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BER Performance Analysis of OFDM, W-OFDM and F-OFDM for 5G Wireless Communications

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Abstract- Orthogonal Frequency Division Multiplexing (OFDM) is a pertinent multi-carrier modulation approach that is more immune to frequency selective fading. In the 5G waveform, in order to reduce the traffic in OFDM based on technology, it is important to re-size the bandwidth. Consequently, a spectrally localized waveform technology called Filtered Orthogonal Frequency Division Multiplexing (F-OFDM), which is primarily an approach to sub-band based filtering is introduced. Windowed-OFDM (W-OFDM), which is basically a classical OFDM scheme where each symbol is windowed and overlapped in the time domain. Each of the different sub-bands can be processed according to the traffic scenario. This paper presents the comparison of the performance analysis of MIMO-OFDM, MIMO-WOFDM, and MIMO-FOFDM systems using BPSK, QPSK, 16-PSK, QAM, 8-QAM and 16-QAM modulation techniques under Rayleigh fading channel.

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Abstract- Orthogonal Frequency Division Multiplexing (OFDM) is a pertinent multi-carrier modulation approach that is more immune to frequency selective fading. In the 5G waveform, in order to reduce the traffic in OFDM based on technology, it is important to re-size the bandwidth. Consequently, a spectrally localized waveform technology called Filtered Orthogonal Frequency Division Multiplexing (F-OFDM), which is primarily an approach to sub-band based filtering is introduced. Windowed-OFDM (W-OFDM), which is basically a classical OFDM scheme where each symbol is windowed and overlapped in the time domain. Each of the different sub-bands can be processed according to the traffic scenario. This paper presents the comparison of the performance analysis of MIMO-OFDM, MIMO-WOFDM, and MIMO-FOFDM systems using BPSK, QPSK, 16-PSK, QAM, 8-QAM and 16-QAM modulation techniques under Rayleigh fading channel. The main aim of this paper is to focus on analyzing the performance of OFDM, W-OFDM, and F-OFDM in terms of Power Spectral Density (PSD), Bit error rate (BER) and signal to noise ratio. The spectral efficiency in F-OFDM is dramatically increased by the reduction of out-of-band (OOB) emission rather than OFDM and W-OFDM. Simulation for the performance analysis of OFDM, W-OFDM, and F-OFDM is represented in terms of PSD and BER have done in MATLAB.

Keywords: OFDM, F-OFDM, W-OFDM, relay, MIMO, BPSK, QAM, BER, ISI.

I. Introduction

After years of discussions through the industry and academia, the requirements and expectations for the 5th generation (5G) cellular networks have been made clear. Whilst the millimeter wave is expected to deliver short-range with high-speed radio access by tens of Gbps the lower frequency bands (e.g., those are currently used by the 4G long-term evolution networks) will continue to provide ubiquitous and reliable radio access, but with an improved spectrum efficiency [1]. To this end, the air interface, mainly the underlying waveform, should be revisited. Next-generation cellular networks present the most challenging issues for researchers and engineers.

The main aim is to improve the actual LTE performance, in order to meet the growing data demand from the newly provisioned technologies and services [2]. For instance, increasing the data rate by a factor 100 with respect to LTE, while decreasing the latency from the actual 15 ms down to as low as approximately, 1 ms. Massive MIMO Enabling new technologies and services, such as Device-to-Device communications (D2D), Wireless Software Defined Networking (WSDN), Millimeter Wave communications and network Densification, are being utilized in order to reach 5G's goals [3] [4].

In this paper, we deal with problems concerning Radio Access techniques. As stated earlier, new services in 5G require high data rates with large spectral efficiency. For this reason, we focus on the spectral efficiency problem of a legacy the Orthogonal Frequency Division Multiplexing (OFDM) system, which has to improve its performance to achieve the required goal. As is well known, OFDM is the most important transmission technique of the recent past, largely used in LTE standards [5]. The principle of OFDM based on sub-carrier the division has been well studied and performed during the years and the first advantage of this scheme is its simplicity of implementation. Moreover, OFDM allows for simple modulation and demodulation and is highly MIMO friendly. On the other side, OFDM suffers from high PAPR (Peak-to-Average Power Ratio) and most of high Out-Of-Band (OOB) emissions. The required Cyclic Prefix (CP) and strict bounds for synchronization are other disadvantages of OFDM. Indeed, in a 5G scenario, it is desirable to use sub-bands that do not need to be perfectly synchronized with each other due to the different requirements of the multitude of devices on the network. In fact, in 5G we will have different kinds of devices that rarely connect to the network [5] [6]. For instance, an IoT (Internet of Things) device needs to send a few control bytes on rare occasions, and several kinds of devices will have a very short battery life. For these causes, it may be desirable to use a waveform with relaxed synchronization requirements [7].

