IMPLEMENTATION OF ENERGY EFFICIENT D2D COMMUNICATION SYSTEM FOR HETEROGENEOUS NETWORKS AND ITS PERFORMANCE ANALYSIS

A PROJECT REPORT

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ABSTRACT

In order to satisfy the increasing need for higher data rates and lower network latencies, Device to Device communication (D2D) is considered as one of the perfect solutions. Device to Device communication is considered to be a near field communication wherein the communicating devices transmit and receive data without the need of a centralized access point or a Base station. This technique is assumed to be the major paradigm shift in the fifth-generation mobile communication networks. In this work, we investigate the Device-to-Device user equipment multiplexing cellular user equipment downlink spectrum resources in D2D communication heterogeneous networks. The main goal of this work is to maximize the energy efficiency of all the D2D links and also to guarantee the quality of service of cellular user equipment. In order to tackle the resource allocation problems, we formulate an energy efficient approach, taking into consideration, power and resource block allocation for the D2D links, which is a non-convex problem. Hence, to convert this original problem into convex optimization problem, we propose an iterative algorithm based on the Dinkelbach and Lagrangian constrained optimization. The numerical results demonstrate that the proposed approach can achieve higher energy efficiency for various different parameters.

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LIST OF ABBREVIATIONS

- BS – Base Station
- CU – Cellular User
- 5G – 5th Generation
- D2D – Device to Device
- ILA – Interference Limited Area
- CIC – Centralized Interference Coordination
- DIC – Decentralized Interference Coordination
- LTE – Long Term Evolution
- 3GPP – 3rd Generation Partnership Project
- OFDM – Orthogonal Frequency Division Multiplexing
- eNB – eNodeB
- QoS – Quality of Service
- CSI – Channel State Information
- SINR – Signal to Interference Noise Ratio
- LOS – Line of Sight
- B2B – Base
- MIMO – Multiple Input Multiple Output
- EE – Energy Efficiency
- KKT – Karush Kuhn Tucker conditions
- RB – Resource Block

CHAPTER 1

INTRODUCTION

To provide cellular broadband wireless access to mobile users in regulated frequency bands, the fourth generation LTE was designed. The major challenges for the next step evolution of LTE are, massive growth in the number of connected devices, traffic volume, tremendous increase of applications with varying requirements such as, live broadcast, video-on-demand, vehicle to vehicle communication, human –machine interactions, etc. and their strict Quality of Service (QoS) requirements . But the large number of connected devices will accelerate the growth of traffic on the internet and this must be handled efficiently by wireless communication systems. Moreover, most of traffic is generated in local areas such as sharing multimedia files in workplaces, colleagues and stadiums, the main concern is how to greatly improve local area services. Thus, the continuously increasing demand for data services of the geographically proximate user has brought great challenges to current mobile communication infrastructure. Also, the battery-limited wireless communication devices are posing a challenge to telecommunication community.

Novel techniques are considered for the next LTE evolution step as it is currently discussed within the Release 12 of 3GPP LTE advanced standards, in order to address the above mentioned challenges. The next LTE evolution i.e., the 5G network will include OFDM-based LTE access and new radio interfaces in a transparent manner.

Device-to-device (D2D) communication is proposed as one promising solution in the 5G cellular network, which might satisfy the strict requirements of the manifold usage scenarios and holds promise to help us tackle this challenge.

Underlay D2D communication allows, physically proximate mobile users to directly communicate with each other by reusing the spectrum and without going through the base station. By allowing direct communication among proximate users' equipment, D2D transmission is capable of enhancing spectrum efficiency, extending cell coverage, and improving energy efficiency. The other major advantages of D2D are the enhanced spatial reuse of radio resource, latency reduction, lower power consumption and traffic offload from congested eNodeBs. The green communication can also be achieved using D2D communication since it is a short distance low power communication technology.

This chapter provides a detail introduction to 5G technology, the various aspects of D2D communication.

1.1 NEED FOR THE PROJECT:

In 5G cellular networks, the presence of a centralized access point infrastructure or a Base Station can cause energy loss, thereby reducing the efficiency and data rate. D2D networks can be efficiently used to avoid these kinds of situations. In smart cities, the number of cellular devices will be high, which in turn increases traffic and results in interference and decrease in efficiency. Hence it is very necessary to implement D2D type of communication.

