"Modelling and Characterizing Millimeter Wave Networks for 5G"

Garima Mahindru

mahindru@ualberta.ca

Supervisor: Sachitha Kusaladharma

kusaladh@ualberta.ca

Courtesy: Dr. Chintha Tellambura

Department of Electrical and Computer Engineering

University of Alberta

April, 2017

Abstract

In recent years, the unprecedented growth in the number of connected devices and the mobile data traffic with the ever-increasing demand for higher transmission speed, the conflict between increased capacity and spectrum shortage has become an issue of critical importance. An attempt to strike a balance between these two important issues, the wireless industries has initiated a road map for transition from 4G to 5G. It is reported that the number of connected devices is estimated to reach 50 billion by 2020, while mobile data traffic is expected to grow to 24.3 Exabyte per month by 2019. Sophisticated signal processing techniques along with new spectrum space for a 5G system are needed to mitigate the physical impairments and fully exploit the system capacity.

One of the basic, yet highly important, challenges in the development of mm-wave technologies for 5G is appropriate channel measurements because the differences in topology can affect how they perform, particularly in dense urban environments. In particular, wireless operators will observe co-channel interference while delivering services if they are in a dense city area where there a number of potential obstructions from buildings and other sources exist. Since every base station transmits signals. At the same frequency, a receiving device might experience interference in its desired signal, from undesired stations. Also, the presence of a station with a higher transmitting power may cause problems in the surrounding stations. At times, this interference might also cause an outage, thus disrupting the service momentarily. This includes Modelling base station and receivers, blockages, fading, and path loss under a mmWave setup and close study on the effects of different channel and transmission parameters on system coverage and throughput.

This project focuses on characterization of such co-channel interference, probability of outage, with respect to the location of mobile device as well as with respect to the received power or distance to the associated station.

Acknowledgment

I would like to take this opportunity to express my profound gratitude and deep regard to *Mr. Sachitha Kusaladharma*, for him exemplary guidance, valuable feedback and constant encouragement throughout the duration of the project. His valuable suggestions were of immense help throughout my project work. His perceptive criticism kept me working to make this project in a much better way. Working under him was an extremely knowledgeable experience for me.

I would like to express my gratitude towards my parents for encouragement who helped me in completion of this project.

Lastly, my thanks and appreciations also go to my colleague in developing the project and people who have willingly helped me out with their abilities.

Table of content

List of Figures

List of Tables:

Chapter 1

1.1 Introduction

With end users ranging from corporate data centers to teenagers with iPhones demanding higher bandwidth, the demand for newer technologies to deliver this bandwidth is higher than ever before. To meet these increased demands for coverage, capacity, and service, the wireless industry has to continuously upgrade itself, and the only possible solution to this problem fifth generation (5G) technology [4]

Millimeter wave generally corresponds to the radio spectrum between 30 GHz to 300 GHz, with wavelength between one and ten millimetres. The 5 GHz of spectrum available in each sub-band of the E-band spectrum can be used as a single, contiguous transmission channel (which means no channelization is required), thereby allowing the most efficient use of the entire band.

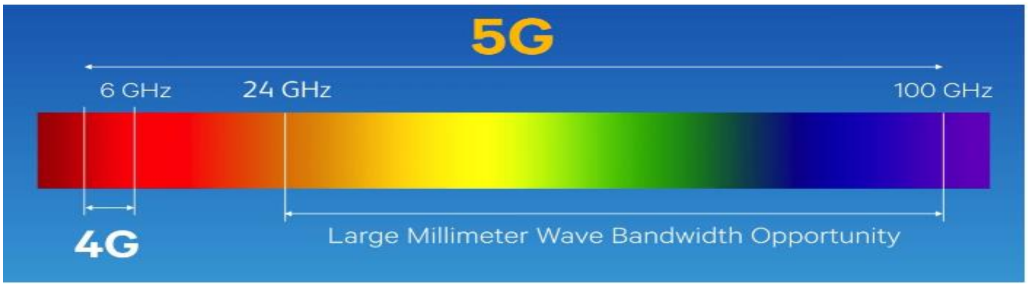

Figure: 1 Proposed 5G millimeter Wave Frame and Sub-frame

Millimeter wave technology came into existence with its early applications in Radio Astronomy in the 1960's, followed by applications in the military in the 70's. In the 80's, the development of millimeter-wave integrated circuits created opportunities for mass manufacturing of millimeter wave products for commercial applications.

By 2020, 5G will support voice and video streaming and a very complex range of communication services over more than nine billion subscribers, as well as billions of devices that will be connected to each other.

1.2 Millimeter Wave Propagation Characteristics

1.2.1 Millimeter Wave Range

Millimeter wave spectrum can classified as electromagnetic spectrum that ranges from 30GHz to 300GHz i.e. corresponding to the range of wavelength 10 millimeters (0.4 inches) to 1millimeter (0.04 inches). With such a rapid growth in cellular industries in past few years, millimeter wave wireless communication can be considered as one of the best candidate for future system.

Further, mm-wave carrier frequencies allow for larger bandwidth allocations, which translate directly to higher data transfer rates. Mm-wave spectrum would allow service providers to significantly expand the channel bandwidths far beyond the present 20 MHz channels used by 4G customers. By increasing the RF channel bandwidth for mobile radio channels, the data capacity is greatly increased, while the latency for digital traffic is greatly decreased, thus supporting much better internet-based access and applications that require minimal latency.

1.2.2 Propagation Characteristics

The propagation characteristics of millimeter wave bands are very different to those below 4GHz. One the serious problem with the millimeter wave is that they are easily affected by the natural changes in the environment. The propagation of millimeter wave through atmosphere depends primarily on atmospheric oxygen, humidity, fog and rain. This may result in the signal loss or reduced coverage for some periods.

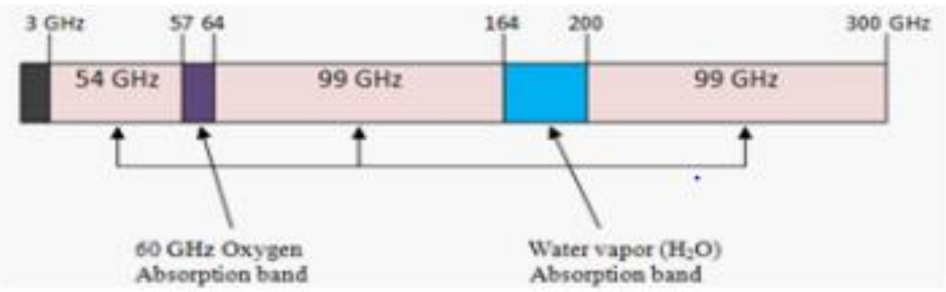

Figure 2: Future 60GHz bandwidth system

The above figure shows the spectrum of millimeter wave, whose range between 57 GHz to 64 GHz occur oxygen Absorption Band and 164 GHz to 200 GHz occur water vapour (H2 O) Absorption Band.

The transmission loss of millimeter wave is given by:

$$L_{FSL} = 49 + 40\log_{10} D + 30\log_{10} f_c$$

Where L_{FSL} is the free-space loss in dB

f_c is the carrier frequency in GHz

D is the distance between transmitter and the receiver in meters.

1.2.3 Penetration Loss

Millimeter waves do not penetrate through most of the hard material. The most significant loss in millimeter wave is foliage losses. In fact, these foliage losses limit the propagation impairment of the signals. The penetration loss is given by :

$$\mathbf{L = 0.2\, f^{0.3}\, R^{0.6}\, dB}$$

Where f is frequency in MHz

R is depth of foliage traversed in meters and R<450m.

1.3 Key Benefits of Millimeter Wave

One of the key advantages of millimeter wave communication technology is the large amount of spectral bandwidth available. With such wide bandwidth available, millimeter wave wireless links can achieve capacities as high as 10 Gbps full duplex, which is unlikely to be matched by any lower frequency RF wireless technologies. Also, unlike microwave links, which cast very wide footprints reducing the achievable amount of reuse of the same spectrum within a specific geographical area, millimeter wave links cast very narrow beams. The narrow beams of millimeter wave links allow for deployment of multiple independent links in close proximity. These two principle advantages have made millimeter wave networks a promising constituent technology for the fifth generation (5G) of cellular network.

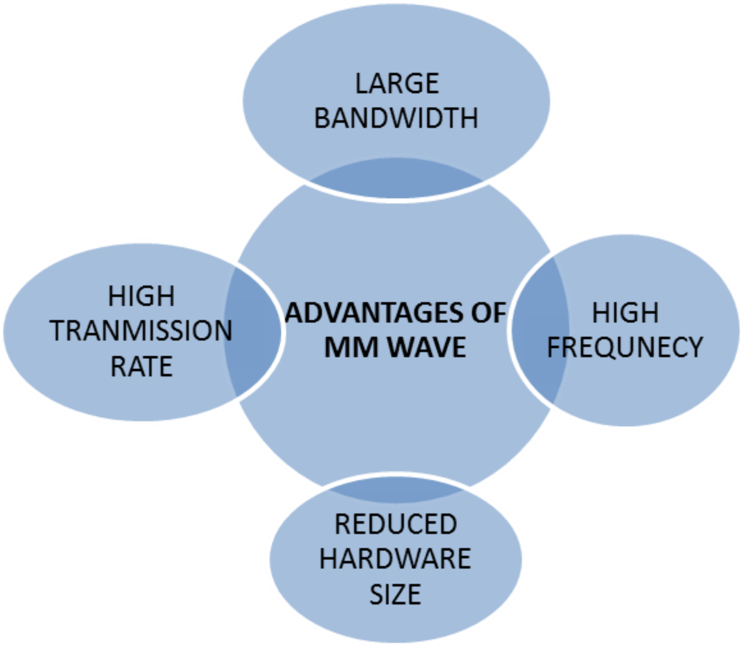

Figure 3: Benefits Of Millimeter Wave

1.4 Possible Application for 30 To 300 GHz

Communication systems operating at millimeter wave frequency can take huge advantage. The limited range of 30 to 300 GHz permits the high degree of frequency reuse as well as millimeter waves are huge benefits for point-to-point systems like local area networks and vehicular radar systems [2]. The major applications of mm waves are:

- Metro network services
- Cellular/WIMAX backhaul
- Cellular distributed antenna system (DAS)
- Enterprise and campus network

The future 5G technology is much more than a new set of technologies and will require enormous upgrades of equipment/devices or machinery as compared with previous generations. The purpose of this technology is to build on the developments achieved by telecommunication systems. The complementary technologies (a combination of core and cloud technologies) employed in much of the existing radio access will be used in 5G to cater for higher data traffic.

In addition to this, in the presence of absorption resonance bands relatively secure communications could be performed. This make it useful for high data rate systems where secure communications with low probability if interference is desired. These bands are also useful for those applications where unlicensed operations are desirable or required.

Chapter 2

2.1 Project Overview

In order to study the millimeter wave technology in 5G, we have to first characterize and analyse of how millimeter (mm) wave works in heterogeneous networks. Although of all the advantages those hyper-dense millimeter wave networks provide, there are some serious issues which limits the performance of the network. Firstly, the problem of interference is very significant challenge. Due to shorter distances between the co-channel cells in network there is lot more disturbances from the neighbouring channels which results in the disruption in the signals. Secondly, the allocation of resources limits the network tier. Thirdly, due to presence of large number of small cells, it results in the backhauling because it is difficult to provide a reliable backhauling dense urban environment. Also, the path loss and blockages are very prominent problem in mm wave networks which needs to be eliminated in order to provide better and high quality service. Moreover, it is important to consider user density area because heterogeneous networks provide significant advantages only in high user density. Since, user density is non-uniform and changes frequently it becomes very difficult to design the heterogeneous topology.

