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Beamforming router as relay to increase 5G cell coverage

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The authors declare that they are the sole authors of this thesis and that they have not used any sources other than those listed in the bibliography and identified as references. They further declare that they have not submitted this thesis at any other institution to obtain a degree.

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Abstract

The growing traffic and global bandwidth shortage for broadband cellular communication networks has motivated to explore the underutilized millimeter wave frequency spectrum for future communications. Fifth generation (5G) is the key to empowering new services and use cases for people, businesses, and society at large. With unprecedented speed and flexibility, 5G carries more data with greater reliability and responsiveness than ever before. As 5G new radio (NR) begins to take full advantage of the high-band spectrum, i.e, the millimeter wave frequencies, new challenges are created. While millimeter waves offer broader bandwidth and high spatial resolution, the drawback is that the millimeter waves experience higher attenuation due to path loss and are more prone to absorption, interference and weather conditions, therefore limiting cell coverage.

This thesis is an attempt to increase the 5G cell coverage by implementing an analogue beamforming router in a cell. Beamforming router acts like a relay, which extends the range of the 5G cell whenever needed, according to the position of the User Equipment (UE) based on the information received from the gNodeB (gNB, logical 5G radio node). This thesis is investigating the downlink Signal-to-Noise Ratio (SNR) gain and thus possible increase in the data rate. Simulation and validation of the overall performance is done using MATLAB. The outcome of this study may be used to increase the 5G cell coverage if it is implemented in a real network scenario.

Keywords: Beamforming, MIMO, 5G, NR, Direction of Arrival, Relay.

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Acronyms

3GPP	3rd Gnenration Partnership Project
4G	Fourth Generation
5G	Fifth Generation
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BFR	Beamforming Router
CP	Cyclic Prefix
DL	Downlink
DoA	Direction of Arrival
EPA	Extended Pedestrian
EPC	Evolved Packet Core
ETU	Extended Typical Urban
EVA	Extended Vehicular A
FDD	Frequency Division Duplexing
Gbps	Giga bits per second
gNB	gNodeB
Gr	Receiver Gain
Gt	Transmission Gain
GUI	Graphical User Interface Distribution Function
IEEE	Institute of Electrical and Electronics Engineers
IID	Independent and Identically Distributed
ISI	Inter Symbol Interference
KPI	Key Performance Indicator
LMSE	Linear Mean Square Error
LOS	Line of Sight
LTE	Long Term Evolution
MIMO	Multiple Input Multiple Output

MISO	Multiple Input Single Output
MMSE	Minimum Mean Square Error
MUSIC	Multiple Signal Classification
MVDR	Minimum Variance Distortionless Response
NLOS	Non Line of Sight
NR	New Radio
NSA	Non-standalone
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
PDSCH	Physical Downlink Shared Channel
Pr	Received Power
Pt	Transmitted Power
PUSCH	Physical Uplink Shared Channel
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
R-ZF	Regularized Zero Forcing
RF	Radio Frequency
RN	Radio Node
RSRP	Reference Signal Received Power
SA	Standalone
SCFDMA	Single Carrier Frequency Division Multipe Access
SNR	Signal-to-Noise Ratio
TDD	Time Division Duplexing
UE	User Equipment
UL	Uplink
ZF	Zero Forcing

Chapter 1

Introduction

Technology advancement in wireless communications such as fifth generation (5G) networks, offers a plethora of new applications and optimization or expansion solutions for existing applications, where large number of devices need to be interconnected in order to collect and exchange large amounts of data while at the same time offer lower latency, higher connection speeds and extended coverage. The introduction of 5G networks added new spectrum and the increased network flexibility enabled different use cases and devices. The 5G vision is to exploit even higher frequency spectrum in order to improve channel capacity thus offer much higher data rates and spectral efficiency. Current Multiple Input Multiple (MIMO) and beamforming technologies are some of the many technologies creating the foundation of the 5G technology [5] [23]. Using MIMO to exploit the multipath propagation together with beamforming techniques that take advantage of the large number of antenna elements within the gNodeB, we can achieve higher data rates, spatial multiplexing, high accuracy positioning of a user terminal (UE) among others in a 5G network cell.

MIMO basically includes three main categories. Beamforming, which increases the received signal power and cancels interference. Diversity, which is a method of exploiting the multipath propagation to reduce fading and thus increase the wireless link's reliability by reducing the Bit Error Rate (BER), and spatial multiplexing, which increases the data rate proportionally to the number of antennas used. In this thesis, we are going to use the beamforming technique.

In general, the free space loss of a radio wave increases with distance by the inverse square law. This loss is even larger for higher frequency bands. In order to compensate this physical phenomenon, various beamforming techniques are used to improve the overall received Signal-to-Noise (SNR) and mitigate interference in complex multipath environments by focusing the transmit power within a narrow beam thus pointing in a very specific direction [9]. There are various beamforming methods that can be used to transmit the signal towards UE such as analogue beamforming, digital beamforming and hybrid beamforming.

1.1 Motivation

Regarding the motivation for this topic, is the fact that 5G networks are in the forefront of telecommunications technology offering 3 new key features: The enhanced mobile throughput (eMBB), the ultra-reliable and low latency communication for real-time and critical connections (URLLC) and the massive machine type communications (mMTC).

1.2 Aim and Objectives

1.2.1 Research Problem

To meet the increasing growth of mobile traffic, communications industry is moving to 5G mobile communications technology, which uses millimeter wave (mm-wave) frequencies to provide higher data rates and spectral efficiency to mobile devices. 5G promises data rates of up to 100 Gbps and is much faster than the 4G networks. Current LTE technology uses MIMO techniques to achieve higher data rates which created foundation for 5G. Using beamforming, as a special MIMO technique, a signal is directed in a specific direction towards the UE making it possible to increase the transmission rate. While millimeter waves have the advantage to offer broader bandwidth and high spatial resolution, they cannot travel longer distance due to their highly attenuation nature and are easily prone to interference, absorption and weather conditions.

To overcome this limitation, beamforming is the key technology to increase coverage and capacity of a 5G cell.

1.2.2 Aim

In this thesis, we implement an analogue Beamforming Router (BFR) which has similar functionality of the traditional base station. The BFR sends the signal to a user based on the information received from the gNB thus increasing the cell coverage.

1.2.3 Objectives

1. To implement the transmitter (gNB), Analogue Beamforming Router (BFR) and the Receiver (UE).

2. Calculating the Direction of Arrival () of a fixed signal from the UE and develop an algorithm to calculate the angles at the BFR which extends the signal received by the gNB.

3. Simulate and validate the performance of an analog beamforming device, whose main role is to beamform user data in a certain direction based on information received from the gNodeB, using MATLAB.

The frequencies between 6 GHz and 100 GHz are considered as high band in 5G so far [25]. In our simulation we will use the 6 GHz band as default because it is one of the mostly used and investigated band and we think that it will provide us with more literature and feedback.

1.3 Research Questions

The research problem is addressed using the following research questions

- RQ1. Which algorithm is used to find the angle at which beamforming router will beamform to increase cell coverage?
- RQ2. What is the performance of the implemented beamforming router?

1.4 Limitations

This project is investigated with a single user, static beamformer and only with one beam which are considered as limitations. Additionally, the main challenge is the limited documentation and papers for 5G NR cellular technology for high bands since it is quite new and still standards and protocols are being altered by 3GPP and new features are added constantly. Therefore, we will also rely on already existing Long Term Evolution (LTE) technology knowledge.

Additionally, the connection between the gNB and the UE is assumed to be already established with a poor link. It is also assumed that the channel between gNB and UE, and BFR and UE are same.

1.5 Outline

The thesis documentation is organized as follows,

- Chapter 1, presents the introduction, research problem, aim and limitations that are considered in this thesis.
- Chapter 2 explains the methodology followed in this thesis for retrieving the research papers from the IEEE and Google scholar databases and how the selection of the research papers is done for further study.
- Chapter 3 presents the background and key technologies in this research area.
- Chapter 4 presents the related work done in the previous research and explains different concepts and technologies related to LTE and 5G that helps the reader to understand a bit depth on the research.
- Chapter 5 presents the results by answering research questions based on the results obtained after implementing the solution.
- Chapter 6 concludes the research and presents the future work that can be done in this area using advanced technologies or using different algorithms to achieve better coverage for 5G cell using millimeter waves.

Chapter 2

Method

2.1 Methodology

The methodology used in this thesis is the quantitative methodology to answer the research questions with the results obtained by analyzing Key Performance Indicators (KPI's). This paper follows three research methods: 1. Literature Review, 2. Formal Experiment, and 3. Documentation. We will see in detail each of the research methods in the following sections.