This article attempts to summarize benefits and disadvantages of these two schemes currently being considered by 3GPP (Third Generation Partnership Project) for 5G applications, namely F-OFDM (Filtered OFDM) and W-OFDM (Windowed OFDM) based one BER, PSD and signal to noise ratio using BPSK, QPSK, 16-PSK, QAM, 8-QAM and 16-QAM modulation, we consider standard OFDM sub-bands, without using any strategy to reduce OOB emissions [8]. In the F-OFDM schemes, we consider low-pass filters in order to attenuate the OOB emissions and have an efficient sub-band divided system [9]. In the W-OFDM scenario, OOB

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emissions are reduced by smoothing the symbol transitions with a time domain window applied on each sub-band. Other results on f-OFDM can be found in the [10], which gives a closed form for ISI (Inter-Symbol Interference), ICI (Inter-Carrier Interference) and ACI (Adjacent-Channel Interference). Suggests a filter-bank version of f-OFDM, while discusses PAPR reduction in F-OFDM.

II. OFDM (Orthogonal Frequency-Division Multiplexing)

OFDM means Orthogonal frequency-division multiplexing. OFDM scheme requires N number of sub-carriers to transmit the number of data streams. Each of these carriers is orthogonal to other and centered at multiples of frequencies. These serial data streams are converted to N parallel data streams and then they are digitally modulated using appropriate modulation techniques like BPSK, QAM, PSK and others [11]. The constellation mapper or Lookup Table is used for the special purpose that is the modulation. For the superimposition of the modulated data on the orthogonal sub-carriers, it demands N sinusoidal oscillators tuned with N orthogonal frequencies that are parallel to each other.

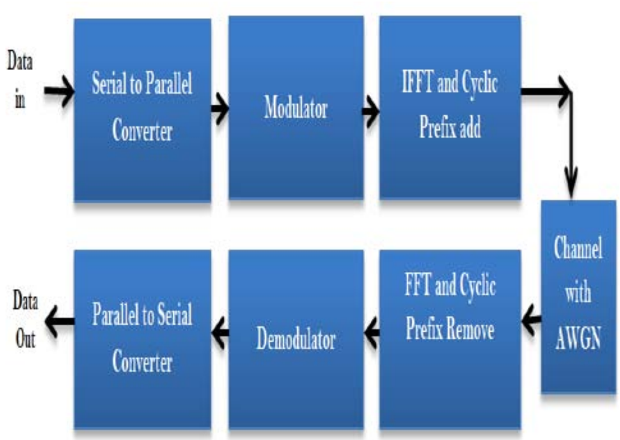

Figure 1: OFDM Architecture

The output of the sinusoidal oscillators is added up together that results to produce an final OFDM signal. These oscillators and the summer are replaced with an IFFT block that was recommended by Weinstein and Ebert to scale down the complexity of OFDM [11] [12]. From the IFFT output, the OFDM symbol samples are attained. The IFFT block switches the signal from frequency domain to time domain. Fig. 1 above shows the OFDM Architecture.

