Effect of Path Loss Models on Performance of 5G Compatible MIMO WINDOW-OFDM Systems

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Abstract— In wireless communication systems, MIMO (multiple-input and multiple-output) antenna architectures have the capability to enhance channel capacity and reliability. OFDM (Orthogonal frequency division multiplexing) is another proposed technique which is popular for high speed data transmission, robustness to frequency selective channels, low OOB (Out of Band) emission, and low PAPR (Peak to Average Power Ratio). To gain very high data rates for vast number of powerful multimedia and AI capable devices employment of mm-waves frequency bands with the above two technologies is one of the major advancements. But the problems of propagating mm-wave frequency signals are time delay, fading, propagation and scattering losses. So to attain better performance, optimizations of propagation parameters are crucial. This paper shows the effect of Path Loss (PL) models (ABG and CI) to design and analysis of 4×4 MIMO W-OFDM system using several modulation techniques (16-DPSK, 16-PSK, and 16-QAM) for 5G wireless communication. For window filters, Blackman, Hamming, and Bartlett windows have been considered.

***Keywords*—** FSPL, ABG (Alpha-Beta-Gamma), CI (Close In), MIMO, BER, MMSE, W-OFDM.

I. Introduction

The growing need for higher data rates and better quality of services in wireless communication systems have forced the designers of the emerging communication systems to invent new approaches toward improvements of the data rates, spectral efficiency, reliability and minimization of bit error rate(BER). It is expected to experience a 23 times increase in data volume in 2021 as compared to entire global Internet traffic in 2005. It is estimated that, in 2020-2030, without machine-to-machine (M2M) communication, the mobile data traffic (MDT) will grow at an annual rate of around 54% and including M2M communication MDT will grow at an annual rate of around 55%. Without M2M communication, estimated global MDT per month will be 543 Extra bytes (EB) in 2025 and 4394 Extra bytes (EB) in 2030. Including M2M communication, global MDT per month would then be estimated to reach to 607 EB in 2025 and 5016 EB in 2030 [1, 2]. To attain the requirements of predicted data traffics several 5G enabling technologies i.e., advance mm-wave frequency, advanced MIMO, W-OFDM, multi-Radio access technology (RAT), multiple access technologies, advanced D2D (device to device) communication and small cell technologies have been considered [3, 4, 5 and 6]. The raw bandwidths available at mm-waves bands are the desired resources to achieve multi Gbps (Gigabit per second) data rate that release data traffic congestion for mobile devices operating at lower frequency bands [7]. The usages of higher order MIMO systems in order to achieve higher data rates and reliability for cellular systems have received significant attention over the last decade [8]. Massive MIMO is one of the promising methods in order to reduce large propagation loss and achieve efficient frequency usage [9]. But having little room in the smartphones, embedding more antennas inside is very challenging. Recently, to enhance the channel capacity researchers propose 10, 16 or 20 antennas based systems which are promising to perform massive MIMO operation [10, 11 and 12]. In this work, we have considered 4-antenna structure for advanced 4×4 MIMO operation for 5G enabled smartphones. For the development of wireless communications waveforms are considered consistent and fundamental factors. The cyclically prefixed OFDM (CP-OFDM) is the key factor for the success of 4G LTE (Long-Term Evaluation). It is formulated to combat against the effect of multipath response by improving spectral efficiency and significantly mitigating ISI (inter-symbol interference). It is also MIMO friendly. However, OFDM cannot fulfill the requirements for 5G heterogeneous network scenarios because it has high OOB emission and large PAPR, and it supports only one kind of waveform parameter within the whole bandwidth. The W-OFDM is one of the proposed techniques for 5G enabled spectrally efficient high data rate services. It uses simple window to regulate OOB emission and PAPR [5, 13 and 14]. In this paper different finite impulse response (FIR) digital filters (Blackman, Hamming and Bartlett) are used as windows and the performances of considered window functions implemented W-OFDM have been discussed. To design accurate and reliable 5G system proper knowledge of the channel characteristics at mmWave frequencies is necessary[15]. In this paper, we have considered two large-scale PL models (ABG and CI) on 4x4 MIMO W-OFDM technologies over mmWave frequency band [16].