1.2 FIFTH GENERATION (5G):

5G is the fifth-generation mobile network. It is considered as the new global standard or as a replacement to the prevailing 4G networks. This fifth-generation network enables an entirely new kind of network that is designed, keeping in mind to connect anything and everything virtually including machines, objects and devices.

This new fifth generation wireless technology is designed in such a way to deliver higher multi-Gbps peak data rate, ultra-low latency, much more reliability and availability. This technology also provides massive network capacity and a more uniform user experience to a large number of users. This higher performance and very high efficiency connect new industries and empower new user experiences.

The fifth-generation mobile network was designed to provide more connectivity that was ever available before and with the available extended capacity, it can enable next-generation user experiences, delegate new user models and implement new services. With relatively very high speeds, negligible latency and exceptional reliability, 5G will augment the mobile ecosystem into new realms. 5G will greatly impact most of the industries, enabling safer transportation, remote healthcare, precision agriculture, digitized logistics and much more.

1.2.1 UNDERLYING TECHNOLOGIES IN 5G:

The fifth-generation mobile networks work based on OFDM (Orthogonal Frequency Division Multiplexing), which is a method to reduce interference, by modulating the digital signal across several different channels. 5G also uses 5G NR air interface alongside OFDM principles, and this 5G NR air interface can further enhance OFDM in order to deliver a much higher degree of scalability and flexibility, which could result in more people accessing 5G for a variety of different use cases.

1.2.2 HOW’S 5G DIFFERENT FROM 4G:

- 5G is a unified platform that is much more capable than the previous 4G networks. While 4G LTE was designed focusing on delivering much faster mobile broadband services than its predecessor, 5G is designed to be a unified, more capable platform that not only increases the mobile broadband experience, but also supports new services including the massive IoT and mission critical communications.
- 5G is also designed to get the most out of every bit of spectrum, since it uses a much better spectrum than 4G, from low bands below 1 GHz to mid bands from 1 GHz to 6 GHz, to high bands known as millimeter waves.
- 5G is significantly faster than 4G, delivering up to 20 Gbps peak data rates. It is also designed to support 100 times increase in traffic capacity and network efficiency. It also has significantly lower latency, in order to deliver more instantaneous, real-time access.

1.3 D2D COMMUNICATION:

The term device to device communication refers to the techniques that enable devices to communicate directly without any base stations or infrastructure of access points. Device to Device communication (D2D) is a promising solution for improving spectrum utilization in the next generation cellular networks. D2D is considered as a key enabling technology in 5G cellular networks, because of the inherent need for high data rate and delay constrained QoS specific communication.

D2D communication was not incorporated in the first three generations of the mobile networks, even though it was always investigated in the unlicensed spectrum. D2D was only introduced in the fourth generation into the licensed spectrum.

D2D communication enables user equipment to transmit data signals to each other using a direct link or over a connection using the cellular resources. D2D communication acts as an underlay to the cellular network and it increases the spectral efficiency and it is expected to be a native component that is to be supported by the next-generation networks.

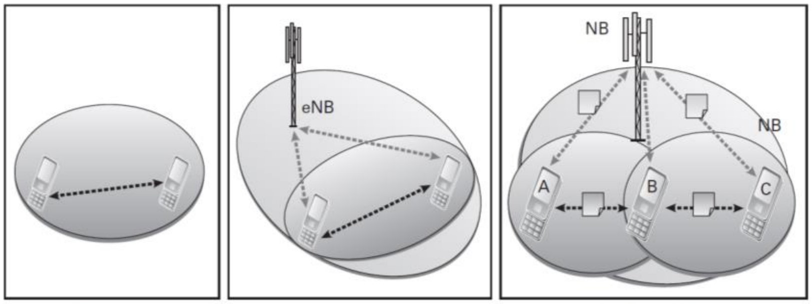
Direct D2D facilitates low-latency communication because of the local communication link between users in proximity and this type of communication is seen as one of the necessary features to support real-time services in the 5G systems.

