Analysis of Hybrid Precoding in Millimeter Wave Communication System

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Statement of Originality

The work I have done in this thesis is not copied nor submitted by anyone before. Literature and information obtained from others work is properly cited.

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Date Muhammad Adnan Nizami

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Dedication

I dedicate my thesis to my Grandfather, Grandmother. To my Parents, and my brothers Jawad and Jamal.

Abstract

The fulfilment of bandwidth requirement is the main challenge in modern communication system due to high rise in cellular data demand. The utilization of 5G mobile network that is based on Millimeter wave (MMW) communication provides an enormous bandwidth. Propagation loss is an important issue that reduces coverage area, signal power and impairs communication performance. Hybrid Precoding has been recently proposed as a powerful technique to realize mm-wave communication in 5G networks. Multi-resolution codebook and adaptive estimation algorithm helps in estimating channel weights efficiently. To realize sufficient link margin, MMW system use large number of antennas at transmitter and receiver side. Due to high cost and power consumption of multiple antennas and RF chains an analysis is performed to select best combination of antennas and RF chains at transmitter and receiver. In this paper, we analyze the performance of estimation algorithm with respect to the selection of RF chains, number of antennas, effect of bit error rate, selection of resolution parameters and precoding vectors. The analysis gives an excellent trade-off between cost, hardware size, critical synchronization time, power consumption and performance. It also helps in selecting proper parameters according to the requirements.

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Chapter 1

Introduction

1.1. Overview

In the modern era, the mobile communication is one of the successful innovation. Fast growing demand of smart devices like tablets, laptops, smart phones and a rapid development of software applications require a large amount of data rate [1]. In [2, 3], Mobile communication subscribers extended to 5 billion in the recent years. For many years, the academia and telecommunication industry have been investing a lot on research work [4], to provide higher data rates to the user, by using the principle of frequency reuse, deploying more base transceiver stations and by improving spectral efficiency.

In a total of mobile traffic nearly 51% is video traffic that is expectedly going to increase to 67% in 2017 [1, 5]. According to research [2], it is expected that 5G network would be capable of offering at least 1 Gigabit per second of data rate to the end user anywhere and up to 5 to 50 Gb/s to the high mobility and pedestrian user respectively.

Many challenges of MMW are presented in [6], that need to be compensated like high path loss, weak diffraction, and small coverage area etc. To reduce these characteristics of MMW, hybrid beamforming can be used with the help of an adaptive algorithm and multi-resolution.

Multi-Resolution robust codebook (matrices in which beamforming weights are placed) is constructed on both sides i.e. at transmitter and receiver. In previous codebooks [7, 8], each vector is defined by the central beam-forming angle and the beam width. In codebook [9], precoding or beamforming vectors are generated with help of digital analog processing to get better characteristic of beamforming patterns. A very important factor of the codebook is presented in [10], that it has a very short setup time which is very useful because directional beamforming is sensitive. It provides a balance between performance and complexity of the system.

The adaptive algorithm reduces setup time and also helps to estimate parameters in small iteration and with high success probability. The main advantage of this algorithm is that it reduces the complexity of Radio Frequency (RF) chains as few RF chains are used. To design this algorithm [9], compressed sensing solution is used. We can also approximate multi-paths beam training and transmission.

According to [2, 11], the electronic components of MMW communication system like antennas, oscillators, low noise amplifiers and analog/digital converters are not only costly but also consume a lot of power. Using multiple RF chains and Antennas, significantly increase complexity.

In order to make it feasible for commercial use, we need balanced components where we not only get optimum performance but also reduce cost, complexity, and size of components. An analysis is performed on various hardware components to check the trade-off results. To balance performance and synchronization time, analysis of N and K is performed. To examine how efficient is the adaptive algorithm is, we checked its BER with a perfect channel model.

1.2. Beamforming of Signal

Beamforming/Precoding is a signal processing technique that uses antenna arrays to send or receive signal in a directional way. Generally, transceiver station can transmit and receive signal using different configuration. In single input and single output (SISO) mode, there is single antenna at transmitter and receiver station to exchange information. Simplicity is the advantage of SISO mode. It requires no processing in terms of diversity.

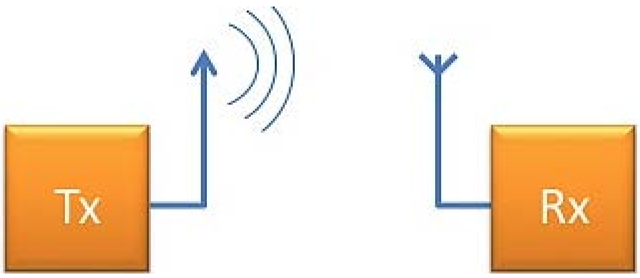


Figure 1.1: Single Input Single Output System

The disadvantage of SISO configuration is its limited performance. Interference and fading has a great impact on this mode and channel bandwidth is also very limited.

In Multiple input and Multiple output configuration, there are multiple antennas at transmitter and receiver side. It provides improved performance. It also reduces interference and fading effects

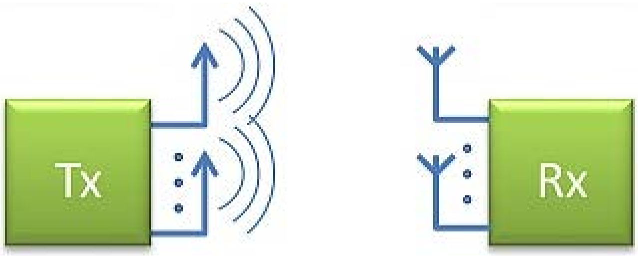


Figure 1.2: Multiple Input Multiple Output System

MIMO provide improved channel throughput and channel robustness. With the help of MIMO configuration, channel capacity(bits/s/Hz), transmission quality(BER) and coverage can also be improved. Through MIMO system, spatial multiplexing can be utilized that help us to improve diversity and array gain. The best advantage of MIMO system is the utilization of Beamforming.

In MMW communication system, wavelength of signal is 10mm-1mm. It provides the facility to use large number of antennas at transmitter and receiver side. Beams are generated with the help of constructive and destructive interference of waves generated by multiple antennas.

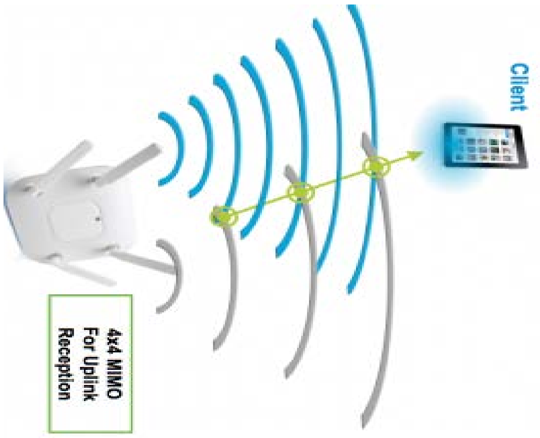


Figure 1.3: How signal reinforce each other

In constructive interference, waves that are in-phase add together to form a larger amplitude wave.

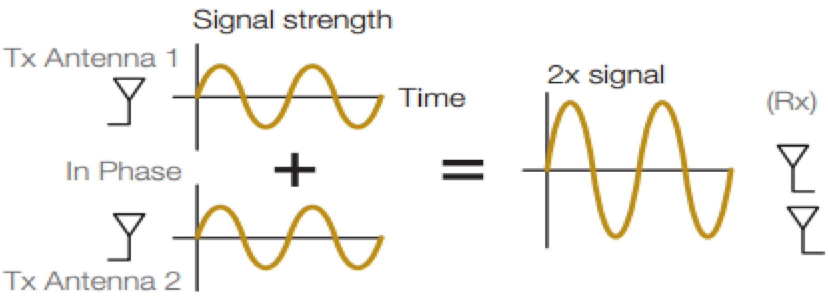


Figure 1.4: Constructive Interference of Signal [12]

In destructive interference, waves that are out of phase, subtract each other and cancel out the effect of each other.

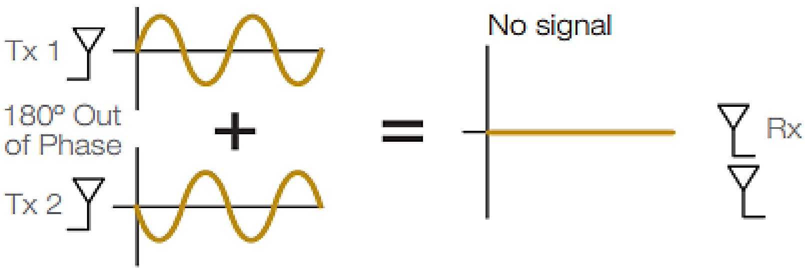


Figure 1.5: Destructive Interference of Signals [12]

Beamforming is based on this concept. Co-channel interference reduction gain and array gain can be achieved by precoding. By weighting the streams of signal, the base station forms a narrow wave beams which is directed towards user direction while suppress the interference from non-directed user. As a result, both interference reduction gain and array gain are achieved.

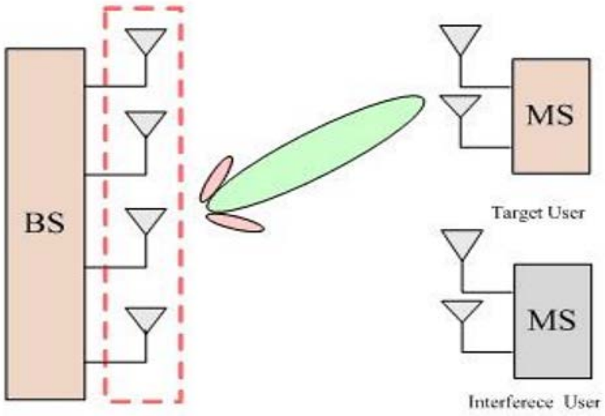


Figure 1.6: Array gain and co-channel interference gain [13]

Conventionally, precoding is based on direction of arrival of beamforming phased array and calculating the beamforming weights. In estimation algorithm and multiresolution codebook, signal beam is based on channel coefficient matrix that helps to obtain precoding weights. Signal from multiple antennas are reinforced with the help of constructive interference and form signal beams.