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II. Free Space Path loss (FSPL) Model

For wireless communication, the radio signal departs from transmitter antenna and it undergoes an experience which is known as FSPL. PL describes that the radio signal travels through the free space (FS), it enlarges outward and that causes reduction in power levels. For all radio signals it is true that high frequency signals (e.g., 6 GHz) experience greater PL as compared to lower frequency signals (e.g., 2 GHz). Link Power Budgets calculate antenna gain and power of transmitter antenna as techniques to compensate for PL. If the ratio of PL minimized the radio signal will be able to propagate more perfectly and efficiently in between transmitter antenna to receiving antenna.

FSPL is the attenuation of radio energy or loss in strength of a signal between the feed points of two antennas. FSPL is calculated by the equation (1).

$$\mathrm{FSPL} = 20 \log_{10}(\mathrm{d}) + 20 \log_{10}(\mathrm{f}) + 20 \operatorname{Log}_{10}\left(\frac{4\pi}{\mathrm{C}}\right) \quad (1)$$

where distance between transmitter to receiver is d = 100 m and operating frequency f = 28 GHz.

For better comparison, we also consider two PL models as stated earlier [16]. First we consider CI FS reference distance PL model. The equation of CI FSPL model is given by the equation (2)

$$\mathrm{PL}^{\mathrm{CI}}(\mathrm{f}, \mathrm{d})\,[\mathrm{dB}] = \mathrm{PL}_{\mathrm{FS}}(\mathrm{f}, d_0)\,[\mathrm{dB}] + 10\, \mathrm{n}\, Log_{10}\left(\frac{\mathrm{d}}{\mathrm{d}_0}\right) \quad (2)$$

$\mathrm{PL}_{\mathrm{FS}}$ (f, d_0) is the FS propagation loss at distance of d_0 = 1 m for isotropic antenna in that equation (2) and n is the PL exponent [18]. For that we can derive equation (3) as below

$$\mathrm{PL}^{\mathrm{CI}}(\mathrm{f}, \mathrm{d})\,[\mathrm{dB}] = \mathrm{PL}_{\mathrm{FS}}(\mathrm{f}, 1m)\,[\mathrm{dB}] + 10\, \mathrm{n}\, \operatorname{Log}_{10}(\mathrm{d}) \quad (3)$$

Now the equation of FS propagation loss at distance d_0 = 1 m becomes

$$\mathrm{PL}_{\mathrm{FS}}(\mathrm{f}, 1m)\,[\mathrm{dB}] = 20 \operatorname{Log}_{10}\left(\frac{4\pi\mathrm{f}}{\mathrm{C}}\right) \quad (4)$$

where C is the speed of light. From equation (3) and (4) we can get the final equation of CI model that is

$$\mathrm{PL}^{\mathrm{CI}}(\mathrm{f}, \mathrm{d})\,[\mathrm{dB}] = 20 \operatorname{Log}_{10}\left(\frac{4\pi\mathrm{f}}{\mathrm{C}}\right) + 10\, \mathrm{n}\, \operatorname{Log}_{10}\left(\frac{\mathrm{d}}{\mathrm{d}_0}\right) \quad (5)$$

The second PL model is ABG model [16, 17]. The equation of ABG model is given by the equation (6)

$$\mathrm{PL}^{\mathrm{ABG}}(\mathrm{f}, \mathrm{d})\,[\mathrm{dB}] = 10 \propto \operatorname{Log}_{10}(\mathrm{d}) + \beta + 10\, \gamma \operatorname{Log}_{10}(\mathrm{f}) \quad (6)$$

where $\mathrm{PL}^{\mathrm{ABG}}$(f, d) [dB] denotes the PL in dB on frequency f and distance d, $\propto$ and γ represent the coefficients dependence of PL on distance and frequency, similarly β represents an optimized offset value for PL in dB, d is the distance between transmitter to receiver and f is the carrier frequency in GHz.

The parameters $\propto$, β and γ are chosen for the line of sight communication in a suburban environment and the value of these parameters are given below by second bracket.

$$\begin{cases} \propto = 1 \\ \beta = 69.4 \\ \gamma = 2 \end{cases}$$

Separation, d, between transmitter and receiver has been considered 100 m and frequency f has been considered 28 GHz for simulations.

