# Performance Analysis of Decoupled Enabled 5G Hybrid Heterogeneous Network Exploiting Dual Slope Path Loss Model

By

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# Approval

It is certified that the contents and form of the thesis entitled "Performance Analysis of Decoupled Enabled 5G Hybrid Heterogeneous Network Exploiting Dual Slope Path Loss Models" submitted by Amber Hina have been found satisfactory for the requirement of the degree

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# Dedication

I dedicate this thesis to my parents and my husband for their valuable support and prayers.

## Certificate of Originality

I hereby declare that this submission titled "Performance Analysis of Decoupled Enabled 5G Hybrid Heterogeneous Network Exploiting Dual Slope Path Loss Models" is my own work. To the best of my knowledge it contains no materials previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any degree or diploma at NUST SEECS or at any other educational institute, except where due acknowledgement has been made in the thesis. Any contribution made to the research by others, with whom I have worked at NUST SEECS or elsewhere, is explicitly acknowledged in the thesis. I also declare that the intellectual content of this thesis is the product of my own work, except for the assistance from others in the project's design and conception or in style, presentation and linguistics, which has been acknowledged. I also verified the originality of contents through plagiarism software.

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# List of Abbreviations

| | |
|---|---|
| MBS | Macro Base Station |
| SBS | Small Base station |
| HetNet | Heterogeneous network |
| mmWave | Millimeter-Wave |
| UHF | Ultra High Frequency |
| SS | Single Slope Path Loss |
| DS | Dual Slope Path Loss |
| DSS | Decoupled with Single Slope Path Loss |
| DDS | Decoupled with Dual Slope Path Loss |
| CSS | Coupled with Single Slope Path Loss |
| CDS | Coupled with Dual Slope Path Loss |
| SNR | Signal-to-Noise Ratio |
| SINR | Signal-to-Interference and Noise Ratio |

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# Abstract

Millimeter-wave (mm-Wave) communication is a promising technology to offer high data rates, thus plays an important role as a key enabler in 5G networks, but they have very high path loss and penetration issues. To cater these issues heterogeneous networks (HetNet) deploy in which low power Small base stations (SBS) are overlaid on Macro Base Station (MBS) so that they can accommodate more number of users and also compensate high path loss. Also multi tier heterogeneous networks (HetNets) plays an important role in offloading data traffic from MBS to SBS. Generally user association criteria are depending upon single slope (SS) path loss model which is imprecise because network increased density and irregular cell patterns have caused so much difference in both link distances and interference's. Therefore multi-slope path loss model is more accurate to estimate the increased variations in the links and interference's. This paper scrutinize the affect of downlink and uplink performance of a three tier hybrid heterogeneous network that comprises of UHF based macro base station (MBS) overlaid with small base station (SBS) operating on both the UHF and mmWave bands, and also suggest an approach for user association with dual slope (DS) path loss model. This paper further explores the effect of Decoupling in a three

tier HetNets exploiting dual slope path loss model. Decoupling with dual slope (DDS) path loss model will improve system performance. In Decoupling the network is designed in such a way that users can connect to different base stations in uplink and downlink so that higher gains can accomplish in dense hybrid heterogeneous environment. Our simulation results show that decoupling can be more prominent while applying with dual slope path loss model and hence improve system performance in terms of coverage and data rate as compared to the stand alone dual slope path loss model in hybrid heterogeneous network.

# Chapter 1

# Introduction

Due to rampant increase in wireless data traffic and increasing number of users around the globe it is mandatory to deviate towards 5G, as 5G provides higher data rates and will accommodate more number of users.Also 5G is 10 times faster than the 4G-LTE so it fulfills the requirement of higher speed as well. In the next generation of mobile networks, the future of networking goes beyond connecting people to connecting everything.From field trials and limited implementation, 5G networks have developed into a capable and scalable network technology [1]. As network demand grows, academia and researchers agree that full-scale 5G implementation is the only way to meet the ever-increasing demands of consumers and networks.Few key performance indicators for 5G as shown in Fig. 1.1 is defined as follows [2].

- User Data Rates: 5G promises to provide higher data rates upto Gigabits per second to a mobile user or device in the coverage area.Average data rates upto 100 megabits per second (Mbps) can achieve. Normally a user can have data rate upto 100 Mbit/s is expected to be enabled for wide area coverage situations, such as in urban and sub-urban areas. In hotspot situations, the user-experienced data rate is supposed to be higher e.g 1 Gbps indoors.

- Spectrum Efficiency: Expanding spectral efficiency has always been a priority for the wireless industry, but its significance has grown as mobile data use has skyrocketed and continues to rise. Several characteristics of 5G technology contribute to its spectral efficiency (bit/s/Hz) such that by using larger spectrum blocks, beamforming and massive mimo techniques .

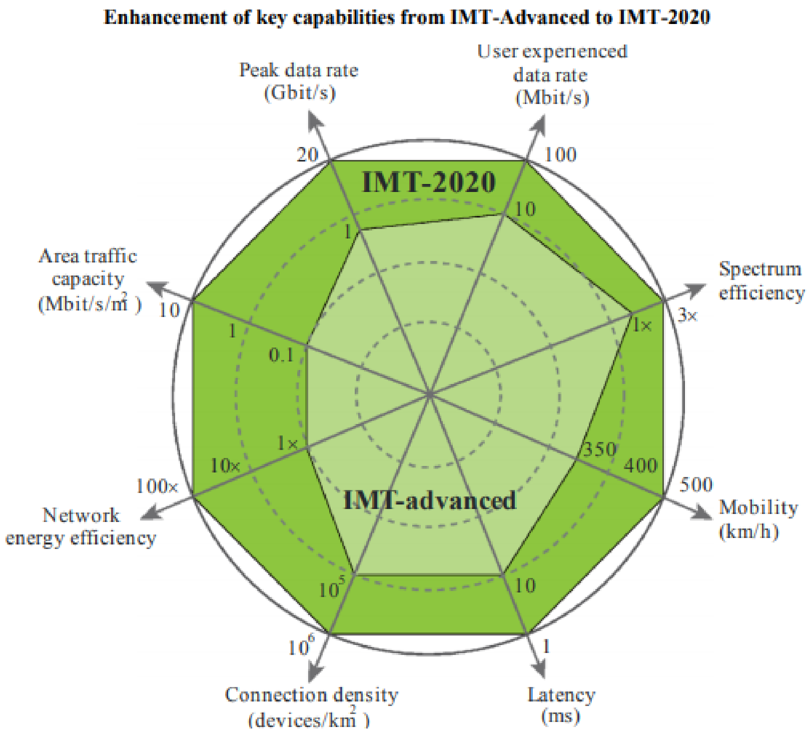


Figure 1.1: Key performance indicators for 5G (Source: ITU-R WP5D, 2015)

- Mobility: 5G provides the maximum speed (in km/h) at which a given service quality and smooth transition between radio nodes belonging to different layers and/or radio access technologies can be attained.

- Latency: 5G can be used to solve a crucial issue such that network latency reduction. Latency specifies the end-to-end communication,calculating the time between the sending of a specified piece of information and the resulting response.So 5G can transmit and receive data in less than a millisecond which will make system faster.

- Massive Connection Density: The advent of concepts such as smart cities, smart parking, and smart cars has increased the need for massive connectivity among devices by orders of magnitude. Massive connectivity in the form of machine-to-machine [3–6] or Internet-of-things (IOT) sensors is needed for future network survival which can only be possible with 5G.

- Network energy efficiency: Energy efficiency has two components: on the network side, it refers to the number of information bits transmitted or received from users per unit of energy consumption of the radio access network (in bits/Joule); on system side, it refers to the number of information bits per unit of energy consumption of the communication mode (in bits/Joule).So according to IMT-2020 5G can enhance network energy efficiency upto 100 times than existed infrastructures.

- Area traffic Capacity: Area traffic capacity can be defined as a total traffic throughput served per geographic area. According to the IMT-2020 standard, 5G is expected to support 10 Mbit/s/m$^2$ area traffic capability, for example in hot spots.

- Peak Data Rates: 5G has the potential to be far faster than 4G LTE, with peak data rates of up to 20 Gigabits per second (Gbps) and typical data rates of 100 Megabits per second (Mbps).

## 1.1 Emerging Innovations for 5G

5G promise to provide high data rates,low latency,higher spectrum,improve network energy efficiency and enhance area traffic capacity.Many technologies have been emerged as a foundation for 5G as shown in Fig.1.2. Few of them are listed below in detail.

