

Performance Analysis of Space Shift Keying and Quadrature Space Shift Keying for MIMO Channels

K. Ragodaya Deepthi^{1,*}, Ch. Laasya¹, K. Khyathi¹

Abstract

In wireless communication the propagation channel is characterized by multipath propagation due to scattering on different obstacles. MIMO takes advantage of multi-path and uses multiple antennas to send multiple parallel signals from transmitter. "Multi-path" occurs when different signals arrive at the receiver at various times. MIMO exploits the space dimension to improve wireless systems capacity, range and reliability. There are two different modulation techniques that exploits the best features of MIMO communication and establish reliable wireless connection between MIMO transmitter and MIMO receiver. They are space shift keying (SSK) and quadrature phase shift keying (QSSK). Unlike other modulation techniques where symbols are transmitted, In SSK the antenna index relays information during transmission. This absence of symbol information eliminates the transceiver elements necessary for APM transmission and detection (such as coherent detectors). As well, the simplicity involved in modulation reduces the detection complexity compared to that of spatial modulation (SM), while achieving almost identical performance gains. In this paper, SSK is implemented for MIMO and also compared the results with QSSK under various conditions like increasing the number of transmitting antennas, increasing number of receiving antennas and proved the later has low probability of error.

Keywords: MIMO, Space Shift keying, quadrature shift keying, spatial modulation, Probability of error

INTRODUCTION

For wireless communications like mobile communications, we use many techniques for efficient transmission and MIMO (Multiple input and multiple output) systems are widely used among them and has been considered in many recent standards such as LTE, WINNER etc. The great advantages like higher data rate, higher reliability it possesses makes it widely used in practical applications. But even MIMO systems have their own disadvantages which led to the development of better versions with MIMO systems [1]. Thus, the MIMO technology with Space Shift Keying (SSK) has been suggested in different researches to achieve that goal for next generation communication technology. QSSK supports the quadrature dimension to enhance the system spectral efficiency, in QSSK, there

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are no RF-chain is needed and only two signals are used they are unmodulated, orthogonal carrier signals ($\cos(2\pi f_c t)$ and $\sin(2\pi f_c t)$). The incoming data will help to control the RF switches to determine that which antenna is to be activated for each signal. In our practical implementation we will check and compare the performance of the system using BER vs SNR plots of SSK and QSSK by varying different parameters and the overall comparison between SSK, QSSK, SM systems

THE SYSTEM AND RECEIVER MODELS

MIMO systems can transfer multiple data from transmitter to receiver with the help of multiple

antennas. We can transfer same symbol through all antennas which is known as diversity (which leads to the concept of diversity gain, where the data can be transmitted with reliability even in case of any failure of any one of the antennas) [2] and we can also transfer different symbols at a time with each antenna known as spatial multiplexing. There are two types of transmission on Figure 1.

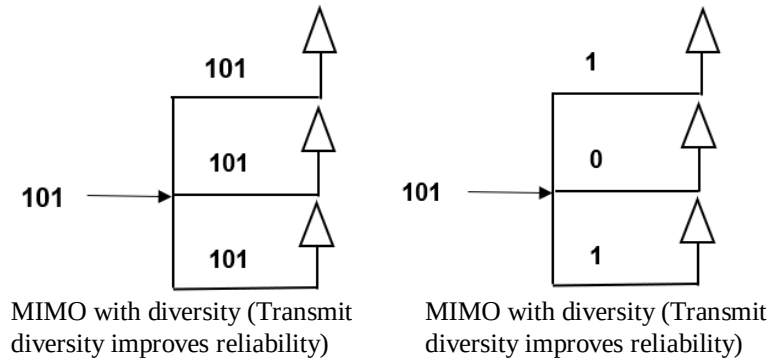


Figure 1. Two types of transmission.

We will look into some parameters and their mathematical equations and understand the limitations. We will see SM (Spatial modulation especially SSK (Space Shift Keying, one of the simplified versions of SM) can overcome the limitations in MIMO systems as depicted in Figure 2.