In the equation (5) CI model have an inherent frequency dependency of PL and it has only one parameter. Its frequency dependence can be expressed primarily by the frequency dependent FSPL term [17].

On the other side equation (6) the ABG models has three parameters alpha, beta and gamma has not only depend on frequency but also depend on several parameters [16].

III. Proposed System Model

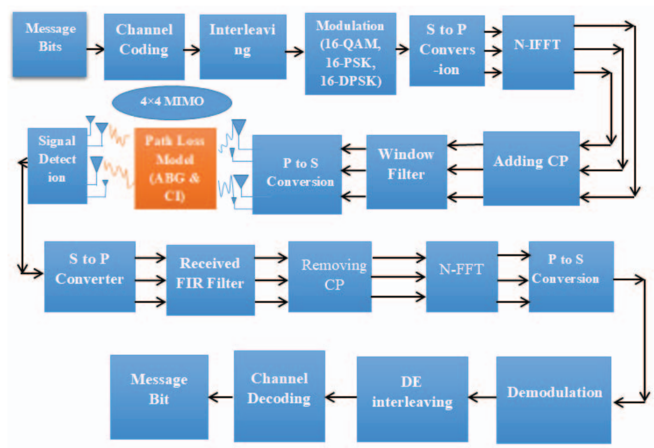

Fig. 1: Proposed system model of 4×4 MIMO for reducing BER using Path loss Models and Window-OFDM.

In order to improve the bit error rate (BER) two types of PL model (ABG & CI) have been used in between transmitter and receiver antenna. Proposed system model is shown in Figure 1. This is based on W-OFDM system instead of conventional OFDM system. Firstly, bits of stream have been used as an input that transmits only a single binary bit of information. Bits of stream pass through the channel coding also known as forward error control coding that will detect and correct bit error in digital communication system. During encoding, data bits are placed to left positioned shift register of length *K*, known as constraint length, and then bits are shifted to the right while the last bit in the register is removed. After finishing channel coding the next step is interleaving. Interleaving is implemented for combating bursts of error, chi n is used as input bit sequence that follows the formulas gamma n = chi pi n, where n = 0,....,N-1, in between pi n and n, the bridge function has been used

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based on a spline linear model. The next step is modulation, that is the process of imposing digital information signal on to a very high-frequency carrier signal. On the other hand demodulation is the reverse process of modulation and is performed at the receiving end. Here three modulations (16-DPSK, 16-QAM, and 16-PSK) techniques have been used.

In the IFFT section we have considered N OFDM Channels. Every channel produces its own OFDM symbol. It receives its N 16-DPSK or 16-PSK or 16-QAM symbols. These N symbols are converted by an IFFT to the N OFDM symbols in time domain. The inverse is made in the receiver path where the N OFDM symbols are converted back to the frequency domain by FFT. In this work N = 256 FFT size has been considered. Cyclic prefix to the prefix of symbol, where a portion of OFDM symbols are added at the end. For reducing inter-symbol interference from the prior symbol, cyclic prefix supplies a guard interval. To design the digital filter window filters have been used. For conversion of the ideal impulse response of infinite duration to the finite impulse response, window filters are used broadly. That is the basic concept of the window method. The Blackman window, Hamming window and Bartlett window have been used in our system model for simulation. 100 m distance has been considered for the proposed system model with two PL models ABG and CI. ABG model is used for reducing the PL for data transmission from transmitter antenna to the receiving antenna. The value of α = 1, β = 69.4 and γ = 2 have been considered for simulation. On the other hand, for minimizing the power loss of radio signal CI FSPL model is one of the popular techniques. Through CI FSPL model the radio signal propagates with proper strength that is the primary requirement for transferring huge rates of data for 5G wireless communication. Proper formulation of the PL model ensures the proper propagation of the radio signals. MIMO is a popular technique that enhances the channel capacity by increasing the numbers of transmitting and receiving antennas. 4×4 MIMO denotes that the number of antennas in the receiving section and the transmitting section are four. In several technologies like 4G LTE, WiMAX, HSPA+ (3G), and IEEE 802.11ac (Wi-Fi) MIMO has become a well-known technology for wireless communications.

