PHASE NOISE COMPENSATION USING PTRS IN 5G MM-WAVE

A Project Report

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THESIS CERTIFICATE

This is to certify that the thesis titled **PHASE NOISE COMPENSATION USING PTRS IN 5G MM-WAVE**, submitted by **Akshay Chintaman Damse**, to the Indian Institute of Technology, Madras, for the award of the degree of **Master of Technology**, is a bona fide record of the research work done by him under our supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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ABSTRACT

KEYWORDS: 5G NR; PTRS, common phase error (CPE).

5G (Fifth Generation) technology is an upcoming technology, makes communication much faster and easier with higher BW, higher download rate, as compared to 4G/LTE. All these are possible with the use of millimeter-wave by 5G technology. It means that the phase noise added to the signal is significantly higher (as we move to higher frequencies -millimetric wave). Hence, it is of paramount importance to reduce or mitigate this phase noise effect in a 5G mm-wave.

In this work, an attempt made to track the phase of the signal using PTRS. Degradation caused by phase noise is studied, and the improvement achieved using PTRS is studied for difference constellation and different PTRS densities.

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ABBREVIATIONS

IITM	Indian Institute of Technology, Madras
5G/NR	Fifth Generation/ New Radio
FDMA	Frequency Division Multiple Access
TDMA	Time Division Multiple Access
CDMA	Code Division Multiple Access
OFDM	Orthogonal Frequency Division Multiplexing
D2D	Device To Device
MIMO	Multiple Input Multiple Output
mm-wave	milli-meter Wave
LTE	Long Term Evolution
3GPP	Third Generation Partnership Project
PTRS	Phase Tracking Reference Signal
DMRS	Demodulation Reference Signal
CPE	Common Phase Error
PSD	Power Spectrum Density
DFT-S-OFDM	Direct Fourier Transform spread OFDM
CP	Cyclic Prefix
RB	Resource Block
IFFT	Inverse Fast Fourier Transform
FFT	Fast Fourier Transform
RF	Radio Frequency
ICI	Inter Channel Interference
ISI	Inter Symbol Interference
CSI-RS	Channel State Information Reference Signal
SRS	Sounding Reference Signal
UP	Up Link
DP	Down Link

NOTATION

μ	Parameter used in 3GPP document for numerology, m
Δf	Sub-carrier spacing KHz
ϕ	Phase noise in degrees
$\sphericalangle$	angle

CHAPTER 1

INTRODUCTION

In the last four decades, we saw four generations of communication technologies. 5G is the next-generation wireless technology. This technology makes communication much faster as it employs very high bandwidth.

1.1 5G is Next Generation Wireless Technology

In 1980, the first generation of communication technology started. 1G provides only voice service. In 1990, the second generation came that having digital transmission and provided messages along with voice service. In 2000, the third generation introduced. 3G provides high-quality mobile broadband service. In 2010, the fourth generation came into the picture that further enhanced mobile broadband and brought all-IP services. In 2012, a discussion on 5G started.

The first generation having frequency 30KHz and bandwidth 2 Kbps with FDMA (Frequency Division Multiple Access). The second generation having a frequency 1.8 GHz and bandwidth of 1.4-64 Kbps. 2G provides secure and reliable communication channel also 2G having TDMA (Time Division Multiple Access) or CDMA (Code Division Multiple Access). The third generation sets the standard for most of the wireless communication technology. 3G having a frequency range from 1.6-2 GHz and bandwidth of 2 Mbps with CDMA (Code Division Multiple Access). 4G having LTE technology with a frequency range from 2-8 GHz and bandwidth of 200 Mbps.4G having CDMA (Code Division Multiple Access) System.

5G is mm-Wave technology, having a frequency range from 3-30 GHz with a bandwidth 1 Gbps and above. 5G having OFDM (Orthogonal Frequency Division Multiplexing). 5G provides ultra-low latency, faster data rate, and higher connection density than 4G. The latency rate is the delay in getting information from the sender to the receiver. The latency in 4G is 200 milliseconds, and 5G is one milli-second. 5G Technology contains some advantage like reliability, high spectral efficiency, low battery consumption with improving coverage area, D2D (Device to Device) communication, high security. The key technology in 5G is massive MIMO (Multiple Input Multiple Output), Small cell, and mm-Wave that gives 1 Gbps bandwidth to the user.

Every new generation of wireless networks delivers and more functionality faster speed to our device. As users are increasing, 4G/LTE network about to reach the limit, and 4G is now fully saturated. Day by day, users need even more data for their devices.

Now we are moving towards 5G/NR, the upcoming wireless technology. This 5G/NR will able to handle a thousand time more traffic than LTE network and 5G is ten times faster than 4G LTE. 5G will be the formulation of IoT, virtual reality, autonomous driving.

1.2 What exactly 5G Network?

Some new technologies are emerging as a foundation of 5G:

1.2.1 mm-Wave:

The device that we are using has particular frequencies on the radio frequency spectrum, typically those under 6 GHz.These frequencies are getting to be more crowded, as more number of devices using this frequency spectrum, speed and service get slower. So the solution to this problem is to use frequencies above 6 GHz.This mm-wave spectrum did not use before, and by using this spectrum, we will get more bandwidth. But there is a catch that mm-wave can not travel through obstacles or buildings and walls. This mm-wave get absorbed by plants and rain, so climate condition also affects mm-wave performance. To get over this problem, 5G having small cell technology.

1.2.2 Small cell:

Today's network using a massive high power tower to send the signal over long distances, but high-frequency mm-wave can not pass through obstacles, which means if the user is behind the tree or wall, the user may lose the signal. A small cell network is introduced in 5G to solve this problem. Small cells contain thousand of small base stations. These small cell base stations would be much close together than the traditional tower.

1.2.3 MIMO:

Massive MIMO will having multiple antennas at the base stations. MIMO is increasing network performance by the factor of 22, but it has its complications. Today's antenna broadcasts information in all directions, and this causes dangerous interference. So, 5G having new technology that is beamforming.

1.2.4 Beam Forming:

In beamforming instead of transmitting the signal in all directions., It will send the message in a specific direction towards the users are positioned, and this is more efficient. Due to this beamforming signal, travel over a considerable distance.

CHAPTER 2

LITERATURE REVIEW

We know the 5G mm-Wave band offers massive spectrum bandwidth, which boosts the system's performance. When the device operated in this mm-Wave band phase, the noise gets added in the signal due to the various channel impairments. This noise highly pronounced in the system operating > 6 GHz as compared to 4G/LTE. Hence, it is of paramount importance to reduce or mitigate this phase noise. This phase noise directly affects the constellation and changes the received data. It becomes challenging to remove this phase noise in 5G, mainly when we used the frequency above 6 GHz, which incorporates provisions in the frame structure to track the phase noise allowing one to compensate for the distortion at the receiver.

3GPP (3rd Generation Partnership Project) released standard to compensate for this phase noise effect. 3GPP introduces PTRS (Phase Tracking Reference Signal) to track the phase. This phase noise remains common along with sub-carriers but changes rapidly along with OFDM symbols, so this phase noise is called as CPE (Common Phase Error) Qi *et al.* (2018). In Qi *et al.* (2018) used multiple pole-zero phase noise model to generate phase noise and using results shows that phase noise gets introduce in the signal as we go above 6 GHz.

References Qi *et al.* (2018); Zheng *et al.* (2018), and 3GPP (2017) specified the design of PTRS , and this shows that using PTRS phase noise can be reduced significantly. By using PTRS, along with OFDM symbols, we can reduce CPE significantly as compared to the placing PTRS along with frequency.

Phase noise compensation scheme discussed inZheng *et al.* (2018) for DFT-S-OFDM in MIMO (Multiple Input Multiple Output) system uses the same multiple pole-zero phase noise model and shows that by using high SINR (Signal To Interference Noise Ratio) to transmit PTRS, we achieve considerable processing gain. Also, by using Pre-DFT and Post-DFT scheme phase, noise is estimated quite accurately Zheng *et al.* (2018). Our primary interest is the phase calculation approach, which discusses in Zheng *et al.* (2018).

The low complexity method for compensation of phase noise clearly explained in Leshem and Yemini (2017). In Leshem and Yemini (2017) phase, the noise process estimated using Karhunen-love representation and the PAST algorithm used for subspace tracking. The PAST algorithm is a very effective method for higher-order modulation, such as 64 and 256 QAM. All 5G/NR challenges discussed in Berardinelli *et al.* (2016) that use DFT-S-OFDM without CP (Cyclic prefix), which reduces the time constraints of OFDM, power consumption, and also reducing latency.

2.1 3GPP 5G/NR Frame Structure

After a long discussion on the 5G/NR frame structure in 3GPP, we have a perfect frame structure for NR (New Radio). 3GPP specified 5G/NR frame structure in 3GPP TS 38.211 document as follows:

1. Sub-carrier Spacing:

LTE has 15 kHz sub-carrier spacing only, whereas 5G/NR supports multiple sub-carrier spacing. This multiple sub-carriers spacing present in 5G is the main difference in LTE and 5G/NR specified in the 3 GPP document.

This sub-carrier spacing is calculated using following formula:

$$\Delta f = 2^{\mu}.15(KHz) \tag{2.1}$$

where, numerology (μ) and Δf is sub-carrier spacing. When $\mu = 0$ then sub-carrier spacing is 15 kHz, this is the only sub-carrier spacing present in LTE.For different values of μ sub-carrier spacing shown below in table 1.1

In the above table 1.1 all sub-carriers having normal cyclic prefix along with this 60 kHz having extended Cyclic prefix also.

Table 2.1: Different sub-carrier spacing present in 5G/NR

μ	sub-carrier spacing (KHz)	Cyclic Prefix
0	15	Normal
1	30	Normal
2	60	Normal/Extended
3	120	Normal
4	240	Normal

2. Slot Length:

In 3GPP, specify slot length based on sub-carrier spacing, as sub-carrier spacing increases slot length decreases. Slot length for different sub- carrier spacing is given below in table 1.2

Table 2.2: Slot length for different sub-carrier spacing specified in 3GPP for 5G/NR

sub-carrier spacing (KHz)	Slot Length
15	1 ms/slot
30	0.5 ms/slot
60	0.25 ms/slot
120	0.125 ms/slot
240	0.0625 ms/slot

The length of the frame is always 10 ms, and the length of the subframe is always 1 ms. One slot contains 14 OFDM symbols, and 1 RB (Resource Block) includes 12 subcarriers.

Table 2.3: Slot length pre frame and per sub frame for different sub-carrier spacing specified in 3GPP for 5G/NR

μ	Symbols per slot	Slot per frame	Slot per sub frame
0	14	10	1
1	14	20	2
2	14	40	4
3	14	80	8
4	14	160	16

Let us consider one example to explain table 1.2 and 1.3. When $\mu = 3$, that is sub-carrier spacing is 120 kHz.

Table 2.4: Calculation of symbol duration for $\mu = 3$ with sub-carrier spacing is 120 KHz.

1 frame	10 ms
1 Sub-frame	1 ms
8 Slot	1 ms
1 Slot	0.125 ms
14 Symbols	0.125 ms
1 Symbol	8.92 μs

3. Sampling Interval:

Time interval between two successive samples of signal is called as sampling interval and inverse of sampling interval is sampling rate. Calculation of sampling interval is specified in 3GPP (2017).

$$T_c = \frac{1}{\Delta f_{max} * N_f} \tag{2.2}$$

where,

Δf_{max} is Sub-carrier spacing.

N_f is FFT length.

T_c is Sampling duration or sampling interval of OFDM symbol in 5G/NR.

$$T_s = \frac{1}{\Delta f_{Ref} * N_{f-Ref}} \tag{2.3}$$

where,

Δf_{Ref} is reference Sub-carrier spacing.

$\Delta f_{Re} = 15KHz$

N_{f-Ref} is reference FFT length.

$N_{f-Ref} = 2048$

T_s is the Sampling duration or sampling interval of the OFDM symbol in LTE.

$T_s = 32.56ns$

4. OFDM Symbol Duration:

As we calculate the OFDM symbol duration in table 1.4 for $\mu = 3$, we estimate this OFDM symbol duration for all sub-carrier spacing and put these values in table 1.5, as given below table 2.5. Table 2.5 also contains Cyclic prefix and even OFDM symbol, including Cyclic prefix durations for each sub-carrier spacing.

Table 2.5: OFDM symbol duration for all sub-carrier spacing or different values of μ.

μ	0	1	2	3	4
Sub-carrier Spacing(KHz)	15	30	60	120	240
OFDM Symbol duration (μs)	66.67	33.33	16.67	8.33	4.17
Cyclic Prefix Duration (μs)	4.69	2.34	1.17	0.57	0.29
OFDM Symbol including CP (μs)	71.95	35.68	17.84	8.92	4.46

CHAPTER 3

SYSTEM MODEL

3.1 OFDM

OFDM is a particular case of frequency division multiplexing (FDM). In OFDM, the sub-carrier signals present in the channel are orthogonal to each other. Because of the orthogonality inter-carrier guard band is not required.

In OFDM there must be accurate frequency synchronization between transmitter and receiver, if there is small frequency deviation, then sub-carrier will not remain orthogonal, which creates inter-carrier interference. The block diagram of the OFDM system shown in the figure below

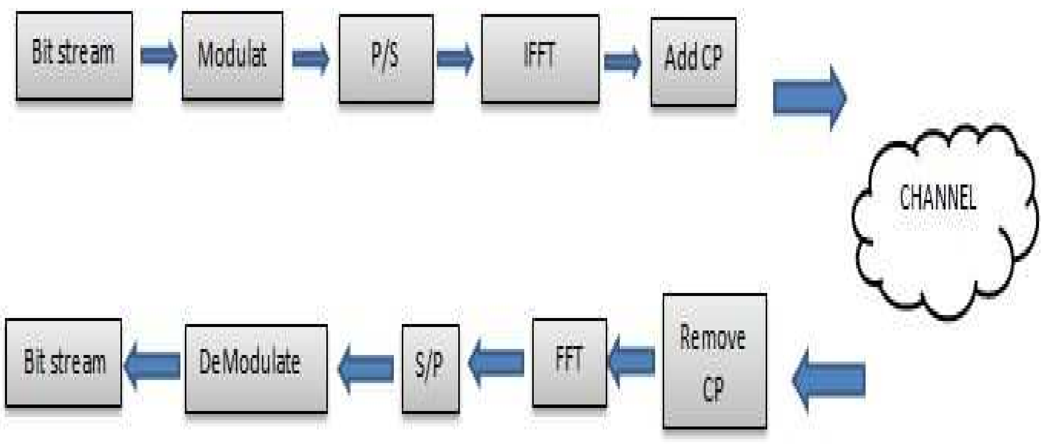

Figure 3.1: Block diagram of OFDM Transmitter and Receiver.

In the OFDM transmitter, bitstream or data is first to modulate with modulation schemes like QPSK, 16 QAM, 64 QAM, and 256 QAM. This modulated data mapped in the resource grid. Then DMRS and PTRS pilot signals are added in this resource grid. DMRS used for demodulation and channel estimation of the associated physical channel. PTRS, which used to track the phase of the OFDM symbols. After modulation and mapping, this parallel data is then converted to serial data and then performs IFFT (Inverse Fast Fourier Transform) operation on this serial data. We are using 1024 point FFT in OFDM system. Then CP (Cyclic prefix) is added in data. CP is just copying the last part of the OFDM symbol and put it in front of the OFDM symbol, and because of a cyclic prefix, we avoid inter-symbol interference. We are using 120 Cp length in OFDM. After adding cp data is converted to an analog signal using digital to analog signal modulate with the carrier, and then this signal is transmitted over channel.

