Device-to-Device (D2D) Communication in Terahertz (THz) Frequency Band

by

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DECLARATION

We hereby declare that the thesis titled "Device-to-Device (D2D) Communication in Terahertz (THz) Frequency band", a thesis submitted to the Department of Electrical and Electronics Engineering of BRAC University in partial fulfillment of the Bachelor of Science in Electrical and Electronics Engineering. This is our original work and this have submitted a part of this thesis in ECCE 2019 titled as 'Energy Efficiency Analysis of Device-to-Device Communication in THz Frequency Band'.

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ACKNOWLEDGEMENT

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ABSTRACT

In recent time the numbers of cellular devices are increasing very rapidly, as a result effective communication network through fifth generation network device to device (D2D) system plays a vital role in wireless communication medium. The D2D communication in THz frequency band is more effective than other frequency band as it is more energy efficient and reduces the communication delay. In this thesis, we have discussed the theoretical model of terahertz frequency band in D2D communication technology. Furthermore, we develop the mathematical expression of data rate, outage probability and energy efficiency for deterministic network and also the mathematical expression of throughput, delay sensitive area spectral efficiency (DSE) for random network. The simulation results show a good improvement in increasing data rate and energy efficiency as well as decreasing the outage probability of D2D communication in terahertz frequency band. For the transmission power of 36 dBm, energy efficiency increases by 8.18% when separation distance between transmitter and receiver are 0.01 km and 0.5 km, respectively. In terms of optimal power transmission of DSE for increasing SINR threshold from 100 dBm to 105 dBm at code rate value 9 npcu, DSE increase by 43.7%.

CHAPTER 1

INTRODUCTION

1.1 Introduction to D2D Communication

Device-to-device (D2D) communications is a new innovation that offer remote distributed administrations and enhance range usage in LTE-advanced network system. D2D interchanges was at first proposed in cell network as another worldview to upgrade network representation. The inspiration for D2D come specifically from the client necessities and D2D interchanges will serve particular future needs. These requirements comprehend new kinds of short range administrations and information concentrated short range applications. D2D communication will permit new sorts of administrations such media downloading, video spilling, web based gaming and distributed (P2P) document sharing.

Device to-Device communication in cellular systems is characterized as immediate correspondence between two versatile users without navigating the Base Station (BS) or center system. D2D communication is usually not transparent and it happens in the cellular frequencies. Depending on the LTE it will naturalize the interoperability among basic open security systems and pervasive commercial systems. In a customary cell arrange, all communications must experience the BS regardless of whether imparting parties are in range for D2D correspondence. Communication with BS suits ordinary low information rate versatile administrations, for example, voice call and content informing in which clients are only rarely close enough for direct correspondence. Be that as it may, portable clients in the present cell systems utilize high information rate administrations (e.g., video sharing, gaming, vicinity mindful long range informal communication) in which they could conceivably be in range for direct interchanges (i.e., D2D). Subsequently, D2D interchanges in such situations can extraordinarily expand the ghastly effectiveness of the network system.

On a basic level, direct communication between adjacent cell devices will enhance range usage, by and large throughput, and vitality productivity, while empowering new distributed and area based applications and administrations. D2D-empowered long term evolution (LTE) devices can possibly wind up focused for fallback open security organizes that must capacity when cell systems are not accessible or come up short. Numerous new difficulties and dangers to the long-standing cell design, which is revolved around the base station BS is presented by D2D communication.

Existing information conveyance conventions in D2D communication for the most part expect that mobile nodes readily take an interest in information conveyance, share their assets with one another, and pursue the guidelines of fundamental systems administration conventions. All things considered, rational nodes in certifiable situations have key co-operations and may act egotistically for different reasons, (for example, asset impediments, the absence of enthusiasm for information, or social inclinations).

Such as example, if a node has restricted battery assets or the expense of the system transmission capacity conveyed by portable system administrators is high, it would not enthusiastically transfer information for others until the point that fitting motivating forces are given. In the interim, pernicious nodes may offensive the system in various approaches to bother the general activity of the information transmission process. Again an example, an opponent may drop gotten messages however deliver manufactured directing measurements or false data with the point of drawing in more messages or shortening its invention likelihood. This issue turns out to be all the more difficult while plotting opponents support their measurements to delude onfall discovery frameworks.

1.2 Applications of D2D Communication

D2D communication is used for three applications. They are:

1.2.1 Local Services

In local service, client information is specifically transmitted straightforwardly among the terminals and doesn't includes form side, e.g. online networking applications, which depend on nearness benefit.

1.2.2 Emergency Communications

If there should be an occurrence of natural calamity like storms, temblor, hurricanes and many more conventional communication systems may not work because of the harm caused. Specially appointed system can be set up by means of D2D which could be utilized for such communication in such circumstances.

1.2.3 IoT Increase

By joining D2D with IoT, a genuinely interconnected wireless network system will be made. Case of D2D-based IoT improvement is vehicle-to-vehicle (V2V) correspondence in the Internet of Vehicles (IoV). When running at high speeds, a vehicle can caution close-by vehicles in D2D mode before it moves to another lane or backs off.

1.3 Classifications of D2D Communications

D2D communication can be classified into two sections and they are, inband D2D and outband D2D. They are based on the band spectrum in which d2d communication arises. These both bands are divided into two sections. Inband D2D is divided into underlay and overlay section on the other hand outband D2D is divided into network controlled and autonomous section. In outband D2D autonomous is divided into two sections they are in coverage and out of coverage.

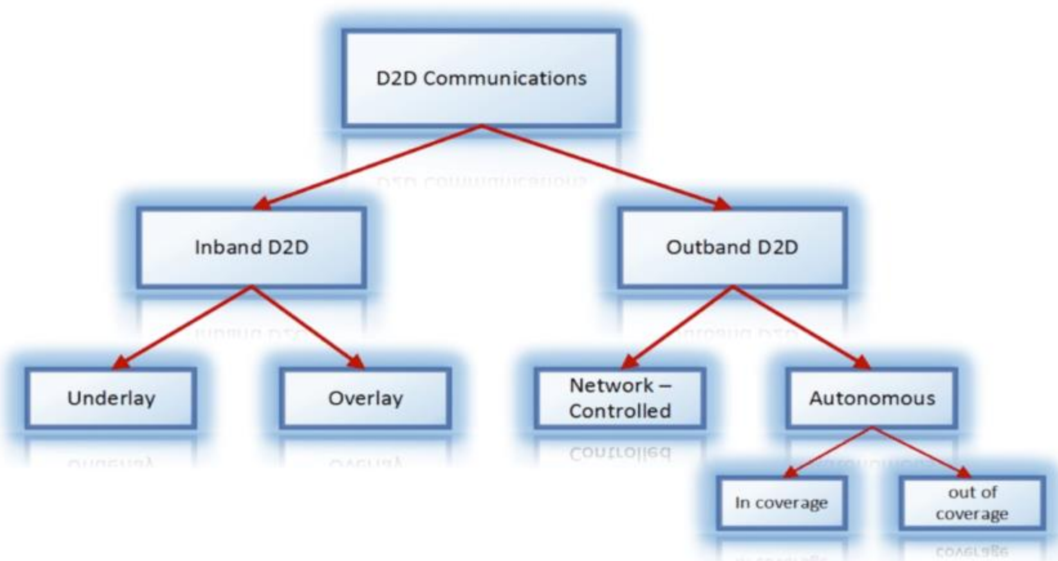

Figure 1.1: Classifications of D2D Communication.

1.4 Review of Previous Works and Observation

Building up the mathematical expressions of information rate, outage probability and energy proficiency, the reproduction results see us a decent enhancement in expanding information rate and energy effectiveness and in addition diminishing the outage probability of D2D communication in terahertz band frequency. Over the years, many researchers have examined and proposed various methods to D2D communication in terahertz band frequency. We have examined some commitment of various creators related to D2D communication in terahertz band frequency in this section.

Nie *et al.* (2017) have developed time-varying channel modeling and tracing for the THz frequency indoor communications. Specifically, a three-dimensional time-varying THz channel demonstrate that catches the eccentricity in propagation parameters is introduced. Depending on the THz channel characteristics an all-inclusive Kalman filtering approach has proposed to precisely follow the viewable pathway segment along the variety. Also, the proposed channel demonstrating and following methodology under a sensible access-point-to-user-equipment situation in an office ambience is assessed in detail [1].