1.3.1 TYPES OF D2D COMMUNICATION:

D2D communications is majorly of three types,

- Peer-to-peer communication, which is the most commonly considered type of communication, since it is a point-to-point communication.
- Cooperative communication, uses mobile devices as relays in order to extend the coverage and it exploits cooperative diversity through multiple collaborative mobile devices, in order to obtain the space diversity.

- Multiple-hop communication is similar to the mobile ad-hoc network type and mesh network type, and it may include data routing and much complex data superposition.



Peer-to-peer communications

Cooperative communications

Multiple-hop communications

Fig. 1.1 Different types of D2D Communication

1.3.2 INTERFERENCE IN D2D:

Even though using D2D communication improves the spectral efficiency and has much larger benefits in terms of system capacity, it also causes interference with the cellular network because of spectrum sharing. By proper resource management, D2D communication can effectively improve the throughput of the system with the interference between D2D transmissions and cellular networks being minimized.

1.3.3 KEY TECHNOLOGIES FOR D2D COMMUNICATION:

1.3.3.1 CONFIGURATION OF D2D COMMUNICATION:

D2D networks are usually configured in three ways in order to either allow or restrict their usage by certain users.

- Network-controlled D2D, in which resource allocation and thereafter communication signalling setup for both D2D users and cellular users are controlled by the core network and the Base station. This configuration enables efficient resource management and interference avoidance. This configuration is useful only when there is a small number of D2D links, because when there are a large number of D2D links, this scheme incurs a very large amount of control signalling and it may result in reducing the spectrum efficiency and increasing the overhead.

- Self-organized D2D, in which D2D users, realize the communication in a self-organizing way, themselves by finding the empty spectrum hole. This configuration allows D2D users to sense the surrounding environment in order to obtain cellular system information, CSI and interference. This configuration, being a distributed method, can effectively avoid the time delay and the controlling signalling overhead. But this configuration may cause communication instability because of the lack of control by the operators in the licensed spectrum.
- Network-assisted D2D, in which D2D users operate in a self-organized way, for managing resources, exchanging with the cellular system a limited amount of controlling information. The status of D2D communication can be used by the cellular network for better control purposes. This configuration method has the merits of the previous two approaches.

1.3.3.2 DEVICE SYNCHRONIZATION AND RECOVERY:

In D2D communication, the necessary component is the synchronization among D2D users themselves and between cellular networks and D2D users, for proper handoff and in order to minimize multiple-access interference. The fundamental problem of device discovery is that the communicating devices have to meet in frequency, time and space without any coordination and this is made possible with some randomized procedure and any one of the communicating devices assumes the responsibility of sending the beacon.

Depending on whether there are responses or not from the discovering user equipment, the discovery approaches can be broadly classified into two categories and based on whether there is network participation in the detection or not, the discovery procedure can be categorized into two different types.

1.3.3.3 SPECTRUM SHARING AND RESOURCE MANAGEMENT:

Spectrum sharing methods in D2D communication can be categorized into two different types:

- Overlay D2D communication, that can completely eliminate cross-tier interference by dividing the licensed spectrum into two parts. In this type, the D2D users occupy vacant cellular spectrum for communication. One part of the divided licensed spectrum will be used by the D2D networks, while the other part will be used by the cellular users. But this approach is very much inefficient in terms of spectrum reuse.
- Underlay D2D communication, in which the spectrum efficiency is greatly improved, because multiple D2D users are allowed to work as an underlay with cellular users. In this spectrum sharing scheme, co-channel assignment of the D2D and cellular users will be profitable and more efficient for operators, but from a technical point of view, this is far more intricate than the overlay scheme.

In general, the overlay approach is very much easy to realize, but it might not be spectrally efficient, while the underlay method can achieve a better overall system performance though it incurs a greater signalling overhead. In order to improve and optimize the overall system performance over spectrum sharing, in both cellular modes and D2D modes, the important feature to be considered is radio resource management.

Radio resource management can be performed in two different ways, a non-cooperative way in which each D2D user can manage its own spectrum in order to provide maximized throughput and quality of service and a cooperative way in which D2D users gather only partial information about spectrum and thus perform spectrum allocation. In this scheme, the average cellular and D2D users' quality of service and throughput, can be locally optimized.