During the modulation, due to local oscillator or some wireless problems, phase noise, get added in signal when we use high frequency (above 6 GHz). The transmitted signal received at the receiver, and this RF signal is demodulated and passed through the analog to digital converter. Then CP is removed and performs FFT operation on that data. This data then demodulated, and we get back the bitstream that is transmitted. In 5G, when we go above 6 GHz, the phase gets added in the signal, and it is difficult to reduce the effect of this phase noise. This phase noise contained two main parts: CPE(Common Phase Error), and the other is ICI (Inter Carrier Interference). We mainly focus on reducing CPE. This error changes rapidly along with the OFDM symbol. To remove this CPE, we use PTRS, this we will see in the next chapter.

3.2 Channel

3.2.1 Complexities in wireless Channel:

Unlike a wired channel, which uses a fixed path through the wire, the signal in a wireless channel can reach a user using multiple ways. Due to this multipath signal, various signals received at the receiver with different delays. This multipath component may have unusual channel gain and time delay. The combined effect causes multipath fading.

2.Delay spread:

As a consequence of multipath propagation, the duration of the symbol gets extended or shifted. This shifted symbol may interfere with the next symbol. This interference called inter-symbol interference (ISI) or cross talk. Guard bands are introduced in between the symbols to avoid cross-talk in LTE.

3.Frequency Selective Fading:

Signal bandwidth must be lesser than the coherence bandwidth of channel for proper reception of the signal. If signal having bandwidth higher than the coherence bandwidth of the channel, then we get attenuation at different frequencies and this distorts the signal and gives rise to frequency selective fading.

4.Inter channel interference:

When signal bandwidth of adjacent carrier frequency overlap with each other, this interference called inter-channel interference, and guard band used to avoid this.

3.2.2 Rayleigh fading channel:

Rayleigh fading channel is an instrumental model in real-world wireless communication. We are using the Matlab 5G toolbox Rayleigh fading channel model with zero Doppler shift. When we use the Rayleigh fading Matlab model, the magnitude of the signal that passes through the communication channel will vary randomly, or we can say fad according to the Rayleigh distribution. In this channel model, we can change parameters like path delay, sample rate, maximum Doppler shift, etc.

Properties of Rayleigh Channel:

1. **Sample Rate:** Input sample rate of this model is 1Hz (Default).

2. **Path Delay:** When we set the value of path delay to scalar quantity in Matlab 5G toolbox Rayleigh fading channel model, then the channel becomes frequency flat and when we set the value to vector quantity then channel become frequency selective. We are using flat frequency channel, so we set the value of path delay

to zero, as default value in Matlab channel model.

3. **Maximum Doppler shift:** This adds Doppler shift in the signal. we do not want any Doppler shift, so we set this value to zero.

3.3 Phase Noise Model

3.3.1 Model 1 (comm.phaseNoise 5G Toolbox Matlab Model):

The output signal, y_k, is related to input signal x_k by $y_k = x_k.e^{\phi_k}$, where ϕ_K is phase noise. The phase noise is filtered Gaussian noise such that $\phi_K = f(n_k)$, where n_k is the noise sequence and f represents a filtering operation.

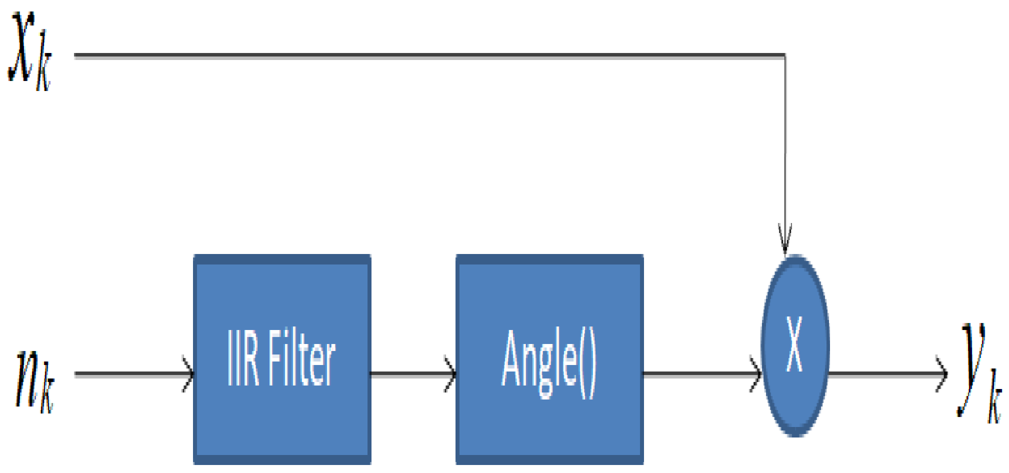

Figure 3.2: Matlab 5G toolbox phase noise generation.

We are using the Matlab 5G toolbox phase noise model with different phase noise levels. In this phase noise model, we can change the different parameters like phase noise level, frequency offset, sample rate, etc.

1. phase Noise Level = -65 dB.
2. phase Noise Level = -75 dB.

This Matlab 5G toolbox adds phase noise to a complex signal, which emulates the local oscillator's noise.

Properties of Phase Noise Model:

1. **Phase Noise Level:** We can set these values to different dB levels between the range of [-60 -80] dB.
2. **Frequency offset:** We are using a 1000 frequency offset level.
3. **Sample Rate:** We are using a different value for sampling rate. This sampling rate we are calculating using the following equation 3.1 and table 2.2 for different sub-carrier spacing.

$$SampleRate = \frac{1ms}{14 * (N_{FFT} + N_{cp})} \tag{3.1}$$

Where, slot length =1 ms for 14 symbols with 15KHz sub-carrier spacing

N_{FFT} = FFT size

N_{cp} = CP length

Samples per symbol= (N_{FFT} +N_{cp})

3.3.2 Model 2:

We generate our phase noise model. This model designed according to our the requirement, in this model phase noise, remain constant along sub-carrier and change along with OFDM symbols.

This phase noise model has a Gaussian distribution. This model also has some correlation across symbols. All these things are taken into consideration while designing this model. Generate Phase noise model equations is given below in equations:

Let W_{no} be a vector of Gaussian Noise.

Let P_{no} be another vector of Phase Noise.

C is constant, C=0.95

$$P_{no}(1) = W_{no}(1) \tag{3.2}$$

$$P_{no}(n) = P_{no}(n-1) + C * W_{no}(n) \tag{3.3}$$

This is the first order AR model. This we used only for simulation This is not optimal model for phase noise.This will introduce correlation across symbols and we can check that PTRS is tracking the phase noise properly.

3.4 5G/NR Reference Signals

To keep the transmission of data within the slot without depending on the other slot and also for increasing protocol efficiency, NR (New Radio) introduced the following four main reference signals.
1)DMRS (Demodulation Reference Signal)
2)PTRS (Phase Tracking Reference Signal)
3)CSI-RS (Channel State Information Reference Signal)
4)SRS (Sounding Reference Signal)

We are studying on DMRS and PTRS signal in this work mainly on PTRS signal to reduce common phase error.

3.4.1 What is new things present in New Radio as compare to LTE.

1) PTRS signal introduced for the tracking phase either alone OFDM symbol or along with sub-carrier frequency. CPE variation faster along with OFDM symbols, so we add PTRS mostly along with OFDM symbols
2) For both uplink(UL) and downlink (DL)channel, the DMRS signal introduced for channel estimation.
3)cell-specific reference signal is not present in 5G/NR.
4) When reference signals are necessary, then only it sends to users in 5G, whereas in LTE, reference signals are continuously transmitting.

3.4.2 DMRS (Demodulation Reference Signal).

DMRS is Demodulation Reference Signal, which specified for the specific user equipment. DMRS signal used for channel estimation and demodulation of the associated physical channel.

When a DMRS signal is necessary, then only this signal is transmitted in uplink or downlink. In MIMO, multiple DMRS signals allocated. These DMRS signals are orthogonal to each other. In our work, we are using QPSK digital modulation to generate this pilot signals at transmitter and QPSK demodulation at the receiver. There is one additional DMRS signal which used for high- mobility scenarios for tracking fast change in the channel, and this also increases the rate of transmission.

DMRS signal design and mapping specified in the 3GPP document of 5G/NR. we are placing this DMRS signal only in 3rd OFDM symbols of resource grid as specified in 3GPP document we are using one DMRS signal in each RB (Resource Block). Each RB is having 12 sub-carriers. so within 12 sub-carriers, 1 DMRS is present. We can also put 1 DMRS signal within 24 sub-carriers. This DMRS is only used to estimate the channel.

3.4.3 PTRS (Phase Tracking Reference Signal)

As we go above 6 GHz, the phase noise gets added in the signal. PTRS plays a crucial role in mm-Wave frequencies to minimize the phase noise effect that gets added due to oscillator. Due to this phase noise, the OFDM symbols constellation get to rotate.

This phase noise is due to frequency offset and local oscillators. This phase noise has two main things: CPE and the other is ISI (Inter Carrier Interference). By using the PTRS signal, we are reducing this CPE (Common Phase Error). This CPE changes rapidly along with the OFDM symbol as compare to the sub-carrier.

Properties of PTRS:

1. The main function of PTRS, track the phase of the signal when the signal transmitted from transmitter to receiver.
2. By using PTRS, CPE gets suppressed, and this CPE can remove easily from the receive symbols.
3. PTRS signal having a low density in frequency and high density in the time domain.
4. We can configure PTRS signal based on time and frequency densities depending on the sub-carrier spacing, quality of local oscillator, and carrier frequency.

3.4.4 ideal case:

Ideal carrier signal is given below:

$$C(t) = A.COS(\omega t) \tag{3.4}$$

The receive signal in discrete time domain is:

$$y(n) = (h(n) \otimes x(n)) + \omega(n) \tag{3.5}$$

Where,

h(n) is a wireless channel.

x(n) is a signal transmitted to the broadcast channel.

y(n) is output or receive signal

When we consider the above equation in the frequency domain, we get,

$$Y(k) = X(k).H(k) + W(k) \tag{3.6}$$

$W(K)$ is noise which we consider as negligible

$$X(k) = \frac{Y(k)}{H(k)} \tag{3.7}$$

OFDM's advantage is that any ISI (Inter Symbol Interference) channel becomes flat in the frequency domain.

3.4.5 Non-Ideal case

Carrier signal in the presence of phase noise at high frequency($>$ 6 GHz).

$$C(t) = A.COS(\omega t + \phi(t)) \tag{3.8}$$

The receive signal in discrete time domain is:

$$y(n) = (h(n) \otimes x(n)).e^{j\phi(n)} + \omega(n) \tag{3.9}$$

Where h(n) is a wireless channel. x(n) is a signal transmitted to the broadcast channel. y(n) is output or receive signal. $\phi(n)$ is phase noise that added in the signal.

When we consider above equation in Frequency domain we get,

$$Y(k) = X(k).H(k).C_{pe} + W(k) \tag{3.10}$$

$W(k)$ is noise which we consider as negligible C_{pe} is Common Phase error which we consider common for all k^{th} sub-carriers.

This phase noise is more dominant in 5G mm-Wave. We are focusing more on reducing this Common Phase Errorr (C_{pe}) using phase tracking reference signal (PTRS) .

$$X(k) = \frac{Y(k)}{H(k).C_{pe}} \tag{3.11}$$

let,

$$H\hat{(k)} = H(k).C_{pe} \tag{3.12}$$

So, we get

$$X(k) = \frac{Y(k)}{H\hat{(k)}} \tag{3.13}$$

Demodulation Reference Signal (DMRS) is use for channel estimation and demodulation of associated physical channel H(k)

3.5 How PTRS help to reduce phase error?

We are assuming that the channel remain un-change and due to CPE we get phase error. This Common Phase Error (C_{pe}) variation is faster than channel variation. DMRS and PTRS pilot signals given in the above resource grid, in the time axis, we had 14 OFDM symbol in 1 slot, and along the frequency axis, we are having 12 sub-carriers in 1 resource block.

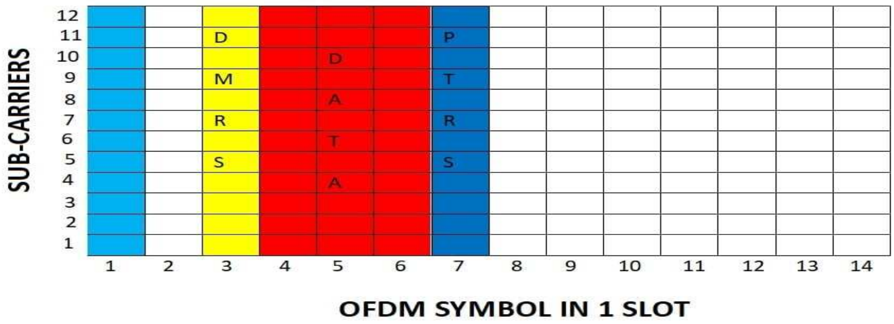

Figure 3.3: Resource grid used in 5G/NR contain 12 sub-carriers and 14 OFDM symbols amd also DMRS and PTRS position in OFDM Symbols .

We are considering above things after receiving and how we reduce phase error

$$H(\hat{k}) = \frac{Y(k)}{X(k)} \tag{3.14}$$

Where,

$H(\hat{k})$ is estimated channel using DMRS.

X(K) is a pilot signal known at the receiver.

Y(K) is the actual receive signal

so,

$$H(\hat{k}, l) = H(k).C_l \tag{3.15}$$

Where, $H(\hat{k}, l)$ is DMRS signal at k^{th} sub-carrier and l^{th} OFDM symbol.

C_l is extra phase added in channel in k^{th} sub-carrier and l^{th} OFDM symbol.

$$H(\hat{k}, p) = H(k).C_p \tag{3.16}$$

Where, $H(\hat{k}, p)$ is PTRS signal at k^{th} sub-carrier and p^{th} OFDM symbol.

C_p is extra phase added in channel in k^{th} sub-carrier and p^{th} OFDM symbol.

$$\frac{H(\hat{k},l)}{H(\hat{k},p)} = \frac{H(k).C_l}{H(k).C_p} \tag{3.17}$$

$$\frac{H(\hat{k},p)}{H(\hat{k},l)} = \frac{C_p}{C_l} \tag{3.18}$$

$$\sphericalangle\frac{H(\hat{k},p)}{H(\hat{k},l)} = \sphericalangle\frac{C_p}{C_l} \tag{3.19}$$

$$\sphericalangle\frac{H(\hat{k},p)}{H(\hat{k},l)} = \sphericalangle C_p - \sphericalangle C_l = \phi(\hat{k,p}) \tag{3.20}$$

$\phi(\hat{k,p})$ is the estimated phase for k^{th} sub-carrier p^{th} OFDM symbol. When we consider the overall sub-carrier, then we have to take an average of $\phi(\hat{k})$ overall PTRS locations and estimate the phase noise for one OFDM symbol. Similarly, we calculate phase noise for all OFDM symbols.