Jia *et al.* (2017) have tentatively illustrated on a photonic multi-channel terahertz (THz) remote transmission framework in the 350-475 GHz band. The work of six THz carriers have regulated with 10 Gbaud Nyquist quadrature stage move scratching baseband signal per transporter results in a general limit of up to 120 Gb/s. The influence of the harmonic has spurs in a THz receiver on the performance of the transmission system has been worked [2].

Dan *et al* (2017) have proposed a dependable technique for describing the disseminating parameters of radio connections working at THz frequencies. The complicated transmit features and the non-idealities of simple transmit-get frontends with quadrature baseband channels can be assessed. Exact gain-recurrence and phase recurrence estimations are illustrated. Also in this paper the standard of estimation and clarifies the key parts of the setup and how to overcome difficulties. In addition, it gives an account of a free space transmission, which describes all the more precisely a reasonable remote connection is described [3].

Dowhuszko *el al* (2017) have proposed a decentralized approach, that took into account the effect of distance to select the per-carrier transmit beamforming weights and powers. For this reason, low-rate feedback data has accounted for from the recipient to the transmission focuses, with the end goal that choices performed locally consider the ones made in the organized set [4].

Song *el al* (2011) have examined the current progress of THz-wave technologies related to applications in the field of communication and talked about a few issues that should be considered for the eventual fate of communications. They have also investigated the most recent improvement in basic technologies for THz communications and discussed various issues that need to be granted for the improvement of applied systems in future [5].

Moldovan *el al* (2017) have been investigated the coverage problem and the achievable data rate performance of the indoor THz wireless networks. The base individual client rate for various asset distribution plans has evaluated, considering the impacts of between image obstruction because of direct scattering in the THz band and as a result of the SFN transmit convention. Results have exhibited that the proposed signal frequency network scheme can give a high minimum attainable client information rate [6].

Khalid *el al* (2017) have explored some networking scenario of full dimension multiple-input-multiple-output based on THz band indoor wireless networks in order to determine the number of nodes which were connected to a base station. They have determined the quantity of nodes that can be associated with a BS as an element of the antenna characteristics [7].

Guizani *el al* (2016) have carried out a resource allocation scheme which was designed to enable D2D communication underlay cellular network in the E-band.The proposed scheme also aims to approach the system throughput and alleviate interference caused by dense networks of D2D pairs. They have revealed insight into how the framework advances when the transmit forces of both user terminals and device terminals increments [8].

Kar *el al* (2017) have evaluated about the primary attributes of D2D communication including its use situations, engineering, specialized highlights, and regions of dynamic research. They additionally have examined the principal attributes of D2D communication including its use situations, design, specialized highlights, and territories of dynamic research [9].

Gandora *el al* (2016) have introduced a broad review on device-to-device (D2D) communication including the in addition to focuses it offers; the key open issues related with it for instance; peer revelation, asset assignment and so forth are requesting unique consideration of the examination network; a portion of its integrant advancements like millimeter wave D2D (mmWave), ultra-dense systems (UNDs), subjective D2D, handover methodology in D2D and its variously utilized cases. Design is expecting to satisfy every one of the endorsers' requests in an ideal way [10].

Wang *el al* (2014) have given that a scientific classification dependent on the D2D conveying range and evaluated thoroughly from the accessible literary works under the proposed scientific categorization. In addition, there has been given new bits of knowledge into the over- investigated and under-investigated regions which drove us recognizing open research issues of D2D communication in cell systems [11].

Jameel *el al* (2018) have evaluated that the examination network is effectively exploring the D2D worldview to understand its maximum capacity and empower its smooth joining into the future cell framework design. They have inspected as of late proposed arrangements in over investigated and under investigated regions in D2D [12].

Höyhtyä *el al* (2018) have inspected that the status of third Generation Partnership Project (3GPP) institutionalization, or, in other words essential institutionalization body for 5G frameworks. They have characterized an arrangement of use situations for D2D communications in 5G systems. They have used the recent models of 3GPP long term evolution (LTE) and WiFi interfaces in analyzing the power consumption from both the infrastructure and user device perspectives [13].

Erturk *el al* (2013) has analyzed here about the spatial circulation of transmit powers and flags to impedance in addition in device-to-device (D2D) systems. They have utilized homogeneous Poisson Point Processes (PPP), aggregate dissemination work (CDF) of the transmit power and SINR logically inferred for a D2D arrange utilizing power control [14].

Al-Hourani *el al* (2016) have logically evaluated the phone organize execution amid huge foundation failure, where a few terminals can assume the job of low-control hand-off nodes framing multi chip communication connects to help promote terminals which are outside of the range of solid system inclusion. They have logically decided the D2D impact in easing the harm caused by the disaster [15].

Chun *el al* (2017) have considered two as of late proposed summed up blurring models, to be specific k - μ and η - μ, to describe the blurring conduct in D2D interchanges. Out and out, these models incorporate the vast majority of the broadly used blurring models in the winter, for example, Rayleigh, Rice (Nakami - n), Nakagami - m, Hoyt (Nakagami - q), and one - sided Gaussian. By utilizing stochastic geometry, they have assessed the unearthly productivity and blackout probability of D2D organizes under summed up blurring conditions and they have additionally exhibited new bits of knowledge into the tradeoffs between the dependability, rate, and mode choice [16].

Al-Hourani *el al* (2016) has showed that a mathematical structure has depicted for assessing the vitality sparing of a hand-off helping of a couple of remote gadgets. They have inferred shut frame articulations for portraying the geometrical zone where transferring was vitality productive. They additionally have gotten the probabilistic dispersion of the vitality sparing presented by transfers that are arbitrarily appropriated by a spatial Poisson point process [17].

1.5 Objective of the Thesis

The objective of the thesis is to analyze and discuss the theoretical model of terahertz frequency band in D2D communication technology. To meet the aim of this thesis, the following objectives have been identified.

1. To establish the pathloss model for THz frequency band in D2D communication.
2. To develop the theoretical expressions of data rate, outage probability, and energy efficiency.
3. To study DSE in various interference, noise and point to point spectrum sharing.
4. To analyze the consequences of determining the optimal transmission power and code rate for maximizing DSE.

1.6 Organization of the Thesis

This thesis is organized in four chapters. They are following:

Chapter-1 is an introductory section. This area contains the diverse age of d2d communication framework, advancement and advances.

Chapter-2 presents the theoretical model of the system in THz band in D2D communication. This part also contains the result of the system through data rate, outage probability and energy efficiency.

Chapter-3 describes the procedure of maximizing delay sensitive area spectral efficiency (DSE). In this chapter we have derived expression of optimal transmission power and code rate. Moreover, we have also derived the equation maximum DSE. Furthermore, in this chapter we have discussed the characteristics of optimal transmission power, SINR threshold and DSE from the curves obtained from MATLAB programs.

Chapter-4 presents the finishing up comments of the considerable number of parts and features some conceivable promising roads of further improvement.

CHAPTER 2

D2D COMMUNICATION FOR THZ FREQUENCY BAND

2.1 System Model

A wireless cellular network consists of macro base station (BS) and mobile users (MUs) shown in Figure 2.1. In device-to-cellular (D2C) communication, MU1 and MU2 communicate with BS or vice versa. In D2D communication, mobile users are communicated with themselves. In simple, MU2 and MU3 are using D2D communication, they are directly communicated with each other. There are types of D2D communication such as in-band D2D and out-band D2D. In in-band D2D communication, both the mobile and D2D users utilize the cellular spectrum. In this situation, BSs monitor and control the radio resources to avoid the interference between cellular users and device users (mobile users). In out-band D2D, D2D users utilize unlicensed frequency band.

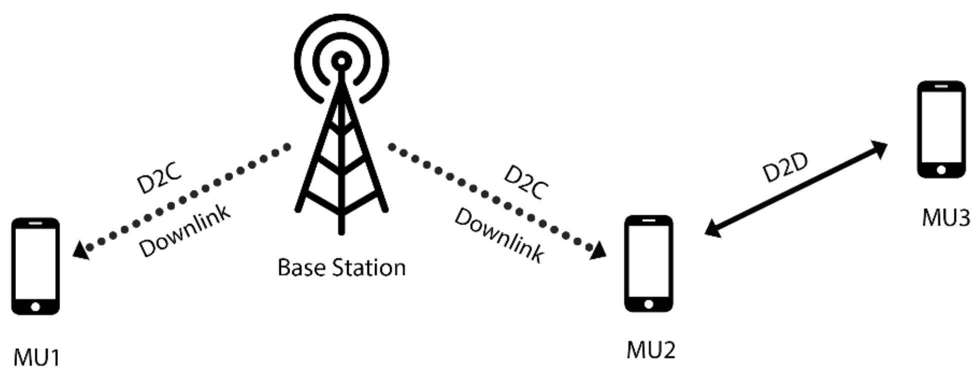

Figure 2.1: Communication Link between D2C & D2D.