1.3.3.4 MODE SELECTION:

One of the most challenging problems in a D2D underlay communication system is, to decide whether communicating devices should use either direct communication mode or cellular mode. In cellular mode, communication requires the source device to transmit to the eNodeB (eNB) and then the destination device receives from the eNB on downlink, while in the D2D mode, data is directly received from the transmitter.

In case of the cellular mode, three different mode selection criteria are considered.

- Cellular mode, in which all the devices are in cellular mode.
- Forced D2D mode, in which D2D mode is selected always for all the communicating devices.
- Path-loss D2D mode, in which D2D mode is selected only if any of the Path Losses between a destination device and its serving eNB or a source device

and its serving eNB, is greater than the Path Loss between the source and destination nodes having a direct link.

1.3.3.5 POWER CONTROL:

An important and effective way to coordinate the co-channel interference is Power control. This can be performed by two methods.

- Network-managed power control, in which both the D2D and cellular users adaptively adjust their transmit power according to the signal-to-interference-plus-noise-ratio (SINR) report. It is an iterative process wherein D2D users control the transmit power first and the cellular users make changes afterward and it terminates only when all the users have satisfied their SINR requirements.
- Self-organized power control, in which D2D users, in a self-organized way make power changes according to a predefined SINR threshold in order to meet the necessary QoS without affecting the cellular users.

In the self-organized method, since the D2D users are treated invisibly, it is not going to change the behaviour of the cellular users. Though this method is simple, it is less efficient than the Network-managed method. The network-controlled approach requires information exchange among D2D users, cellular users and the eNB, and it allows all of the users to adjust their transmit powers.

1.4 CLASSIFICATIONS OF D2D COMMUNICATION:

Based on the spectrum in which D2D Communication occurs, D2D in cellular networks are categorized into inband and outband D2D. Further inband D2D is divided into underlay and overlay modes (i.e.) when D2D communication uses the cellular resources and spectrum it is called “Inband Underlay Mode” and when the cellular resources are allocated for the two D2D end devices that communicate directly then it is termed as “Inband Overlay Mode”. Moreover, outband D2D communication eliminates the interference between D2D links.

1.4.1 INBAND D2D COMMUNICATION:

The key motivation factor for choosing the inband D2D communication is high control over the licensed spectrum. To improve the spectrum efficiency, the D2D inband can reuse the time and frequency resources by D2D users (Underlay) or allocating time and frequency resources occupied by D2D users (Overlay). The main disadvantage of inband communication is interference and this can be mitigated by introducing high complexity resource allocation methods, which further increases the computational overhead of the eNodeB of D2D users.

1.4.1.1 UNDERLAY INBAND D2D MODE:

Here the cellular and D2D communication shares the same radio resources. Underlay inband mode can improve and enhance the performance of different targets such as spectrum efficiency, energy efficiency and cellular coverage by the use of different techniques including diversity techniques, interference reduction, resource allocation and by using network coding. Finally, by allowing underlay D2D communications, LTE-advanced mobile networks can offer several advantages such as low end-to-end latency and high spectral efficiency.

1.4.1.2 OVERLAY INBAND D2D MODE:

In this mode, cellular and D2D are given dedicated cellular resources and those cellular resources are subtracted from cellular users in order to eliminate interference for the D2D communications on cellular transmissions.

1.4.2 OUTBAND D2D COMMUNICATION:

D2D communication is performed in the unlicensed spectrum such as ISM 2.4G which makes the interference between D2D and cellular communications impossible. On the other hand, outband D2D may suffer from the uncontrolled nature of unlicensed spectrum. To exploit this unlicensed spectrum, it is necessary to have an extra interface that implements Wi-Fi direct, ZigBee or Bluetooth.

Outband D2D communication can be classified into two categories or modes depending on the occurrence of the second interface. These modes are called controlled mode, when the second interface is under cellular network or autonomous when D2D control is done by users and the occurrence of the second interface is not under cellular network.

1.4.2.1 D2D OUTBAND COMMUNICATIONS: CONTROLLED MODE

In this category of D2D communications, all the literature proposes to use the cellular network advanced management features to control D2D communication in order to improve the efficiency and reliability of D2D communications and also improve the system performance in terms of throughput, power efficiency and multicast.

1.4.2.2 D2D OUTBAND COMMUNICATIONS: AUTONOMOUS MODE

The overhead of cellular networks can be reduced by autonomous D2D communication. This category doesn't require any changes at the base station (eNB) and can be deployed easily. The major performance requirements are to increase the power expenditure in this approach.

