PHYSICAL CHANNEL ESTIMATION ON DOWNLINK CHAIN IN 5G NR STANDARD USING DMRS

A Project Report

submitted by

NIKHIL KUMAR

(EE18M050)

in partial fulfillment for the

the award of the degree of

MASTER OF TECHNOLOGY

DEPARTMENT OF ELECTRICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY MADRAS

MAY 2020

DECLARATION

This dissertation is for the fulfillment of **M.Tech. Degree in Communication and Signal Processing** is a presentation of my original research work. Wherever contributions of others are involved, every effort is made to indicate this clearly, with due reference to the literature, and acknowledgement of collaborative research and discussions. According to my best knowledge, no part of this project/dissertation has been submitted to any other University or Institute for the award of any Degree or Diploma. The work was done under the guidance of **Dr. R. Manivaskan**, at the **Indian Institute of Technology Madras, Chennai.**

Signature:

Candidate's Full Name: **Nikhil Kumar**

Date:

Place:

<u>CERTIFICATE</u>

This is to certify that the Project entitled **<u>Physical Channel Estimation on Downlink chain in 5G NR standard using of DRMS</u>** is a bonafide record of independent research work done by **<u>Nikhil Kumar</u>** (Roll No.: EE18M050) under my supervision and submitted to **Indian Institute of Technology Madras, Chennai** in partial fulfillment for the award of the Degree of MASTER OF TECHNOLOGY IN COMMUNICATION AND SIGNAL PROCESSING.

Signature of Co-Guide	Signature of Supervisor
Mr. Shiv Shankar	Dr. R. Manivaskan
Research Engineer	Assistant Professor
CEWIT, IIT Madras, Chennai	IIT Madras, Chennai

ACKNOWLEDGEMNT

First and foremost, I would like to render my warmest thanks to Indian Institute of Technology Madras, Chennai, for providing me with magnificent opportunity to undertake and receive life changing internship training in the excellent work environment of this distinguished organization.

I with utmost delight express my deepest indebtedness and sincerest gratitude to my supervisor assigned and mentor **Dr. R. Manivaskan** (Assistant Professor, Dept. Of Electrical Engineering, IIT Madras) for their unfailing support, timely advice, overwhelming perspective, scientific approach, accurate supervision and immense knowledge that became my stepping-stones for framing the lattice of my work-piece.

It is my immense privilege to thank **Dr. J. Klutto Milleth**, **Mr. Shiv Shankar** and **Mrs. T R Ramya**, Central for Excellence in Wireless Technology, IIT Madras, for their valuable mentoring, kind help and unfaltering encouragement throughout my study prior in the university and providing me the great platform to furnish my thesis and dissertation.

Also, I am extremely thankful to my colleagues in Electrical Department, IITM for their passionate participation and inputs of providing necessary technical suggestions during my survey and research work.

I am very fortunate and honored to place my unfathomable graciousness and tribute to my parents for their eternal blessings, endless support and guidance throughout the period of completing my dissertation for the fulfillment of degree in Remote Sensing.

My acknowledgement would certainly be incomplete without giving recognition to my dear friends, who provided me with outstanding enthusiasm and kept gearing me up in pursuing my research work.

I also place my sincere thanks to all the other near ones who directly and indirectly helped, encouraged and inspired me all through this wonderful experience of a lifetime.

Sincere thanks and appreciations to you all!

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

NR	: New Radio
OFDM	: Orthogonal Frequency Division Multiplexing
RB	: Resource Block
PDSCH	: Physical Downlink Shared Channel
PBCH	: Physical Broadcast Channel
PDCCH	: Physical Downlink Control Channel
DMRS	: Demodulated Reference Signal
PTRS	: Phase Tracking Reference Signal
CSI-RS	: Channel State Information Reference Signal
PSS	: Primary Synchronization Signal
SSS	: Secondary Synchronization Signal
CORESET	: Control Resource Set
FR1	: Frequency Range 1
IE	: Information Element
CRB	: Common resource block
REG	: Resource Element Group
PRB	: Physical Resource Block
CCE	: Control Channel Element
LTE	: Long Term Evolution
IQ	: In-phase Quadrature
VRB	: Virtual Resource Block
DCI	: Downlink Control Information
BWP	: Bandwidth part
CP	: Cyclic Prefix
RG	: Resource Grid
CRC	: Cyclic Redundancy Code
3GPP	: 3rd Generation Partnership Project
eMBB	: Enhanced Mobile Broadband
mMTC	: massive Mobile Type Communication
URLLC	: Ultra Reliable Low Latency Communication

BPSK	: Binary Phase Shift Keying
QPSK	: Quadrature Phase Shift Keying
QAM	: Quadrature Amplitude Modulation
EVM	: Error Vector Magnitude
RMS	: Root Mean Square
dB	: deciBel
LDPC	: Low Density Parity Check

ABSTRACT

This thesis is related to estimation characteristics of channel with help of demodulated signal. Our working frequency range is FR1 that is sub 6-GHz. The modulation technique we are using is 64-QAM. The carrier spacing of OFDM signal is 30 KHz. We have used PDSCH mapping of type A. We transmit the 64-QAM OFDM signal and observe the constellation for each of the symbol from 3 to 13. We have developed a model to compensate for the distortion in the constellation for each symbol. We have estimated and compensate for the distortion int phase and amplitude due to channel. Our model also provide compensation due to receiver impairment due to non-ideal RF front-end component of the receiver.Our model includes DC offset compensator, Blind IQ compensator and Pilot based compensator to compensate for receiver impairment. We also plot the constellation diagram for compensated signal, actual received signal and desired signal i.e reference signal. We have compare the compensated signal and desired signal; and calculate Error Vector Magnitude (dB), RMS EVM and Peak EVM for each symbol. At the last we have done short comparison of our result with similar work done previously.

CHAPTER 1

INTRODUCTION

According to 3GPP, the official name of 5G is NR that stands for New Radio Technology. There is no single definition of NR. Different organization define it by their own ways. The most simple definition of NR as it collection of technology from Physical layer to Core Network that needs to fulfill three features as explained below. The terms described in below diagrams are also formal 3GPP terms.

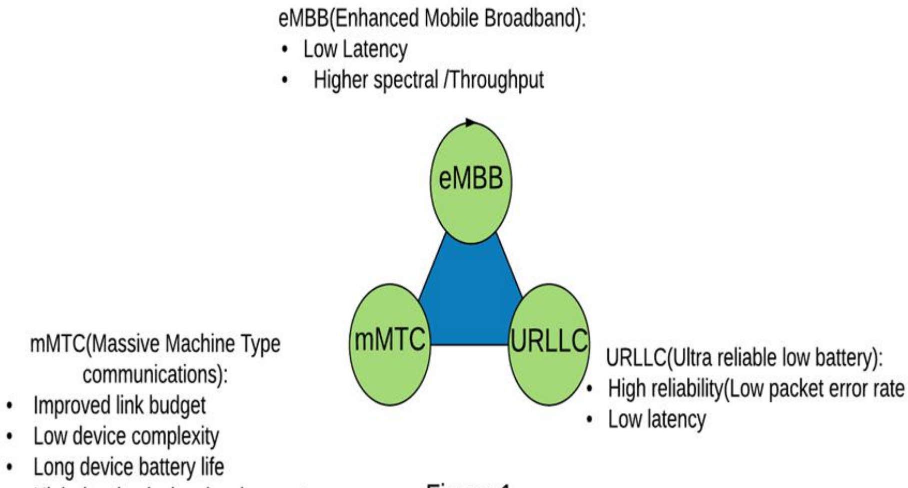


Figure 1

Technical Requirement proposed by Mobile and Wireless Communication Enablers for Twenty-twenty Information Society (METIS) to meet 5G goal are:

- 10-100 times higher user data rate, where in a highly dense urban environment the typical user data rate will vary from 1Gbit/s to 10Gbit/s;
- 1,000 times more mobile data per area (per user);
- Supports for 10-100 times more connected devices;
- 10 times longer battery life for low-power massive machine communications where devices such as sensors or pagers will have battery that lasts for decades;

- Supports of Ultra-fast application response times having end-to-end latency less than 5ms with very reliability;
- Ability to meet these requirements under a similar cost and power dissipation per area as present cellular systems.

5G mobile communication systems all the above requirements over a very wide frequency range from below 1 GHz to 52.6 GHz.

1.1 5G Frame Structure

The Diagrammatic Representation displayed underneath reflects upon the 5GNR frame structure. The time span of a frame is of 10ms and contains 10 sub frames. Each sub frames, according to spacing on the sub carrier spacing can contain 14 OFDM symbols (for 15 K Hz), 24 OFDM symbols (for 30 K Hz) and so on, OFDM symbols. A group of 14 OFDM symbols is called a slot or a resource block element (RE). A group of 12 REs makes one resource block (RB). In our case an OFDM symbol has 256 RBs, giving us 256 X 12 = 3072 REs.

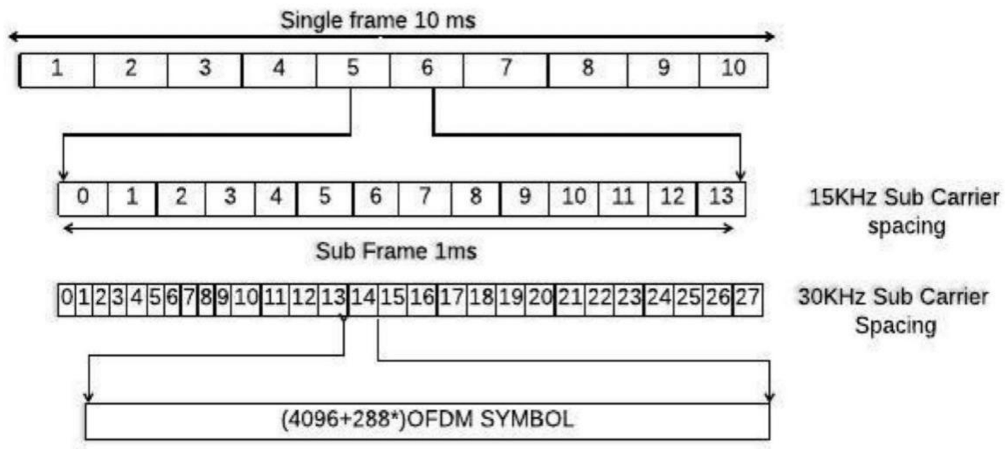


Figure 2: Frame Structure

1.2 Downlink Transmission:

Various physical channels and reference signals are needed to be mapped on the resource grid which is present in the downlink section as under:

1. Physical channels:
    - Physical Downlink Shared Channel (PDSCH)
    - Physical Broadcast Channel (PBCH)
    - Physical Downlink Control Channel (PDCCH)

2. Physical signal
    - Demodulated Reference Signal (DMRS)
    - Phase Tracking Reference Signal (PTRS)
    - Channel State Information Reference Signal (CSI-RS)
    - Primary Synchronization Signal (PSS)
    - Secondary Synchronization Signal (SSS)

1.3 Physical Channels:

All the three physical channel namely PDSCH, PBCH and PDCCH are described briefly below. These channels contain system frames and information, along with data, that are required to initiate initial access and establishment of frame synchronization with a NR cell.

1.3.1 Physical Downlink Shared Channel (PDSCH):

- For each antenna step, a resource grid is created. Within the resource grid, each of the resource element (RE) is filled with PDSCH data from the lowest frequency to higher frequency
- On reaching the RE at the highest frequency of the assigned PDSCH resource block, it switches to the RE at the lowest frequency of next OFDM symbol. This needs 3072 X 14 array for storage and also the next module, has to wait till the first OFDM symbol is filled fully so the symbol can go for further processing.

- To prevent the excessive BRAM (memory) usage and large latency, there is a need of user interleaved block, which provide the data according to an OFDM symbol in a continuous fashion. Hence the whole RB mapping design works on one symbol at time.

- Below diagram describes the transport process of PDSCH.
- PDSCH is not allowed to use the REs that are assigned for given below purpose:
    - ❖ REs assigned for DMRS associated with the PDSCH to be transmitted
    - ❖ REs assigned for DMRS intended for other co-scheduled UEs
    - ❖ REs for non-zero power CSI-RS
    - ❖ REs for PTRS
    - ❖ REs declared as 'not available' for PDSCH

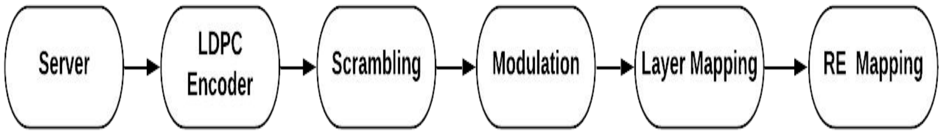


Figure 3: Transport process in PDSCH

1.3.2 Physical Broadcast Channel (PBCH)

PBCH is a special channel that carries Master Information Block (MIB) and possesses following characteristics:

- It uses QPSK modulation.
- It centers around DC sub carrier and is transmitted in a periodic fashion.
- Assigned to REs which is not reserved for transmission of reference signals and PDCCH
- The below diagram shows the mapping of PBCH on resource grid and PBCH transport process.