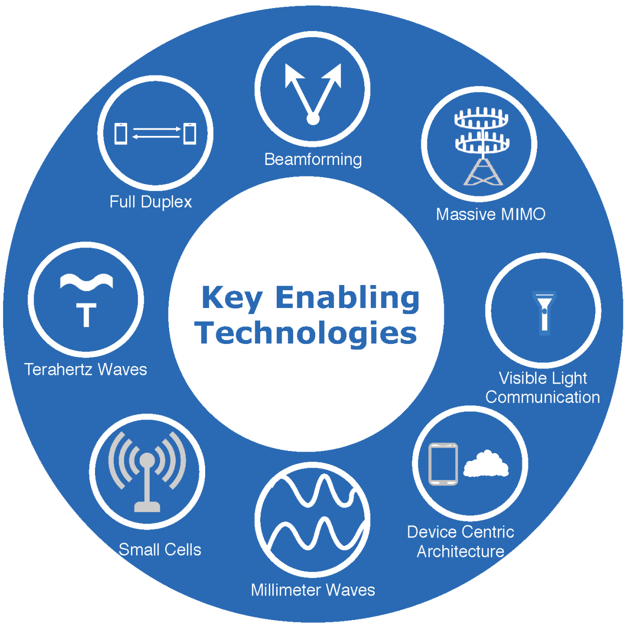


Figure 1.2: Emerging innovations for 5G (Source: MDPI, Sensors 2020)

### 1.1.1 Millimeter Wave

Millimeter wave (mmWave) is one of the important key enabler for 5G. It uses wider spectrum above 6GHz bands as shown in Fig. 1.3. So due to the larger spectrum available its feasible to accommodate more number of users and also can accomplish higher data rates by using millimeter wave spectrum. Data rates upto 2 gigabit-per-second (Gbps) at a distance upto 1km can accomplish in an urban environment [7] shows that mm-Wave band will be extremely useful for the evolution of 5G cellular communications. However, apart from offering larger spectrum mmWave band suffers from higher path losses which occur over longer distances also the effects of blockages is not negligible here.

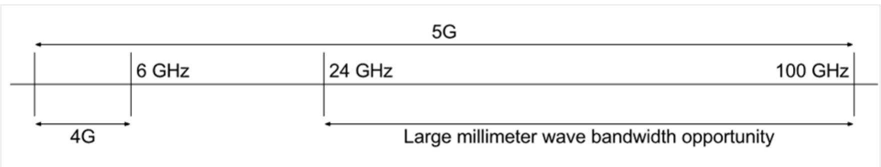


Figure 1.3: Larger spectrum for mmWave

### 1.1.2 Small Cells

Small cells also called mini base stations work exactly similar to traditional base station. The only difference is these are low power small base station that deployed closer to traditional towers and users, so that data traffic can offload from macro base stations to mini base stations. This traffic offloading will improve data rates for users and also can accommodate more number of users, hence small cells are also an important enabler for 5G. Another advantage of small cells is that they can handle the major issue related to mmWave band, that is higher path loss occur over longer distances. By deploying small cells, users will now come closer to the base station and hence it reduce the path losses, which is a major issue with mmWave spectrum. There are different types of small cells e.g femtocells, and picocells as shown in Fig. 1.4.

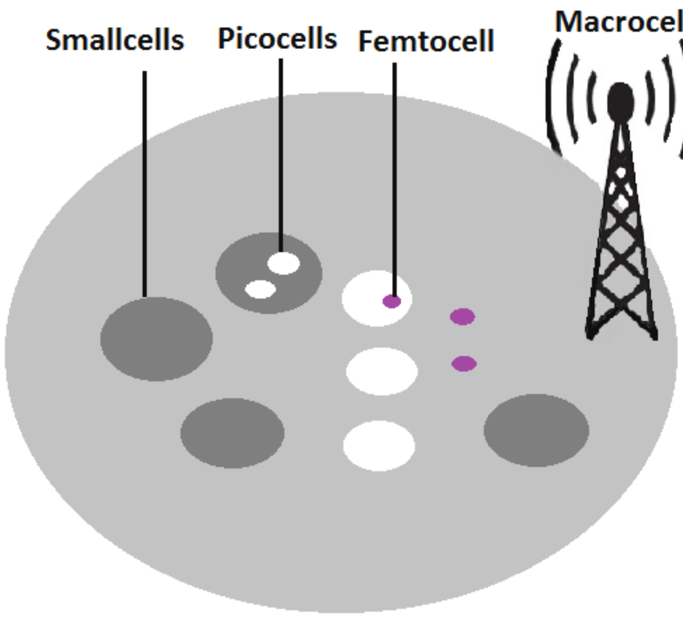


Figure 1.4: Types of small cells

### 1.1.3 Massive MIMO

Massive multiple-input, multiple-output, or massive MIMO systems are an essential component of today's wireless systems, and they have been widely used in recent years to attained high spectral performance and energy efficiency. Massive MIMO, is a strategy for improving throughput and spectrum efficiency by grouping together antennas at the transmitter and receiver. As this technique will support hundreds of ports on antennas, that can increase the capacity to meet the requirement for 5G.So this technology is being considered by 5G networks as a possible solution to the problem caused by massive data traffic and users. But the issue with massive MIMO is severe interference that cause due to multiple antennas ports.

### 1.1.4 Beamforming

In beam-forming method, base station transmits a focus stream of data towards receiver, rather than spreading the signal in all directions from a broadcast antenna, as it happened in traditional case. Beam-forming assists the base station in determining the best route to transmit data to the user while also reducing interference with other users along the path. Depending on the circumstances, beam-forming technology in future networks can be applied in a variety of ways. Beam-forming improves spectrum performance in large MIMO systems, and it improves data rate in millimetre waves. In large MIMO systems, the base station can send data to the user through multiple routes, and beam-forming coordinates packet movement and arrival time to enable more users to send data at the same time. So beam-forming can resolve the issue of massive MIMO as now focused stream of data transmitted towards the receiver and no such interference occur in this case.So its an essential element of 5G.

### 1.1.5 Full Duplex

Wireless transmission and reception are usually not performed at the same frequency bands to prevent interference. To obtain orthogonal non-interfering signals, any bidirectional device must distinguish the uplink and downlink channels using time or frequency domain. In full duplex technique a transceiver would be able to send and receive data by using different frequency bands at the same time, which will make it faster also double the capacity of wireless networks.5G networks can also use full-duplex signal propagation to effectively double network bandwidth, which is advantageous for higher layers. Full duplex, on the other hand, has the drawback of creating additional signal interference in the form of an unpleasant echo. When a transmitter sends out a signal, it is significantly closer to the device's antenna and hence far more effective than any signal it receives. An antenna will be able to communicate and listen at the same time owing to special echo-canceling technology.

## 1.2 Thesis Motivation

This thesis is inspired by the implementation of a decoupled enabled hybrid heterogeneous network that uses a dual slope path loss model to improve coverage and data rate of a network.Work is done on decoupling and dual slope path loss independently. As both techniques improve system performance and provide accurate and realistic results. so intuitively it is clear that we can have better results by combining both techniques to make our network more efficient and reliable. User data rate criteria must be met in the region where the mmWave Small base station is deployed because mmWave base stations can provide 2 gigabit-per-second (Gbps) at a distance upto 1km in an urban environment Ḣybrid HetNets offers ability for on demand and rapid deployment also can provide bandwidth expansion.

## 1.3 Thesis Contribution

The main purpose of this thesis is to provide following contributions.

- We evaluate the performance of three tier hybrid heterogeneous network having decoupling with dual slope path loss model (DDS) to see its performance in terms of rate, coverage and spectral efficiency.
- For the first time, coexistence of mmWave and UHF frequency bands in the same geographical area has been suggested for decoupling and a dual slope path loss model that will provide useful insights into such a network for researchers.
- We examine network behaviour by varying the number of small base stations in a heterogeneous environment that correspond to the macro base station deployed at the centre,and then analyze the network performance in terms of sum rate, association probabilities, rate coverage and coverage gain.
- We suggest an optimal number of mmWave and UHF small base stations in the network, based on the network characteristics.
- The increase in data rates is clearly visible as the number of small base stations increases, as more users link to mmWave base stations.

- To the best of our knowledge this is the first work that figure out the advantage of decoupling and dual slope path loss together in hybrid heterogeneous network.

## 1.4 Thesis Organization

The rest of the thesis is constructed as follows: Chapter 2 presents the literature review in which related research work and proposed research will be explained. In Chapter 3 system model is conferred, in which decoupling with dual slope path loss model (DDS) is introduced in hybrid heterogeneous environment. Also performance analysis is done for our proposed system model in terms of coverage,data rates and energy efficiency. In Chapter 4, we discuss in detail the results after detailed performance analysis of our proposed scheme DDS. In the end, we present conclusions and future work of our proposed study in Chapter 5.

# Chapter 2

# Background and Literature Review

This chapter provides background information and a literature review on next generation mobile network technologies. It addresses the benefits of various network deployments, such as hybrid and heterogeneous networks. It also goes into the detail of decoupling technique with dual slope path loss, highlighting its significance in this context. In the next generation of mobile networks, the future of networking goes beyond connecting people to connecting everything [1, 8]. In this respect, 5G will usher in a new age of wireless networking by incorporating a globally unified radio access technology into today's generation of 4G networks. A lot work has been done on 5G and beyond 5G systems [9–39]. So that new research directions are needed to deploy the architecture of 5G cellular network. Author in [40] propose 5 fundamentals as a key enabler for 5G, device centring architectures, millimeter wave, massive MIMO, smarter devices, and initial support for machine to machine communications. Each technology have their different impacts on 5G cellular networks. Author in [41–43] also represent terrestrial and aerial combination for key enabler for 5G and 6G.New techniques also introduced to enhance spectral efficiency and provide ultra reliable and low latency communication. [44–46].

