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Offset Phase Shift Keying Modulation in Multiple-Input Multiple-Output Spatial Multiplexing

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ABSTRACT

The increasing demand for multimedia data transmission in mobile wireless communication poses a challenge to reliable signal reception. In order to have good signal quality, a robust digital modulation scheme is required at the transmitter. However, the conventional M-ary Phase Shift Keying (MPSK) commonly used in multiple-input multiple-output (MIMO) communication systems with non-linear radio frequency (RF) power amplifiers causes a relative increase in intercarrier interference (ICI). This paper presents a development of offset-MPSK (O-MPSK) modulation scheme in MIMO spatial multiplexing over the Rayleigh fading channel.

The O-MPSK modulation schemes were developed for 4, 8, 16, 32 and 64 constellation sizes. The development of the O-MPSK was done by shifting the phase of the conventional QPSK, 8-PSK, 16-PSK, 32-PSK and 64-PSK by an odd multiple of pi (π) to give $\pi/2$-QPSK, $\pi/4$-8PSK, $\pi/8$-16PSK, $\pi/16$-32PSK and $\pi/32$-64PSK, respectively, with a view to reducing the spectral spreading in the power amplifiers at the receiver of a MIMO system. The MIMO techniques used was MIMO Spatial Multiplexing (MIMO–SM). The system models were developed around these schemes and later simulated using MATLAB application toolkit. The performances of the O-MPSK schemes were evaluated using bit error rate (BER) at signal-to-noise ratio (SNR) range of 0 to 20 dB and compared with the conventional MPSK schemes.

The results obtained for all the SNRs in MIMO-SM showed that mean BER of 0.0024, 0.0040, 0.0085, 0.0183 and 0.036 were obtained for $\pi/2$-QPSK, $\pi/4$-8PSK, $\pi/8$-16PSK, $\pi/16$-32PSK and $\pi/32$-64PSK respectively as against mean BER of 0.0025, 0.0044, 0.0088, 0.0178 and 0.0358 obtained for conventional QPSK, 8PSK, 16PSK, 32PSK and 64PSK respectively.

The mean BER values obtained reveal that the developed O-MPSK outperforms the conventional MPSK due to the relatively lower BER of O-MPSK schemes compared with the MPSK schemes. This is as a result of the reduction in the amplitude variations and spectral spreading at the receiver of the MIMO system.

Keywords: Offset, digital modulation, Spatial Multiplexing, MIMO, M-PSK scheme, Intercarrier Interference

1 Introduction

The goal of an ideal digital wireless communication system is to produce the exact replica of transmitted data at the receiver [1]. This has necessitated the corresponding numerous tremendous researches carried out in digital communications industry which leads to rapid growth recorded in

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the past two decades especially in its various applications [2]. This growth, in turn, has spawned an increasing need to seek automated methods of analyzing the performance of digital modulation types using the latest mathematical software or programming language. Digital modulation schemes practically in use now are Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK), Phase Shift Keying (PSK) and Quadrature Amplitude Modulation (QAM) with each having their distinctive features and characteristics. In the case of ASK, the use of amplitude modulated analogue carriers to transport digital information always results in a relatively low quality output. Although it is a low cost type of digital modulation, this is seldom used except for a very low speed telemetry circuits. FSK has a poorer error performance than PSK or QAM and consequently is not used regularly for high-performance digital radio systems [3];[4];[5];[6];[7].

QAM is a modulation scheme in which two schemes (ASK and PSK) are combined to improve the performance of the conventional counterpart modulation making this technique a little complex [8];[9]. It is mainly used for few specific applications [10]. The PSK schemes have constant envelope but discontinuous phase transitions from symbol to symbol and it is the most commonly used digital modulation technique. Some multi-level modulation techniques that permit high data rates within fixed bandwidth known as M-ary PSK schemes are employed in quasi-optical wireless array applications, compressed image communication in mobile fading channel, space applications, Tracking and Data Relay Satellites System (TDRSS) [1].