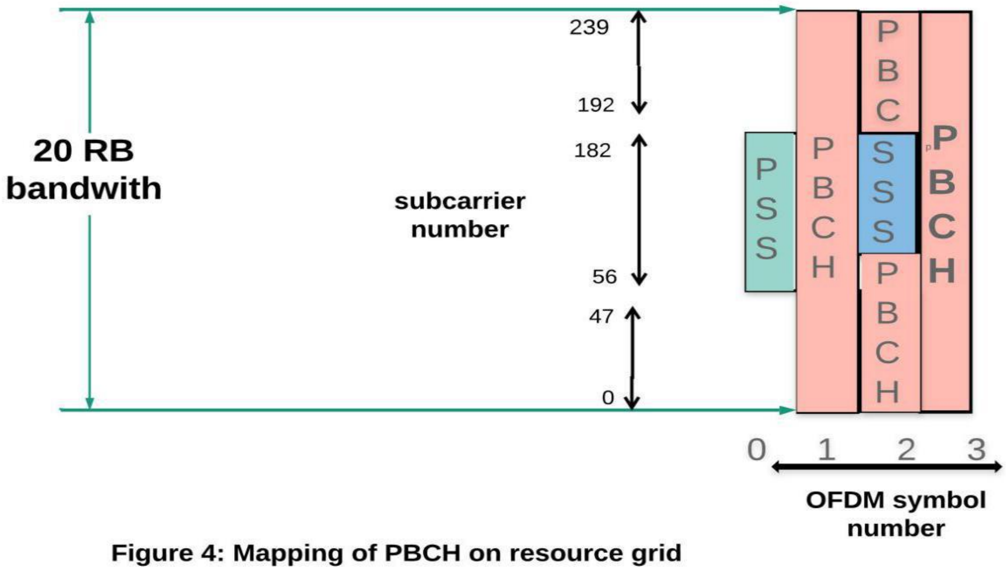


Figure 4: Mapping of PBCH on resource grid

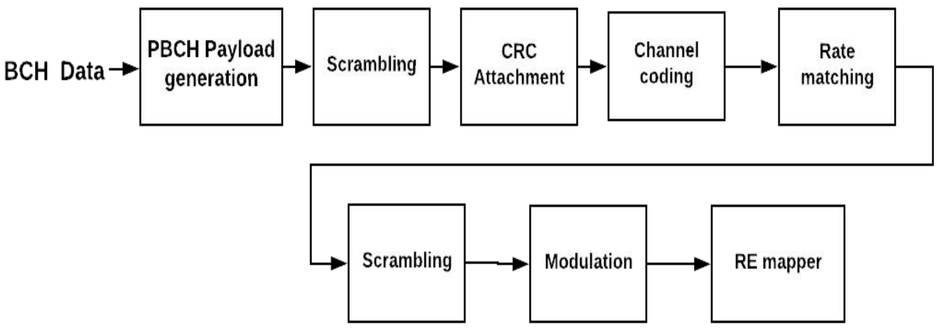


Figure 5: Transport process of PBCH

1.3.3 Physical Downlink Control Channel (PDCCH):

PDCCH is a special channel to carry Downlink Control Information (DCI) and possesses the following characteristics:

- The set of physical resources (i.e, a specific area on NR Downlink Resource Grid) and parameters that is used to carry PDCCH/DCI is called CORESET (COntrol REsource SET).
- In NR both the frequency and time domain length of CORESET is defined by the RRC (Radio Resource Control) parameter.

- PDCCH mapping on resource grid and the PDCCH transport process is shown below

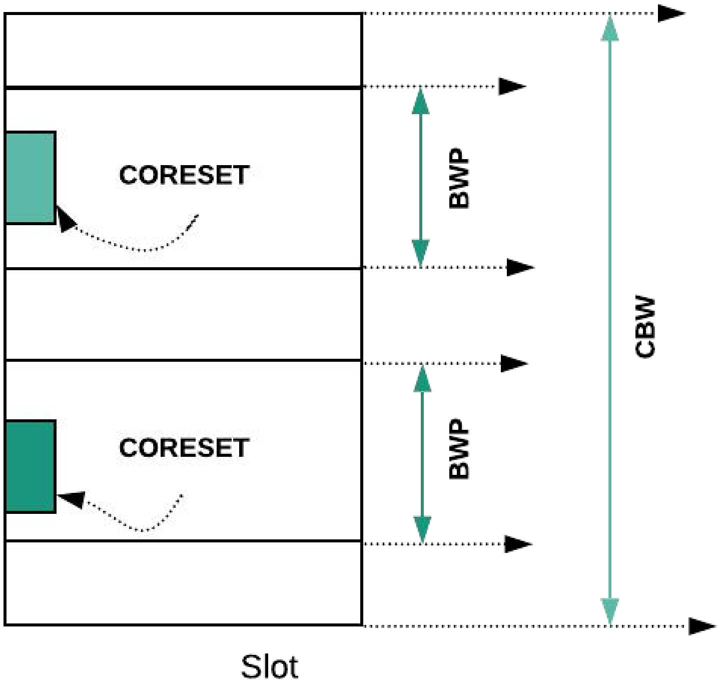


Figure 6: PDCCH mapping on resource grid

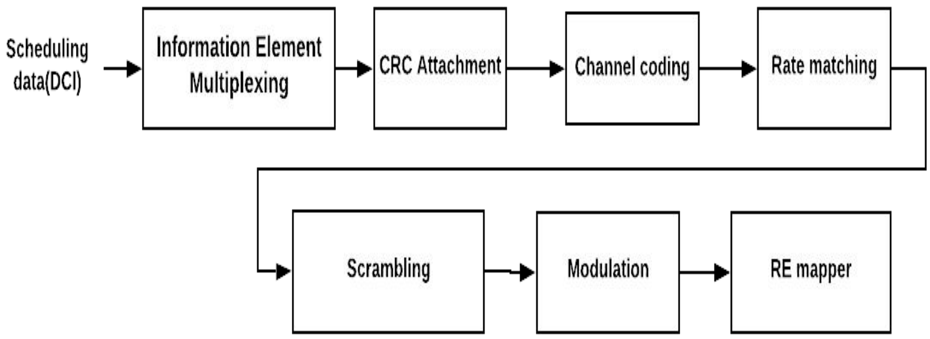


Figure 7: Transport process in PDCCH

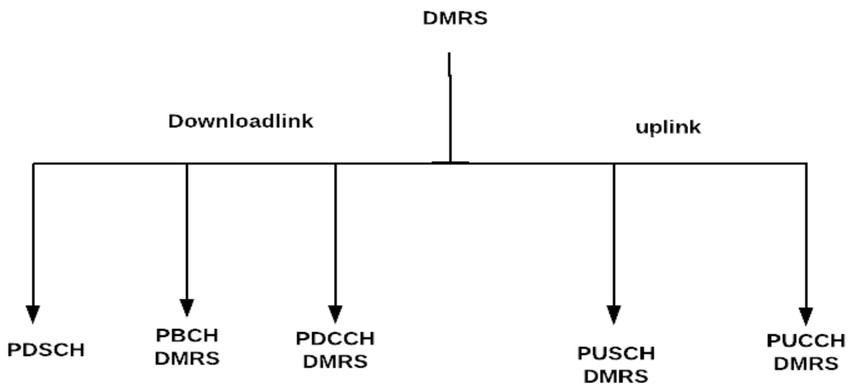
1.4 Physical Reference Signals:

The Reference Signal structure is same as that of LTE while achieving the flexibility to adapt to operation in various different frequency bands. If an Reference Signal is transmitted constantly, it may limits for possible RS and channel designs in future. Hence, NR tries to avoid specifying an RS that is transmitted regularly (e.g. Cell-specific Reference Signal (CRS) in LTE), and implements the function of CRS by using multiple RSs instead.

Specifically, the CSI-RS, Demodulation RS (DMRS) and Tracking RS (TRS) are specified for channel state information estimation, data demodulation and time/frequency tracking, respectively.

1.4.1 Demodulation Reference Signal (DMRS):

DMRS is used by 5G NR receiver for channel estimations for demodulation of associated physical channel. The design and mapping of DMRS is specific to each of the 5G physical channels viz. PBCH, PDCCH, PDSCH, PUSCH and PUCCH. DMRS is specific for specific UE, and transmitted on demand.



1.4.1.1 PDSCH DMRS (Single User):

- Slot based (DMRS Mapping type-A):
  - ❖ Fixed OFDM symbol regardless of PDSCH assignment.
  - ❖ Configurable between $lo = \{2,3\}$ determined by DMRS type-A position

- Non-slot based (DMRS Mapping type-B):
    - ❖ First OFDM symbol is assigned for PDSCH.
- Additional DMRS symbols can also be configured for high speed scenarios.
- **PDSCH DMRS MAPPING:**

With the assumption of the UE, the PDSCH DMRS being mapped to physical resources according to configuration 1 or configuration 2 as given by the higher-layer parameter DMRS - Type.

Mapping table for PDSCH DMRS for single-symbol DMRS is given below.

Table 1:PDSCH DM-RS positions l for single-symbol DM-RS

Duration in symbols	DM-RS positions l							
	PDSCH mapping type A dmrs-Additional position				PDSCH mapping type B drms-Additional position			
	0	1	2	3	0	1	2	3
2	–	–	–	–	l_0	l_0		
3	l_0	l_0	l_0	l_0	–	–		
4	l_0	l_0	l_0	l_0	l_0	l_0		
5	l_0	l_0	l_0	l_0	–	–		
6	l_0	l_0	l_0	l_0	l_0	l_0		
7	l_0	l_0	l_0	l_0	l_0	l_0		
8	l_0	l_0,7	l_0,7	l_0,7	–	–		
9	l_0	l_0,7	l_0,7	l_0,7	–	–		
10	l_0	l_0,9	l_0,6,9	l_0,6,9	–	–		
11	l_0	l_0,9	l_0,6,9	l_0,6,9	–	–		
12	l_0	l_0,9	l_0,6,9	l_0,5,8,11	–	–		
13	l_0	l_0,11	l_0,7,11	l_0,5,8,11	–	–		
14	l_0	l_0,11	l_0,7,11	l_0,5,8,11	–	–		

Mapping table for PDSCH DMRS for single-symbol DMRS is given below.

Table 2:PDSCH DM-RS positions *l* for double-symbol DM-RS

Duration in symbols	DM-RS positions l							
	PDSCH mapping type A dmrs-Additional position				PDSCH mapping type B drms-Additional position			
	0	1	2		0	1	2	3
<4	–	–			-	-		
4	l_0	l_0			–	–		
5	l_0	l_0			-	-		
6	l_0	l_0			l_0	l_0		
7	l_0	l_0			l_0	l_0		
8	l_0	l_0			-	-		
9	l_0	l_0			–	–		
10	l_0	l_0,8			–	–		
11	l_0	l_0,8			–	–		
12	l_0	l_0,8			–	–		
13	l_0	l_0,10			–	–		
14	l_0	l_0,10			–	–		

1.4.1.2 PDSCH DMRS (Multi User):

- The higher layer parameters for DMRS generation varies from user to user and therefore for multiuser PDSCH, the seed value and length of DMRS sequence vary for different users, the below diagram is a source grid with three different users and there DMRS.

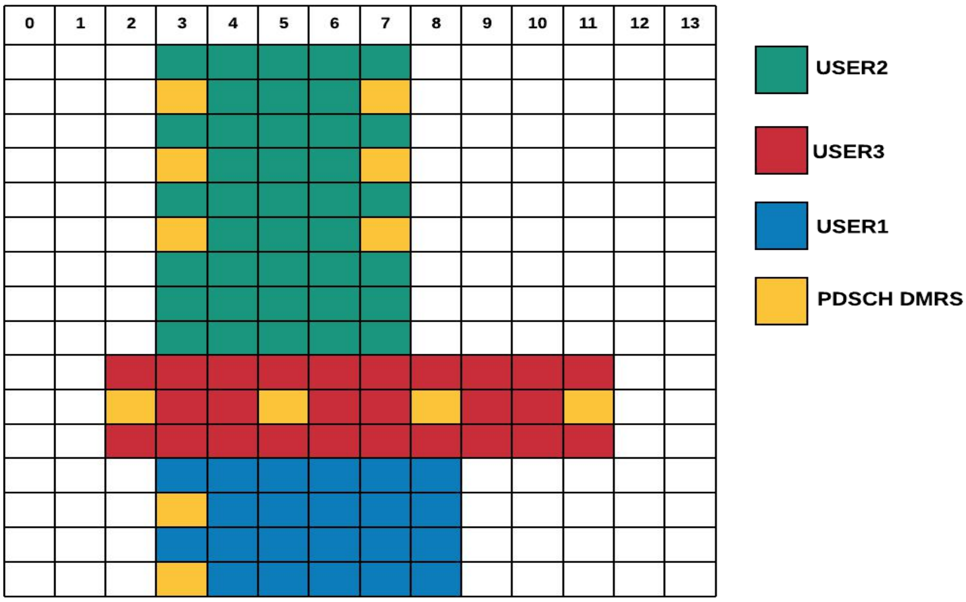


Figure 8: Reference Signal configuration for different users

- Since the RE mapper fills the OFDM symbol with the incoming data starting from sub carrier 0, as observed from the above diagram it is needed to fill the the user 1 data first followed by user 3 and user 2 for symbol number 3.
- An user interleaver requires to be designed which will correctly schedule the user's data.
- Since the higher layer parameters for PDSCH DMRS will be different for different users, it is needed higher layer parameters is also scheduled in the same manner WRT that opubf user's data.
- A slot can accommodate a maximum of 48 users, therefore we require that many higher layer parameters to generate the DMRS.
- The problem of multi user is eliminated using a 2D array of 48 X 14 dimension.
- As in the above example of the 3rd symbol contains DMRS for user 1 and user 2, in a worst case scenario there can be 48 users data and their DMRS , for that

particular symbol we require to have 48 seed values to generate the DMRS, this can be extended to remaining 14 symbols.

1.4.1.3 PBCH DMRS:

- PBCH DMRS is a special type of physical layer signal which is used as a reference signal for decoding PBCH.
- For LTE, CRS (Cell Specific Reference Signal) is used for PBCH decoding.
- However, in 5G/NR there is no CRS. Therefore, there is need of DMRS dedicated for PBCH decoding.