2.1.1 Literature Review

We studied scientific papers and reliable related articles that include information about DoA, Multiple Input Single Output (MISO) and beamforming techniques for 5G cells as well as basic procedures regarding the current LTE system and communication channels in LTE/5G cellular networks. Also, we will investigate how the new high-band frequencies may respond to the various techniques we intend to use.

For this purpose, the search string is created which is used to retrieve papers from scientific data bases. The libraries used in this thesis were IEEE, Google Scholar and ACM digital library since they have most of the papers related to the research area. The keywords used for searching were "Direction of Arrival OR DoA" AND "Beamforming techniques" AND "LTE OR Long Term Evolution" AND "5G OR 5th Generation" AND "Relay".

Screening of papers

Screening of papers is used to make sure only the relevant papers are investigated which addresses the research problem to further narrow down the retrieved papers. The criteria used to do screening is the Inclusion and Exclusion criteria from which we will understand if we need to include the paper to the final study or to exclude it. We include the paper to the final study if the paper meets all the points mentioned in the inclusion and exclusion criteria.

Inclusion Criteria

- Papers that address the research problem.
- Papers which are written in English
- Papers published between the years "2000" and "2020".

Exclusion Criteria

- The research papers that are not available as full text are excluded from the study
- Papers that do not address the research problem.
- Duplicate and repeated papers.

Execution of Literature Review
This section shows the total number of papers included for full reading after screening. Table 2.1 shows the number of papers obtained after the initial search process and the total papers considered after applying Inclusion and Exclusion Criteria and after excluding papers by the title and abstracts.

Table 2.1: Search process.

Step	Process	Result
1	Search	190 Papers
2	Inclusion and exclusion Criteria	90 Papers
3	Removed by title	48 Papers
4	Reading abstracts	27 Papers
5	Reading full paper	25 Papers included

The table 2.2 shows the total number of papers resulted and included for full reading from each database.

Table 2.2: Papers screened from each database.

Database	Result	Included
IEEE	50	9
Google Scholar	77	13
ACM	63	3
Total	190	25

2.1.2 Solution - Formal Experiment

This method is where we implement the proposed solution of implementing beamforming router in a 5G cell and to investigate downlink SNR and power in comparison to the traditional transmission using gNB – UE scenario. Once the screening of research papers is completed, we will be able to start investigating existing beamforming algorithms and begin implementing our own algorithm in MATLAB using analog beamformer, which is physically located far away from the gNodeB (gNB in 5G), to calculate the DOA of the incoming signal from the UE. Then, using the 6 GHz band, since this band is more commonly used so far making it easier for us to find more information and assistance on the topic, we will simulate various scenarios with different UE positions to see if we achieve positive results, such as good enough cell coverage, steady traffic with acceptable reliability and data rate. The performance of the BFR is also analyzed by increasing the number of antennas at both the transmitters from 10 to 16.

In this section, the characteristics and implementation of the beamforming router are introduced and analyzed. The focus here is on the physical layer which is the aim of this work.

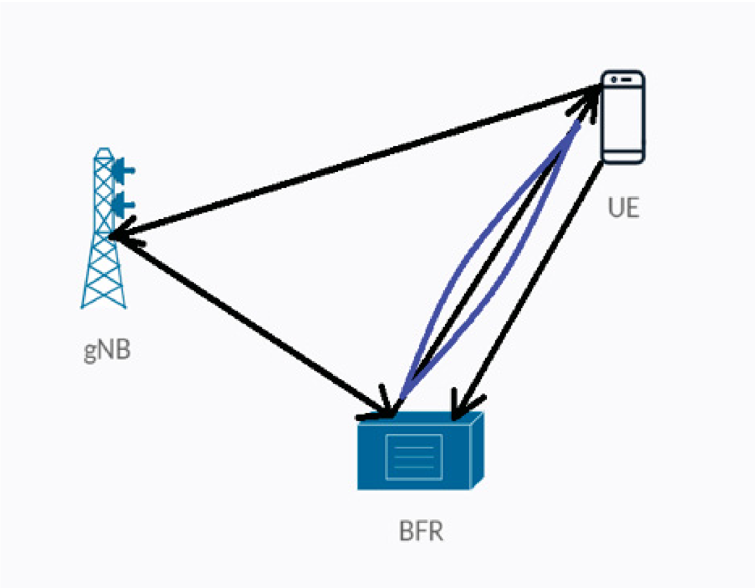


Figure 2.1: Experiment setup.

Figure 2.1 shows the overview of the setup used for this thesis with two transmitters (gNB and BFR) and one receiver (UE). UE broadcasts the reference signal to both gNB and BFR at the same time to calculate the DoA.The curved blue lines in the figure from BFR to UE indicate that we use the concept of beamforming to transmit the signal in the downlink form BFR to UE.

The focus in this thesis is to analyse the performance of the BFR in a 5G cell. The BFR acts as a kind of relay that extends the range of the 5G cell whenever needed according to the position of the UE in relation to the gNB. If, for example, the UE is on the cell's border where the link to the gNB is quite bad for an adequate data transmission, then the gNB will estimate the situation and use the beamforming router as an intermediate step in the Downlink (DL) procedure in order to transmit the data to the UE using analog beamforming.

Based on the calculated DoA of the reference signal from UE, BFR uses the phased array beamforming algorithm to beamform the signal in the direction towards the UE. This selection was used as it is an efficient and well known method to improve the power received from a transmitting beamformer. In this method, the beamforming algorithm produces a number of beam weights, which are used to transmit signal to the user.

2.1.3 Implementation

Simulation and implementation of this thesis is done using the MATLAB app designer tool which offers a Graphical User Interface (GUI) for easier parameter changes and embedded result containing all the plots and settings making relative comparisons and model evaluation more intuitive. Through simulations we evaluated whether we achieved better reception at the UE by using the static BFR in comparison with the direct link between gNB and UE.

a) Designing the simulator

An important step considered to perform simulations is to design and develop MATLAB app designer to carry out simulations. The code or the simulator should support 5G NR specifications along with a suitable channel model, namely spatial consistency or spatial correlation in order to calculate the DoA.

While designing the simulator there are four steps that should be considered as shown in the Figure 2.3. The first step in the process is to identify the blocks that are

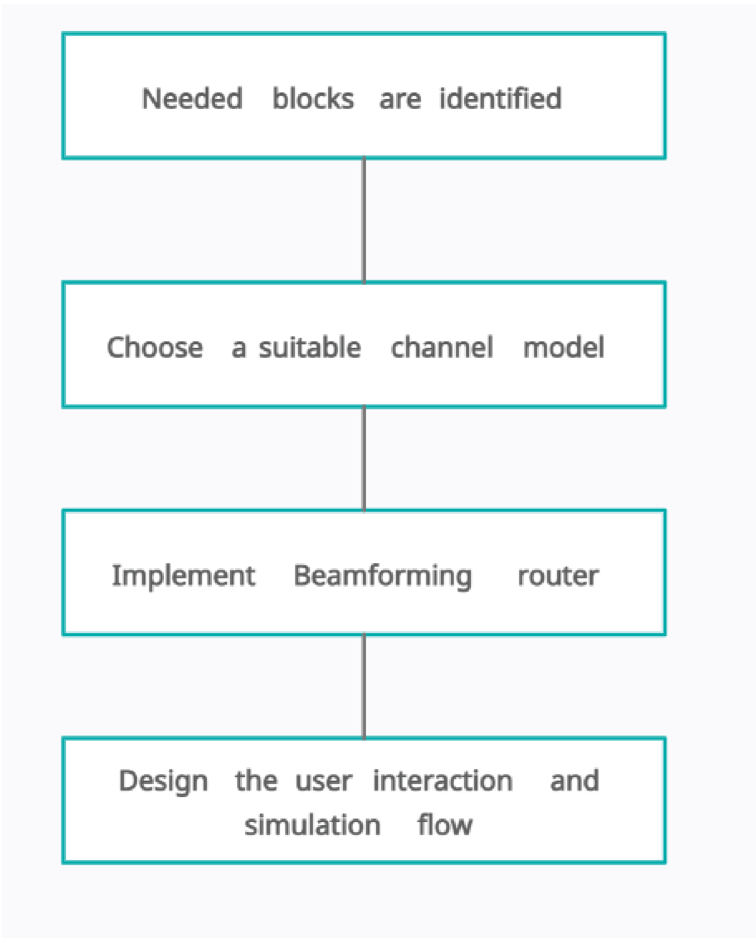


Figure 2.2: Process involved in designing the simulator.

needed to implement a basic transmitter (gNB) and receiver (UE) in a cell. For the downlink from gNB and BFR to UE, uplink from UE to gNB and BFR we considered

Physical Uplink Shared Channel (PUSCH) and Physical Downlink Shared Channel (PDSCH) processing chains as shown in the Figure 3.2 and Figure 3.1.