The Inter-symbol-Interference (ISI) imposes a negative impact on the OFDM which is induced by the specific delay spread. Delay spread occurs since multiple copies of the transmitted signals are received at different intervals of time rather than a single time. But the ISI results when the delay spread goes beyond the symbol time duration. The ISI can be eliminated by the use of the cyclic prefix [12]. The cyclic prefix is a manner of adjoining some portion of the OFDM symbol at the beginning of the OFDM symbol. The Inter-carrier-interference (ICI) can also be eliminated by the proper use of the cyclic prefix. The channel portion adds AWGN (Additive White Gaussian noise) to the received signal. The reverse operation of transmitter section appears at the receiver side. At the receiver section, the transmitted signal is converted from analog to digital and then removes the cyclic prefix portion. The receiver has to perform synchronization (both channel timing and frequency), channel estimation, demodulation, and decoding systems. The output from FFT and the input of the IFFT are same range [13] [14]. Finally, the original signal can be recovered by reassembling all data streams from the individual carrier.

III. Windowed OFDM (W-OFDM)

In this section, we illustrate time domain windowing strategy. Since, the signal high frequency components are generated by the discontinuities between adjacent OFDM symbols, softening these singularities with a proper transition lowers the OOB emissions [10].

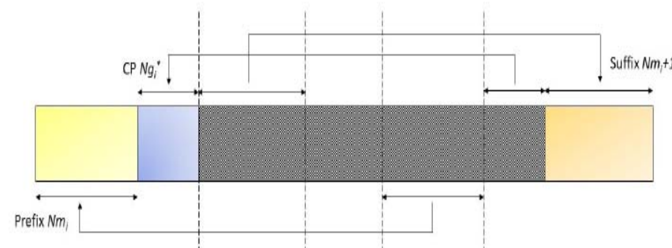

Figure 2: CP, prefix and suffix extension for a W-OFDM symbol

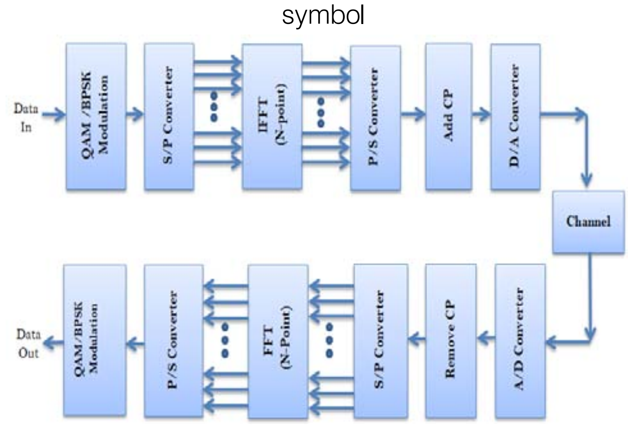

Figure 3: W-OFDM Architecture

The OFDM symbols must be elongated with the insertion of CP, prefix and suffix, then windowed and finally concatenated (by partially overlapping two consecutive symbols) according to fig.2. W-OFDM Architecture model is denoted by fig.3.

The first operation is to extend the OFDM symbol by copying the last N_{gi} samples of the native OFDM symbol at the beginning of the new W-OFDM symbol, as typically done for CP-OFDM [15]. The first N_{mi} samples are denoted as "prefix", while the remaining N_{gi} are denoted by CP. The W- OFDM symbol is then further extended by copying the first $N_{mi}+1$ samples of the native OFDM symbol at the end of the new W-OFDM symbol, as shown in the Figure. Native OFDM symbols in each sub-band may have different lengths; hence the parameter N_{mi} is used to denote the prefix or suffix parameter for the i^{th} sub-band. At this point the W-OFDM symbol that is denoted as X_i contains $N_i^W = N_i + N_{gi} + 2N_{mi} + 1$ samples [16]. However, prefix and suffix both will be smoothed with a windowing operation, and then the suffix of the i^{th} W-OFDM symbol will be overlapped with the first $N_{mi}+1$ samples of the $(i+1)^{th}$) W-OFDM symbol. The windowed symbol x_m is obtained from the extended symbol x via equation (1).

$$x_m = x_i \, . \, w_i \tag{1}$$

Where, w_i represents the window of length $N_i^{(w)}$. We use a window defined via equation (2).

$$w_i = \begin{bmatrix} 0^{(N_{mi} - N_{tri}/2)} . \\ 1^{(N_i + N_{gi} - N_{tri} + 1)} . \\ 0^{(N_{mi} - N_{tri}/2)} . \end{bmatrix} \tag{2}$$

Where, 0^Lrepresents a column vector of L elements filled by zeros, likewise 1^L is the similar type of vector filled by ones. The parameter N_{th} represents the window transition length, i.e. the number of samples the window spends to go from zero-to-one and from one-to-zero, N_{ri} is the transition length in the i^{th} of sub-band.