3.6 Algorithm And Flowchart

3.6.1 Algorithm To Estimate Phase Noise

Step 1: Start

Step 2: Estimate $H(\hat{K},l)$ channel using DMRS.

Step 3: Estimate $H(\hat{K},p)$ channel at PTRS sub-carrier location.

Step 4: Ratio between $H(\hat{K},p)$ and $H(\hat{K},l)$ is $H_r(\hat{K},p)$.

Step 5: Calculating angle of $H_r(\hat{K},p)$.

Step 6: Calculating average of angle of $H_r(\hat{K},p)$. This give phase noise.

Step 7:Divide (estimated phase*estimated channel) to receive signal y(n), and eliminating phase noise from receive signal.

Step 8:Stop.

3.6.2 Flowchart

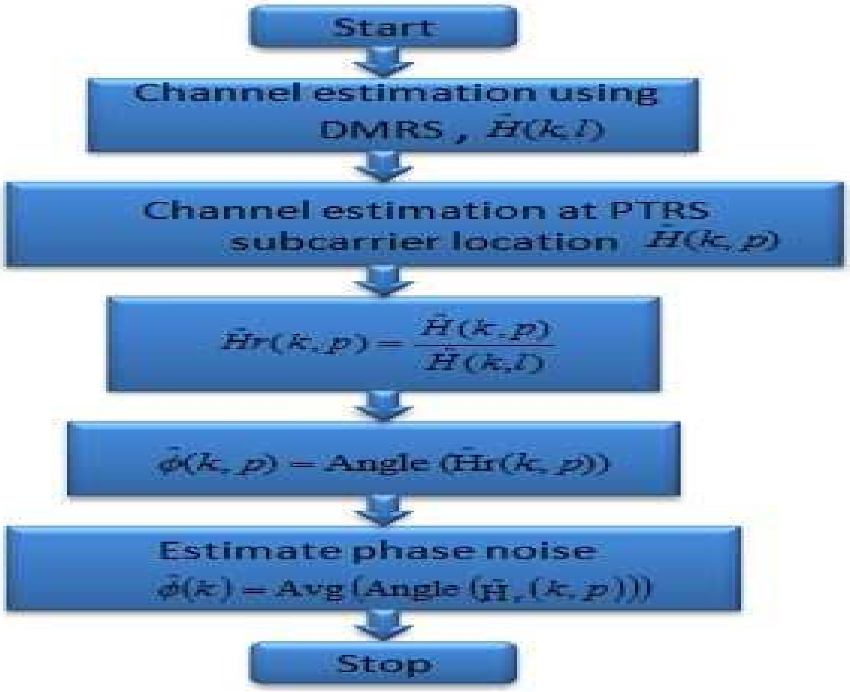

Figure 3.4: Flowchart to estimate phase noise

CHAPTER 4

RESULTS

SINR Vs. BER Results:

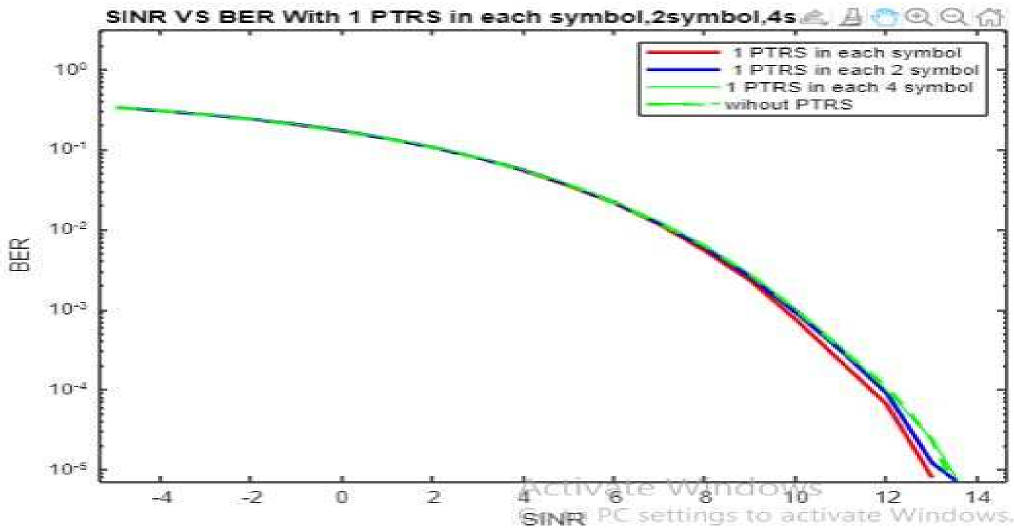

Figure 4.1: SINR Vs. BER with 1 PTRS in each one symbol, two symbols, four symbols for QPSK, without channel, with Matlab Phase Noise model, with phase noise level=-65dB

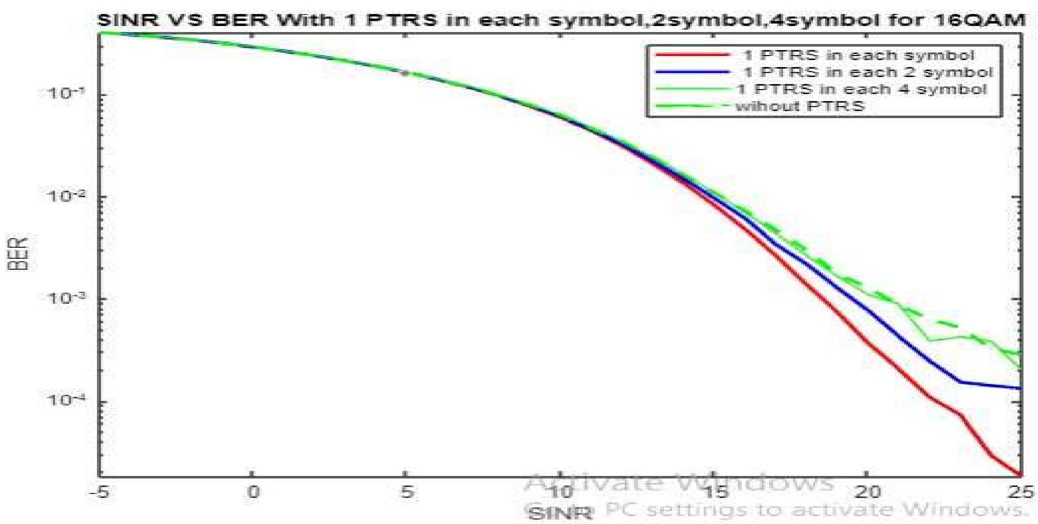

Figure 4.2: SINR Vs. BER with 1 PTRS in each one symbol, two symbols, four symbols for 16QAM, without channel, with Matlab Phase Noise model, with phase noise level=-65dB

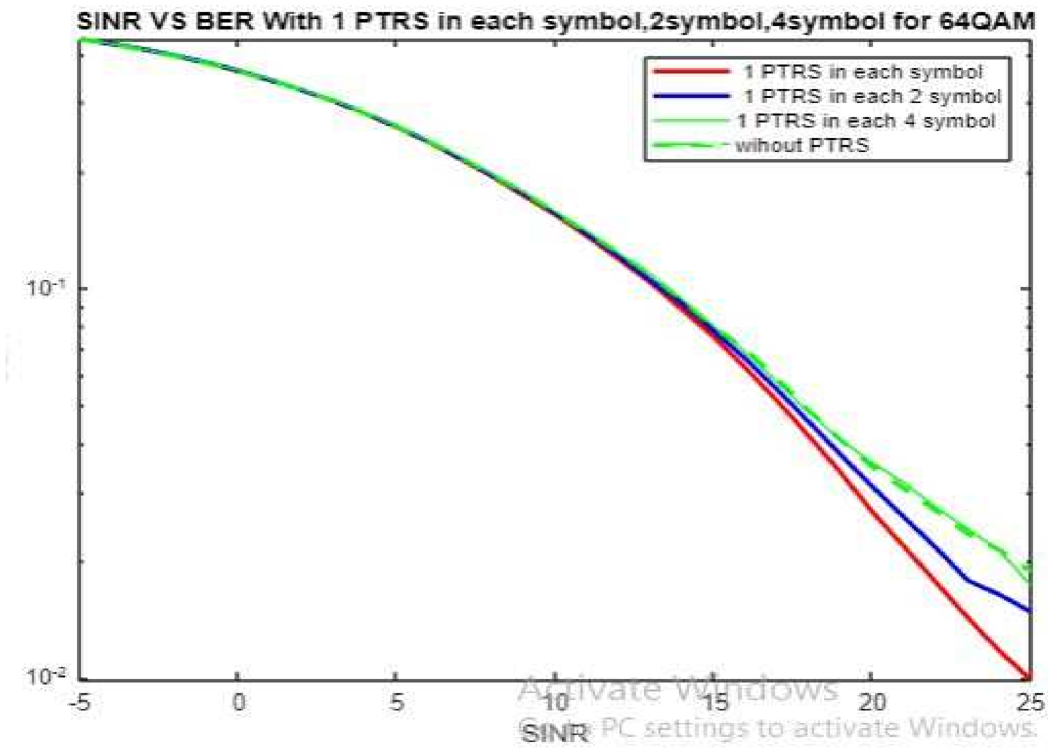

Figure 4.3: SINR Vs. BER with 1 PTRS in each one symbol, two symbols, four symbols for 64QAM, without channel, with Matlab Phase Noise model, with phase noise level=-65dB

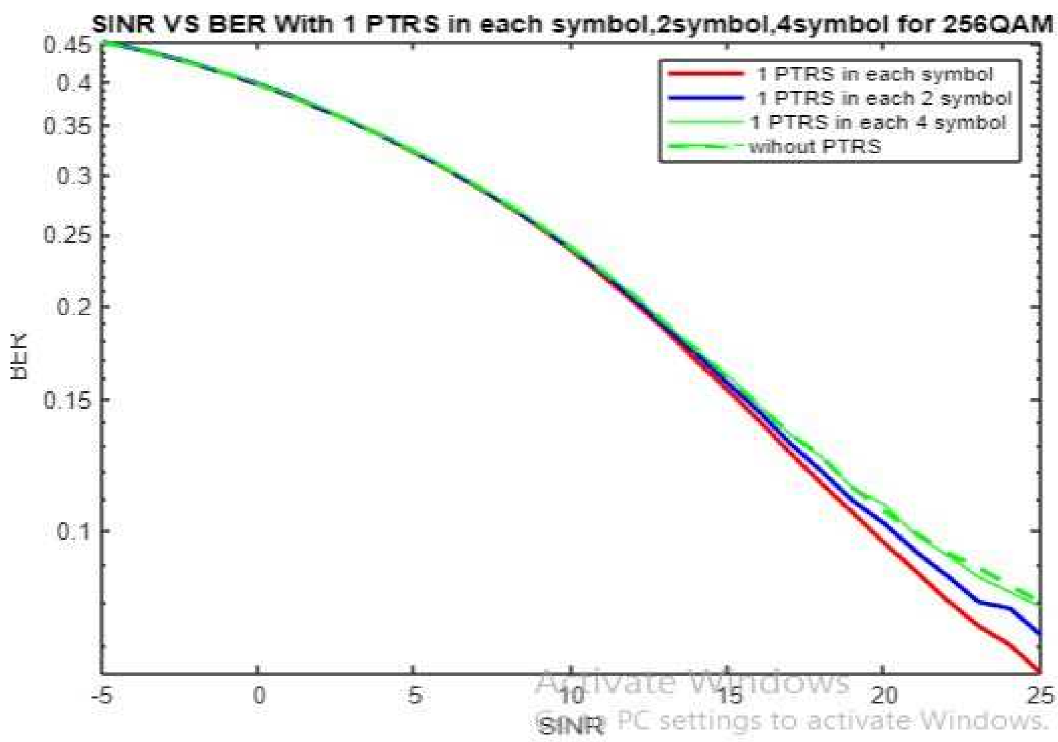

Figure 4.4: SINR Vs. BER with 1 PTRS in each one symbol, two symbols, four symbols for 256QAM, without channel, with Matlab Phase Noise model, with phase noise level=-65dB

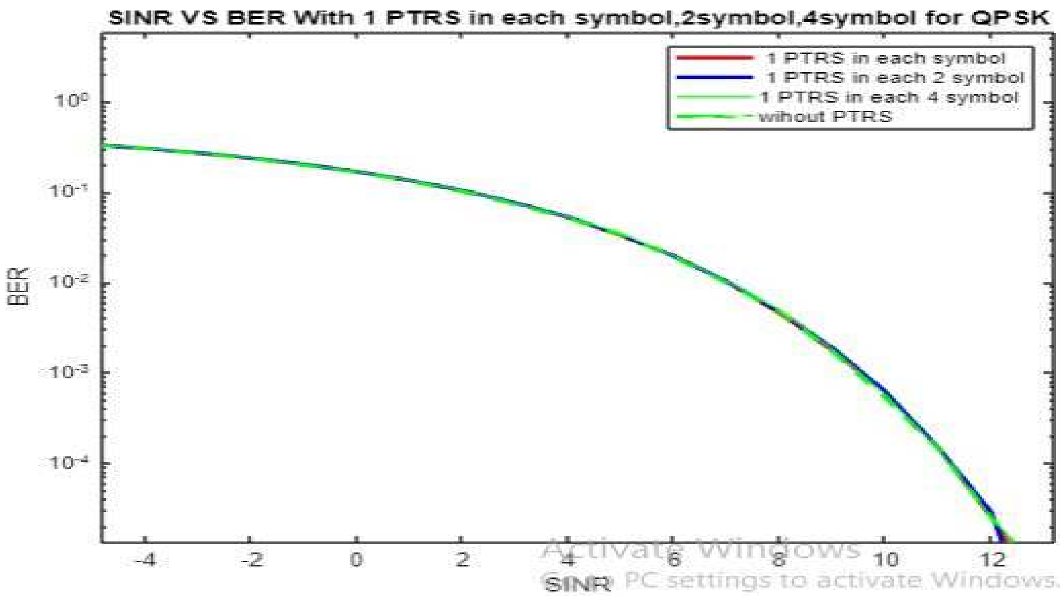

Figure 4.5: SINR Vs. BER with 1 PTRS in each one symbol, two symbols, four symbols for QPSK, without channel, with Matlab Phase Noise model, with phase noise level=-75dB