The second step is to choose an appropriate channel model namely spatial consistency or spatial correlation as they would take into account the layout scenario in order to find the DoA of the signal coming form the UE. Check section for clear understanding regarding channel model.

Once the link between gNB and UE is up and running by giving us good downlink SNR and the powers. The third step in designing the simulator is to implement the beamforming router (relay) in the same layout at a distance of 300 meters from the gNB.

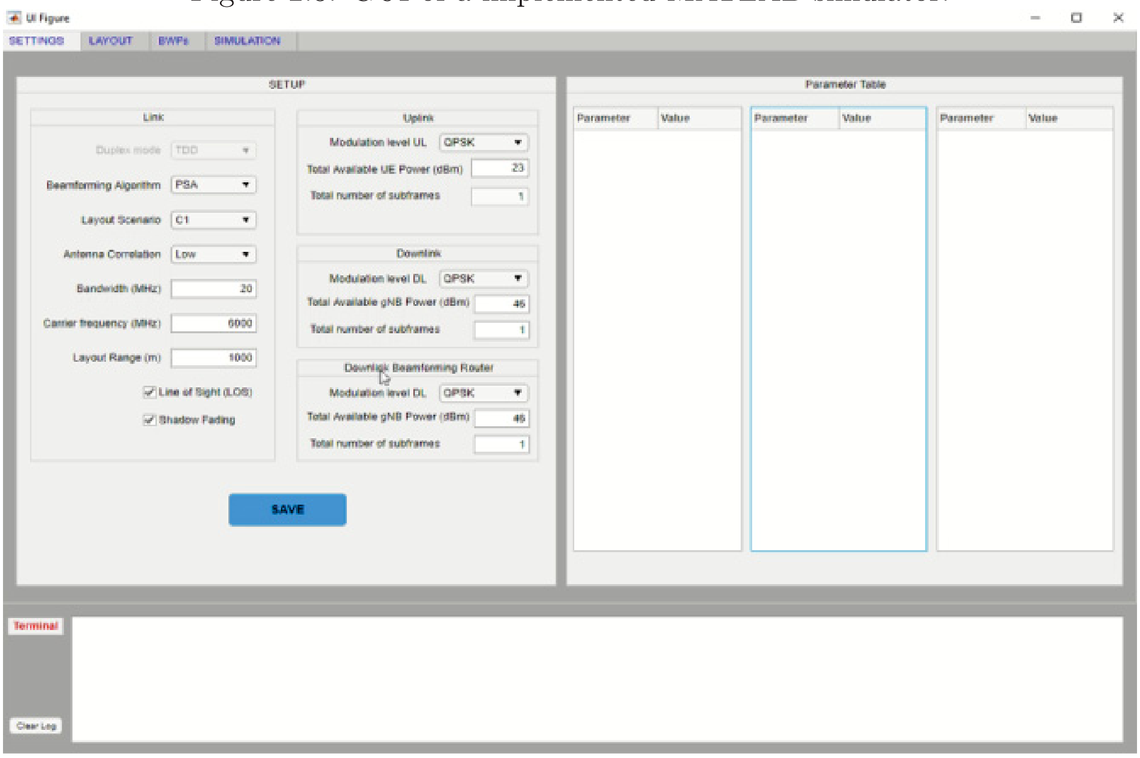
Once the setup for simulating is ready, it is important to know which metrics we are more focused on analyzing. Once we figured that out we can have those results shown up in the terminal at the bottom of GUI.

In this thesis, since we are investigating on the possible increase of the SNR, we see SNR, Reference Signal Received Power (RSRP) and the total received power of the grid along with DoA plots form both gNB and BFR in the terminal after every simulation.

b) Implementing the simulator

After designing the simulator, the next step is to implement it. MATLAB app designer starts by introducing the GUI and has great features which allows us to create easy interactive tabs and model evaluation easy. The Figure 2.3 shows all the four tabs of the GUI,which are: This features help in guiding the user through the

Figure 2.3: GUI of a implemented MATLAB simulator.



entire setup and separating the results which are shown at the bottom in terminal.

- **Settings:** The initial step is to select a setup for simulation.
- **Layout:** The layout tab shows the gNB, BFR and UE positions that are selected. The next step is to generate channels between gNB-UE, gNB-BFR and BFR-UE.
- **Simulation:** Simulation tab is used to simulate for one UE position by selecting the channel as WINNER II. The settings have to be reset to perform multiple simulations with different positions of UE.

The main challenge is to integrate the WINNER II channel model into the simulator. This channel model is developed by MATLAB and can be downloaded from the WINNER II website. More information regarding the WINNER II channel is discussed in detail in Chapter 3.

2.1.4 Documentation

This method is used to document the obtained results from the implemented solution which is discussed in detail in Section 2.1.2.

Chapter 3

Background

3.1 5G Technology

The fifth generation of mobile communications, commonly known as 5G, started being discussed by 3GPP in 2012. However, this evolution is not just another upgrade of the existing LTE technology that just allows higher end-user data rates. Although, LTE could be seen as an essential part of the 5G radio-access solution and a necessary step to accelerate the 5G implementation some new requirements cannot be met with LTE or even LTE advanced. Hence, a new radio access technology needed to be developed by the 3GPP, known as 5G NR.

The initial 5G roll-out where the Evolved Packet Core (EPC) by the existing LTE infrastructure was used as the support for initial access to some use-cases was the Non-Standalone (NSA) network. Here, some 5G-enabled devices could connect to 5G frequencies for data-throughput improvements but will still use LTE for non-data duties such as talking to the cell towers and servers. The second step, in which the NR is now independent from the LTE was the Standalone (SA) mode where along the way new features are added all the time. Often the term 5G is mistakenly used to refer to the new 5G radio access technology. However, 5G is a much more general concept that refers to a wide range of new applications and use-cases [22] [21].

3.1.1 5G Use-Cases

The 3GPP organizes the main use cases into three key categories [24]:

- enhanced Mobile Broadband (eMBB)
- Ultra-Reliable and Low Latency Communications (URLLC) for real-time and critical connections.
- massive Machine Type Communications (mMTC)

' The eMBB will provide larger data rates and bandwidth complemented by moderate latency improvements. This will improve mobile broadband use cases such as emerging Augmented Reality (AR)/ Virtual Reality (VR) applications, Ultra High-Defination (HD) and 360 degree video streaming and much more enhancing user experience. The mMTC will require the full deployment of the 5G Core network in order to provide real end-to-end latency reduction. Mission critical applications that are especially latency-sensitive are found usually on factory floors where a massive number of devices need to be interconnected such as remote sensors, actuators etc. In most of the situations, these devices have low complexity, low battery consumption and use a narrow bandwidth, and very small amounts of data are transferred [19]. Finally, URLLC is used, in many applications where data need to be transferred reliably and with minimal latency. Some examples are autonomous vehicles, AR, remote surgery etc.

3.2 5G Resources

There have been discussions on how the radio frame structure of 5G NR would look like in both 3GPP and academia [21]. The difference between NR numerology and LTE is that LTE numerology has only a single type of subcarrier spacing, i.e., 15 kHz, while 5G supports multiple subcarrier spacing as shown in Table 3.1

Table 3.1: Supported multiple subcarrier spacing [1].

μ	Δf = 2μ . 15 [kHz]	Cyclic prefix
0	0	Normal
1	30	Normal
2	60	Normal, Extended
3	120	Normal
4	240	Normal

3.2.1 Physical Channels

There are two physical channels to transmit the UE data, namely PUSCH for uplink data transmission and PDSCH for downlink data transmission [16]. Data transmission from UE to gNB is called uplink transmission and the data transmission from gNB to UE is called downlink transmission. In 5G NR, not every numerology supports every physical channel and signals although majority of them supports. This can be explained using the table 3.2

Table 3.2: Supported transmission numerology for data and synchronization [1].