1.5 Primary Synchronization Signal (PSS) / Secondary Synchronization Signal (SSS):

- PSS and SSS are specific layer signals that functions as radio frame synchronization.
- Mapped to 127 active sub carriers around the lower end of the system bandwidth (sub carrier 80~206).
- Made up of 127 m-Sequence Values.
- Used for Downlink frame synchronization.
- One of the critical factor of determining Physical Cell ID.
- Uses BPSK.
- The correlation between the ideal sequence and a received sequence is greatest when the lag is zero.

1.6 OFDM

Modulations like QPSK, BPSK, QAM etc are single carrier modulation technique, in which the information is modulated over a single carrier. OFDM is a multicarrier modulation technique which divides the available spectrum into a large number of narrow-band subchannels. The data stream of every subchannel is modulated using MPSK/MQAM modulation. The modulated symbols in all the subchannel are collectively known as an OFDM symbol. In a frequency selective environment, each narrowband subchannel in an OFDM symbol, faces flat-fading and therefore complex equalizers are made overlapping and orthogonal, hence the name orthogonal frequency division multiplexing.

With relatively simpler implementation, OFDM provides an efficient way to deal with multipath propagation effects. OFDM transmission is the most robust against narrowband interference. Sensitivity to frequency/phase offsets and high peak-to-average power ratio (PAPR) resulting to lowered efficiency to RF amplifier, are few demerits of an OFDM system.

A CP-OFDM transceiver architecture is implemented using inverse discrete Fourier transform (IDFT) and discrete Fourier transform (DFT) blocks. The output of the IDFT block, viewed as time domain samples, results in an OFDM symbol. Such OFDM symbols are then sent across a channel with certain impulse response (CIR). On the other side, the receiver applies DFT over the received OFDM symbols for further demodulation for the information in the individual subcarriers.

The idea behind using OFDM is to tackle frequency selective fading, where different frequency components of a signal can undergo different levels of fading. The OFDM divides the available spectrum into small chunks of subchannels. The fading experienced by the individual modulated symbol can be considered flat within the subchannels. This gives the opportunity to use a simple frequency domain equalizer to neutralize the channel effects in the individual subchannels.

The simple block diagram of OFDM transmitter and the receiver with a simple frequency domain equalizer is shown below:

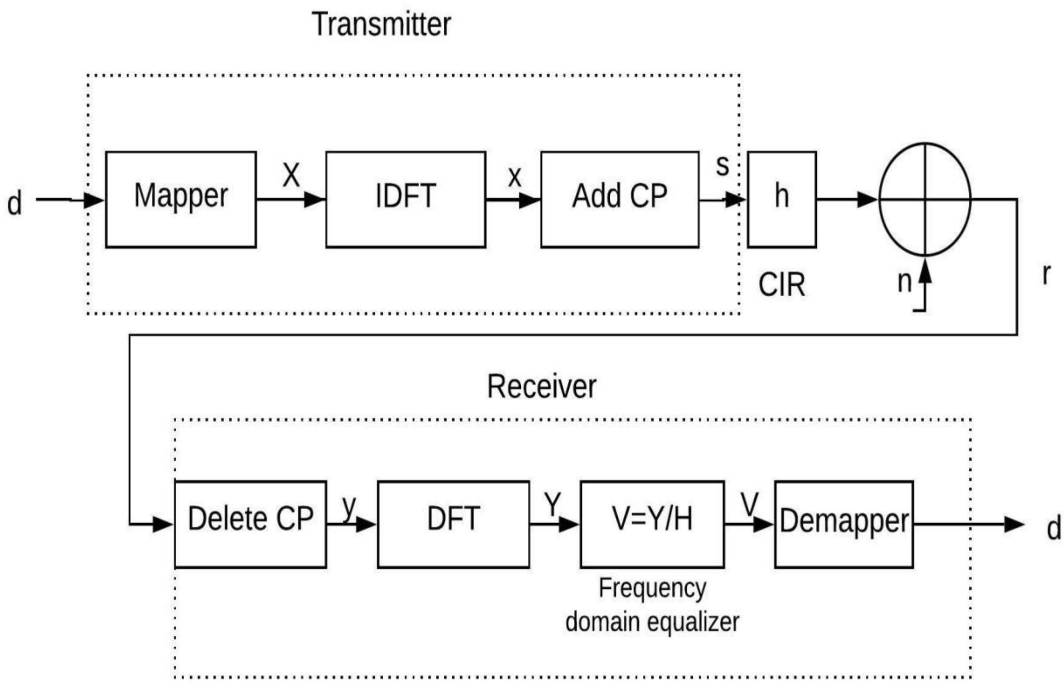


Figure 9: OFDM transmitter and receiver with a simple frequency domain equalizer

CHAPTER 2

OBJECTIVES

The present study is planned with the goal of Physical Channel estimation on Downlink chain in 5G NR standard. Using DMRS signals as the reference values Physical channel (PDSCH) is being estimated for different user and system configurations, using Matlab. The major objectives are:

I. Observe the Constellation of DMRS receive signal for mapping of Type A and Subcarrier Spacing 30 KHz for different OFDM symbols (from symbol 3 to symbol 13).

II. Analyse the rotation in constellation of received DMRS signal for different symbols.

III. Develop an algorithm to compensation in phase and amplitude due to Chanel and as well receiver impairment .

IV. Plot the Constellation of Compensated received signal.

V. Calculate Error Vector Magnitude % for constellation of each of symbol.

VI. Comparison of our result with previously similar work done.

As per present we have taken the signal received at symbol 3 as reference signal and compared the constellation for compensated signal with respect to reference signal. In EVM calculation we calculated EVM (dB), RMS EVM and Peak EVM ; and finally made comparative analysis of the compensated signals for different symbol varying from symbol 3 to symbol 13.

CHAPTER 3

Methodology

When we send DMRS signal through wireless channel it gets distorted because of many factors. The prominent factors are Gain and Phase distortion due to channel; and distortion due to imperfection in analog component in RF font-end of Receiver. In our method of Compensating distortion in receive signal we will focus first on Estimation and Compensation in Phase and Gain due to wireless channel. After doing so we will then shift our focus towards compensation in distortion due to receiver components.

3.1 Phase and Gain Estimation and Compensation

In this method, we will take signal of first symbol to be reference signal. We will calculate the phase and average gain of bits of each of the symbol.

Let the average phase difference between the reference signal and signal to be compensated to be θ (in radian) and the average gain ratio of reference signal and signal to be compensated signal be *g*. Let the signal to be compensated to be (Z) and the Compensated Signal (r) then,

$R_i = real(Z); \; R_q = imag(Z);$

$r_i = g*(-Sin(\theta)*Z_q + Cos(\theta)*Zi);$

$r_q = g*(Sin(\theta)*Z_i + Cos(\theta)*Zq);$

$r = r_i + j\, r_q;$

Once we get Compensated Signal due to channel we go will Receiver Impairment Estimation and Compensation to get our final signal.

3.2 Receiver Impairments and Compensation

The IQ imbalance results due to non-ideal RF front-end components due to power imbalance or/and non-orthogonality of Inphase (I) and Quadrature(Q) branches caused by imperfect local oscillator outputs. The effect of IQ imbalance can be quite disastrous for higher order modulation. Moreover, the RF front-end may also introduce DC offsets in the IQ branches, leading to more performance degradation.

3.2.1 Receiver Impairment Model

In this method first will be design a model to study the effect due to receiver impairment effect of imbalance IQ.

The followings are effect of RF receiver impairments

- Phase imbalance and cross-talk on I,Q branches due to local oscillator phase mismatch-*Ø*
- Gain imbalance on I,Q branches- *g*.
- DC offsets in the I and Q branches- dc_i , dc_q.

In our model, the complex signal $r = r_i + j\ r_q$ is the perfect unimpaired signal to the receiver and $z = z_i + j\ z_q$ is the signal after the introduction of IQ imbalance and DC offset effect in the receiver front-end. The diagram of model is as below :

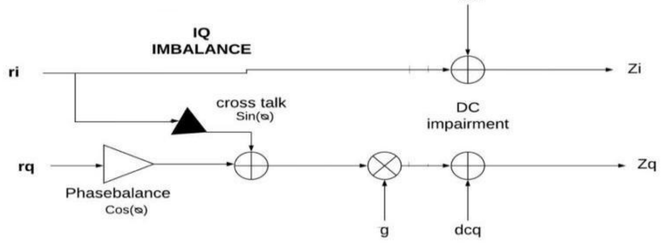


Fig.10 : RF receiver impairment model

The RF impairment model depicted above contains two types of impairments namely DC offset impairment and IQ imbalance impairment. DC offsets dc_i and dc_q on the IQ branches are simply modelled by additive factors of received signal.

$z = r + (dc_i + j\, dc_q)$.

Two IQ imbalance models, namely, *double-branch IQ imbalance model* and *single-branch IQ imbalance model*, are in used. Our model is single-branch IQ imbalance. In our model, the IQ mismatch is model as amplitude and phase error in only one of the branches (say Q branch).

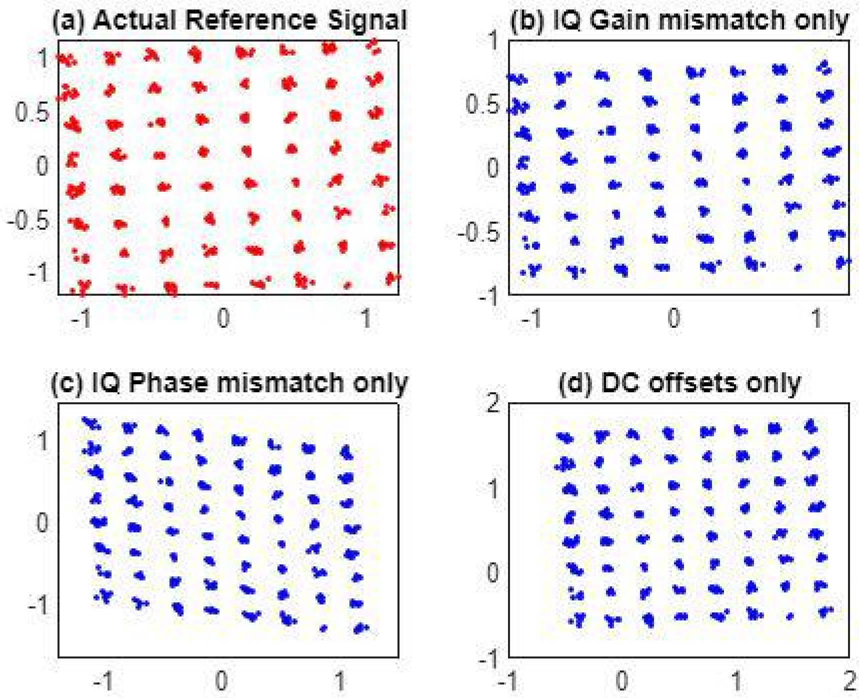
Let $r = r_i + r_q$ be the perfect unimpaired signal and $z = z_i + z_q$ be the signal with IQ imbalance. The gain g be the gain term in the Q branch only. The presence of phase error $Ø$ in the output of local oscillator, manifests as cross-talk between Q and I branches. Both the gain imbalance g and the phase error $Ø$ in the impaired signal on the I,Q branches can be shown as

$$z_i = r_i$$

$$z_q = -g*\sin(Ø_{rad})*r_i + g*\cos(Ø_{rad})*r_q$$

3.2.2 Visualizing the effect of receiver impairments

With the receiver impairment model, the effect of IQ impairment can be visualized in a complex plane. We have consider the 64-QAM symbol as an actual reference signal as which is unimpaired signal. The receiver impairments like DC offsets and IQ imbalance are added to the reference signal. The constellation diagram below shows the effect of receiver impairment.



Constellation plots for (a) unimpaired symbol in red and impaired version in blue for

(b) Gain mismatch g =0.7 (c) Phase mismatch $\emptyset = 13^o$ (d) DC offsets dc_i =0.6, dc_q =0.6

3.2.3 DC offsets Compensation

The RF impairment model in the above figure 9 contains two types of impairments namely IQ imbalance and DC offset impairment. DC offsets dc_i and dc_q on the I and Q branches are additive factor on the incoming signal.

Correspondingly, the DC offsets on the branches are simply removed by subtracting the mean of the incoming signal on the I, Q branches.

```
iDC = mean(real(r)) ;

qDC = mean(imag(r)) ;
```

V= r-(iDC + jqDC);

3.2.4 IQ Imbalance Compensation

After DC offset compensation, we focus on the IQ imbalance compensation. In this we will use two compensation models back to back to get the required final signal. The two IQ imbalance models are: Blind estimation and compensation; and Pilot based estimation and compensation model.

3.2.4.1 Blind Estimation and Compensation Model:

The blind technique is a simple, less complexed algorithm, that is based on the statistical property of the incoming complex signal. It doesn't need additional processing overheads like preamble or training symbols for the estimation of IQ imbalance.

The blind Compensation model is shown below in figure 11. Let $v = v_i + jv_q$ be the IQ imbalance-impaired complex baseband signal, that is to be compensated. First, the complex baseband signal z is used to estimate three imbalance parameters θ_1, θ_2 ,and θ_3.