2.2 Problem of statement

Enabling mmWave cellular systems in practice, however, requires properly dealing with the channel impairments and propagation characteristics of the high frequency bands. In mmWave bands: free-space path loss is much larger in mmWave due to the higher carrier frequency, scattering is less significant which reduce the available diversity, non-line-of-sight paths are weaker, and blockages occur due to the signal being obstructed by an object. Furthermore, the received signal in dense areas may suffer from the presence of obstacles and multiple reflections. Some models for these fading phenomena are presented in this report, including Rayleigh and Nakagami-m fading model.

In this report, a new mathematical framework to the analysis of millimeter wave cellular networks is presented to analyse system performance in terms of coverage and throughput using simulations. The new stage of outage is represented which reflects the blockage system at high frequencies and which shows that signal might be too weak to be established. In addition to this, it is shown that large scale antenna is used for directional beam-forming in mm wave system in order to eliminate the path loss as well as interference issues in the network.

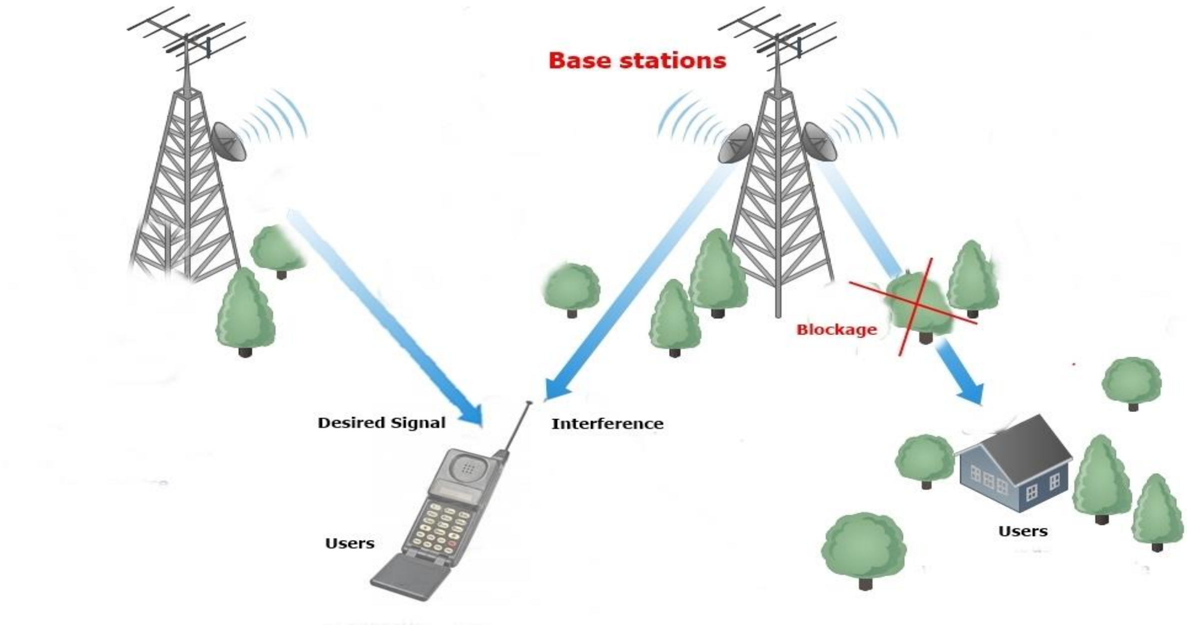

Figure 4: Basic 5G Network

It is seen that, the evaluation of the system-level performance of the cellular network is a big challenge as it cannot be traced mathematically. This is because of the absence of tractable methodologies for displaying the areas of the BSs and the other-cell obstruction. Just as of late, another scientific strategy has picked up noticeable quality because of its systematic tractability, its capability of capturing the inherent performance trends of currently deployed cellular networks, and the possibility of studying next-generation heterogeneous network deployments. This rising methodology uses stochastic geometry which enables to model base stations (BSs) as points of point processes. In general, we would first plot a number of base station and users in a network and model them to study the outage occurrence, Signal-to-noise ratio (SINR), power transmitted between receiver and transmitter, beam forming pattern as well as blockages. All this analysis would be done using stochastic approach with the aid of Poisson point processes which enables us to model the base station and users. The ultimate goal is to create numerical structures particularly custom fitted to represent the quirks of mmWave engendering channels and transmission plans. Using above approach some discussion is presented on these results and some practical conclusions are taken.

2.3 Contributions and Outline

The main contribution of this report is regarding the analysis approximation and evaluating the performance of millimeter (mm) wave technology for 5G. they are broadly listed below:

- Using stochastic geometry with the aid of Poison point process (PPP), plotting and modelling of base stations and users

- Finding the nearest base station with respect to each user and hence calculate the power transmitted by ach of them respectively.

- Development of Rayleigh model to study the interference from neighbouring base stations and finally find the probability of the occurrence of outage.

- Modelling the directional beam-forming

- Lastly, characterizing the probability of the number of base stations being blocked.

The work is organised as below:

Chapter 1

In chapter 1, a detailed outline about millimeter wave and its origin is introduced and what are the issues faced by the normal frequency waves and how mm wave can be the best solution to it.

Chapter 2

In chapter 2, an introductory text with the overview of project is portrayed and what are the problems that are currently being faced to model and analyse the characteristics of millimeter wave technology for 5G.

Chapter 3

In chapter 3, basic background concepts and the models for fading, path-loss and interference are presented.

Chapter 4

In chapter 4, a brief introduction to normal frequency waves with some representation of simulation results are presented.

Chapter 5

Chapter 5 introduces to millimeter wave technology for 5G with the application of the models used and some simulation results.

Chapter 3

3.1 Background Theory

Generating and receiving millimeter wave is a challenge but the biggest and the most challenging factor with these high frequencies is the travelling media. These frequencies experience poor foliage penetration as well as atmospheric and free-space path loss [2]. Moreover, the mmWave length signals experiences large number of blockages while transmission [2]. To study the interference in millimeter networks and overcome these blockages, various models and tools are used.

So, to model millimeter wavelength frequency we analyse the heterogeneous network in which random number of base station and Pico-cells are distribute in a particular area. Each user associate with a particular base station. Then using the simulation process their performance is calculated.

In this report different models are used to stimulate the behaviour of network as well as stochastic geometry tools are used to characterize the signal-to-interference-plus-noise ratio (SINR) at a particular user and hence find the outage for each.

The different models used for simulation and the various assumptions taken into account in the project are presented below:

3.2 Poisson Point Process

In past ten years spatial distribution and associated techniques have been implemented and adapted to study the interference in the cellular networks. In this work, the Poisson point process is used to study the base station and user communication of heterogeneous networks. We consider heterogeneous cellular network with K number of base station and N number of users located randomly with transmitting power Pi, and have a SINR target of threshold T. Base station in the network is assumed to be spatially distributed according to a Poisson point process (PPP). Each user connects to its nearest base station. So, for a two dimensional homogenous the probability of having n nodes n region B is given by

$$p(N(B) = n) = \frac{(\lambda.\, v(B))^n}{n!} e^{-\lambda.v(B)}$$

where n=1,2,3…

λ is the intensity parameter

$\nu(B)$ is the area

In the case of non-homogenous poisson point process, the intensity parameter is dependent of the location.

3.3 Path Loss Model

Path loss is the reduction of signal amplitude over distance between the transmitter and receiver. Various propagation models indicate that average received power decreases logarithmically with distance. Since at mmWave frequencies there is increased attenuation as compared to traditional frequencies, beam forming and beam combining methods have been envisioned to mitigate path loss, to increase coverage distance which will in return would support high data rates.

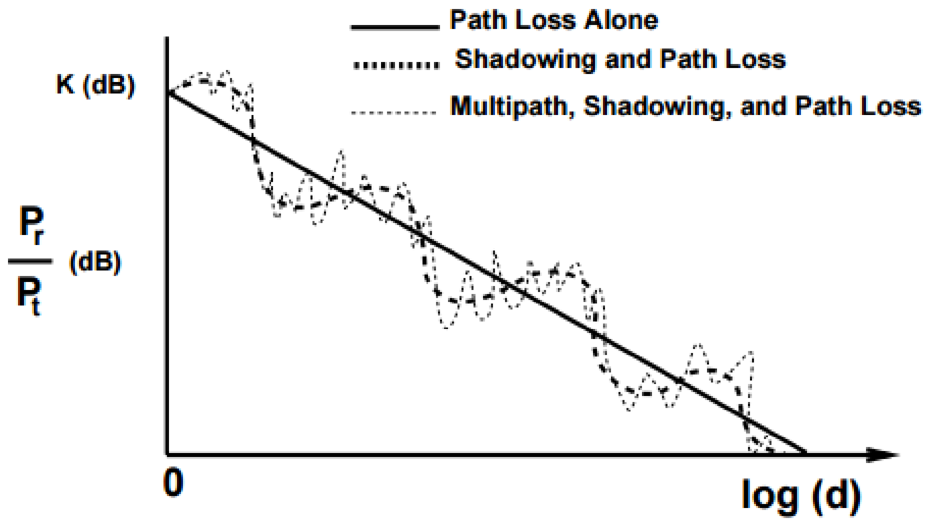

Figure 5: Path Loss, Shadowing and Multipath versus Distance

One of the simplest model through which path loss can be calculated is Free space path loss model the expression for the same is given by:

$$FSL \propto \left(\frac{4\pi d}{\lambda}\right)^2$$

Where d is the distance
ƛ is the wavelength of the signal

3.4 Empirical Path Loss Model

Due to complexity of signal propagations it is very difficult to obtain a single model that characterizes path loss accurately across a range of different environments. Thus, to calculate accurate path loss, we use different empirical path loss model. One of those are Okumura model, Hata model, COST 231 Hata model, and COST 231 Wolfisch-Ikegami model.
For the COST 213 Hata model is given by (in dB)

$$PL= 46.3+33.9\log_{10}(f_c)-13.82\log_{10}(h_t) - a(h_r) + (44.9-6.55\log_{10}(h_t))\log_{10}(d)+C_M$$

With h_t is the transmit antenna height
h_r is the receiver antenna height,
f_c is the transmit signal frequency,
d is the distance between the transmitter and receiver.

For small cities, $a(h_r)$ is defined as:

$$A(h_r)=(1.1\log_{10}(f_c)-0.7)\,h_r - (1.56\log_{10}(f_c)\,0.8)$$

C_M is 0 for small cities suburbs while 3 for the large cities.

On the other side, beam combining practices are effective in NLOS scenarios where signals can be weak due to obstructions in the environment, but where energy still reaches the receiver by scattering and reflection at many angles of arrival.

Environment	Path Loss Exponent, *n*
Free space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban cellular radio	3 to 5
In building line-of-sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

Table 1: Typical path loss exponent

3.5 Shadow Fading

In addition to path loss, a signal also experience random variation due to various blockages from objects in the signal path which results into a random variation about the path loss at a specific distance. Moreover, there might be random variation about the path loss if there are changes in reflecting surfaces and scattering objects. Thus, a model for the random attenuation due to these effects is also needed. Since the location, size, and dielectric properties of the blocking objects as well as the changes in reflecting surfaces and scattering objects that cause the random attenuation are generally unknown, statistical models are widely used to characterize this attenuation.