## 2.1 Why Hybrid Heterogeneous Network

Due to the enormous network applications, there is a paucity of spectrum, which has compelled academia and researchers to further explore the radio wave spectrum in order to address the spectrum shortage problem. The millimeter-wave (mmWave) spectrum allows us to use vast amount of previously inaccessible bandwidth to meet the data rate requirements of bandwidth-hungry applications [47–50]. However, the propagation properties of the mmWave band vary greatly from that of the ultra high frequency (UHF) band so directional beam forming require [51, 52]. On the other hand, efficient deployment of mmWave base stations is needed to compensate for the increased mmWave path loss. So hybrid network comes up as a compelling solution to the problem as discuss in [53–56] and in [57, 58].

This paper examine the uplink of an Internet-of-thing (IoT) network here users send their information to a base station [59]. Authors in [53] have proposed hybrid network deployment, in which base stations that operate on UHF frequency band and mmWave frequency band coexist in a particular geographical region. The rate coverage of hybrid cellular networks is almost equivalent to that of a standalone mmWave network and significantly higher than that of a standalone UHF network [53]. So hybrid network plays a significant role in evolution of 5G. Also due to the both frequency bands available in hybrid deployment, coverage will improve due to UHF frequency band and rate will improve due to mmWave frequency band, as only mmWave base station cannot have good coverage over longer distance due to higher path losses.

Apart from the hybrid network, over the past few years heterogeneous network (HetNet) have grabbed the interest of researchers, as user association schemes for load balancing in such networks are also a highly contentious topic [60–62]. HetNet with hybrid network has paved the way of bandwidth extension [63, 64]. HetNets work on different transmit powers for different tiers. Authors in [65, 66] conducted a research on coverage and rate study of such a network with mmWave MBS overlaid with mmWave SBS. By using efficient resource allocation schemes, mmWave HetNet which are not only increasing network rate and coverage can be make more energy efficient [61,67,68]. In HetNets low power small base station are deployed closer to macro base station and users, so that data traffic can offload from macro base stations to small base stations [69].This integrated implementation of low-power base stations, in comparison to the original cellular network, has a tremendous potential to deal with the dramatic increase in wireless data traffic by enabling the convergence of technologies, frequency bands, cell sizes, and network infrastructures [70]. Also traffic offloading will improve data rates for users and also can reduce path loss which occur over longer distances [71, 72]. Another significant reason for deploying HetNet is to create an energy-efficient system, because in HetNet small base station (SBS) with

limited coverage range enables base stations and users to communicate at low powers, resulting in lower energy consumption and interference [67].
A detailed analysis on coverage of mmWave UAV's and THz enabled heterogeneous network is given in paper [73]. Advantage of small base station in terrestrial and aerial network is explained in [74, 75]. HetNet guarantee a major improvement in overall network capacity,including fast data speeds and increased cell coverage [76, 77]. So HetNets emanate as an imperative solution to cater issues related to mmWave path losses, offloading data traffic from MBS to SBS and also to make energy efficient system.

## 2.2 Decoupling and Dual Slope

Current literature implements single slope path loss model to reflect path loss across the entire coverage range. Although the single slope model is simple to learn and evaluate, but it can represent the network in an unrealistic and less accurate manner at sometimes.So this deterioration occurs is due to the fact that this model does not perfectly capture the dependence of the path loss exponent on the link distance [78]. As author in [79] stated that, although the free space signal loss (also known as the Friis equation) is well-motivated by the standard path loss model, it is also well-known to be very idealised and does not capture the distance-dependence of the path loss exponent, which is experimentally known. Studies and research show that single slope path loss model is less accurate and less realistic to estimate the path loss.As it is experimentally proven in [80] that path loss is not smoothly decreasing with increasing distance. Actually after certain distance ($d_0$) called critical distance the slope varies as we can see in Fig 2.1. So its clear that after certain distance which in environment dependent the value of path loss exponent must be changed to estimate the realistic and accurate behavior of the network. So the trend deviate towards dual slope path loss (DS) model, as dual slope model can better approximate the link. Multi slope path loss models use different values of path loss exponents for different connection lengths, resulting in better dense network efficiency. This model was first investigated in the LoS setting for the free space reference distance presented in [81] and in the indoor paradigm in [82].

To reduce the root mean square (rms) error between mean path loss samples and the path loss model in the NLoS environment, a dual slope path loss model technique has been developed [83].

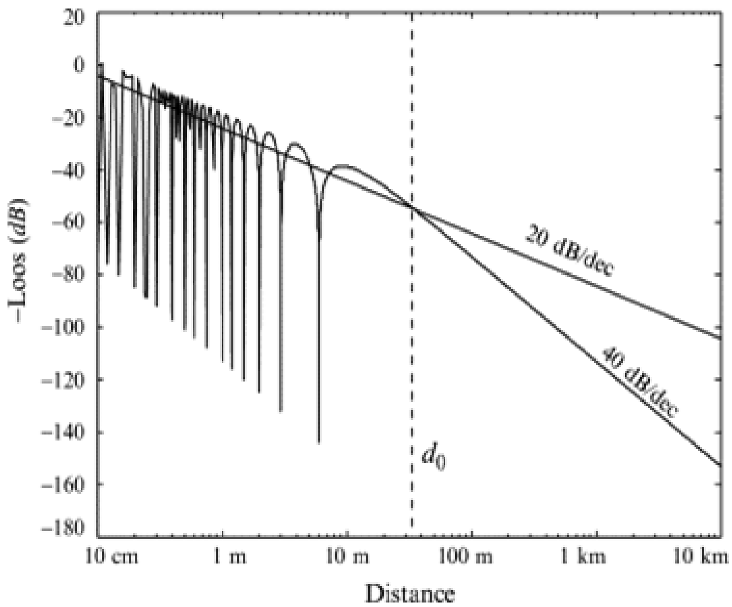


Figure 2.1: Path loss(dB) versus distance(m)

In [84], On the downlink of a cellular network, coverage likelihood and network throughput were investigated in detail using a multi slope path loss model. Author in [85], studied dual slope path loss models (DS) for coverage probability with different number of users taken into account. Further research has been done by using dual slope path loss model for user association in HetNets [71]. The role of biasing factor on user association is investigated using a dual slope model [71].Also in dual slope path loss model user association gains in dense networks are found to be highly sensitive to the path loss exponent beyond the critical distance [86]. This research [87] looked into the efficiency of a two tier HetNet with dual slope path loss models on both tiers and flexible duplexing for users. The critical distance in dual slope path loss models and the adaptive threshold distance in flexible duplexing mode have been demonstrated to be significant parameters that have a direct effect on the system's sum rates, coverage and energy efficiency.

Decoupling is another important approach that is used in this paper to boost system efficiency in terms of uplink data rates and network coverage. Ever since the advent of wireless communication, the downlink and uplink of cellular networks have been coupled, that is, mobile terminals have been confined to communicate with the same base station in both the downlink and uplink directions. New patterns in network increased density and cellular data demand, reinforce the disadvantages of this restriction, implying that it should be revisited. As authors in [88] illustrate that decoupling can result in drastic increases in system performance, outage, and power efficiency at a lower cost compare to other solutions that offer similar or lower gains.

According to the study in [89],the network is designed in such a way that users can connect to different base stations in uplink and downlink called decoupling, so that higher gains can accomplish in dense hybrid heterogeneous environment.Traditionally user is bound to communicate to the same base station in uplink and downlink, called coupled scenario.While in decoupling user is allowed to connect to different base station in uplink and downlink. In coupled scenario users don't have open access so the disadvantage is that if a user is closer to another base station it cannot transmit to that BS as it is bound to transmit data to the same base station form where it is receiving in downlink, resulting in reduction of uplink data rates.

In [90] authors address decoupling as a potential part of heterogeneous network. When decoupling is used during user association, it demonstrates a substantial improvement in rate and signal-to-interference plus noise ratio (SINR).Authors investigated the impact of decoupling in a two-tier heterogeneous environment having UHF and mmWave deployment [91]. While in [92] gives a comprehensive analysis of downlink and uplink decoupling in the mmWave and UHF hybrid network. But this analysis is based on simple two tier hybrid heterogeneous environment, it does not considered decoupling in different blockage environments which is an important factor.

In [93] and [53] both suggested a simple stochastic blockage model. The random shape theory is used to model blockages using a Boolean model of rectangles. Now the effects of decoupling are more prominent in urban and suburban environment. So due to many benefits, integration of decoupling with dual slope path loss model can be an interesting area of research.But limited research has been done in combining decoupling with dual slope in heterogeneous environment.

As in paper [94] downlink uplink decoupled multi tier heterogeneous networks, the effect of changing path loss exponent on user association probability, decoupled uplink coverage probability, and decoupled uplink average spectral efficiency is investigated.As already mentioned in [86], the role of uplink and downlink decoupling and biasing factor is studied on user association exploiting dual slope path loss model.

## 2.3 Related Work

The authors in [3] and [7] discuss about the importance of mmWave spectrum usage, as we can accomplish high data rates upto 2 gigabit-per-second (Gbps) at a distance upto 1km in an urban environment hence [7] shows that mm-wave band will be extremely useful for the evolution of 5G cellular communications. The rate coverage analysis of hybrid cellular network is done in [53] ,which shows that hybrid network consisted on both mmWave and UHF bands can attain higher rate coverage as compare to stand alone mmWave networks and stand alone UHF stand alone networks. A more precise analytical study on hybrid network is presented in [53]. HetNets are important to offload data traffic from MBS to SBS, also use to cater issues related to mmWave higher path loss [60]. Deployment of Dual slope model in heterogeneous network and with flexible duplexing is explained in [71] and in [87], which shows that dual slope better approximate the link as well as it offloads more users towards small base station which results in load balancing and hence data rates for users also increases. Decoupling advanatge is explained in [88, 90], while author in [89] shows the performance improvement accomplished by using decoupling in rural and urban environment. In order to improve more performance in terms of data rate, coverage and energy efficiency, this paper will investigate the advantages of uplink/downlink decoupling with dual slope path loss model in hybrid heterogeneous networks while considering two types of environment moderate and harsh to better illustrate the results.