θ_1 = -E{sgn(v_i)v_q}

θ_2 = E{|v_i|}

θ_3 = E{|v_q|}

where, sgn(x) is signum function

$$sgn(x) = \begin{cases} -1 & x < 0 \\ 0 & x = 0 \\ 1 & x > 0 \end{cases}$$

The compensator coefficient c_1 and c_2 are then calculated from the estimates of θ_1, θ_2 ,and θ_3.

$$c_1 = \frac{\theta 1}{\theta 2} \qquad c_2 = \sqrt{\frac{\theta_3^2 - \theta_1^2}{\theta_2^2}}$$

Finally, the impaired and quadrature components of the compensated signal $d = d_i + d_q$, are calculated as

$$d_i = v_i \qquad d_q = (c_1 v_i + v_q)/(c_2)$$

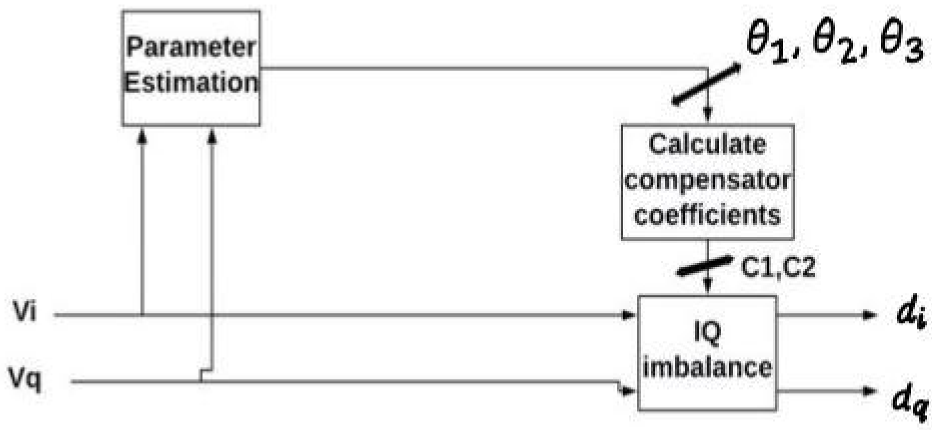


Fig.11 :Blind estimation and compensation for IQ imbalance

3.2.4.2 Pilot based Estimation and Compensation Model:

Pilot based estimation algorithm is frequently used to estimate various channel properties. The transmitter transmit a pilot sequence and the IQ imbalance is estimated depending on the received sequence at the baseband signal processor. It uses a preamble of length L to estimate the gain imbalance (K_{est}) and phase error P_{est}.

$$K_{est} = \sqrt{\frac{\sum_{k=1}^{L} z_q^2[k]}{\sum_{k=1}^{L} z_i^2[k]}}$$

$$P_{est} = \frac{\sum_{k=1}^{L} (z_i[k].z_q[k])}{\sum_{k=1}^{L} z_i^2[k]}$$

Where, the complex signal $z = z_i + jz_q$, is the impaired version of the long preamble.

Let $d = d_i + jd_j$ be the impaired complex signal received as an output of Blind compensation model during normal data transmission interval. The compensated output signal after Pilot compensation model is $w = w_i + jw_q$.

$$w_i = d_i$$

$$w_q = \frac{d_q - d_i P_{est}}{k_{est}\sqrt{1 - P_{est}^2}}$$

The Complete Receiver Impairment model can be shown as below in the figure 12. It includes Receiver Impairment; and DC compensation as well as IQ compensation.

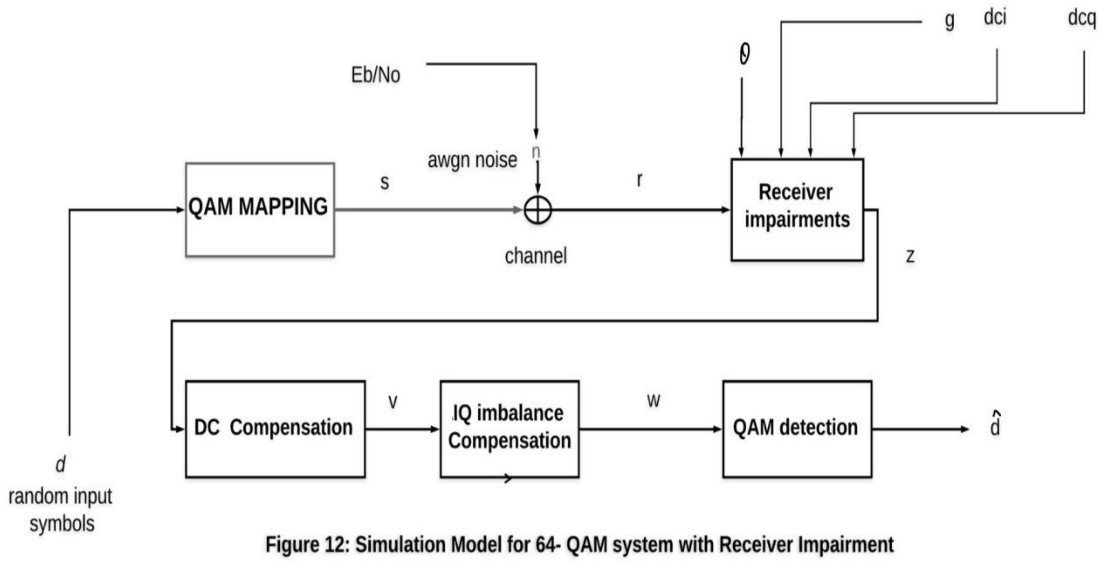


Figure 12: Simulation Model for 64- QAM system with Receiver Impairment

In this model we have analyzed the received signal and provided the phase and gain compensation and the finally passed through receiver impairment compensator which includes DC compensation and IQ compensation.

3.3 Working Algorithm

Step 1: Phase and Gain Estimation and Compensation

Let ‘Z’ be actual received signal and ‘r’ be compensated signal. θ (in radian) average phase difference between reference signal and signal to be compensated and *g* be the average gain of reference signal to signal to be compensated.

Z_i = real(Z); Z_q = imag(Z);

$r_i = g*(-Sin(\theta)*Z_q + Cos(\theta)*Zi);$

$r_q = g*(Sin(\theta)*Z_i + Cos(\theta)*Zq);$

$r = r_i + j\, r_q;$

Step 2: DC offset Compensation

The DD offsets on the branches are simply removed by subtracting the mean of the incoming signal on the I, Q branches.

iDC = mean(real(r)) ;

qDC = mean(imag(r)) ;

v= r-(iDC + jqDC);

Step 3: Blind Estimation and Compensation

Let $v = v_i + jv_q$ be the output of DC offset Compensator and $d = d_i + jd_q$ the output of the blind estimation and compensation block.

$\theta_1 = -E\{sgn(v_i)v_q\}$

$\theta_2 = E\{|v_i|\}$

$\theta_3 = E\{|v_q|\}$

where, sgn(x) is signum function

$c_1 = \frac{\theta 1}{\theta 2}$ $\quad c_2 = \sqrt{\frac{\theta_3^2 - \theta_1^2}{\theta_2^2}}$

$d_i = v_i$ $\quad d_q = (c_1 v_i + v_q)/(c_2)$

Step 4 : Pilot based estimation and compensation

Let the output signal after Pilot based compensation model be $w = w_i + j\, w_q$.

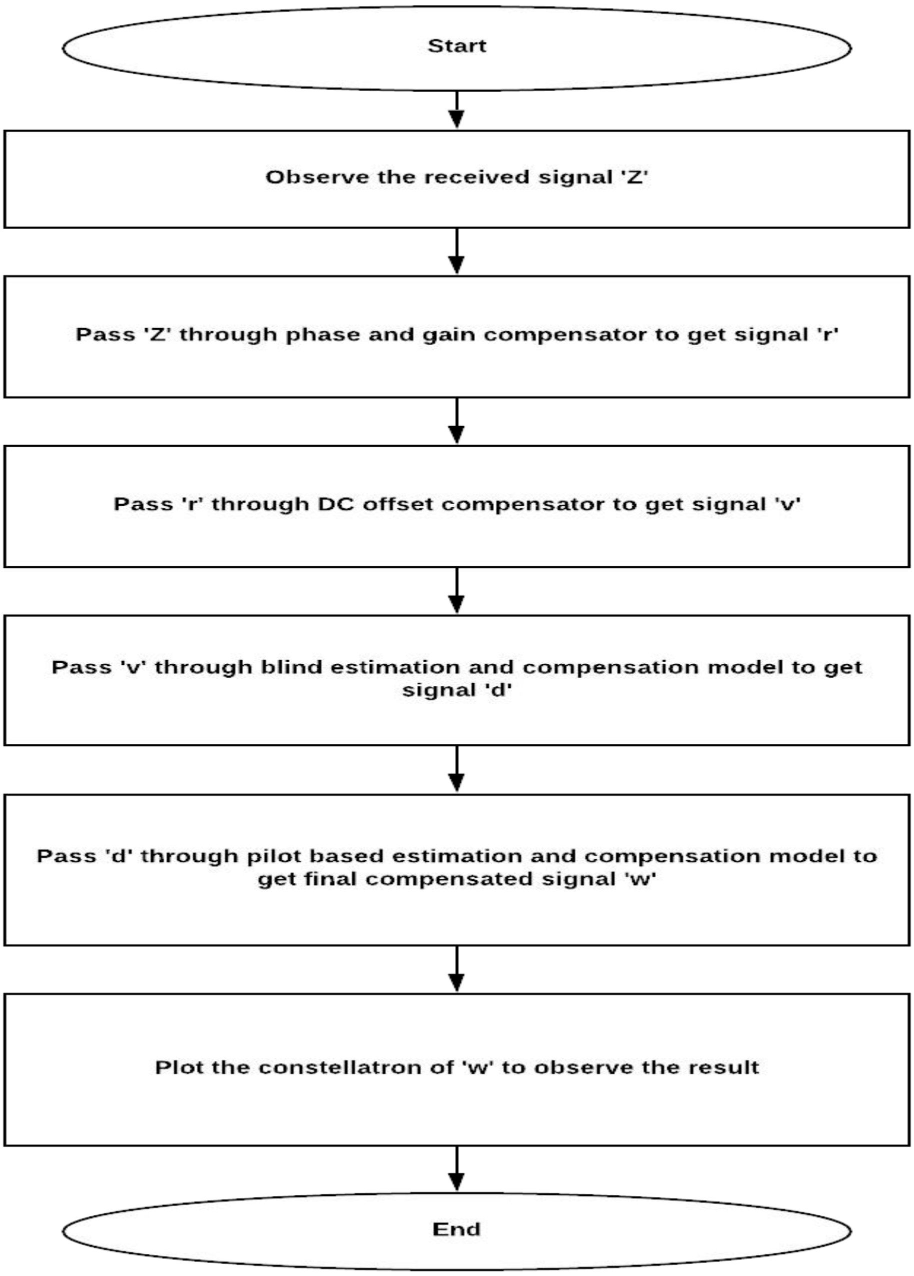
$$K_{est} = \sqrt{\frac{\sum_{k=1}^{L} z_q^2[k]}{\sum_{k=1}^{L} z_i^2\,[k]}}$$

$$P_{est} = \frac{\sum_{k=1}^{L} (z_i[k].\, z_q[k])}{\sum_{k=1}^{L} z_i^2[k]}$$

$$w_i = d_i\ ;\ \ w_q = \frac{d_q - d_i P_{est}}{k_{est}\sqrt{1 - P_{est}^2}}$$

Step 5: Plot the constellation of 'w' to observe the compensated signal.