The most common model for this additional attenuation is log-normal shadowing. This model has been confirmed empirically to accurately model the variation in path loss or received power in both outdoor and indoor radio propagation environments. Its expression is given by:

$$p(\psi) = \frac{\xi}{\sqrt{2\pi}\sigma_{\psi_{dB}}\psi}\exp\left[-\frac{(10\log_{10}\psi - \mu_{\psi_{dB}})^2}{2\sigma_{\psi_{dB}}^2}\right], \ \psi > 0,$$

Where $\xi = 10/\ln 10$,

$\sigma_{\psi dB}$ is the standard deviation of ψ_{dB} ,

$\mu_{\psi dB}$ is the mean of $\psi_{dB} = 10 \log 10\ \psi$

3.6 Signal to Interference plus Noise Ratio

Interference is the predominant problem in millimeter wave network due to same frequencies of some pico-cells. The base station is denoted by its location while the user is at origin (0,0). So, the expression for the signal to noise ratio is given by:

$$SINR = \frac{G_{ii}P_i}{\sum_{j\neq i}^{N_{stations}} G_{ij}P_j + \sigma^2}$$

where Gii and Gij are the gains associated with the transmitter I and j respectively. Higher is the Gii, better is the performance with respect to the interference. On the other side opposite effect of Gij is observed.

The quantity of interest in this work is the outage probability Po at the typical receiver, that is to realise that the probability that outage will occur is if SINR is less than threshold i.e.

$$P\ (SINR < T) = OUTAGE \quad \text{i.e.}$$

$$P\left(\frac{G_{ii}P_i}{\sum_{j\neq i}^{N_{stations}} G_{ij}P_j + \sigma^2} < T \right)$$

Where, T is the Threshold. In this case, the value of Gii and Gij is considered to be 1 and interference is tested as function of T.

The derived expressions of SINR for the heterogeneous networks were examined to guarantee that they are valid for all interference mitigation methods. This validation was carried out by applying the expressions for the different methods in the literature.

3.7 Outage Probability

As we already know that outage occurs when SINR drops below a certain threshold. So, the spatially averaged outage probability is a useful and popular metric for characterizing the performance of wireless networks, as it captures in a single quantity the dynamics of both the channel (e.g., fading and shadowing) and the random locations of the interferers [12] and The most common approach to compute the spatially averaged outage probability is to expect that the configuration of the network is modeled as spatial point process such as binomial point process (BPP) or Poisson Point Process (PPP) and then with the aid of stochastic geometry we can compute the outrage probability.

Chapter 4

Normal Frequency Waves

4.1 Overview

Wireless communication is the one of the fastest growing segment of the communications industry. It biggest contribution to mankind of all time and has grown exponentially in terms of technology and users over the past decades. Today, wireless communications provides variety of application and standards which includes:

- Mobile Telephony
- Broadcast Technology
- Wireless Local Area Networks
- Fixed Wireless Access
- Cordless Telephony
- Paging system

However, many technical challenges remain in designing robust wireless networks that deliver the performance necessary to support emerging applications. The spectral efficiency gains i.e. the rate at which data can be sent over a unit bandwidth have decreased over the past few years.

Cellular phones have experienced exponential growth over the last decade, and this growth has been continues undoubtedly worldwide.

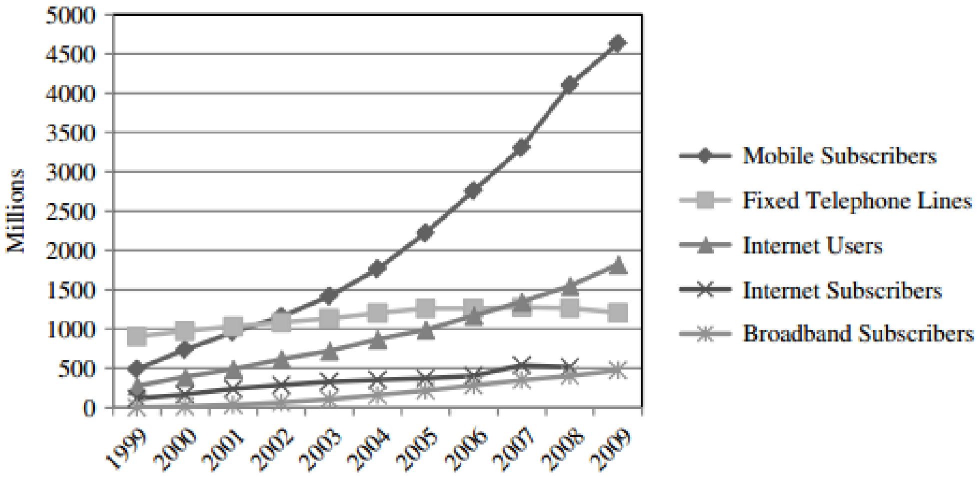

Figure 6: Global growth of mobile, Internet, broadband and fixed telephone line subscribers from 1998–2009 [5]

The explosive growth of wireless systems coupled with the proliferation of laptop and palmtop computers indicate a bright future for wireless networks, both as stand-alone systems and as part of the larger networking infrastructure.

4.2 Evolution of Cellular Systems through Generations

A number of generation changes have been experienced by mobile technologies, which have transformed the cellular background into global set of interrelated networks. The FCC also decides which frequencies of spectrum can be used for which purposes. For mobile phones, it has allocated spectrum generally between 700 MHz and 2.6 GHz. It started to emerge in 1980: first generation analog FM cellular systems in 1981; second generation digital technology in 1992, 3G in 2001, and 4G LTE-A in 2011.

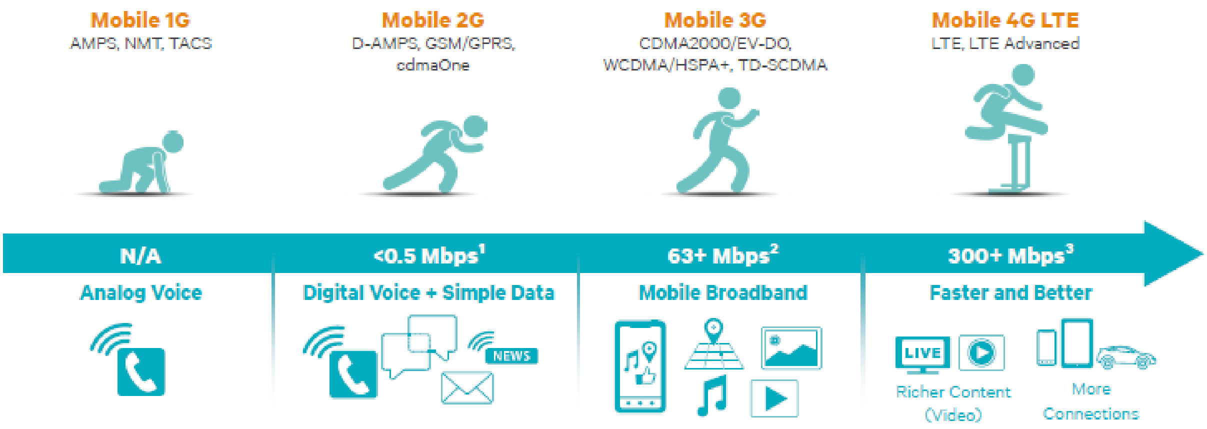

Figure 7: Evolution of mobile technology over the past few years

4.2.1 First Generation Cellular system:

First generation cellular networks were basic analog systems designed for voice communications. The first generation systems were characterized by their analog modulation schemes and were designed primarily for delivering voice services. They were different from their predecessor mobile communications systems in that they used the cellular concept and provided automatic switching and handover of on-going calls.

One of the most successful first generation systems were AMPS (Advanced mobile phone service) in the United States and its variant Total Access Communication Systems (ETACS and NTACS) in Europe and Japan [5]. These systems were almost identical from a radio standpoint but the allocated spectrum bandwidth was different for them. The AMPS system was built on a 30kHz channel size, whereas ETACS and NTACS used 25kHz and 12.5kHz, respectively.

4.2.2 2G Digital Cellular System

A move to early data services and improved spectral efficiency was realized in 2G systems through the use of digital modulations and time division or code division multiple access. It was a major shift in the way mobile communications is used worldwide.

The most notable upgrade of 2G over its predecessor is the digital encryption of telephone conversations, and considerably higher efficiency on the spectrum, which allows for greater penetration level for mobile phones. 2G also introduced mobile data services, beginning with SMS text messaging. On the other side, 2g signals degenerate over distances or sometimes signals cuts off or losses and gets distorted dramatically [5].

4.2.3 3G Broadband wireless system

Clearly 2G provided only low data rate support and limited capacity therefore 3G came into existence which provided much higher data rates, increase voice capacity with supporting of many more advanced services.

3Gwas a major leap over 2G. It introduced high-speed Internet access, highly improved video and audio streaming capabilities by using technologies such as Wideband Code Division Multiple Access (W-CDMA) and High Speed Packet Access (HSPA).

4.2.4 Fourth generation cellular system

4G came into existence in 2011 and is usually known as successor of 3G and 4G. 4G technologies include HSPA+ 21/42, the now obsolete WiMAX, and LTE. 4G is around five times faster than existing 3G services. 4G LTE aims to offer users faster, more reliable mobile broadband internet for devices like smartphones, tablets and laptops.

The evolution from 1G to 5G is summarized in Table 1.

Generation→ Features↓	1G	2G	3G	4G	5G
Deployment	1970 – 1980	1990 - 2001	2001-2010	2011	2015-20 onwards
Data Rates	2kbps	14.4-64kbps	2Mbps	200 Mbps to 1 Gbps	1Gbps and higher
Technology	Analog Cellular Technology	Digital Cellular Technology: Digital narrow band circuit data Packet data	Digital Broadband Packet data: CDMA 2000 EVDO UMTS EDGE	Digital Broadband Packet data: WiMax LTE Wi-Fi	wwww Unified IP seamless combination of broadband LAN PAN MAN WLAN
Service	Analog voice service No data service	Digital voice with higher clarity SMS, MMS Higher capacity packetized data	Enhanced audio video streaming video conferencing support Web browsing at higher speeds IPTV support	Enhanced audio, video streaming IP telephony HD mobile TV	Dynamic Information access, Wearable devices with AI Capabilities
Multiplexing Switching	FDMA	TDMA, CDMA	CDMA	CDMA	CDMA
Core Network	PSTN	PSTN	Packet N/W	Internet	Internet
Standards	MTS AMTS IMTS	2G:GSM 2.5:GPRS 2.75:EDGE	IMT-2000 3.5G-HSDPA 3.75G:HSUPA	Single unified standard LTE, WiMAX	Single unified standard
WEB Standard		www	www(IPv4)	www (IPv4)	wwww (IPv6)
Handoff	Horizontal only	Horizontal only	Horizontal & Vertical	Horizontal & Vertical	Horizontal & Vertical
Shortfalls	Low capacity, Unreliable handoff, Poor voice links, Less secure	Digital signals were reliant on location & proximity, required strong digital signals to help mobile phones	Need to accommodate higher network capacity	Being deployed	Yet to be implemented

Table 2: Comparison of different generations in wireless communication

4.3 Cellular Frequencies and Band in Use Today

In telecommunication world, a frequency band is a specific range of frequencies in radio frequency (RF) spectrum which varies from very low frequency (VLF) to extremely high frequency (EHF) [3]. International use of radio spectrum is regulated by International

Telecommunication union (ITU). The bands, frequency ranges and allocation of frequency spectrum is as below:

- **Very low frequencies (vlf)** range from 3 to 30 kilohertz (kHz). Time signals and standard frequencies are among the users of this band.
- **Low frequencies (lf)** range from 30 to 300 kHz. Fixed, maritime mobile and navigational systems and radio broadcasting are among the users of this band.
- **Medium frequencies (mf)** range from 300 to 3000 kHz. Land, maritime mobile and radio broadcasting are among the users of this band.
- **High frequencies (hf)** - also called *shortwaves* - range from 3 to 30 megahertz (MHz). Fixed, mobile, aeronautical and marine mobile, amateur radio, and radio broadcasting are among the users of this band.
- **Very high frequencies (vhf)** range from 30 to 300 MHz. Fixed, mobile, aeronautical and marine mobile, amateur radio, television and radio broadcasting, and radio navigation are among the users of this band.
- **Ultra high frequencies (uhf)** range from 300 to 3000 MHz. Fixed, mobile, aeronautical and marine mobile, amateur radio, television, radio navigation and location, meteorological, and space communication are among the users of this band.
- **Super high frequencies (shf)** range from 3 to 30 gigahertz (GHz). Fixed, mobile, radio navigation and location, and space and satellite communication are among the users of this band. [3]

Spectrum is the lifeline of the industry and as more and more consumers buy smartphones there is greater need of high data rates as well as high bandwidth. Therefore, the ITU launched Extremely high frequencies (ehf) also known as millimeter wave which ranges from 30 to 300 GHz. Amateur radio, satellite, and earth and space exploration are among the users of this band.