## 2.4 Research Gap and Proposed Research

To the best of my knowledge in existing literature, performance analysis is done on dual slope path loss model and on decoupling independently. And later on research is done by combining both techniques in heterogeneous network but only considering UHF band .Up till now no work has been done by considering mmWave band which is an essential element for 5G. We can achieve better and realistic results by applying decoupling phenomenon in 5G hybrid HetNets exploiting dual slope path loss model. By combining dual slope path loss model and decoupling in hybrid heterogeneous network will provide higher coverage gain as well as higher uplink data rates. The effect of decoupling will be more prominent while applying with dual slope model, which will prove by simulations.After that we will compare our proposed scheme decoupled with dual slope (DDS) with three other schemes i-e decoupled with singlele slope (DSS),coupled with dual slope (CDS) and coupled with single slope (CSS) to develop better understanding about this research.

# Chapter 3

# Decoupling with Dual Slope Path Loss Model

In this chapter, we present a system model of decoupled with dual slope path loss model in hybrid heterogeneous network.Two environments are encountered separately to check the system performance in terms of coverage and data rates. We compare our proposed scheme DDS with three other schemes i-e coupled with single slope path loss model (CSS) and with dual slope path loss model (CDS) and with decoupled with single slope path loss model (DSS) . All these four cases are examined for moderate and harsh environment separately to show the comparison in a more effective way. As authors in [89] have shown that uplink and downlink decoupling have different impacts in harsh and moderate environment, because both environments have different blockage model thus having different blocking parameter for each environment. Also its important to note that performance improvement due to decoupling is environment dependant.

Simulation results will show that decoupling with dual slope path loss model (DDS) outperforms the decoupling with single slope path loss model (DSS), coupled with dual slope (CDS) and coupled with single slope (CSS).

## 3.1 System Model

Consider a 3-tier HetNet where a UHF based macro base station (MBS) is deployed at the center of the circle of radius 500m, while low power small base stations (SBS) consisting on UHF and mmWave frequency bands are uniformly overlaid on MBS. Image of a 3-tier hybrid HetNet is shown in Fig 3.1, where tiers are shown with coupled and decoupled techniques for better illustration. Dual slope path loss model is applied on UHF macro base station (MBS) and on UHF small base station (SBS) in downlink, because according to the study in [95] dual slope model found to be unnecessary for mmWave frequency band, as distance range for mmWave bands are very small so it does not provide the significant improvement in this case. Also dual slope path loss model appears overly complex for mmWave frequencies. Left right dashed arrows indicate the uplink and downlink association with same base station defining the behavior of coupled scenario. While single dashed arrows show the uplink and downlink association with different base station which is called decoupling. Critical radius for UHF macro base station and UHF small base station is shown in red circle describing the behavior of dual slope path loss model. Path loss models for UHF and mmWave bands will be explained in section 3.1.1 in detail.

The macro base station (MBS) is denoted by $M$ while small base stations

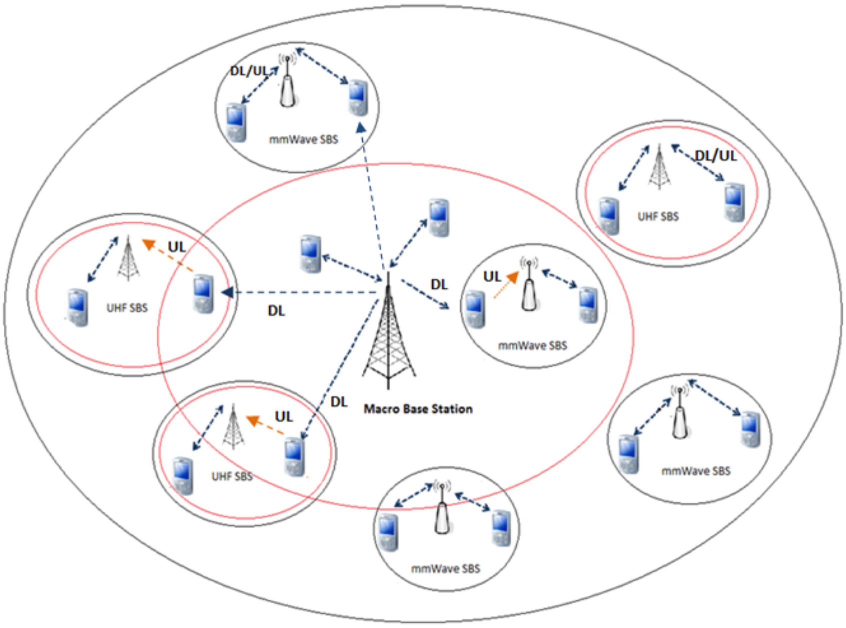


Figure 3.1: System model for coupled and decoupled with dual slope path loss model

(SBS) which are overlaid on MBS are denoted with $Su$ and $Sm$ representing UHF and mmWave frequency bands respectively. Total SBS are equal to, $S=$ $Su$ U $Sm$. Here density of $Su$ and $Sm$ are considered to be equal unless otherwise stated in all cases. Let $U$ be the set of total users deployed uniformly in the entire geographic area, and $U = Um$ U $Us$ where $Um$ and $Us$ are the number of users served by MBS and SBS respectively. UHF and mmWave SBS are uniformly distributed in entire given area with equal intensity. We assume open access which means user is allowed to associate to any BS in uplink and downlink. We assume nakagami fading. Here maximum biased received power is chosen as association metric in downlink and uplink. Simulation parameters for path loss models are stated in Table 4.1 for moderate and harsh environment.

### 3.1.1 Path Loss Model

Path loss model $L_{mm}(d)$ for mmWave link in dB is given as :

$$L_{mm}(d) = \begin{cases} \rho + 10\alpha_l log(d) + \delta_l & for LoS \\ \rho + 10\alpha_n log(d) + \delta_n & for NLoS \end{cases} \tag{3.1}$$

In above equation 3.1, $\rho$ is fixed path loss is given by $\rho = 32.4 + 20log(f_{mm})$ where $f_{mm}$ is carrier frequency for millimeter wave and $d$ is the radial distance between base station and user measured in meters. The path loss exponent is denoted by $\alpha_l$ and $\alpha_n$ for LoS and NLoS mmWave links respectively. While $\delta_l$ and $\delta_n$ are log normal random variables with zero mean and variance $\sigma^2$ which express the shadowing impact in LoS and NLoS mmWave link respectively. To cater the LoS and NLoS mmWave links we assume simple probability model as suggested in [53, 93]. A user is assumed to be in Los and in NLoS with certain probability given in equation 3.2 and 3.3 respectively.

$$P_l(d) = e^{-\beta d} for LoS \tag{3.2}$$

$$P_n(d) = 1 - P_l(d) for NLoS \tag{3.3}$$

Here $d$ is the distance between base station and user in meters and $\beta$ is the blocking parameter which is estimated using building measurements for region of interest (ROI) including density and average blockage size in the considered area. $\beta$ is calculated as 3.4

$$\beta = \frac{-\psi ln(1-\omega)}{\pi A} \tag{3.4}$$

In above equation 3.4, $\psi$ is the average building perimeter (m) in the region of interest, $\omega$ is the fraction of area covered by buildings and A is the average area of the buildings in $m^2$. Using the Quantum Geographic Information System (QGIS) application, these parameters are derived for a variety of real-world environments. Authors in [89] calculated the the value of blocking parameter $\beta$ for moderate and harsh environments which are given in Table 4.1. We measure the path loss for each millimetre wave tier based on these probabilities, after determining the $P_l(d)$ and $P_n(d)$ using equation 3.2 3.3 respectively.

For UHF band single slope path loss model $L_{uhf}(d)$ in dB is given as :

$$L_{uhf}(d) = 20log\left(4\pi f_{uhf}\right) + 10\alpha log(d) + \delta_{uhf} \tag{3.5}$$

In above equation 3.5, $f_{uhf}$ is the carrier frequency for UHF band, and $d$ is the distance between base station and user measured in meters. The path loss exponent is denoted by $\alpha$ and $\delta_{uhf}$ represent shadowing effect with zero mean and variance $\sigma^2$ in UHF link. Although the single slope path loss model is the conventional path loss model, but it fails to adequately explain the path loss exponent dependence on the external surroundings in crowded and millimetre wave compatible networks.These constraints result in the dual-slope path loss model. [71]

For UHF band dual slope path loss model $L_{uhf}(d)$ in dB is given as :

$$L_{uhf}(d) = \begin{cases} \rho + 10\alpha_1 log(d) + \zeta_{uhf} & d \leq r_{th} \\ \rho + 10\alpha_1 log(r_{th}) + 10\alpha_2 log(\frac{d}{r_{th}}) + \zeta_{uhf} & d > r_{th} \end{cases} \tag{3.6}$$

In above equation 3.6, $\rho$ is fixed path loss is given by $\rho = 32.4 + 20log(f_{uhf})$ where $f_{uhf}$ is the carrier frequency for UHF band and $d$ is the distance between base station and user measured in meters, $r_{th}$ is the threshold radius for UHF macro base station and UHF small base station. After threshold radius $r_{th}$ the value of path loss exponent changes according to the tiers. While $\alpha_1$ and $\alpha_2$ are two path loss exponents for below and beyond threshold radius given in Table 4.1 for moderate and harsh environments.
$\zeta_{uhf}$ is log normal random variable with zero mean and variance $\sigma^2$ which express the shadowing effect.