2.1.1 Resource Block

A resource block (RB) is the smallest unit of resources that is allocated to a cellular or device user [18]. For calculating the available RBs in THz frequency band, theoretical expression can be defined as

$$Available\ resource\ blocks = \frac{BW * 0.9}{BW_{single}} = \frac{600\ GHz * 0.9}{60\ GHz} = 9 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

$$BW = (0.9 - 0.3) * 10^{12} = 0.6\text{ THz} = 600\text{ GHz} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2.2)$$

$$BW_{single} = \frac{bandwidth}{UE} = \frac{600\ GHz}{10} = 60\ GHz \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2.3)$$

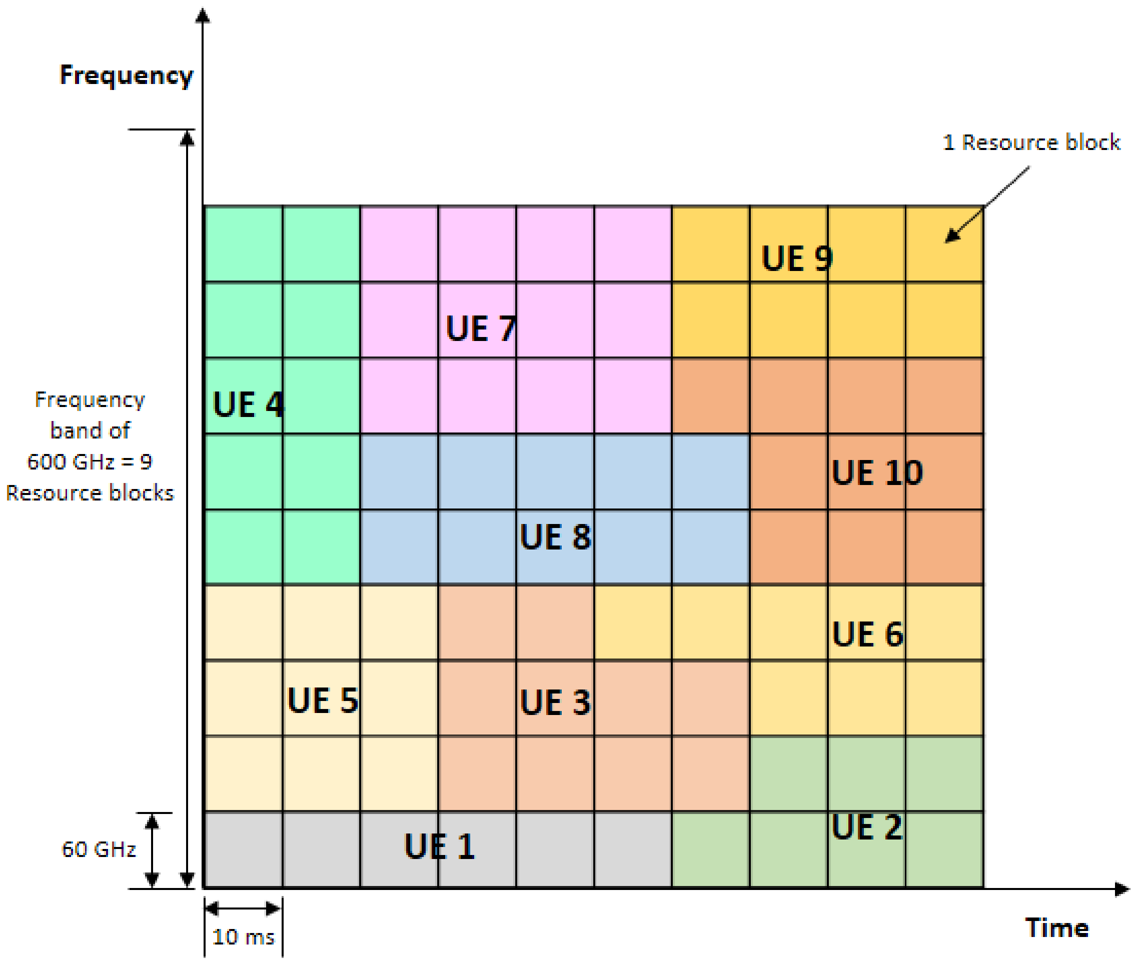

Figure 2.2: Resource Allocation in LTE.

where BW is total bandwidth considered as 600 GHz for approximately 10 users, the bandwidth of single resource block BW_{single} is 60 GHz, the factor 0.9 takes into account 10% guard band and 90% information bits. So from the eq. (2.1), available RBs have 9 for 600 GHz.

2.1.2 Pathloss Model

Pathloss describes signal dissipation through the function of propagation distance between transmitter and receiver and other parameters (e.g., antenna height and carrier frequency) in a transmission process. We consider non-line-of-sight (NLOS) for evaluating this model [19]. Substituting the value of carrier frequency 1 THz in [19], pathloss model for D2C and D2D links can be expressed as

$$PL_{celluler} = 36.7\ log_{10}\ (d[m])\ +\ 40.9 + 26\ log_{10}\ (f_c\ [GHz]/5)$$
$$= 36.7\ log_{10}\ (d[m])\ +\ 40.9 + 26\ log_{10}\ \left(\frac{1000}{5}\right)$$
$$= 36.7\ log_{10}\ (d[m])\ +\ 100.73 \ldots\ldots\ldots\ldots\ldots\ldots (2.4)$$

$$PL_{D2D} = 40\ log_{10}\ (d[km])\ + 30\ log_{10}\ (f_c\ [MHz]) + 49$$
$$= 40\ log_{10}\ (d[km])\ + 30\ log_{10}\ (1000000) + 49$$
$$= 40\ log_{10}\ (d[km])\ +\ 229 \ldots\ldots\ldots\ldots\ldots\ldots (2.5)$$

where $PL_{celluler}$ denotes the pathloss for D2C at a distance from MU to BS in meter and PL_{D2D} denotes the pathloss for D2D at a distance from MU1 (device) to MU2 (device) in kilometer.

2.1.3 Signal to Interference plus Noise Ratio of D2D

Signal to interference plus noise ratio (SINR) of D2D is calculated the strength of a signal compare to noise and interference. In this model three cases of SINR are assumed as follows:

2.1.3.1 Case 1: In this case, both cellular interference and device interference (I_C and I_D) are present so both signals are not orthogonal. The theoretical expression of SINR in worstcase scenario can be expressed as

$$SINR_{D2D}^{(1)} = \frac{\frac{P_0^D}{L_0^D}}{m * (I_C +\ I_D + N)} \ldots\ldots\ldots\ldots\ldots\ldots (2.6)$$

where P_0^D is intended device signal power. L_0^D is the pathloss of intended devices. N is the additive white Gaussian noise and m is the number of resource blocks. $I_C = \sum_{j \in N_C} \frac{P_j^C}{L_j^C}$ the cellular interference where P^C is the cellular signal power, L^C is the pathloss of cellular denoted as

$PL_{celluler}$ and N_C is number of cellular devices operating D2C communication. $I_D = \sum_{i\in N_D\setminus\{0\}} \frac{P_i^D}{L_i^D}$ is the device interference where P^D is the device signal power, L^D is the pathloss of D2D denoted as PL_{D2D}, N_D is number of devices operating D2D communication and 0 is the intended device.

2.1.3.2 Case 2: In this case, only cellular interference (I_C) is present so device signals are orthogonal. For case 2, the theoretical expression of SINR can be expressed as

$$SINR_{D2D}^{(2)} = \frac{\frac{P_0^D}{L_0^D}}{m * (I_C + N)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.7)$$

2.1.3.3 Case 3: In this case, neither device interference nor cellular interference is present so signals are completely orthogonal. The theoretical expression of signal to interference plus noise ratio (SNR) of D2D can be expressed as

$$SNR_{D2D}^{(3)} = \frac{P_0^D}{m * L_0^D * N} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.8)$$

2.1.4 Performance Metric

2.1.4.1 Data Rate: Data rate defines the speed of information transferring between devices. Data rate (RD2D) can be defined by the following Shannon's formula

$$R_{D2D} = m * 60GHz * \log_2(1 + SINR_{D2D}) \ldots\ldots\ldots\ldots (2.9)$$

2.1.4.2 Outage Probability: Outage probability can be defined as the probability that the SINR of the device user is less than the SINR threshold value [20]. The mathematical expression can be expressed as

$$\begin{aligned} OP_{D2D} &= P_r\,[SINR_{D2D} < T] \\ &= 1 - P_r\,[SINR_{D2D} > T] \\ &= 1 - \exp(-\frac{T * m * L_0^D * (I_C + I_D + N)}{P_0^D} \ldots\ldots\ldots (2.10) \end{aligned}$$

where T is the SINR threshold.