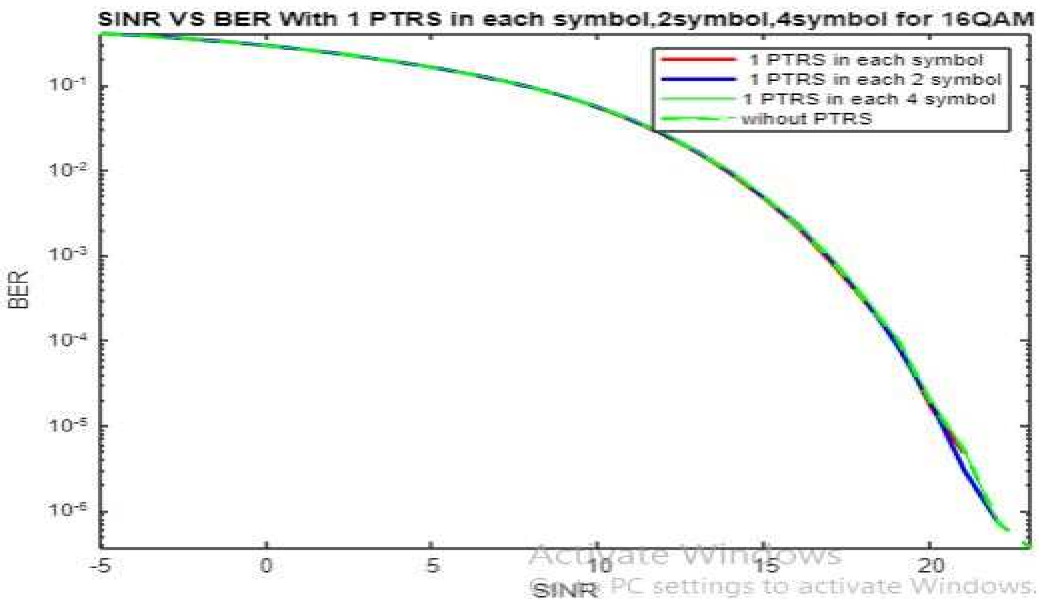

Figure 4.6: SINR Vs BER with 1 PTRS in each 1 symbol,2 symbols,4 symbols for 16QAM,wihout channel,with Matlab Phase Noise model,with phase noise level=-75dB

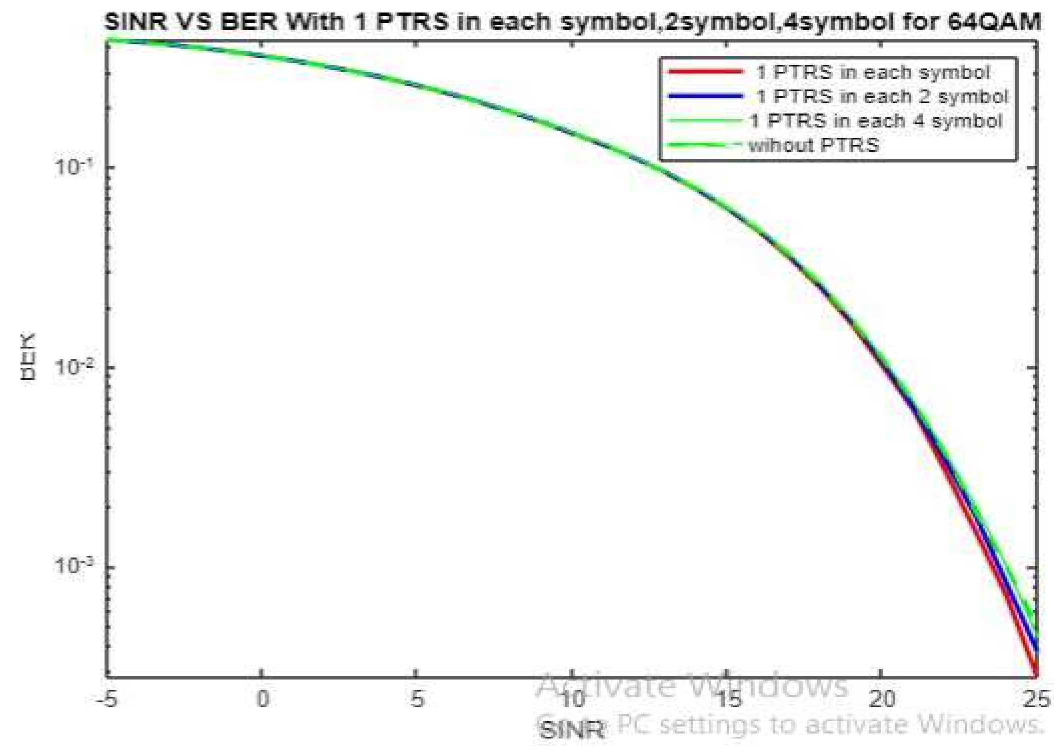

Figure 4.7: SINR Vs. BER with 1 PTRS in each one symbol, two symbols, four symbols for 64QAM, without channel, with Matlab Phase Noise model, with phase noise level=-75dB

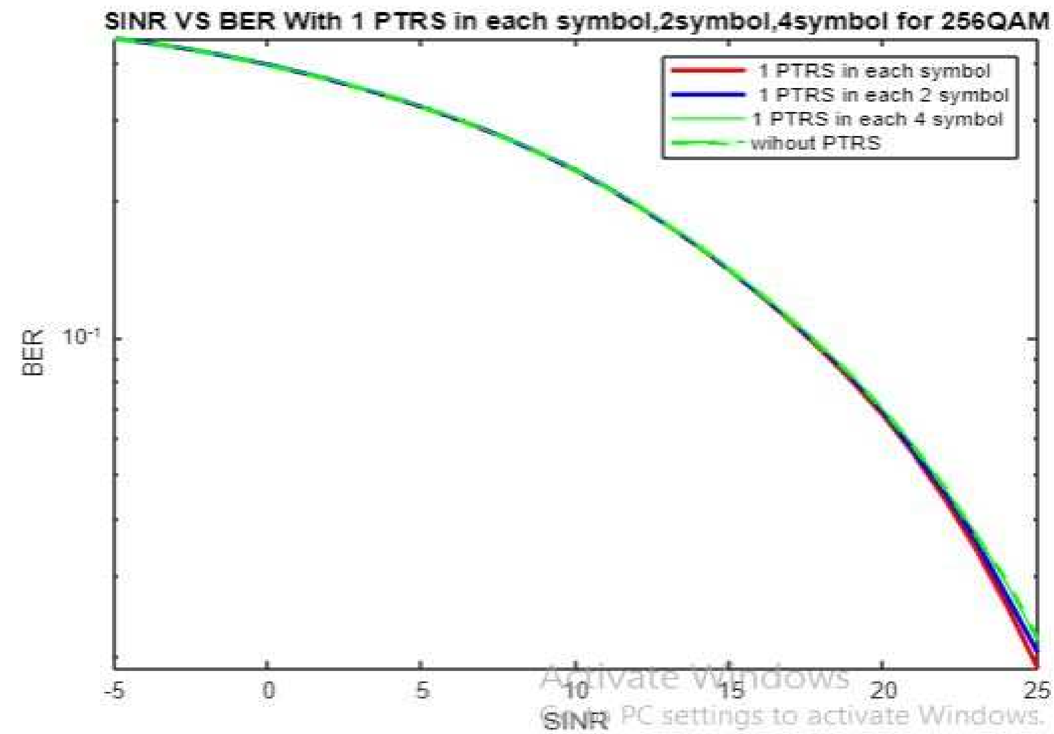

Figure 4.8: SINR Vs BER with 1 PTRS in each 1 symbol,2 symbols,4 symbols for 256QAM,wihout channel,with Matlab Phase Noise model,with phase noise level=-75dB

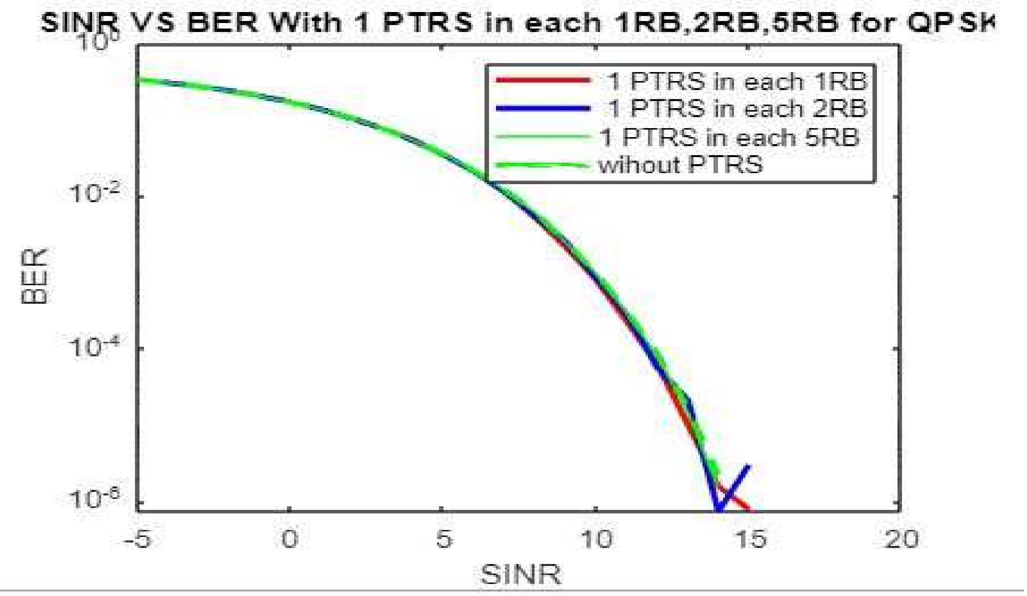

Figure 4.9: SINR Vs. BER with 1 PTRS in each 1RB,2RB,5RB for QPSK, without the channel, with Matlab Phase Noise model, with phase noise level=-65dB

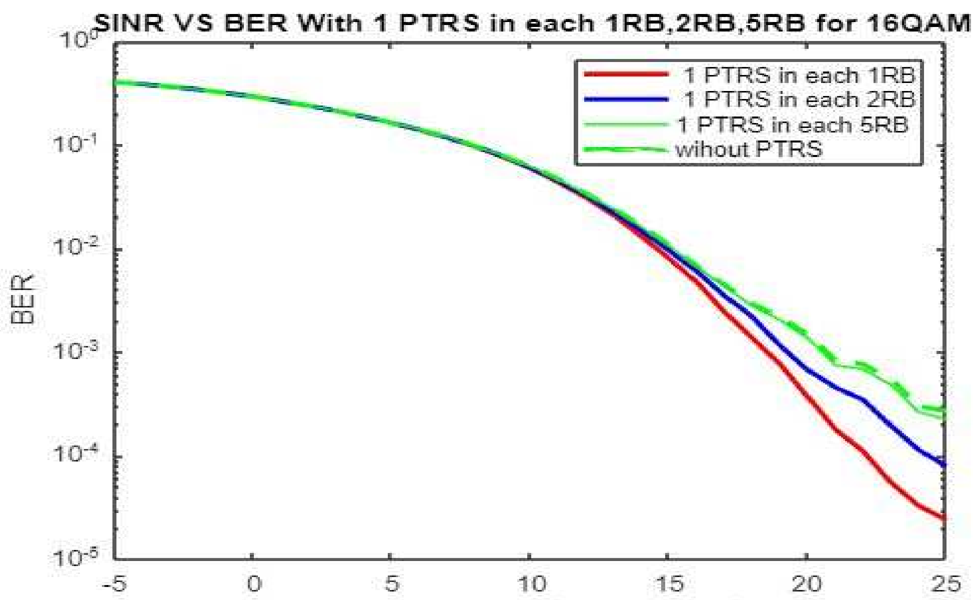

Figure 4.10: SINR Vs. BER with 1 PTRS in each 1RB,2RB,5RB for 16QAM, without the channel, with Matlab Phase Noise model, with phase noise level=-65dB

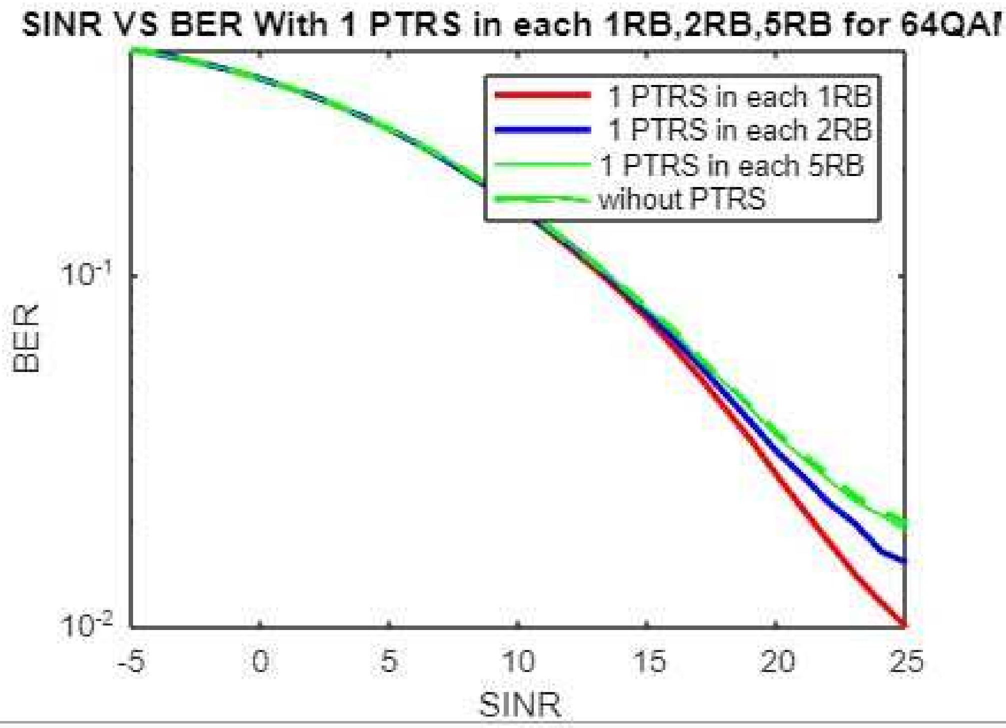

Figure 4.11: SINR Vs. BER with 1 PTRS in each 1RB,2RB,5RB for 64QAM, without the channel, with Matlab Phase Noise model, with phase noise level=-65dB

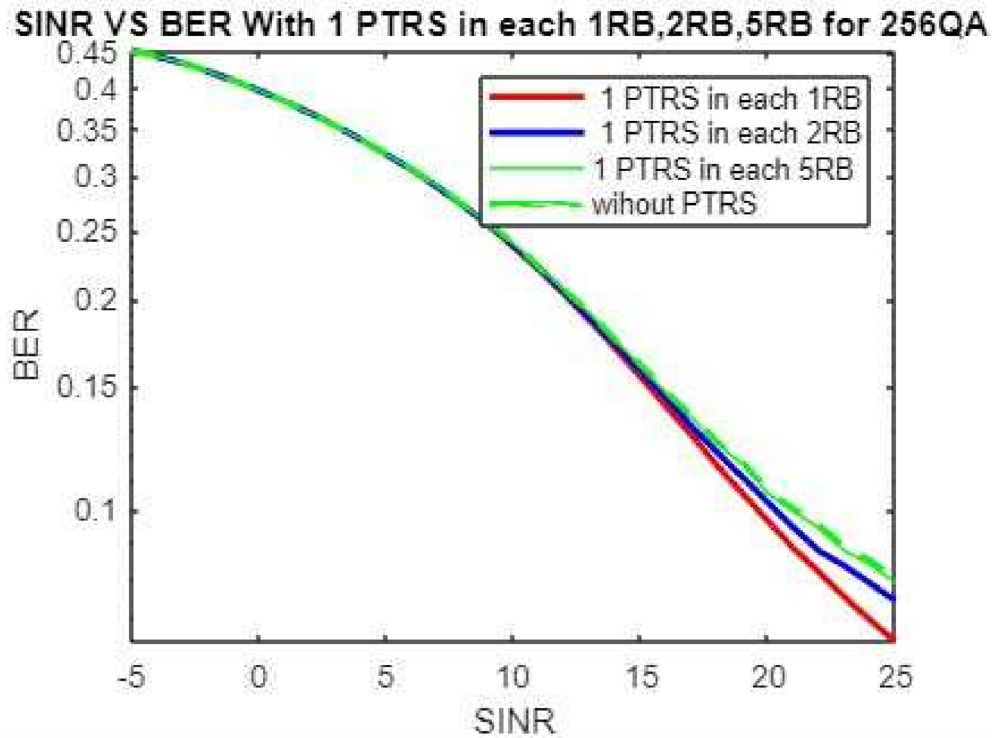

Figure 4.12: SINR Vs BER with 1 PTRS in each 1RB,2RB,5RB for 256QAM,wihout channel,with Matlab Phase Noise model,with phase noise level=-65dB