### 3.1.2 User Association Criteria

We assume open access which means user can connect to any BS in uplink and downlink. Both the uplink and downlink user associations are analyzed according to the maximum biased received power, so that user will associate to that BS which provides maximum power to it.

Consider the downlink user association, then receive power $P_{rx,dl}$ at each user is calculated in dB for both the mmWave and UHF link is as follows:

$$P_{rx,dl} = P_{tx,dl} - PL(d) + BF + G(\theta) + \mu \tag{3.7}$$

Where $P_{tx,dl}$ is the downlink transmitted power from all tiers, which is 46 dBm for MBS and 30 dBm for SBS as mentioned in Table 4.1, PL(d) is the path loss measured at a distance a $d$, BF is the biasing factor for mmWave band while for UHF SBS and for MBS its equal to unity, $G(\theta)$ represents the antenna gain for mmWave. $G(\theta)$ is also assumed to be unity for MBS and for UHF Small base station. The biasing factor is an important parameter for mmWave tier because it offloads data traffic from UHF base stations to mmWave base stations based on netwrok and user requirement, so that high data rates can accomplish. Here $\mu$ represent multi-path fading based on whether the link is formed is UHF or mmWave. We consider a Nakagami-m fading with m = 1 for NLoS links which represent Rayleigh fading and m = 5 for LoS links.

Based on equation given in 3.7, which base station provides maximum biased received power to user, user will associate to that base station in downlink. We calculated the antenna gain given in equation below

$$G(\theta) = \frac{2}{1 - cos(\theta)} \tag{3.8}$$

where $\theta$ is the azimuthal angle of UHF and mmWave base station beam alignment.Similarly for uplink user association same strategy is considered, only uplink transmit power will be changed. So uplink received power $P_{rx,ul}$ in dB is calculated as follows

$$P_{rx,ul} = P_{tx,ul} - PL(d) + BF + G(\theta) + \mu \tag{3.9}$$

## 3.2 Performance Analysis

Due to open access user can now connect to best base station in downlink and in uplink results in higher uplink and downlink data rates as well as higher coverage probability can accomplish by using decoupling. Although most prominent effect can be seen in uplink data rates. As dual slope model is implemented on UHF macro base station and UHF small base station the effect of decoupling is more prominent depending upon the environment type, because dual slope path loss model now better estimates the results as its switch data traffic towards small base stations. We calculated the signal to interference plus noise ratio as follows

Consider a user associated with a BS from where it is receiving highest power.Then downlink $SINR_{,dl}$ for such a user is given by the following equation

$$SINR_{,dl} = \frac{P_{rx,dl}}{I_{dl} + N_0} \tag{3.10}$$

Where $P_{rx,dl}$ is downlink maximum received power at user from associated base station, $I_{dl}$ is the interference at that user and $N_0$ is the noise power.Noise power (dB) is calculated by as $N_0$= 10log($BW$)+NF-204(dB), where NF is the noise figure of receiver which is 10dB and $BW$ is bandwidth of the system.

$$I_{dl,k} = \sum_{allBS \backslash m} P_{rx,dl} \tag{3.11}$$

Here UHF macro base station and UHF small base station interfere each other as they are sharing same frequency band while mmWave small base stations only produce interference for mmWave small base stations.There will be no interference in downlink and uplink communication as different frequency bands are used for both transmission. $I_{dl,k}$ is the downlink interference at certain $k_{th}$ user which is associated to certain $m_{th}$ base station in downlink, so powers coming from all other base stations are interference for that user. Downlink interference at certain user can b calculated as given in equation 3.11.

For $M$ number of users associated to certain tier, we calculate the downlink data rate as given by following equation 3.12.

$$R_{,dl} = \frac{BW}{M} \log_2(1 + SINR_{,dl}) \tag{3.12}$$

We then find the sum rate of the network for all 4 cases decoupled with dual slope (DDS),decoupled with single slope (DSS), coupled with dual slope (CDS), and coupled with single (CSS) to check which technique will give better results. Another parameter we choose to evaluate the performance of the system is rate coverage probability against increasing number of small base stations.

Rate coverage probability at given threshold $\tau$ is calculated as

$$\mathbb{P}_{cov(\tau)} = R_{,dl} > \tau \tag{3.13}$$

At last we calculate the energy efficiency (EE) of the system ,which is an important parameter because in heterogeneous environment it is necessary to deploy optimal number of small base station so that we can have better performance with optimal resource usage. Energy efficiency simply defines using less amount of energy to perform same job. To calculate the energy efficiency of the system is given as follows 3.14

$$EE = \frac{SumRate}{TotalPower} \tag{3.14}$$

AS we know energy efficiency is equal to output divided by input, so here sum rate is output and total power from all base station is input.
Similarly uplink $SINR_{,ul}$ is given as follows

$$SINR_{,ul} = \frac{P_{rx,ul}}{I_{ul} + N_0} \tag{3.15}$$

$$I_{ul,k} = \sum_{allUE \backslash k} P_{rx,ul} \tag{3.16}$$

Here $P_{rx,ul}$ is the uplink maximum received power at certain associated base station from certain user, $I_{ul}$ is the uplink interference created by other users and $N_0$ is the noise power of the system. In uplink interference $I_{ul,k}$ ,interference is coming from all users who are connected to UHF Small base station or UHF MBS except user k. Similarly the uplink interference is calculated for all users who are connected to mmWave band.
For $N$ number of users connected to certain tier in uplink ,we calculate the uplink data rate as given by following equation 3.17

$$R_{,ul} = \frac{BW}{N} \log_2(1 + SINR_{,ul}) \tag{3.17}$$

Similarly uplink rate coverage probability is calculated for all the scenarios, which is stated below.

Rate coverage probability at given threshold $\tau$ is calculated as

$$\mathbb{P}_{cov(\tau)} = R_{,ul} > \tau \tag{3.18}$$

### 3.2.1 Coupled and Decoupled with Single Slope and Dual Slope Path Loss Model

Since the advent of wireless communication, the downlink and uplink of cellular networks have been coupled, that is, mobile equipments have been confined to communicate with the same base station in downlink as well as in uplink directions. New patterns in network increased density and cellular data demand, reinforce the disadvantages of this restriction, implying that it should be re-examined. As a solution to the problem decoupling can result in drastic increases in system performance, outage, and power efficiency at a lower cost compare to other solutions that offer similar or lower gains. According to the study in [87],the network is designed in such a way that users can connect to different base stations in uplink and downlink called decoupling, so that higher gains can accomplish in dense hybrid heterogeneous environment.We will compare our proposed scheme which is decoupled with dual slope (DDS) with three other schemes which are decoupled with single slope (DSS), coupled with dual slope (CDS) and coupled with single slope (CSS) to see its perfromance in terms of data rates,coverage and energy efficiency of the network.

# Chapter 4

# Results and Discussions

Performance analysis of the proposed model is done through Matlab R2018a using extensive simulations.

## 4.1 Simulation Results

In this section, we show the performance of our proposed model with respect to different parameters of the network. We consider a circular cell of 500 meters radius where the SBS and the UE's are uniformly dispersed over the entire geographic area and MBS is fixed at the center of the circle. All user equipments have the same transmit power of 20 dBm. While MBS having transmit power of 46 dBm and small base station operate on 30 dBm, as all these values are given in Table 4.1.

In Table 4.1 all the simulation parameters are written for two different kind of environments i.e., moderate and harsh environments. The dual slope path loss exponents (PLE) $[\alpha_1\ \alpha_2]$ and $[\beta_1\ \beta_2]$ are stated for both moderate and harsh environments. While $[\alpha_l \; \alpha_n]$ are LoS and NLoS path loss exponents for mmWave small base stations. The system bandwidth is $BW$ = 20MHz and $BW_{mm}$=2GHz, and the minimum acceptable date rate $R_{min}$ for the UE's is set to be 2Mbps unless otherwise stated.

We compared our proposed scheme DDS with three other schemes i.e., DSS, CDS and CSS. The first comparison is done in moderate environment where different set of path loss exponents and blocking parameter is used with different values of threshold radius. Threshold radius of MBS and UHF SBS changes in both the environments as we know $r_{th}$ is environment dependent so it decreases with increasing blocking parameter. On the other hand, the second comparison is done in harsh environment. Results from both environments will then compare to see its performance in terms of rate coverage probability, sum rate and energy efficiency.