Numerology	Subcarrier Spacing (kHz)	CP type	Supported for Data (PDSCH, PUSCH etc)	Supported for Sync (PSS,SSS,PBCH)	PRACH
N/A	1.25		No	No	Long Preamble
N/A	5		No	No	Long Preamble
0	15	Normal	Yes	Yes	Short Preamble
1	30	Normal	Yes	Yes	Short Preamble
2	60	Normal,Extended	Yes	No	Short Preamble
3	120	Normal	Yes	Yes	Short Preamble
4	240	Normal	No	Yes	

3.2.2 TDD DL/UL Configuration

Uplink (UL) and DL transmissions are carried using two techniques: 1. tdd which uses one frequency band for UL and DL. 2. FDD which has two separate frequency bands for UL and DL transmission.

In this thesis, we use TDD as a duplex technique instead of FDD, as the number of users simulated is one, which also gives the advantage of using channel reciprocity [8] meaning that the UL and DL channels are highly correlated almost constant, since the same frequency is used which makes things easier for the channel estimation and beamforming [23].

Resource block for uplink and downlink is show in the table 3.3 which is different from LTE resource block

Table 3.3: Minimum and maximum number of resource blocks [1].

μ	Min RB, DL	Max RB, DL	Min RB, UL	Max RB, UL
0	24	275	24	275
1	24	275	24	275
2	24	275	24	275
3	24	275	24	275
4	24	138	24	138

Downlink portion converted into frequency bandwidth to have the idea of maximum RF bandwidth that UE / gNB supports for a single carrier (see Table 3.4.

Table 3.4: Maximum RF bandwidth supported for a single carrier [1].

u	min RB	Max RB	sub carrier spacing (kHz)	Freq BW min (MHz)	Freq BW max (MHz)
0	24	275	15	4.32	49.5
1	24	275	30	8.64	99
2	24	275	60	17.28	198
3	24	275	120	34.56	396
4	24	138	240	69.12	397.44

3.2.3 Transmission of User Data

User data is transferred using two channels PUSCH and PDSCH for UL and DL transmissions [10]. Resource elements in the channels are allocated for data symbols. Data arrives in the form of bits at the transmitter called as codeword, few steps are done before transmitting the codeword from antennas which includes symbol modulation, layer mapping, precoding, resource mapping and OFDMA or SCFDMA modulation [21]. The simple transmitter chain is shown in Figure 3.1 Symbol modu-

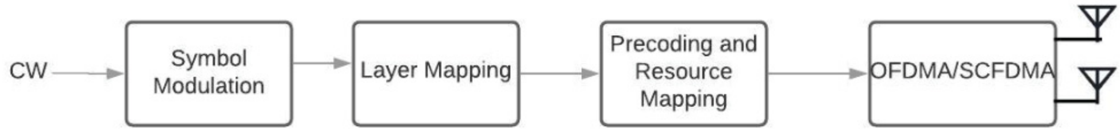


Figure 3.1: Transmitter Chain [1].

lation can be done in different types of schemes such as Quadrature Phase Shift Keying (QPSK), Quadrature Amplitude Modulation (16QAM), 64QAM, and 256QAM. Higher symbol modulation means higher data rate but also higher probability of error if the channel conditions are poor. Therefore, modulation scheme should always adapt to channel condition to achieve reliable and balanced transmission.

In this thesis, we do not need to have a layer mapping since the available resources are assigned to a single user. We have one codeword and one layer overall.

The next step after layer mapping is precoding. In case of digital beamforming, we would have the precoding stage, where we assign some weights to the symbols and map them to the specific antenna to create the resource grid. Since we use analogue beamforming in this thesis due to the reasons mentioned above, this step is done in the Radio Frequency (RF) domain.

The final step before mapping the layer to physical antennas is to create a waveform using Orthogonal Frequency Division Multiplexing (OFDM) which also includes insertion of Cyclic Prefix (CP) to decrease the impact of Inter Symbol Intereference (ISI) due to the multipath effect of the channel and then to apply beamforming weights [17].

3.2.4 Reception of User Data

The steps involved in the reception of user data are inverse to the ones present in the transmitter chain, which are Orthogonal Frequency Division Multiple Access (OFDMA) demodulation and Single Carrier Frequency Division Multiple Access (SCFDMA) demodulation, layer de-mapping and symbol demodulation also including channel estimation and channel equalization which are the important steps in the wireless transmission. The steps involved at the receiver are shown in 3.2.

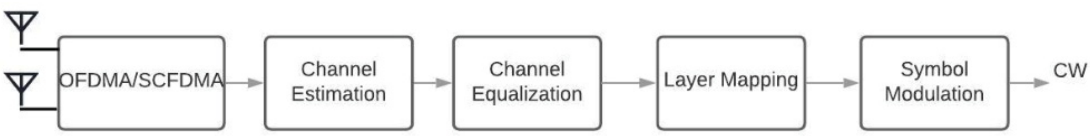


Figure 3.2: Reception Chain [1].

We need channel estimation because signals lose their features while transmitting over a wireless channel due to various reasons like interference, path loss, fading and noise due to which the signal changes its amplitude and phase at the receiver. To mitigate this, we use the reference symbols placed at specific places, depending on the transmission mode, in the resource grid during the transmission [17].

Then, we perform channel equalization which is basically removing the channel effect to restore the distorted data symbols [17]. To achieve this there are many techniques from which the most commonly used are the Linear Mean Square Error (LMSE), Zero Forcing (ZF) and Regularized Zero Forcing (R-ZF). Minimum Mean Square Error (MMSE) is the more balanced of all. ZF is mitigating the interference but does not consider the noise factor.

3.3 Wireless Channel

The wireless channel fading between the gNB and the UE typically follows a Rayleigh probability distribution if we have a Non Line of Sight (NLOS) scenario and a Rician probability distribution if there is a direct line-of-sight scenario. Generally, we can never be sure if there is a LOS between the gNB and the UE and how strong is that component. Therefore, we usually consider the channel complex valued coefficients to have a Rayleigh probability distribution.

The wireless channel, in general, has a negative effect on the transmitted signal. It consists of the four main phenomena: Free-space path loss, large-scale fading , small-scale fading.

If the UE is moving, then we have a time-variant channel experiencing fast fading due to constructive and destructive interference and Doppler shifts depending on the UE's moving speed. This phenomenon is characterized by the channel's Doppler spectrum. In reality, the channel is never static because other objects between the gNB and the UE are usually moving causing similar problems due to the change of amplitude of the total sum of the signals. This effect becomes even more intense when we have mm Wave frequencies. To simplify the model, we are assuming that the movement is so slow that the channel remains static within the coherence time.

For simulating the different scenarios according to the tap delays and power losses we are going to use three typically use case scenarios, the Extended pedestrain (EPA), the Extended vehicular (EVA) and the Extended typical Urban (ETU).

From each antenna on the gNB there is a channel towards the UE with a different delay and attenuation. These are the parameters of the channel filter and are assumed to be uncorrelated between the different gNB antennas.

Except fast fading, we also come across the slow fading, i.e,large scale or shadow fading phenomenon, which happens due to obstruction from large obstacles like buildings, mountains etc. This type of fading follows a log-normal distribution [25].

Additionally, we have the free space pathloss which depends on the distance between the gNB-UE, BFR-UE, and the carrier frequency used for the transmission. In order to calculate the total power that is received, we use the link budget calculation that includes the antenna gains Gt, Gr. It is stated that the high path loss for mm Waves is given by the following equation:

$$Pr = Pt + Gt + Gr + 20log(c/4\pi Rf)[dBm] \tag{3.1}$$

where Pt is the total transmitted power, Pr is the total receiver power, Gt is the transmit antenna gain and Gr is the receive antenna gain, R is the distance between the transmitter and the receiver in meters, f is the carrier frequency and c is the speed of light. The received power can easily be seen as inversely proportional to the frequency squared when an ideal isotropic radiator (Gt = 1) and an ideal isotropic receiver (Gr = 1) are used at each end.

Finally, to all that we are adding the noise which for simulations is typically modeled as an Additive White Guassian Noise (AWGN) or thermal noise with a specific mean and variance.

Selection of channel model is the important step in implementing and designing the simulator. The channel model selected in this thesis is the WINNER II. This channel can be used in wireless communications for various comparisons in terms of algorithms and technologies [2].The motivation to choose the WINNER II channel model is because the channel supports multi hop networks and has the characteristic of spatial consistency or spatial correlation which is needed to estimate the DoA of the signal from the UE. The channel can be applied to both LOS and NLOS conditions and various propagation scenarios. The simulations performed in this thesis were done under suburban metropol scenario. The channel modelled between gNB-UE, and BFR-UE is the WINNER II. [2].

3.4 MIMO

Massive MIMO (mMIMO) and beamforming are widely used buzzwords when referring to 5G and latest advancements of LTE. MIMO comes in different ways and some of them have already been used in LTE networks. MIMO refers to the usage of large number of antennas at the transmitter and receiver to increase the performance of the system by increasing the gain of transmitted signals [23].