2.1.4.3 Energy Efficiency: Energy efficiency can be defined as the ratio of data rate to the total power consumption by the device [21]. The expression of energy efficiency (η_{D2D}) can be expressed as

$$\eta_{D2D} = \frac{R_{D2D}}{P_{idle} + P_0^D * t} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (2.11)$$

where P_{idle} is the idle power consumption without transmission, P_0^D is intended device transmission power and t is transmission time interval.

2.2 Simulation Results

We now provide numerical results to confirm the analysis presented in the above section. The simulation parameters are chosen: T = 1 dB, P_0^D = 30 dBm, P_C= 40 dBm, N= -45 dB, P_{idle} = 0.128 W, and t = 10 ms. In this simulation, three cellular interferers are assumed to transmit same power, but different distances are considered such as 200 m, 300 m and 400 m. For the D2D communication, three device interferers transmit same power, but different distances are assumed such as 1 km, 2 km and 3 km.

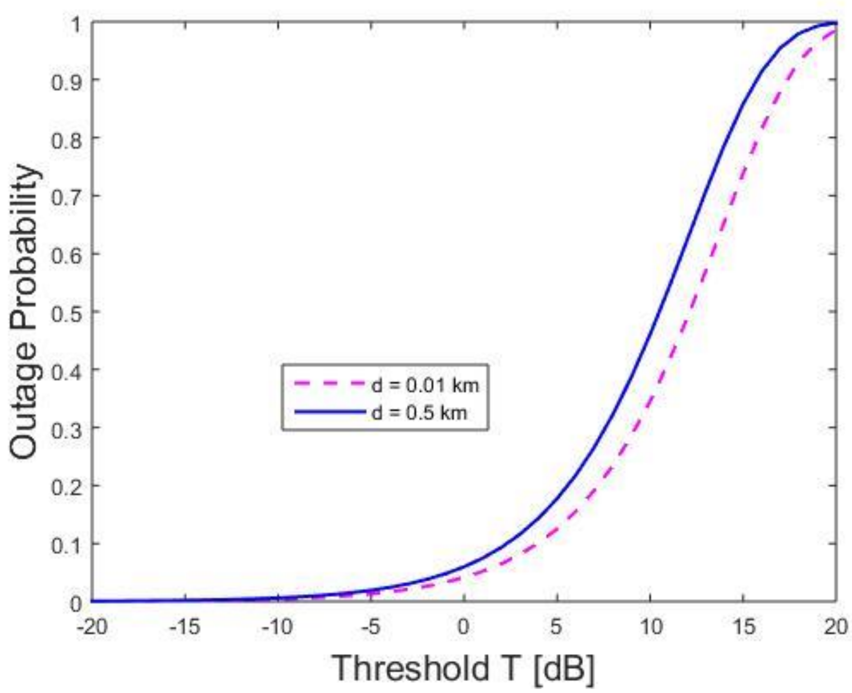

Figure 2.3: Outage Probability vs. Threshold.

In Figure 2.3, D2D outage probability exponentially increases, as threshold value increases. Lower outage probability indicates good performance of D2D communication as it means less interference. Moreover, as distance increases, the outage probability also increases. From Fig. 2.3, we see that outage probability decreases by 29.2% when threshold value is 5 dB for decreasing distance from 0.5 km to 0.01 km.

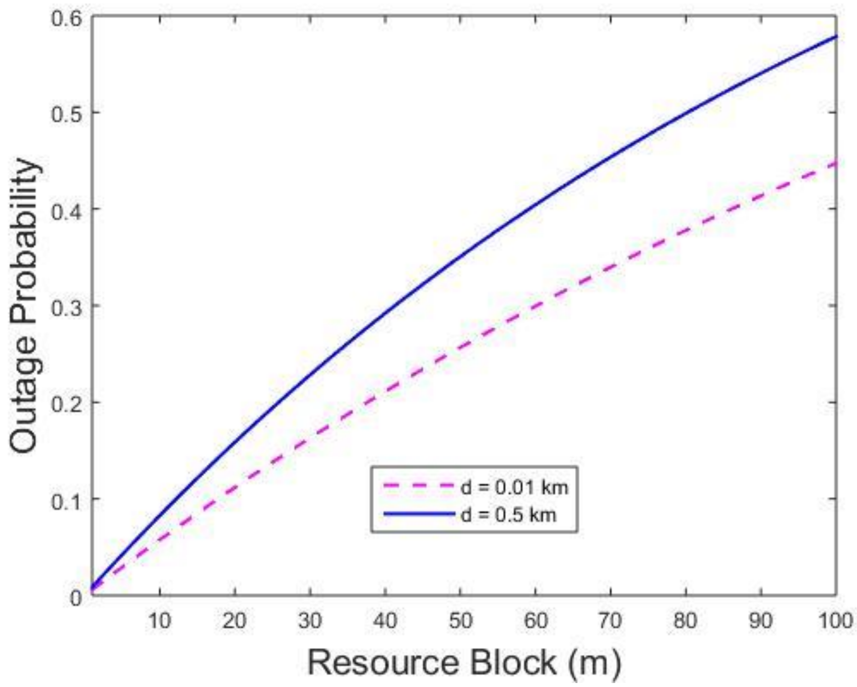

Figure 2.4: Outage Probability vs. Resource Blocks.

Figure 2.4 reveals that as the number of resource block increases, D2D outage probability also increases. If user increases, then more interference occurs. So reducing resource block brings higher coverage probability. We see that less distance with less resource block creates better communication. In Fig. 2.4, with 20 resource blocks in 0.01 km distance outage probability is increased by 25.97% than distance in 0.5 km distance.

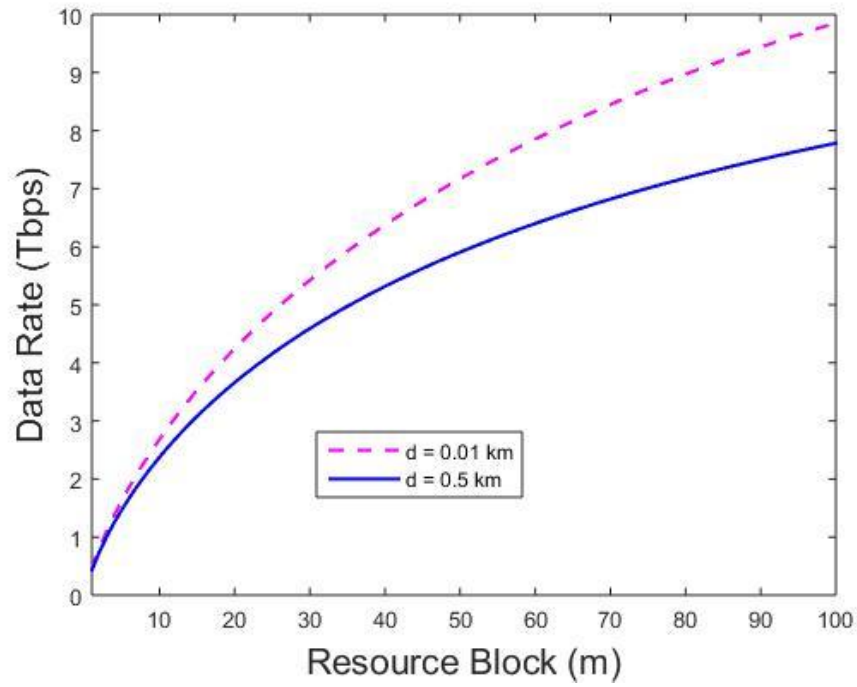

Figure 2.5: Data Rate vs. Resource Blocks.

Figure 2.5 shows that the data rate increases with the increasing of resource blocks because the data rate is related linearly to resource block given in eq. (2.9).