The demands for high data rate wireless communication in recent years have continued to increase rapidly for wireless multimedia services. Multiple-input, multiple-output (MIMO) systems are now the popular approaches to meet these demands [11];[12]. The use of multiple antennas at both transmitter and receiver in wireless communication links provides a means of maximizing the system performance of wireless systems. MIMO technology provides diversity by making the receiver to receive multiple replicas of the same information-bearing signal; and this provides a more reliable signal reception [13];[14];[15];[16];[17].

The conventional M-ary phase shift keying such as QPSK does not have constant amplitude for transition with a phase shift equal to π ($\pm 180^o$). The phase transitions make QPSK signals suffer from large envelope variations when passed through a nonlinear power amplifier operating at saturation. The resulting effects are nonlinear amplitude and phase distortions which cause spectral spreading of the transmitted signal, intercarrier interference (ICI) and degradation of the performance of the communication system. However, Offset Quadrature Phase Shift Keying, OQPSK, suffers from lower envelope variations as a result of the smaller phase transitions as each transition is limited to $\pm 90^o$. This results in relatively more constant envelope after pulse shaping [18];[19].

Many researchers have worked using different modulation schemes like [20] carried out performance analysis of a 2x2 spatial multiplexing MIMO technique with high order M-PSK and a combination of ZF and minimum mean square error (MMSE) equalizers without channel state information (CSI) at the transmitter. The system was simulated over the Rician fading channel. Simulation results showed significant improvement in BER performance at SNR value of 40 dB and above for 32-PSK, 64-PSK, 128- PSK, 256-PSK, 512-PSK and 1024-PSK. The implication of the results is that more power is needed to achieving a target BER; and this would not provide the desired power efficiency of the system especially for mobile applications. Mangla and Singh in [22] compared the BER performances of higher order M-QAM and M-PSK modulation schemes in a MIMO-OFDM system. The system was simulated for M = 16, 64, 256, 512 and 1024. The results showed that spectral efficiency increases with increasing modulation order M. Also, M-QAM gives better BER performance than M-PSK. The BER of the higher order modulations can be reduced but at the cost of increasing the SNR. Increasing the SNR is however not advisable because excessive power consumption would adversely affect system lifespan. Hence, this paper presents O-MPSK in MIMO spatial multiplexing (MIMO-SM) communication systems in order to reduce the ICI towards improving the systems' performances.

2 Development of the Offset M-PSK Schemes

A modulated signal consists of a combination of the carrier signal and the message (or information) signal. The *M*-ary PSK modulation is achieved by shifting the carrier in phase according to the message data. A modulated signal *s(t)* in time (t) domain can be expressed as:

$$s(t) = Re\{\mathrm{g}(t)\exp(j\omega_c t)\} \tag{1}$$

where Re{.} denotes the real component of the complex function indicated by j,
$\omega_c = 2\pi f_c$,
f_c *= the carrier frequency,*
$\mathrm{g}(t)$ *= the complex baseband envelope of* $s(t)$.

This complex baseband envelope $\mathrm{g}(t)$ is a function of the message signal $m(t)$ and can be expressed as:

$$\mathrm{g}(t) = Am(t)\exp[j\theta(t)] \tag{2}$$

where A is a constant amplitude
$\theta(t)$ *= the phase of the signal*

Substituting equation (2) into (1) gives:

$$s(t) = Am(t)\cos[\omega_c t + \theta(t)] \tag{3}$$

Applying trigonometric identity to Equation (3), the equation can be expressed in cosine and sine forms as:

$$s(t) = Am(t)[cos\omega_c tcos\theta(t) - sin\omega_c tsin\theta(t)] \tag{4}$$

The constant amplitude *A* is a function of the signal power; and it is given as:

$$A = \sqrt{2P} \tag{5}$$

where *P* is the signal power. Also, *P* is a function of the energy contained in symbol duration; and is given as:

$$P = \frac{E}{T_s} \tag{6}$$

where T_s *is the symbol period;*
E is the energy contained in the symbol period.
Substituting Equation (6) into (5) gives:

$$A = \sqrt{\frac{2E}{T_s}} \tag{7}$$

With'A' into equation 4 gives:

$$s(t) = m(t)\sqrt{\frac{2E}{T_s}}[cos\omega_c tcos\theta t - sin\omega_c tsin\theta t] \tag{8}$$

By shifting the carrier in phase, Equation 8 becomes:

$$s(t) = m(t)\sqrt{\frac{2E}{T_s}}[cos\omega_c tcos(\theta_i - \theta_0)t - sin\omega_c tsin(\theta_i - \theta_0)t] \tag{9}$$

with

$$\theta_i = \frac{2\pi}{M} i, \quad for\ i = 1,2,3, \ldots M \tag{10}$$

and θ_o is the initial phase given as:

$$\theta_0 = \frac{2\pi}{M} \tag{11}$$

where *M* is the constellation size of the *M*-ary PSK; the phase takes on one of *M* possible values.

