDM as well as f-OFDM signal with noticeably better out-of-band suppression using 16 QAM technique. Apart from this,

Table 2 — Comparison of SNR (dB) & PAPR (dB) in proposed f-OFDM system with existing literature

Modulation Scheme	SNR (dB)			PAPR (dB)	
	Existing	Proposed	Improvement	Existing	Proposed
BPSK	18	24	33%	9.68	11.371
QPSK	19.6	24	22.4%	10.07	5.35
16-QAM	16	25	56.25%	NA	6.069

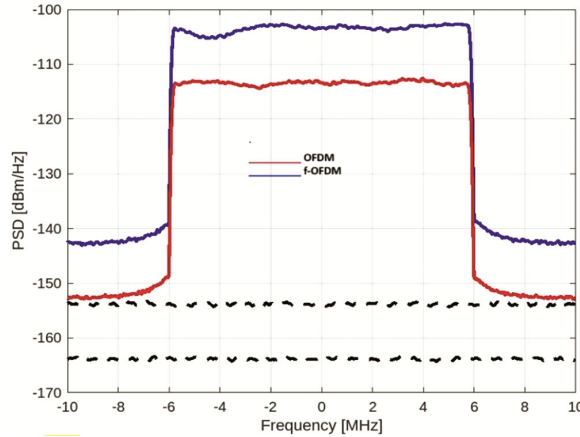


Fig. 10 — Comparison of power spectral density for OFDM & f-OFDM

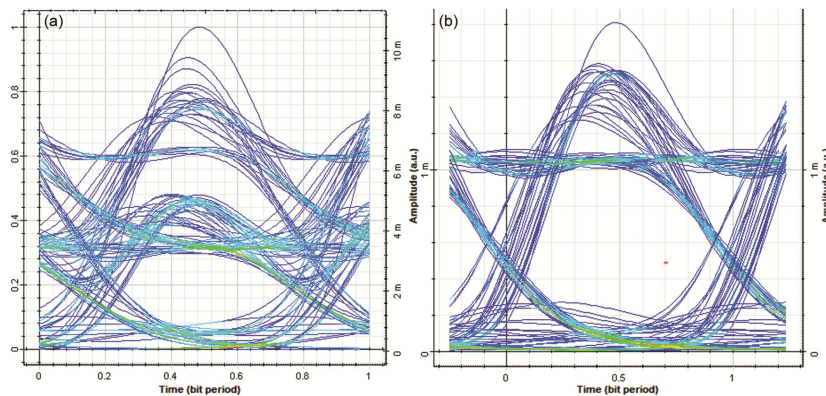


Fig. 11 — Illustration of eye diagram for (a) OFDM & (b) f-OFDM

eye diagram is also considered suggesting benefits of optical based f-OFDM system.

The integrity of signal and quality are defined by eye diagram in communication system which is shown in Fig.11 that depicts clearer waveform for f-OFDM system thus ensuring reduced inter symbol interference. F-OFDM shows a very low BER of -7.3 dB and a quite acceptable eye opening of $0.130e-06$ whereas eye opening in case of OFDM is lesser with higher BER (-5.7 dB).

Conclusions

This Paper evaluates the performance of OFDM & f-OFDM system using different modulation schemes like BPSK, QPSK, 8 PSK and 16 QAM using parameters namely- BER, SNR, PAPR and PSD. Simulation results depict an increase of 24.84% in SNR to 29.5% using QAM and also 16% less occurrence of error is observed by using f-OFDM as compared to traditional OFDM. The simulative analysis reveals the compatibility of system for IoT and guides pathway for OWC. With reference to future scope, the research can also be extended to Hybrid System with Equalizers & PAPR reduction schemes for enhanced performance. Most suitable application of this study involves prevention of unauthorized access in Defense, Medical sector and Intelligence Agencies. The limitation of the above study is high PAPR value which can affect the efficient data transmission. The system is applicative for indoor scenarios where path loss and environmental factors are less.

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