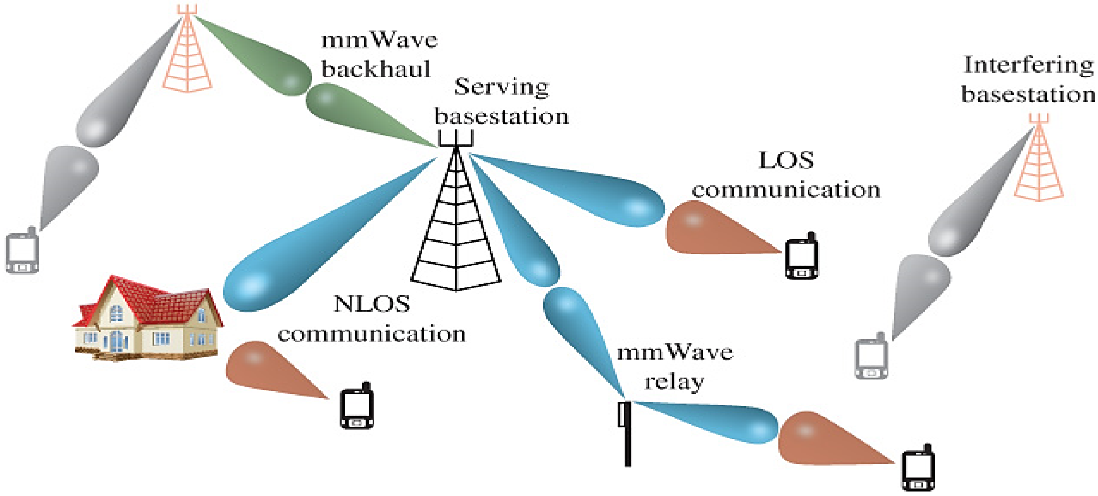
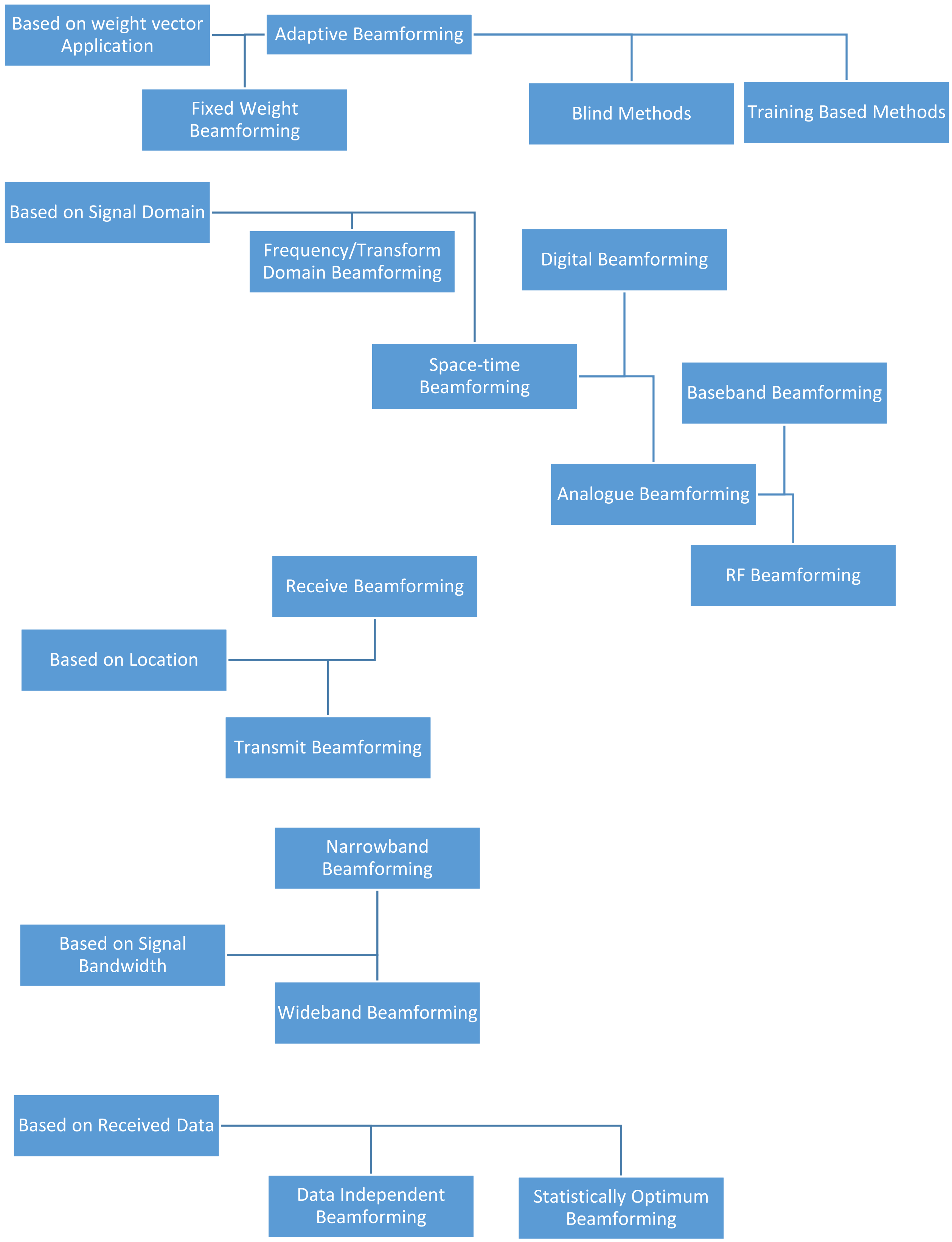


Figure 1.7: Beamforming of signal [14]

The main objective of beamforming is to shape the beam patterns by steering so the received signal to noise ratio is maximized.

1.2.1. Classification of Beamforming Approaches.

There are different classification for Beamforming. One specific classification [10] is shown below



1.2.2. Beamforming are of three types

1. Digital Beamforming.

Digital Beamforming uses a discrete set of weights. It provides better performance and higher degree of freedom at the expense of complexity i.e. high-resolution ADC, signal mixers etc. It also helps the receiver by giving information of channel and also enables Multiple input multiple output [4].

2. Analogue Beamforming.

It uses continuous weights. It is not confined to a specific set of values. It may not use ADC at all. It can be used with analog modulation. Complex coefficient is applied to manipulate the radio frequency signals by means of controlling variable gain amplifiers and phase shifters [4].
Analogue Beamforming is a very simple technique. It uses large number of antennas to generate beams. It is very cost effective and less complex.

3. Hybrid Beamforming

It uses both analog and digital Beamforming. It is actually a trade-off between performance and simplicity as the sharp beams formed by analog beamforming to reduce path loss and digital Beamforming provides high flexibility that enables to perform multi-beam MIMO. Hybrid Precoder is divided into analog and digital domain due to power consumption and the high cost of mixed signal components. Hybrid precoding with the help of multi-resolution codebook and precoding algorithm can reach the performance of digital beamforming. Directional precoding is the only solution to support longer outdoor links. Due to very small wavelength in Millimeter-wave i.e. 10mm to 1mm, it is possible to pack large antenna arrays into small form factor as usually the distance between the antenna arrays is $\lambda/2$.
Precoding matrices design, largely dependent on channel state information, which is very difficult to achieve in Millimeter-wave because of low SNR and a large array of antenna elements. In Analogue precoding, a network of antenna's phase shifters controls phases of signals [11]. Analogue beamforming is a very good solution as it reduces the hardware limitations of radio frequency but there are also many limitations one disadvantage is that the beams generated by this scheme are usually converged towards only one communication [11],[15],[16]. Signal phase control are low resolution and analogue phase shifters have constant amplitude constraint. Digital Beamforming has an excellent performance but due to high cost and power consumption of components, it is not feasible.

The Hybrid precoding algorithm and multi-resolution codebook analysis is done in this thesis for a Millimeter wave system [9]. The system has massive MIMO antennas at both the transceiver stations. The main advantage of this algorithm is that it reduces the complexity of Radio Frequency (RF) chains as few RF chains are used. To design this algorithm, compressed sensing solution is used. The Multi resolution codebook used for algorithm relies on the processing of analog and digital domains. In this algorithm, we estimate channel parameter like angle of arrival, angle of departure and path gain, after estimating we develop hybrid precoders for compensating channel. It also reduces the setup time and estimates channel parameters in a very small iteration. Instead of a single path, algorithm also works on multipath. It also performs for both uniform linear array and non-uniform linear array. The performance of the algorithm is almost similar to digital beamforming [9].

1.3. MMW Communication System

The spectrum of Millimeter Wave (MMW) is 30 GHz to 300 GHz. Currently, a lot of research is being done for 5G wireless broad technology on MMW spectrum. According to the International Telecommunications Union, it is also known as Extremely High Frequency (EHF). MMW spectrum is undeveloped from a long time, it can be used for broadband services because of enormous bandwidth. It has the capacity to provide data rate up to 10 Gbps to the end user. It has short wavelength ranges from 10mm to 1mm, that allow us to pack large number of antennas for Massive MIMO services. Mostly research is being done on 71GHz – 76 GHz, 81 GHz – 86 GHz and 92 GHz to 95 GHz. It has various opportunities and challenges. MMW have following characteristics High propagation loss, Directivity, Sensitivity to Blockage, Mobility issues, Weak Diffraction, Small Coverage Area, Nonlinear distortion of power amplifiers, Deafness problem, Interference between different base service stations and Low throughput etc. that need to be tackle.

1.3.1. High Propagation Loss

MMW suffers from huge propagation loss due to very high frequency. The rain attenuation, atmospheric and molecular absorption usually limits the range of MMW. The propagation loss in free space communication is proportional to the carrier frequency square. In 60 GHZ band of Millimeter wave, the oxygen absorption is about 15 to 30 DB/km [17]. According to research non-line-of-sight signals experience high power loss due to weak diffraction. For reliable communication, it is preferred that MMW communication should be use in line of sight environment [18]. Multipath and high attenuation effect can be minimized by using specific antennas like circular polarization [19]. We can also suppress the effect of rain attenuation, molecular absorption, and humidity effect, if we implement femtocell concept, in which cell size is usually 200 m [20].

1.3.2. Directivity

Due to propagation losses, multipath effects and spectral efficiency, wireless bandwidth becomes a bottleneck. Using directional antennas also reduce propagation loss and to achieve high antenna gain. Beamforming is also a very good solution to combat these issues.

Following are the proposed antennas.

The novel design of phased array antenna is presented by Hong et al. that operates at 28 GHz sufficiently reduces the propagation loss effect [21]. For Millimeter wave communication, cavity-backed slot (CBS) antenna for Millimeter-wave applications is proposed. The size of the cavity is reduced by a percentage of 76.8%, because of polymer material [22]. A novel planar aperture antenna is proposed by Liao et al. for maintaining high gain transmission. The main factor of this proposed antenna is that it has a compact size and low cost [23]. A new planar antenna is presented by Zwick et al. that maintains 80% efficiency [24].

1.3.3. Sensitivity to Blockage

MMW are sensitive to blockage because of weak diffraction. They usually absorb in building, furniture and the human body. According to research, the human body may cause a loss of 20-30dB in crowded area [18]. 1% to 2% signal is interrupted in an indoor environment for one to five persons [25].

Multi-hop transmission scheme (MHTS) can be used to combat path loss and blockage issue [26]. The scheme selects appropriate hop for switching traffic. Spatial multiplexing can also be used to enable concurrent transmission. Another approach is presented [27] for indoor environment, in which access points can be placed on the ceiling that reduces the interruption of blockage but as user moves towards edges the blockage probability will be increased. A scheme called Particle Swarm Optimization is proposed by Scott-Hayward et al. for multimedia applications by allocating channel time field. Through this scheme, resources can be allocated even the blockage occurs [28]. A spatial diversity scheme is presented called equal gain (EG) in which multiple beams are formed. When an obstacle blocks high SNR beam. Other beams are connected to maintain transmission but it will add complexity and overhead of beamforming process degrades systems performance [29].

1.3.4. Mobility Issues

User mobility is a big challenge for MMW communication in terms of signal quality. To handle these kind of issues, smooth handovers and channel state adoption mechanisms should be adopted [30]. It is found in [31], that through lower heights base station deeper coverage can be achieved. Another solution is to use a lot of access points but it will increase cost. However, 98% propagation path visibility can be achieved using diversity switching between two access points [32].

1.3.5. Weak Diffraction.

Diffraction is defined as bending of a wave around or away from the edges of obstacles. MMW have weak diffraction. An approach is presented [33], in which static reflectors can be used to tackle diffraction effect. In [34], a research is done that resolve link blockage by switching the beam path from a LOS link to a NLOS link.

1.3.6. Small coverage area

Due to extremely high frequency, MMW is able to cover only a very short distance. As a result, MMW communication is preferable to use indoor. Femto-cell concept can be used by making cell size of 200m [20].

Distance (m)	**1**	**2**	**4**	**6**	**8**	**10**
Capacity (Gbps)	**16.02**	**12.51**	**9.05**	**7.08**	**5.74**	**4.75**

Table 1.1: MMW data rate with distance [35]

Microcells and directional antennas can be deployed to combat this issue. The number of access points should be increased to a great extent.

1.3.7. Nonlinear distortion of power amplifiers

60GHZ band of MMW suffer from nonlinear distortion of power amplifiers, phase noise and IQ imbalance due to high power and enormous bandwidth [35, 36]. Research progress and effective solutions on in-package and on-chip antennas, oscillators, power amplifiers etc. are presented in a research paper to combat integrated circuit related issues [37].

1.3.8. Deafness problem

It is a misalignment between transmitter and receiver beams. It requires a lot of synchronization time [38]. Network capacity can be enhanced and deafness problem can be reduced using coordination mechanism and concurrent transmission [39]. To avoid WiFi service issues, piconet controller operates in Omni-direction using IEEE 802.15.3c protocol but it may not be feasible for MMW having multi-gigabit transmission and it may lead to asymmetricity in gain [40]. Carrier sense multiple access can be used that adopts VCS (virtual carrier sensing) to reduce deafness problem. Asymmetry in gain can be solved using Directional to Directional MAC (DtMAC) protocol, where both sender and receiver operate in directional mode [40].

1.3.9. Interference among different Base service stations.

There are usually two types of interference in network. Interference within each base service station. Interference among different service stations.

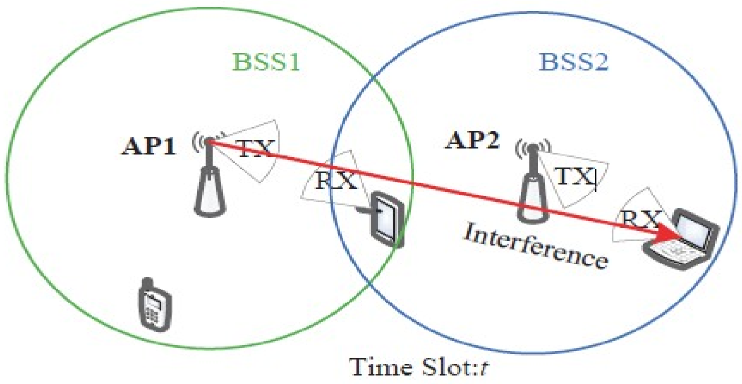


Figure 1.8: Interference among different base transceiver stations [41]

When the two base service stations are communicating in the same time slot. In above figure Access point 1 sends its signal towards laptop and cause interference because laptop is in range of BSS2, access point 2 is already communicating with laptop. This interference is due to different service stations. To reduce degradation of the network performance, Interference management mechanism such as transmission coordination and power control should be applied [24, 42, 43].

