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Performance Comparison of Modulation Technique and Coding Algorithms

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Abstract
Transforming information-carrying signals from source to destination is called the process of communication. We carry out modulation for long-distance transmission by transmitting the message signal after modifying the carrier wave's phase, frequency, or phase. Channel coding is used for error detection and repair. In this project, we use MATLAB to model the modulation methods M-PSK and M-QAM and compare them to bit error rates. We model channel equalization strategies such as Maximum Likelihood beamforming, Minimum Mean Square Equalizer, and Zero Forcing Equalizer. To increase the reliability of communication in presence of fading we simulate a multiple input multiple output system with diversity using MATLAB. We compare the capacity of multiple input multiple output, single input multiple output, single input single output and multiple input single output and capacity of a MIMO system for a different number of transmit and receive antennas. We simulate the performance of MIMO with Alamouti coding in presence of Rayleigh fading. We also simulate the performance of various multiple access techniques orthogonal frequency division multiple access, single carrier frequency division multiple access, code division multiple access using gold codes.

1. Introduction

Signals are the primary means of communication. Typically, sound signals which are Analog in nature are being used. These analogue signals must be converted into digital signals before being transferred over a wire and relayed via transmitters and receivers when they need to travel a distance. (Shaikh, Uddin, and Moinuddin) This communication is also called digital communication. The two most important resources are average power and transmission bandwidth. In mobile communication the channel is limited because they are battery operated. Considering all these requirements, for optimum digital communication we must send high data rates in a limited frequency band using limited power.

To achieve this energy efficient system, there are 2 solutions:

- Low power higher modulation techniques (OFDM, MPSK, MQAM)
- Coding techniques (Gold codes, Block codes)

In a communication system the frequency spectrum is a scarce resource, so we need to implement bandwidth efficient modulation technique. Prescribed, although the various table text styles are provided. (Pappa, Ramesh, and Kumar) The formatter will need to create these components, incorporating the applicable criteria that follow.

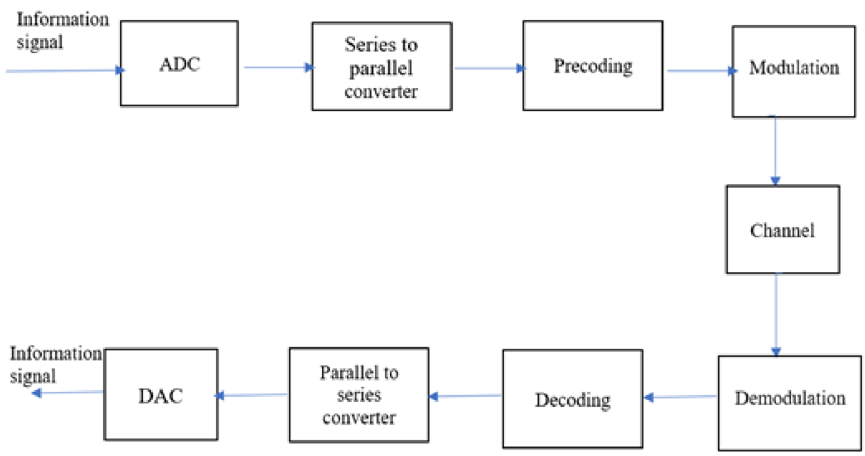

FIGURE 1. Block Diagram

1.1. Digital Modulation Schemes:

1.1.1. MQAM:

M-PSK uses a circular constellation and has transmission speed of n=$\log_2$ M bits/symbol. The constellation points are distributed in terms of phase.

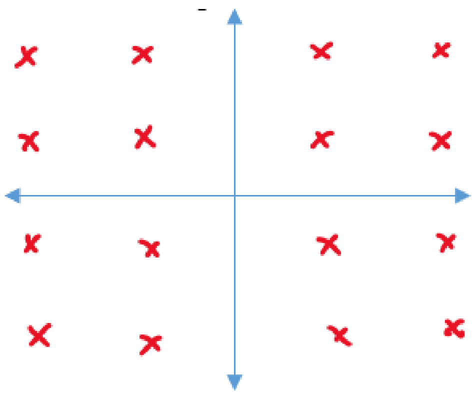

FIGURE 2. Constellation Diagram For 16-QAM

1.1.2. MPSK:

M-PSK uses a circular constellation and has transmission speed of n=log2 M bits/symbol. The constellation points are distributed in terms of phase

1.1.3. OFDM:

The multiplexing technique known as OFDM (Orthogonal Frequency Division Multiplexing) (Riadi, Boulouird, and Hassani) is utilized for numerous wireless and communications protocols, including satellite, Wi-Fi 802.11ac, 4G and 5G phone technologies, and many others.