Equation (9) represents an *M*-ary PSK modulated signal. The phases of an MPSK constellation can be represented with a polar diagram in Inphase/Quadrature (I/Q) format. The cosine component of the modulated signal $s(t)$ takes the inphase axis while the sine component takes the quadrature axis.

The offset MPSK (OMPSK) modulation can be implemented by delaying the input bit stream of the quadrature part by one bit period T_b. The bit period is given as:

$$T_b = \frac{T_s}{k} = \frac{T_s}{\log_2 M} \tag{12}$$

where k is the number of bits that represents a symbol. Therefore, the conventional MPSK modulation Equation 9 can be modified for the OMPSK as:

$$s(t) = m(t)\sqrt{\frac{2E}{T_s}}\left[\cos\omega_c t\cos(\theta_i - \theta_0)t - \sin\omega_c t\sin[(\theta_i - \theta_0)(t - T_b)]\right] \tag{13}$$

2.1 Offset QPSK Scheme

The least complex form of the offset *M*-ary PSK is the offset 4-ary PSK (OQPSK). For the OQPSK the number of bits per symbol k is 2; hence, the bit period $T_b = T_s/2$. Also, Equation 11 shows that the phase is shifted by $\pi/2$ when *M* = 4. Figure 1(a) shows the designed scheme for implementing OQPSK modulation. The modulation is achieved by transmitting the odd-numbered input bits via the inphase, I(t) branch while the even-numbered bits are transmitted via the quadrature, Q(t) branch with the use of a serial-to-parallel (S/P) converter. The data on the Q(t) part is delayed by $T_s/2$ with respect to that on the I(t) part to create an offset. This is followed by unipolar-to-bipolar (U/B) converters which convert the binary data to polar non return-to-zero (NRZ). The bipolar (±1) signals are then passed through rectangular pulse-shaping filters, and then modulated by cosine and sine carriers.

At the receiver, the signal is demodulated as shown in Figure 1(b). The arriving OQPSK signal is passed through a carrier recovery circuit which demodulates the signal by the inphase and quadrature carriers. The resulting I(t) and Q(t) signals are then passed through the Integrate and Dump filters followed by the detection of the binary data by the threshold detector. The inphase, I(t) stream is then delayed with respect to that on the Q(t) stream by $T_s/2$ to remove the offset introduced at the modulator. The I(t) and Q(t) streams are then combined by a parallel-to-serial (P/S) converter to produce the received bit stream. This strategy helps to reduce spectral spreading when the signal passes through a nonlinear high power amplifier because the offset makes the signal to have lower envelope variation when compared with the conventional QPSK.

2.2 Offset 8-PSK Scheme

The offset 8-PSK (O8-PSK) modulator and demodulator are shown in Figures 2(a) and (b) respectively. The modulation and demodulation processes of O8-PSK are similar to those of OQPSK except that the phase is shifted by $\pi/4$ and the number of bits per symbol k is 3.

2.3 Offset 16-PSK Scheme

The offset 16-PSK (O16-PSK) modulator and demodulator are shown in Figures 3(a) and (b) respectively. The modulation and demodulation processes of O16-PSK are similar to those of OQPSK except that the phase is shifted by $\pi/8$ and the number of bits per symbol k is 4.