1.3.10. Low Throughput

Due to the limited range of Millimeter wave communication, the successful transfer of messages from transmitter to receiver on long distances is a challenge. Frame-based directive MAC protocol (FDMAC) can be used with help of frequency reuse phenomena. It greatly enhances throughput compared with MRMAC [18] and memory-guided directional MAC (MDMAC) [44]. FDMA can also be utilized that also give good performance and low complexity. In directional cooperative MAC protocol, direct path having poor quality can be replaced by establishing two hop path having high channel quality from transmitter station to receiver station. Two hop relaying and D-CoopMAC also significantly improves the throughput of the system [44]. A similar idea of the alternative communication path by using two-hop relaying is presented under harsh environment [45, 46]. Research proposed an incremental multicast grouping (IMG) scheme, that enhances the throughput from 28% to 79% compared with the conventional multicast scheme [47].Another deflection routing scheme is presented to transfer data between direct path and relay path that reduces complexity and improves throughput [48].

To overcome path loss, weak diffraction and small coverage area beamforming can be used. It also helps in sending signal in the desired direction. The short wavelength of MMW allows us to use large antenna arrays because antenna spacing is usually λ/2.

1.4. Beamforming Architecture for Millimeter Wave

A geometric channel model is used to describe the architecture of hybrid precoder. It consist of A_{BS} transmitter antenna and A_{MS} receiver antennas. The number RF chains on transmitter side areC_{RF}. Usually the number of antennas and RF chains on mobile station are less than the base station. Base station and Mobile station communicate through data streams D_s. Generally antennas are larger in number than RF chains and the number of data streams [9].

Precoder at transmitter side is T_T is divided into baseband precoder T_{BB} which is digital based and RF precoder T_{RF} which is analogue based.

$T_{BB} = C_{RF} * D_S$	1.1
$T_{RF} = A_{BS} * C_{RF}$	1.2
$T_T = T_{RF} * T_{BB} = A_{BS} * D_S$	1.3

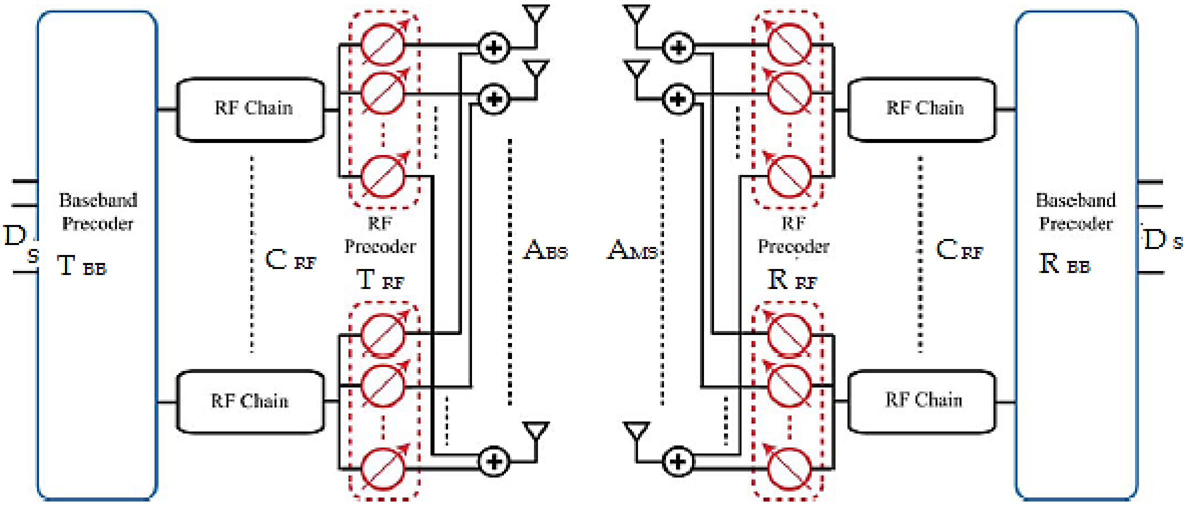


Figure 1.9: MMW Beamforming System Model [49]

Using hybrid precoder if we send signal s through a channel effected by white Gaussian noise. Our signal at receiver's antenna before precoders processing will be

$x = HT_T s + N$	1.4

When this signal is processed at user's precoder, it changed to

$z = R_T^H HT_T s + R_T^H N$	1.5

R_T^H Represents precoder at user end. We have used transpose, to satisfy matrix multiplication.

The geometric channel model H with L path is equal to

$H = \sqrt{A_{BS} * A_{MS}/\rho} \sum_{l=1}^{L} a_l a_{MS(\varphi l)} a_{BS(\theta l)}$ [15]	1.6

Where a_l is the complex path gain of l^{th} path. The path gains are assumed Rayleigh Distributed. $a_{MS(\varphi l)}$ and $a_{BS(\theta l)}$ are antenna array vectors at mobile and base station.

$a_{MS(\varphi l)} = \frac{1}{\sqrt{A_{BS}}} [1, e^{j\left(\frac{2\pi}{\lambda}\right) d sin(\varphi l)}, e^{2j\left(\frac{2\pi}{\lambda}\right) d sin(\varphi l)} \ldots\ldots, e^{j()\left(\frac{2\pi}{\lambda}\right) d sin(\varphi l)}]$ [9]	1.7

.

1.4.1. How connection establish between mobile and base station through Hybrid Beamforming

The array antenna consists of oscillators, phase shifters, Analog to digital converter, digital to analog converter and other mixed components. It is connected to radio frequency unit. To make beam in desired direction, set of phase shifters control signal phases with the help of constructive interference and destructive interference phenomena. A set of beam pair is already defined to reduce feedback overhead [4].

For downlink transmission, BS first send its signal in Omni-direction, because at first both base station and mobile station don't know the position of each other. MS then feedback to BS about specific semi-Omni pattern. On the basis of MS feedback, BS then send its signal in just that specific semi Omni-pattern in the form of sectors. MS then feedback the specific sector in which it is present. In next stage, BS start sending low-resolution beams in this specific sectors and MS feedback. Both Base station and mobile station continue refining beams until both reached at the high-resolution beam. After that, both BS station and MS station start communication on that specific high-resolution beam. The communications link setup for the uplink is done in an analogous way where the roles of the base station and mobile stations are interchanged.

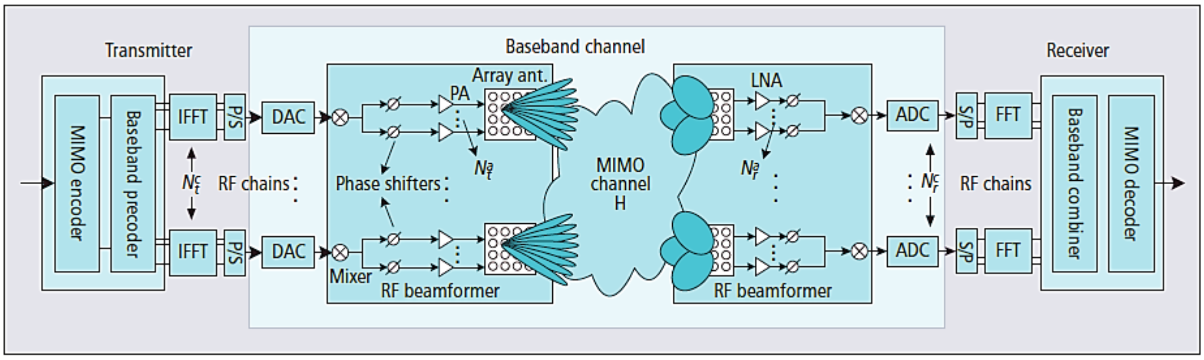


Figure 1.10: Hybrid Beamforming Architecture [4]

In above figure, digital beamforming is carried out before the Inverse Fast Fourier Transform (IFFT) at the transmitter and after Fast Fourier Transform (FFT) at the receiver. Whereas Analogue beamforming is carried out after the Inverse Fast Fourier Transform (IFFT) at the transmitter and before Fast Fourier Transform (FFT) at the receiver [4].

DACs are used at the transmitter to convert discrete weights of digital beamforming into continuous weights for analog processing and ADC is used at receiver to convert back continuous weights into discrete for digital processing like combining and decoding etc.

1.4.2. Synchronization of beams

The base station sends a synchronization signal to the mobile station to synchronize with the frame timer and to scan the best sector or slice pair. After selection of best pair, transmitter, and mobile station further narrow down the beams with in the paired sector and then transmit signal through this narrow beam for better channel quality and maximizes the received signal power. The responsibility of synchronization module is beam identification, frequency and time synchronization [50]

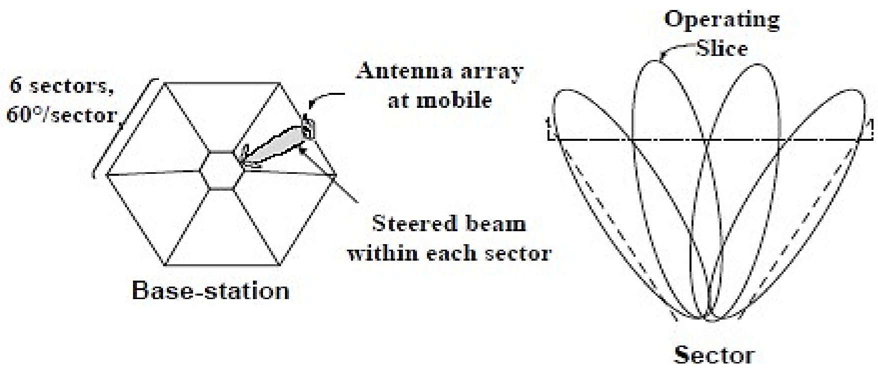


Figure 1.11: Base station sector and beam phase [4]

The MMW communication is operating in a system where there are large number of antenna and few RF chains. Large number of antenna are used because of small wavelength of MMW that enable massive MIMO technique to increase signal quality, coverage area and to reduce attenuation. RF chains that consist of oscillators, power amplifiers, and low noise amplifiers. It processes communication signal. Before communication, BS and MS need to align their beams. An efficient protocol can be used in selecting the best beam pair. This protocol is known as Beam Training Protocol. Another new beamforming training technique called beam coding assign unique signature code. By coding multiple beam angles and steering at their angles simultaneously in a training packet, the beat beam pair can be selected in a few seconds [32].

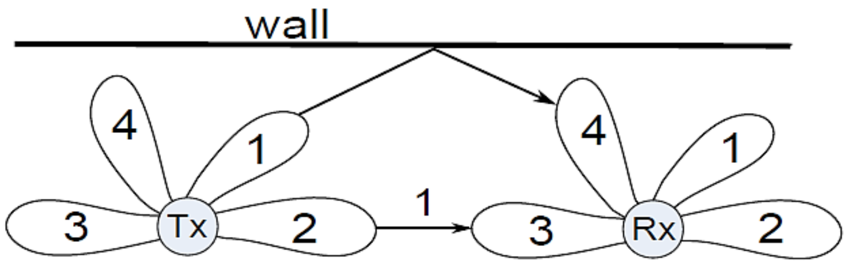


Figure 1.12: Synchronization using four beams of transmitter and receiver [51]

1.5. Research Objectives

Analysis of adaptive estimation algorithm is performed on the basis of cost, hardware size, complexity and performance. Antennas and Radio Frequency chains have a great impact on spectral efficiency.

Massive MIMO technique requires multiple RF chains which is a critical component of transmitter and receiver. It is a combination of oscillators, analogue to digital converters, digital to analogue converters, amplifiers etc. It is a very costly hardware component. Using one or two RF chains will not give us satisfactory results. Similarly using many RF chains on both sides is also not a good decision, although it gives an excellent result. But hardware cost and complexity will be increased. Multiple RF chains also consume a lot of power.

MMW have very small wavelength, normally antenna spacing is $\frac{\lambda}{2}$. It gives us facility to use large number of antennas at BS and MS to synthesize high directional beam. Using multiple antennas at both sides also increase spectral efficiency. But it also increases cost, hardware size, power consumption and complexity.

Usually, less RF chains and Antennas are used at MS as compare to BS because we cannot afford enough power at MS [9].

Spectral efficiency also increases if we vary codebook parameters resolution ‘N’ and precoding vector ‘K’. There is also a trade-off between performance and synchronization time that must need to consider.

During research, variation in spectral efficiency according to different perspective are observed. Below are the main points on the basis of which we analyze the algorithm

- Impact on Spectral Efficiency, when precoding vectors and resolution parameters are varied.
- Transmitter and Receiver antennas trade-off’s impact on Spectral Efficiency using Hybrid Precoding Algorithm.
- Impact of RF chains on Spectral Efficiency using Hybrid Precoding Algorithm.
- BER to check the efficiency of Hybrid Precoding Algorithm.