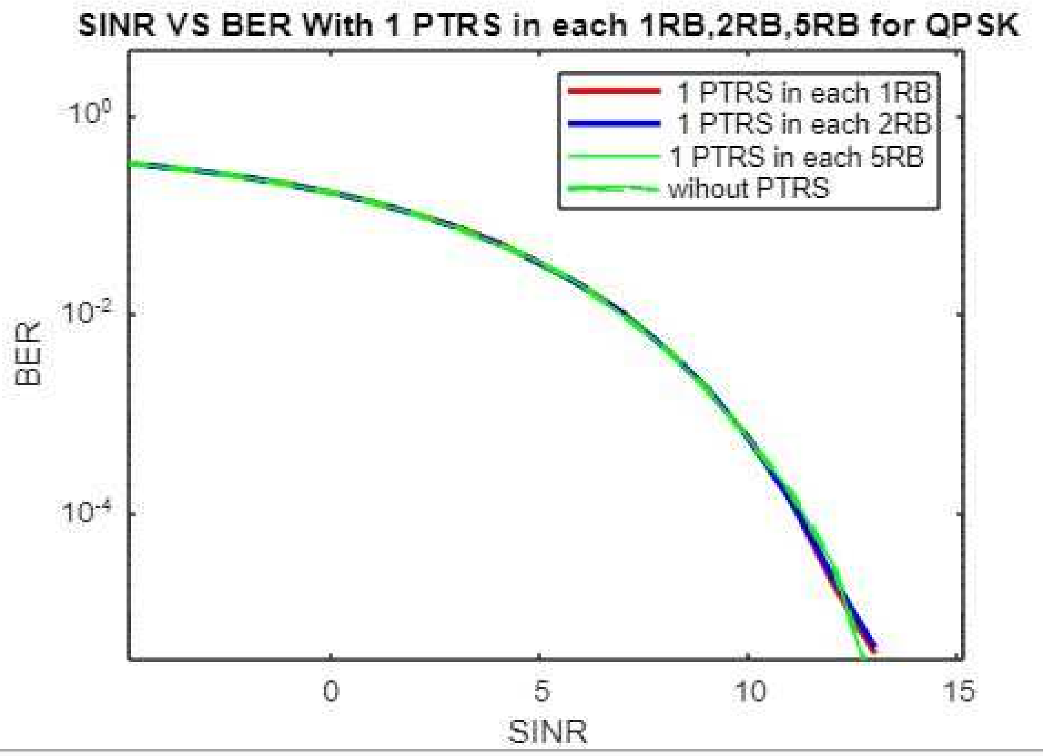

Figure 4.13: SINR Vs. BER with 1 PTRS in each 1RB,2RB,5RB for QPSK, without the channel, with Matlab Phase Noise model, with phase noise level=-75dB

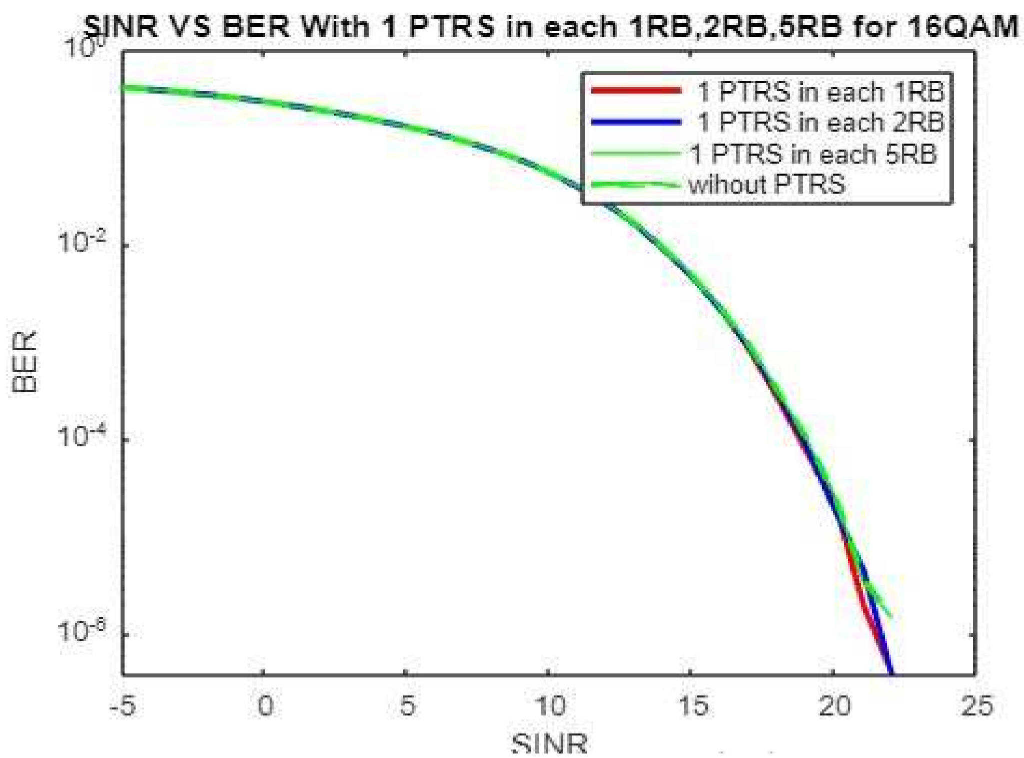

Figure 4.14: SINR Vs BER with 1 PTRS in each 1RB,2RB,5RB for 16QAM,wihout channel,with Matlab Phase Noise model,with phase noise level=-75dB

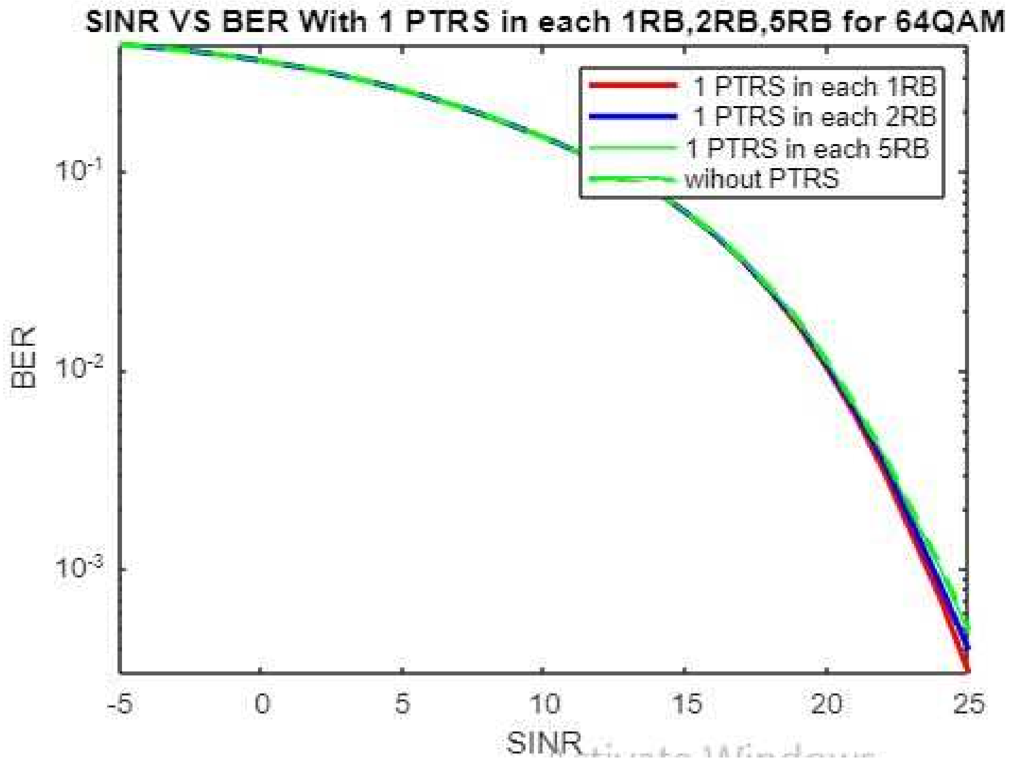

Figure 4.15: SINR Vs BER with 1 PTRS in each 1RB,2RB,5RB for 64QAM,wihout channel,with Matlab Phase Noise model,with phase noise level=-75dB

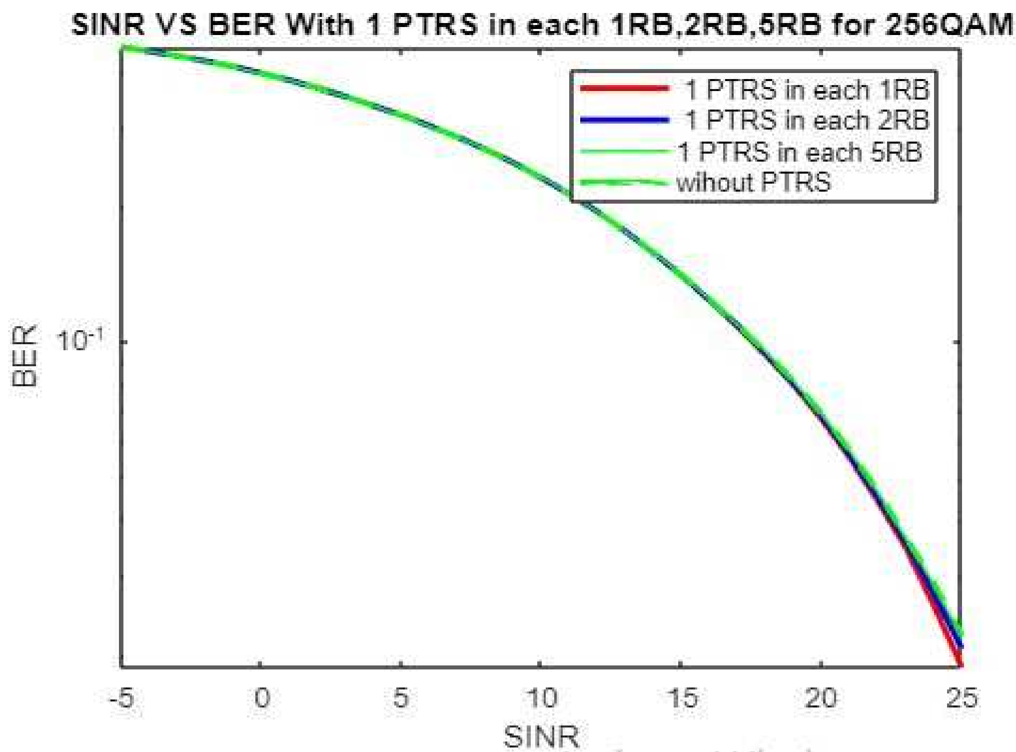

Figure 4.16: SINR Vs BER with 1 PTRS in each 1RB,2RB,5RB for 256QAM,wihout channel,with Matlab Phase Noise model,with phase noise level=-75dB

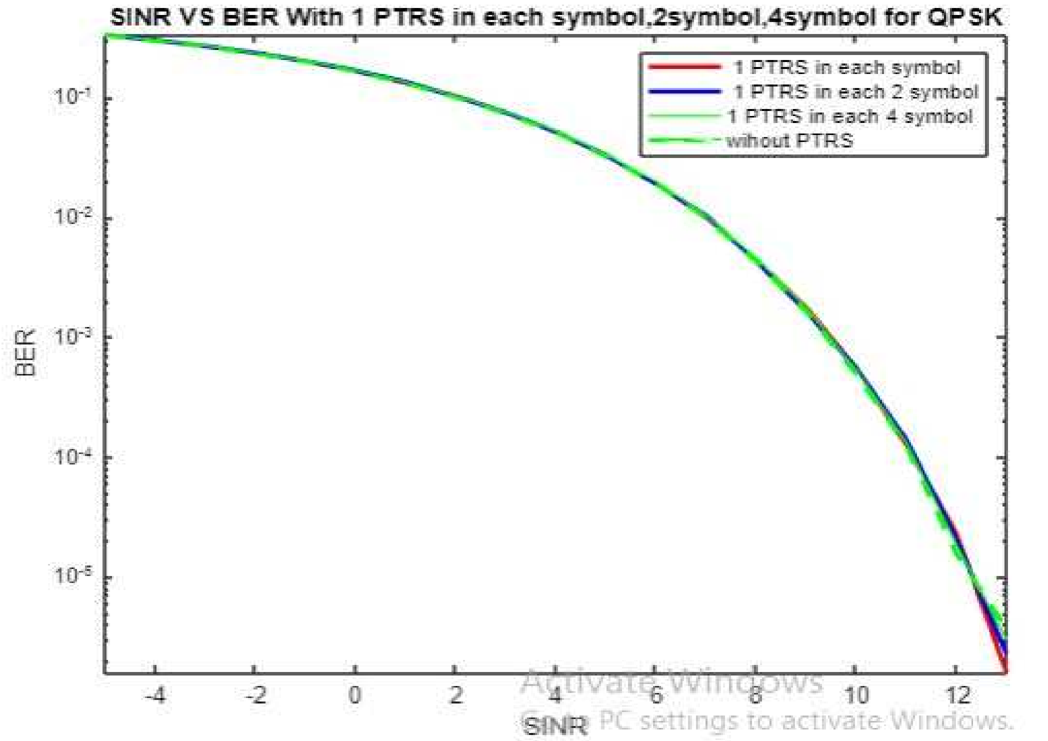

Figure 4.17: SINR Vs. BER for QPSK, without channel, without Matlab Phase Noise model