As discussed before, to analyse the mm wave technology we would model the heterogeneous network and see the difference that mm wave can bring to present life. Heterogeneous network is a widely accepted solution to improve the overall network performance. Heterogeneous network aims to combine all the wireless transmission standards and spectrum bands under one network control plane. HetNets provide large number of small cells such as pico-cells so that it can provide increased bandwidth per cell as well as increased throughput to the end users.

4.4Simulation Results & Analysis in Heterogeneous Networks

Association to closest base station:

As referred before with the sight of heterogeneous system, the user can pick the base station it needs to associate with. Having various alternatives, the objective is to discover a station with a high receiving power yet while, is not very far. Moreover, any farther base station with high receiving power should not force any user to connect with it as there is only limited spectrum to be used among all the users and the base stations. These are some of the contemplations that lead to various association schemes.

In this section, simulation results are shown for the outage as experienced by the user in the heterogeneous network as a function of the threshold T. To recall, the outage would only occur when

$$\mathrm{P}\left(\frac{G_{ii}P_i}{\sum_{j\neq i}^{N_{stations}} G_{ij}P_j + \sigma^2} < \mathrm{T} \right)$$

I.e. P (SINR < T) = OUTAGE

For each set of simulations, a network of stations is generated, and the outage probability of a user is computed, depending on the varying parameters (simulation dependent), for different values of the outage threshold T.

To obtain the results, we focus on typical user located at the orign(0,0) cooperate by jointly transmitting a message to this tagged receiver and assume that it is a subset of the total ensemble of base stations. In this case the service area of base station is the voronoi cell associated with it.

A typical distribution of two layes of cells, with different intensity parameter distributed according to poisson point process is as shown in he following figure

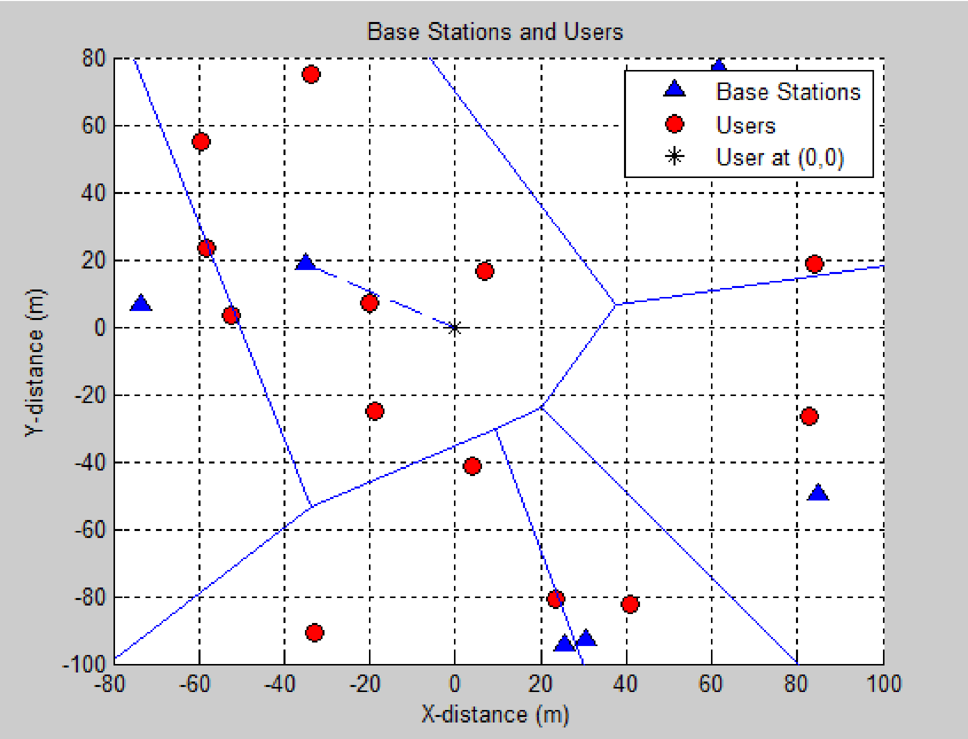

Figure 8-A typical distribution of base stations (blue triangles), pico-cells (red dots) and user location (black star), distributed as independent Poisson Point Processes. The dotted lines show the closest base station and pico-cell with respect to the user. The cell boundaries are shown by using Voronoi tessellation.

So, in order to obtain general results, a large number of simulations are performed with different samples of networks following a PPP model with given intensity parameters.

4.4.1 Dependence on path loss exponent

In different environment conditions, the path loss exponent is affected by different factors such as received power, threshold or interference. The impact of path loss exponent on optimal base station and minimum power consumption is not straightforward rather it highly depends upon the power received and transmitted.

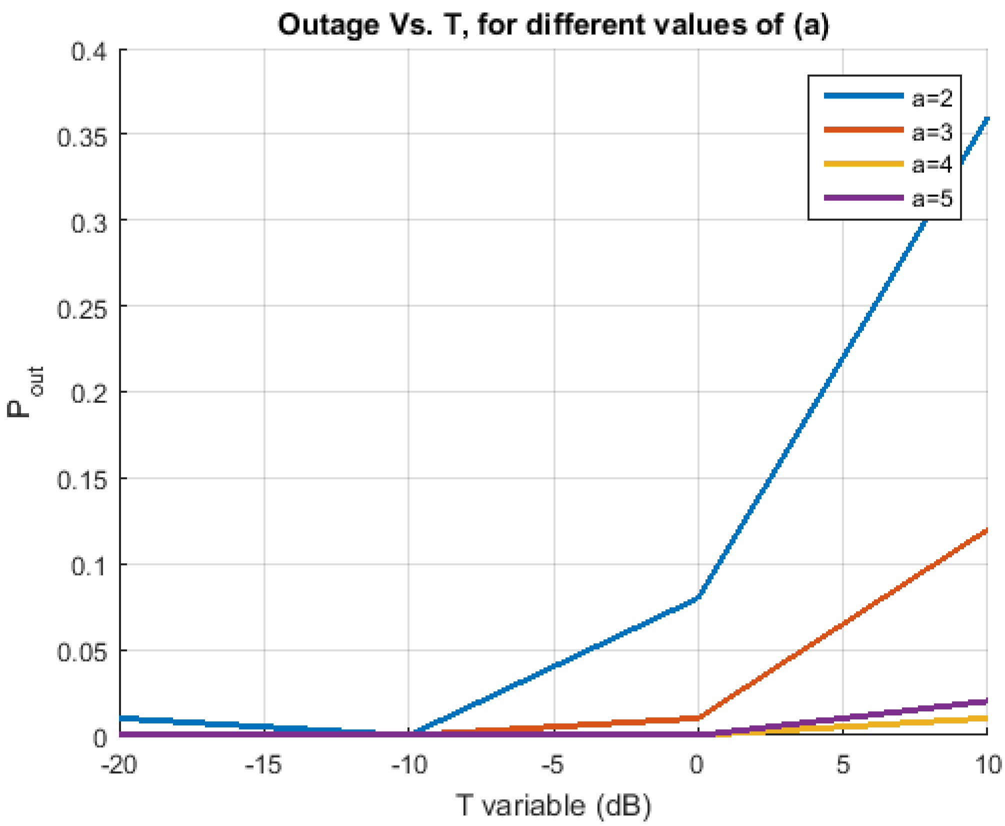

Figure 9: Simulation results to study the interference and outage with different values of Path-loss exponent with $\lambda=10^{-4}$ and $\lambda_1=10^{-3}$

Figure 9 depicts that, the bigger is the value of path- loss exponent (a), lesser is the distance between the available base stations hence there is low amount of interference effect. It is also important to see as the value of path loss exponent increase with the increase in the threshold T, the probability of the occurrence of outage decreases. Therefore, it is concluded that both threshold and path loss exponent is an important factor while designing the efficient network.

4.4.2 Dependence on receiver sensitivity

Sensitivity in a receiver is normally taken as the minimum input signal required producing a specified output signal having a specified signal-to-noise (S/N) ratio and is defined as the minimum signal-to-noise ratio times the mean noise power. [7]

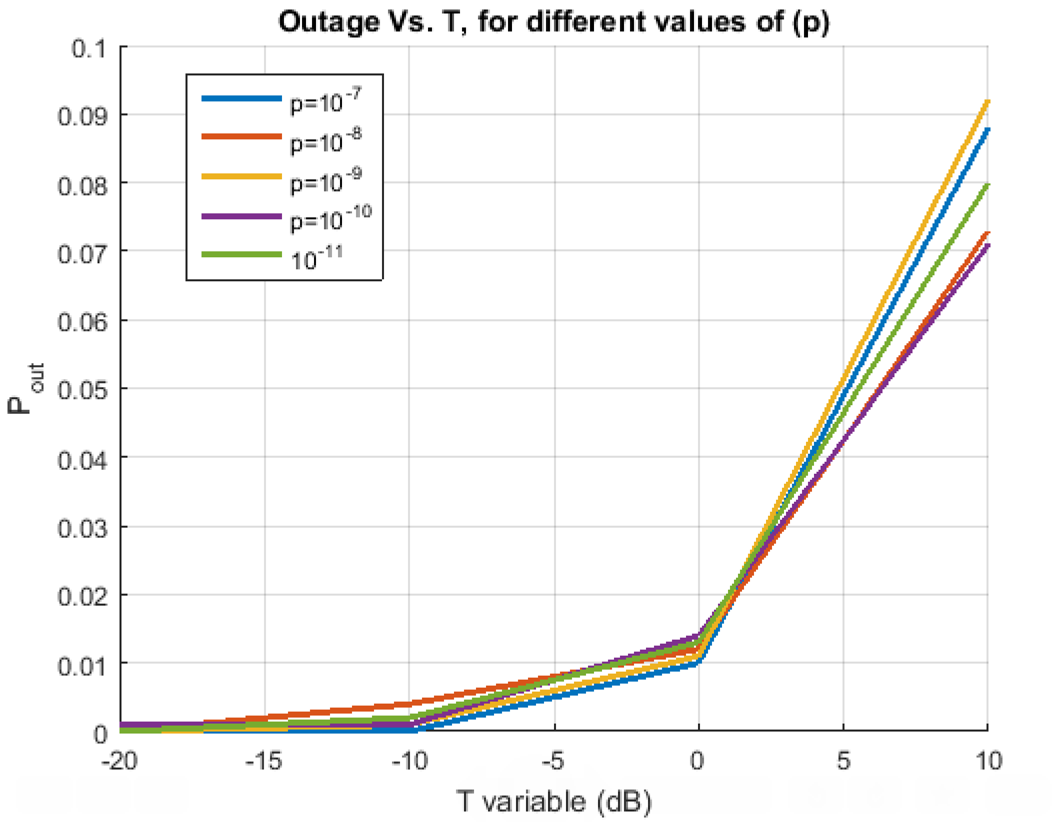

Figure 10: Simulation results to review power transmitted and received with different values of receiver sensitivity p.