Chapter 2

Beamforming Approaches

2.1. Classification of Beamforming Approaches

There are many beamforming schemes. These are IEEE 802.11ad, IEEE 802.15c, Multiresolution codebook based beamforming, coding of beams. These are discussed in detail below.

The IEEE 802.11 ad standard is developed for indoor communication that operates in 60 GHz band. IEEE 802.11 ad works on physical and MAC layer as given.

2.1.1. Beamforming Protocol in IEEE 802.11 ad

It is a selection based standard for precoding in 3 sections [10]

1. Sector Level

In Sector Level, transmitter and receiver antennas use semi-Omni patterns to select high SNR sector.

2. Beam Refinement Level.

In this Level, after the best sector is selected. BS and MS then refine the high-resolution beam having finer beam width with in the best-selected sector.

3. Beam Tracking Phase.

It is employed to adjust for channel variation during the transmission of data. It is performed by adding the training field to data packets. Automatic Gain Control (AGC) field is also present. That calculate an appropriate AGC of receiver signal in case of channel variation. It also contains channel estimation (CE) field, to improve the tap delay estimation.

The IEEE 802.11 ad protocol procedure is shown in a given figure

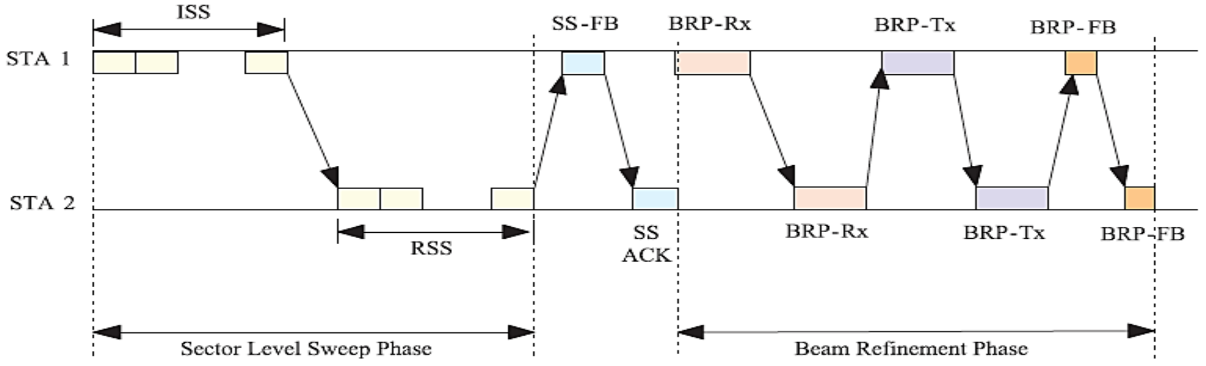


Figure 2.1: IEEE 802.11 ad protocol's frame exchange illustration during Beamforming [10]

During Sector Level, transmitter sends training signal through predefined sectors. Sector is a low-resolution beam or broad radiation pattern having large beamwidth. It is generated by changing the weights like angle of arrival, angle of departure and gain of phased array elements.

In Sector Level, receiver always in Omni-direction and after selecting the best sector of transmitter, provides feedback to the transmitter. Training packets are usually low powered and low rate modulated, ensuring the communication established during the initial beamforming link is reliable.

According to Figure 2.1, the station 1 (STA 1) that starts the training of beamforming is called initiator and the other station 2 (STA 2) that receive the signal from (STA 1) is the responder. Sector Level consists of initiator sector sweep (ISS), sector sweep feedback (SS-FB), responder sector sweep (RSS) and sector sweep acknowledgment (SS-ACK)

Beam refinement phase (BRP) consists of multiple sector ID and beam combining (BC) sub-phases. High resolution beams set, having fair link qualities are identified within the premises of best sector and tested in beam refinement phase. The beam combining phase is used to reduce delay during the testing of selected beams. For transmission Best-refined beam pair is used, after the completion of Sector level and Beam refinement phase.

Beam tracking phase helps the communication link to be in good condition, when the channel link is susceptible to variations. It appends the training sequence with the payload. The physical packet structure of IEEE 802.11ad consists of many fields like channel estimation, time synchronization, cyclic redundancy checks and automatic gain control fields.

2.2. Codebook Based Beam Switching Technique

Codebook based design is a major challenge in case of Millimeter wave communication because of wide channel bandwidths. The spacing between the element arrays is dependent on the wavelength. A small difference due to channel variation in center frequency cause the pattern rotation and it results in error in selecting the best beam. To compensate this kind of issues, a robust design is considered as in below fig.

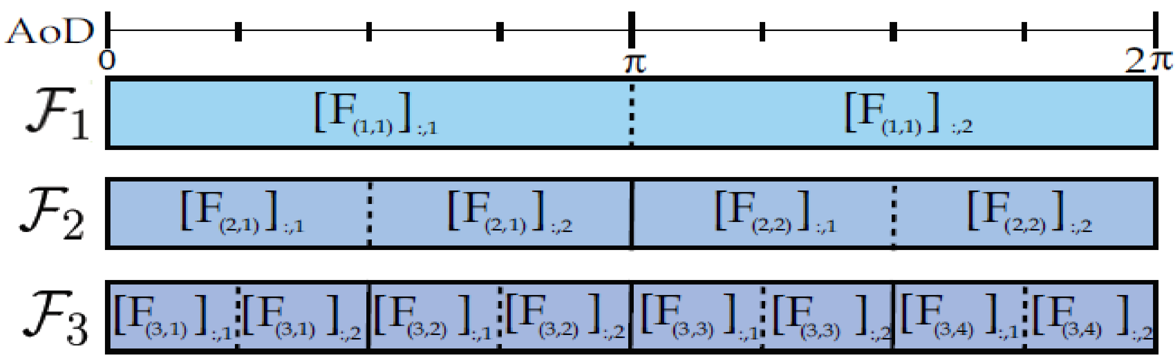


Figure 2.2: Multiresolution codebook [9]

Codebook consist of fixed beam patterns and antenna weight vectors having information of angle of arrival, angle of departure and path gains that are maintained at both sides i.e. at transmitter and receiver. Codebook columns specify the weight vectors of beamforming that represents the unique beam pattern.

Antennas having phased arrays have discrete phase shifts on each element. To reduce interference from large number of beams that are used for multiple users, the columns of codebook are made orthogonal. To create a wider beam, multiple sharp beams in the same direction can also be synthesized. Protocols based on beam codebook have three steps. N-bit codebook results in improved efficiency, resolution and maximum gain pattern with sharp beams.

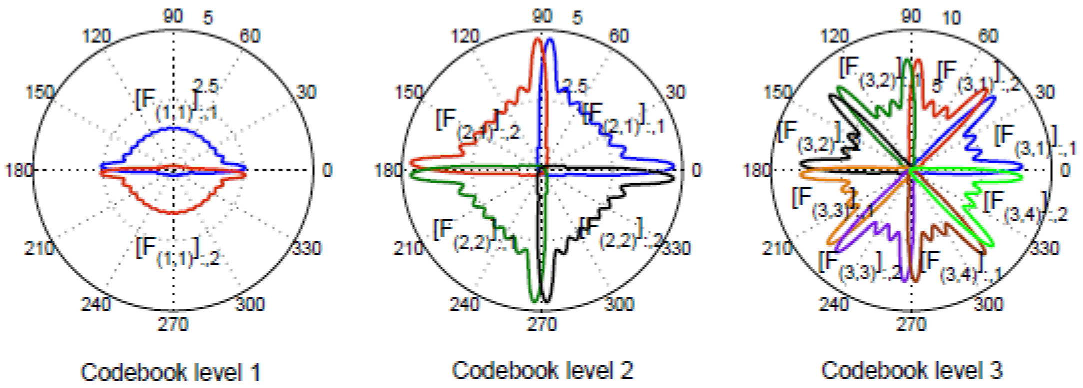


Figure 2.3: Patterns of Beamforming vectors of 3 levels [9]

2.2.1. Advantages of Codebook based beam switching technique

Codebook based beamforming is applicable to a variety of antenna structure having a uniform and non-uniform array geometries. It provides flexibility in case of size, number and the spacing between the antenna elements. It provides a balance between performance and complexity of the system. To obtain processing power saving, beam pattern may generate without amplitude adjustment. A very important factor of codebook-based beamforming is that it has a very short setup time. A short setup time is useful because beamforming is very sensitive to rain, humidity, and oxygen absorption as a result channel variation can cause frequent link failures. In this case, sometime whole process need to be repeated to re-establish the link. In codebook, a major challenge occurs when two adjacent beams generated by codebook intersects. This intersection adversely effects Bit Error Rate performance. To mitigate that kind of issue an additional codebook can be employed. When the receiver beam falls at the gain intersection point, the extra codebook is used to generate new beam with maximum gain in this direction [52]

2.3. IEEE 802.15.3c Beamforming Protocol [53]

IEEE802.15.3c is an exhaustive beamforming protocol have an excellent performance. But its computational complexity is very high. The beam search phase should have low computational time in generating high SNR link.

Computational complexity is related, to preambles number that selects the high-resolution beam pair having high Signal to Noise ratio.

According to IEEE 802.15.3c, if there are 64 antennas at transmitter (N_t) and 32 antennas at receiver (N_r). During sector level, transmitter switches over all the transmit sector beams and receiver maintains semi-omnidirectional pattern. The procedures will be reversed in order to select the best transmit receive sector. The total computational steps just for sector level will be

Computational Steps for sector level = $N_t * N_r = 64 * 32 = 2048$

The complexity will increase to a high level when we have to search beams in selected sector.

Let, total number of beams at the transmitter and receiver is $N_t^{(s)(b)}$ and $N_r^{(s)(b)}$ in each sector are 10. Total complexity for whole process $= N_t * N_r + N_t^{(s)(b)} * N_r^{(s)(b)} = 2048 + 100 = 2148$

2.4. Beamforming codebook with specific four phase per antenna element [11]

A codebook is actually a matrix consist of beamforming weight vectors. Each column specifies beam pattern. In order to reduce power consumption and simplify the phase shifters, the codebook is designed for phased antenna array implementing only four phase shifts per element (0° 90° 180° 270°). Below is an example of codebook of four antenna elements having eight patterns. The spacing between the elements is λ/2.

Pattern ID = 0 1 2 3 4 5 6 7

$$W = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ -1 & -j & -j & -j & 1 & j & j & j \\ 1 & j & -1 & -j & 1 & j & -1 & -j \\ -1 & 1 & j & -1 & 1 & -1 & -j & 1 \end{bmatrix}$$

Figure 2.4: Codebook having beam pattern ID's [11]

The graphical representation of above codebook is as given

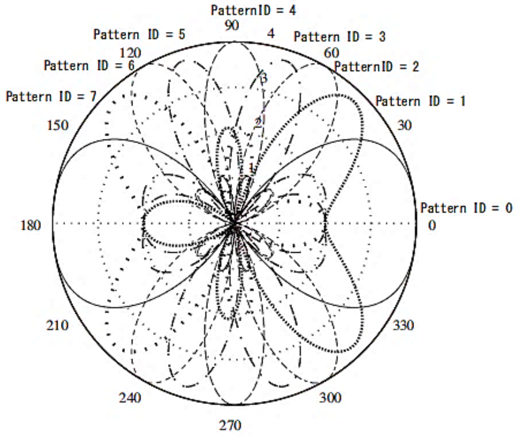


Figure 2.5: Beam pattern of antenna element separated by 90 degrees [11]

Beamforming Setup time is near 619.8µs, 246.7µs is for device-to-device linking and 373.07µs is for sector level and beam refinement phase. If packet error rate increase from 0 to 0.5, total setup time may increase to 701.6µs. In Exhaustive case setup time increases to 31.57ms [4]. Two high setup is because in exhaustive standard, transmitter and base station antennas have to try all possible combination. If there are 64 antennas at both sides, the possible combinations will be 4096.

2.5. BeamCoding

Beamcoding is a new beamforming technique[51], in which beam angle is given a unique code. Best beam angle pair is selected in a very short time, by coding multiple angles of beam and steering at specific angle in a training field.