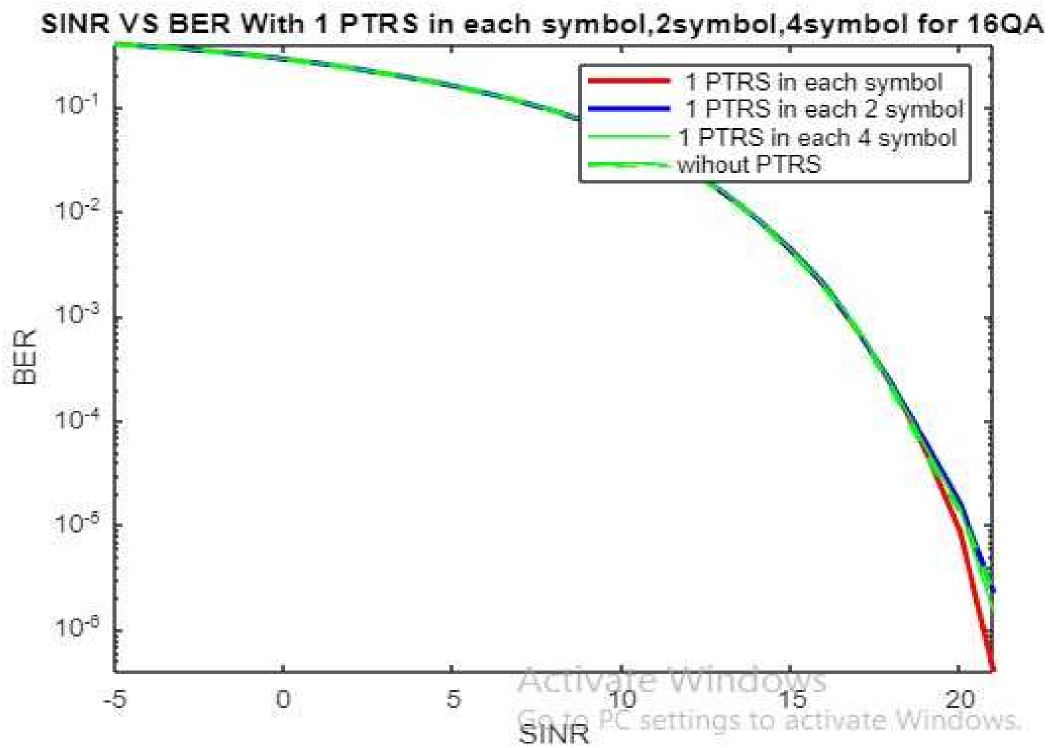

Figure 4.18: SINR Vs. BER for 16QAM, without channel, without Matlab Phase Noise model

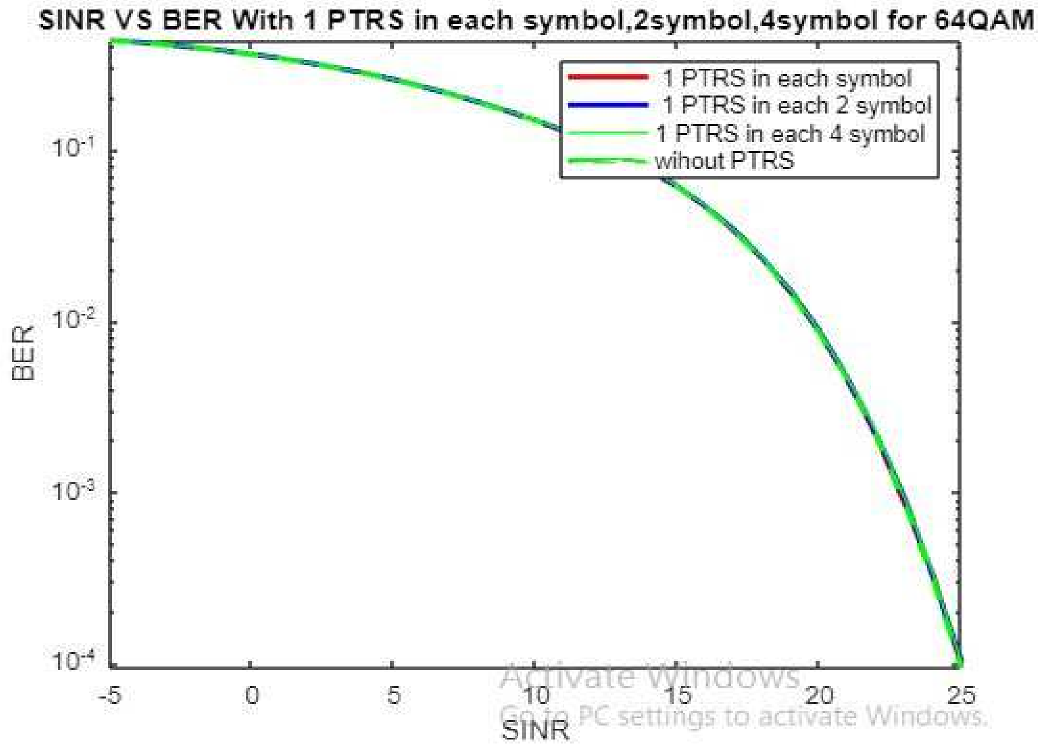

Figure 4.19: SINR Vs. BER for 64QAM, without channel, without Matlab Phase Noise model

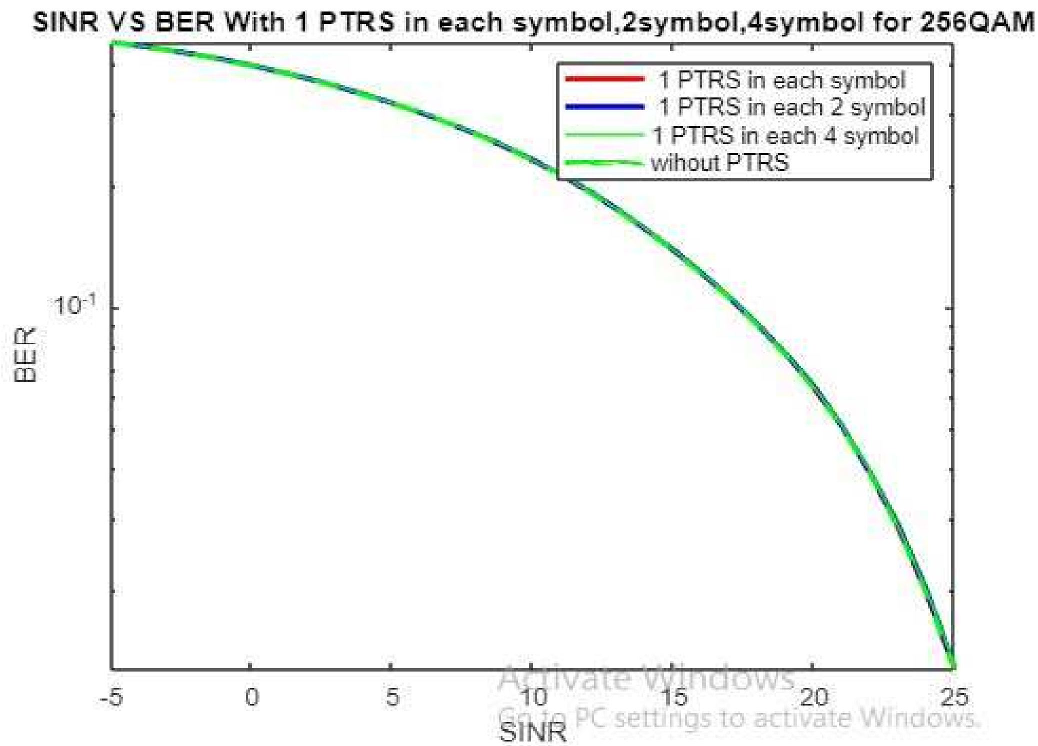

Figure 4.20: SINR Vs. BER for 256QAM, without channel, without Matlab Phase Noise model

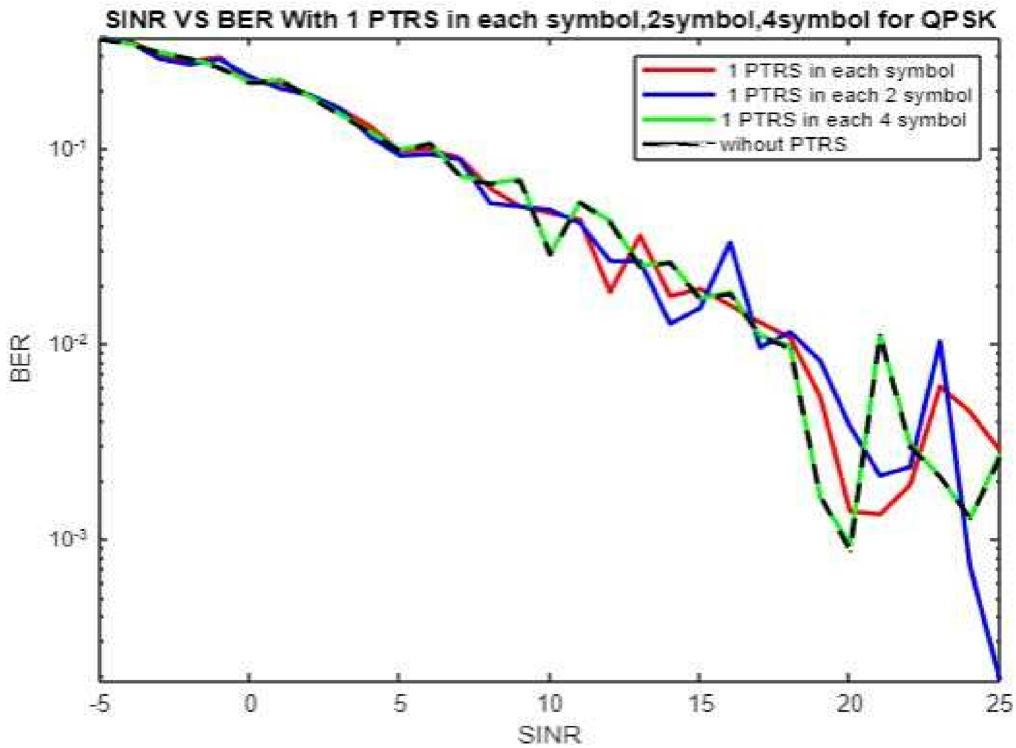

Figure 4.21: SINR Vs BER with 1 PTRS in each 1 symbol,2 symbols,4 symbols for QPSK,With channel , with phase noise ,SCS=60KHz ;phase Noise=-65db ; freq. Offset=1000.

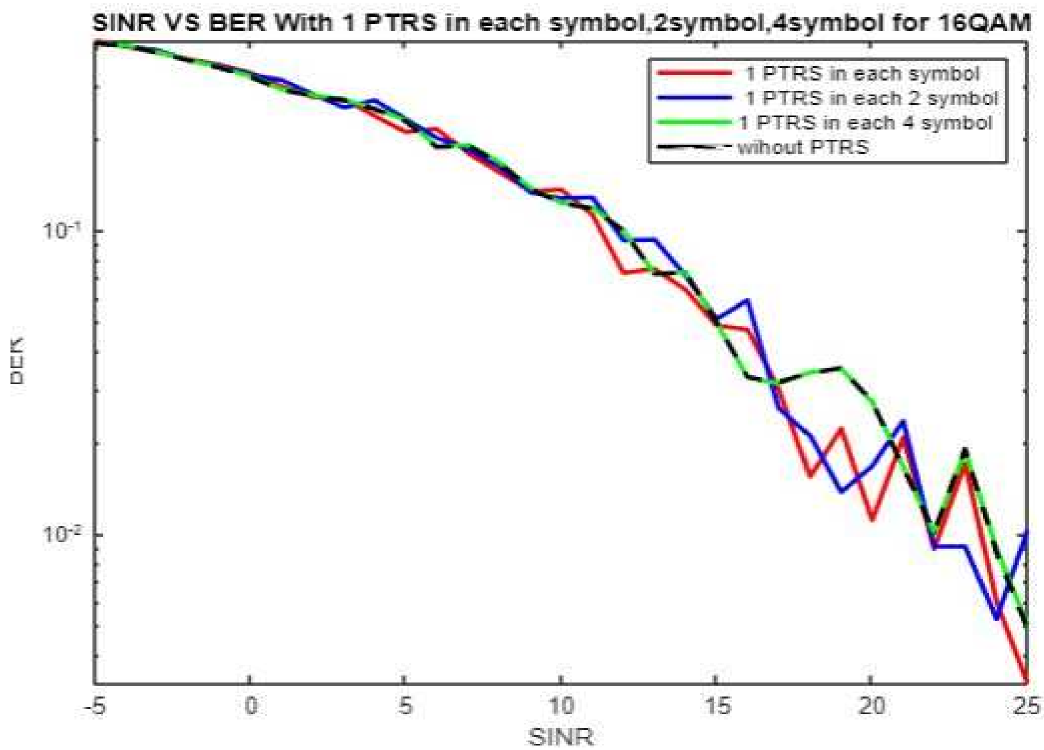

Figure 4.22: SINR Vs BER with 1 PTRS in each 1 symbol,2 symbols,4 symbols for 16 QAM,With channel , with phase noise ,SCS=60KHz ;phase Noise=-65db ; freq. Offset=1000.

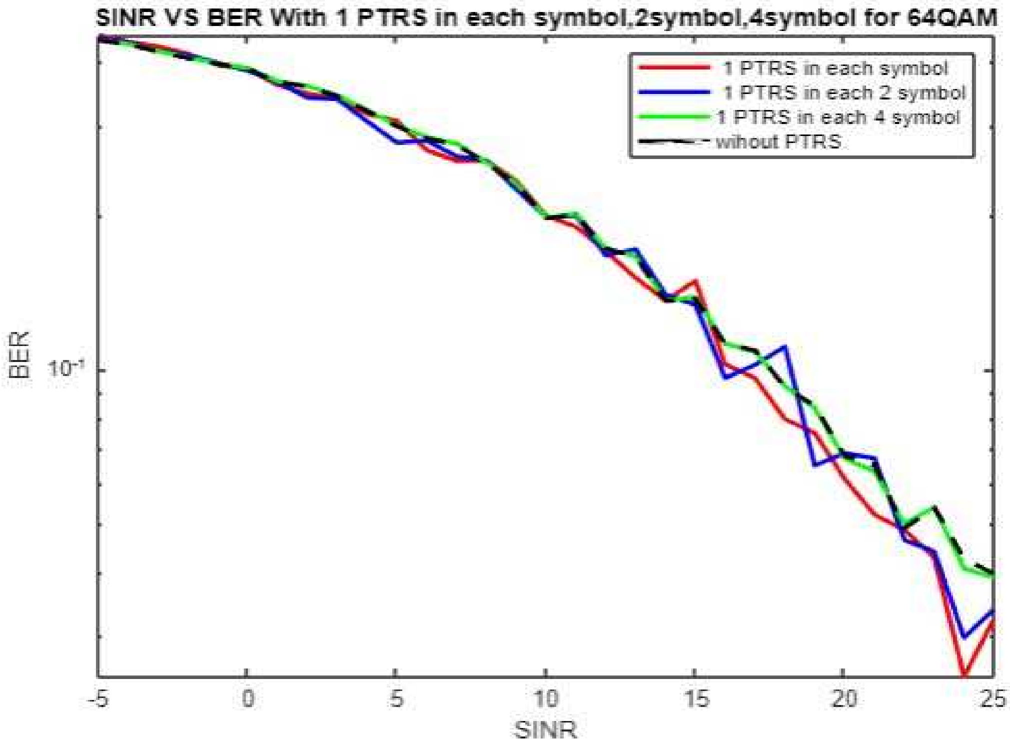

Figure 4.23: SINR Vs BER with 1 PTRS in each 1 symbol,2 symbols,4 symbols for 64 QAM,With channel , with phase noise ,SCS=60KHz ;phase Noise=-65db ; freq. Offset=1000.