IV. RESULTS AND ANALYSIS

TABLE 1
Summary of Simulated Model Parameters

Parameters	Types
Matlab Version	2014a
Message Type	12800 binary bits
Operating frequency (f)	28 GHz
Carrier Spacing	60 kHz
Data Rate	48 Mbps
Bandwidth	20 MHz
Antenna configuration	4x4
Channel Coding	½ Rated Convolutional Code
d_0	1
Alpha (α)	1
Beta (β)	69.4
Gamma (γ)	2
Digital Modulation	16-DPSK, 16-QAM, 16-PSK
IFFT / FFT Size	256
FIR (Band pass) Filters	Bartlett, Hamming, Blackman
Signal Detection(Channel Estimation) Scheme	MMSE (Minimum Mean Square Error)
SNR	-10 to 8 dB
Channel	Geometric channel
Distance Considered (d)	100 m

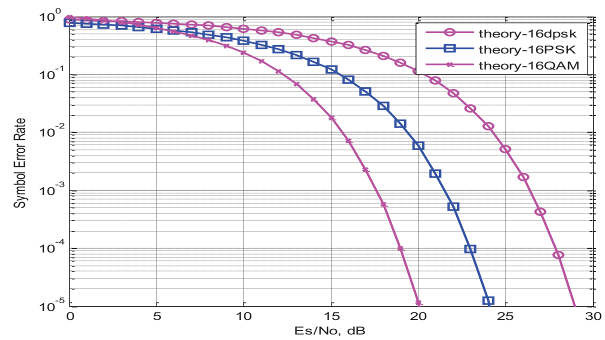

Fig. 2: Probability of Symbol Error curve for 16-DPSK, 16-QAM, and 16-PSK.

Fig. 2 provides that the probability of symbol error is minimum for the 16-QAM then 16-PSK and finally 16-DPSK. By decreasing the symbol error probability we can transfer the data accurately. If the symbol error probability is increasing then the probability of error will be increased. Considering above issue we can compare the probability of symbol error for digital modulations that is probability of symbol error is 16-DPSK > 16-PSK > 16-QAM.

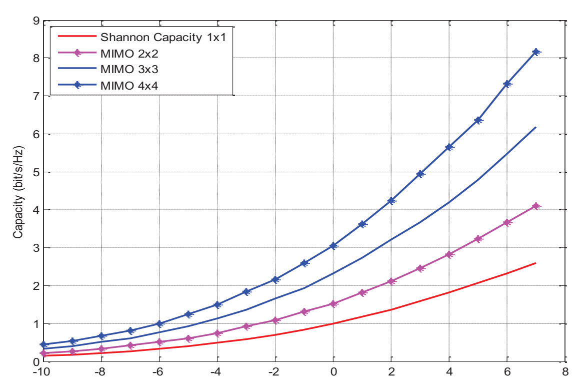

Fig.3: Channel Capacity for SISO and various MIMO configurations.

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Fig. 3 provides the Channel Capacity for SISO and various MIMO configurations. If the number of antenna increased the capacity will be increased, for this reason the channel capacity will be maximum for MIMO 4×4 and channel capacity will be minimum for SISO.

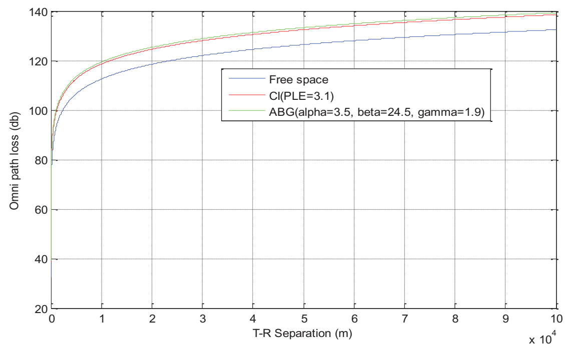

Fig. 4: Comparison of FS, CI, and ABG PL Models.

Fig. 4 provides the comparison of FS, CI and ABG PL Models. Among the three PL models, the FSPL model provides the minimum PL than the CI model and then ABG (alpha = 3.5, beta = 24.5, gamma = 1.9) model.