IV. Filtered OFDM (f-OFDM)

The transmission chain for f-OFDM is similar to that for the CP-OFDM, with an additional low-pass filter introduced

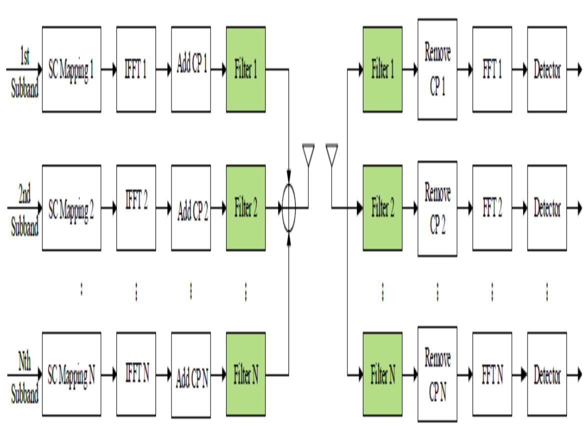

Figure 4: Downlink transceiver structure of F-OFDM

After the CP concatenation and the frequency shift in order to reduce the OOB emissions. Downlink transceiver structure of F-OFDM. is denoted by fig.4. Clearly, the structure of the transmitter low-pass filter is numerous important for reducing OOB emissions and possible interference. we want a filter perfectly flat in pass-band and zero outside this band, with null transition bands [17] [18]. This kind of filter is unrealizable but can be approximated by truncating and windowing the ideal sinc (.) impulse response. This operation introduces the new element in this framework, the filter transition bands. It is important to note that the transition bands are completely independent of frequency guard bands. Obviously having the transition band contained in the guard band could guarantee better performances. The filter has to be as flat as possible in the pass-band with tight transition bands section. To achieve this specific goal we have chosen a windowed-sinc filter with ideal impulse response

$$p_i\,(n) = \mathrm{Sinc}\,(\Delta f_i (N_{ui} + 2R_i)\; {}^{n}/_{N_i}\,) \tag{3}$$

For $-\lceil L_i/2 \rceil \leq n \leq \lceil L_i/2 \rceil$, Where L_i represents the filter order and $\Delta f_i R_i$ the transition band in one side. p_i (n) doesn't represent our final filter, it is only a truncated based sinc. The Role of transition bands of the filter is given below by the fig.5.

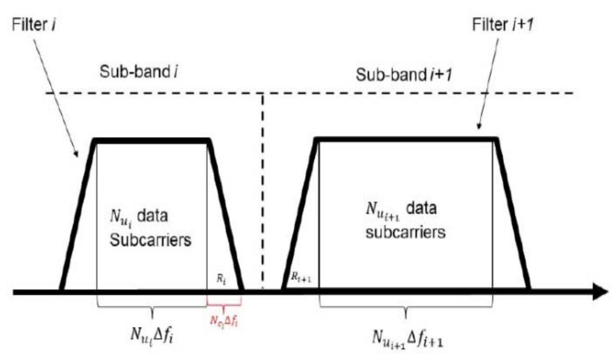

Figure 5: Role of transition bands of the filter

The final coefficients of our normalized low pass filters are given by the equation (4).

$$f_i\,(n) = \frac{p_i(n).w_i(n)}{\sum_k p_i(k).w_i(k)} \tag{4}$$

$$w_i(n) = (0.5(1+\cos(\tfrac{2\pi n}{L_i - 1})))^{0.5} \tag{5}$$

Where, n is bounded as in equation. The filter impulse response contains $2L_i+1$ samples, that causes a signal extension in the time domain by 2 L_i samples. Fortunately, this kind of filter has the major part of its energy concentrated in the Sinc lobe, so the elongation is important just for a small time period during the CP of the symbol [19]. For this reason, it is not necessary to choose Li to be very small, specifically L_i can be larger than L_{gi} (length of the cyclic prefix).