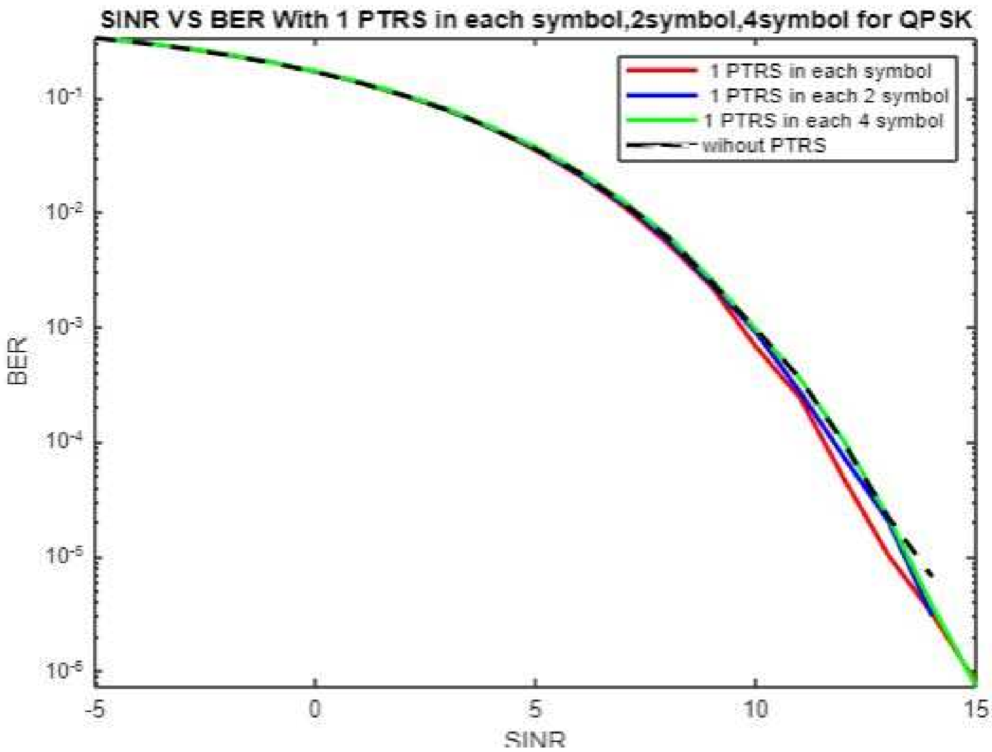

Figure 4.24: SINR Vs BER with 1 PTRS in each 1 symbol,2 symbols,4 symbols for QPSK,Without channel , with phase noise ,SCS=60KHz ;phase Noise=-65db ; freq. Offset=1000.

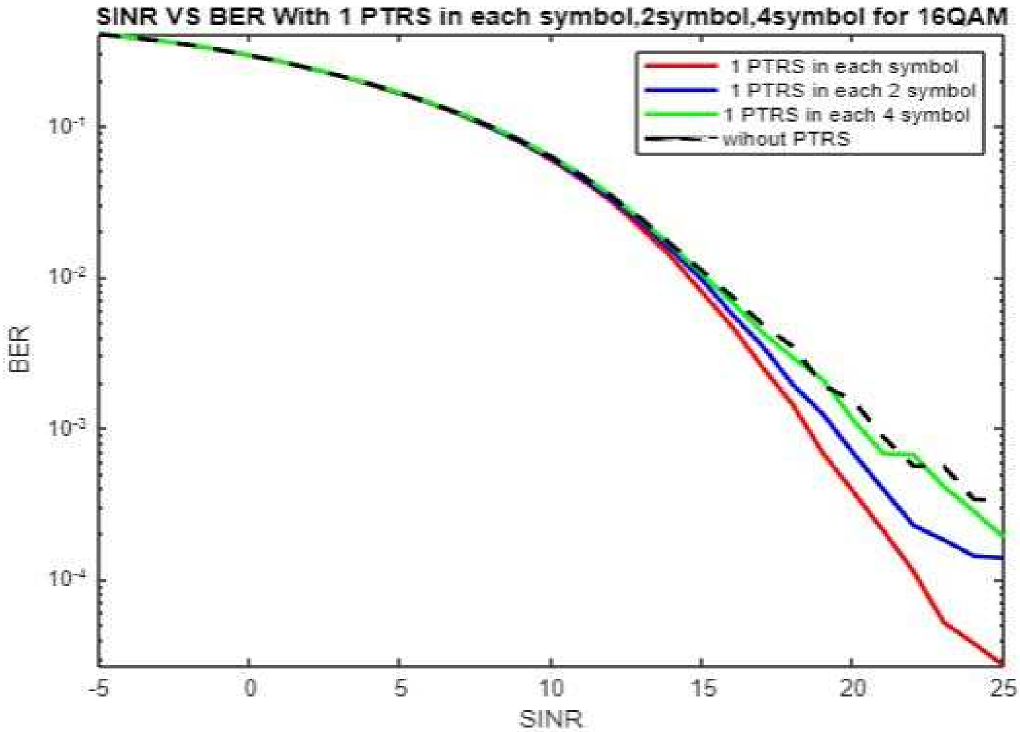

Figure 4.25: SINR Vs BER with 1 PTRS in each 1 symbol,2 symbols,4 symbols for 16 QAM,Without channel , with phase noise ,SCS=60KHz ;phase Noise=-65db ; freq. Offset=1000.

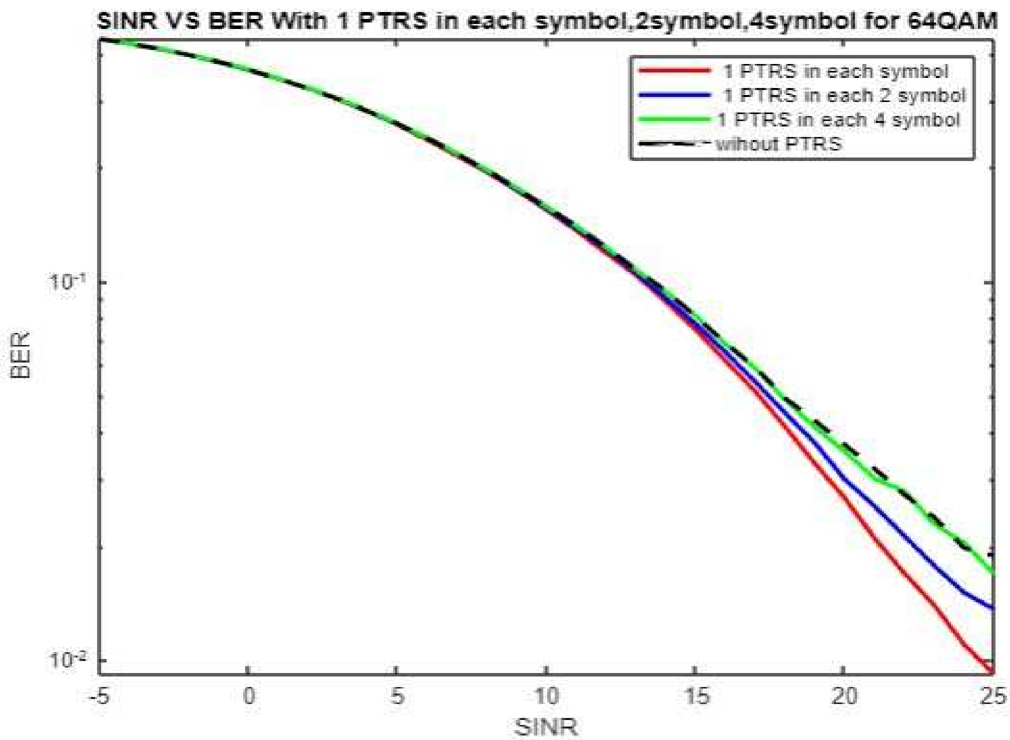

Figure 4.26: SINR Vs BER with 1 PTRS in each 1 symbol,2 symbols,4 symbols for 64 QAM,Without channel , with phase noise ,SCS=60KHz ;phase Noise=-65db ; freq. Offset=1000.

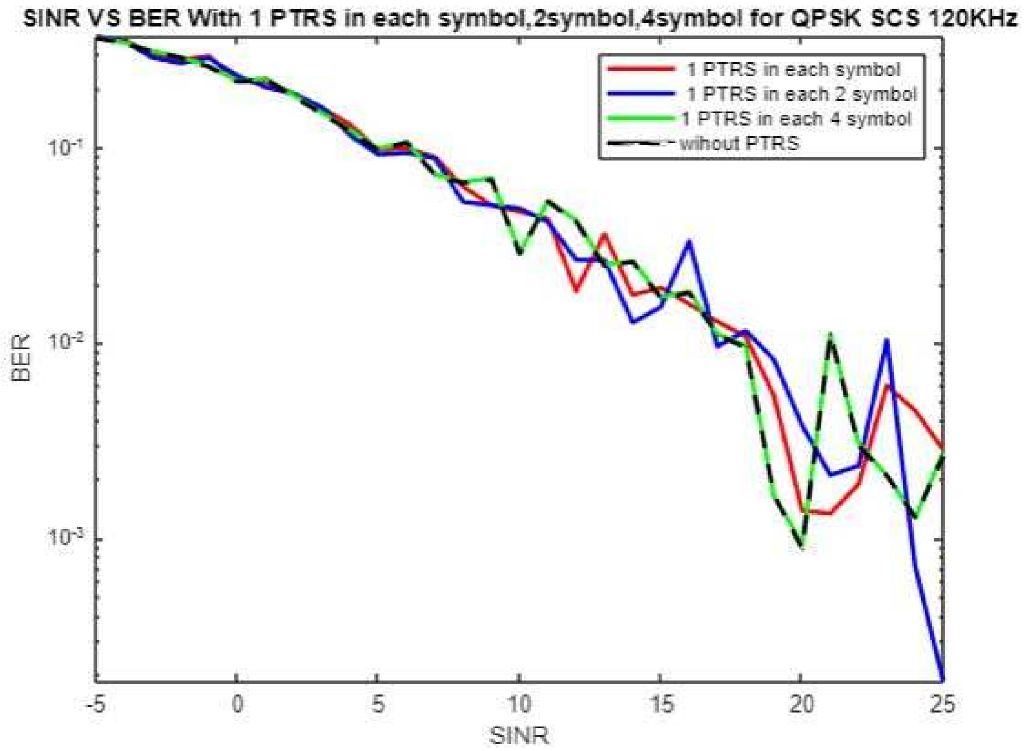

Figure 4.27: SINR Vs BER with 1 PTRS in each 1 symbol,2 symbols,4 symbols for QPSK,With channel , with phase noise ,SCS=120KHz ;phase Noise=-65db ; freq. Offset=1000.

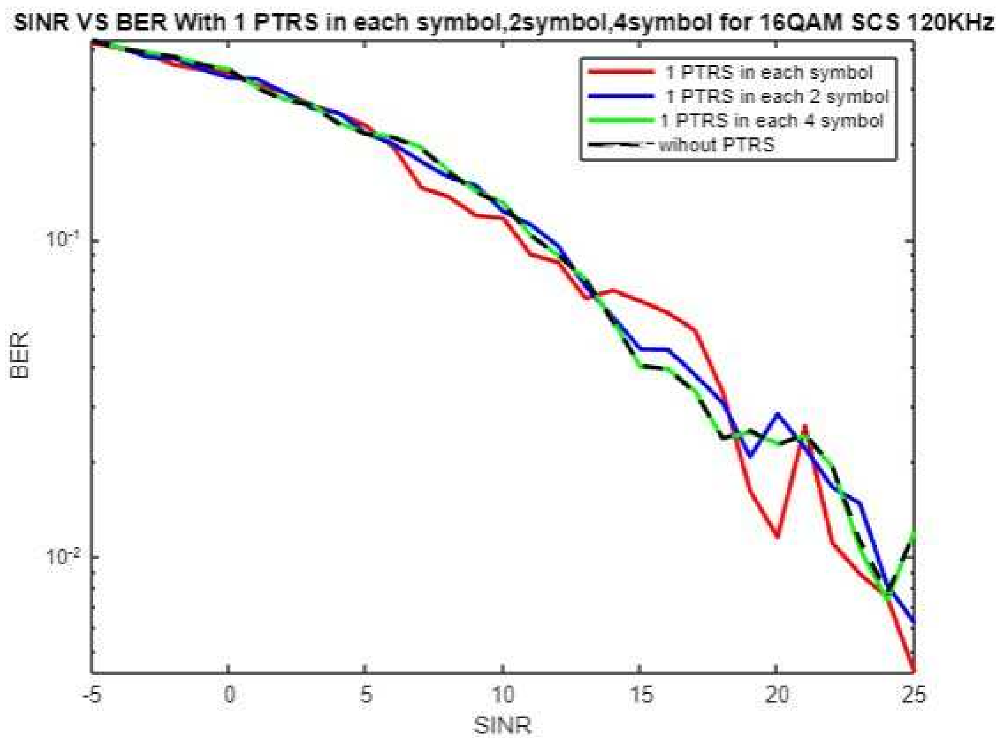

Figure 4.28: SINR Vs BER with 1 PTRS in each 1 symbol,2 symbols,4 symbols for 16 QAM,With channel , with phase noise ,SCS=120KHz ;phase Noise=-65db ; freq. Offset=1000.

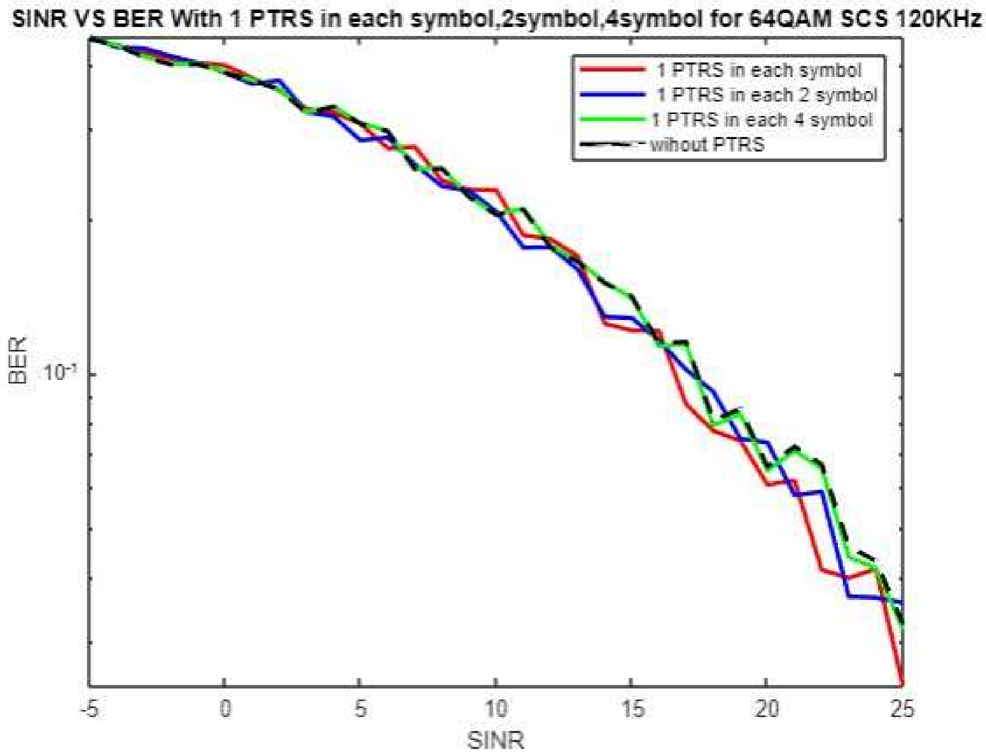

Figure 4.29: SINR Vs BER with 1 PTRS in each 1 symbol,2 symbols,4 symbols for 64 QAM,With channel , with phase noise ,SCS=120KHz ;phase Noise=-65db ; freq. Offset=1000.