Although MIMO has benefits of achieving higher data rates which helps in increasing downlink and uplink throughput and reduction in Bit Error Rate (BER), it adds complexity to the system in terms of number of antennas required and processing.

MIMO basically includes three main categories. Beamforming, which increases the received signal power and cancels interference [23]. Diversity, which is a method of exploiting the multipath propagation to reduce fading and thus increase the wireless link's reliability by reducing the BER, and spatial multiplexing, which increases the data rate proportionally to the number of antennas used. In this thesis, we used the beamforming technique.

3.5 Direction of Arrival Estimation

Direction of arrival (DoA) is an important step in this thesis to estimate and calculate the angle of a fixed signal received from the UE and to know the position of the UE, so that we could beamform in the specific direction from gNB and beamforming router [6].

There are various algorithms which are used to estimate the DoA of a signal.

Algorithms such as Multiple Signal Classification (MUSIC), Root MUSIC and Estimation of Signal Parameters via Rotational Invariance Techniques (ESPIRIT) could be used at the beamforming router to determine the DoA of a signal and thus find the user location [6]. MUSIC is a spectral estimation technique which can be applied to linear and nonlinear array of antennas. MUSIC estimates DoA of multiple signals and works on the principle of eigen decomposition. The algorithm is implemented as shown in Figure 3.3

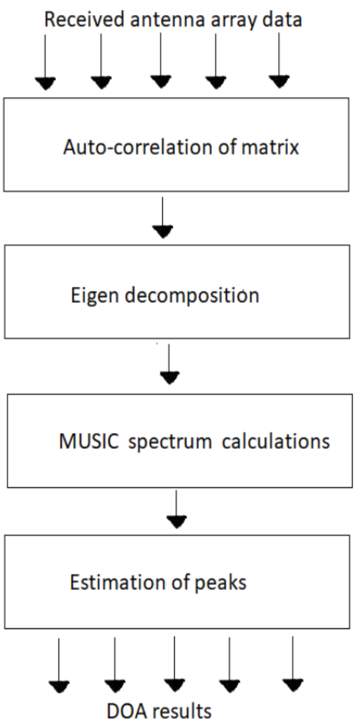


Figure 3.3: Steps involved in the MUSIC algorithm [18].

3.6 Beamforming Algorithm

Beamforming is the technique used to direct the signal to a particular user by cancelling the interference of signals in other directions. There are various beamforming techniques that can be applied both at transmitter and receiver. Beamforming techniques can be broadly divided into two categories: Conventional beamformers and adaptive or phased array beamformers [11]. Beamforming is used for faster, stronger and more reliable wireless communication. It has many applications in fields like medicine, wireless communications, radar, sensors etc.

The transmitted signal is received by the user in one of the three beamforming types: they are 1. Analog beamforming, 2. Digital beamforming, and 3. Hybrid Beamforming. Analog beamforming is the way of sending the single data stream signal with different phases from multiple antennas using phase shifters. Digital beamforming sends different data stream signals from multiple antennas. Hybrid beamforming is the combination of analog and digital beamforming.

As we are using high band frequencies in this thesis and investigating with the single user in a 5G cell, the method used in this thesis is analogue beamforming.

By knowing the channel information between the UE and gNB, UE and BFR we can find the beam weight of each element of antenna array and phase shift the same incident signal at the antenna array in order to transmit the signal and steer the beam towards the user. The more the number of antennas in the array, the narrower the beam can become, thus focusing the power into a smaller area. The parameter that affects the beamforming weights is the channel coherence time (Tc) which is the time duration which the channel is not varying. The idea in this thesis is to increase the signal's SNR, so that we can modulate the signal with a higher modulation scheme order thus achieving higher throughput at the UE using beamforming. In order to achieve this, we need to know the channel between the gNB and the UE and use that information to form the beam weights. Generally, the model in our case looks like this: where y is the received signal at the UE, h is the complex Gaussian channel vector, w is the beam weight vector, x is the data signal and n is Independent and Identically Distributed IID Gaussian noise vector. To form the beam, we can use many beamforming techniques with the most popular being maximum ratio transmission, Zero Forcing, R-ZF and phased array beamforming.

3.6.1 Phased Array Beamforming

In wireless communication, there are different types of antennas used to transmit the signals large number of antennas grouped together is called as antenna array.The number of antennas that can be used is large. In an antenna array, each antenna

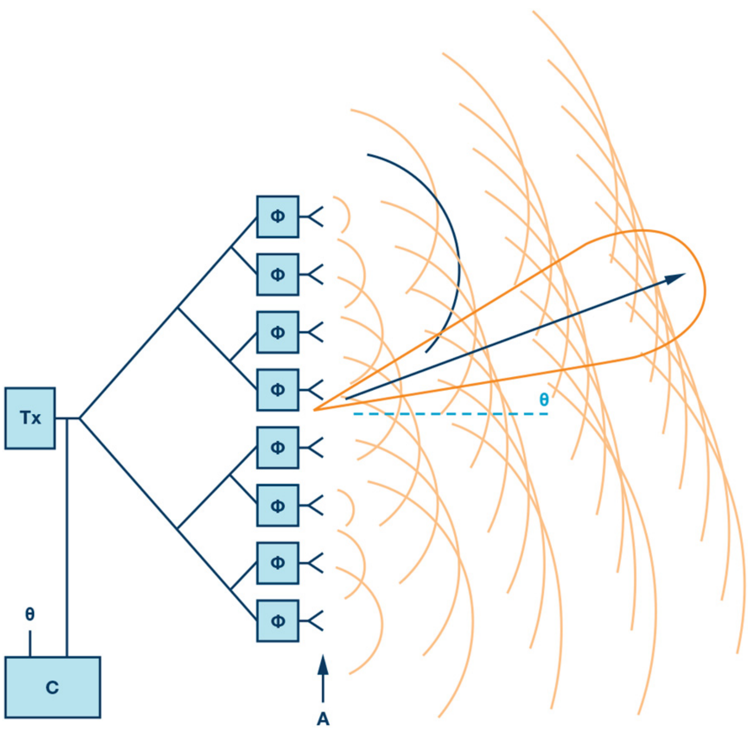


Figure 3.4: Phased array beamforming [3].

element is arranged in a specific manner so that all the antenna elements sum up to transmit the signal for a better performance of the system when compared with the a single antenna. The advantage of using the phased array is that the signal can be steered in a desired direction without physically moving the antennas.

In this thesis, we are using phased array beamforming to transmit the signals to the UE. Signal with same frequency is transmitted from all the antenna elements but with different phases using phase shifters. Determining the phase shift of a signal in order to beamform in the desired direction towards the UE involves large mathematical calculation which is done using MATLAB. Phased array is best to use for high frequency applications as the antenna size is inversely proportional to the operating frequency. This makes phased array antennas a best choice for 5G applications [3].

The type of beamforming used in this thesis is analogue beamforming where the antenna array used is the phased array. Analogue beamforming is similar to phased array where it has the single RF path for the antenna array to transmit the signal of same frequency.

Chapter 4

Related Work

This section describes the related work done in the field of LTE two hop relay systems which helps in increasing the coverage (cell radius) and beamforming techniques to improve cell throughput.There are several works being researched in the field of 5G and possible increase in the cell coverage using mm wave frequencies.Some of these research works are listed below.

[13] has discussed the importance of deploying Radio Node (RNs) in the cell to increase coverage and the cell capacity. The authors investigated to find the optimal position to place the RN in LTE-A network as the placement of the RN affects the SNR of the received signal at the UE. They have addressed the placement of RN for both DL and UL transmission scenarios.

[20] has discussed the use of implementing the relays in the cellular networks especially to have strong signal strength for the cell edge users which in turn increasing the cell coverage. The authors have also given an overview of a relay techniques and the protocols that are used when relays are deployed in the cellular network. The authors use amplify-and-forward relay protocol for two hop relay system as it is the simplest protocol which amplifies the received signal from base station to the UE with the relay as an intermediate node without encoding and decoding process. The paper investigated the performance with two scenarios, first is with fixed eNB and RN as UE moves, second is with fixed eNB and UE, as RN moves.