3.4 Flow Chart

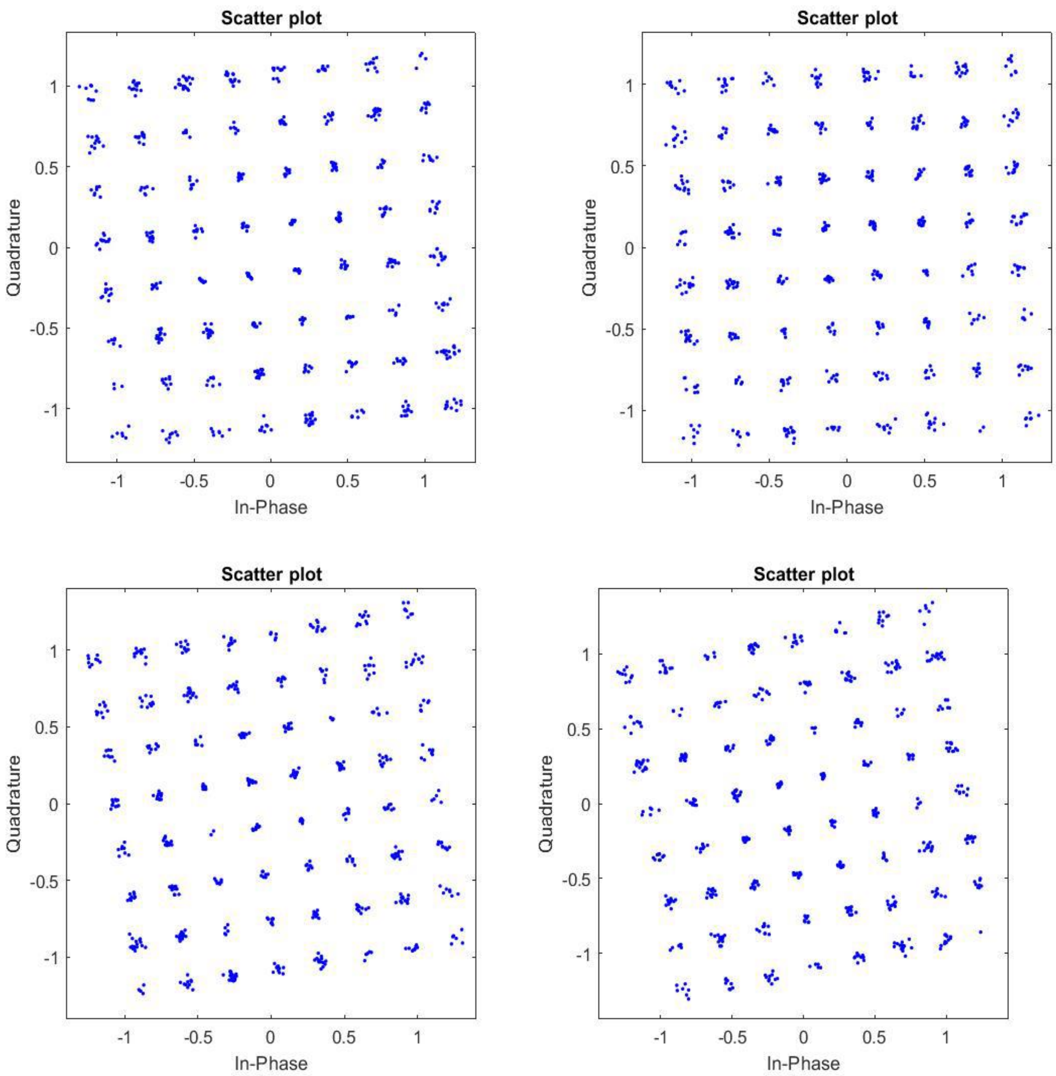


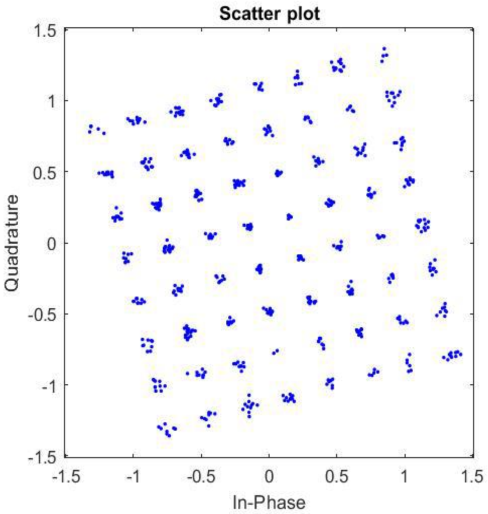
<u>**CHAPTER 4**</u>

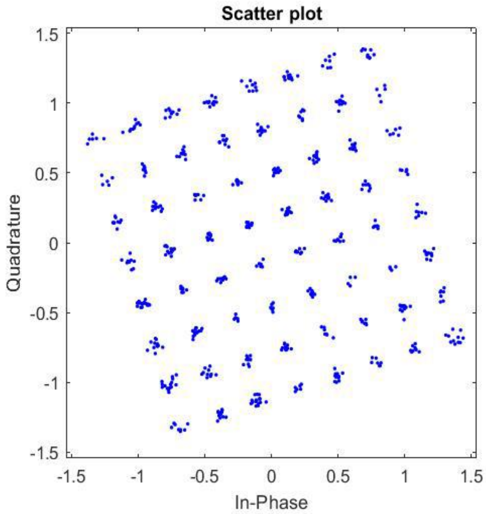
RESULTS AND DISSCUSSIONS

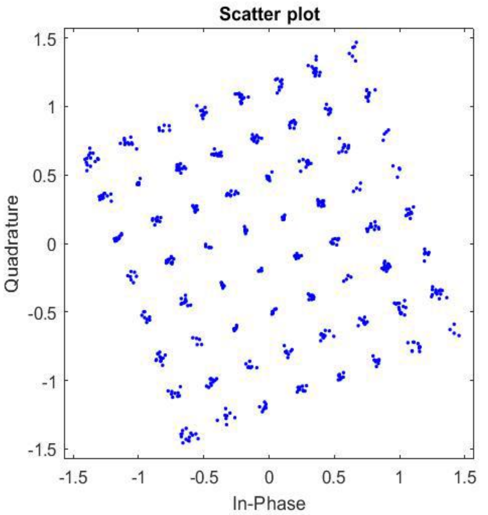
4.1 INPUT CONSTELLATION

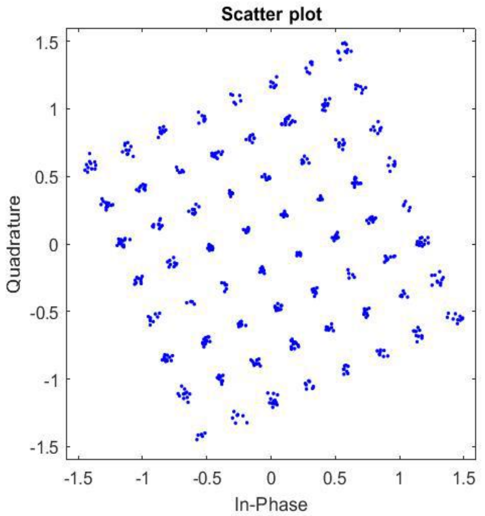
The given below is the constellation of the received OFDM signal for symbol 3 to 13 of frame structure of NR. We observe that as we move from symbol number 3 to symbol 13 there is tilt in constellations because of which constellations get rotated in anticlockwise. We need to pass each of the constellation from our compensating model to correct the constellation.