By dividing available bandwidth into numerous sub-channels, OFDM is used to enable multiple users to share a single channel. In FDM, the

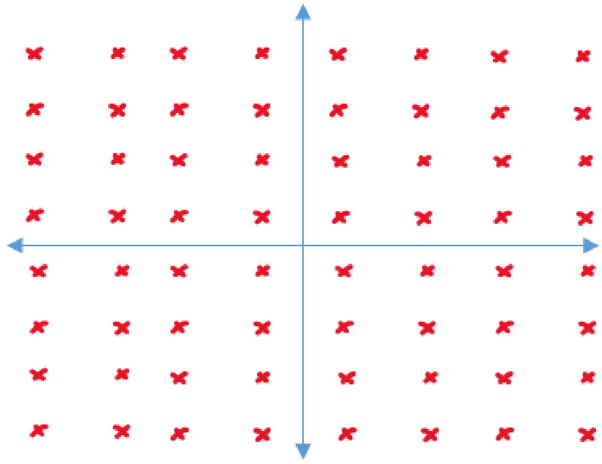

FIGURE 3. Constellation Diagram For 64-QAM

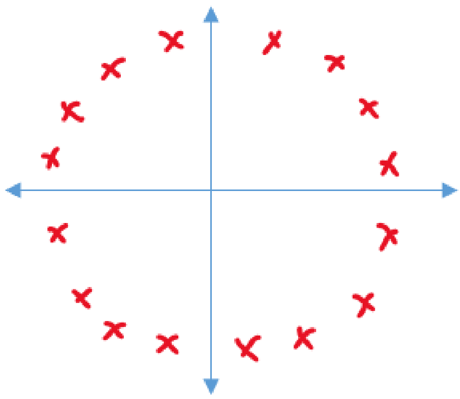

FIGURE 4. Constellation Diagram For 16-PSK

same procedure is followed, but a guard band is put between each sub-channel before it is deployed. so that many signals can operate without conflicting with one another (Vorobyov, Upadhya, and Vehkaperä) .

While in OFDM, all the sub-channels are positioned near together with no guard band in between. As a result, we can send more data using the same bandwidth that was allocated for FDM.

In OFDM, the sub-channels are placed orthogonally multiplexed so that when one signal peaks, the other signals are at their trough, preventing interference.

Therefore, OFDM would offer more data transmission than FDM and make greater use of the existing bandwidth. (Tosaka et al.)

1.1.4. MQAM vs MPSK:

Both have same bits per symbol => n = log2M Same bandwidth efficiency M-QAM is more noise immune compared to M-PSK. Because of more distance between constellation points compared to M-PSK

At high frequency, M-PSK is preferred since we need to do both amplitude and phase shift in M-QAM, but M-PSK has fixed amplitude, so it costs less (circuit wise).

1.1.5. MIMO Using Diversity

Diversity:

Diversity is implemented by multiple sub-channels instead of one channel, using multiple transmitter and receiver antennas. So that when a situation arrives where there is data loss in one of the sub-channels, there are other sub-channels to accommodate for the transmission. (Das, Bandopadhaya, and Rout)

Factors that affect the capacity of the channel are bandwidth, noise, error rate.

The power is allocated among all the sub-channels equally in an uninformed transmitter, where the channel knowledge is unknown to the transmitter. In this case, capacity of the MIMO (Kanmani and Kannan) system can be calculated as,

$$C = max[\log_2 \left| I_{Mr} + \frac{E_s}{M_t N_0} H Q H^H \right|] \quad (1)$$

M_r, M_t – number of antennas at receiver and transmitter respectively.

I_{Mr}– identity matrix of size (M_r, M_r).

E_s – total power.

N_o – noise power.

H – channel coefficient matrix.