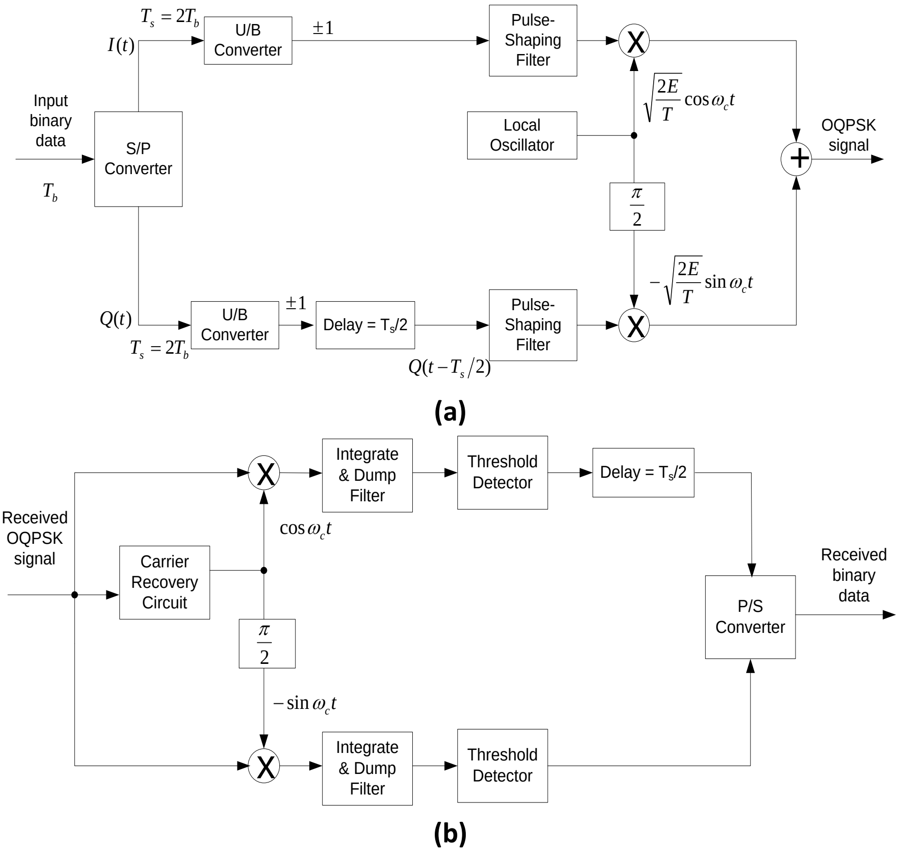
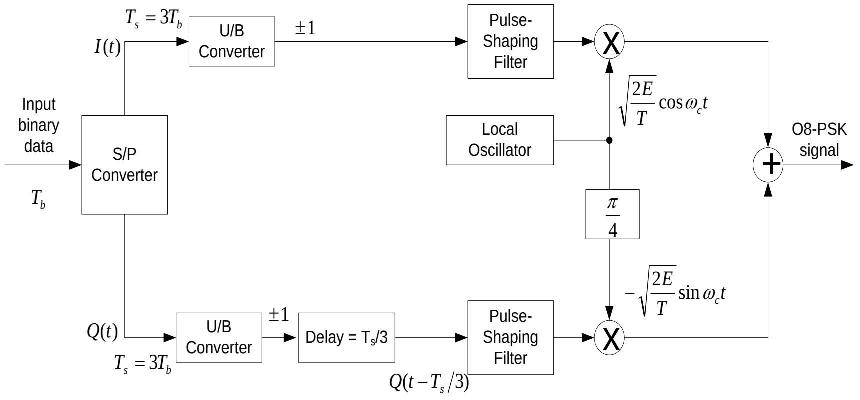
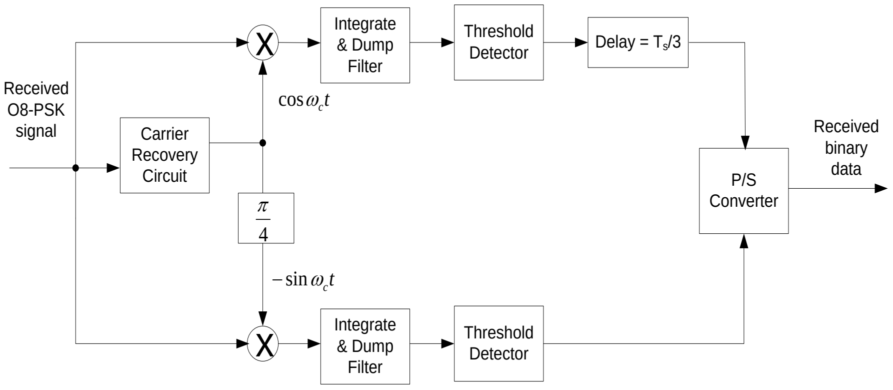