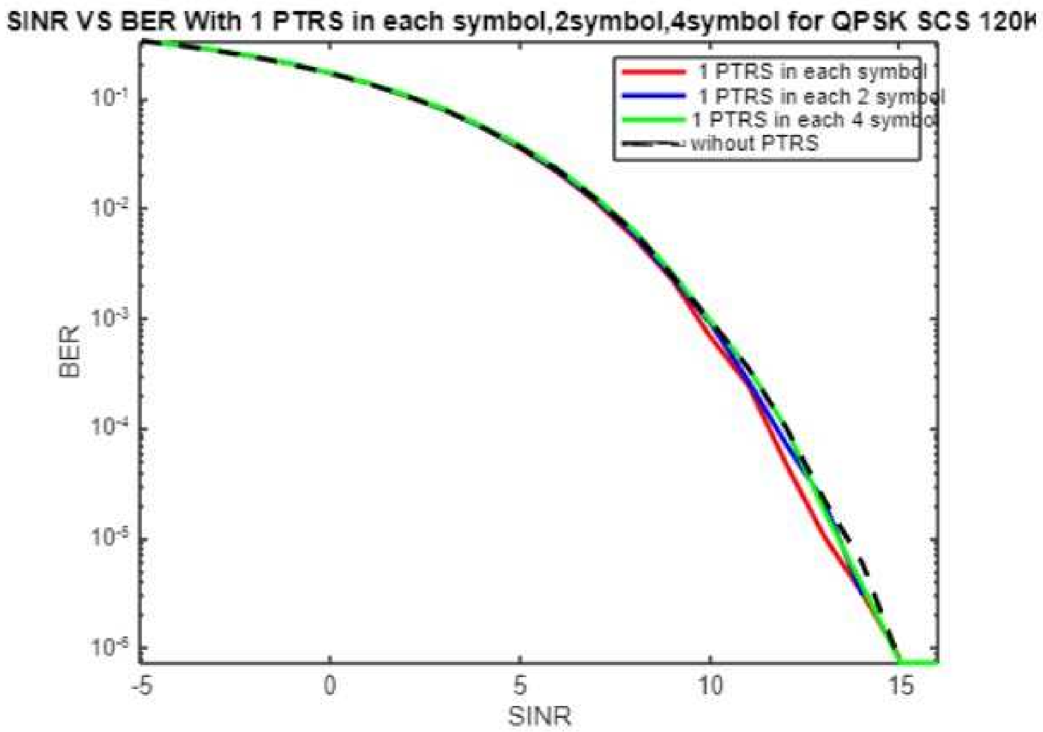

Figure 4.30: SINR Vs BER with 1 PTRS in each 1 symbol,2 symbols,4 symbols for QPSK,Without channel , with phase noise ,SCS=120KHz ;phase Noise=-65db ; freq. Offset=1000.

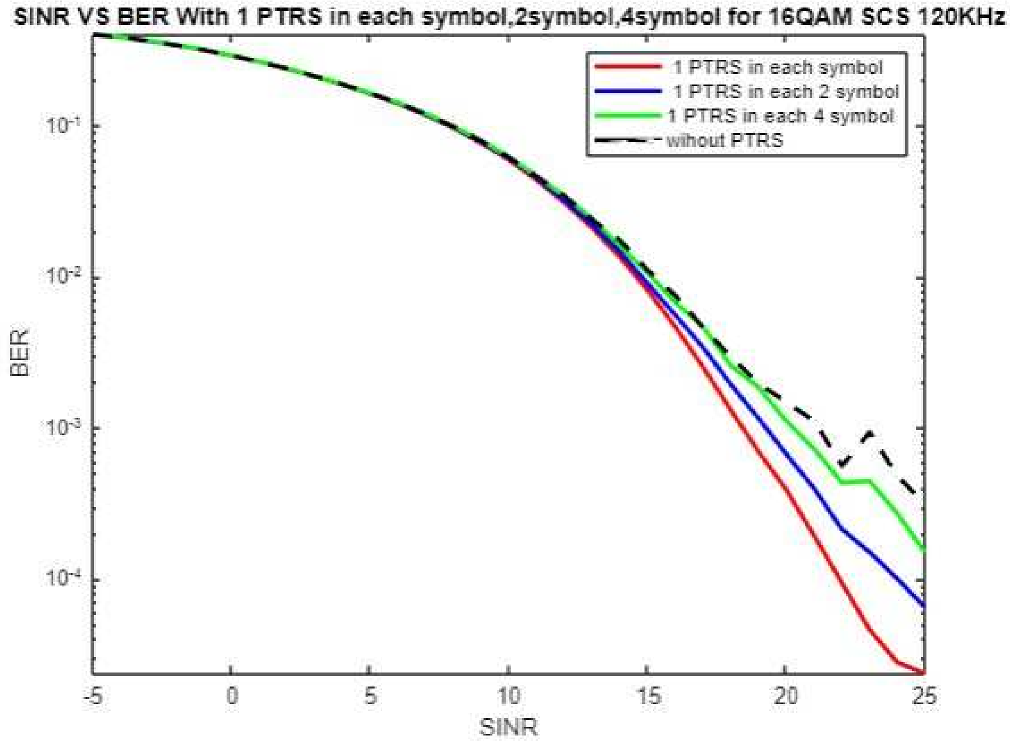

Figure 4.31: SINR Vs BER with 1 PTRS in each 1 symbol,2 symbols,4 symbols for 16 QAM,Without channel , with phase noise ,SCS=120KHz ;phase Noise=-65db ; freq. Offset=1000.

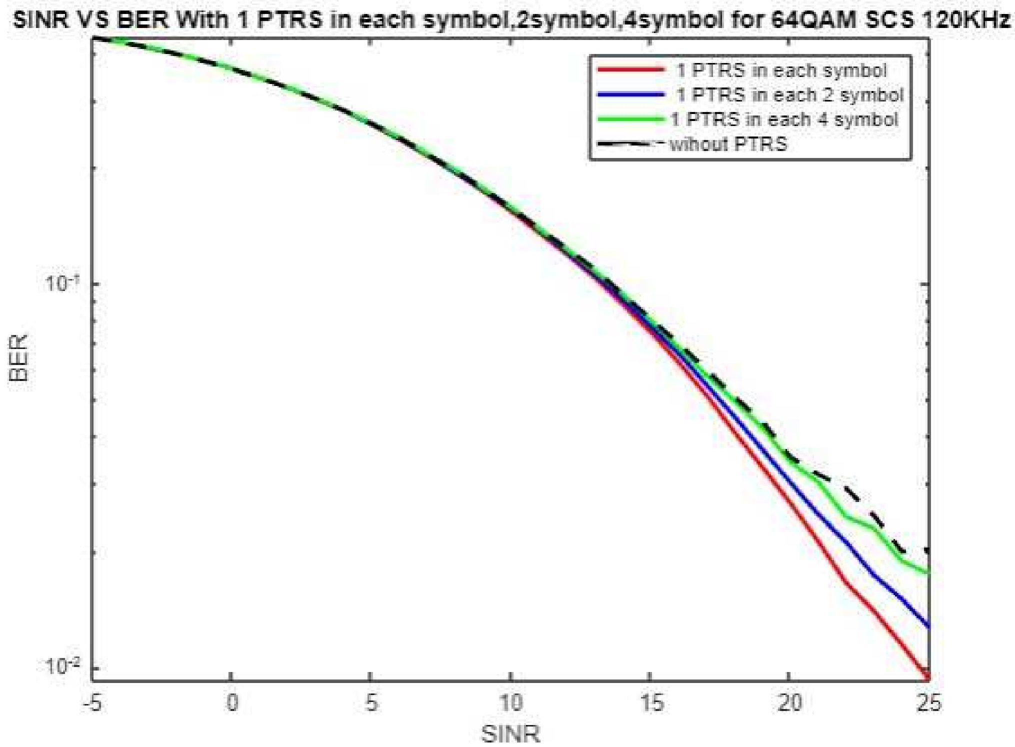

Figure 4.32: SINR Vs BER with 1 PTRS in each 1 symbol,2 symbols,4 symbols for 64 QAM,Without channel , with phase noise ,SCS=120KHz ;phase Noise=-65db ; freq. Offset=1000.

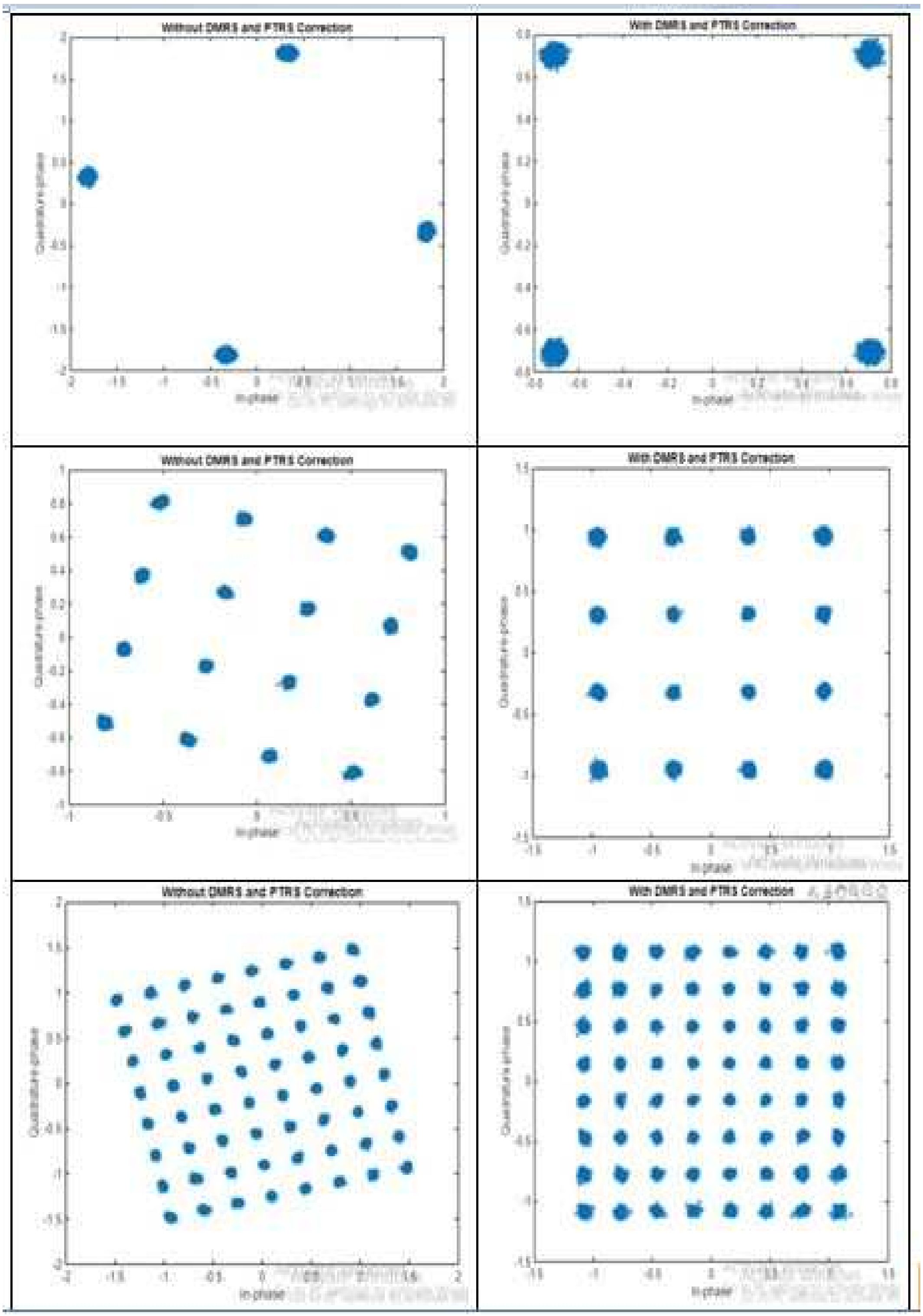

Figure 4.33: Constellation of QPSK,16 QAM, and 64 QAM before and after PTRS correction

Figure 4.1 - 4.4 and figure 4.5 - 4.8 shows plots of SINR Vs. BER with 1 PTRS in each one symbol, two symbols, four symbols for QPSK, 16 QAM, 64 QAM, and 256 QAM without channel, with Matlab Phase Noise model, with phase noise level=-65 dB and -75 dB respectively. This plot shows the effect of phase noise increases with an increase in level. This effect demonstrated by comparing the scenarios for level -65 and -75 dB.

Figure 4.9 - 4.12 and figure 4.13 - 4.16 shows plots of SINR Vs. BER with 1 PTRS in each 1 RB, 2 RB, 5 RB for QPSK, 16 QAM, 64 QAM, and 256 QAM without channel, with Matlab Phase Noise model, with phase noise level=-65 dB and -75 dB respectively. These plots show that When we used -65 dB noise level, it shows more BER than -75 dB noise level.

Also, phase noise degradation is higher for higher-order modulation, such as 64 QAM rather than QPSK. By comparing figure 4.1 with 4.3 and 4.5 with 4.7 we observe that BER is higher for 64 QAM. This because phase noise causes two effects: phase rotation and ICI. This effect we can see in figure 4.33. The ICI caused further degradation in SINR. Also, since points in QPSK constellation are far apart. Therefore phase rotation or ICI does not create a significant impact. But the points in 64 QAM constellation are close to each other. Due to this, the ICI and phase rotation lead to more errors in decision making.

Figure 4.17 - 4.20 shows plots of SINR Vs. BER, without channel, without Matlab Phase Noise model, for all constellation. This plot shows results of without PTRS, and with PTRS correction is the same, that means the OFDM system that we are using is correctly working.

Figure 4.21 - 4.23 SINR Vs BER with 1 PTRS in each 1 symbol,2 symbols,4symbols for QPSK, 16 QAM, 64 QAM,With channel , with phase noise ,SCS=60KHz ;phase Noise=-65db; freq. Offset=1000 and figure 4.24 - 4.26 shows plot without channel. Figure 4.27 - 4.29 SINR Vs BER with 1 PTRS in each 1 symbol,2 symbols,4symbols for QPSK, 16 QAM, 64 QAM,With channel , with phase noise ,SCS=60KHz ;phase Noise=-65db; freq. Offset=1000 and figure 4.30 - 4.32 shows plot without channel.This plots that performance degradation is less with higher sub-carrier spacing.

PTRS helps to correct the effect of phase noise. When one PTRS is present in each symbol, BER is less, as compared to without PTRS. When we compare 1 PTRS present in each symbol with 1 PTRS present in 2 Symbols and four symbols, we observe PTRS density increases, and the BER decreases, these we can see in figure 4.1 - 4.4, 4.10 - 4.12.

CHAPTER 5

CONCLUSION

In this work, a phase noise compensation scheme is per-posed for the OFDM system. By using PTRS with different densities in time and frequency, with a different configuration, achieve a considerable reduction in CPE. When we used frequency above 6 GHz phase noise added in the signal, we can find the performance degradation due to phase noise by observing the plot of SINR vs. BER without channel, with phase noise. BER reduces and performance improvement with PTRS density, and degradation due to phase noise is more for higher-order modulations, such as 64 QAM rather than QPSK. When the phase noise level increases, the degradation is more, and BER increases. The performance degradation is less with high Sub-carrier spacing.

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