V. System Model

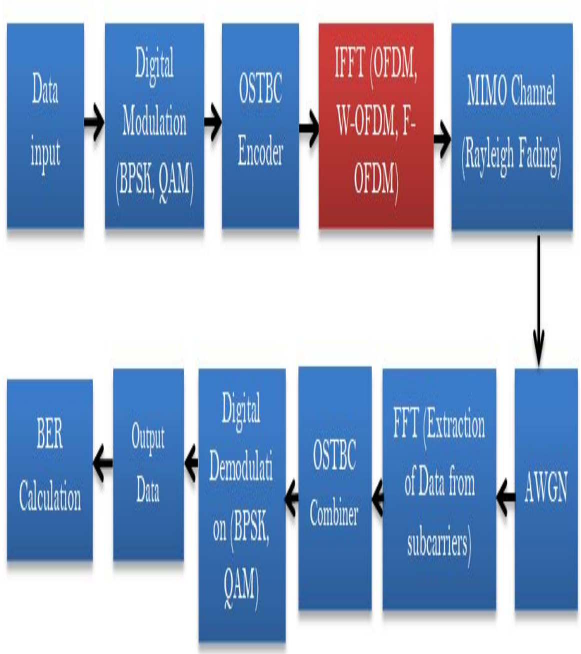

Figure 6: MIMO incorporated OFDM, WOFDM and F-OFDM wireless system

The MIMO incorporated OFDM, W-OFDM and F-OFDM-WOFDM systems are modeled using Orthogonal Space Time Block Coding (OSTBC) technique, having symbol wise maximum likelihood (ML) decoding, to attain the high diversity gains in order to obtain higher data rates. The proposed system model is demonstrated in Fig.6. For simulation, the random binary signal is created and modulated by employing the different modulation techniques such as BPSK, QPSK, 16-PSK, QAM, 8-QAM and 16-QAM. The signals are encoded via orthogonal space time block codes for transmission over the Rayleigh fading channel. Five independent antennas links are formed, out of which four are served as transmitting antennas and the remaining four are acting as receiving antennas. During the transmission through the channel, IDWT transformation is performed after the OSTBC encoding. For W-OFDM transmission, the information is first grouped and mapped according to the modulation and hen, is sent to inverse discrete wavelet transform (IDWT), which converts frequency domain signal into time domain signal and also provides orthogonality similarly for F-OFDM. The simulation adds white the Gaussian noise at the receiver process. Then, it combines the signals from both receive antennas into a single stream for the demodulation. Afterward, DWT is applied at the receiver side to reconstruct the signal in frequency domain. Total of 192 Samples per frame have been taken. Bits per symbol considered for the simulation is 100. W-OFDM and F-OFDM symbol rates are 10Ksps and the symbol period is 10-6s. The system is designed over four transmitting antennas and four receiving antennas (4 x 4) employing an independent Rayleigh fading for transmission of data.

VI. Results and Analysis

Table 1: Summary of Simulated Model Parameters

Parameter	Considerations for Simulation
Modulation Scheme	BPSK,QPSK,16-PSK,QAM,8QAM, and 16-QAM
Channel	Rayleigh Fading Channel
Multiplexing	OFDM, W-OFDM, F-OFDM
Samples per frame	192
No. of transmitting & receiving antennas	4*4
Signal to Noise Ratio	0 to 25dB