Here simulation results depict that there is a dependence of receiver sensitivity p for each value of threshold T. It is interesting to note that as SINR values comes closer to zero, the Rayleigh fading coefficient factor influences the outage probability.

4.4.3 Mean analysis for conventional networks

In the following figure, the mean interference scenario for omnidirectional antennas is illustrated and simulation data is obtained when blocking is not taken into the account. The simulations results have been obtained and show that mean interference in the beginning is very low, but gradually the interference increases at the receiver sensitivity increases because interference from neighbouring station also increases as they also transmit the signals at very high power.

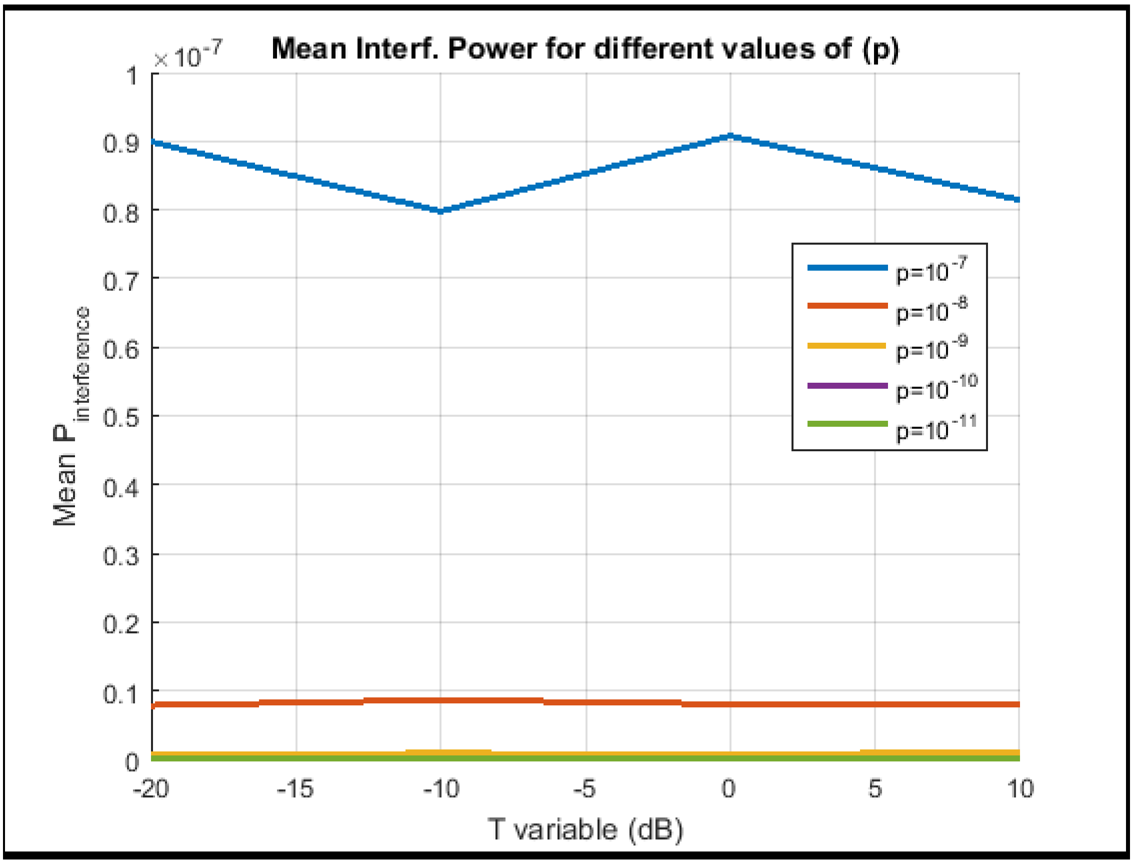

Figure 11: Simulation results for mean and variance of the heterogeneous network and finally calculating mean interference power for different values of p and T

```
Command Window
>> load('Task_07.mat')
>> disp(Results);
    'TdB'    'Mean Pow. Interf.'    'Var Pow. Interf.'
    [-20]    [       8.3261e-12]    [       1.1050e-22]
    [-10]    [       7.6814e-12]    [       1.0162e-22]
    [  0]    [       8.5473e-12]    [       1.0402e-22]
    [ 10]    [       8.6046e-12]    [       1.2461e-22]

>>
```

Table 3: Mean and Variance Values for Different Values of T and P

Chapter 5

Understanding millimeter wave wireless communication

5.1 Introduction

Until recently, millimeter wave (mm Wave) frequencies – spreading over from 30-300 GHz were not considered valuable for the dynamic communication environment such as cellular systems. Millimeter waves have been utilized widely for long-distance point-to-point communication in satellite and terrestrial applications, but now they are examined and developed for the commercial cellular systems. This new application is a great deal all the more difficult because of eccentric proliferation situations and strict limitations on size, cost, and power utilization. Given the extreme shortage of available spectrum at traditional cellular frequencies alongside a blasting interest for broadband and other wireless data services, the possibility of using mm Waves for cellular has generated intense interest starting about few years ago [8].

The high transmission capacity and inadequate existing use make millimeter wave correspondence exceedingly appealing. Furthermore, the reduced antenna sizes at these frequencies enable a large number of antenna elements within a small space, and thus provide exciting prospects for other candidate technologies such as massive multiple input multiple-output (MIMO). This thus, will conceivably lessen out of cell obstruction, and give beam forming picks up for the coveted connections. However, high path loss, the sensitivity to blockages, atmospheric absorption, and high noise powers give noteworthy difficulties to effectively consolidating millimeter wave frequencies [9].

On the other hand, device to device (D2D) systems underlaying the cellular network empowers transmission between neighbouring cell for specific applications which spares transmission power and network resources. In this way, empowering D2D communications has likewise been a foundation for 5G.

5.2 Motivation and Contribution

In this work, our goal is to study and characterize the outage performance of a device to device network under laid upon a millimeter wave cellular network. Although millimeter wave frequencies show relatively lower interferences due to directionality but at the same time mmWave signals are highly vulnerable to shadowing and blocking. It is seen that there is high rate of degradation in the signals due to blockages which results in the outage intermittent channel quality [10].

As described previously, in this work, we would model the cellular base stations and users as independent homogenous Poisson point process to incorporate spatial randomness. A simplified Boolean blockage model is assumed, and line-of-sight (LOS) and non-line-of-sight (NLOS) conditions are modelled separately with different long-distance path loss exponents and Nakagami fading parameters. Moreover, directional antenna patterns are assumed for all devices, and antenna alignment takes place before any data transmission attempt. Each cellular user is assumed to connect to its nearest base station while a D2D receiver connects with the transmitter corresponding to the cluster head [9]. Once the mobile is served by one BS, the signal received by this BS will be the useful signal, and we assume that the considered system other signal received by other BS using the same frequency is interference. So, in order to make communication with the BS, the signal-to-noise-plus interferences ratio (SINR) at this mobile location must be excess some threshold, in this case the mobile is covered, in contrary it is in outage [11].

5.3 Modelling Aspects

This section introduces the system parameters and models used throughout the rest of the work.

A. Blockages

As discussed before, the obstacles in the environment affect wireless communication channels attributable to reflection, diffraction, scattering, absorption, and refraction. These effects are complicated and environment-specific, and so the received signal power from a transmitter is often modelled statistically, as a function of distance [8]. The blockage from random objects significantly impacts the received signal characteristics. So we used stochastic approach to model blockages and these blockages are considered to be stationary and isotropic. The probability that a signal of length r with no blockages is given by: $e^{-\beta r}$ where β is a constant relating to the size and density of the blockages. Similarly, the probability of a NLOS link is given by $1-e^{-\beta r}$. Using these assumptions we simulated the mmWave network to find out the probability of a particular station being blocked or not and the results were as follows:

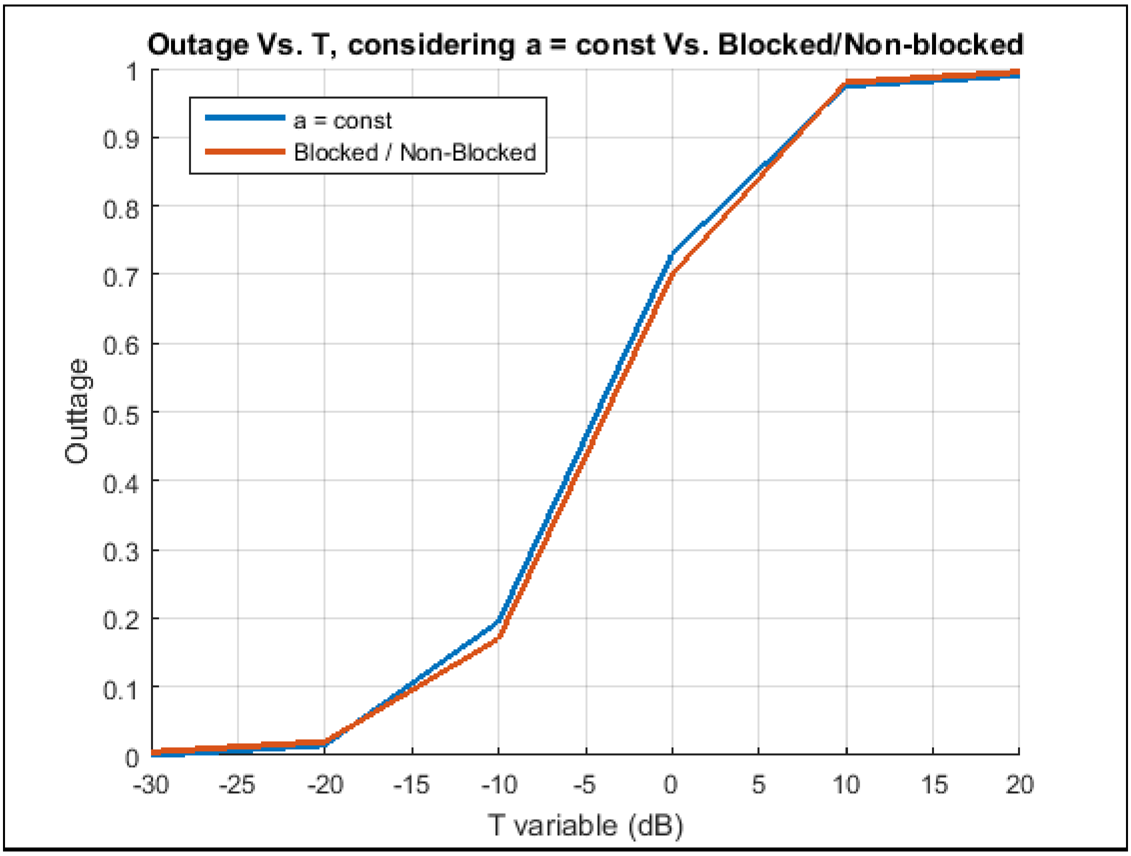

Figure 12: Simulation results showing the probability of a base station being blocked with th constant value of path loss exponent i.e. a = 3

Simulation results show that blockage not only adds the randomness to the average path loss, but also changes the effective path loss exponent. In the presence of blocking, the path loss in the NLOS links can be much higher, as diffractions are weak and a larger fraction of signal energy is scattered in the mmWave bands. On the positive side, it should be noted that blocking also applies to interfering signals but even more so, since interferers are typically farther than the desired transmitter and thus more likely to be blocked [8].