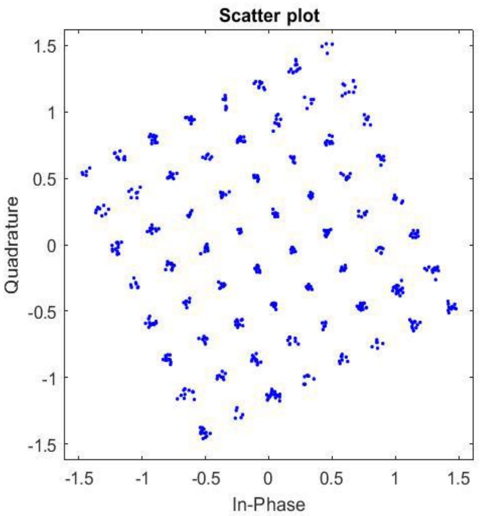


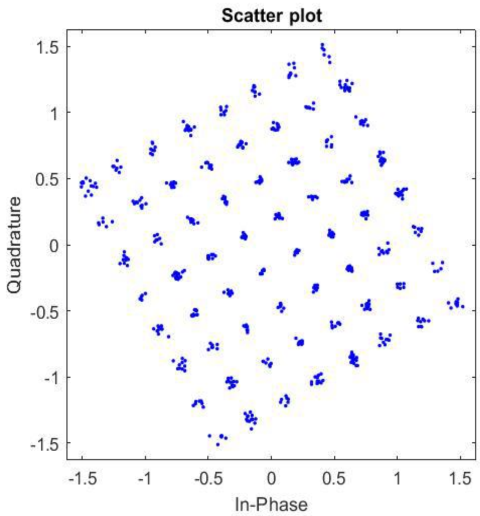

Scatter plot
Quadrature
In-Phase

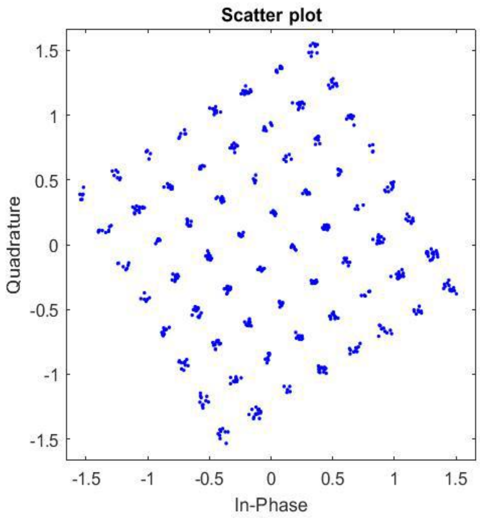

Scatter plot
Quadrature
In-Phase


Scatter plot
Quadrature
In-Phase


Scatter plot
Quadrature
In-Phase

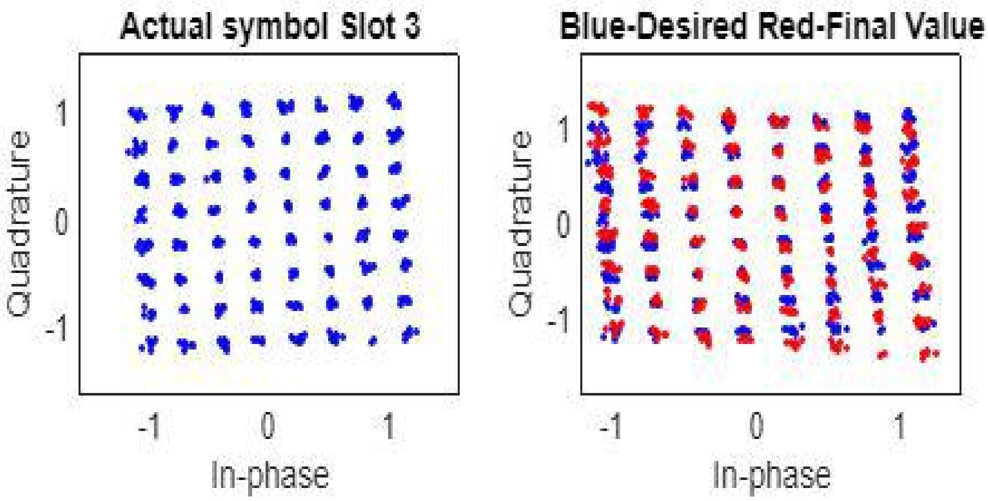

Scatter plot
Quadrature
In-Phase

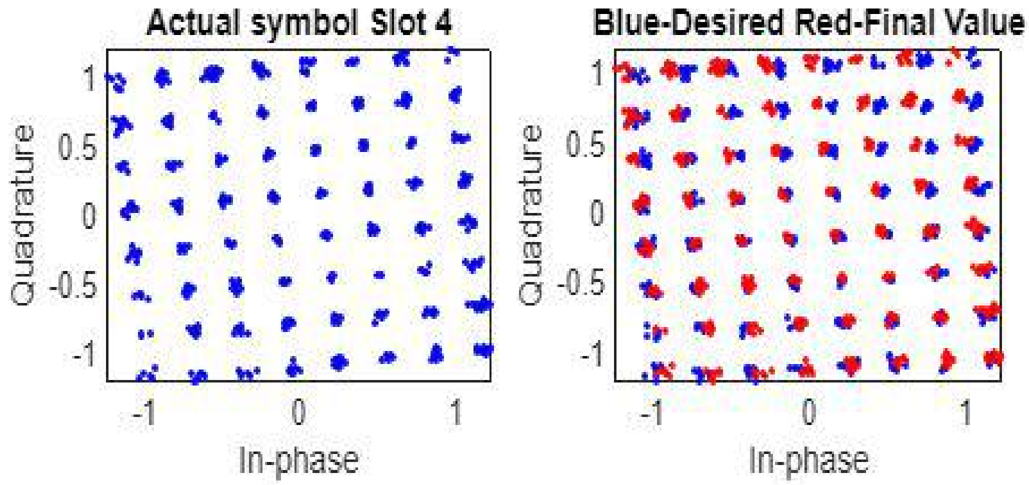

Scatter plot
Quadrature
In-Phase

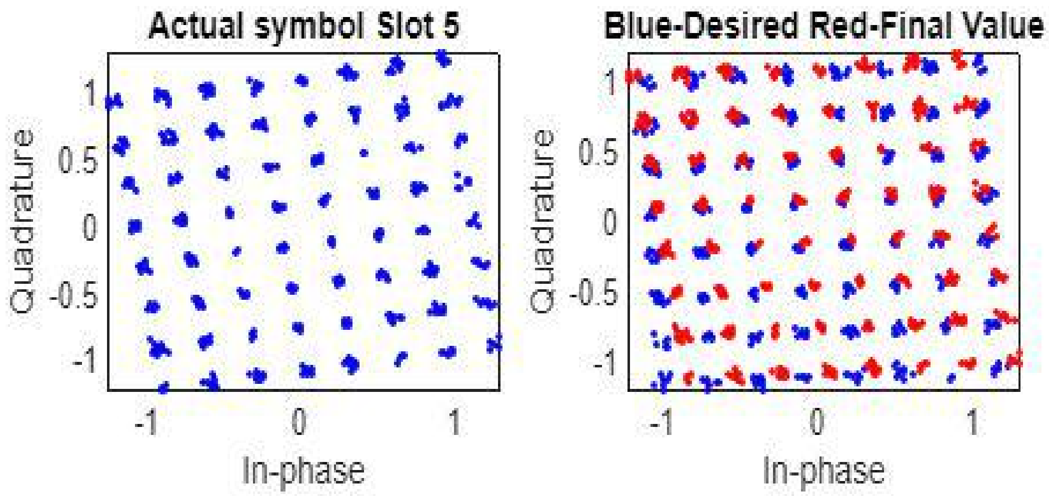


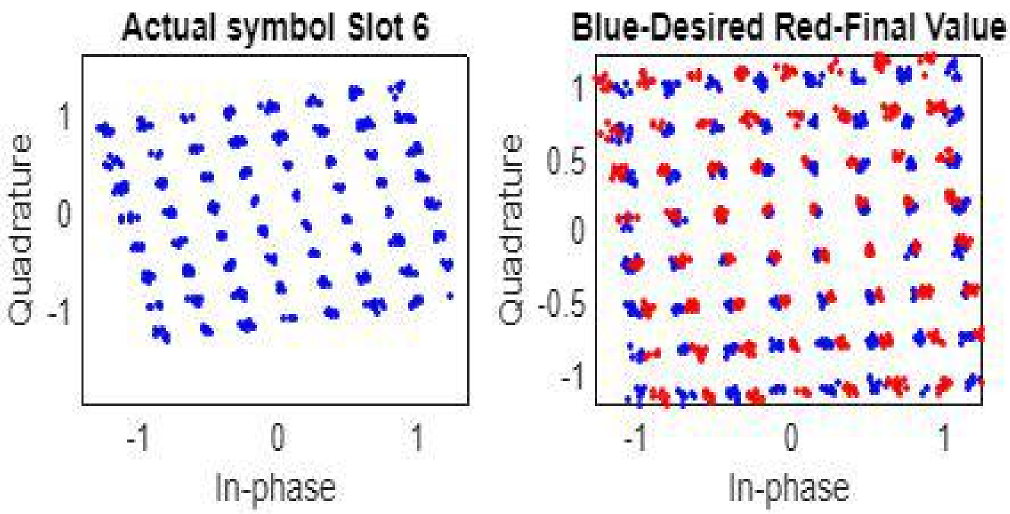
4.2 COMPENSATED CONTELLATION

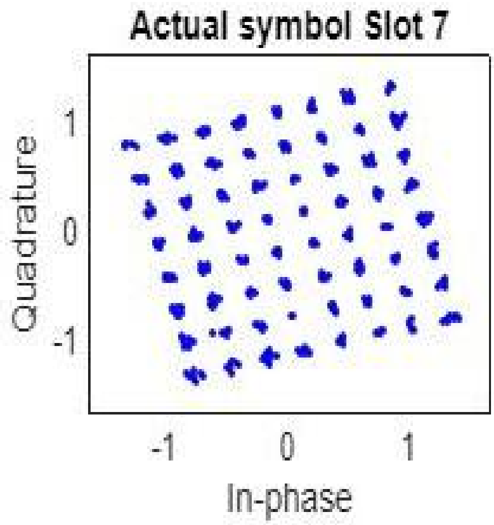
The given is compensated constellation of OFDM signal from time symbol 3 to 13.We have taken OFDM symbol as reference symbol and we have plotted the constellation of compensated signal.The constellation of actual received signal of each symbol is shown in the left hand side. On the right, the constellation of desired reference signal is plotted in blue and the constellation of compensated symbol of respective symbol is plotted in red.

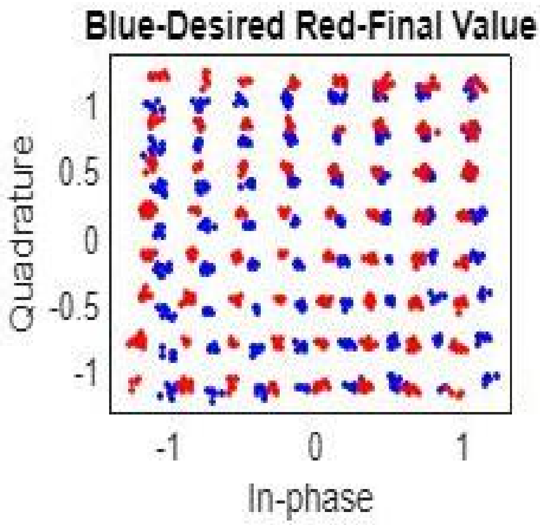


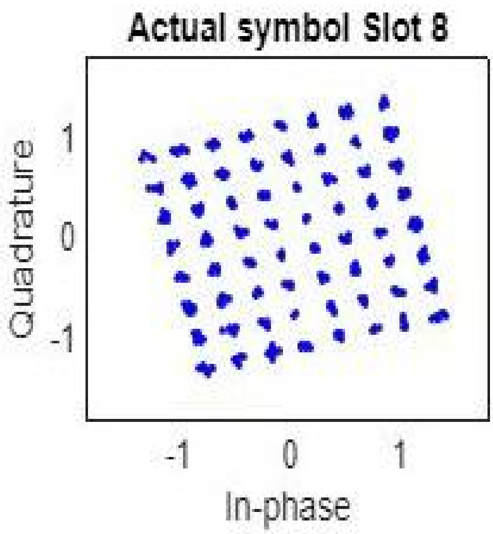

Actual symbol Slot 4
Blue-Desired Red-Final Value
Quadrature
In-phase

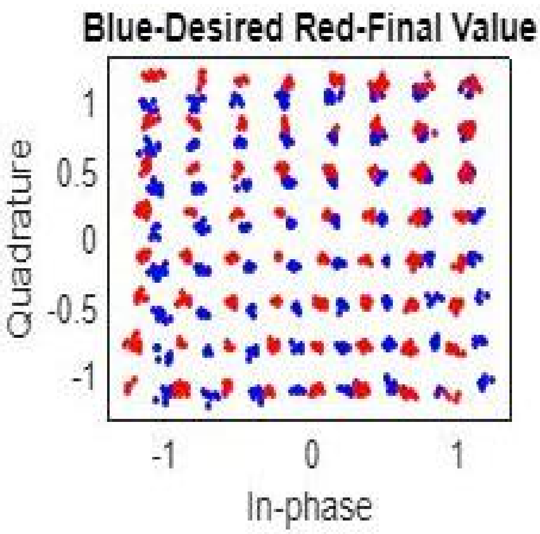

Actual symbol Slot 5
Blue-Desired Red-Final Value
Quadrature
In-phase

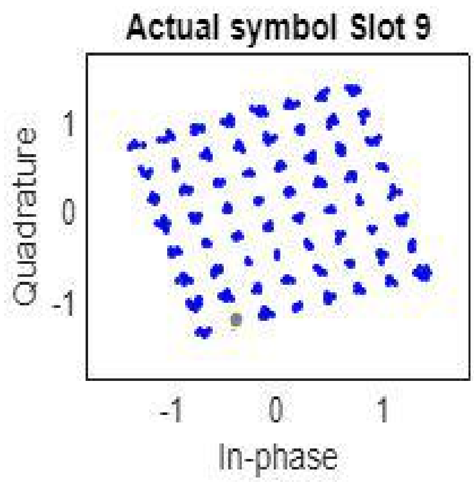

Actual symbol Slot 6
Blue-Desired Red-Final Value
Quadrature
In-phase

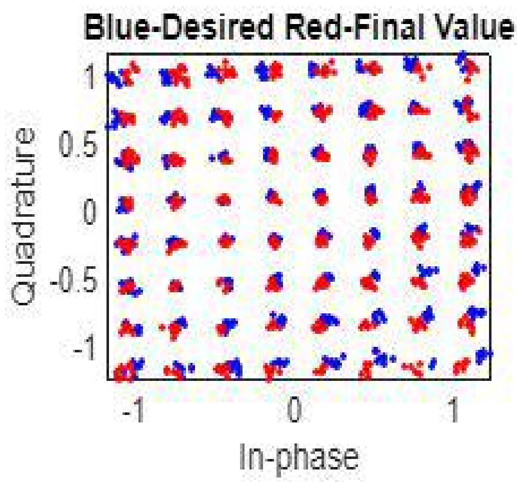

Actual symbol Slot 7
Quadrature
1
0
-1
-1
0
1
In-phase

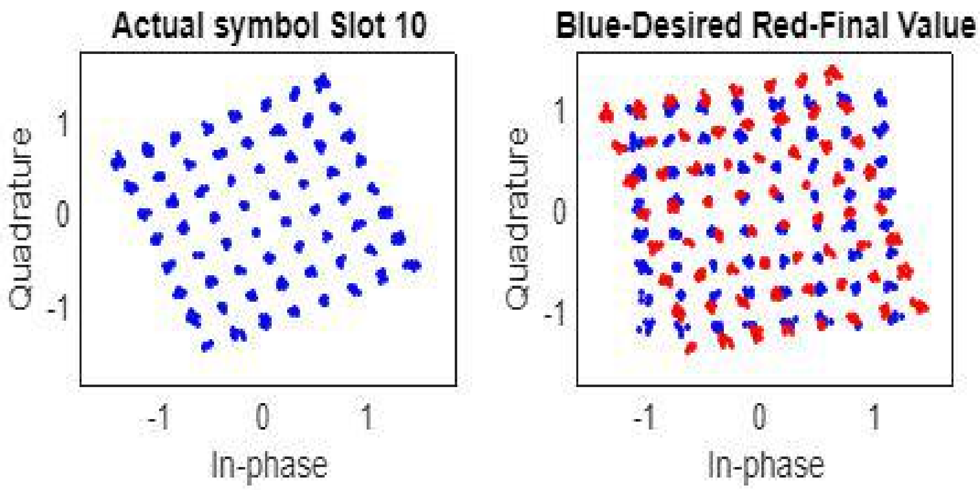

Blue-Desired Red-Final Value
Quadrature
1
0.5
0
-0.5
-1
-1
0
1
In-phase

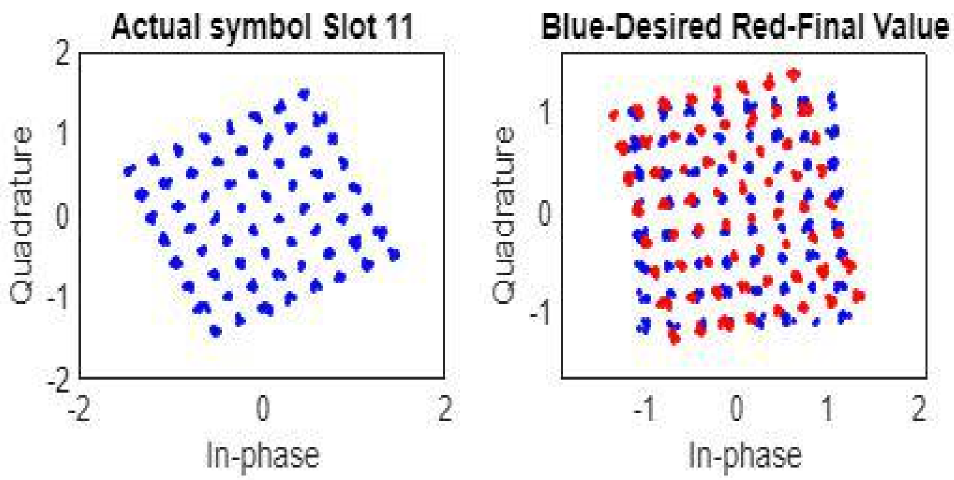

Actual symbol Slot 8
Quadrature
1
0
-1
-1
0
1
In-phase

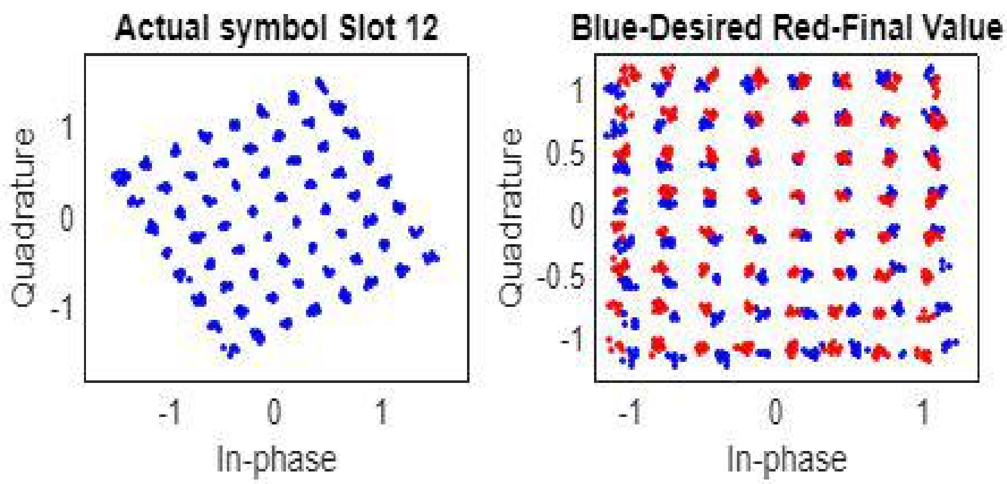

Blue-Desired Red-Final Value
Quadrature
1
0.5
0
-0.5
-1
-1
0
1
In-phase

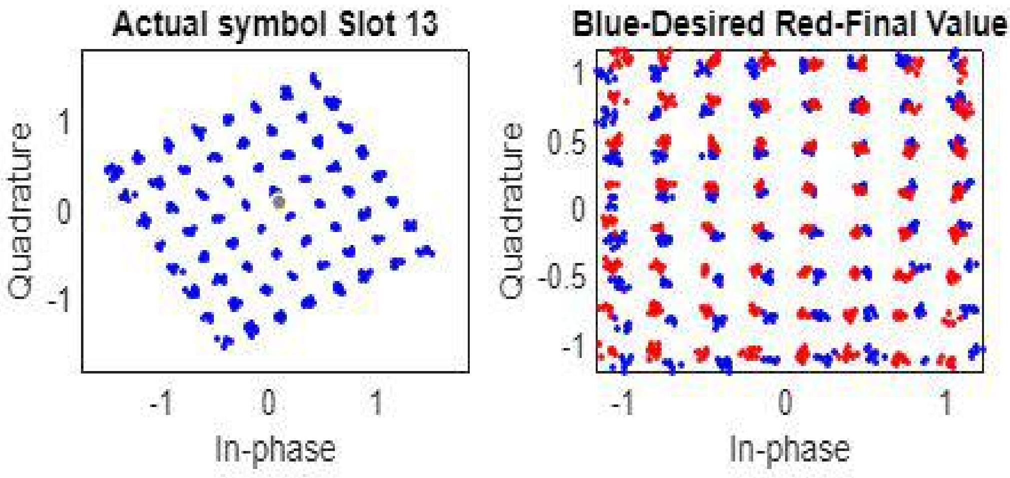

Actual symbol Slot 9
Quadrature
1
0
-1
-1
0
1
In-phase


Blue-Desired Red-Final Value
Quadrature
1
0.5
0
-0.5
-1
-1
0
1
In-phase


Actual symbol Slot 10
Quadrature
In-phase
1
0
-1
-1
0
1
Blue-Desired Red-Final Value
Quadrature
In-phase
1
0
-1
-1
0
1