Q – input matrix

But when there is a bad sub-channel present, the power allocated to that sub-channel gets squandered. To avoid this, we perform the same process with an informed transmitter, where there is a possibility of transmitter learning about the channel state information (CSI)

before it transmits the signal. Here the power is allocated according to the state of the channel. If the sub-channel is a good channel, the power is allocated more and vice versa. To implement this, we use the Water Filling algorithm.

Water filling algorithm:

μ – represents water level

$$\mu = \frac{M_t}{r-p+1}[1 + \frac{N_0}{E_s}\sum_{i=1}^{r-p+1}\frac{1}{\lambda_i}] \quad (2)$$

The count **p** is set to 1.

i^{th} sub channel power (γ_i) using equation (2):

$$\gamma_i = \left(\mu - \frac{M_t N_o}{E_s \lambda_i}\right], \; i = 1, \; 2, \; 3, \ldots, r-p+1 \quad (3)$$

If, γ_i is negative i.e less than zero (bad sub channel)

Then, $\gamma_{r-p+1}^{opt} = 0$

And the algorithm is rerun by incrementing **p** by 1,

The algorithm is represented until all good sub channels are allocated with optimal power.

Optimized input matrix **Q,**

$$Qopt = diag\{\gamma_1^{opt}, \gamma_2^{opt}, \gamma_3^{opt}, \ldots, \gamma_r^{opt} \quad (4)$$

Then the capacity equation (1) becomes,

$$C = max[\log_2 \left| I_{M_r} + \frac{E_s}{M_t N_0} H Q^{opt} H^H \right|] \quad (5)$$

Relation between number of transmitter and receiver antennas (Mt, Mr):

When Mt=Mr,It is better that the channel knowledge is known for better capacity.

When Mt>Mr,The channel knowledge is very important for increasing capacity significantly especially in the low SNR regime, large systems. This is because when there are multiple transmitting antennas, there is more data sent but to receive the data there are not enough receiver antennas. Data loss will occur.

When Mt<Mr,The lack of channel knowledge is compensated by increasing the number of receiver antennas. Since not every signal transmitted from a

base station is intended for a user, the relevance of uplink is greater because every signal sent by a user is intended for the base station.

When there are less users, the complexity is less. But when the users are more or equal to the users that a base station can withhold, complexity increases in which the optimal power allocation is used for better channel capacity. In which the power is allocated depending on each sub-channel power level (Water Filling Algorithm-to provide each sub-band the optimal power).

Channel Estimation:

When the transmission of signal or data takes place from transmitter to receiver there are few distortions observed in the channel. To remove these distortions, we use channel estimation techniques.

MMSE:

Minimum mean square error (MMSE) as an equalizer is an algorithm that helps to figure out the received data that is as close to the transmitted data as possible.

Because of the rise of base station (BS) antennas, for multi-user large Multiple-Input Multiple-Output (MIMO) (Thalapalli and Pandey Kanmani and Kannan) systems, minimum mean square error (MMSE) can achieve bit error rate (BER) Performance.

MMSE (Cherif and Bouallegue) equation:

$$W = [H^H H + N_0 I]^{-1} H^H \tag{3}$$

Where $H^H = H^T$ and N_0 is the noise.

Zero forcing:

Forcing the noise to become zero is called zero forcing. From the MMSE equation when the noise is zero, we get zero forcing.

By applying ZF (Cherif and Bouallegue) equalizer technique there is a possibility to reduce the value of Inter Symbol Interference (ISI) at zero for a noise free channel.

It basically tries to nullify the interference.

Error equation is

$$f(x) = \| y - Hx \|^2 \tag{4}$$

y=received signal

x=transmitted signal

H= Channel matrix with Attenuation and noise as we are using Rayleigh fading channel (Cherif and Bouallegue)

H is complex in nature and is a predicted value. The main aim is to make the channel matrix and transmitted signal equal so that the difference becomes null.

In general, the value of the channel matrix cannot be predicted, therefore this process is iterative because the transmitted and received signals are fixed and only the value of H (Channel Matrix) can be changed. For this reason, we use channel estimation, if the channel is good, the channel matrix and transmitted signal are equal and hence gives minimal error.

We need minimal errors so when a threshold is given and if it meets that threshold then the channel is good otherwise it keeps estimating the channel. As the value of H is complex, we take the absolute value of it (power or energy).