B. Channel model Antenna pattern

Beam forming or spatial filtering is the method of creating the radiation pattern of the antenna array by constructively adding the phase of the signals in the direction of the targets/mobiles desired, and nulling the pattern of the targets/mobiles that are undesired. Specifically, beam forming is achieved by adapting the amplitude and phase of the signal from each antenna element by using the product of each user's signal and weight vectors. Moreover whenever there is absorption between the transmitter and receiver, beam steering techniques can be applied to produce a link by rotating the beam towards non-line-of-sight reflector.

Now days, to identify spatial signals there are smart antennas, which employs beam forming algorithm and is also utilized to calculate beam forming vectors to track the antenna beam on the receiver. The overall radiation pattern of an antenna array is determined by the radiation pattern of the individual elements, their positions, orientations in space, and the relative phase and amplitudes of the feeding currents to the elements.

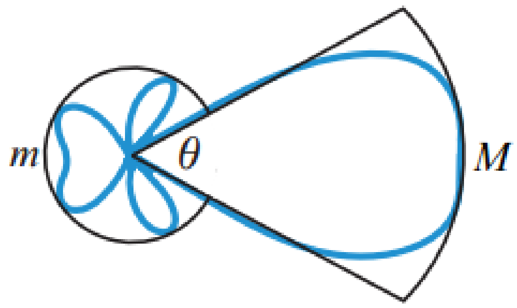

Figure 13: Approximated sectored-pattern antenna model with main-lobe gain M, side-lobe gain m, and main-lobe beam-width Θ[8]

Some simulations were performed to study the transmission of the signals using antenna directivity. So, we took theta which is changing from 0 to pi/3 (0 to 60 degrees) in increments of pi/36 (5 degrees) and the results were as follows:

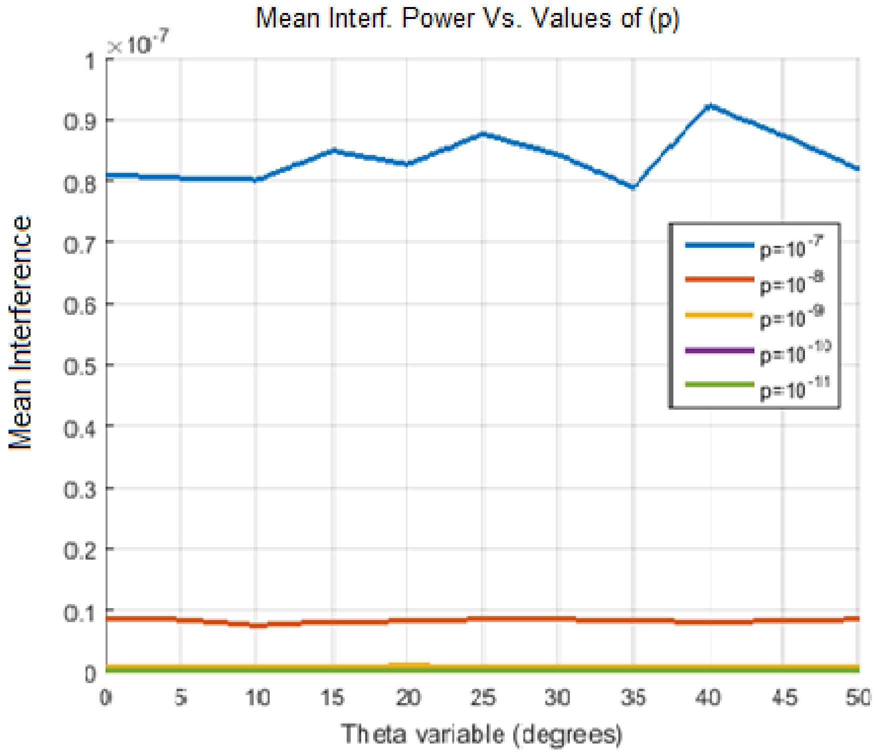

Figure 14: Simulation results showing the variations in the mean interference with theta changing from 0^{0} to 60^{0} and for the different values of p.

For the traceability of the mmWave, approximation of the actual array beam pattern by a step function with a constant main-lobe over the beam-width and a constant side-lobe is done. Such a model is used for tractable coverage and rate analysis of mmWave cellular networks [8]. It is clearly seen that in the beginning that the interference is very high but as the angle of the antenna increases i.e. there is more directivity towards the receiver the interference from the other station also minimizes as the signal is sent directly to receiver with narrow beam hence, experiencing less signal disruption.

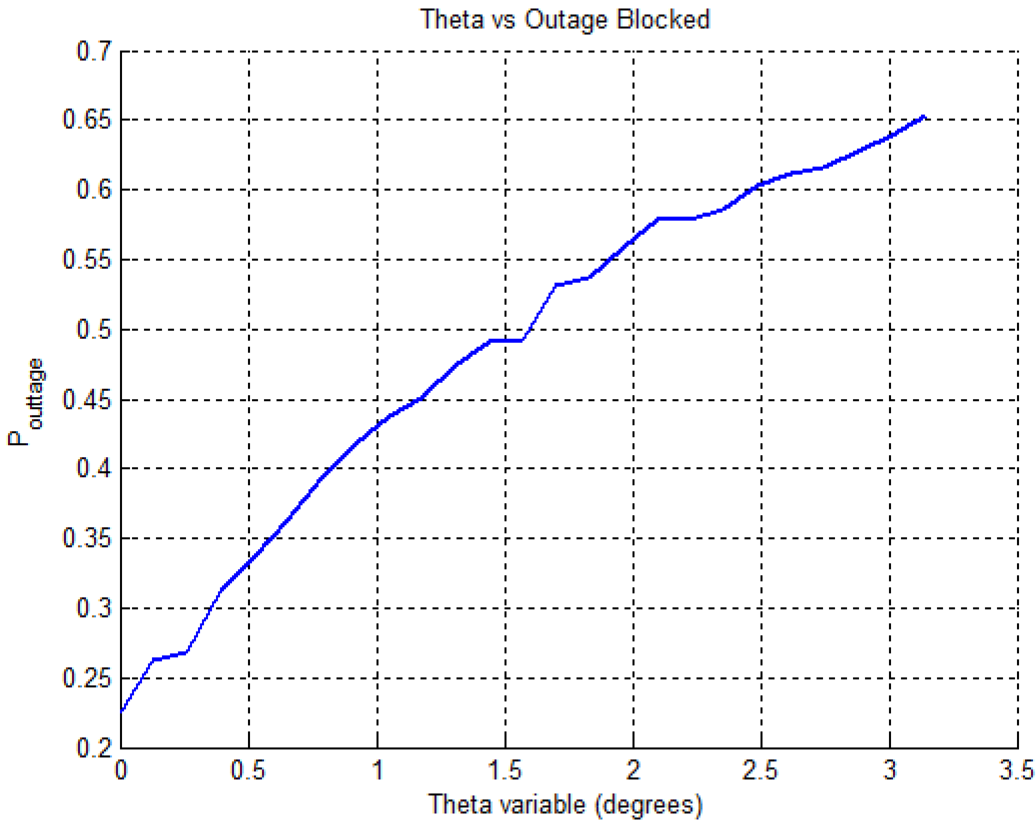

Figure15: Simulation Results To Study the Outage as the Theta Changes From 0 To pi/3 With p = 10^{-7} , M=100 and m=1/100.

It is clear from the above simulation result that the probability of the occurrence of outage increases as the value theta is increased. It is interesting to note that interference from other base station gets higher as the antenna gain of the receiver increases because higher the value of theta, more disruption in the signal is experienced Therefore, minimizing the performance of the mmWave networks.

The following table shows the outage mean and outage variance for different angle theta with constant value of p and correspondingly the standard error. Standard error helps to evaluate the performance of the network and is calculated using the formula:

STANDARD ERROR = √ (VARIANCE / NO. OF ITERATIONS)

Command Window

```
'Theta'      'Mean Pow. Outtage'     'Var Pow. Outtage'
[      0]    [           0.0796]     [          0.0733]
[0.1309]     [           0.0844]     [          0.0773]
[0.2618]     [           0.0696]     [          0.0648]
[0.3927]     [           0.0790]     [          0.0728]
[0.5236]     [           0.0738]     [          0.0684]
[0.6545]     [           0.0782]     [          0.0721]
[0.7854]     [           0.0744]     [          0.0689]
[0.9163]     [           0.0790]     [          0.0728]
[1.0472]     [           0.0776]     [          0.0716]
[1.1781]     [           0.0730]     [          0.0677]
[1.3090]     [           0.0822]     [          0.0755]
[1.4399]     [           0.0776]     [          0.0716]
[1.5708]     [           0.0730]     [          0.0677]
```

Table4: Output for the variance and mean outages.

SNo.	Standard Error
1.	0.003828
2.	0.003931
3.	0.003600
4.	0.003815
5.	0.003698
6.	0.003797
7.	0.003712
8.	0.003815
9.	0.003784
10.	0.003679
11.	0.00388
12.	0.003784
13.	0.003679

Table5: Results for the Standard Error with respect to Variance Outage

As it seen from the table 5 that standard error of the variance outage constantly increases as the angle of the antenna increases hence , indicating that wider the theta, higher the interference. Thus, this leads to increased outage which reduces the performance of the network.

The following table shows the mean and variance as the angle theta with the change in the value of p

'Theta'	'Mean Pow. Interf.'	'Var Pow. Interf.'
[0]	[8.4710e-12]	[1.1551e-22]
[5]	[8.6230e-12]	[1.1988e-22]
[10]	[8.7967e-12]	[1.3184e-22]
[15]	[8.4806e-12]	[1.0545e-22]
[20]	[8.2249e-12]	[9.4782e-23]
[25]	[8.2381e-12]	[9.7381e-23]
[30]	[8.4150e-12]	[1.1011e-22]
[35]	[9.0527e-12]	[1.5491e-22]
[40]	[8.7324e-12]	[1.1935e-22]
[45]	[8.5076e-12]	[1.1153e-22]
[50]	[8.5008e-12]	[1.2276e-22]

Table 6 : The results of mean interference and variance after performing the simulation for antenna directivity.

Finally, standard error of the mean is calculated

SNo.	Standard Error
1.	3.3986e - 13
2.	3.4623e - 13
3.	3.6309e - 13
4.	3.2473e - 13
5.	3.0786e - 13
6.	3.1205-e -13
7.	3.3182e - 13
8.	3.9358e - 13
9.	3.4547e - 13
10.	3.3396e - 13
11.	3.5037e - 13

Table 7: Standard Error of the Variance Interference

It is clearly seen from table 6 and 7 that point where the interference in the network increases, the standard error also gets increases hence decreasing the efficiency of the network.

C. Mean And Variance Association

C.1 Simulation performed for mean and variance:

The following figure is the simulation result of mean interference power for different values of p and it clearly states that when receiver sensitivity i.e. $p=10^{-7}$, the base stations needs to transmit the signals at high power and therefore high interference is experienced. As the value of p decreases the, interference level also decreases simultaneously.