1.5 D2D IN 5G &MILLIMETER WAVES

1.5.1 DEVICE TO DEVICE COMMUNICATION IN 5G:

D2D is currently being specified by 3GPP in LTE Rel-12. D2D is also recognized as one of the technology components of the evolving 5G architecture.D2D communication, which refers to direct communication between devices (i.e., users) without data traffic going through any infrastructure node, has been widely foreseen to be an important cornerstone to improve system performance and support new services in the future fifth generation (5G).

In 5G, there are 2 types of D2D communication namely local D2D and global D2D. Local D2D uses the same base station and global D2D uses different base stations (involves device to base and base to base).

For effective communication, all the links share the resources. When a device-to-device link and a device to base station link use the same resources in the same time slot, it is said to be concurrent transmission. But there is a high chance of interference here which has to be managed efficiently.

Resource sharing can be done in two modes namely Orthogonal and Non-Orthogonal sharing.

- Orthogonal sharing, in which local device to device and device to base/ base to base links will divide the resources. This method is simple to implement as there is no interference but resources are not utilized effectively.

- Non-Orthogonal sharing in which local device to device and device to base/ base to base links reuse the resources. Interference will occur which needs to be managed effectively. Effective resource utilization/sharing algorithm is required. Large number of users can be accommodated in the network since we are enabling the reusability of resources. Hence, non-orthogonal sharing is good when compared to orthogonal sharing.

D2D, D2B and B2B links relays on line of sight(LOS). Resource sharing determines a collection of active links for each timeslot. Heuristic approach is used for optimal resource allocation.

1.5.2 MILLIMETER WAVES IN 5G:

Millimetre wave bands have high frequency signals. Since there is a large amount of unused spectrum at these high frequencies, these are most preferred in 5G. More bandwidth will be allocated while using millimetre waves and hence, faster and higher quality multimedia content will be received.

Enabling millimetre waves in 5G requires overcoming the channel impairments and propagation characteristics of high frequency bands. Millimetre waves are susceptible to blockage from buildings and other structures. Hence, intelligent beam forming and beam tracking techniques are necessary.

Device to device communication is expected to be an essential feature of millimetre wave 5G cellular network to improve network capacity and build connections between two wireless devices. The millimetre wave has a high frequency and hence, it has high propagation loss. A high directional antenna is favoured to compensate for this propagation loss and to reduce shadowing effect.

Millimetre waves have a low multi user interface. In millimetre wave 5G cellular networks, device to device communication faces two kinds of potential interference. One is among different local device to device links and other is between local device to device and device to base/base to base links. Most of the device-to-device communications focus on resource sharing algorithms to manage interference.

For an outdoor environment, millimetre wave base stations communicating with directional antennas have negligible interference which is called Pseudo wired. Millimetre wave base stations need not be deployed in cells. Dense mesh networks can be adopted. These are used in High data rate multimedia applications like virtual games.

In communication among millimetre wave base stations, interference for concurrent communication is negligible because of highly directional antennas and communication is social for a long time. But in communication among D2D and D2B/B2B, interference for concurrent transmission is accountable. But since interference occurs only during allocation of time slots, a millimetre wave base station can be used to centrally control the allocation thereby managing interference.

By using millimetre waves for D2D communication in 5G, network capacity is increased and high transmission rate is achieved.

1.6 INTERFERENCE MANAGEMENT

One of the impairments affecting D2D communication is the interference from CUs. Interference issues are caused by co-existence of D2D pairs and CUs and reuse of cellular resources. D2D users, depending on the mode of operation of D2D networks, suffer from both intercell and intracell interference. Interference management scheme can be classified into interference avoidance, interference coordination and interference cancellation.

1.6.1 INTERFERENCE AVOIDANCE:

This technique involves the manipulation of transmissions in order to avoid interaction between interfering nodes. An ILA based approach, in which a geographical area around the D2D user is delimited and the CUs in that area are not allowed to transmit simultaneously with the D2D users. The scenario of multiple D2D pairs and cellular users is the practical topology of network with regards to 5G D2D. So, the ILA based approach will serve as a great measure to avoid interference between the D2Dpairs and even between the D2D pair and cellular user. In addition, the transmit power of both D2D users and CU can be reduced in order to reduce interference.