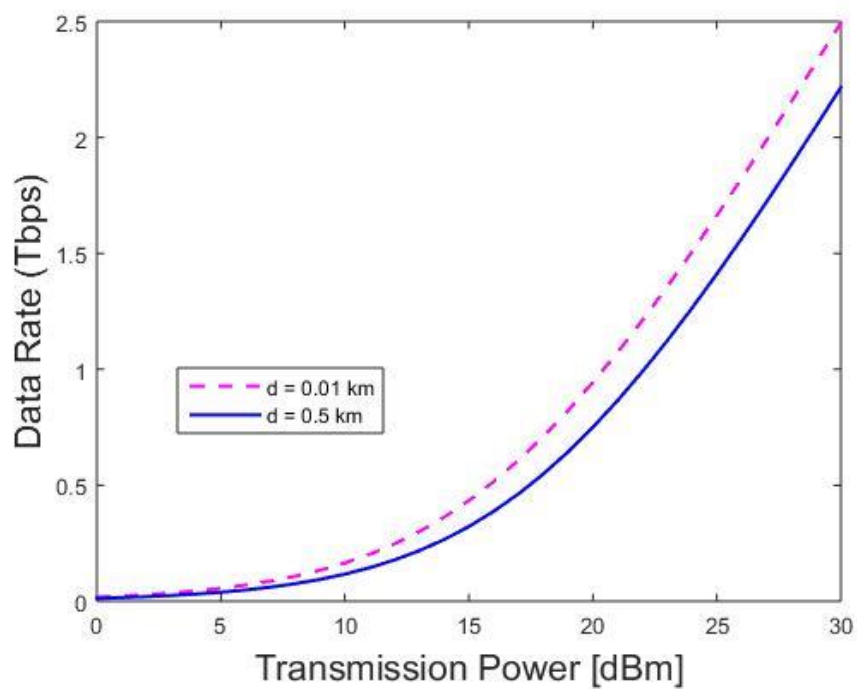

Figure 2.6: Data Rate vs. Transmission Power.

Figure 2.6 illustrates that data rate are 0.750 Tbps for 0.5 km and 0.944 Tbps for 0.01 km consideration of transmission power of 20 dBm. As transmission power increases, D2D data rate increases. In addition, more transmission power in less distance makes higher data rate in the wireless networks.

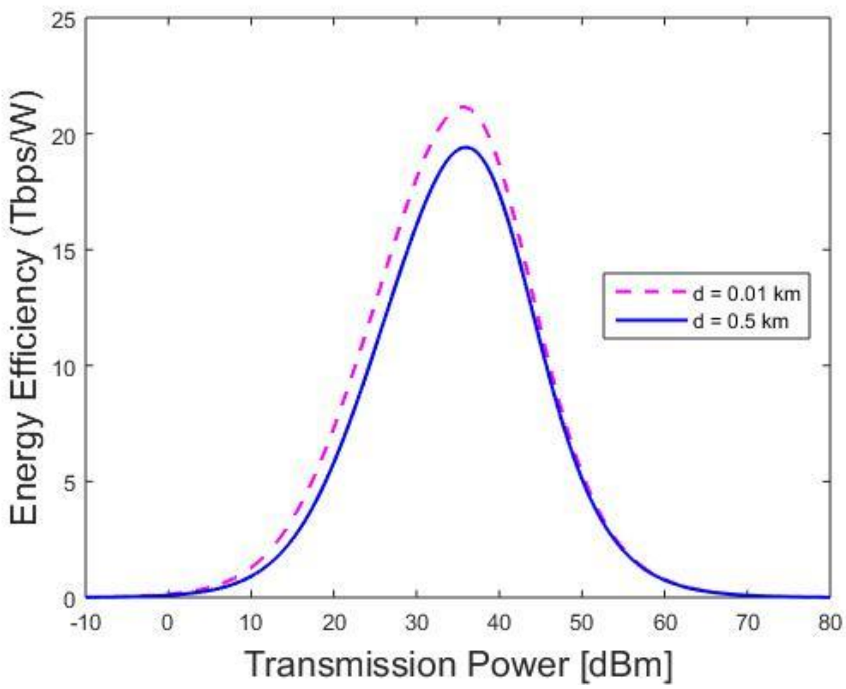

Figure 2.7: Energy Efficiency vs. Transmission Power.

Figure 2.7 shows the transmission power vs. energy efficiency. Initially, transmission power increases as the energy efficiency increases. However, for the transmission power 36 dBm, energy efficiency is highest then energy efficiency decreases. The figure shows that for less distance between devices, the network is more energy efficient. For the transmission power of 36 dBm, energy efficiency increases 8.18% by decreasing distance between devices from 0.5 km to 0.01 km.

CHAPTER 3

RANDOM D2D COMMUNICATION

3.1 Scenario Description and System Model

In this chapter firstly we have described the scenario of the relay assisted device to device communication coexisting with mobile network, and then described the channel and network model in detail.

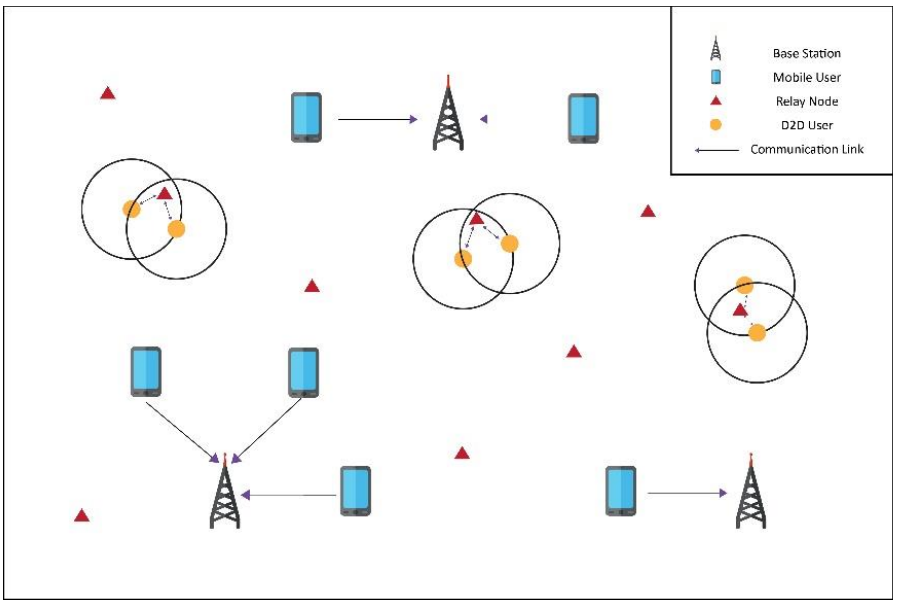

Figure 3.1: Relay Assisted D2D Communication in Mobile Networks.

3.1.1 Scenario Description

In Figure (3.1) device to device users, potential relay nodes and mobile users are denoted as U_0, U_1 and U_2 respectively. First of all, mobile networks deploy on its frequency spectrum and device to device communication use the resources. These networks work in a particular mode known as time division duplex mode. In time division duplex mode uplink is detached from downlink in terms of different time slot at same frequency band. Moreover, the mobile uplink frequency spectrums are divided into flat frequency sub channels by using orthogonal frequency division multiplexing technology. Here, both D2D users and mobile users use full set of the sub channels in the network.

3.1.2 Network Models

Based on stochastic geometry theory [15] few assumptions are made:

Case 1: Mobile users form stationary poison point process (PPP) on two dimensional plane $\Re$ that is denoted as Π_0 with density λ_0. The mobile user transmission power is P_M.

Case 2: The transmitters of device to device users form a poison point process (PPP) is Π_1 with density λ_1 on two dimensional plane $\Re$. The D2D transmission power is P_D.

Case 3: The potential relay nodes form a stationary poison point process (PPP) that is Π_2 with density λ_2 on $\Re$. The transmission power of relay node is P_{RN}.

3.1.3 Channel Models

For our channel if P_{tx} and P_{rx} represent the transmitter power and receiver power respectively then channel model can be expressed as

$$P_{rx} = \delta P_{tx} |D|^{-\alpha} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \quad (3.1)$$

Here δ represents Rayleigh fading co-efficient that is an independent exponential distribution and D represents distance between receiver and transmitter and α represents pathloss exponent. When device to device communication reuses the mobile resources, the typical receiver get affected by the interference and noise generated by mobile users, relay nodes and D2D users.

3.1.3.1 Signal to Interference plus Noise Ratio

Signal to interference plus noise ratio (SINR) is defined as the ratio of certain signal power and interference plus noise power [22]. For obtaining successful transmission probability our major considerations are mobile users, relay nodes and device to device (D2D) users. Assuming the network is interference and noise limited, then the (SINR) can be expressed as

$$SINR_n = \frac{P_n h_n r^{-\alpha}}{\sum I_s + N} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \quad (3.2)$$

Here, h_n and r are the channel gain and the distance from the intended transmitter to the typical receiver respectively and αis the pathloss exponent and P_n is the transmission power.