PSD -40 dB

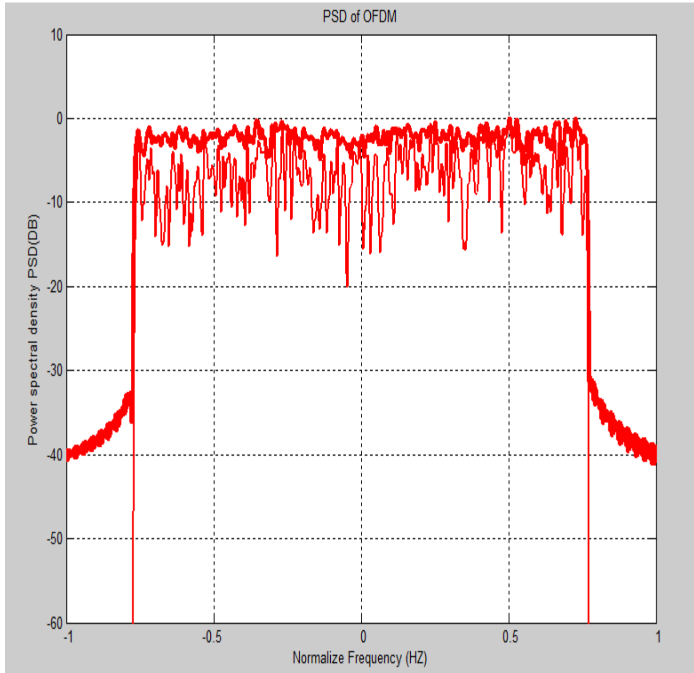

Figure 7: Power spectral density (PSD) of OFDM.

PSD -50 dB

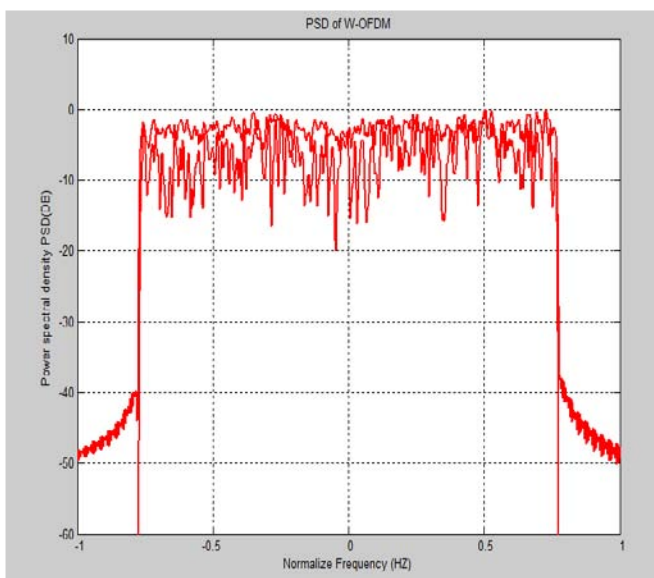

Figure 8: Power spectral density (PSD) of W-OFDM

PSD -60 dB

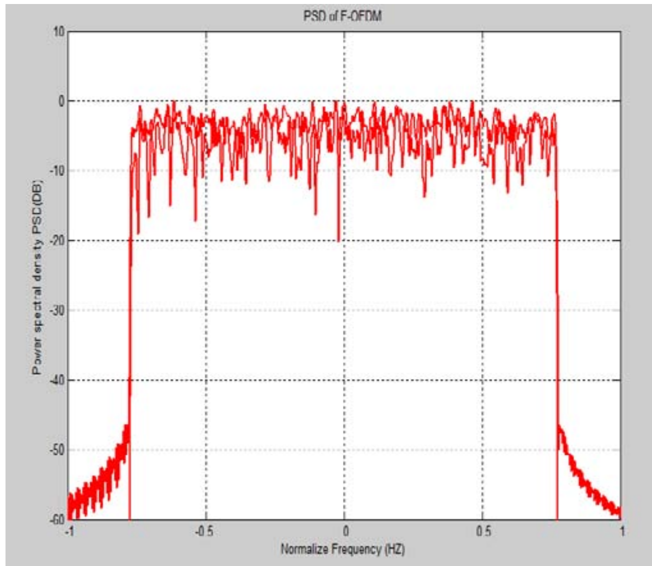

Figure 9: Power spectral density (PSD) of F-OFDM

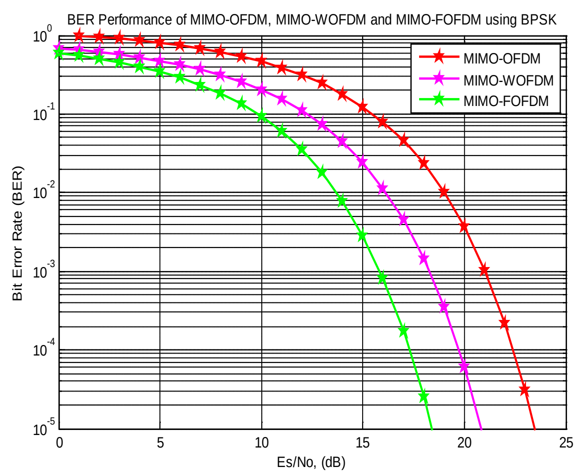

Figure 10: BER FOR MIMO-OFDM, MIMO-WOFDM and MIMO-FOFDM over Rayleigh Fading Channel using BPSK