Zero forcing equation:

$$W = [H^H H]^{-1} H^H \tag{5}$$

Where $H^H = H^T$

Maximum Likelihood:

It is used to measure the distances between the received signals and finds the least value from all transmitted signals in the channel.

Maximum likelihood receiver:

$$\widehat{\theta} = \sum_{i=1}^{n} \frac{x_i^2}{2n} \tag{6}$$

Coding Techniques:

Alamouti Coding technique:

Alamouti is a space-time block coding technique through which we can achieve diversity, by employing multiple antennas at the transmitter and simple linear processing at the receiver. It does not require channel knowledge.

Received signal at time stamp 1,

r1= s1.h1 + s2.h2 + noise

Received signal at time stamp 2,

r2= -h1.s2 + h2.s1 + noise

Combining Rx:

$$w1.r1, h1 * . \, r1 = h1 * \{h1.s1 + h2.s2 + noise\} \tag{7}$$

$$w2.r2, h2 * . \, r2 = h2 * \{-h1.s2 + h2.s1 + noise\} \tag{8}$$

where w1 and w2 are the weights at the receivers

$$h1 * . \, r1 = h1 * .h1.s1 + h1 * .h1 .s2 + noise \tag{9}$$

Conjugating equation (8),

$$\{h2*.r2\}* = -h2.h1.s2 + h2.h2 *.s1 + noise \quad (10)$$

Sum of the equations (9) and (10),

$$z1 = h1*.r1 + h2.r2* = (|h1|^2 + |h2|^2) .s1 + noise \quad (11)$$

from equation (11) symbol estimate can be written as,

$$\widehat{S_1} = \frac{z_1}{|h_1|^2 + |h_2|^2} \quad (12)$$

Similarly, to find,

$$z2 = h1*.r1 - h2.r2* = (|h1|^2 + |h2|^2) .s2 + noise \quad (13)$$

from equation (13),

$$\widehat{S_2} = \frac{z_2}{|h_1|^2 + |h_2|^2} \quad (13)$$

Gold coding technique:

A set of specific sequences known as ”Gold codes” are used in systems that employ spread spectrum or CDMA (code-division multiple access) technology. CDMA networks enable numerous users to communicate at once over the same wide-band channel. Two pseudo-random sequences are combined to create gold codes, which are then produced by modulo two adding or XORing the results. These codes have unique cross-correlation properties that enable multiple users with no or little interference.

2. Results and Discussion

2.1. QPSK Simulation:

In the below simulation, BER vs SNR is implemented for QPSK technique. From the results, we can obtain that when SNR increases, BER decreases.

2.2. Simulation of 64-QAM:

In the simulation below, BER vs SNR is implemented for 64-QAM technique. From the results, we can obtain that when SNR increases, BER decreases.

QPSK is better than QAM in terms of BER vs SNR by 28%.

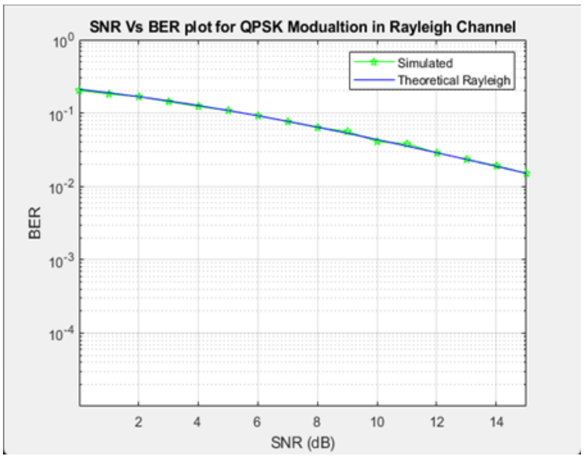

FIGURE 5. QPSK Simulation

TABLE 1. BER and SNR values for QPSK

SNR	BER
-3	0.2146
-2	0.1867
-1	0.1675
0	0.1442
1	0.1284
2	0.1081
3	0.0877
4	0.0792
5	0.0591
6	0.0542
7	0.045
8	0.036
9	0.0298
10	0.0236
11	0.0179
12	0.016
13	0.0118
14	0.0105
15	0.00785

2.3. OFDM Simulation:

The below figure illustrates OFDM (Rao and Kartheek Riadi, Boulouird, and Hassani) modulation technique. This contains four carrier signals with different frequencies. Considering, when the amplitude of the one carrier signal is to its maximum, the other carrier signals amplitude will be zero (orthogonal to each other). Since there is no interference between the signals and hence guard bands are not necessary.