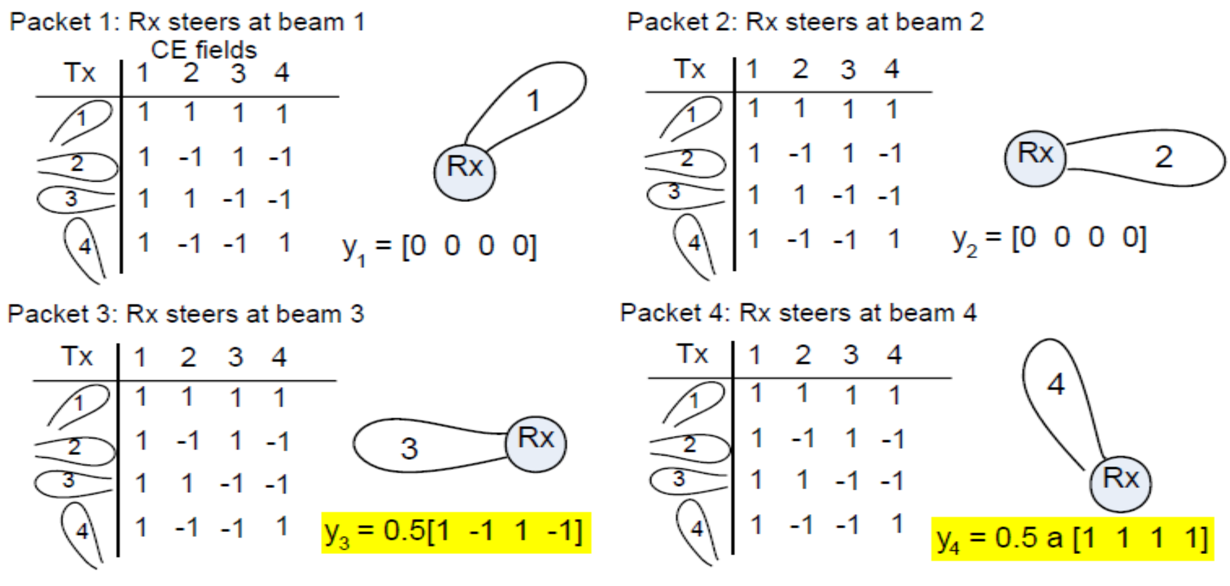


Figure 2.6: Coding multiple beams with unique ID [51]

Chapter 3

Methodology

3.1. Channel Estimation.

Measuring or estimating the channel of Millimeter wave is somewhat similar to measuring Angle of arrival, angle of departure and path gains. To do that with no mistake and low overhead, both station needs to carefully design their matrix. We can estimate different channel estimation parameters at low overhead by utilizing the Millimeter channel's sparse nature.

If t_p precoding vector is used by the base station and to receive this vector mobile station uses r_p vector, the resulting signal will be

$z_{q,p} = r_q^p H t_p s_p + r_q^p n_{q,p}$ [9]	3.1

If N_{MS} and N_{BS} measurements are performed by the mobile station and base station, then the resulting signal is written as

$Z = R^H HTS + Nq$ [9]	3.2

Where N_q is and $N_{MS} * N_{BS} = L * L$ matrix.

If we check received signal's matrix

For L paths

$Z = L \times A_{MS} * A_{MS} \times A_{BS} * A_{BS} \times L * L \times L + N_{MS} * N_{BS}$	3.3

As above

$N_{MS} * N_{BS} = L * L$	3.4
$Z = L * L$	3.5

Means received signal vector depends on the number of paths. This resultant is after the combining process.

3.2. Algorithm Strategy

Strategy of the whole process is as given in smart art

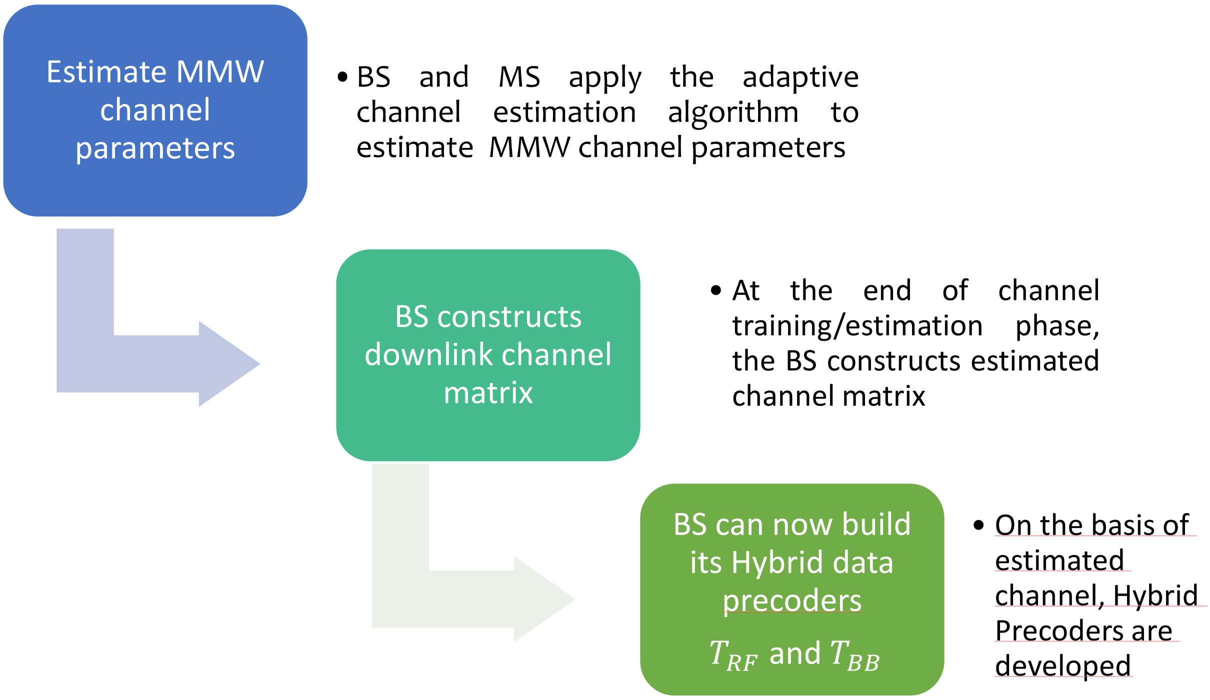


Figure 3.1: Strategy of developing Hybrid Precoders

The whole strategy is explained in detail below

3.2.1. Synchronization of transmitter and receiver

How to synchronize transmitter and receiver through beams, when they have not any channel knowledge?

Figure 3.2: Synchronization of transmitter and receiver

3.2.2. Transmitter and receiver training in Omni Pattern

First, transmitter and receiver send signal in Omni-direction. Currently, at this point, both stations are unaware of the location of each other. If the receiver gets signal from transmitter it feedbacks the transmitter about its quasi-Omni pattern, that from that pattern I am getting signal. As shown below

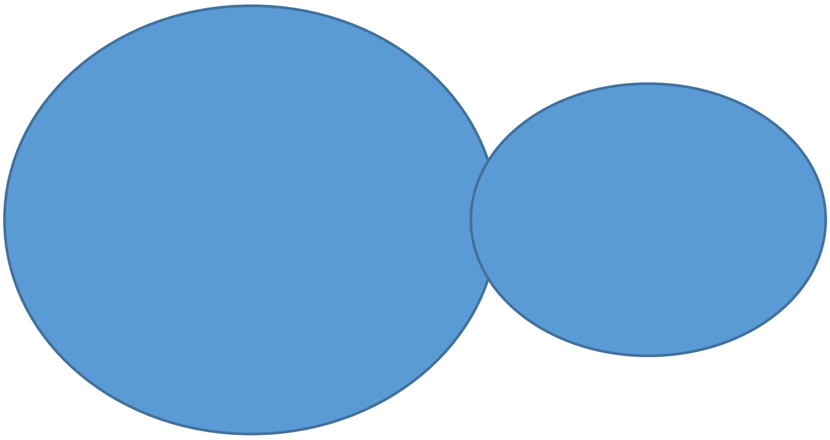


Figure 3.3: First Step: Training in Omni Direction

3.2.3. Transmitter and receiver training in Omni Pattern

After getting feedback from receiver i.e. the receiver in its right, half pattern. It transmits signal in semi Omni pattern. Similarly, receiver after getting acknowledgment from transmitter starts sending signal in its left half pattern.

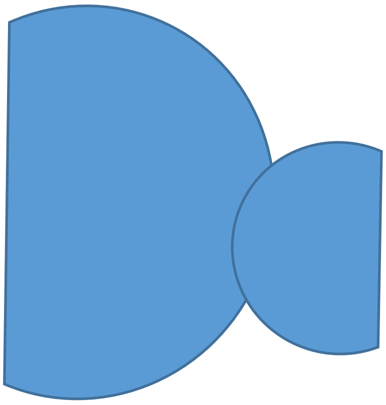


Figure 3.4: Second step: Training in Semi Omni pattern

3.2.4. Training in Sector Level.

In this step transmitter and receiver selects the best sector. Both stations start sending signal in sector way. As training is reaching to next level, receive signal SNR continuously increasing.

Figure 3.5: Sector Level training

3.2.5. Training in Beam refinement phase.

In this step, transmitter and receiver start sending signal in a specific sector to select the best beam pair. This is the last step where transmitter and receiver select the high SNR beam.

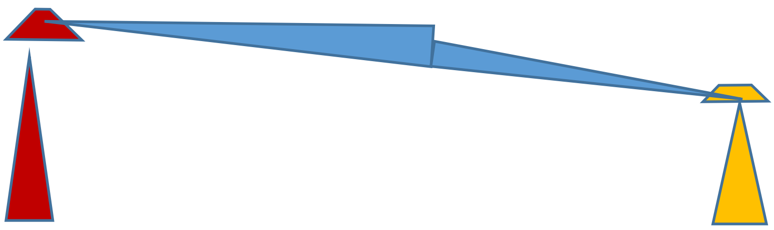


Figure 3.6: Beam Refinement Phase

To complete problem, we assumed that angle of arrival and angle of departure are chosen from a uniform grid having N points. φ_l and $\emptyset_l$belong to $[0, \frac{2\pi}{N}, \ldots \ldots .2\pi(N-1)/N]$.

According to the compressed sensing solution, the training step is divided into a number of stages and each stage depends on the output of the previous stage, as precoding matrices are not determined prior. The resultant vector of stage second is dependent on the resultant vector of stage first. Similarly, stage N is dependent on $N-1$. The beamforming vectors used in our codebook are based on bisection concept [9].

In codebook, if the number of beamforming vectors used in each stage is K. Then the number of stages will be S=$\log_K N$. For example, if there are 192 resolution 'N' and two beamforming vector 'K'. Then stages will be six.

3.3. Codebook Structure.

A multi-resolution codebook consists of S stages. Each stage consists of beamforming vectors. These are divided into K^{s-1} subsets. Each subset contains K beamforming vector. Each subset of codebook is linked with unique angle of arrival/ angle of departure range, which equals to

$\{2\pi\mu/N\}\mu \in I_{(s,k),}$	3.6
$I_{(s,k)} = \{\frac{(k-1)N}{K^{s-1}}, \dots\dots, \frac{kN}{K^{s-1}}\}$ [9]	3.7

Where

N= Maximum Resolution of codebook

K=Beamforming vector

k= subset number

The beamforming vector is designed as

$A_{BS}^{H} F_{(s,k)} = C_s G_{(s,k)}$ [9]	3.8

Where

A_{BS}^{H} = Antenna array vector.

$F_{(s,k)}$=Beamforming of S stage and k subset.

$G_{(s,k)}$= N × K matrix having one and zeros in location where μ∈ $I_{(s,k,m)}$

In codebook [F(s,k)]:,m is a beamforming vector in which

s=stage

k=subset number

m= represents beamforming vector number.

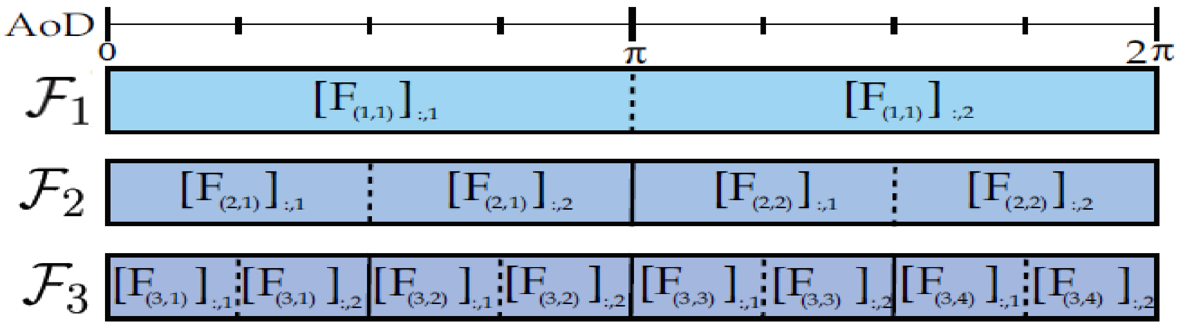


Figure 3.7: Multiresolution codebook [9]

If we consider single path, our transmitter-precoding matrix will be initiated by one subset having two beamforming vectors. One beamforming vector [F(1,1):,1] will cover from 0° to 180° and other beamforming vector [F(1,1)]:,2 will cover 180° to 360° as in figure 3.7

In next stage, there are two subsets each with two beamforming vector. In one subset, [F(2,1):,1] beamforming vector will cover from 0° to 90° and [F(2,1):,2] beamforming vector will cover 90° to 180°. In the second subset, [F(2,2):,1] will cover 180° to 270°. [F(2,2):,2] will cover 270° to 360°. In the same way, we keep on refining the channel to select the best beam.