The paper [12] aims at analysing the performance of various DoA estimation algorithms. The authors have also discussed the importance of calculating the accurate DoA of the signal. The authors have presented that the DoA algorithms are classified into two groups namely conventional or classical algorithms and subspace-based algorithms. Conventional algorithms scan the beam by measuring the maximum power which is considered as the DoA of the signal. Examples of conventional or classical algorithms are beam scan and Minimum Variance Distortionless Response (MVDR) algorithms. Subspace based algorithms estimates the angle either from signal subspace and noise subspace by eigen decomposition of covarience matrix. Examples of subspace based algorithms discussed in this paper are MUSIC and minimum norm algorithm. The paper proposes that the MUSIC algorithm is the promising solution to estimate DoA for 5G networks.

[7] discusses the advantage of moving from microwave to mm wave frequencies. One such advantage discussed is to use beamforming which directs the signal from large number of antennas to the receiver to increase coverage and capacity of the 5G cell. The paper discusses various beamforming techniques such as analog, digital and hybrid can improve cell throughput. This paper also introduces two important

features of mm Wave networks which are blockages and beamforming. The authors have discussed the hybrid beamforming which require the processing between the analog and digital domains.

[4] discussed and analysed existing relaying techniques in LTE. The performance of the network understood by transmission efficiency, system throughput using the WINNER II channel model. The overall network is analyzed by calculating the received powers from direct link and relayed link.

In [14], the authors discussed and analyzed the performance of two hop relaying in LTE. The downlink and uplink transmission used OFDMA and SCFDMA. peak to average power ratio (PAPR) is used for relaying which uses the advantages of both OFDMA and SCFDMA. The performance of the network is analyzed using Symbol Error Rate (SER) and gain which shows that the two hop link which uses the relay performs better than the a single hop. The obtained results are analyzed under the AWGN channel model.

The paper [15] proposed the link balancing scheme based on MIMO switching based on two hop MIMO relays. The authors presented different types of relays and there categorization. They have also discussed about the two main protocols AF and Decode-and-forward (DF) used by relays to transmit information.The concluded that the MU-MIMO mode is more feasible to RN-UE link to be compared to the eNB-RN

In this work, BFR (Relay) is implemented in the 5G cell which uses the AF protocol to transmit the signal to the UE using analogue beamforming.

Chapter 5

Discussion and Analysis

This chapter discusses and emphasizes on the results obtained from MATLAB simulations for different scenarios after implementing the beamforming router. The solution to the research problem is discussed in order to achieve the aim.

5.1 Research Questions and Answers

In this section, we will answer the research questions using the knowledge obtained form literature review and MATLAB simulations. We will discuss the research questions and the answers to it below.

RQ1: Which algorithm is used to find the angle at which beamforming router will beamform to increase cell coverage?

This research questions explains the significance of calculating direction of arrival of a signal and the algorithm that is used to calculate DoA in this thesis.

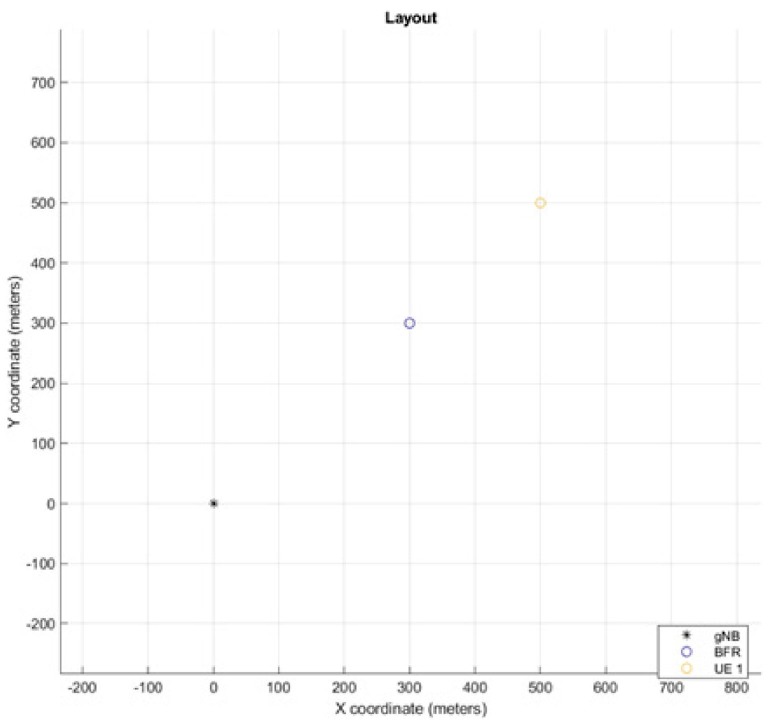


Figure 5.1: Initial layout of the system along with the DoA estimations.

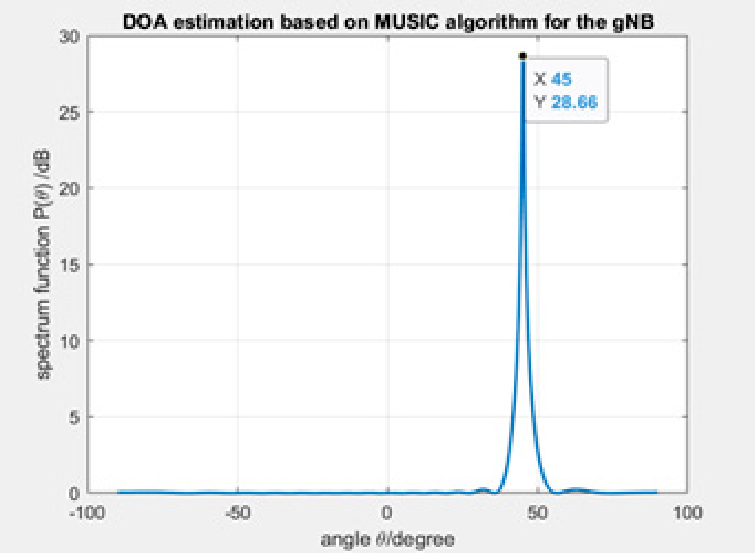


Figure 5.2: DoA estimation at gNB.

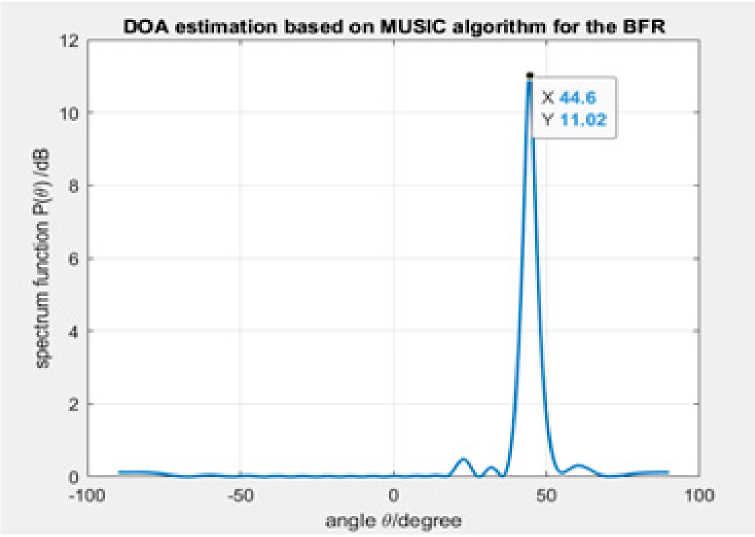


Figure 5.3: DoA estimation at BFR.

One of the important objectives in this thesis is to exactly estimate the direction of arrival. UE broadcasts the signal both to gNB and BFR at the same time and to estimate the angle of a received signal at the gNB and BFR coming from the UE, channel estimation is first performed so that the received signal from the UE is equalized. After equalization, subframe and the symbols are extracted from it. With these extracted symbols, a new subframe is created and then the channel effect is applied again (as it contains the information related to DoA of a signal) for the new subframes to receive the information of the angle of arrival. Then the subframe grid is OFDM-modulated to obtain time domain signal of a user. Later MUSIC algorithm is called to obtain the power profile of a user, where the algorithm undergoes few steps as shown in the flow diagram of MUSIC algorithm, Figure 3.3 and estimates the angle in degrees.

In order to validate the music algorithm, we theoretically calculated the bearing angle between the UE and gNB, UE and BFR in degrees using a MATLAB function ' atand ' and compared it with the estimated angle from the MUSIC algorithm.