3.1.3.2 Outage Probability

The probability of certain information rate is less than the required threshold of that information rate is defined by outage probability (OP) [23]. If interference and noise is represent by I_s and N then outage probability can be expressed as

$$\mathrm{OP} = \Pr\left[\ln\left(1 + \frac{P_n h_n r^{-\alpha}}{\sum I_s + N}\right) < R\right]$$

$$= \Pr\left[1 + \frac{P_n h_n r^{-\alpha}}{\sum I_s + N} < e^R\right]$$

$$= Pr\left[\frac{P_n h_n r^{-\alpha}}{\sum I_s + N} < e^R - 1\right]$$

$$= \Pr\left[h_n < \frac{(e^R - 1)(\sum I_s + N)r^{\alpha}}{P_n}\right]$$

$$OP \ = F_g\left\{\frac{(e^R - 1)(\sum I_s + N)r^{\alpha}}{P_n}\right\} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.3)$$

3.1.3.3 Throughput

If, R is the code rate and the transmitter encodes K nats information into a codeword having L length then R is defined as $R = \frac{K}{L}$ nats per channel use (npcu). If the system throughput is η then it is expressed as

$$\eta = R(1 - \mathrm{OP})$$

$$\eta \ = R\left[1 - F_g\left\{\frac{(e^R - 1)(\sum I_s + N)r^{\alpha}}{P_n}\right\}\right] \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.4)$$

3.1.3.4 Affected Area

The surrounding area of transmitter where radio frequency (RF) pollution occurs is defined as affected area (A). Negative effect of wireless communication is also defined by affected. If T is the SINR threshold then the affected area can be expressed as

$$A = 2\pi \int_0^{\infty} r e^{-\frac{T(\sum I_s + N)r^{\alpha}}{P_n}} dr$$

$$A = \frac{2\pi\, \Gamma\left(\frac{2}{\alpha}\right)}{\alpha\left\{\frac{T(\sum I_s + N)}{P_n}\right\}^{\frac{2}{\alpha}}} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . (3.5)$$

Proof: The proof is given in appendix A.

3.1.3.5 Delay Sensitive Area Spectral Efficiency

Maximum data per unit bandwidth experienced by a user randomly that is situated in the mobile coverage area over which has similar spectrum is defined as area spectral efficiency (ASE). Analyzing the output of delay sensitive communications, it is necessary to incorporate metrics that catch the impact of the data transmission delay in the analysis of the performance. The ratio between the achievable throughput η and the affected area A is defined as delay sensitive area spectral efficiency (DSE) [24]. This can be expressed as

$$DSE = \frac{\eta}{A}$$

$$= \frac{R\left[1 - F_g\left\{\frac{(e^R - 1)(\sum I_s + N)r^\alpha}{P_n}\right\}\right]}{\frac{2\pi\,\Gamma\left(\frac{2}{\alpha}\right)}{\alpha\left\{\frac{T(\sum I_s + N)}{P_n}\right\}^{\frac{2}{\alpha}}}}$$

$$DSE = \frac{R\alpha(\frac{T}{P_n})^{\frac{2}{\alpha}}(\sum I_s + N)^{\frac{2}{\alpha}}e^{-\left\{\frac{(e^R-1)(\sum I_s+N)r^\alpha}{P_n}\right\}}}{2\pi\,\Gamma\left(\frac{2}{\alpha}\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.6)$$

For more information about DSE and its application, we have done some research on the optimal rates of delay sensitive area spectral efficiency (DSE)

3.1.3.6 Optimal Transmission Power

For finding the optimal transmission power of DSE, we consider the derivative of (3.6) with respect to power (P) is equal to zero.

$$P_{opt}\,|_R = \arg\left\{\frac{dDSE}{dP} = 0\right\}$$

$$P_{opt}\,|_R = \frac{\alpha(e^R - 1)(\sum I_s + N)r^\alpha}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3.7)$$

Proof: The proof is given in appendix B.

Here, the optimal power of maximum DSE is not dependent of the received threshold power T. As a result, for given rate R, DSE can be expressed as

$$DSE_{opt}\,|_R = \frac{R\alpha(T)^{\frac{2}{\alpha}}(\sum I_s + N)^{\frac{2}{\alpha}}e^{-\left\{\frac{2(e^R-1)(\sum I_s+N)r^\alpha}{\alpha(e^R-1)(\sum I_s+N)r^\alpha}\right\}}}{2\pi\,\Gamma\left(\frac{2}{\alpha}\right)\{\frac{\alpha(e^R - 1)(\sum I_s + N)r^\alpha}{2}\}^{\frac{2}{\alpha}}}$$

$$DSE_{opt} \mid_{R} = \frac{R\alpha(2T)^{\frac{2}{\alpha}}e^{-\left(\frac{2}{\alpha}\right)}}{2\pi\,\Gamma\left(\frac{2}{\alpha}\right)\{\alpha(e^{R}-1)(\sum I_s + N)\}^{\frac{2}{\alpha}} r^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.8)$$

3.1.3.7 Optimal Transmission Rate

For another perspective we consider the derivatives of (3.6) with respect to R equal to zero.

$$R_{opt} \mid_{P} = arg_{R}\left\{\frac{dDSE}{dR} = 0\right\}$$

$$R_{opt} \mid_{P} = W\left\{\frac{P_n}{(\sum I_s + N)r^{\alpha}}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.9)$$

Proof: The proof is given in appendix C.

We can express $DSE_{opt} \mid_{P}$ as

$$DSE_{opt} \mid_{P} = \frac{W\left\{\frac{P_n}{(\sum I_s + N)r^{\alpha}}\right\}\alpha\left(\frac{T}{P_n}\right)^{\frac{2}{\alpha}}(\sum I_s + N)^{\frac{2}{\alpha}} e^{-\frac{\left[e^{W\left\{\frac{P_n}{(\sum I_s + N)r^{\alpha}}\right\}}-1\right](\sum I_s + N)r^{\alpha}}{P_n}}}{2\pi\,\Gamma\left(\frac{2}{\alpha}\right)} \quad \ldots\ldots\ldots\ldots\ldots (3.10)$$

3.2 Simulation Results

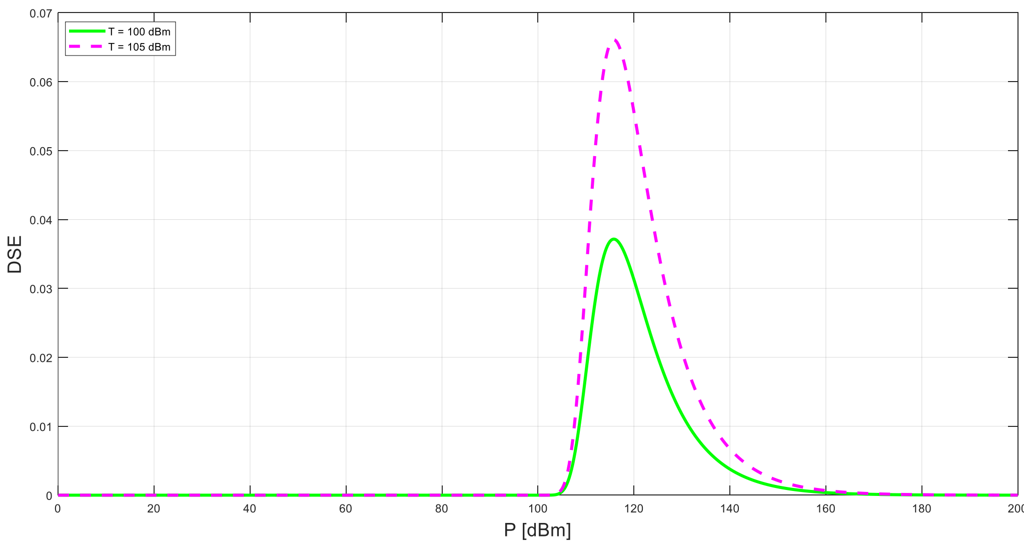

Figure 3.2: DSE vs. Transmission Power.

Figure 3.2 shows DSE versus transmission power P_n. When P_n = 84 dBm, DSE = 0 after that DSE start increasing rapidly and when P_n = 115.8 dBm, DSE is maximum which is 0.06608 after reaching maximum point DSE start decreasing with the increment of transmission power.

Furthermore, varying SINR threshold (T) we get different value. In terms of increasing DSE we consider higher value of T. Also we have considered affected area (A) = 1 as a result increasing the value of throughput we can achieve maximum DSE.