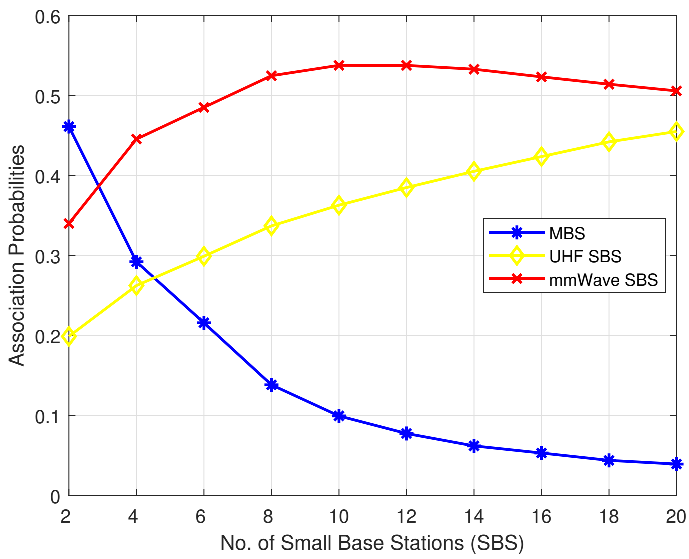


Figure 4.1: Downlink association probability for varying number of small base stations, and N=100, (DDS-M)

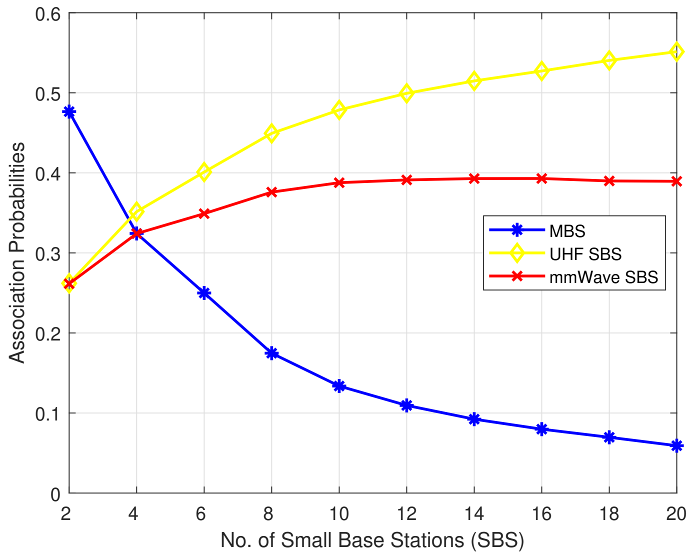


Figure 4.2: Downlink association probability for varying number of small base stations, and N=100, (DDS-H)

As decoupling is environment dependent so first we compare our proposed scheme in moderate and harsh environment conditions to see its performance. Figure 4.1 and figure 4.2 shows the association probabilities of our proposed scheme decoupling with dual slope (DDS) in moderate and harsh environments. As we know decoupling allows user to connect to best base station in uplink and downlink. Also dual slope offloads data traffic towards small base stations. So its clear from the figure 4.1 that as number of small base station increases, association with MBS decreases and association with UHF and with mmWave SBS increases. As number of small base stations increases will cause users to come to closer to the small base station, also due to dual slope path loss model more users switch towards small base stations. Similarly the effect is seen in figure 4.2 where as number of small base stations increases more users are connected towards SBS ,hence association probability with MBS decreases and association probability with SBS increases. If we compare both figures ,we can see in moderate environment more users are connected to mmWave small base station while in harsh environment more users are connected to UHF small base station, the reason behind is, in moderate environment due to less blocking parameter users have more LoS links establish with mmWave small base station so due to having highest biased received power from mmWave small base station users will associate to mmWave bands. While in harsh environment due to more blockages are there, its difficult to create LoS links with mmWave SBS and hence users confront higher path loses from mmWave bands. So less number of users are connected towards mmWave SBS in this case while more users connect to UHF SBS.

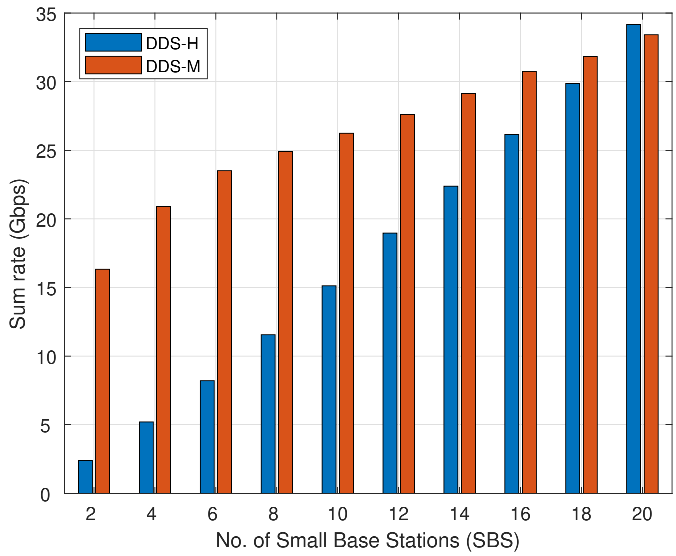


Figure 4.3: Downlink sum rate of the network for varying number of small base stations, N=100, for moderate and harsh environments (DDS)

Figure 4.3 and 4.4 shows the comparison of downlink and uplink sum

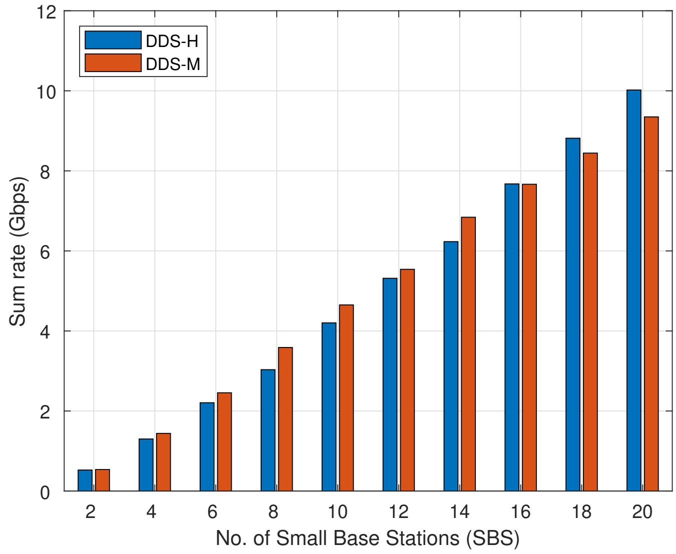


Figure 4.4: Uplink sum rate of the network for varying number of small base stations, N=100, for moderate and harsh environments (DDS)

rate of the network for decoupled with dual slope (DDS) model in moderate and harsh environments respectively. It can be seen more downlink sum rate can be achieved in moderate environment rather than harsh environment due to more number of users are connected to mmWave small base station. But its important to note that as we increases number of SBS,downlink sum rate of DDS in harsh environment increases faster than the moderate environment. Because in moderate environment users already have more LoS links so increasing SBS does not have more effect on in, while in harsh environment as we increase SBS users gets closer to mmWave base stations and hence can make more LoS connections. The effect is prominent in harsh environment as we increase SBS. So optimal number of SBS should deploy in moderate environment to make it energy efficient as well.

Similarly uplink sum rate of the network is compared for both environments as shown in figure 4.4. From figure its clear that decoupled with dual slope (DDS) initially achieve higher uplink data rates in moderate environment rather than harsh environment.But later on as SBS increases will increases uplink sum rate for DDS in harsh environment. There is not a prominent difference can be seen for uplink sum rate as we can see in downlink sum rate. It is due to the fact that in uplink there is no dual slope model applied, while in DL dual slope model is present which cause a significant change in data rates. Further we compared the rate coverage probability for minimum rate

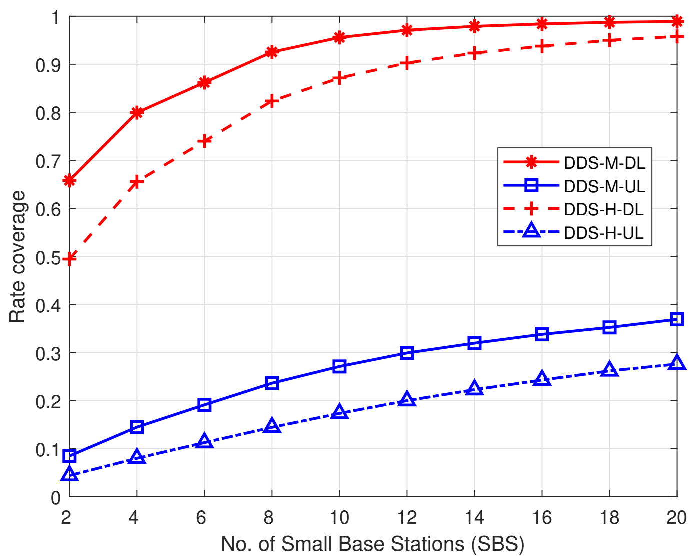


Figure 4.5: DL/UL rate coverage probability of the network for varying number of small base stations, and N=100, for moderate and harsh environments (DDS)

threshold $R_{min}$ given in Table 4.1 for moderate and harsh environments. It is obvious from Figure 4.5 that DDS performs better in moderate environments as compared to harsh environment. Because the intensity of shadowing has a huge effect on coverage, and in harsh environments there are more blockages are present so less number of users covered in harsh environment as compared to moderate environment. Also in moderate scenario more number of users are connected to mmWave small base stations due to having more LoS link in, while in harsh scenario more user connect to UHF small base station which considerably lower the data rates so downlink and uplink rate coverage probability is lower for harsh condition as compare to moderate condition.