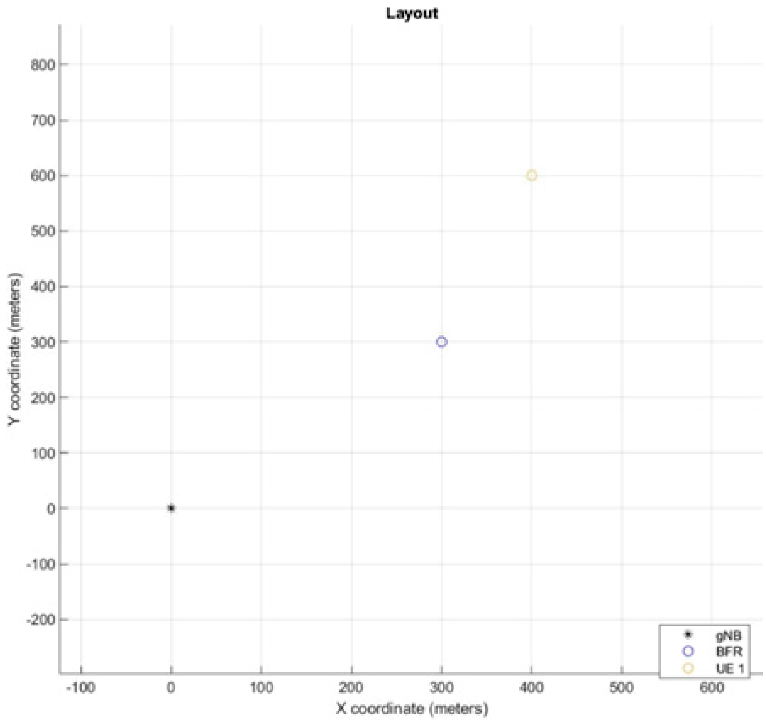


Figure 5.4: Layout which makes different angles with gNB and BFR with respective to UE.

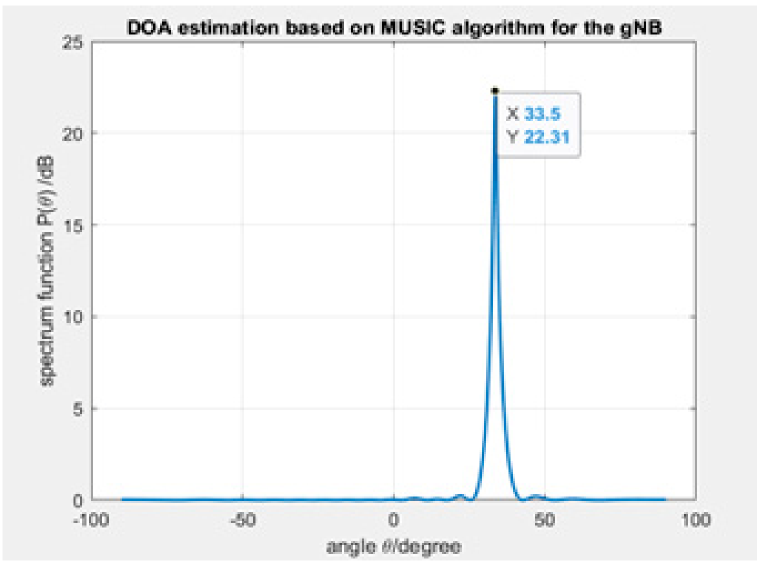


Figure 5.5: DoA estimation at gNB.

The initial layout with the base station (gNB), relay (BFR) and the User Equipment (UE) making an angle of 45 degrees with each other as shown in Figure 5.3, along with the arrival of the signal at the gNB and BFR from UE is shown in the plots to the right. We can also validate the MUSIC algorithm with this layout since all the three nodes are diagonal to each other and the expected angle should be 45 degrees theoretically.

From the simulation results obtained as shown in Figure 5.3, we understand that the algorithm is working efficiently.

In Figure 5.6, the angles are calculated by changing the positions of the BFR and the UE and the estimated DoA of the signals are plotted to the right.

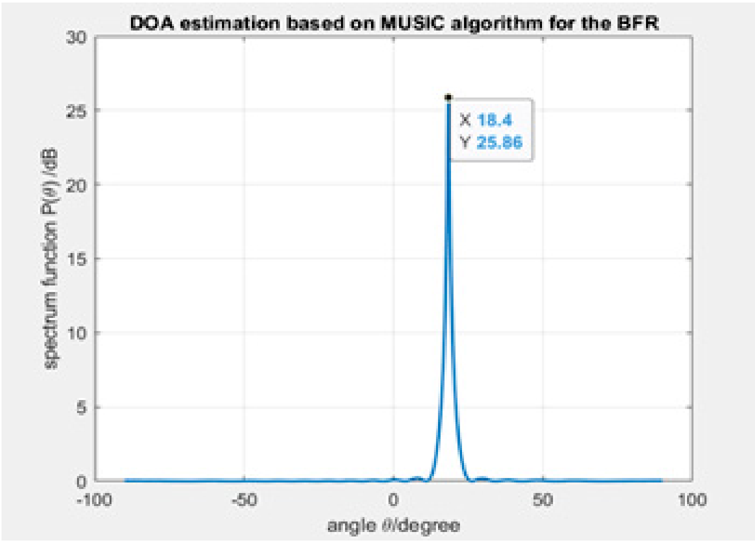


Figure 5.6: DoA estimation at beamforming router.

RQ2:What is the performance of the implemented beamforming router?

In this section, we will discuss in detail the performance of the beamforming router and the overall system using Key Performance Indicators (KPI´s) which are SNR and Power and RSRP.

From the figure 5.7, we understand the behaviour of the BFR in a 5G cell. The Figure 5.7 has three subplots of SNR, RSRP and the received power that are calculated for different user positions as the user moves away from the base station. All the three subplots have the common X axis which shows the distance of the UE from gNB in meters and the Y axis shows the SNR for subplot 1, RSRP for subplot 2 and received powers for subplot 3 received at the UE in dBm.

The simulations are performed with 16 number of antennas at the gNB and BFR and with one receiving antenna at the UE.

We are going to discuss these results in detail and the performance of each KPI individually in later subsections.

1. Signal-to-Noise Ratio

SNR is one of the important performance metrics to be analyzed in order to compare the level of a desired signal to the level of background noise. However, in cellular system, as the user moves away from the base station, the received signal power decreases in turn increasing the background noise due to increase in the path loss. We see the similar performance that matches the theory with our simulations with both base station and beamforming router as shown in the Figure 5.7.

The blue line indicates the performance of the base station whereas the red line

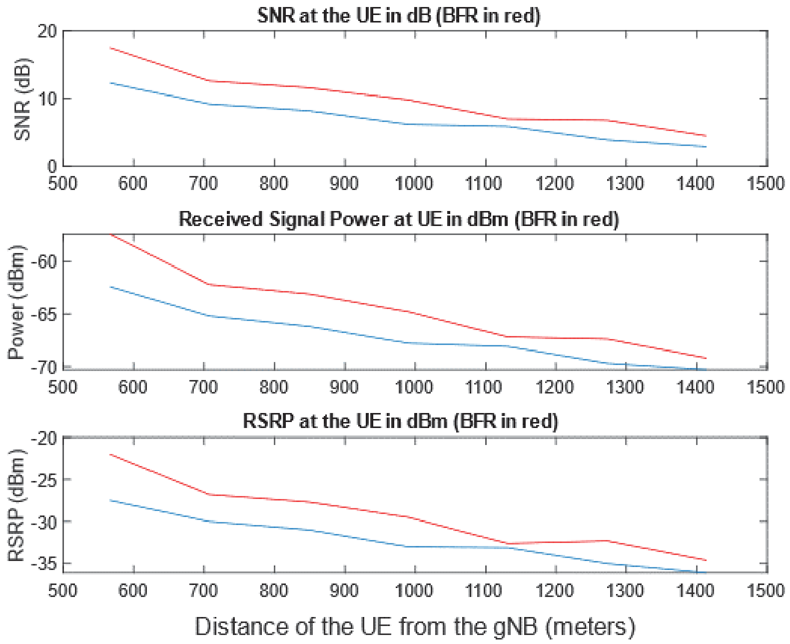


Figure 5.7: Downlink SNR performance as the UE moves away from gNB and BFR.

indicates the performance of the analogue beamforming router. When the user is moving towards the edge of the cell starting from the position at 600 meters away from the gNB to until 1400 meters, we see that there is a decrease in the downlink SNR from both the transmitters (gNB and BFR).

As the focus in this thesis is on the performance of the beamforming router, from the subplot of SNR, we see that the transmission through beamforming router increases the down link SNR by almost 10 dBm when compared to the traditional gNB - UE transmission.