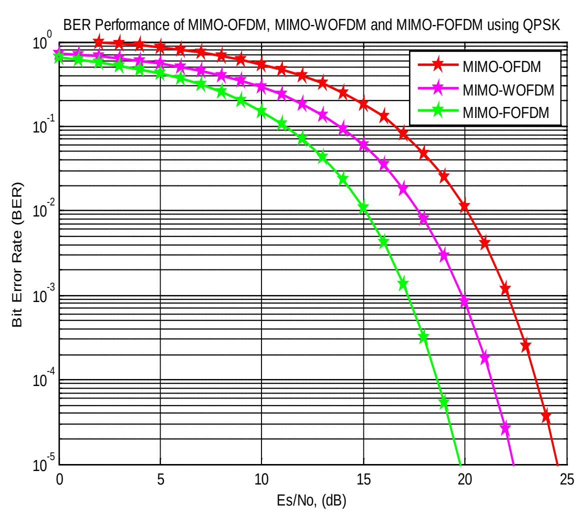

Figure 11: BER For MIMO-OFDM, MIMO-WOFDM and MIMO-FOFDM over Rayleigh Fading Channel using QPSK

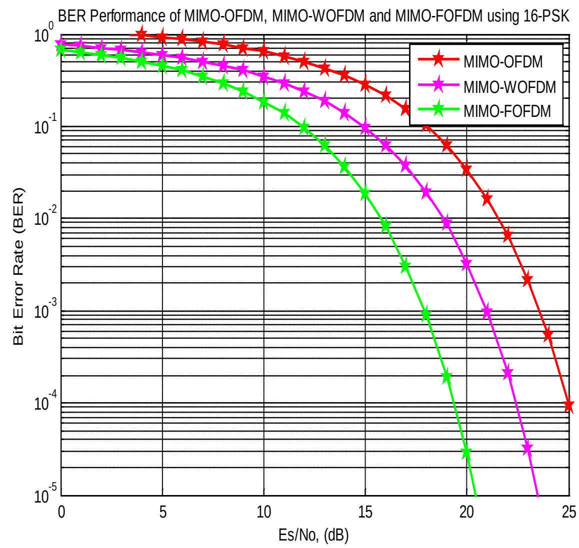

Figure 12: BER for MIMO-OFDM, MIMO-WOFDM and MIMO-FOFDM over Rayleigh fading channel using 16-PSK

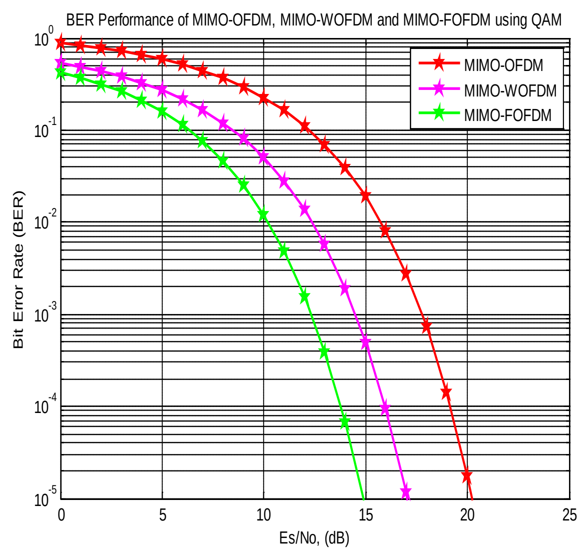

Figure 13: BER for MIMO-OFDM, MIMO-WOFDM and MIMO-FOFDM over Rayleigh fading channel using QAM