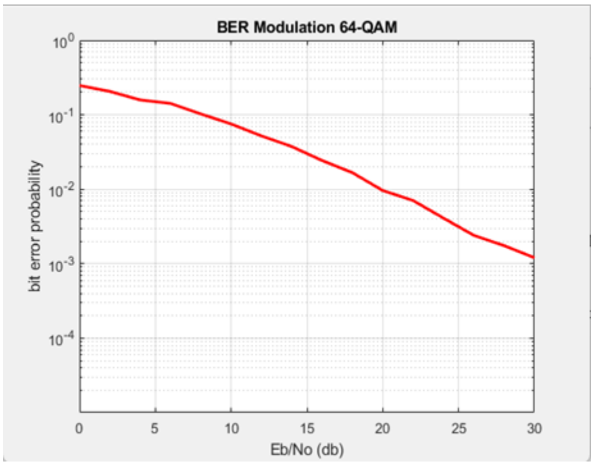

FIGURE 6. **64-QAM Simulation**

TABLE 2. **BER and SNR values for 64-QAM**

SNR	BER
0	0.247
2	0.205
4	0.158
6	0.142
8	0.102
10	0.075
12	0.052
14	0.037
16	0.024
18	0.016
20	0.009
22	0.007
24	0.004
26	0.002
28	0.001
30	0.001

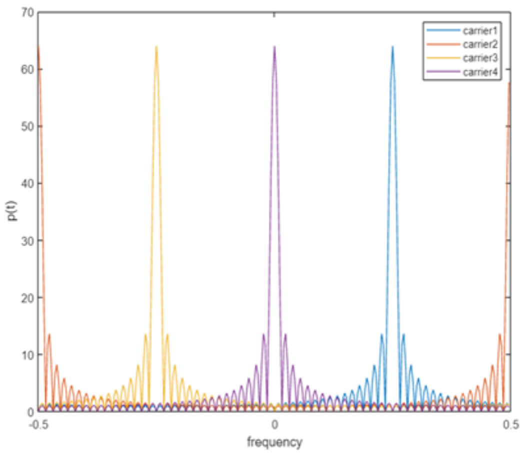

FIGURE 7. **OFDM Simulation**

2.4. MIMO and Diversity Simulation:

In the simulation below, we compare diversity schemes for transmitters with and without channel knowledge. When there are more receivers than transmitters, the capacity is better compared to capacity when there are more transmitters than receivers. This is because a greater number of receivers compensate for channel knowledge. Single transmitter and single receiver show the worse capacity among others for transmitter with CSI and without CSI. Equal number of multiple receivers and transmitters show the optimal capacity for both transmitter with and without channel knowledge. There is huge increase in capacity when the transmitter learns about CSI in the case of more transmitters than receivers.

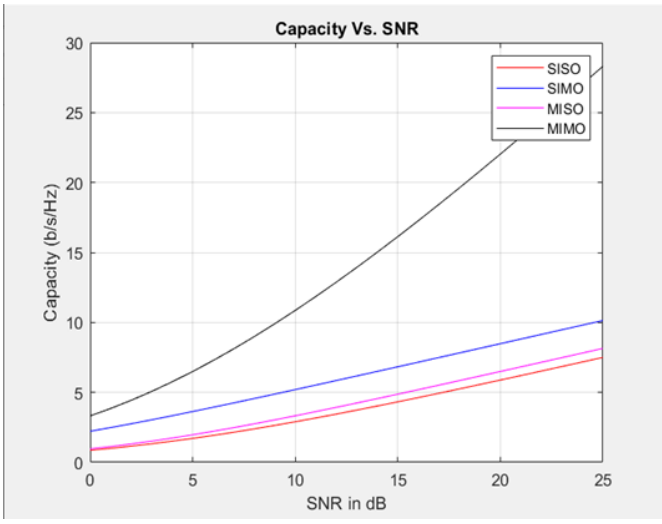

FIGURE 8. **Capacity vs SNR performance**

2.5. Digital receiver Simulation:

As shown in the below figure:

1) MMSE receiver shows better performance than ZF however in higher order modulation the ZF receiver shows the same pace of curve to the MMSE receiver.