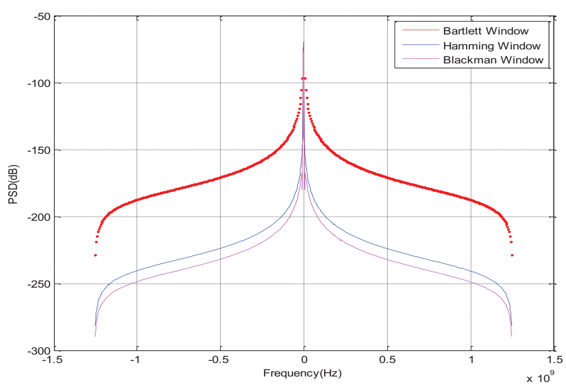

Fig. 5: Power spectral density (PSD) of Bartlett, Hamming and Blackman filters.

Fig. 5 presents the estimated Power Spectral Density (PSD) of Bartlett, Hamming, and Blackman window filters for window length 1024. It is quite noticeable that the Blackman windowing technique provides the best stop-band rejection performance in comparison to other windowing filters. The estimated OOB power for Bartlett, Hamming, and Blackman filters are 228.5222 dB, 281.5992 dB and 289.7492 dB respectively.

From Fig. 6 to Fig. 11, we can observe that the BER curves provide distinguishable differences among system performances under implementation of MIMO with MMSE signal detection and various digital modulation (16-DPSK, 16-PSK, and 16-QAM) schemes with W-OFDM and PL Models (ABG and CI). From these figures, we can clearly notice that combination gives better performance through BER performance comparison according to SNR.

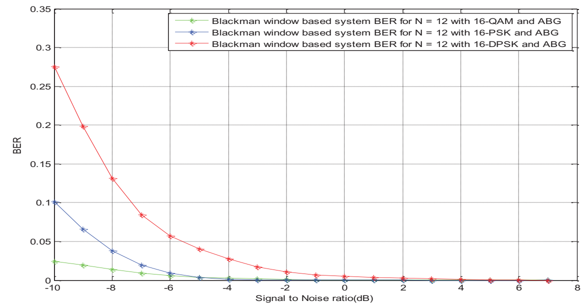

Fig. 6: Blackman window based MIMO W-OFDM system BER for N = 12 with 16-DPSK, 16-PSK, 16-QAM and ABG model.

From fig. 6 the BER values of 16-DPSK, 16-PSK, and 16-QAM are 0.275, 0.100, and 0.023 respectively at -10 dB SNR. Now we can find the minimum BER above three modulations, that is **16-QAM (BER = 0.023**) < 16-PSK (BER = 0.100) < 16-DPSK (BER = 0.275).

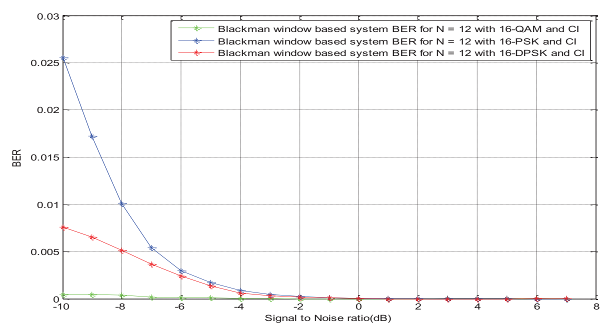

Fig. 7: Blackman window based MIMO W-OFDM system BER for N = 12 with 16-DPSK, 16-PSK, 16-QAM and CI model.

From fig. 7 the BER values of 16-DPSK, 16-PSK and 16-QAM are 0.026, 0.007 and 0.002 respectively at -10 dB SNR. Now we can find the minimum BER above three modulations, that is, **16-QAM (BER = 0.002**) < 16-PSK (BER = 0.007) < 16-DPSK (BER = 0.026)

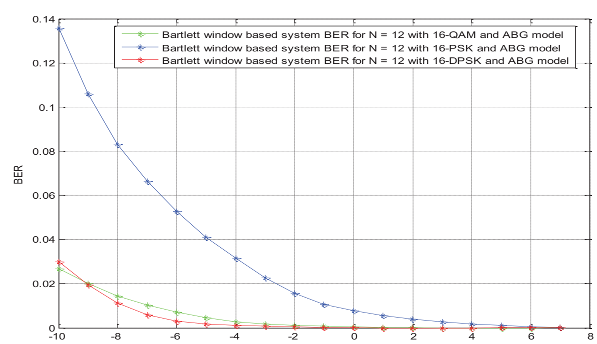

Fig. 8: Bartlett window based MIMO W-OFDM system BER for N = 12 with 16-DPSK, 16-PSK, 16-QAM and ABG model.