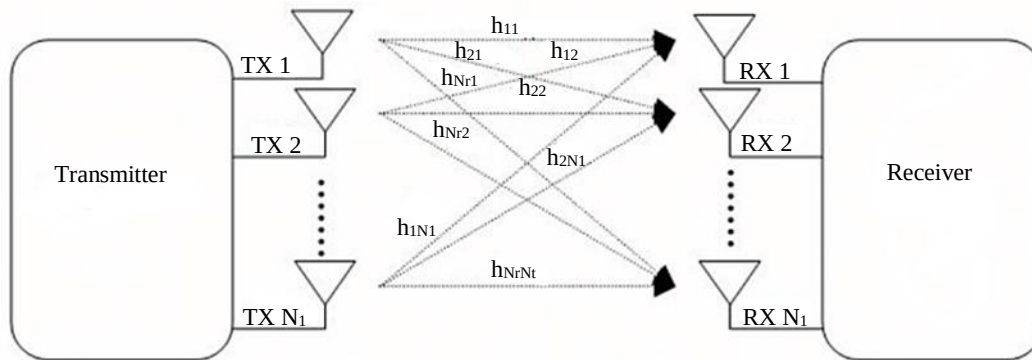


Figure 2. MIMO system.

C/B (Data rate per band width)

$$= \eta_{SE} = \log(1 + (P/N_0B)) \quad (1)$$

C/P (Energy rate per 1 watt)

$$= (\eta_{SE})(B)/((N_0B(2\eta_{SE}-1))) \quad (2)$$

Firstly, from equation 2, from the denominator of the expression it is seen that energy efficiency is inversely proportional to spectral efficiency. This is considered as one of the major limitations. The signal received in a MIMO system can be expressed as

$$\begin{bmatrix} Y_1 \\ Y_2 \\ \dots \\ Y_{Nr} \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{13} & \dots & h_{1Nt} \\ h_{21} & h_{22} & h_{23} & \dots & h_{2Nt} \\ \dots & \dots & \dots & \dots & \dots \\ h_{Nr1} & h_{Nr2} & h_{Nr3} & \dots & h_{NrNt} \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \\ \dots \\ X_{Nt} \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ \dots \\ n_{Nr} \end{bmatrix}$$

$$\bar{Y} = H\bar{X} + \bar{n} \quad (3)$$

Considering the output equation at 1st antenna

$$Y_1 = h_{11}X_1 + h_{12}X_2 + h_{13}X_3 + \dots + h_{1N_t}X_{N_t} \quad (4)$$

Secondly, considering eq.3, we can observe the high probability of inter channel interference and a need for inter channel synchronization. To identify the X vector, we use methods like maximum likelihood detection which involve calculating squared error values which increase complexity.

Complexity is measured considering number of real multiplications [3].

$$\text{For MIMO Complexity} = 4 N_r (N_t+1) 2\eta_{SE} \quad (5)$$

for all values of X vector. (Where N_r = receiver antennas, N_t is number of transmit antennas).

This increase in computation will lead to increase in latency. In MIMO we as many numbers of RF chains (cascade of power amplifiers, attenuators, filters, mixers, detectors etc.) as that of number of transmit antennas. This increases hardware complexity and in turn increases power consumption.

We will look into one of the greatest advantages of MIMO systems i.e. spectral efficiency.

$$\eta_{smux} = N_t \times \log_2(m) b_{pcu} \quad (6)$$

m =modulation order based on the type of modulation technique (QAM) used. (For ex: BPSK $m=2$).

The working and transmission using MIMO systems and the hardware implementation can be seen in [4].

To eliminate all the above discussed problems, we use spatial modulation. Spatial modulation uses multiple antennas to convey extra information bits in particular. The extra information is in corded in the physical location of transmitting antenna as such it requires no additional bandwidth yet still results in increase of data rates [5]. Systems become more spectral efficient. Spatial modulation requires only 1 RF chain because we activate only one antenna and providing zero power to other antennas. Spatial modulation is one of the pragmatic approaches for conveying information through conventional digital modulation as well as through index of antenna [6]. This is known as index modulation (some of the types are spreading codes, sub modulation etc.). SSK (Space Shift Keying) is the simplified version of SM. It involves no modulation and this is how it differs from SM. There is no signal or symbol transferred, only the antenna index is identified. In SSK we have less bit error rate, lower complexity etc., but SSK involves larger antenna arrays for more spectral efficiency and there is no benefit of modulation in SSK. In SSK diversity gain is achieved through multiple receive antennas but there is no transmit diversity. We will look into SM and SSK working and see how MIMO system limitations are eliminated and see how greater performance is achieved.