2)When compared to ZF and MMSE, ML (Thallapalli and Pandey) shows slightly better performance as it has low bit error.

3)At the same SNR values, we observe lower BER as seen in the figure.

2.6. Coding techniques:

2.6.1. Alamouti Simulation:

Below figure shows that BER performance of the Alamouti scheme with 2 transmitter and 1 receiver

TABLE 3. SNR and MXN

MxN	4x4		1x4		4x1	
SNR	**UNINFORMED**	**INFORMED**	**UNINFORMED**	**INFORMED**	**UNINFORMED**	**INFORMED**
1	3.8499	4.7502	2.4844	2.4675	1.1184	2.4809
3	5.0701	5.9638	3.0408	3.0346	1.5021	3.0132
5	6.4952	7.3362	3.6316	3.6139	1.9528	3.6155
7	8.1123	8.9037	4.247	4.2317	2.4612	4.2224
9	9.9041	10.6386	4.8793	4.8618	3.0159	4.8536
11	11.8511	12.4568	5.523	5.504	3.6054	5.5151
13	13.9339	14.4591	6.1741	6.1555	4.2199	6.1436
15	16.1336	16.5476	6.83	6.8148	4.8517	6.8122
17	18.4324	18.7865	7.4891	7.463	5.495	7.4629
19	20.8137	21.1136	8.15	8.1184	6.1458	8.1166
21	23.2624	23.4463	8.8123	8.7964	6.8016	8.7946
23	25.7645	25.9619	9.4753	8.4501	7.4605	9.4643
25	28.3081	28.4821	10.1388	10.1226	8.1214	10.1197
mean	14.76394615	15.295877	6.221207692	6.2026385	4.365515385	6.2011231
% Improvement	3.602903747		-0.298482733		42.04790341	

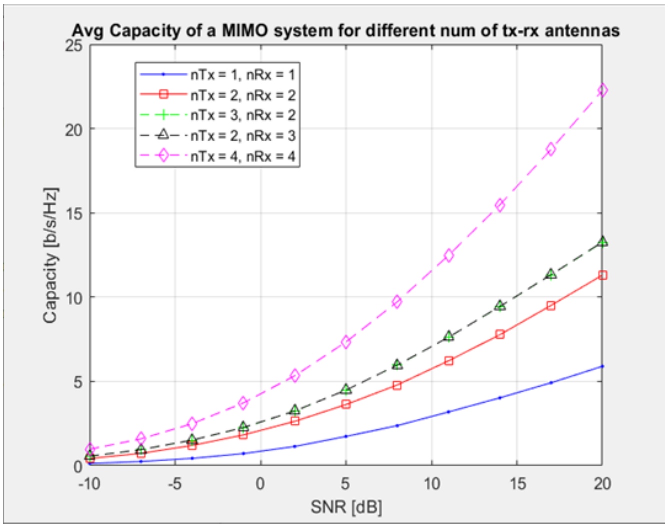

FIGURE 9. Average capacity for different number of transmitting and receiving antennas.

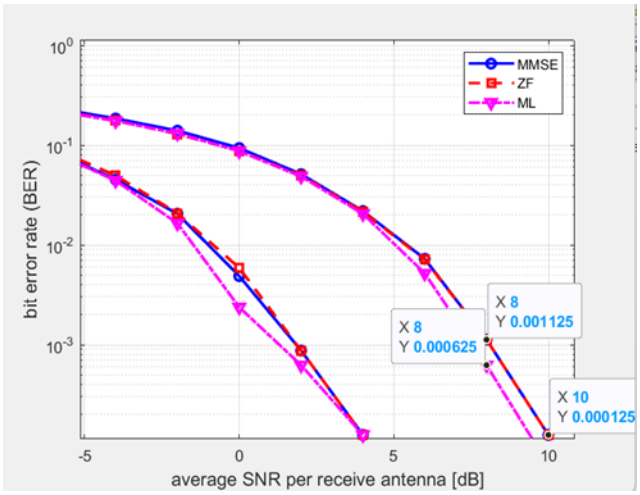

FIGURE 10. Comparative analysis - BER vs SNR Plot for MMSE, ZF and ML

is better than without Alamouti scheme of 1 transmitter and 1 receiver for same SNR Values.