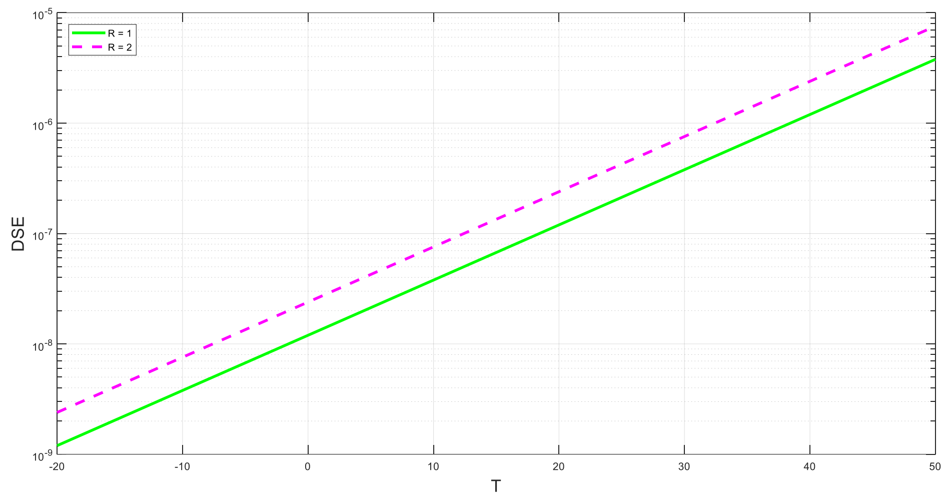

Figure 3.3: DSE vs. SINR Threshold.

Figure 3.3 shows DSE versus SINR threshold (T). We observe that for any value of code rate (R) DSE increases with T linearly. Here we consider two value of R. For R = 2 we get higher value than R = 1. If we increase the value of R then we can achieve higher value of DSE at higher T.

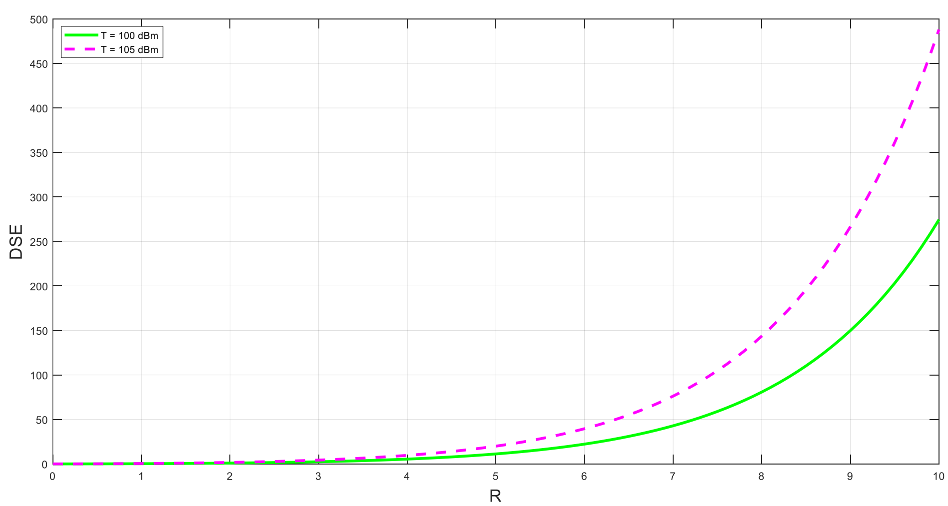

Figure 3.4: DSE vs. Optimum Code Rate.

Figure 3.4 shows the characteristics of the $DSE_{opt}|_R$. Here, we observe that DSE increases exponentially as R increases. Moreover, DSE increase by 43.7% when code rate value is 9 npcu for increasing SINR threshold from 100 dBm to 105 dBm.

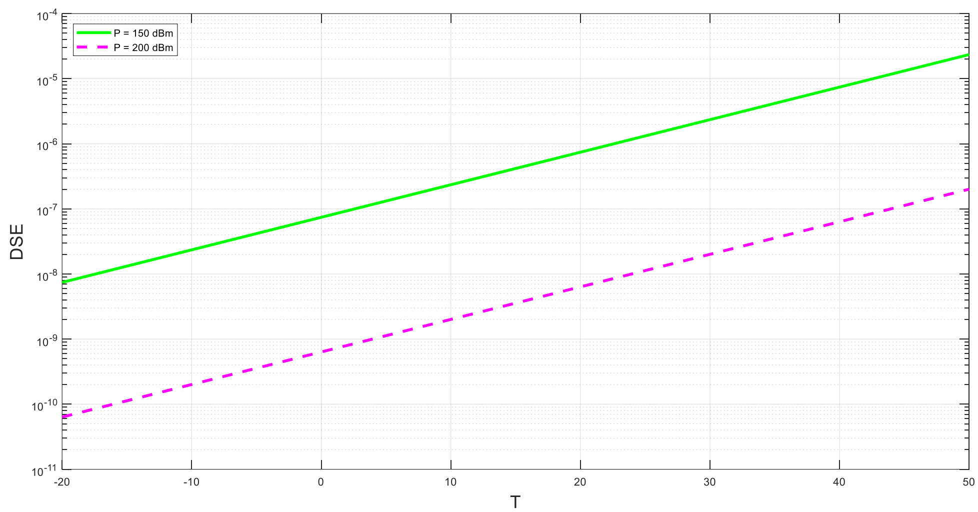

Figure 3.5: DSE vs. SINR Threshold.

Figure 3.5 shows DSE versus SINR threshold. We observe that the value of DSE is increasing linearly with the value of T. For maximizing DSE we need higher value of T. Moreover, for maximum value of DSE we need to consider greater value of transmission power.

CHAPTER 4
CONCLUSION AND FUTURE WORK

4.1 Conclusion

A detailed theoretical and mathematical analysis is provided to improve the D2D communication for 5G network in THz frequency band. In terms of providing the theoretical model we have established theoretical expression for outage probability, energy efficiency and data rate. Furthermore, we develop the theoretical expression for pathloss model for THz frequency in D2D communication. Moreover, we provide detailed theoretical model for maximizing DSE for sustainable D2D communication. The major aspects of our work are given below:

i. In the case of outage probability we have improved it in low threshold. We constructed a theoretical model between OP and T that results in achieving better performance for D2D communication.

ii. In terms of higher network coverage probability resource block (RB) need to be reduced as it increase the interference in the communication network. We have developed a relation between the RB and data rate to minimize the data loss in D2D communication.

iii. We have developed a model of transmission power and data rate. The results of our model shows that the data rate increases exponentially with transmission power. In this case, increasing the transmission power will result in transmitting high amount of data.

iv. We have shown that energy efficiency can be improved by transmission power. Increasing the transmission power will result in increasing energy efficiency. Thus at certain point we will achieve the maximum value energy efficiency after that increasing the power will result in decreasing the value of energy efficiency. In our case, we the value of maximum efficient energy occurred when our transmission power is 36 dBm.

v. In terms of effective communication network maximum delay sensitive area spectral efficiency is highly considerable. For maximizing DSE high value of throughput is necessary. We have developed a model that will increase DSE at high throughput. Here we considered the value of affected area (A) = 1.

vi. In the case of maximizing DSE we have developed a model of relation between DSE and optimal transmission rate (R). We get maximum output of DSE at P_n = 115.8 dBm. After that DSE start decreasing while increasing transmission power because of the noise and interference.

vii. We have developed a theoretical model of DSE with respect to SINR threshold (T). In terms of mobile users communication signal noise and interference hampers the communication process. In this case we have developed the model to achieve maximum DSE by reducing signal noise and interference.

4.2 Future Work

- ❖ We will investigate cognitive D2D communication in uplink modeling. [21]
- ❖ We will investigate cognitive D2D communication for two slope pathloss model. [25]
- ❖ We will investigate the detection of intelligent malicious user in cognitive D2D communication. [26]
- ❖ We will investigate cognitive D2D communication for D2D transmit antenna selection technique. [27]
- ❖ We will investigate co-operative D2D communication.