In SSK, as shown in Figure 3, only one antenna remains active during transmission. Ideally only one RF chain is required (Generalized SSK can involve more than one RF transmitter). SSK uses ultrawide band (UWB), since pulse shaping is not required in the UWB framework, the cost of RF chains is fixed in that case, regardless of the number of antennas. Therefore, at the most, we would require the number of RF chains to equal the number of symbol period durations in the transmitted pulse. This is how it is useful to reduce the complexity. The vector x specifies the activated antenna, during which all other antennas remain idle, and has the following form:

$$X_j = [0 \ 0 \ \dots \ 1 \ \dots \ 0 \ \dots \ 0]^T$$

 **jth position**

Let us consider an example for better understanding:

Table 1. Representation of different combinations.

$\mathbf{b}=[b_1 \ b_2]$	Symbol	Antenna index j	$\mathbf{X}=[x_1 \dots x_4]^T$
[0 0]	0	1	$[1 \ 0 \ 0 \ 0]^T$
[0 1]	1	2	$[0 \ 1 \ 0 \ 0]^T$
[1 0]	2	3	$[0 \ 0 \ 1 \ 0]^T$
[1 1]	3	4	$[0 \ 0 \ 0 \ 1]^T$

In this 4×4 MIMO channel, where only one antenna is activated at a time, so there is great possibility of reducing the interference, can have less bit error.

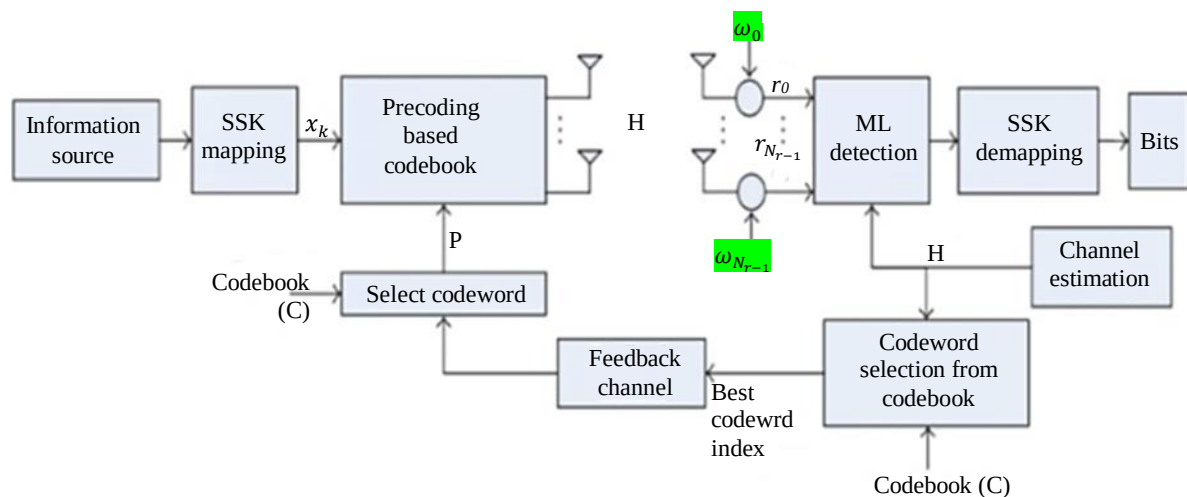
The output vector at the receiver side in SSK can be as

$$\mathbf{Y} = \mathbf{H}_j + \mathbf{n} \quad (7)$$

Where $j=1, 2, 3, 4, \dots, N_t$.

Consider antenna 1 is transmitting in 4×4 MIMO system

$$\begin{bmatrix} Y_1 \\ Y_2 \\ Y_3 \\ Y_4 \end{bmatrix} = \begin{bmatrix} h_{11} \\ h_{21} \\ h_{31} \\ h_{41} \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \end{bmatrix} \quad (8)$$

**Figure 3.** Basic block diagram of SSK.

$$\text{Spectral efficiency } \eta_{\text{ssk}} = \log_2(N_t) \text{ bpcu} \quad (9)$$

for the above example: $k=2$ bpcu.

The data sequence is inferred as 10|11|10|00|..... (3rd antenna is going to transmit unmodulated carrier signal then 4th antenna and then 3rd antenna.....).

$$\text{Neglecting the noise, the squared error } \|\mathbf{y} - \mathbf{h}_j\|^2 \quad (10)$$

We substitute the $\mathbf{h}$ vector values. The $\mathbf{h}$ value for which the error is minimum, that antenna is identified as transmit antenna. The process of detecting antenna index can be in seen in detail [7].