2.6.2. Gold code with SS-CDMA, SC-FDMA and OFDMA Simulation:

In the simulation below we compare the multiple access techniques OFDMA, SC-FDMA, and DS-CDMA for 16 and 64 QAM techniques. The results show SC-FDMA having the best BER results and DS-CDMA having the worst BER results among the three techniques.

3. Conclusion

We chose QAM over PSK since QAM is more immune to noise and the results has shown better BER results in QAM. For MIMO using diversity, More the receiver antennas, better the capacity since more receiver antennas compensate for lack of channel state information. When the transmitter antennas are more than receiver antennas, channel knowledge is very important since there is a drastic decrease in capacity when transmitter has no channel knowledge compared to transmitter with

TABLE 4. Comparative analysis for different multiple access schemes

	OFDMA		SC-FDMA		DS-CDMA	
SNR	**16QAM**	**64QAM**	**16QAM**	**64QAM**	**16QAM**	**64QAM**
0	0.1410	0.1998	0.1410	0.1998	0.3763	0.4143
3	0.1251	0.1840	0.1019	0.1611	0.3580	0.4052
6	0.1019	0.1611	0.0500	0.1096	0.3413	0.3993
9	0.0798	0.1395	0.0152	0.0644	0.3279	0.3941
12	0.0593	0.1192	0.0019	0.0276	0.3167	0.3878
15	0.0413	0.1001	$5.0977\text{x}10^{-5}$	0.0066	0.3098	0.3879
18	0.0263	0.0818	$7.2167\text{x}10^{-8}$	$5.4296\text{x}10^{-4}$	0.3073	0.3855
21	0.0152	0.0644	$4.5223\text{x}10^{-13}$	$6.3511\text{x}10^{-6}$	0.3021	0.3847
24	0.0076	0.0483	$1.1881\text{x}10^{-22}$	$2.0066\text{x}10^{-9}$	0.3013	0.3863
27	0.0032	0.0339	$0.2216\text{x}10^{-40}$	$7.7419\text{x}10^{-16}$	0.3020	0.3855
30	0.0011	0.0220	$2.8113\text{x}10^{-73}$	$1.1363\text{x}10^{-27}$	0.3018	0.3842

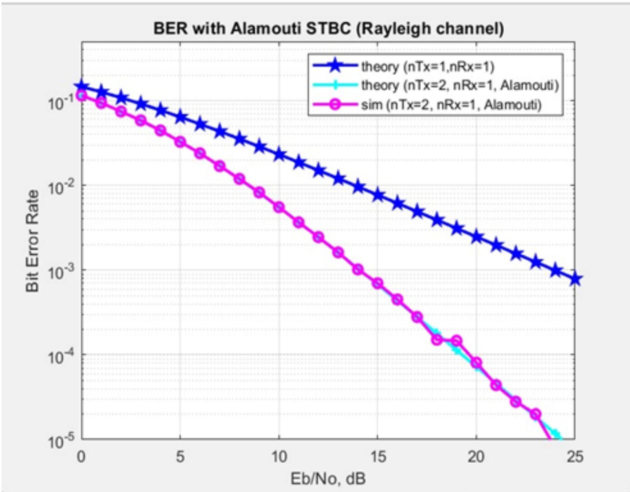

FIGURE 11. With and Without Alamouti Plot

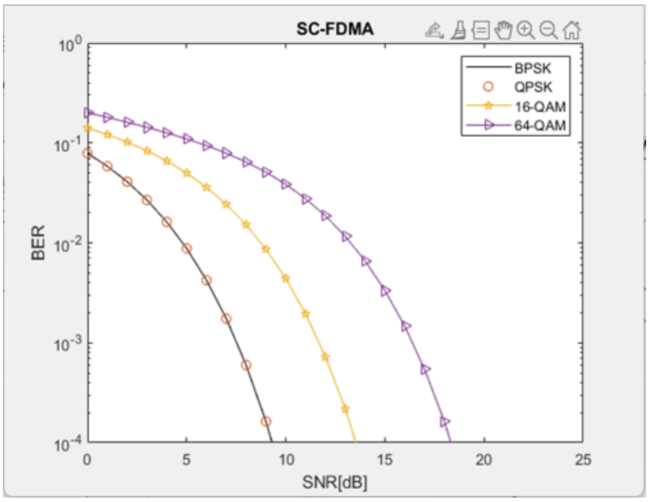

FIGURE 12. Comparison of multiple access technique (SC-FDMA) using gold sequence codes