| **Symbol** | **Parameter** | **Value** |
|---|---|---|
| $f_{mm}$ | mmWave carrier frequency | 73 GHZ |
| $f_{uhf}$ | UHF carrier frequency | 2.4 GHz |
| $BW_{mm}$ | mmWave bandwidth | 2 GHz |
| $BW_{uhf}$ | UHF bandwidth | 20 MHz |
| $\alpha_1$ , $\alpha_2$ | Dual slope PLE for MBS (Moderate) | 3,4 |
| $\alpha_1$ , $\alpha_2$ | Dual slope PLE for MBS (Harsh) | 4,5 |
| $\beta_1$ , $\beta_2$ | Dual slope PLE for UHF SBS (Moderate) | 2,4 |
| $\beta_1$ , $\beta_2$ | Dual slope PLE for UHF SBS (Harsh) | 3,4 |
| $\alpha_l$ , $\alpha_n$ | LoS/NLoS PLE for mmWave | 2, 3.3 |
| Bf | Biasing factor for mmWave | 10 dB |
| $R_{min}$ | Rate thershold | 2Mbps |
| $P_{tx,1}$ | MBS transmit power | 46 dBm |
| $P_{tx,2}$ | SBS transmit power | 30 dBm |
| $P_{tx,3}$ | UE transmit power | 20 dBm |
| rad | radius of the circle | 500 m |
| $r_{th,m}$ | Threshold radius of MBS (Moderate) | 350 m |
| $r_{th,m}$ | Threshold radius of UHF SBS (Moderate) | 100 m |
| $r_{th,h}$ | Threshold radius of MBS (Harsh) | 250 m |
| $r_{th,h}$ | Threshold radius of UHF SBS (Harsh) | 50 m |
| $\beta_m$ , $\beta_h$ | Blocking parameter | 0.0014 , 0.0224 |

Table 4.1: Simulation parameters for moderate and harsh environments

### 4.1.1 Comparison of Various Schemes in Moderate and Harsh Environments

In this section we have compared our proposed scheme decoupled with dual slope (DDS) with three other schemes which are decoupled with single slope (DSS), coupled with dual slope (CDS) and coupled with single slope (CSS) . The first comparison is done in moderate environment and the second comparison is done in harsh environment. Then we combine results attained from all the schemes to compare its performance in terms of sum rate, coverage probability and energy efficiency of the system. All parameters for both environments are stated in Table 4.1.

In DSS single slope path loss model is used, which is a traditional way of estimating the path loss. All other parameters remain same here, except path loss exponents. While in CDS , dual slope model is applied as its applied in DDS, here only the difference is user associated to same base station in uplink from where its associated in downlink. On the other hand in CSS , user associated with same base station in downlink and in uplink, its a conventional way of association. Also here single slope path loss model is applied. We used same geographic area of 500m, same number of users which is $N = 100$ in all cases unless otherwise stated, and increasing number of small base stations for all schemes to better illustrate their performance. First comparison is done on uplink rate coverage probability. In Figure 4.6 attained uplink rate coverage probability is shown for all schemes in moderate and harsh environments. As we can see that as SBS increases uplink rate coverage probability also increases for all mentioned cases. Because it's evident that as number of

SBS increases, distance between user and base station decreases so more users can be covered, also high data rates can attained in uplink so it increases coverage probability. From the Figure 4.6 it's clear that DDS outperform in moderate environment from all other schemes, because decoupling shows significant improvement in uplink data rates, so higher uplink rate coverage can be accomplished in this case. But it's important to note that DDS have

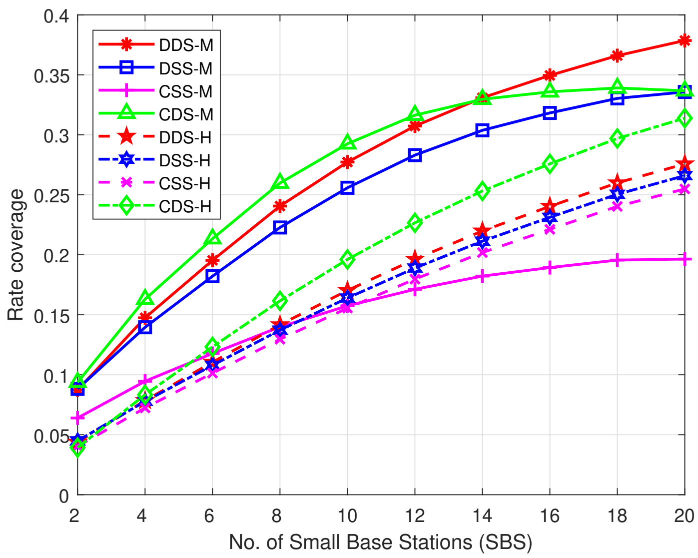


Figure 4.6: Comparison of uplink rate coverage probability of the network for varying number of small base stations, and N=100

higher uplink rate coverage at higher number of SBS, while CDS have better rate coverage probability at lower number of SBS. So it shows that to decouple all base stations will require more number of SBS for better coverage probability which is cost inefficient as well as energy inefficient. To make it cost and energy efficient some of the base station must be coupled and some decoupled to have better coverage probability with optimal deployment of SBS. DSS performs better than CSS in moderate environment, as decoupling allows more user to connect to mmWave SBS in uplink. Its important to note that rate coverage probability of CSS also increases as number of SBS increases, this is due to the fact of hybrid heterogeneous deployment. Similarly the performance of all four schemes can be compared in harsh environment. Here CDS performs better than other schemes, which shows that coupled and decoupled should combine to have better performance in terms of coverage and data rates. While DDS is at second number in harsh condition. Low performance can be seen in case of CSS, as here user is bound to connect with same base station in uplink and downlink and also due to single slope path loss model few number of users switch towards SBS.

Downlink rate coverage probability is compared in Figure 4.7. As we can see here again DDS performs better than all other schemes in moderate environment. Because higher downlink data rates achieved in moderate condition and thus higher downlink coverage probability can be achieved. After DDS, CDS achieved higher downlink rate coverage probability in moderate condition because more number of users are switched towards small base station due to dual slope model. We can see that DSS have better downlink rate coverage probability as compare to CSS in moderate scenario. But its important to note that in harsh environment DSS and CSS perform better than the DSS and CSS in moderate scenario. Another important thing to notice is that initially DDS and CDS in harsh environment do not have good performance as compare to DSS and CSS but as number of small base station increases coverage for DDS and CDS increases. So again it shows that to have better coverage in harsh environment coupled and decoupled should combine to have better performance in terms of coverage.

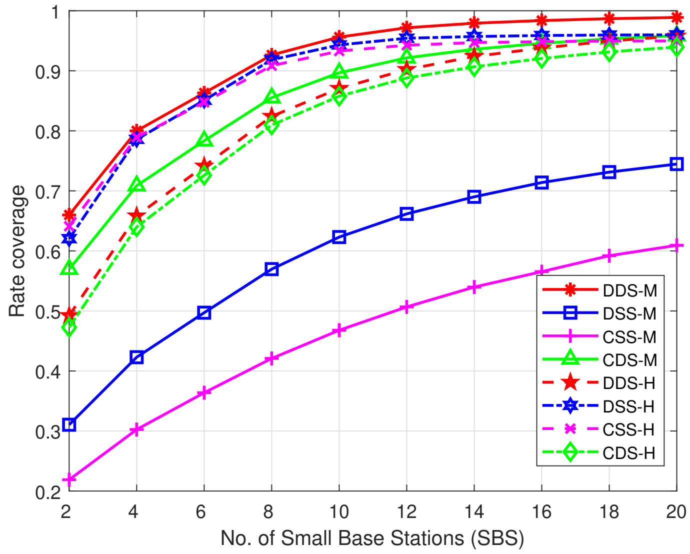


Figure 4.7: Comparison of downlink rate coverage probability of the network for varying number of small base stations, and N=100

Downlink and uplink sum rate of the network are shown in Figure 4.8 and 4.9. As we can see in the Figure 4.8 that DDS has higher downlink sum rate in both environments as compare to other schemes. A significant increase can be seen in harsh condition. As here more users are going to connect to mmWave bands with increasing number of SBS. In moderate condition limited number of SBS should deploy to achieve better performance as well as to have optimal resource allocation. Because after certain number of SBS the increase is not prominent because in moderate scenario mostly users are already connected to mmWave bands due more LoS connections so increasing SBS does not cause significance improvement as it does in case of harsh scenario. On the other hand in Figure 4.9 uplink sum rate is compared for all mentioned schemes in both environments, DDS outperforms in both moderate and harsh environment conditions which prove the significance of our proposed scheme. Also it is clear from the graph that as number of SBS increases shows significant improvement in harsh environment as compare to moderate environment.