Compare eq 3 and eq 7. The identification and transmission is similar to that of SM. In SM it transmits information (which is then mapped to identify original information based on the modulation

order) and antenna index. The spectral efficiency is more in SM than SSK. Refer [8, 9] for detail working of SM. **The hardware implementation.** The transmission process is employed in practical implementation to compare the performance of the systems. From eq 10 and eq 8,

$$\text{we can write complexity} = 4N_r(2\eta_{\text{SSK}}) \quad (11)$$

After comparing the equations of MIMO and SSK, we can infer that hardware and computational complexity is reduced (no real multiplications in SSK), interference is reduced, spectral efficiency is directly proportional to number of transmit antennas as shown in Figure 4.

IMPLEMENTATION

We have look into some of the basic concepts of SM, SSK, QSSK and to decide which technique can be used in which applications based on their limitations and advantages. For further explanation on QSSK [10].

In our practical implementation we will check and compare the performance of the system using BER vs SNR plots of SSK and QSSK by varying different parameters

We will look into overall comparison between SSK, QSSK, SM systems. SSK Technique is used over SM to decrease the complexity by only transmitting antenna index. For same Spectral efficiency we need more number of Antennas in SSK than SM. Therefore, we have slightly large BER values. QSSK is implemented to increase diversity gain by activating one or atmost two antennas.

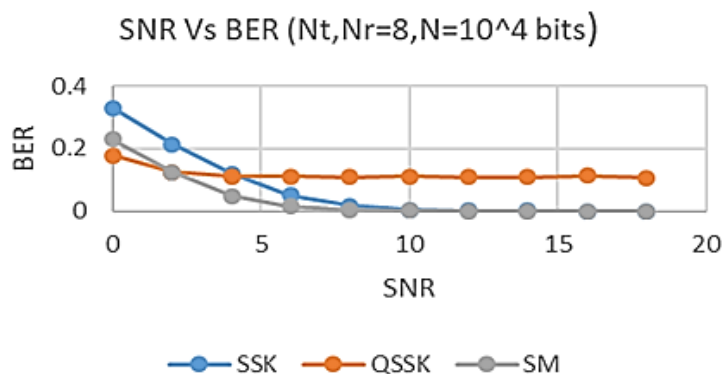


Figure 4. Comparison b/w SSK, QSSK, SM on given parameters.

Simulation Time (seconds):

1. SSK-5.6356
2. QSSK-21.1555
3. SM-29.8203

We will look into different BER Vs SNR plots, which are used to analysis the performance of SSK systems under different conditions.

In SSK, by increasing number transmit and receiving antennas we can improve diversity and can transmit with less BER for same $N=10^4$. On increasing N_t with constant N_r , we can observe increase in BER w.r.t SNR. For $N_t < N_r$, the difference between each plot is less. Whereas, the gaps widen and is more for $N_t > N_r$. On increasing Number of receiving antenna, we can achieve less error rates. We can see for $N=10^4$, if $N_r=128$, the error is almost zero throughout in current scenario. If we observe even from the above plots (Figure 5), the time taken can be understood by comparing the stimulation time s of the implementation. By increasing antennas on either side, we require more time for implementing as depicting in Figure 6.

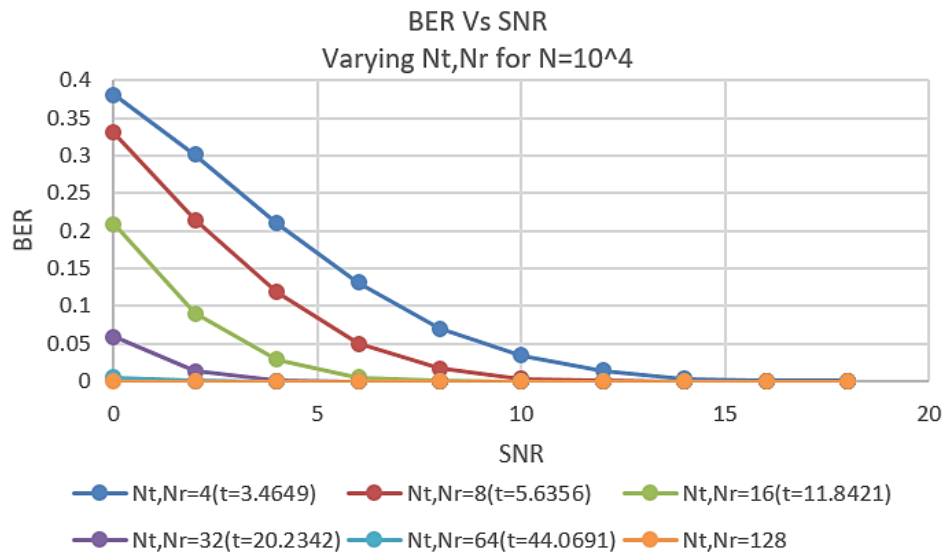


Figure 5. Plot varying number of transmitter and receiver antennas.