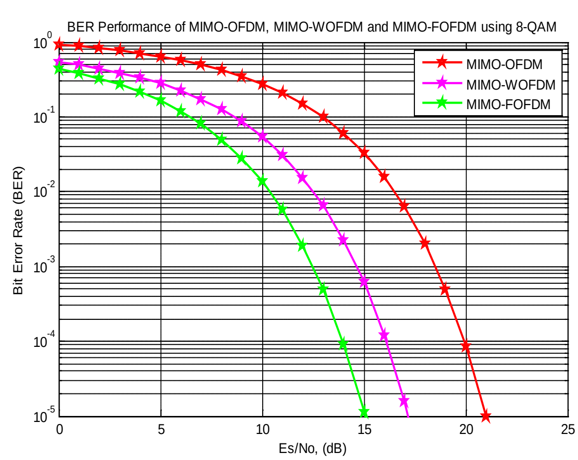

Figure 14: BER for MIMO-OFDM,MIMO-WOFDM and MIMO-FOFDM over Rayleigh fading channel using 8-QAM.

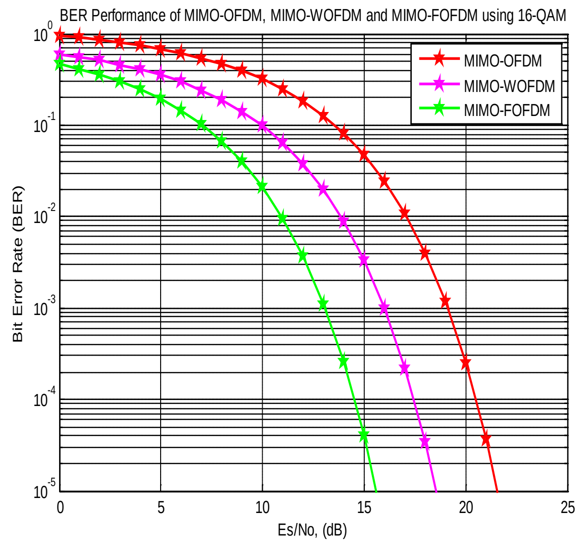

Figure 15: BER for MIMO-OFDM, MIMO-WOFDM and MIMO-FOFDM over Rayleigh fading channel using 16-QAM

Table 2: Data Table of Modulations, Multiplexing, Ber (Bit Error Rate) and Snr (Signal to Noise Ratio)

Modulation	Multiplexing	BER	SNR
BPSK	OFDM	10^{-5}	23 dB
	W-OFDM	10^{-5}	21 dB
	F-OFDM	10^{-5}	18 dB
QPSK	OFDM	10^{-5}	24 dB
	W-OFDM	10^{-5}	23 dB
	F-OFDM	10^{-5}	19.6 dB
16-PSK	OFDM	10^{-5}	29 dB
	W-OFDM	10^{-5}	24 dB
	F-OFDM	10^{-5}	21 dB
QAM	OFDM	10^{-5}	21 dB
	W-OFDM	10^{-5}	17 dB
	F-OFDM	10^{-5}	14.8 dB
8-QAM	OFDM	10^{-5}	22 dB
	W-OFDM	10^{-5}	17 dB
	F-OFDM	10^{-5}	15 dB
16-QAM	OFDM	10^{-5}	22 dB
	W-OFDM	10^{-5}	18 dB
	F-OFDM	10^{-5}	16 dB

VII. Conclusions

In this paper, the performance of MIMO-WOFDM system and its assessment with MIMO-OFDM, MIMO-WOFDM and MIMO-FOFDM systems by means of various modulations techniques is presented in this work. The SNR requirements for higher order PSK schemes are more to the acceptable range of BER over the simulated channel. It is also noteworthy that the higher orders of the QAM scheme have a little bit of significant influence over the performance of the both simulated systems. Moreover, QAM requests lesser SNR as contrast to PSK for suitable BER for both the systems. To analyze BER, PSD and signal to noise ratio with BPSK, QPSK, 16-PSK, QAM, 8-QAM and 16-QAM modulation it can be concluded that among three multiplexers (OFDM, W-OFDM, and F-OFDM) F-OFDM provides high performance and bandwidth efficient in the wireless system.

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