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From fig. 8 the BER values of 16-DPSK, 16-PSK and 16-QAM are 0.030, 0.138 and 0.028 respectively at -10 dB SNR. Now we can find the minimum BER above three modulations, that is, **QAM (BER = 0.028)** < **16-DPSK (BER = 0.030)** < 16-PSK (BER = 0.138).

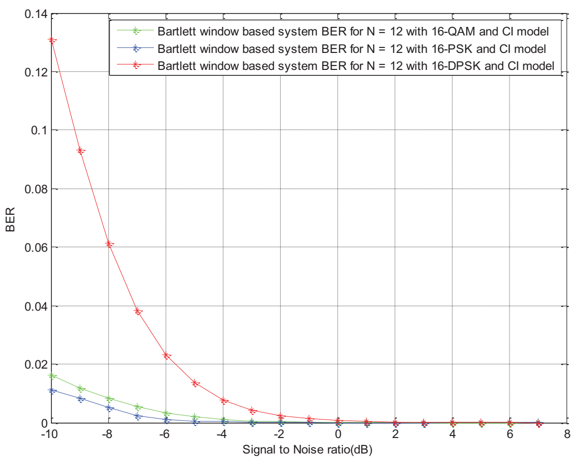

Fig. 9: Bartlett window based MIMO W-OFDM system BER for N = 12 with 16-DPSK, 16-PSK, 16-QAM and CI model.

From fig. 9 the BER values for 16-DPSK, 16-PSK, and 16-QAM are 0.130, 0.015, and 0.018 at -10 dB SNR. Now we can find the minimum BER above three modulations, that is, **16-PSK (BER = 0.015**) < 16-QAM (BER = 0.018) < 16-DPSK (BER = 0.130).

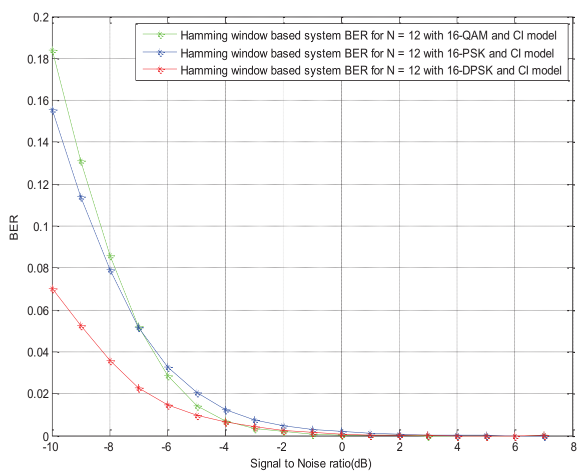

Fig. 10: Hamming window based MIMO W-OFDM system BER for N = 12 with 16-DPSK, 16-PSK, 16-QAM and CI model.

From fig. 10 the BER values for 16-DPSK, 16-PSK, and 16-QAM are 0.070**,** 0.158, and 0.182 respectively at -10 dB SNR. Now we can find the minimum Bit Error Rate (BER) above three modulations, that is, **16-DPSK (BER = 0.070**) < 16-PSK (BER = 0.158) < 16-QAM (BER = 0.182).