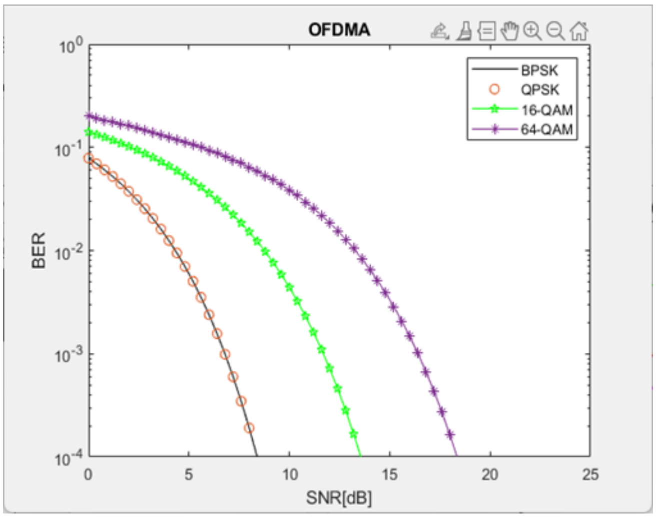

FIGURE 13. Comparison of multiple access technique (OFDM) using gold sequence codes.

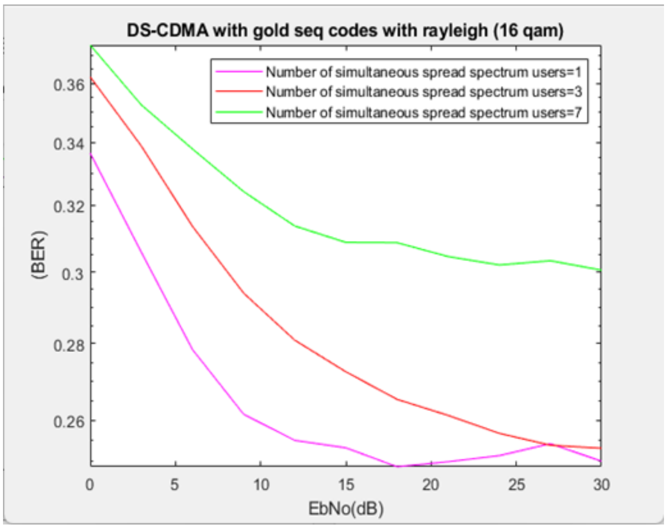

FIGURE 14. Comparison of multiple access technique (DS-CDMA with 16 QAM) using gold sequence codes

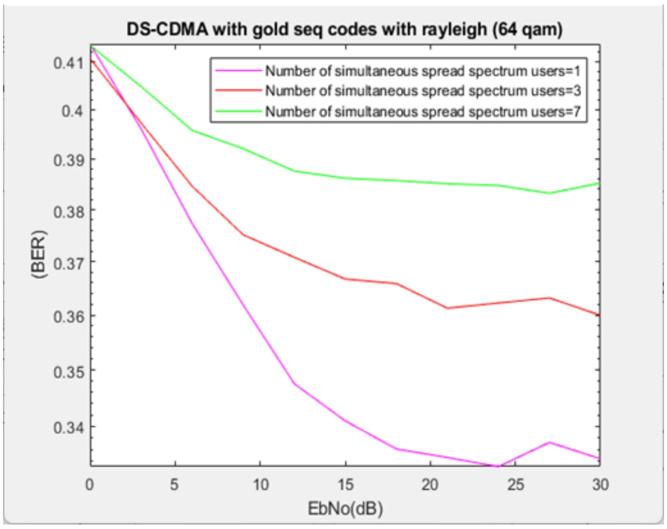

FIGURE 15. Comparison of multiple access technique (DS-CDMA with 64 QAM) using gold sequence codes.

CSI. When the number of transmitter and receiver antennas are equal, channel knowledge is needed for better capacity. Sequence Code Division Multiple Access) shows higher bit errors among the multiple access techniques.

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