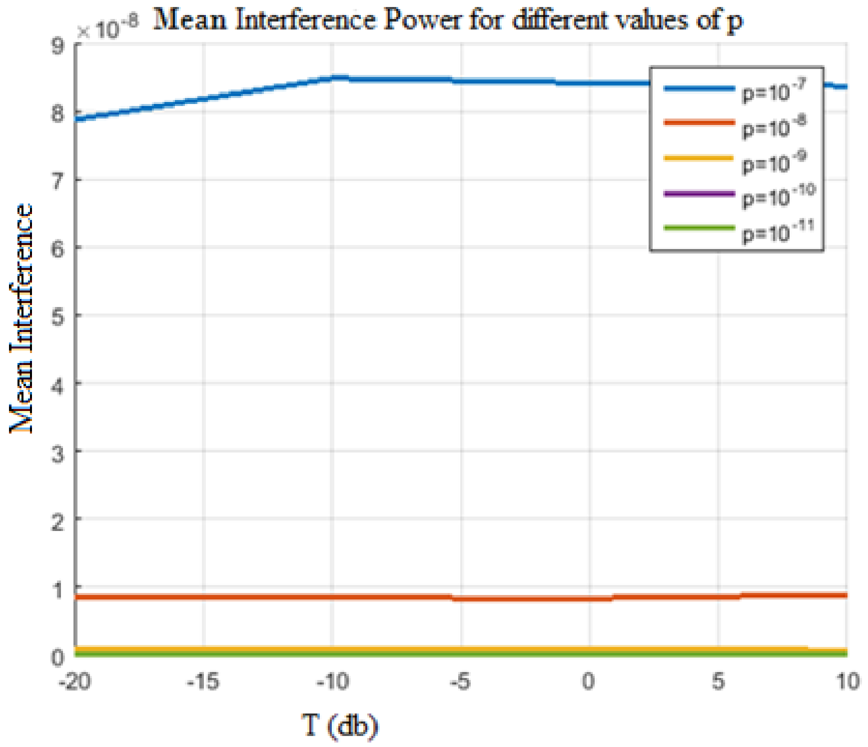

Figure 16: Simulation results to find mean and variance of the mm wave and finally calculate mean interference power for different values of p and T

'TdB'	'Mean Blocked Pow. Interf.'	'Var Blocked Pow. Interf.'
[-20]	[8.6589e-12]	[1.1986e-22]
[-10]	[8.5479e-12]	[1.1790e-22]
[0]	[8.9180e-12]	[1.3293e-22]
[10]	[8.4963e-12]	[1.0601e-22]

Table 8: The mean and variance result for the above simulation results.

SNo.	Standard Error
1.	3.4620e-13
2.	3.4336 e-13
3.	3.6459e-13
4.	3.2559e-13

Table 9: Standard Error of the Mean Interference

C.2 Simulation results to observe outage for the three distinct cases:

1. alphaN=2 alphaB=4

M=100 m=1/10

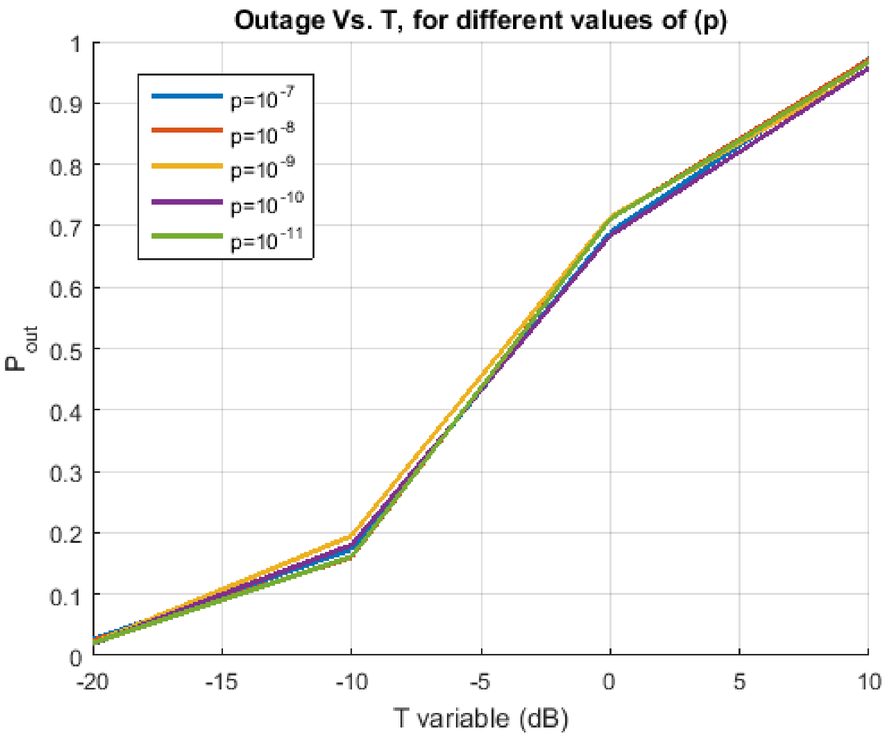

Figure 17: The outage probability (Pout) vs. T in dB for different values of p and T where alphaN=2 and alphaB=4.

2. alphaN=3 alphaB=5

M=100 m=1/10

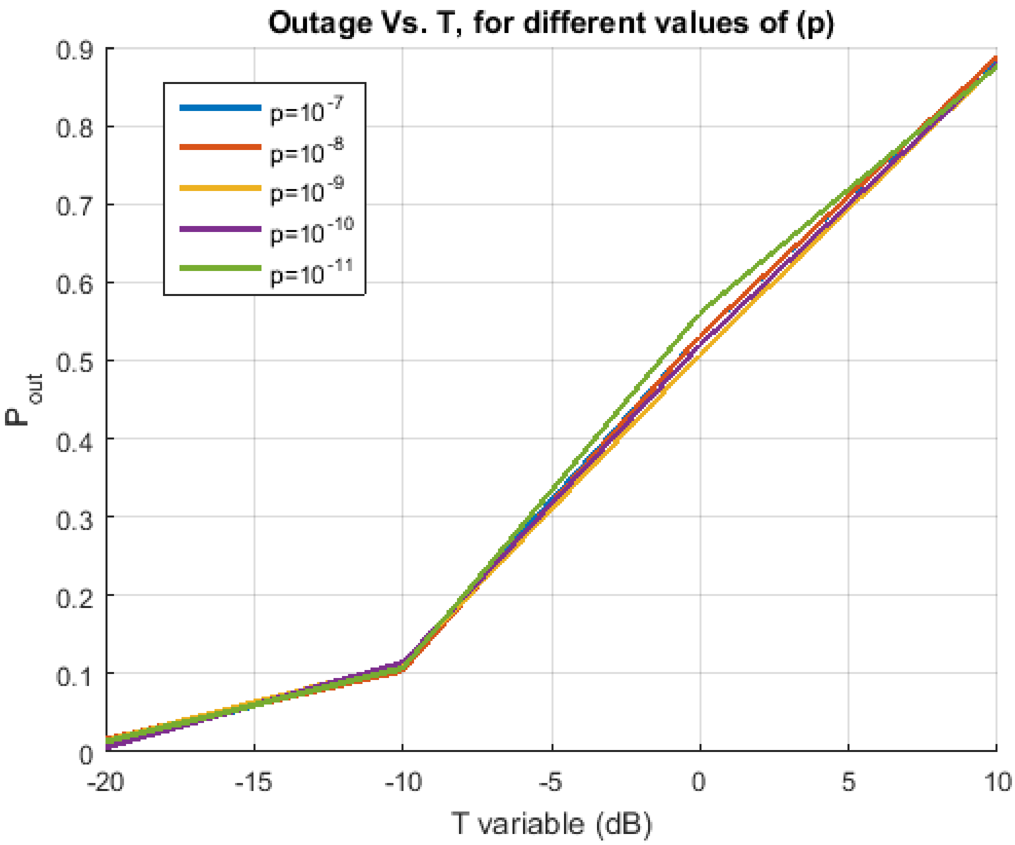

Figure 18: The outage probability (Pout) vs. T in dB for different values of p and T where alphaN=3 and alphaB=5.

3. alphaN=2 alphaB=5
M=100 m=1/10

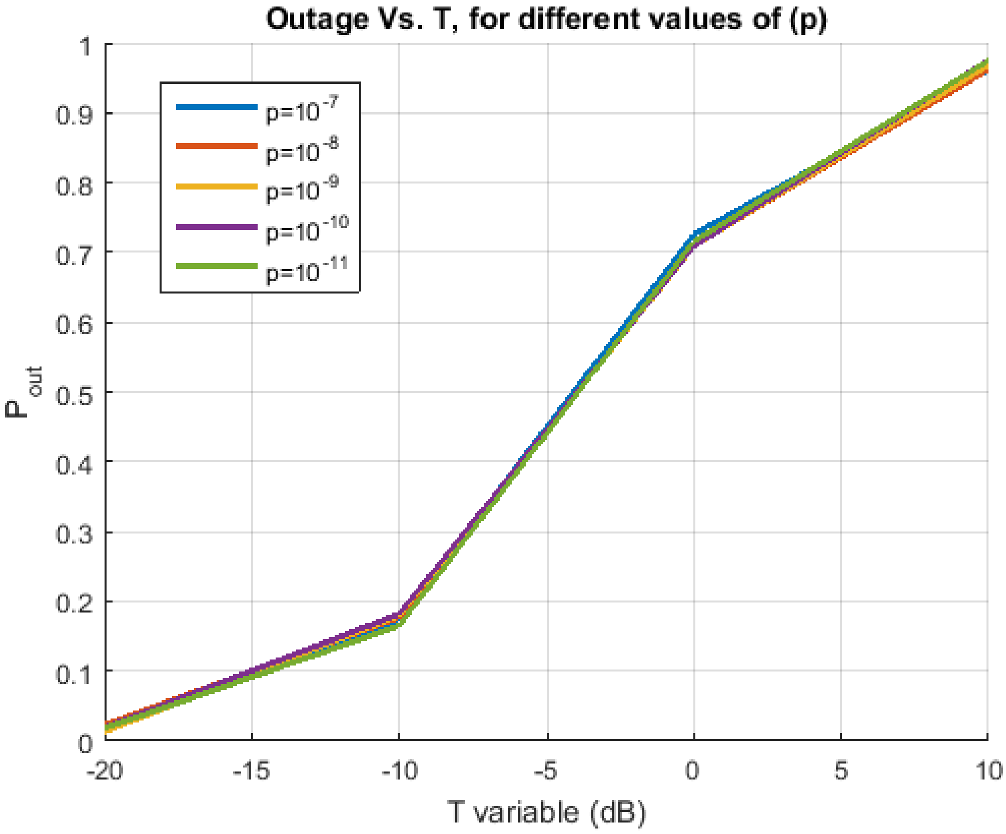

Figure 19: The outage probability (Pout) vs. T in dB for different values of p and T where alphaN=2 and alphaB=5.

From the above results it is clearly seen that, while comparing the mean interference power with the conventional network with that of mm wave, it depicts that the mean interference power of the mmWave is much less than that of heterogeneous networks because in mm wave network some of the interference are blocked while others are non-blocked so interference power at the receiver is reduced. Interestingly, note that the outage probability increases when alphaB is increased from 4 to 5 while on the other side curves for alphaN = 1 and alphaN = 3 is almost similar.

Chapter 6

6.1 Discussion

After conducting the simulations on both heterogeneous as well as millimeter wave network, it is observed that definitely millimeter wave frequency outperforms as compared to conventional frequencies.

The superiority of the millimeter wave networks is seen even in realistic propagation conditions, including all the aspects that typically are expected to limit millimeter wave communications, such as NLOS propagation, limited link range, environment shadowing and human body shadowing. Remarkably, even in such realistic conditions, the millimeter wave network shows very competitive performance with respect to heterogeneous network.

When path loss model is compared for the entire network it is evident that due to the presence of higher attenuation in free space and through walls at mm frequencies, the same frequency can be reused at shorter distances whereas this not possible in traditional frequency waves. Also, when we look towards the mean interference, it is seen that the mean interference of the mm wave is much lower that of the heterogeneous networks due to antenna directivity and blockages. Hence, it can be concluded that the inherent security and privacy is better at mm-wave frequencies because of the limited range and the relatively narrow beam widths that can be achieved.

6.2 Conclusion

The upcoming standardization and development of mmWave cellular systems is one of the largest leaps forward in wireless communications in the last two decades [8] It is seen that mm Wave will impact every aspect of the cellular communication. Going through the mmWave though introduces novel design challenges and research questions. This report describes the two utmost important challenges- susceptibility to blockages and need for strong beam directionality.