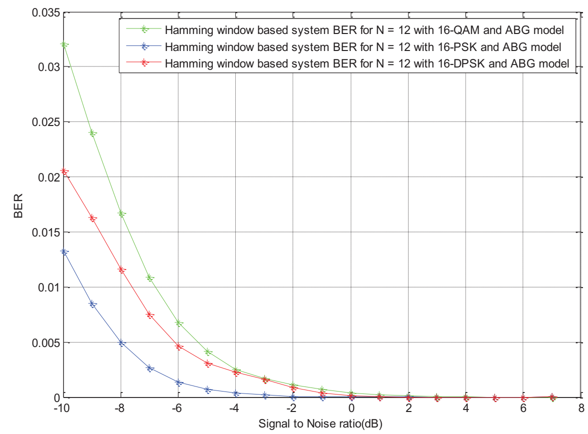

Fig. 11: Hamming window based MIMO W-OFDM system BER for N = 12 with 16-DPSK, 16-PSK, 16-QAM and ABG model.

From fig. 11 The BER values for 16-DPSK, 16-PSK and 16-QAM are 0.021, 0.013, and 0.032 respectively at -10 dB SNR. Now we can find the minimum BER for above three modulations, that is, **16-PSK (BER = 0.013**) < 16-DPSK (BER = 0.021) < 16-QAM (BER = 0.032).

TABLE 2

Selections of minimum BER based on PL Models, different window and modulation systems.

Window Name	Path Loss Model (ABG & CI)	Modulation Name	SNR (db)	BER	Selection
Blackman	ABG	16-QAM	-10	0.023	✓
		16-PSK	-10	0.100	
		16-DPSK	-10	0.275	
Blackman	CI	16-QAM	-10	0.002	✓
		16-PSK	-10	0.007	
		16-DPSK	-10	0.026	
Bartlett	ABG	16-QAM	-10	0.028	✓
		16-PSK	-10	0.138	
		16-DPSK	-10	0.030	
Bartlett	CI	16-QAM	-10	0.018	
		16-PSK	-10	0.015	✓
		16-DPSK	-10	0.130	
Hamming	ABG	16-QAM	-10	0.032	
		16-PSK	-10	0.013	✓
		16-DPSK	-10	0.021	
Hamming	CI	16-QAM	-10	0.182	
		16-PSK	-10	0.158	
		16-DPSK	-10	0.070	✓

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TABLE 3

Second Selections of minimum BER based on PL Models, and different window and modulation systems.

Window Name	Path Loss Model (ABG & CI)	Modulation Name	SNR (db)	BER	Selection
Blackman	ABG	16-QAM	-10	0.023	
Blackman	CI	16-QAM	-10	0.002	✓
Bartlett	ABG	16- QAM	-10	0.028	
Bartlett	CI	16-PSK	-10	0.015	✓
Hamming	ABG	16-PSK	-10	0.013	✓
Hamming	CI	16-DPSK	-10	0.070	

TABLE 4

Final Selections of minimum BER based on PL Models, and different window and modulation systems.

Window Name	Path Loss Model (ABG & CI)	Modulation Name	SNR (db)	BER
Blackman	**CI**	**16-QAM**	**-10**	**0.002**
Bartlett	CI	16-PSK	-10	0.015
Hamming	ABG	16-PSK	-10	0.013

From Table 4 it is clear that Blackman window, CI PL model and 16-QAM digital modulation based MIMO W-OFDM system shows minimum BER performance as compared to other two combinations. At -10 dB SNR, Blackman window, CI PL model and 16-QAM digital modulation based MIMO W-OFDM system performs enhancement of 8.12 dB as compared to Bartlett window, CI PL model and 16-PSK digital modulation based MIMO W-OFDM system and 8.75 dB as compared to Hamming window, ABG PL model and 16-PSK digital modulation based MIMO W-OFDM system.

In the perspective of PAPR, the estimated values are 9.401 dB and 9.4523 dB in case of W-OFDM system and CP OFDM system respectively. Such PAPR values show that the PAPR performance of W-OFDM is better than CP-OFDM system.

V. Conclusions

In this paper, a comprehensive study of MIMO W-OFDM system has been made by exploiting ABG and CI PL models to analyze minimum BER, channel capacity of various MIMO configurations, PSD of filters and PAPR by using 16-DPSK, 16-PSK, 16-QAM digital modulations and Blackman, Bartlett and Hamming window filters under the implementation of MMSE signal detection scheme. From simulation study it can be said that CI PL model based MIMO W-OFDM system with Blackman window and 16-QAM digital modulation is very much robust and effective in retrieving transmitted signals.

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