2. Reference Signal Received Power

From 3GPP definition, Reference Signal Received Power (RSRP) is defined as the average power of resource elements that carry cell specific reference signals over the entire bandwidth. RSRP is known by measuring the power of the symbols that carry the reference signals. From the reference, we see that the RSRP greater than -80 dBm has an excellent signal strength with maximum data speeds. In our investigation, by measuring RSRP we understand there is a good data reception at the UE from the static beamforming router in comparison with the performance of gNB.

From Figure 5.7, RSRP is measured at the UE from both base station and beamforming router. The blue line indicates gNB and red line indicates BFR. We have good reception at the UE from both the transmitters and additionally, the beam forming router is improving the system´s overall performance.

3. Received Power

Received signal power at the receiver is another important performance metric to measure in wireless communications. In general, the received power is measured using the link budget calculation considering the transmitted power, antenna gain and the path loss that the signal experience while travelling from transmitter through the channel to receiver. It also takes into account the randomly varied channel fading.

The transmit power considered from both gNB and BFR is 20 dBm and the transmit power at the user is considered as 10 dBm for all the simulations.

The subplot of the received power in Figure 5.7 shows the signal strength is measured at different positions of UE received from gNB and BFR.

4. Bit Error Rate

Here, we are analyzing the BER of our simulation scenarios as a means to check if the system performs well enough to be considered as realistic enough in real use case.

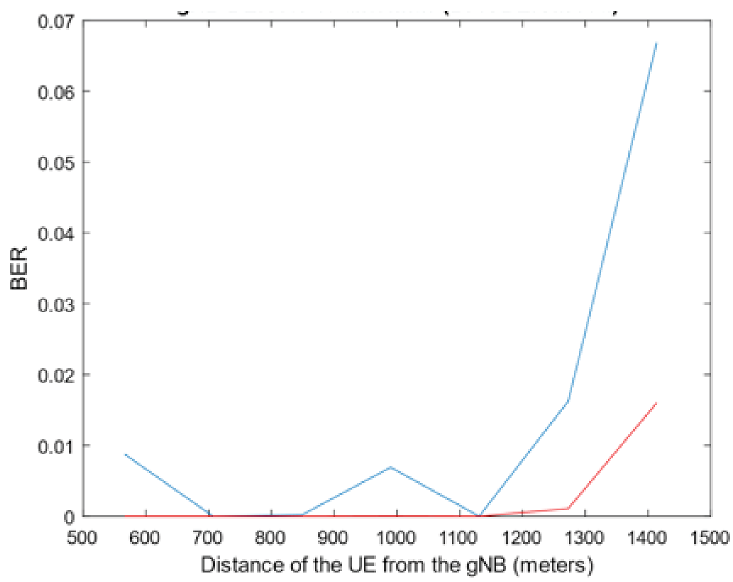


Figure 5.8: Downlink BER performance.

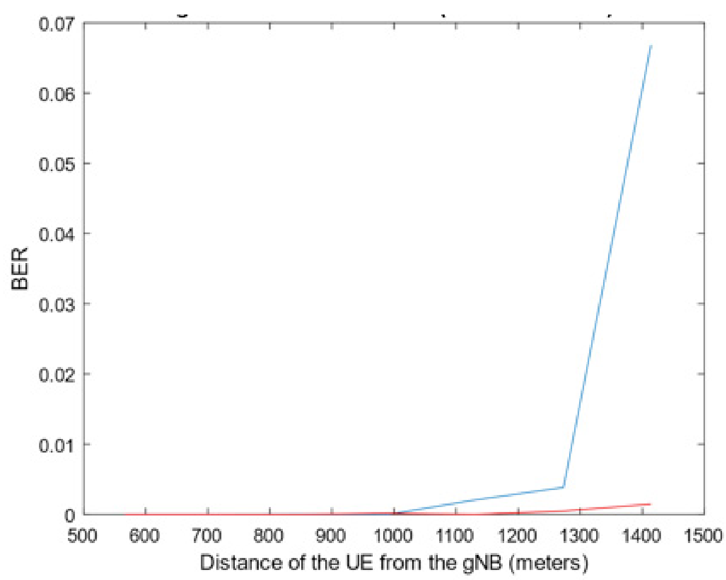


Figure 5.9: Downlink BER performance as the UE moves away from gNB and BFR with 16 antennas.

In Figure 5.8 we are simulating for the same scenario as 5.7 with 10 antenna elements at both the gNB and the BFR.

In Figure 5.9 we are simulating for the exact same scenario as in Figure 5.8 but we have increased the antenna elements at both the gNB and the BFR to 16.

From Figure5.9 it is obvious that the BFR is performing either similarly or better, meaning the BER is close or lower, than the gNB for all the distances up to a little over 1400 meters from the gNB which is a realistic distance for the 6 GHz frequency band.

5.2 Performance With Multiple Transmitting Antennas

In this thesis, we performed few simulations considering multiple antennas at the transmitter side and a single receiving antenna at the user. By using multiple transmit antennas, we are making use of the beamforming concept in which the signal is pointed in the direction forming a narrow beam towards the user, by decreasing the unwanted side lobes which in turn increases the SNR of the user.

All the simulations are done by comparing the results with both 10 and 16 number of transmitting antennas and 1 receiving antenna. The results for these simulations are shown using Figure 5.10, and Figure 5.7.

From these figures, we see that the performance of the system improved when we increased the number of transmitting antennas from 10 to 16.

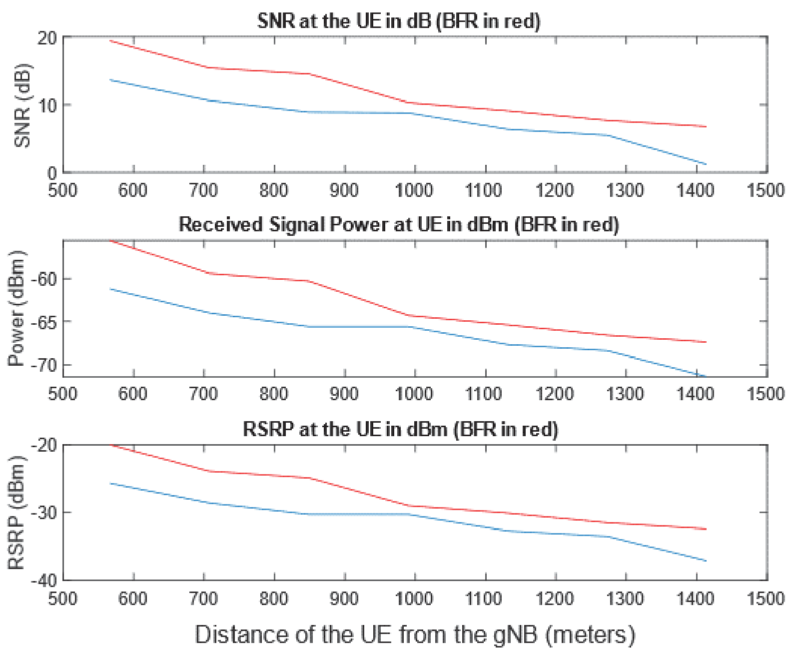


Figure 5.10: Performance of the metrics with 16 transmitting antennas.

Chapter 6

Conclusion and Future Work

6.1 Conclusion

This research has started with the motivation to increase 5G cell coverage as to address the limitation of millimeter waves that cannot travel longer distances. Literature review is performed in order to get a knowledge on the existing channel models, beamforming algorithms and LTE relay techniques. This work helped to a great extent to increase our knowledge on 5G NR. With the drawback of free space path loss, attenuation and scattering, millimeter waves cannot travel longer distances limiting the cell coverage.

In this thesis, we have successfully implemented beamforming router (relay) in a 5G cell which increases the coverage. This research work has successfully achieved the objectives of estimating the DoA of a reference signal coming from the UE using MUSIC algorithm and used phased array beamforming in order to beamform the received signal from the gNodeB towards the user. The channel modelled between gNB-UE and BFR-UE is the WINNER II which corresponds to suburban scenario. The simulation for various scenarios and performance of the model is validated using MATLAB app designer.

The metrics measured in order to validate the experimental setup are SNR, RSRP, received signal power and BER. Simulations were performed with multi transmitting antennas to evaluate the performance of the BFR when the transmitting antennas are increased from 10 to 16 with 1 receiving antenna at the UE.

6.2 Future work

As a potential future work on the subject, there are plenty of experimentation and improvements to be made. The work in this project with beamforming router can further be developed and analyzed by introducing more than one fixed beamforming routers in a cell and select the best suitable beamforming router to transmit the signal. This work can also be investigated by introducing mobility at the UE side. This work can be tested in real time where many factors such as latency, throughput and implementation costs would affect the network performance.

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