Figure 1: Offset QPSK Scheme (a) Modulator (b) Demodulator

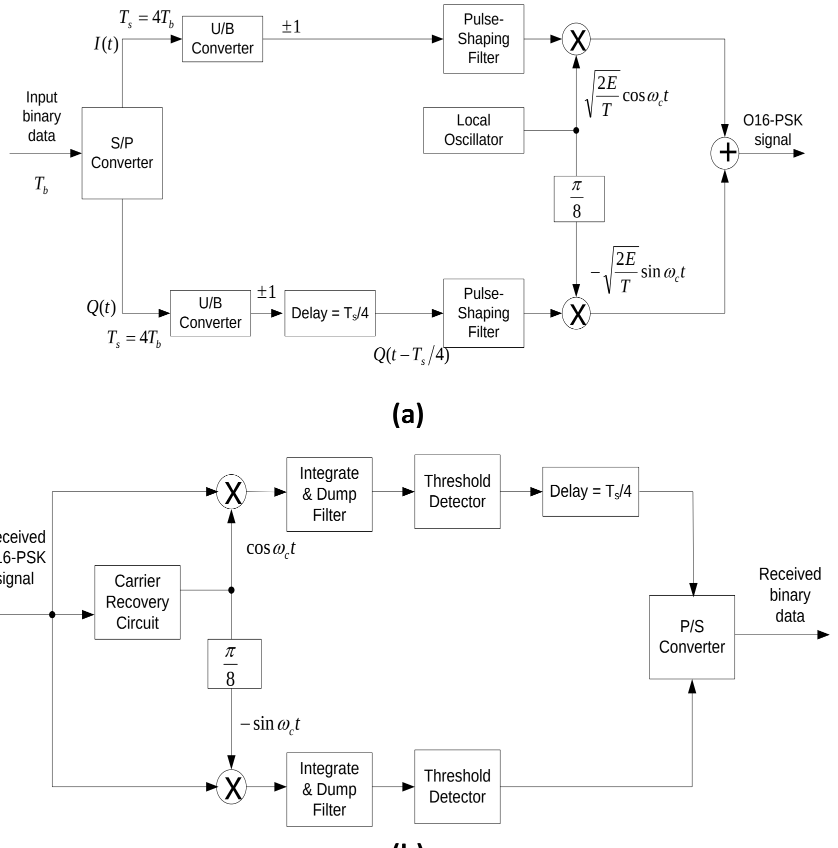


(a)



(b)

Figure 2: Offset 8-PSK Scheme (a) Modulator (b) Demodulator



(a)

(b)

Figure 3: Offset 16-PSK Scheme (a) Modulator (b) Demodulator

2.4 Offset 32-PSK Scheme

The offset 32-PSK (O32-PSK) modulator and demodulator are similar to those of OQPSK except that the phase is shifted by $\pi/16$ and the number of bits per symbol k is 5.

2.5 Offset 64-PSK Scheme

The modulation and demodulation processes of O64-PSK scheme are similar to those of OQPSK except that the phase is shifted by $\pi/32$ and the number of bits per symbol k is 6.

3 System Simulation Model and Tool

The investigation was carried out by developing the MIMO-SM system simulation models using the OMPSK modulation schemes. The developed system models were implemented by simulation of the developed models.

3.1 System Simulation Models

A simulation model for 2x2 MIMO-SM with OMPSK modulation scheme is shown in Figure 4. The transmitted message is a randomly generated bit stream. At the transmitter, the bit stream is passed through the OMPSK modulator. The output signal from the modulator is split into even and odd symbols; and the even symbols are transmitted through the antenna 1 while the odd symbols are transmitted through antenna 2. The two signals pass through a Rayleigh fading channel with the additive white Gaussian noise (AWGN). At the receiver, channel estimation is performed on the received signals to nullify the effect of fading. The signals are then multiplexed and the resulting OMPSK signal is demodulated to obtain the received binary data.