3.4. Adaptive Estimation Algorithm for single path [9]

Input: N, K and F, W

Initialization: $\mathbf{k1^{BS} = 1, k1^{MS} = 1}$

$S = \log_K N$

for $s \leq S$

for $m_{BS} \leq K$

$F_{s,k}\ (:, m_{BS})$

for $m_{MS} \leq K$

$W_{(s,k)}(:, m_{MS})$

$Y_{mBS} = \sqrt{P_s} W_{(s,k)} H F_{s,k} + n_{mBS},$

$Y_{(s)} = [y_1, y_2, \dots \dots y_K]$

$(m^*_{BS}, m^*_{MS}) = argmax\,[Y_s \odot Y^*_s]$

$$k_{s+1}^{BS} = K(m_{BS}^{*} - 1), \quad k_{s+1}^{MS} = K(m_{MS}^{*} - 1)$$

$$\hat{\phi} = \bar{\phi} k_{S+1}^{BS}, \ \hat{\theta} = \bar{\theta} k_{S+1}^{MS}$$

$$\hat{a} = \sqrt{\frac{\rho}{P_{(s)} G_{(s)}}} \left[Y_{(s)}\right] m_{MS}^{*}, m_{BS}^{*}$$

Similarly, we measure the angle of arrival, angle of departure and path gains of next stages.

At the start, both the precoding and combining matrices have knowledge of maximum number of resolution and number of beamforming vectors. In single path, we initialize with one subset having two beamforming vector. The algorithm will move from the first stage to the last stage. In the first stage, the Base station uses K beamforming vectors of the codebook A_{BS}. To receive the signal from base station, Mobile station will also use K measurement vector of its combining matrices A_{MS}. After the K^2 precoding combining steps, the mobile station compares K^2 received signal's powers, and select the one with maximum signal to noise ratio. The signal output of the first stage that have highest power value will be used in next stage to determine the beamforming vector subset of stage s+1. Mobile station is actually a decision-making component that selects the best SNR beamforming vector and feedbacks it to the base station to use its next stage.

3.5. Algorithm for Multipath [9]

Through this algorithm, BS and MS estimate channel parameters. After assessing parameters, BS constructs channel matrix and develop hybrid precoders on the basis of estimated parameters. Hybrid Precoder helps in compensating channel variations. Algorithm selects precoding vector from the codebook and select those parameters from the codebook that give high SNR (Mobile station feedback high SNR parameters to base station), these parameters are actually estimated parameters.

Input: BS and MS know N,K,Ld, and have F,W

Initialization: TBS (1,1) = {1,...,1},TMS (1,1) = {1,...,1}

$\mathrm{S} = \log_{\mathrm{K}} \mathrm{N/L}$

for $\mathrm{l} \leq \mathrm{L}$ do

for $\mathrm{s} \leq \mathrm{S}$

for $\mathrm{m_{BS}} \leq \mathrm{KL}$

BS uses $\left[\mathbf{F}_{(\mathbf{s},\mathbf{k})}\right]:, \mathrm{m_{BS}}$

for $m_{MS} \le KL$

MS uses $[w_{(s,k)}]:, m_{MS}$

$Y_{m_{BS}} = \sqrt{P_s}\ [W_{(s,}k^{MS}]H[F(s,k^{BS})]:, m_{BS} + n_{mBS}$

$Y_{(s)} = [y_1, y_2, \dots \dots y_K]$

for $p = 1 \le l - 1$

Project out the contributions of the previously estimated paths

$$g = F^{T}_{\left(S,T^{BS}_{(p,s)}\right)}[A^{*}_{BS,D}]:, T^{BS}_{(p,s+1)} \otimes W^{T}_{\left(S,T^{MS}_{(p,s)}\right)}[A^{*}_{MS,D}]:, T^{MS}_{(p,s+1)}$$

$$y(s) = y(s) - y^{H}_{(s)} g(g^{H} g) g$$

$Y = \text{matrix}(y_{(s)})$Return $y_{(s)}$ to the matrix form

$(m^{*}_{BS}, m^{*}_{MS}) = \text{argmax}\ [Y_s \odot Y^{*}_s]$

$T^{BS}_{(l.s+1)}(1) = K(m^{*}_{BS} - 1) + 1$

$T^{MS}_{(l.s+1)}(1) = K(m^{*}_{MS} - 1) + 1$

for $p = 1 \le l - 1$

$T\_BS_{(l,s+1)} = T(p, s+1)$

$T\_MS_{(l,s+1)} = T(p, s+1)$

$\hat{\phi} = \bar{\phi} k^{BS}_{S+1}$, $\hat{\theta} = \bar{\theta} k^{MS}_{S+1}$

$$g = F^{T}_{\left(S,T^{BS}_{(l,s)}\right)}[A^{*}_{BS,D}]:, T^{BS}_{(l,s+1)} \otimes W^{T}_{\left(S,T^{MS}_{(l,s)}\right)}[A^{*}_{MS,D}]:, T^{MS}_{(l,s+1)}$$

For detail see in[9]

Algorithm initialize with the first stage, having L*K precoding and combining vectors. For multiple paths, algorithm repeatedly execute to detect one more path. The total number of steps to estimate all paths is $K^2 L^2 S$.

The signal output of the first stage that have highest power value will be used in next stage to determine the beamforming vector subset of stage s+1. The mobile station is actually a decision-making component that selects the best SNR beamforming vector and feedbacks it to the base station to use it in next stage.

Before determining the new path, weights of the last path is projected out. In every stage on the basis of stored path weights, next different path is selected.

Through this algorithm, we can estimate millimeter wave parameters with a small number of iterations and with high success probability. We can approximate multi-paths beam training and transmission. Instead of the just single path as in other algorithms. We can use this algorithm for both linear and nonlinear antenna array. Results of this algorithm are almost equal to perfect channel estimation algorithm. Setup time (sync of transmitter and receiver) of this algorithm is in a microsecond. Due to channel variation, the robust codebook helps to reconnect the beams in no time.

Chapter 4

Results and Discussion

4.1. Research Aims

- **Impact on Spectral Efficiency, when beamforming vectors and resolution parameters are varied.**

Resolution parameter N and precoding vector K have a great impact on spectral efficiency. Resolution is related to last subset of the precoder, where we refine down to achieve high resolution beam and precoding vector K is related to how many subsets we require in every level of precoder, after selecting the best subset.

Higher the resolution parameter and the precoding vector, higher the spectral efficiency. If we increase precoding vector to a limit of K=N/L, it become exhaustive. At this limit, we have several beams that need to be sync one by one. It will increase synchronization time.

In multipath, the total number of steps required to reach N using algorithm [9] are

$\mathbf{K^2L^3\log_K^{N/L}}$	4.1

And total number of stages of precoder, according to algorithm are

S=log (N/L)/log (K)	4.2

If we increase Resolution parameter to a large value, number of stages and steps of precoder to reach last subset will also be increases. It also increases training overhead.

- **Transmitter and Receiver antennas trade-off's impact on Spectral Efficiency using Hybrid Precoding Algorithm.**

In Radio frequency evolution, fast emergence of cellular communication and sensor applications in MMW require cost, compact size, power consumption and performance as a driving forces [54]. Due to MMW, large number of antennas can be used in compact form that helps to achieve large array gain and give us the facility to implement massive MIMO concept [55] that can be exploited in different ways. Highly effective diversity system can be created to combat fading effects. Multiple antennas generate several parallel data streams that help in increasing the capacity of the system.

The main drawback of massive MIMO is the increase complexity, power consumption, size and cost. The main challenge [56] in achieving the gains of multi antenna is the power consumption that scales linearly with sampling rate and exponentially with bits per samples. According to Research [57], in specific scenario power consumption of transmitting single stream is 1.3 W, while MIMO system having 2 antennas consumption increases to 2.0 W and with 3 antennas it goes to 2.1 W. In case of receiver having single antenna, power consumption for single stream is 0.94 W, for 2 antennas, it is 1.27 W and for 3 antennas, 1.60 W.

In MMW communication system we are going to implement massive MIMO concept, it's very hard to afford power on transmitter and receiver side. We must need balance between performance, cost, complexity and power consumption. In analysis section, trade-off be-tween spectral efficiency and number of antennas is provided, so individual can select according to the requirement.

- **Impact of RF chains on Spectral Efficiency using Hybrid Precoding Algorithm.**

To implement massive MIMO concept in MMW for transmission and reception, a device must have multiple Radio Frequency chains. As in [57], other component of transmitter and receiver like DSP chip and radio frequency oscillator can be instantiated once and can be used by all RF chains and antennas. By activating all RF chains and antennas, a device can receive weak signal more reliably and strong signal with higher data rate. With multiple RF chain, signal will be process very fast.

With single RF chain, according to algorithm [9] the number of steps to select parameter N are

$\mathrm{K}^2\mathrm{L}^3\log_{\mathrm{K}}^{\mathrm{N/L}}$	4.3

If we have 'X' RF chains, the number of steps reduce to

$\dfrac{K^2L^3log_K^{N/L}}{X}$	4.4

Massive MIMO system implies high power consumption. As extra RF chains consume more power, increase complexity and hardware size. At the same time, using few RF chain degrade performance and add processing delays. We need optimum system where there is a balance between cost, complexity, power consumption and performance. In numerical analysis trade-off is performed between spectral efficiency and RF chain

- **BER to check the efficiency of Hybrid Precoding Algorithm.**

Bit error rate is used to find the quality of the digital signal. Less the bit error rate, higher the quality of the signal. In this research aim, we check the efficiency of Hybrid Precoding Algorithm, using BER. For this, we take reference signal, which is processed without hybrid precoder, to estimate how close our hybrid-precoding signal is to the ideal signal. In this case, we used BPSK modulation

4.2. Impact on Spectral Efficiency, when Resolution parameter 'N' is varied.

Spectral Efficiency also known as spectrum efficiency or Bandwidth Efficiency is the optimized use of bandwidth so that we can transmit the maximum amount of data through spectrum with lowest errors. It can also be referred as the information that can be sent in an efficient way over a bandwidth.

Spectral Efficiency = Capacity/Bandwidth = Data Rate/Frequency = Bits per Second/Hertz

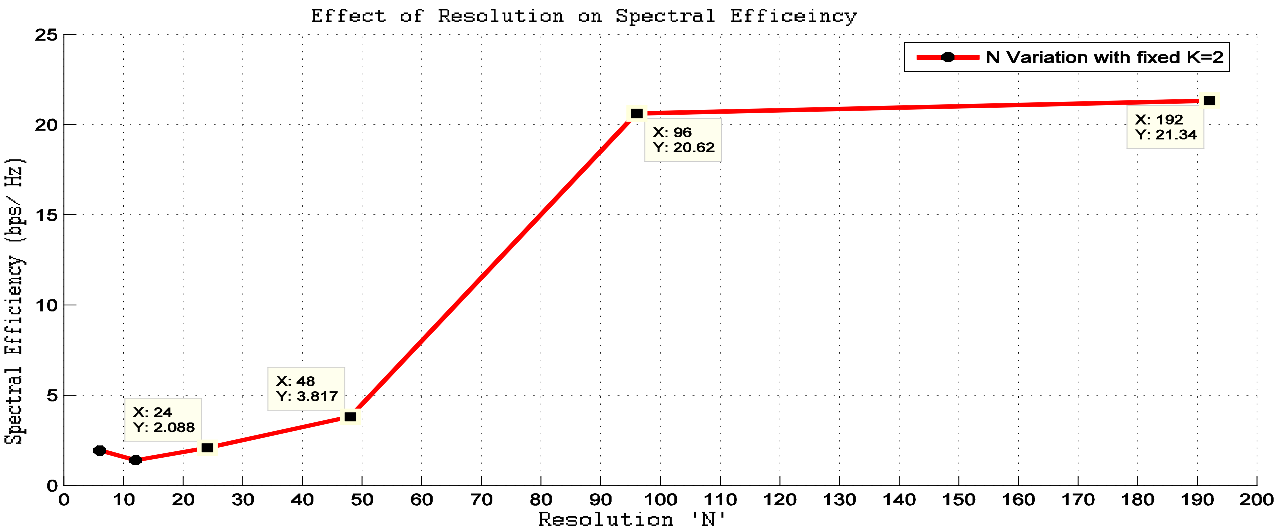


Figure 4.1: Effect of Resolution parameter 'N' on spectral efficiency

If we increase the resolution, spectral efficiency also increases. There will be a compromise between training overhead and performance. If we increase the resolution, our critical parameter synchronization time will also increase. One more thing if we increase the resolution to a large number, it will not give us much improvement. For example, in figure 4.1 when N=96, spectral efficiency is 20.62 bps/Hz. If we doubled the resolution to 192, spectral efficiency is 21.34 bps/Hz. There is just improvement of 0.42 bps/Hz.