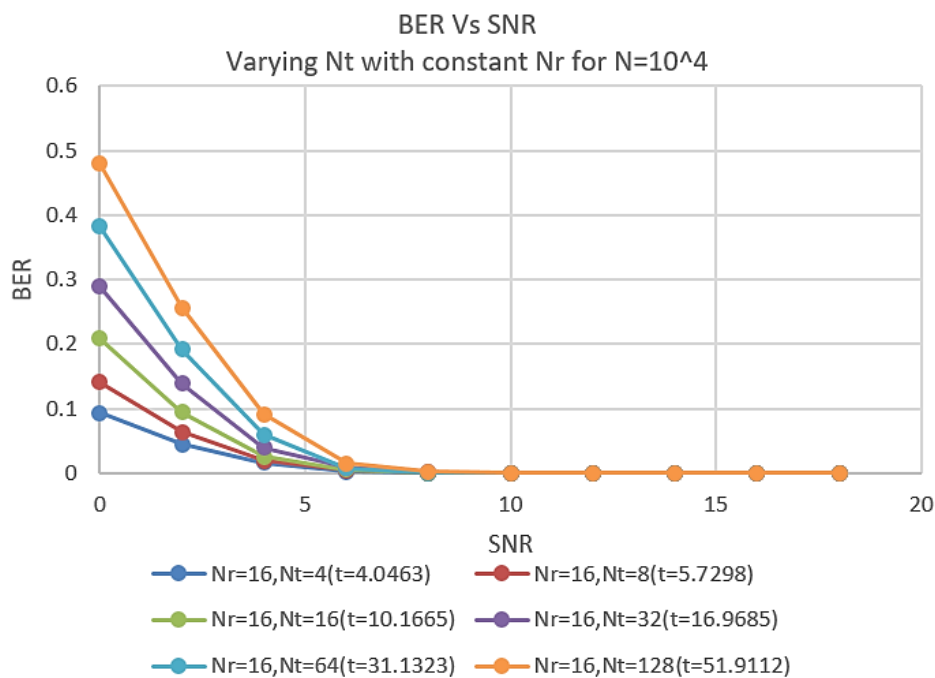


Figure 6. Varying number of transmitting antennas with constant receiving antennas of 16.

Though we increase N to 10 times each time, there is no much difference when considering N_t , $N_r=8$. As N increase the probability of error increases.

The same specific results are drawn after implementing QSSK. Let us note the differences. The plot in Figure 7 are represented in correspondence with the above graphs.

In Comparison with SSK, the plot is not that exponentially decreasing and lowest error values is not as low as SSK as shown in Figure 8. But, the average error probability value of QSSK is less compared to SSK. Using QSSK we can decrease the Error even with increasing transmitting antennas unlike SSK. We can bring out the advantaged of SM with increasing antenna arrays with more transmit and receive diversity.

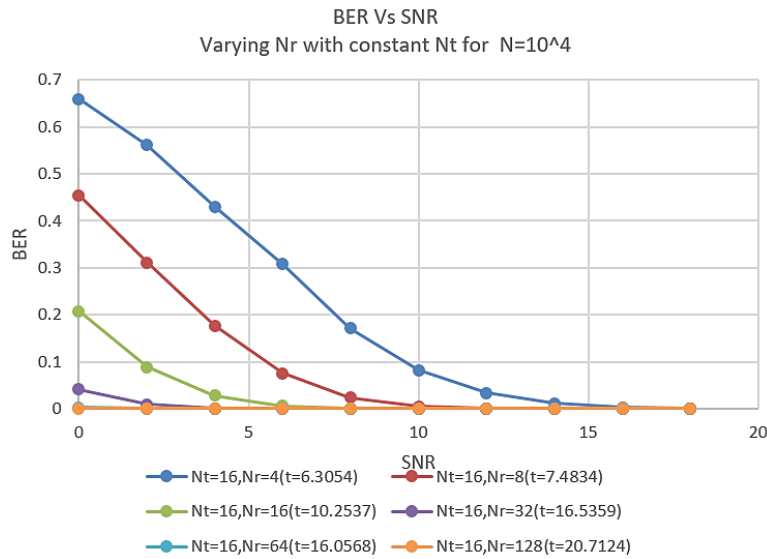


Figure 7. Varying number of transmitting antennas with constant receiving antennas of 16.