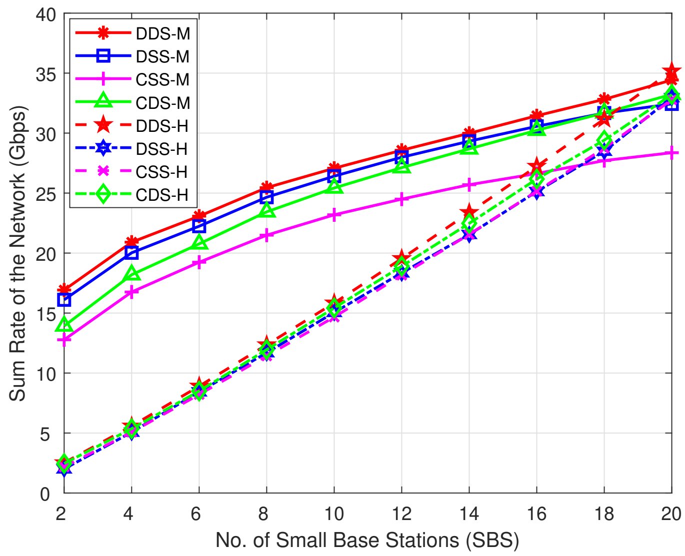


Figure 4.8: Comparison of downlink sum rate of the network for varying number of small base stations, and N=100

It's important to note that the as number of SBS increases, transmit power also increases, which make system cost and energy inefficient. So energy efficiency of system is very important factor. Energy efficiency of a system is shown in Figure 4.10. Here DDS in moderate environment have higher energy efficiency, but after certain point its value tends to saturate which shows that in moderate environment there is no need to deploy more number of SBS. Because after certain limit the performance of network stop increasing, although sum rate increasing but this increase is very small that will not show a significant improvement. While in case of harsh environment

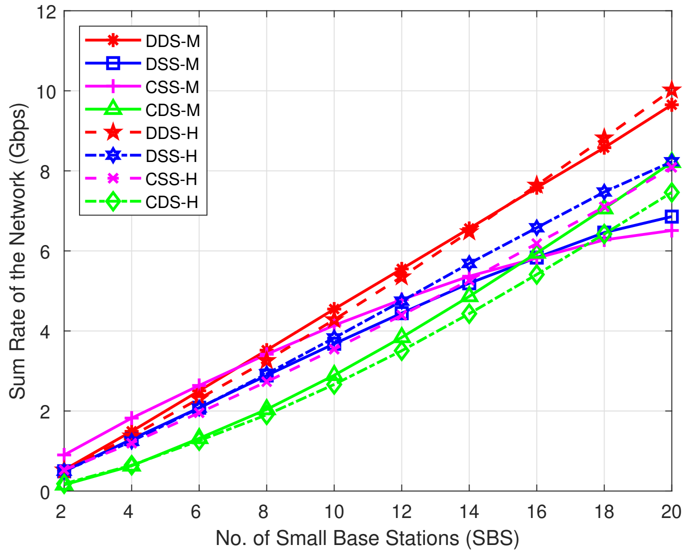


Figure 4.9: Comparison of uplink sum rate of the network for varying number of small base stations, and N=100

due to significant improvement in sum rate will make it more energy efficient. Although if we keep on increasing small base station then the graph will start decreasing which is due the fact as number of small base stations increases interference also increases which will degrade system performance. Comparison of various schemes is shown in Table 4.2 for both environments. If we compare all values in moderate scenario then it's clear that DDS perform better than all other schemes in terms of downlink and uplink sum rate as well as downlink and uplink rate coverage probability and in energy efficiency. While in harsh scenario DDS has better downlink and uplink sum rate but coverage here is not as good as we can see in coupled scenario. CDS have better uplink rate coverage probability, while downlink rate coverage for all schemes is almost equal but this is at the highest number of SBS. If we see the DL rate coverage graph then its clear that initially DDS does not have better downlink rate coverage as other scheme had. So it is important to coupled and decoupled together to have better performance in terms of coverage as well.

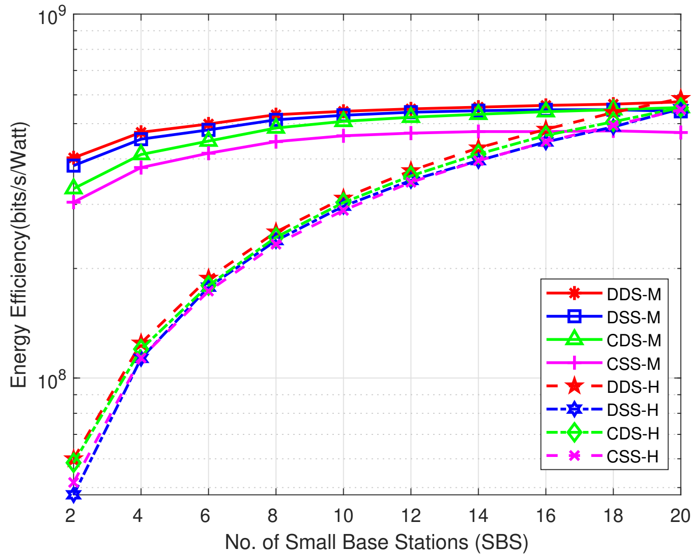


Figure 4.10: Comparison of energy efficiency of the network for varying number of small base stations,and N=100

| **Environment** | **Moderate** | | | | **Harsh** | | | |
|---|---|---|---|---|---|---|---|---|
| | **DDS** | **CDS** | **DSS** | **CSS** | **DDS** | **CDS** | **DSS** | **CSS** |
| UL Sum Rate | 9.65e9 | 8.21e9 | 6.86e9 | 6.51e9 | 10e9 | 8.29e9 | 8.23e9 | 8.1e9 |
| UL Cov | 0.37 | 0.32 | 0.33 | 0.19 | 0.28 | 0.31 | 0.26 | 0.25 |
| DL Sum Rate | 3.44e10 | 3.32e10 | 3.24e10 | 2.83e10 | 3.52e10 | 3.32e10 | 3.29e10 | 3.27e10 |
| DL Cov | 0.99 | 0.96 | 0.74 | 0.61 | 0.96 | 0.95 | 0.96 | 0.95 |
| EE | 5.73e8 | 5.53e8 | 5.40e8 | 4.73e8 | 5.86e8 | 5.53e8 | 5.49e8 | 5.46e8 |

Table 4.2: Comparison of various schemes in moderate and harsh environments

# Chapter 5

# Conclusion & Future Work

## 5.1 Concluding Remarks

Future communication networks will need a lot of bandwidth and network resources to keep working and meet the QoS requirements for their users. In the next generation of mobile networks, the future of networking goes beyond connecting people to connecting everything. In this respect, 5G will usher in a new age of wireless networking by incorporating a globally unified radio access technology into today's generation of 5G networks. So that new research directions are needed to deploy the architecture of 5G cellular network. Because 5G and beyond networks impose a priority on rapid connection and integration, mmWave networks comes up as a cost-effective, adaptable, and quick way to address such network demand. It uses wider spectrum above 6GHz bands. So due to the larger spectrum available its feasible to accommodate more number of users and also can accomplish higher data rates by using millimeter wave spectrum. Data rates upto 2 gigabit-per-second (Gbps) at a distance upto 1km can accomplish in an urban environment shows that mm-Wave band will be extremely useful for the evolution of 5G cellular communications. A stand alone mmWave network will always have coverage gaps because of higher path loss issue. Hybrid heterogeneous network, which combine sub-6GHz and mmWave tiny base stations, are a practical solution to the problem.

The efficient placement of SBS within networks will increase the capacity of the existing network. Furthermore, we can improve communication service by strategically placing small cells. UHF SBS will improve effective coverage, while mmWave SBS will boost network capacity in terms of data rates. However, to accomplish specified QoS requirements in terms of rate and coverage, network configuration changes will be required. Apart form hybrid heterogeneous network we use dual slope path loss model which provide us more realistic results as compare to single slope path loss model, also dual slope model will offload data traffic towards SBS so it provides load balancing as well. Decoupling is applied with dual slope path loss model to to further enhance the system performance in terms of uplink data rates, coverage probability and energy efficiency of the system. The following is a summary of the work done in this thesis:

- HetNets emanate as an imperative solution to cater issues related to mmWave path losses, offloading data traffic from MBS to SBS and also to make energy efficient system
- A hybrid heterogeneous network is designed to meet the requirement of high data rate and coverage

- Decoupling is applied in downlink and uplink so that user can connect to best base station, and higher uplink data rates and coverage can accomplish

- We combine decoupling with dual slope to have better performance in terms of data rates and coverage

- We compare our proposed scheme with three schemes to analyse its performance in moderate and harsh environment conditions

- DDS outperforms in terms of data rates from all other schemes. Although it has better coverage at certain number of SBS. Also it has better energy efficiency as compare to other schemes

## 5.2 Future Work

Decoupling with dual slope (DDS) provide benefits in terms of downlink and uplink sum rates and coverage. However to decouple all base stations is cost inefficient because in decoupling, it require high synchronization between base station which is quite expensive. Also from results its obvious that CDS have better coverage at lower number of SBS while DDS have better coverage at higher number of SBS.So in future work we can have coupled and decoupled base station scenario together to enhance system performance as well as to keep it cost efficient. Another thing that can be use is flexible duplexing i-e distance dependent duplex mode selection either HD or FD can be added with DDS which will further enhance system performance in terms of spectral efficiency and coverage.

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