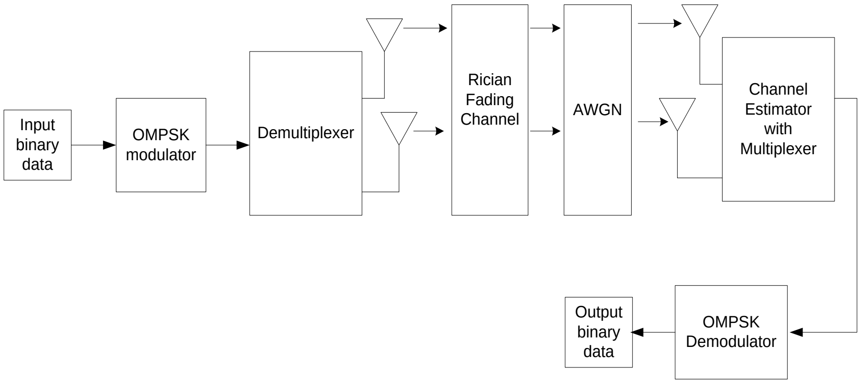


Figure 4: System simulation model for 2x2 MIMO-SM with OMPSK modulation scheme

4 Results and Discussion

MIMO Spatial Multiplexing (MIMO-SM) and MIMO Beamforming (MIMO-BF) schemes were simulated using the O-MPSK modulation technique as well as the conventional MPSK modulation technique over a Rayleigh fading channel; and comparisons are made in terms of BER between the two schemes. The BER is evaluated for SNR values of 0 to 20 dB as presented in Table 1. The BER performances of QPSK and $\pi/2$-QPSK in MIMO-SM over Rayleigh fading channel are shown in Figure 5. Taking SNR of 10 dB, QPSK gives a BER value of 0.0012 while $\pi/2$-QPSK gives 0.0010; also, the mean BER values for all the SNRs are 0.0025 and 0.0024 for QPSK and $\pi/2$-QPSK respectively. The subsequent lower BER values given by $\pi/2$-QPSK reveals the efficiency of $\pi/2$-QPSK over the QPSK.

Figure 6 presents the BER performances of 8PSK and $\pi/4$-8PSK in MIMO-SM over Rayleigh fading channel. Taking SNR of 10 dB, the BER values for 8PSK and $\pi/4$-8PSK are 0.0018 and 0.0016 respectively, and the mean BER values are 0.0044 and 0.0040 for 8PSK and $\pi/4$-8PSK respectively. The $\pi/4$-8PSK has relatively lower BER compared to 8PSK. The BER performances of 16PSK and $\pi/8$-16PSK in MIMO-SM over Rayleigh fading channel are shown in Figure 7; the 16PSK modulation gives a BER value of 0.0044 while the $\pi/8$-16PSK modulation gives a closer 0.0045 at SNR of 10 dB. The mean BER values for 16PSK and $\pi/8$-16PSK are 0.0088 and 0.0085 respectively. This result reveals that the $\pi/8$-16PSK has relatively better BER performance compared to 16PSK.

Table 1: BER values for 2x2 MIMO spatial multiplexing over Rayleigh fading channel

SNR[dB]	QPSK	$(\frac{\pi}{2})$-QPSK	8PSK	$(\frac{\pi}{4})$-8PSK	16PSK	$(\frac{\pi}{8})$-16PSK	32PSK	$(\frac{\pi}{16})$-32PSK	64PSK	$(\frac{\pi}{32})$-64PSK
0	0.0075	0.0083	0.0153	0.0136	0.0310	0.0279	0.0585	0.0583	0.1040	0.1043
2	0.0064	0.0062	0.0117	0.0110	0.0215	0.0208	0.0430	0.0444	0.0796	0.0807
4	0.0045	0.0044	0.0084	0.0078	0.0158	0.0156	0.0323	0.0336	0.0634	0.0642
6	0.0032	0.0029	0.0056	0.0053	0.0104	0.0109	0.0221	0.0235	0.0470	0.0476
8	0.0022	0.0017	0.0032	0.0031	0.0071	0.0074	0.0153	0.0157	0.0344	0.0349
10	0.0012	0.0010	0.0018	0.0016	0.0044	0.0045	0.0100	0.0105	0.0244	0.0245
12	0.0009	0.0007	0.0011	0.0009	0.0026	0.0026	0.0065	0.0069	0.0170	0.0172
14	0.0006	0.0005	0.0005	0.0005	0.0017	0.0017	0.0040	0.0041	0.0110	0.0108
16	0.0004	0.0003	0.0003	0.0004	0.0010	0.0008	0.0026	0.0027	0.0070	0.0068
18	0.0002	0.0002	0.0002	0.0002	0.0005	0.0005	0.0011	0.0012	0.0042	0.0038
20	0.0002	0.0001	0	0	0.0004	0.0004	0.0007	0.0006	0.0014	0.0013