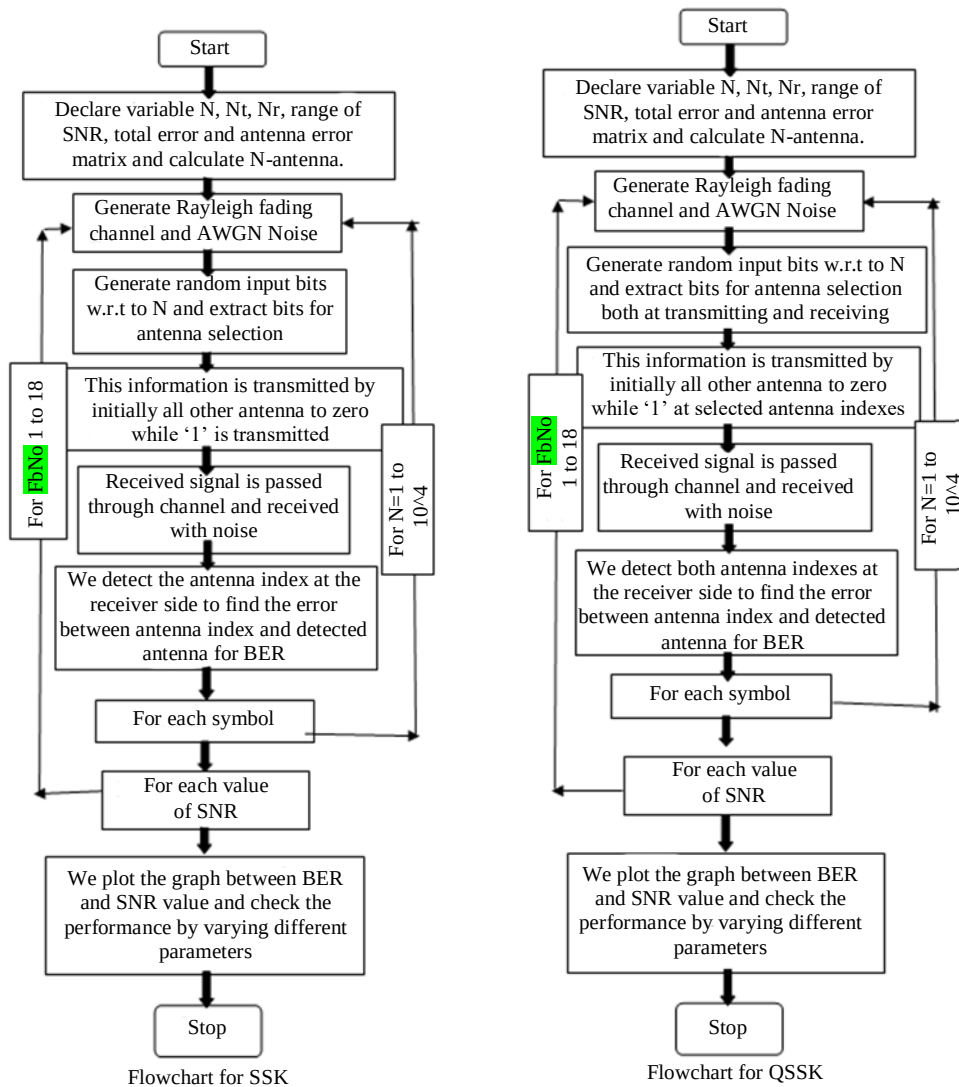


Figure 8. Flowchart for SSK & QSSK.

From Figure 9, it is shown that if SNR is increased, BER decreases. Irrespective of number of bits that are transmitted, the graph between SNR and BER remains the same.

Figures 9–11 depicts the variation of Ber with SNR for increase in number of bits that are transmitted. All these graphs show a common result that the transmission bit rate does not affect the diversity of MIMO.