Actual symbol Slot 11
Quadrature
In-phase
2
1
0
-1
-2
-2
0
2
Blue-Desired Red-Final Value
Quadrature
In-phase
1
0
-1
-1
0
1
2

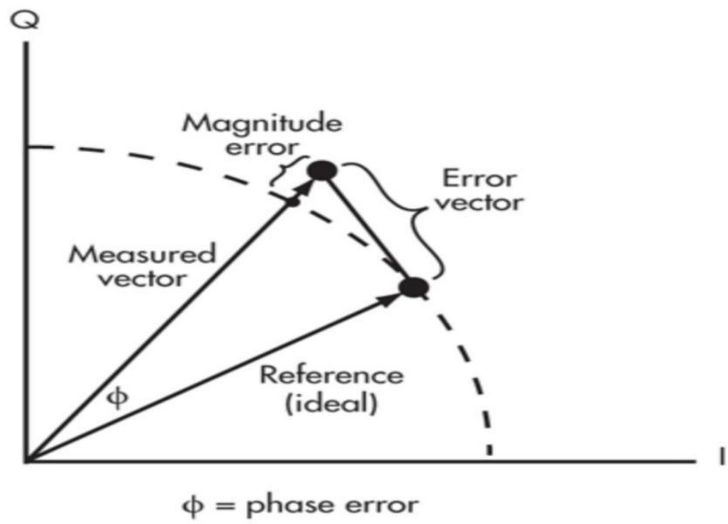

Actual symbol Slot 12
Quadrature
In-phase
1
0
-1
-1
0
1
Blue-Desired Red-Final Value
Quadrature
In-phase
1
0.5
0
-0.5
-1
-1
0
1



4.3 ERROR VECTOR MAGNITUDE (EVM)

EVM is a figure of merit of modulation accuracy. It provides a method to measure and evaluate multi-level and multi-phase modulation methods like M-QAM and M-PSK. EVM considers all of the possible phase and amplitude distortions as well as noise and ensures a single comprehensive measurement figure for determining the quality of signal.

Using phasors in the I/Q plane, EVM is shown below which illustrates the reference or ideal symbol vector location and size compared to the actual measured vector. The difference between the vector is the EVM .



EVM is the ration of the mean of the error vector power (P_{error}) to the mean reference vector power (P_{ref}) expressed in decibels. The means are taken over multiple symbol periods:

EVM (dB) = 10 log (P_{error} /P_{ref})

Higher the negative value of EVM (in dB) better the the quality of signal.

RMS EVM is the square root of the mean of the squares of all the values of the EVM. It is specified as a positive numeric scalar.

Peak EVM is the largest single EVM value calculated across all the input value. It is also specified as a positive numeric scalar.

The below table is of EVM (dB), RMS EVM and Peak EVM of the OFDM signal after compensation for different time symbols that varies from symbol 3 to symbol 13.

Table 3: EVM Evaluation

Symbol No.	Peak EVM	RMS EVM	EVM (dB)
3	0.3088	0.1295	-17.75
4	.0571	.0333	-29.55
5	0.1157	.0722	-22.83
6	0.1979	0.099	-20.03
7	0.2710	0.114	-18.82
8	0.3994	0.2374	-12.49
9	0.1153	0.0588	-24.61
10	0.3994	0.1859	-14.61

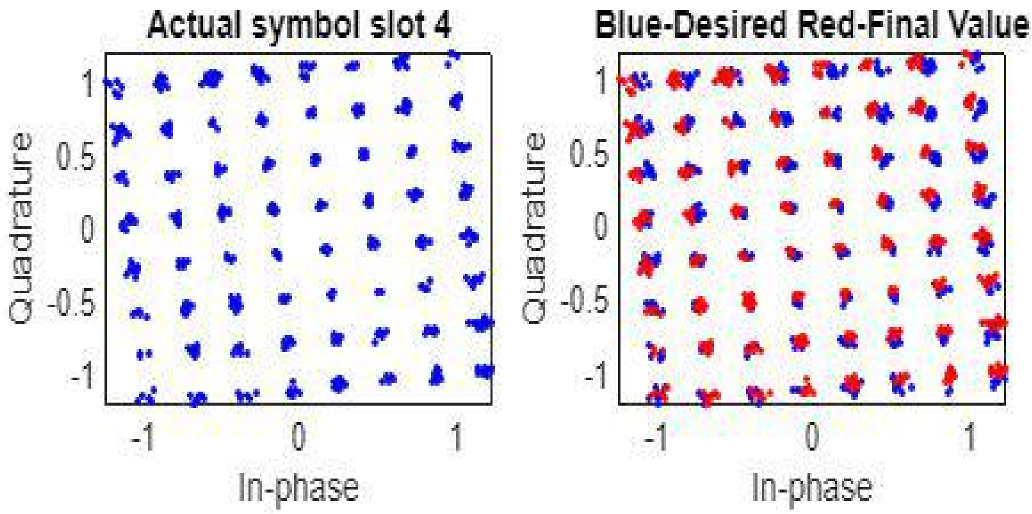
11	**0.4478**	**0.2204**	**-13.14**
12	**0.2142**	**0.0971**	**-20.26**
13	**0.4742**	**0.2152**	**-13.34**

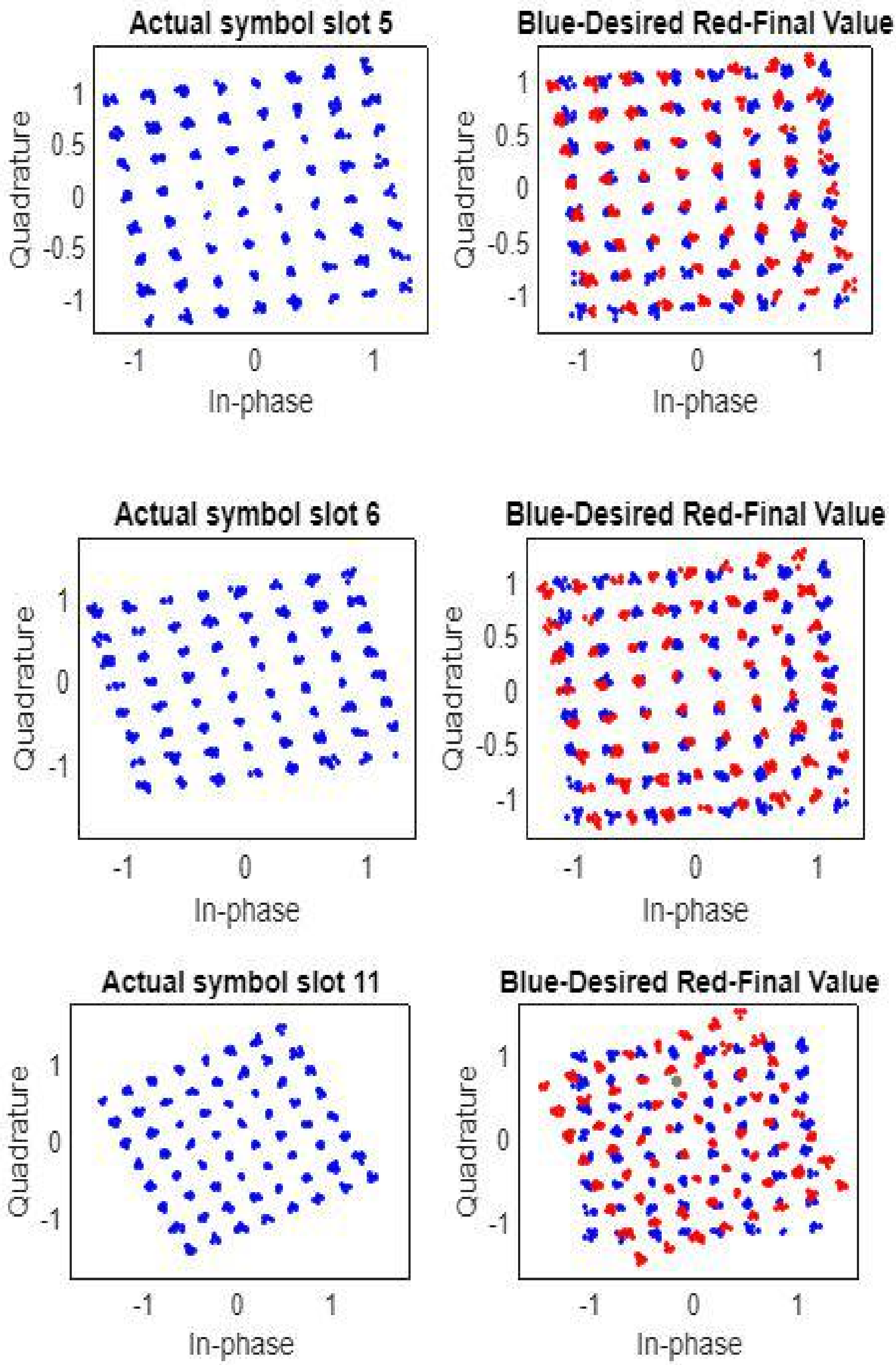
4.4 Equivalent Work and its performance

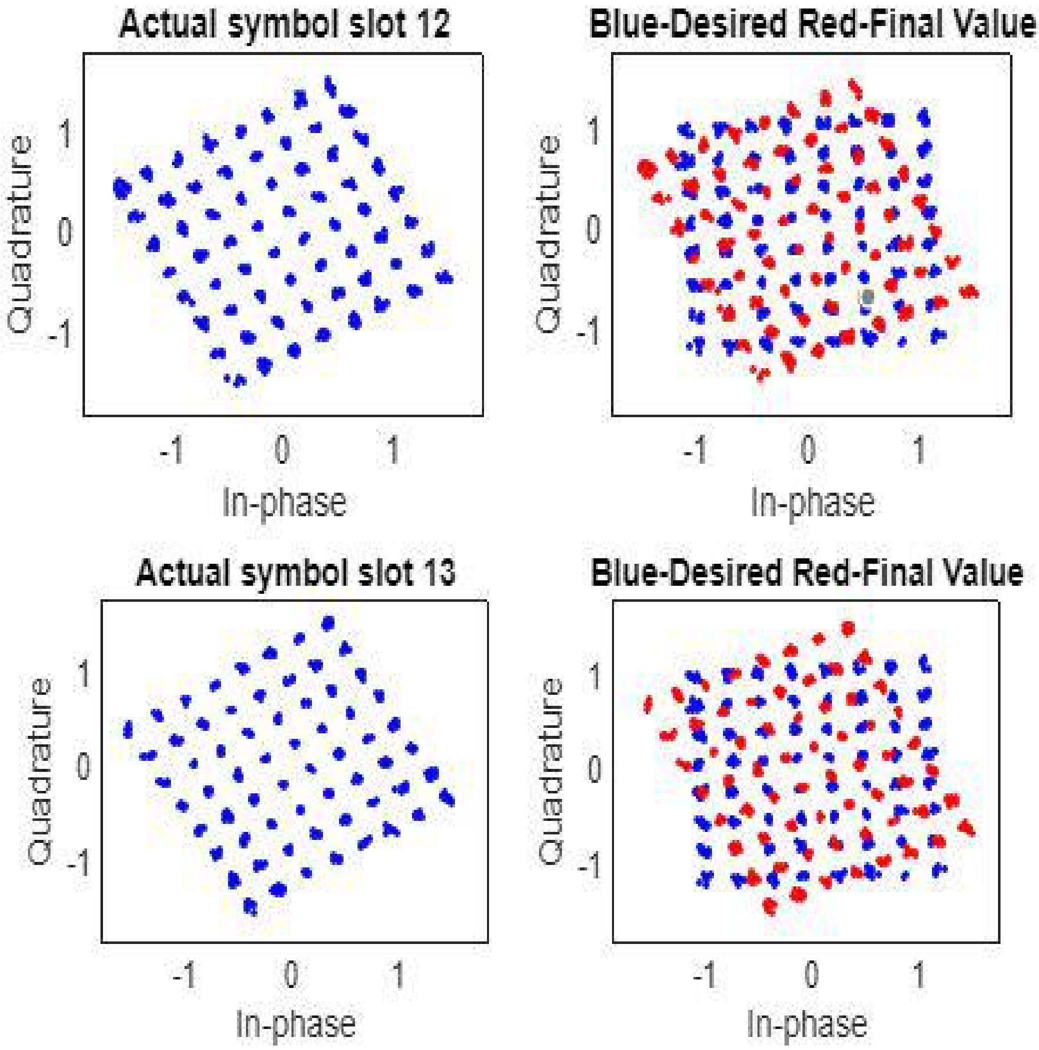
Similar works on direct conversion image rejection receivers for IQ processing have done previously. Two popular works are ‘A Low-complexity Feed-forward I/Q Imbalance Compensation Algorithm (also called Blind estimation and Compensation algorithm)’ and ‘Implementation of Digital IQ Imbalance Compensation in OFDM WLAN Receiver (Pilot based estimation and Compensation)’. We have used both the algorithm in our works and tried to measure performance of each and compared the performance with our algorithm.

4.4.1 Performance of Blind estimation and compensation algorithm

We have applied this algorithm for symbol 4 to 6 and symbol 11 to 13; and plotted the constellation of compensated signals.