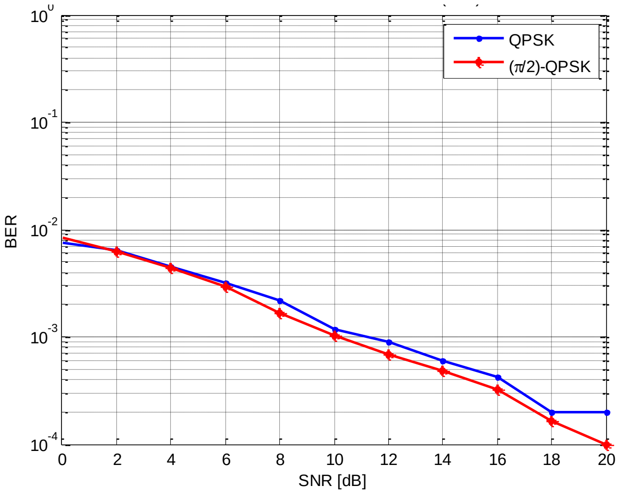


Figure 5: BER performances of QPSK and $\pi/2$-QPSK in2x2 MIMO-SM over Rayleigh Fading Channel

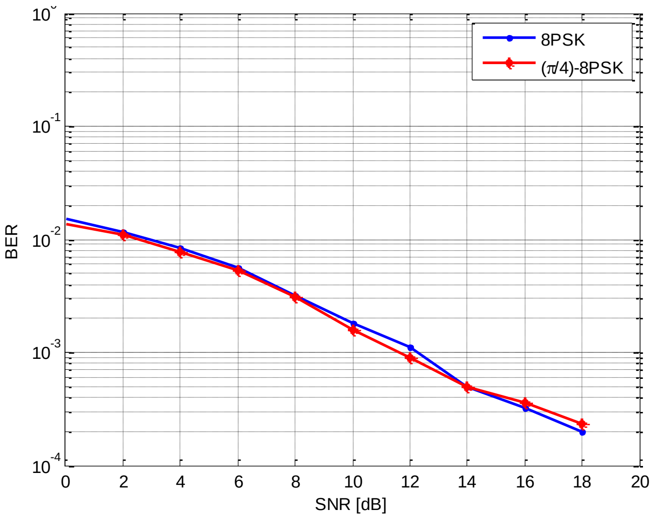


Figure 6: BER performances of 8PSK and $\pi/4$-8PSK in2x2 MIMO-SM over Rayleigh Fading Channel