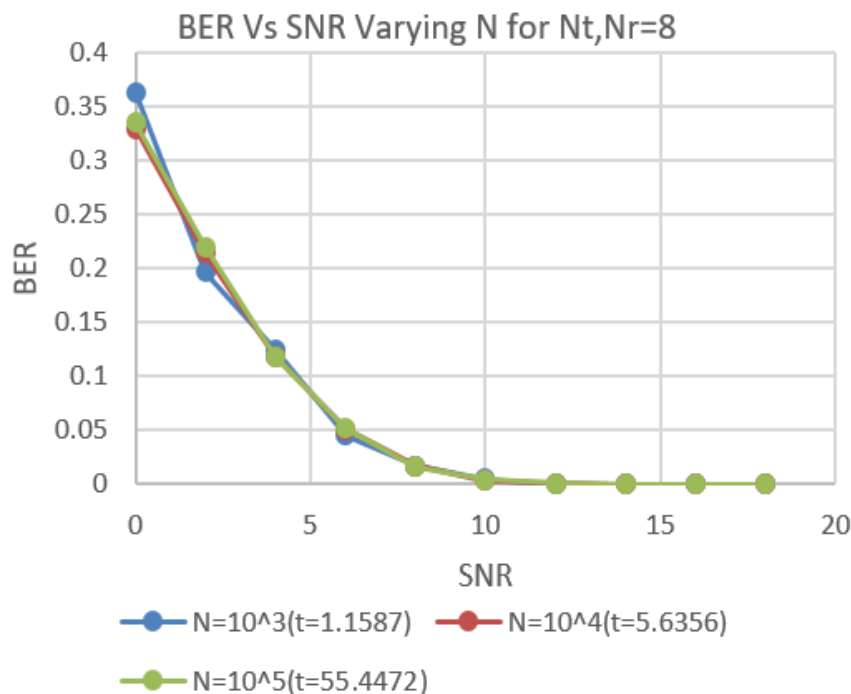


Figure 9. Varying number of bits to be transmitted with transmitting and receiving antennas to be 8.

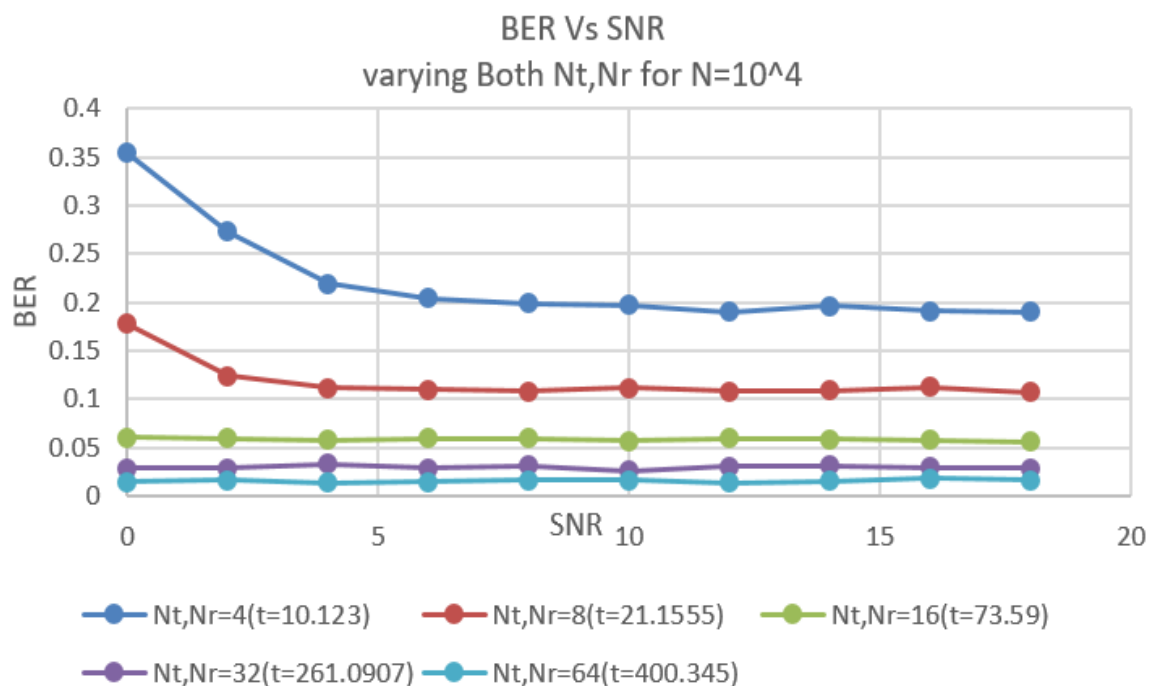


Figure 10. Variation of BER with a diversity of 10^4 .