4.3. Increasing K with fixed N

It is obvious that if we increase N, our spectrum efficiency also increases. However, if increase training precoding vector 'K' what will be the effect?

Usually, we start training by dividing the Omni pattern into two semi-Omni patterns, to concise our search than dividing the semi Omni pattern into two low-resolution sectors. Instead of dividing the Omni pattern into two-semi Omni pattern, if we divide it into 3, 4, 5…...N (beamforming resolution parameter) precoding vector just after Omni pattern, spectral efficiency also increases.

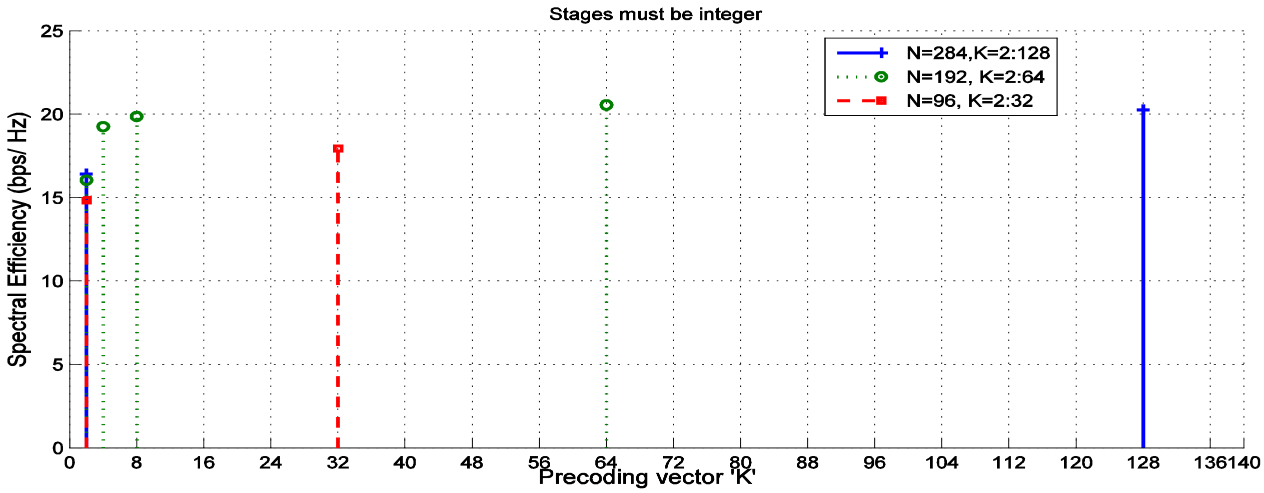


Figure 4.2: Effect on spectral efficiency by taking different values of K with fixed N

In above figure 4.2, **blue line** representing that if we divide the Omni pattern into 4 sectors our spectral efficiency is 18.19 bps/Hz. If we divide the Omni pattern into 8 sectors, spectral efficiency increases to 19.01 bps/Hz and if we divide it into 64 sectors, which is actually somewhat exhaustive, spectral efficiency increases to 20.12 bps/Hz.

One Important thing we just cannot increase our parameter K randomly against any fixed N. Like in above figure **blue line** if we divide Omni pattern into 3 or 5 precoding vector our spectral efficiency will reduce to zero. We must take care of stages of precoder that must be integers. From the figure we can see if N=384, L=3 we can divide semi Omni pattern into either 2 or 384 training vector. Because between these two points, precoder stages condition do not meet.

4.4. Spectral Efficiency comparison when we vary K and N

We know that if we increase the resolution 'N' our spectral efficiency also increases up to some limit. In below fig 4.3, we compared different values of resolution N like 64 and 1024 with some common precoding vector 'k'.

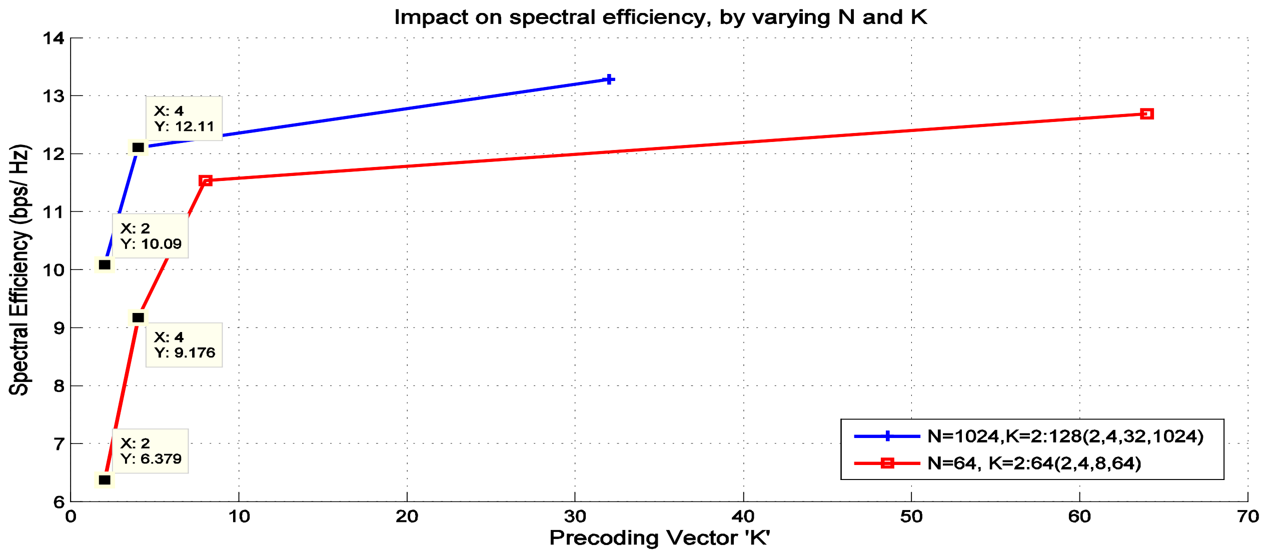


Figure 4.3: Spectral Efficiency Comparison

we observed that resolution has a great impact on spectral efficiency like if we set N=64, spectral efficiency at K=2 is 6.379 bps/Hz and when we set N=1024, spectral efficiency at K increases to 10.09 bps/Hz. Similarly, at K=4, spectral efficiency is 9.176 dB and 12.11 dB when N is 64 and 1024. At common precoding vector, one which have high resolution parameter have high spectral efficiency.

4.5. For Different K, different N is required

From above we observed that by increasing K and N spectral efficiency also increases. However, it is not like random selection of K and N in increasing order to get high spectral efficiency. If we fix N to 64 and start increasing K from 2 to onward 64. We will see there are many points where our spectral efficiency is almost zero. For example, at K=2, we will get good spectral efficiency but at K=3, our spectral efficiency reduced to zero. Then again at K=4, we will get somewhat good spectral efficiency as compare to K=2, then again at K=5, spectral efficiency reduces to zero.

N=192, L=3, SNR= 5dB									
K	2	3	4	5	6	7	8	9	10
S. E	21.21	0.931	23.37	2.14	2.012	3.83	21.35	2.25	1.91
K	11	12	13	14	15	16	17	18	19
S. E	2.04	1.81	2.56	1.69	1.22	1.23	1.164	2.44	1.69

Table 4.1: For different N, different K is designed

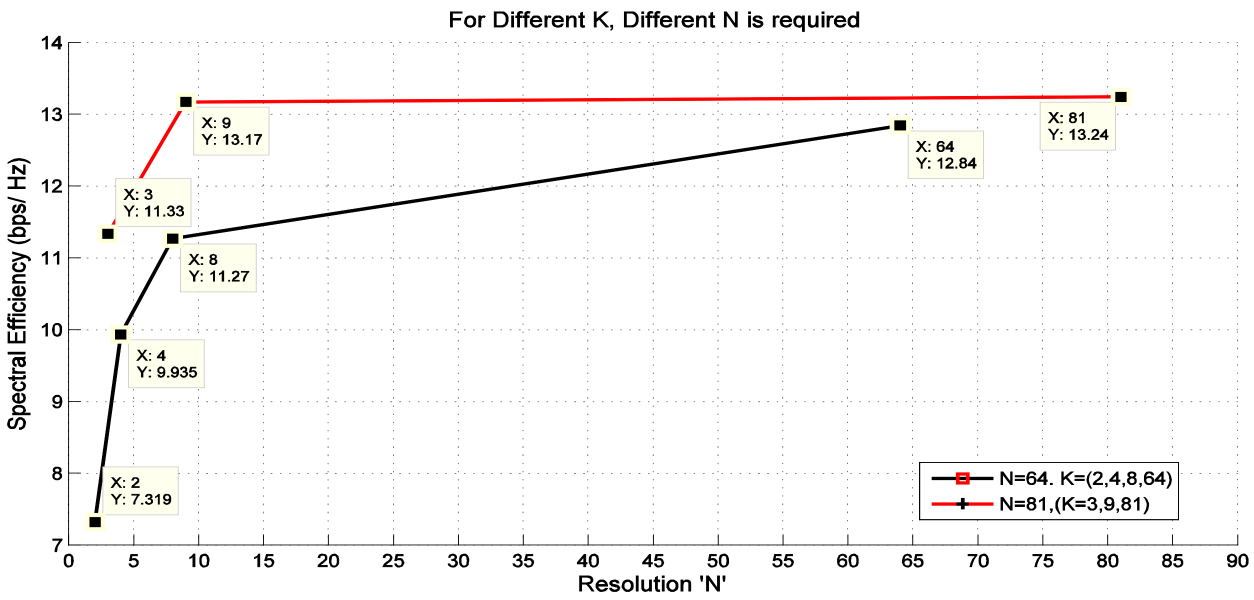


Figure 4.4: Stages must be integer

To get spectral efficiency we must need to set both K and N in such a way that the stages of precoders should be integer.

We can find out the stages of precoder by this formula S=log (N/L)/log (K). Here

If we divide Omni pattern into 3 sectors and if we have three paths, S=log (192/3)/log (3) = 3.7856. It is not possible to have 3.785 stages of precoder. As above explained stages must be an integer.

For N=64, we have just four values of K like, 2, 4, 8 and 64 where we get spectral efficiency because these points satisfy the equation. Similarly, for N=81, K must be 3, 9 or 81.

4.6. Transmitter and Receiver antennas trade-offs impact on Spectral Efficiency using Hybrid Precoding Algorithm.

Another important parameter that has a great impact on spectral efficiency is number of antennas. If we increase the number of antennas, spectral efficiency also increases. Usually, at BS side, number of antennas are greater as compared to MS side. However, increasing antennas also increases cost and size of transmitter and receiver.

Therefore, we must need an optimum combination of BS and MS antennas. In below fig, we observed four combinations.

1- Number of antennas at both sides i.e. BS and MS are equal.
2- Number of antennas at MS is one-half of BS antennas.
3- Number of antennas at MS is one-third of BS antennas.
4- Number of antennas at MS is one-fourth of BS antennas.

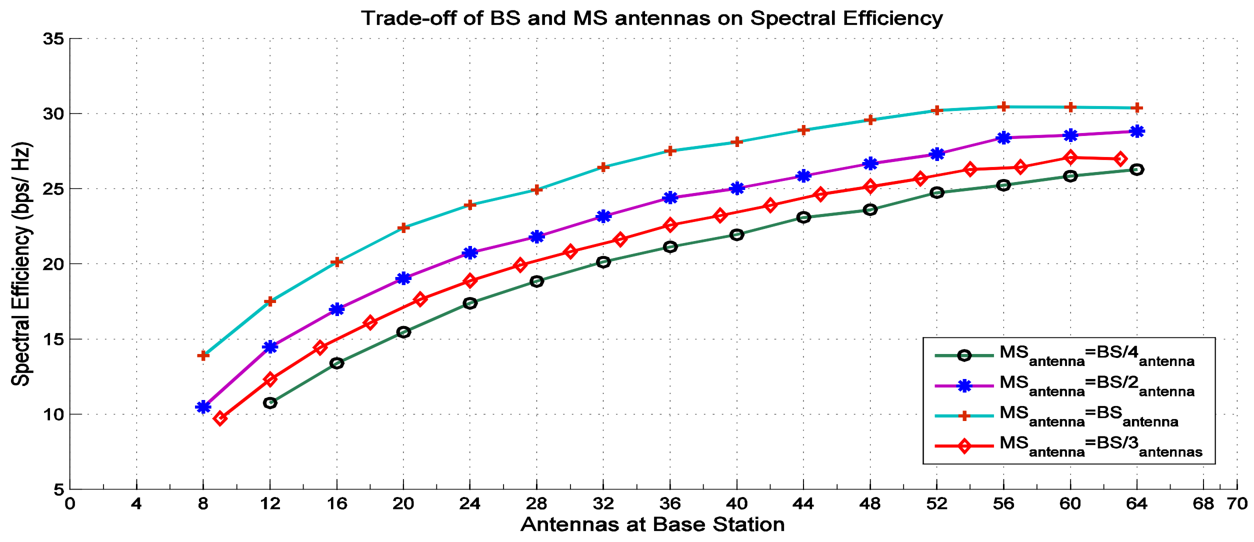


Figure 4.5: Antennas Impact on Spectral Efficiency

From fig 4.5, we observed that the spectral efficiency difference is only 2bps/Hz when we have one-half antennas at MS and when taking one-fourth antennas at MS as compare to BS.