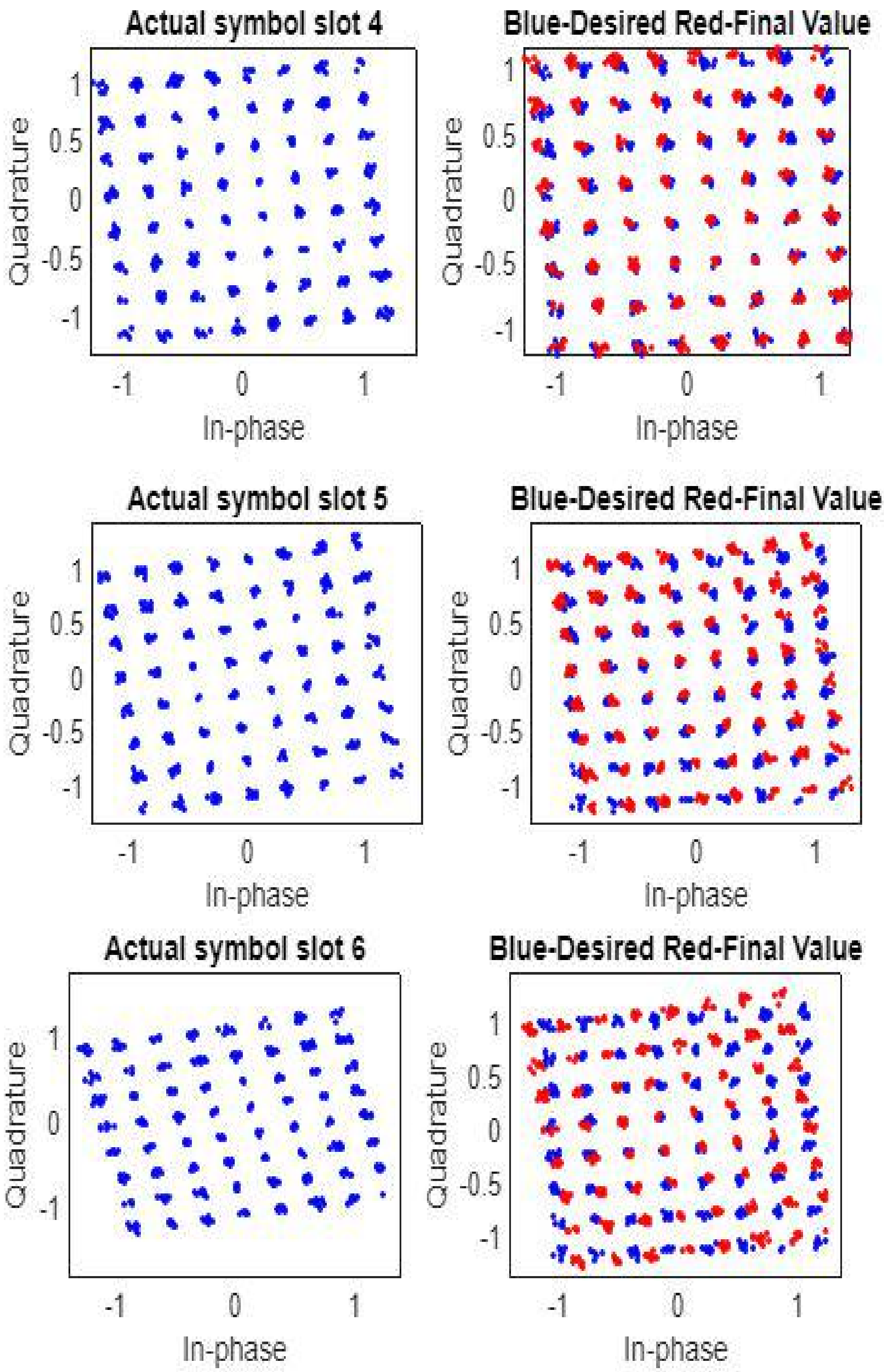

Actual symbol slot 5
Blue-Desired Red-Final Value
Actual symbol slot 6
Blue-Desired Red-Final Value
Actual symbol slot 11
Blue-Desired Red-Final Value
Quadrature
In-phase

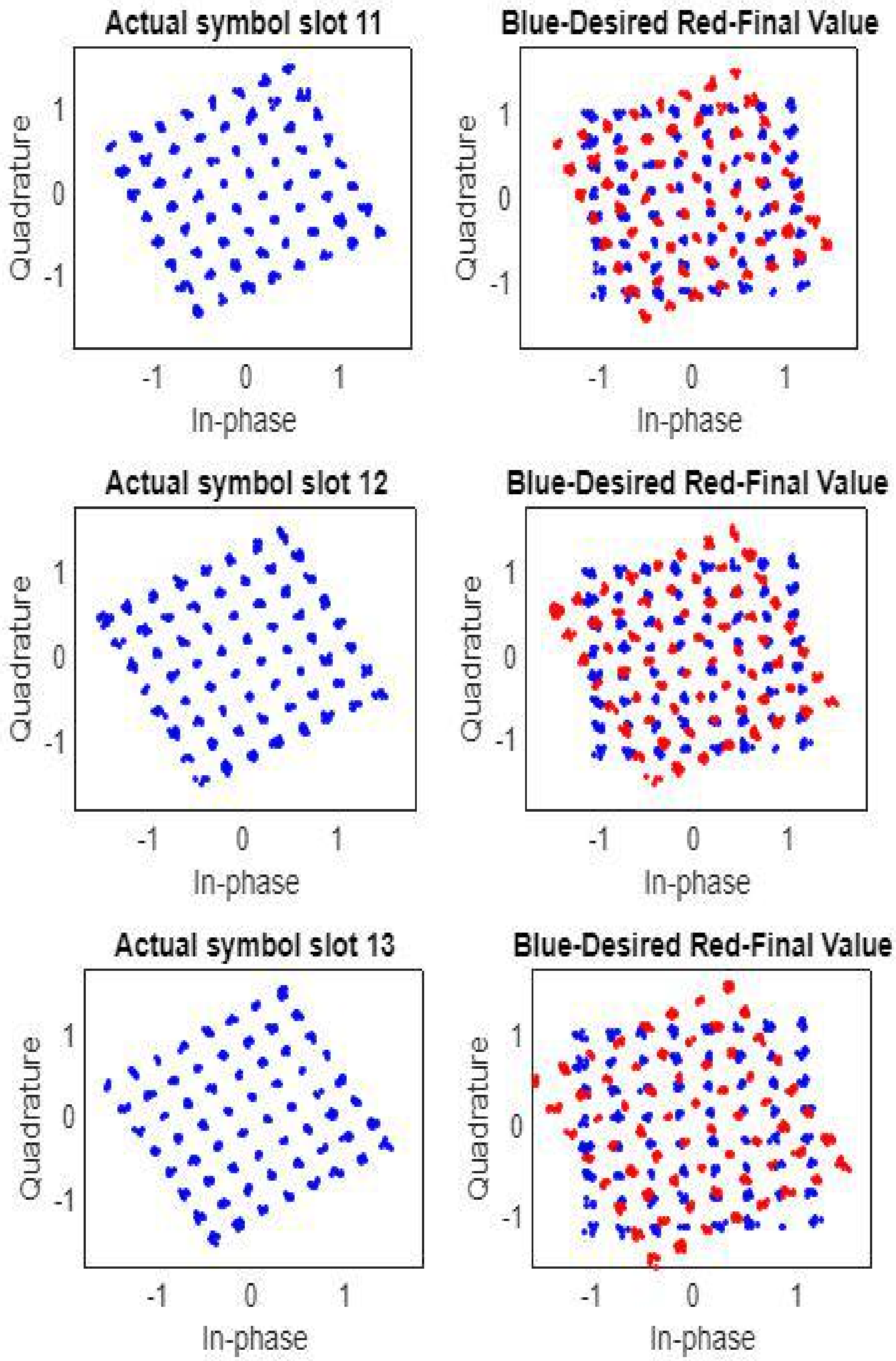


The above algorithm gives better result when distortion is low but it performance degrades as distortion increases. From above constellation we can clearly observe that it is give better compensation for lower distortion as in case of symbol 4 to 6. But for symbol 11 to 13, its performance is very poor.

4.4.2 Performance of Pilot based estimation and compensation algorithm

We have now applied this algorithm for symbol 4 to 6 and symbol 11 to 13; and plotted the constellation of compensated signals.


Actual symbol slot 4
Blue-Desired Red-Final Value
Actual symbol slot 5
Blue-Desired Red-Final Value
Actual symbol slot 6
Blue-Desired Red-Final Value
Quadrature
In-phase


Actual symbol slot 11
Blue-Desired Red-Final Value
Actual symbol slot 12
Blue-Desired Red-Final Value
Actual symbol slot 13
Blue-Desired Red-Final Value
Quadrature
In-phase
1
0
-1

The algorithm is simple to implement but it suitable when distortion of the signal is less. From above constellation we can conclude that it gives better result for symbol 4 to 6 but for symbol 11 to 13 it gives poor compensation.

When we compare both these algorithm then we conclude that our algorithm is complex to implement but it is suitable for lower as well as higher distortion.

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

The entire study which is based on compensation model of 64 QAM OFDM signal. We have designed a model which provide compensation to the distortion of signal because of variation in gain and phase in the channel; and due to non-ideal RF front-end components of receiver which results DC offset and IQ impairment. In our model , we are able to compensate the distortion in constellation of 64 QAM. We have taken the first signal i.e signal of symbol 3 as reference signal and done comparative analysis of all the compensated signal corresponding to different symbols. By our model we get Peak EVM varying from 0.0571 to 0.4742 whereas RMS EVM varies from 0.0333 (-29.55) to 0.2374 (-12.49 dB). Our model is simple and less complex and we can use this for BPSK,QPSK, 16-QAM , 64-QAM and somewhat 128-QAM.

5.2 FUTURE THRUSTS

More complex model can be designed to give more accurate result and less peak and rms evm. In our model we considered the IQ mismatch as amplitude and phase error in only one the branches but one can model the compensator considering the IQ mismatch as amplitude and phase errors in both the I and Q branches to get even better result for higher modulation like 128-QAM and 256-QAM. Even one can consider frequency offset effect to get more accurate result.

CHAPTER 6

REFERENCES

1. 3GPP TS38.101-1 V15.3.0: “NR; User Equipment (UE) radio transmission and reception,” Sep. 2018.

2. T.H. Meng W. Namgoong, Direct-conversion RF receiver design, IEEE Transaction on Communications, 49(3):518–529, March 2001.

3. A. Abidi, Direct-conversion radio transceivers for digital communications,IEEE Journal of Solid-State Circuits, 30:1399–1410, December 1995.

4. B. Razavi, RF microelectronics, ISBN 978-0137134731, Prentice Hall, 2 edition, October 2011.

5. Moseley, Niels A., and Cornelis H. Slump. A low-complexity feed-forward I/Q imbalance compensation algorithm, 17th Annual Workshop on Circuits, 23-24 Nov 2006, Veldhoven, The Netherlands. pp. 158-164. Technology Foundation STW. ISBN 978-90-73461-44-4.

6. K.H Lin et al., Implementation of Digital IQ Imbalance Compensation in OFDM WLAN Receivers, IEEE International Symposium on Circuits and Systems, 2006.

7. Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: High-Speed Physical Layer in the 5 GHz Band, IEEE Standard 802.11a-1999-Part II, Sep.1999.

8. S.B. Weinstein and Paul M. Ebert,Data Transmission by Frequency-Division Multiplexing Using the Discrete Fourier Transform, IEEE Transactions on communication technology, Vol 19, Issue 5, October 1971.

9. A. Peled and A. Ruiz, Frequency domain data transmission using reduced computational complexity algorithms, in Proc. IEEE ICASSP- 80, Vol. 5, pp.964 - 967, April 1980. 3. H. Sari, G. Karam, and I. Jeanclaude, Transmission Techniques

for Digital Terrestrial TV Broadcasting, IEEE Commun. Magazine, Vol. 33, pp. 100-109, Feb. 1995.

10. Scott, A.W., Frobenius, Rex, RF Measurements for Cellular Phones and Wireless Data Systems, Wiley/IEEE, 2008

11. Shafik, R.A., et al., On the Error Vector Magnitude as a Performance Metric and Comparative Analysis, IEEE 2nd International Conference on Emerging Technologies, November 2006

12. S. Rangan, T. S. Rappaport, and E. Erkip, “Millimeter-Wave Cellular Wireless Networks: Potentials and Challenges,” Proceedings of the IEEE, vol. 102, no. 3, pp. 366–385, March 2014.

13. D. L´opez-P´erez, M. Ding, H. Claussen, and A. H. Jafari, “Towards 1 Gbps/UE in Cellular Systems: Understanding Ultra-Dense Small Cell Deployments,” IEEE Communications Surveys and Tutorials, vol. 17, no. 4, pp. 2078–2101, Fourth quarter 2015.

14. N. Makris, C. Zarafetas, P. Basaras, T. Korakis, N. Nikaein, and L. Tassiulas, “Cloud-based Convergence of Heterogeneous RANs in 5G Disaggregated Architectures,” in IEEE International Conference on Communications (ICC). IEEE, 2018

15. A. Ometov, D. Moltchanov, M. Komarov, S. V. Volvenko, and Y. Koucheryavy “Packet Level Performance Assessment of mmWave Backhauling Technology for 3GPP NR Systems,” IEEE Access, vol. 7, pp. 9860–9871, 2019.

16. M. Mezzavilla, M. Zhang, M. Polese, R. Ford, S. Dutta, S. Rangan, and M. Zorzi, “End-to-End Simulation of 5G mmWave Networks,” IEEE Communications Surveys and Tutorials, vol. 20, no. 3, pp. 2237–2263, Third quarter 2018.