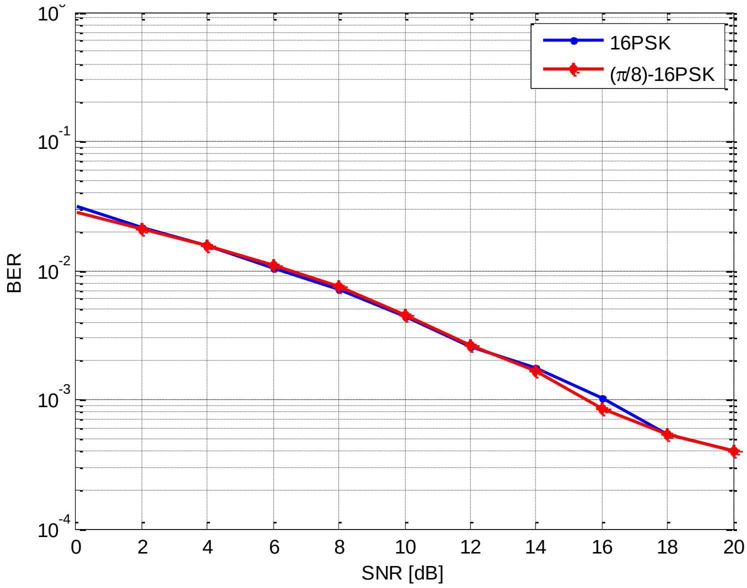


Figure 7: BER performances of 16PSK and $\pi/8$-16PSK in2x2 MIMO-SM over Rayleigh Fading Channel

The BER performances of the off-set M-PSK in MIMO-SM for comparison over Rayleigh fading channel are presented in Figure 8. At SNR of 10 dB, the BER values for 32PSK and $\pi/16$-32PSK are 0.0100 and 0.0105 respectively, and the mean BER values are 0.0178 and 0.0183 for 32PSK and $\pi/16$-32PSK respectively. This result revealed that 32PSK has better BER performance compared to $\pi/16$-32PSK. The BER performances of 64PSK and $\pi/32$-64PSK gave BER values of 0.0244 and 0.0245 respectively at SNR of 10 dB. The mean BER values for 64PSK and $\pi/32$-64PSK are 0.0358 and 0.036 respectively. This result revealed that the 64PSK gave relatively better BER performance compared to $\pi/32$-64PSK.

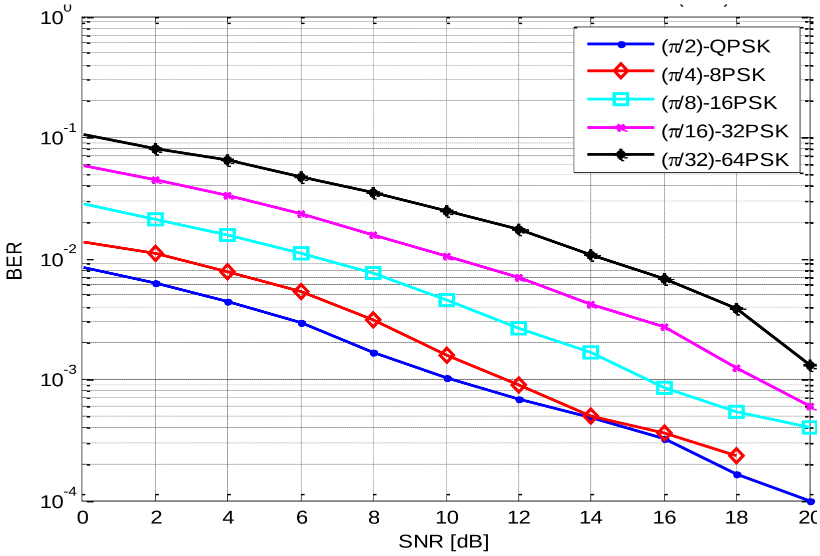


Figure 8: Comparison of the O-MPSK in 2x2MIMO-SM over Rayleigh Fading Channel

5 Conclusion

In this paper, O-QPSK, O-8PSK, O-16PSK, O-32PSK and O-64PSK modulation schemes have been developed, the system simulation models incorporating a 2x2 MIMO Spatial Multiplexing (MIMO–SM) using the O-MPSK modulation schemes was developed over Rayleigh fading channel, simulated using MATLAB application package. The models were evaluated to determine the performance using bit error rate (BER) and compare with the conventional (non-offset) MPSK. The O-MPSK schemes were compared with MPSK scheme in terms of BER for SNR values of 0 to 20 dB. The O-MPSK investigated include $\pi/2$-QPSK, $\pi/4$-8PSK, $\pi/8$-16PSK, $\pi/16$-32PSK and $\pi/32$-64PSK. The results revealed that the O-MPSK schemes outperform the MPSK schemes in MIMO-SM as the O-MPSK schemes gave relatively lower mean BER compared to the MPSK schemes. Also, the results revealed that the best performance was obtained with the $\pi/2$-QPSK scheme.

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