APPENDIX A

Derivation of Affected Area

$$A = 2\pi \int_0^\infty r e^{-\frac{T(\sum I_s + N) r^\alpha}{P_n}} dr$$

Let, $r = z^2$ and $r = \sqrt{z}$

$=> 2rdr = dz$ $=> r^\alpha = z^{\frac{\alpha}{2}}$

$=> rdr = \frac{dz}{2}$

$$A = 2\pi \int_0^\infty \frac{dz}{2} e^{-\frac{T(\sum I_s + N) z^{\frac{\alpha}{2}}}{P_n}}$$

$$= \pi \int_0^\infty e^{-\frac{T(\sum I_s + N) z^{\frac{\alpha}{2}}}{P_n}} dz$$

Let, $t = z^{\frac{\alpha}{2}}$ and $z = t^{\frac{\alpha}{2}}$

$=> dt = \frac{\alpha}{2} z^{(\frac{\alpha}{2} - 1)} dz$

$=> dz = \frac{2}{\alpha} z^{\left(1 - \frac{\alpha}{2}\right)} dt$

Now,

$$A = \pi \int_0^\infty \frac{2}{\alpha} z^{(1-\frac{\alpha}{2})} e^{-\frac{T(\sum I_s + N)(t^{\frac{2}{\alpha}})^{\frac{\alpha}{2}}}{P_n}} dt$$

$$= \frac{2\pi}{\alpha} \int_0^\infty (t^{\frac{2}{\alpha}})^{(1-\frac{\alpha}{2})} e^{-\frac{T(\sum I_s + N)(t^{\frac{2}{\alpha}})^{\frac{\alpha}{2}}}{P_n}} dt$$

$$= \frac{2\pi}{\alpha} \int_0^\infty t^{(\frac{2}{\alpha} - 1)} e^{-\frac{T(\sum I_s + N) t}{P_n}} dt$$

$$A = \frac{2\pi \, \Gamma\left(\frac{2}{\alpha}\right)}{\alpha \left\{\frac{T(\sum I_s + N)}{P_n}\right\}^{\frac{2}{\alpha}}}$$

APPENDIX B

Derivation of Optimal Transmission Power

$$P_{opt}\mid_R = \arg\left\{\frac{dDSE}{dP} = 0\right\}$$

Let, $DSE = CP_n^{-\frac{2}{\alpha}} e^{-\left\{\frac{(e^R-1)(\sum I_s+N)r^\alpha}{P_n}\right\}}$

Here, $C = \frac{R\alpha(T)^{\frac{2}{\alpha}}(\sum I_s+N)^{\frac{2}{\alpha}}}{2\pi\,\Gamma\left(\frac{2}{\alpha}\right)}$

$$\frac{dDSE}{dP} = \frac{d}{dP}\left\{CP_n^{-\frac{2}{\alpha}} e^{-\left\{\frac{(e^R-1)(\sum I_s+N)r^\alpha}{P_n}\right\}}\right\} = 0$$

$$=> e^{-\left\{\frac{(e^R-1)(\sum I_s+N)r^\alpha}{P_n}\right\}} \frac{(e^R-1)(\sum I_s+N)r^\alpha}{P_n^2 P_n^{\frac{2}{\alpha}}} - \frac{2}{\alpha} P_n^{-\left(\frac{2}{\alpha}-1\right)} e^{-\left\{\frac{(e^R-1)(\sum I_s+N)r^\alpha}{P_n}\right\}} = 0$$

$$=> \frac{(e^R-1)(\sum I_s+N)r^\alpha}{P_n^2 P_n^{\frac{2}{\alpha}}} = \frac{\frac{2}{\alpha}}{P_n P_n^{\frac{2}{\alpha}}}$$

$$=> \frac{(e^R-1)(\sum I_s+N)r^\alpha}{P_n} = \frac{2}{\alpha}$$

$$=> P_{opt}\mid_R = \frac{\alpha(e^R-1)(\sum I_s+N)r^\alpha}{2}$$

$$\therefore DSE_{opt}\mid_R = \frac{R\alpha(T)^{\frac{2}{\alpha}}(\sum I_s+N)^{\frac{2}{\alpha}} e^{-\left\{\frac{2(e^R-1)(\sum I_s+N)r^\alpha}{\alpha(e^R-1)(\sum I_s+N)r^\alpha}\right\}}}{2\pi\,\Gamma\left(\frac{2}{\alpha}\right)\left\{\frac{\alpha(e^R-1)(\sum I_s+N)r^\alpha}{2}\right\}^{\frac{2}{\alpha}}}$$

$$= \frac{R\alpha(2T)^{\frac{2}{\alpha}} e^{-\left(\frac{2}{\alpha}\right)}}{2\pi\,\Gamma\left(\frac{2}{\alpha}\right)\{\alpha(e^R-1)(\sum I_s+N)\}^{\frac{2}{\alpha}} r^2}$$

APPENDIX C

Derivation of Optimal Code Rate

$$R_{opt} \mid_P = arg_R \left\{ \frac{dDSE}{dR} = 0 \right\}$$

$$=> arg_R \left[\frac{d}{dR} \left[C_1 R e^{-\left\{ \frac{(e^R - 1)(\sum I_s + N) r^\alpha}{P_n} \right\}} \right] \right] = 0$$

Here,

$$C_1 = \frac{\alpha (\frac{T}{P_n})^{\frac{2}{\alpha}} (\sum I_s + N)^{\frac{2}{\alpha}}}{2\pi \,\Gamma\left(\frac{2}{\alpha}\right)}$$

$$\frac{dDSE}{dR} = \frac{d}{dR} \left\{ R e^{-\left\{ \frac{e^R (\sum I_s + N) r^\alpha}{P_n} \right\}} e^{\left\{ \frac{(\sum I_s + N) r^\alpha}{P_n} \right\}} \right\} = 0$$

$$= e^{\left\{ \frac{(\sum I_s + N) r^\alpha}{P_n} \right\}} \frac{d}{dR} \left\{ R e^{-\left\{ \frac{e^R (\sum I_s + N) r^\alpha}{P_n} \right\}} \right\} = 0$$

$$= R \frac{d}{dR} \left\{ e^{-\left\{ \frac{e^R (\sum I_s + N) r^\alpha}{P_n} \right\}} \right\} + e^{-\left\{ \frac{e^R (\sum I_s + N) r^\alpha}{P_n} \right\}} = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (i)$$

Let,

$$y = e^{-\left\{ \frac{e^R (\sum I_s + N) r^\alpha}{P_n} \right\}} \qquad \& \qquad z = \frac{e^R (\sum I_s + N) r^\alpha}{P_n}$$

$$\therefore y = e^{-z} \qquad\qquad => dz = \frac{e^R (\sum I_s + N) r^\alpha}{P_n} dR$$

$$=> dy = -e^{-z} dz \qquad\qquad => \frac{dy}{dz} = \frac{e^R (\sum I_s + N) r^\alpha}{P_n}$$

$$=> \frac{dy}{dz} = -e^{-z}$$

$$\therefore \left(\frac{dy}{dz}\right)\left(\frac{dz}{dy}\right) = -e^{-z}\left\{\frac{e^{R}(\sum I_s + N)r^{\alpha}}{P_n}\right\}$$

$$\frac{dy}{dR} = -e^{-\left\{\frac{e^{R}(\sum I_s+N)r^{\alpha}}{P_n}\right\}}\left\{\frac{e^{R}(\sum I_s + N)r^{\alpha}}{P_n}\right\}$$

$From\ equation\ (i)$

$$=> -Re^{-\left\{\frac{e^{R}(\sum I_s+N)r^{\alpha}}{P_n}\right\}}\left\{\frac{e^{R}(\sum I_s + N)r^{\alpha}}{P_n}\right\} + e^{-\left\{\frac{e^{R}(\sum I_s+N)r^{\alpha}}{P_n}\right\}} = 0$$

$$=> -R\left\{\frac{e^{R}(\sum I_s + N)r^{\alpha}}{P_n}\right\} + 1 = 0$$

$$=> R = \frac{P_n}{e^{R}(\sum I_s + N)r^{\alpha}}$$

$$=> Re^{R} = \frac{P_n}{(\sum I_s + N)r^{\alpha}}$$

$Lambert\ W\ function = xe^{x} = y; => x = W(y)$

$$R_{opt}\mid_{P} = W\left\{\frac{P_n}{(\sum I_s + N)r^{\alpha}}\right\}$$

$$\therefore DSE_{opt}\mid_{P} = \frac{W\left\{\frac{P_n}{(\sum I_s + N)r^{\alpha}}\right\}\alpha(\frac{T}{P_n})^{\frac{2}{\alpha}}(\sum I_s + N)^{\frac{2}{\alpha}}e^{-\frac{[e^{W\left\{\frac{P_n}{(\sum I_s+N)r^{\alpha}}\right\}}-1](\sum I_s+N)r^{\alpha}}{P_n}}}{2\pi\,\Gamma\left(\frac{2}{\alpha}\right)}$$

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