There are still some aspects to be discovered and analysed to make efficient use of mm wave technology and to able to launch 5g in this spectrum. There are many open questions remaining like how to do load balancing and offloading in light of directionality and blocking. The support of the mobility is also not been discussed here which would need considerable effort (and system overhead) to keep the beams aligned in both the downlink and uplink directions. We expect the models discussed in this work will continue to be improved and extended to help aid the understanding and design of these mmWave cellular systems [8].

References:

[1] Andrea Goldsmith, “WIRELESS COMMUNICATIONS”

[2] https://www.nutaq.com/blog/millimeter-waves-how-we-got-here-physical-challenges-and-5g-opportunities

[3] http://searchnetworking.techtarget.com/definition/band

[4] “Millimeter Wave Equipment Market is considered as One of the Rapidly Growing market by 2024”

[5] Marco Di Renzo, Senior Member, IEEE “Stochastic Geometry Modeling and Analysis of Multi-Tier Millimeter Wave Cellular Networks”

[6] By Sundeep Rangan, Senior Member IEEE, Theodore S. Rappaport, Fellow IEEE, and Elza Erkip, Fellow IEEE, “Millimeter-Wave Cellular Wireless Networks: Potentials and Challenges”

[7] L. Decreusefond, P. Martins, T. T. Vu Institut Telecom Telecom Paristech CNRS LTCI Paris, France,” An analytical model for evaluating outage and handover probability of cellular wireless networks”

[8] Jeffrey G. Andrews, Tianyang Bai, Mandar Kulkarni, Ahmed Alkhateeb, Abhishek Gupta, Robert W. Heath, Jr., “Modeling and Analyzing Millimeter Wave Cellular Systems”

[9] S. Kusaladharma and C. Tellambura, Fellow, IEEE, “Interference and Outage in Random D2D Networks under Millimeter Wave Channels”

[10] RECEIVER SENSITIVITY / NOISE, http://www.phys.hawaii.edu/~anita/new/papers /militaryHandbook/rcvr_sen.pdf”

[11] Sunil Srinivasa and Martin Haenggi, “Path Loss Exponent Estimation in Large Wireless Networks”

[12] L. Decreusefond, P. Martins, T. T. Vu,” An analytical model for evaluating outage and handover probability of cellular wireless networks”

[13] Steven Weber, Member, IEEE, Jeffrey G. Andrews, Senior Member, IEEE, Nihar Jindal, Member, IEEE, “The effect of fading, channel inversion, and threshold scheduling on ad hoc networks”

Appendix

```
clc, clear, close all;

R = 200;
sizeW = pi*(R^2);
lambda1= 0.001;
lambda = 0.0001;
p = 10^(-11);
a = 3; %constant

TdB = -30:10:20;

%creating a new figure for display:
figure, grid on, hold on
title('Outage Vs. T, for different No. of Simulations');
xlabel('T variable (dB)'); ylabel('Outtage');

%The values of simulations required:
Nsim_val = 200;

for t = 1:length(Nsim_val)
Nsim = Nsim_val(t);  %the corresponding values of simulation number
OUT = zeros(1,length(TdB));  %initialize a vector of zeros for the out
OUT_blocked = zeros(1,length(TdB));  %initialize a vector of zeros for the
out considering blocked
for itr1 = 1:length(TdB)
    T = 10^(TdB(itr1)/10);
    OUT(itr1) = 0; %initialize to zero
    OUT_blocked(itr1) = 0;  %initialize to zero
    for itr=1:Nsim
        %For Base Station
        N = poissrnd(lambda*sizeW); if N == 0; N = 1; end  %just to avoid
case of N = 0
        r = sqrt(R^2*rand(1,N));
        th = 2*pi*rand(1,N);
        X = r.*cos(th);
        Y = r.*sin(th);

        %For users
        Nusers = poissrnd(lambda1*sizeW);
        r1 = sqrt((R^2)*rand(1,Nusers));
        th1 = 2*pi*rand(1,Nusers);
        X1 = r1.*cos(th1);
        Y1= r1.*sin(th1);
        % hold on
        min_distance = zeros(1,Nusers);
        bs_location = zeros(1,Nusers);

        for counter1 = 1:Nusers
            NUsersVector = (X1(counter1)+ Y1(counter1)*1i).*ones(1,N);
            Nvector = X+Y*1i;
            distance = abs(NUsersVector - Nvector);
            [minimum1, location] = min(distance);
            min_distance(counter1) = minimum1;
```

```
            bs_location(counter1) = location;
        end

        random_distance = zeros(1,N);
        for counter2 = 1:N
            AA = bs_location==counter2;
            BB =min_distance.*AA;
            L = BB(BB~=0);
            if L>0
                random_distance(counter2) = L(randi(size(L)));
            else
                random_distance(counter2) = 0 ;
            end
        end

        %Creating user at (0,0)
        User_ID = Nusers + 1; %adding a user to the current vector of
generated users
        X1(User_ID) = 0; Y1(User_ID) = 0; %initializing the user position
to zeros

        %acquiring the user's position:
        user_posx = X1(User_ID);
        user_posy = Y1(User_ID);

        %Looping over the total number of stations to calculate the
distance
        %between each station and the user defined:
        distance_stations = zeros(1,N);
        for i = 1:N
            pos_station = [X(i) Y(i)];
            pos_user = [user_posx user_posy];
            distance_stations(i) = pdist([pos_station;pos_user]);
        end

        %finding out the minimum distance between the user and the base
stations:
        nearest_station = find(distance_stations ==
min(distance_stations)); %station number

        %Task 01: (Excluding the base station nearest to user from BS
vector):
%======================================================================
        pos_station = [X(nearest_station) Y(nearest_station)]; %its
position
        N_new = N - 1; %The new number of BS after excluding the closest
BS.
        BS_available = 1:1:nearest_station-1;
        BS_available = [BS_available, nearest_station+1:1:N];
        distance_BS_available = distance_stations (BS_available);
        %displaying messages:
        %outage=0;

        %Task 02: (Finding the transmit power):
        %=======================================
        d = nearest_station;
        nearest_stat_dist = distance_stations(d);  %distance of nearest
station
        Power_transmitted = p * nearest_stat_dist^a; %The transmitted power
```

```
        %displaying messages:

        %Task 03: (Received Power):
        %============================
        ray_fading = exprnd(1,1,1); %the rayleigh fading coefficient
        Power_received = p * ray_fading; %The received power calculations
        %displaying messages:

        %Task 04: (Interference and SINR):
        %====================================
        inter_fading = exprnd(1,1,N_new); %The fading effect during
interference
        inter_distances = distance_BS_available.^(-a);
        inter_effect = Power_transmitted .* inter_fading .*
inter_distances;
        Power_interference = sum(inter_effect); %calculating the
interference power
        SINR = Power_received / Power_interference;
        %displaying messages:
        if SINR < T
            OUT(itr1) = OUT(itr1) + 1 ;  %increment the outtage at this T
level by one
        end

        %Task 05: (Antenna Directivity):
        %===================================
        theta = pi/6; %30 degrees
        Bern_var = zeros(1,N);  %Initialize the bernoulli variable for all
available antennas
        G = zeros(1,N);  %initialize the G (antenna gain) variable for all
antennas
        for stat = 1:N  %for all available antennas
            Bern_var(1,stat) = randi([0,1]);  %random integer for bernouli
variable for the nth antenna
            if Bern_var(1,stat) == 1  %bernoulli variable is one
                M = theta/(2*pi);
                G(1,stat) = M;
            else %the bernoulli variable is zero
                m = (2*pi) - (theta/(2*pi));
                G(1,stat) = m;
            end
        end

        %Task 06: (probability blocked or Not)
        %========================================
        alpha_N = 4;  %if the base station is blocked
        alpha_B = 2;  %if the base station is not blocked
        prob_blocked = zeros(1,N);  %initialize the probability of being
blocked to be zero
        a_blocked = zeros(1,N); %initialize the (a) value after checking
block or not

        for stat = 1:N  %for all available stations
            stat_dist = distance_stations(stat);  %distance of each station
from user
            prob_blocked(1,stat) = 1 - exp(-stat_dist);
            if prob_blocked(1,stat) > 0.5
                a_blocked(1,stat) = alpha_B;  % not blocked
            else
                a_blocked(1,stat) = alpha_N;  % blocked
```

```
            end
        end

        %Then calculate the interference using recalculated values of a:
        d = nearest_station;
        nearest_stat_dist = distance_stations(d);  %distance of nearest
station
        a = a_blocked(1,d);  %the value of (a) for nearest station
        Power_transmitted = p * nearest_stat_dist^a; %The transmitted power

        %Calculating the power  interference and SINR considering block
        inter_fading = exprnd(1,1,N_new); %The fading effect during
interference
        inter_distances_blocked = zeros(1,N_new);  %initialize new to zeros
        for stat = 1:N_new  %for all available stations (excluding nearest
to user)
            val = BS_available(stat);  %the current BS station
            a = a_blocked(1,val);  %the value of (a) for current station
            inter_distances_blocked(1,stat) =
distance_BS_available(1,stat).^(-a);
        end
        inter_effect_blocked = Power_transmitted .* inter_fading .*
inter_distances_blocked;
        Power_interference_blocked = sum(inter_effect_blocked);
%calculating the interference power
        SINR_blocked = Power_received / Power_interference_blocked;

        if SINR_blocked < T
            OUT_blocked(itr1) = OUT_blocked(itr1) + 1 ;  %increment the
outtage at this T level by one
        end

    end
end



%Task 07: Nearest station updates:
        %====================================
        d = nearest_station;
        G(1,d) = M;  %The gain for nearest station is always (M).
        stat_dist = distance_stations(d);  %distance of this station from
user
        prob_blocked(1,d) = 1 - exp(-stat_dist);
        binomial_random_variable = binornd(1, prob_blocked(1, d));
        if binomial_random_variable == 0
            a_blocked(1,d) = alpha_B;  % not blocked
        else
            a_blocked(1,d) = alpha_N;  % blocked
        end

        %Then calculate the interference using recalculated values of a:
        %==============================================================
        d = nearest_station;
        nearest_stat_dist = distance_stations(d);  %distance of nearest
station
        a = a_blocked(1,d);  %the value of (a) for nearest station
        Power_transmitted = p * nearest_stat_dist^a; %The transmitted power

        %Calculating the power  interference and SINR considering block
```

```
        inter_fading = exprnd(1,1,N_new); %The fading effect during
interference
        inter_distances_blocked = zeros(1,N_new);  %initialize new to zeros
        for stat = 1:N_new  %for all available stations (excluding nearest
to user)
            val = BS_available(stat);  %the current BS station
            a = a_blocked(1,val);  %the value of (a) for current station
            inter_distances_blocked(1,stat) =
distance_BS_available(1,stat).^(-a);
        end
        inter_effect_blocked = Power_transmitted .* inter_fading .*
inter_distances_blocked;
        Power_interference_blocked = sum(inter_effect_blocked);
%calculating the interference power
        Interference_blocked(itr1, itr) = Power_interference_blocked;
        SINR_blocked = Power_received / Power_interference_blocked;

        if SINR_blocked < T
            OUT_blocked(itr1) = OUT_blocked(itr1) + 1 ;  %increment the
outtage at this T level by one
        end
    end
    %calculating the mean and variance for the conducted Nsim:
    Mean_Interference(itr1,1) = mean(Interference(itr1,:));
    Mean_Interference_blocked(itr1,1) = mean(Interference_blocked(itr1,:));
    Var_Interference(itr1,1) = var(Interference(itr1,:));
    Var_Interference_blocked(itr1,1) = var(Interference_blocked(itr1,:));
end
```