So it would be optimum according to systems engineering if we select MS=BS/4 combination. We will not only get good spectral efficiency but also reduces cost and size.

4.7. Impact of RF chains on Spectral Efficiency using Hybrid Precoding Algorithm.

RF chain is a critical component of transmitter and receiver. It actually processes our signal. Radio Frequency chain is a combination of oscillators, analog to digital converters, digital to analog converters, amplifiers etc. It is a very costly hardware component. By increasing number of RF chains, spectral efficiency also increases. We must need to observe the trade-off of RF chains at BS and MS to select the optimum combination, where we not only get required spectral efficiency but also reduce cost, hardware size and power consumption. Usually, at MS, side number of RF chains are less, because we cannot afford power at MS side.

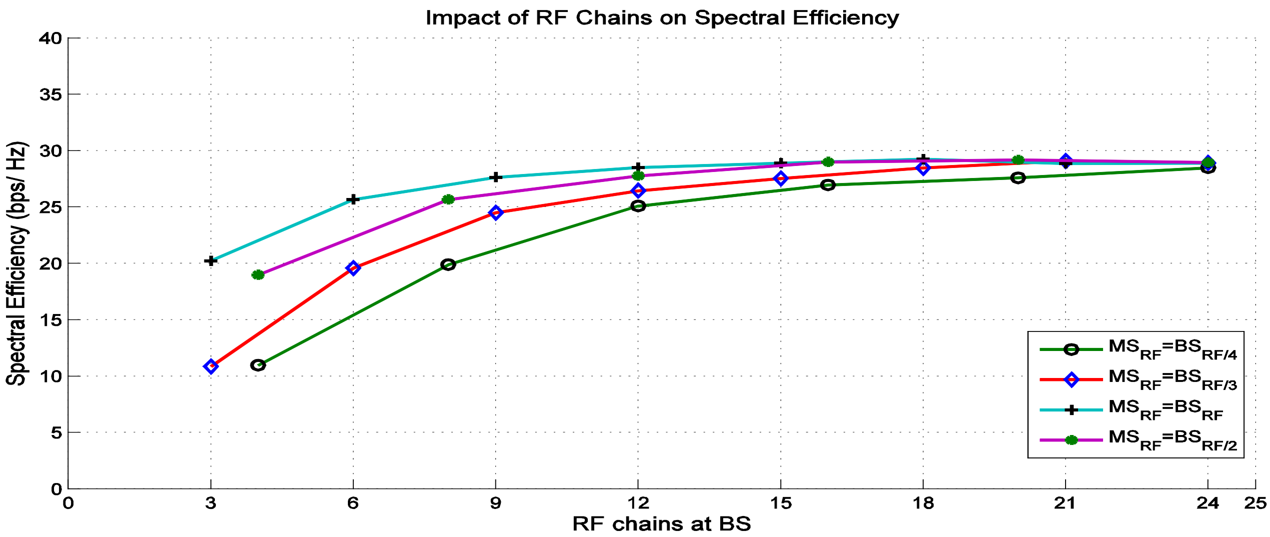


Figure 4.6: Effect of RF chains on spectral efficiency

As in fig 4.6, we observed 4 combinations

1- Number of RF chains at both sides i.e. BS and MS are equal.
2- Number of RF chains at MS is one-half of BS antennas.
3- Number of RF chains at MS is one-third of BS antennas.
4- Number of chains at MS is one-fourth of BS antennas.

The optimum combination is MS_RF=BS_RF/3. Because the spectral efficiency, difference is only 2 to 8 bps/Hz when we have one third RF chains (RF chain/3) as compare to BS RF chains and when we have equal number of RF chains at both sides. Spectral Efficiency difference reduced to zero, if we continuously increase RF chains like in analysis at 24 RF chains, all combination has same spectral efficiency. In device to device communication or base station backhauling it will be optimum to use this combination MS_RF=BS_RF/3. In this way, we will not only get balanced power but also reduce cost, complexity, power consumption and hardware size

4.8. BER to check the efficiency of Hybrid Precoding Algorithm.

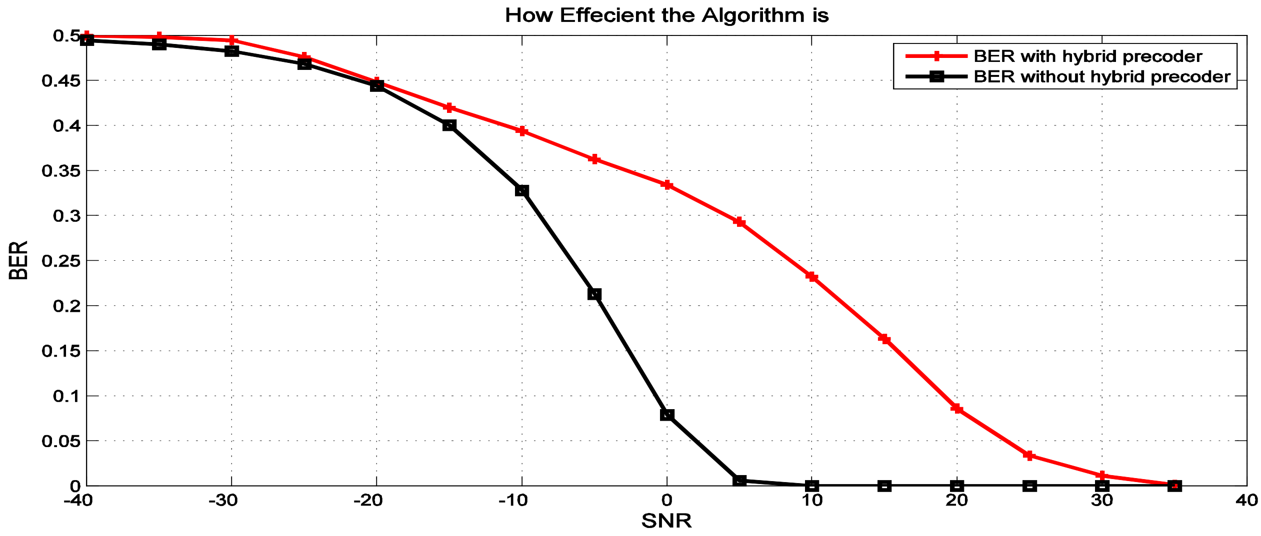


Figure 4.7: BER Effect

From fig 4.7, we observed that our reference signal reached to ‘0’ BER at SNR ’10 dB’. But hybrid precoding signal reached to zero ‘0’ BER at SNR ’35 dB’. The difference is about ’25 dB’ SNR. Difference can also be reduced if we use better modulation scheme like QPSK etc.

In beamforming, signal is sensitive to weather conditions like rain, humidity, fog etc. and different obstacles like trees, moving vehicles around. We must need higher signal power to reduce attenuation, fading and scattering effects.

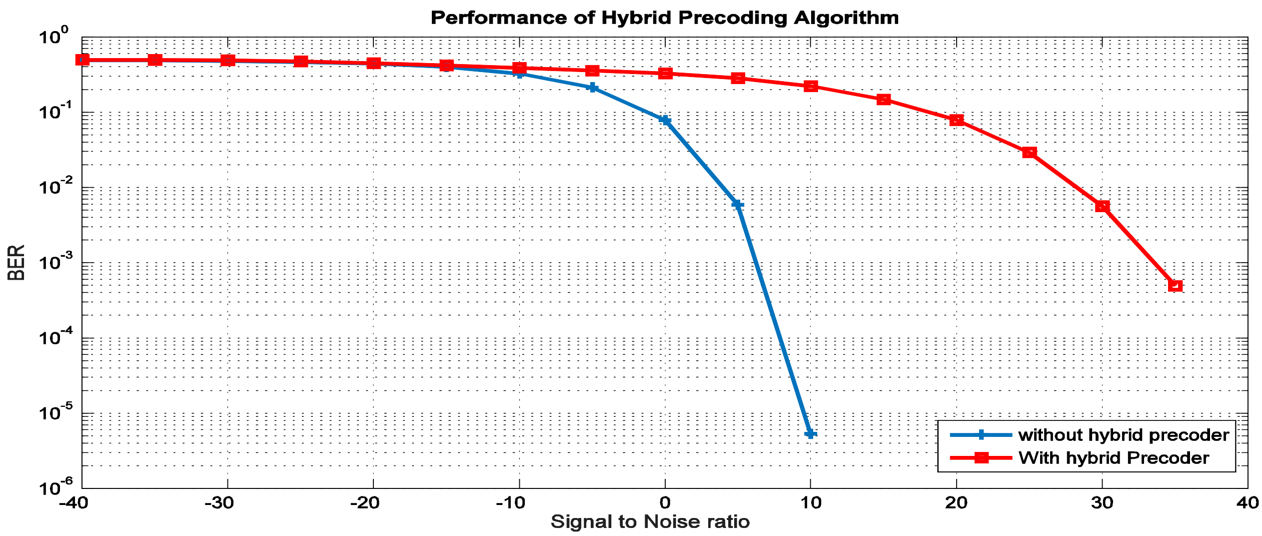


Figure 4.8: Performance of Hybrid Precoding Algorithm by BER analysis

Conclusion

To compensate MMW characteristics which are not favorable for mobile communication like high attenuation and low coverage area. Beamforming is the best option to resolve these issues. Hybrid precoding has been recently proposed as a powerful technique to realize mm-wave communication in 5G networks. It generates high efficient beams of signal with the help of digital and analogue domain of precoder such that the combined signal at each receiver antenna has maximum gain. The beam is generated by weighting each signal according to a precoding matrix, which is continuously updated. The estimation of weights follows optimality condition. Adaptive estimation and multiresolution codebook help in the efficient operation of beamforming.

To enhance the data rate of wireless access, even under conditions of signal fading and interference, massive MIMO concept can be used with the help of multiple RF chains and antennas at both transmitter and receiver side. electronic components of MMW communication system like antennas, oscillators, low noise amplifiers and analog/digital converters are not only costly but also consume a lot of power and significantly increases complexity.

In order to make it feasible for commercial use, we need balanced components where we not only get optimum performance but also reduce cost, complexity, and size of components. An analysis is performed on various hardware components like antennas and radio frequency chains to check the trade-off results. To balance performance and synchronization time, analysis of Resolution parameter ‘N’ and Precoding vector ‘K’ is performed. To examine how efficient is the adaptive algorithm is, we checked its BER with a perfect model.

In simulation section, we observed that spectral efficiency difference is only 3 bps/Hz when we have one half antennas at Mobile Station (MS) and when we have one-fourth antennas at MS as compare to BS. In case of RF chains, we observed that spectral efficiency difference is 5-7 bps/Hz when using one-fourth RF chains at MS and when using one-half RF chains at MS as compare to BS. Spectral Efficiency difference between the two combinations (RF chains/4 and RF chains/2) continuously decreases as RF chains are increases. A point come usually at high number of RF chains, where the spectral efficiency difference becomes zero. We observed that spectral efficiency continuously increases by increasing resolution ‘N’ parameter and precoding vector ‘K’ but at the same time it also increases setup time. To design precoder, precoding vector and resolution parameter are set in such a way that stages of precoder should be integer. The BER results shows that the adaptive estimation algorithm has a very good performance. It has a very low BER. With the help of analysis on different components and parameters, the optimum combination can be found that helps to reduce cost, hardware size, power consumption and complexity-related issues.

Future Work

In examined Hybrid precoding design, beams are generated with help of multiresolution codebook and adaptive estimation algorithm. For which adaptive algorithm have to send signal in both semi-Omni directions. If we develop prediction model with the help of Markov decision process, our synchronization time between transmitter and receiver can be highly reduce. In this way signal are send first in that direction that have high probability of receiver presence.

In Beamforming, Mobility of user is a main issue. Dynamic precoding design can be developed to resolve this issue. In this model we can develop a codebook that continuously update itself according to the location of the receiver.

In this model, research is done on quantized beam steering directions i.e. quantized angle of arrival/ angle of departure. Future work can be done on unquantized model to enhance its efficiency. Effect of Intersymbol interference and Intercell interference effect in hybrid precoding design is an emerging topic. Scattering Effects are observed only in azimuth direction in investigated model. Work can be done azimuth (horizontal) as well in elevation (vertical).

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