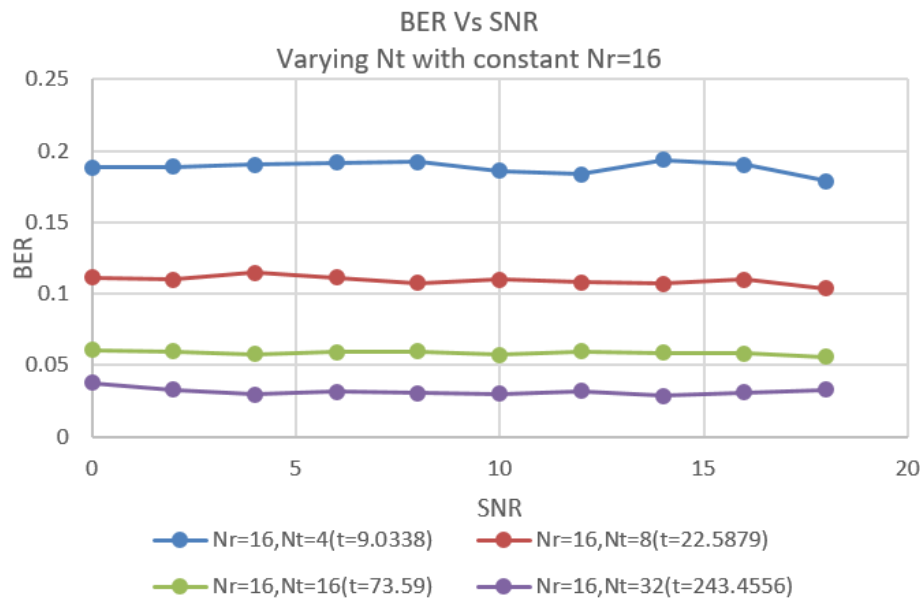


Figure 11. Effect of transmit diversity on BER.

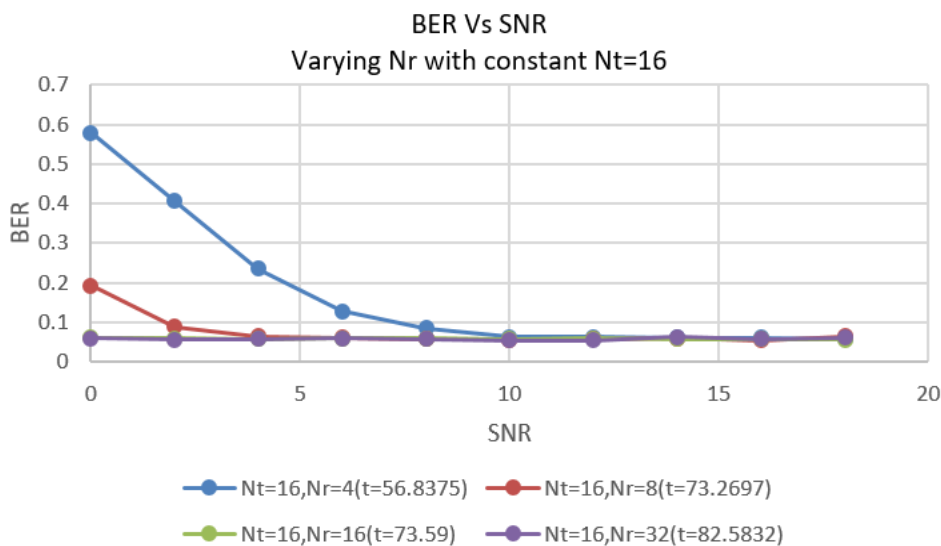


Figure 12. Effect of receiver diversity on BER.

CONCLUSION

We have seen different techniques used in Wireless Communications. We have seen the advantages and disadvantages from different techniques. There are many experiments going on to find suitable techniques for communication by varying certain parameters of existing technology. For example, Time orthogonal signal design technique is a SSK method which is used to achieve both transmit and receive diversity along diversity gain which is not possible alone with SSK. Another case where we are trying to modify Spatial modulation to achieve high rates and high efficiency as that of Smux. We try to buildup new methodologies to satisfy all cases and produce a high-performance communication system.

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