1.6.2 INTERFERENCE COORDINATION:

The schemes of Interference coordination gain significant relevance in network scenarios with Inband D2D communication. CIC involves the supervision of BS whereas in the case of DIC, the coordination mechanism involves participation of D2D nodes with minimal supervision of the BS.

1.7 ENERGY EFFICIENCY

Energy efficiency acts as the performance indicator for the device to device (D2D) communication. D2D communication is an energy efficient technology in the 5G standard. Since D2D communications reduces transmission power and increases data rates, it increases both spectral efficiency and energy efficiency.

Energy efficiency can be increased by using Massive Multiple-Input Multiple-Output (Massive MIMO) antennas. These antennas transmit the signal only in the direction of the communicating mobile as beams thereby increasing the throughput. Here, multiple beams can be used simultaneously by reusing the cell’s frequencies.

Energy efficiency (EE) is a vital overall performance indicator for the device-to-device (D2D) conversation underlying mobile networks because of constrained battery potential and critical interference among consumer equipment. In this study, we proposed energy manipulate and channel allocation scheme for the EE maximization of the D2D pairs, whilst together reusing uplink–downlink resources and ensuring the mobile users (CUs) first-class of service (QoS).

Device-to-Device (D2D) communication is expected to satisfy the rapidly growing capacity, and it can also alleviate the burden of base stations (BSs) by offloading onto direct links in a 5G mobile system, which can help high-speed data rate for neighbourhood customers and offer strength-saving services, while enhancing the electricity efficiency (EE) of the worldwide community.

Therefore, we version the EE of world community under laid or overlaid D2D direct communications, wherein the express relationships among EE and the offloading strategy radius are signified through quantifying various community parameters (i.e., density of BSs and customers, information-price and system bandwidth, etc.).

More importantly, we analytically understand the EE and user’s common transmission strength in each D2D mode, that is, underlay and overlay. Furthermore, offloading chance of cell customers and lively chance of D2D transmitters are analytically obtained. Simulations are executed and display that worldwide community EE may be significantly advanced through the use of D2D communication.

Moreover, in overlay mode, whilst the D2D bandwidth is identical with underlay mode, customers eat much less strength for transmission, due to the fact the interference is removed on the rate of saving benefit on the electricity and spectrum as the full bandwidth turns into larger.

1.7.1 NEED FOR ENERGY EFFICIENCY:

There has been a large-scale construction of smart cities lately and these smart cities combine information technology with urban construction, which in turn aim to efficiently exploit urban resources. However, there has been a surge in the number of multimedia terminals and the information processing will be much more time consuming and complicated.

In the current society, the global climate change has become more serious because of the huge greenhouse gas emissions. The significantly large number of communicating devices is also an important cause for the greenhouse gas emissions. Because of the large number of devices, the communication is getting more and more complicated and time consuming.

Hence, reducing energy consumption is very much beneficial in fighting global climate change and efficient use of energy can also prove to be very economical. Energy efficient solutions should aim at supporting high data rate demand and at decreasing the power consumption, without utilizing the central base station.

The discovery process and the control mode of D2D communication affect energy efficiency.

CHAPTER 2

LITERATURE SURVEY AND MATHEMATICAL PRELIMINARIES

2.1 LITERATURE SURVEY

The research on Energy Efficient Resource Allocation for 5G Full-Duplex enabled D2D Communication carried out by Rui Tang, Jihong Zhao, Hua Qu and Zhenwei Zhang (2016) published on IEEE Globecom Workshops proposed the optimization of energy efficiency by incorporating channel assignment and power control under additional quality of service requirements.

The research work on Energy Efficient D2D Communication in Cellular Networks carried out by Bodong Shang, Liqiang Zhao, Kwang-Cheng Chen and Guogang Zhao (2016) published in the IEEE 83rd Vehicular Technology Conference proposed the modelling of the D2D communication systems, where the relationship between Energy Efficiency and offloading strategy radius are signified by quantifying data-rate and system bandwidth.

The research work on channel and power allocation in a heterogeneous cellular network-supported D2D communication carried out by Amal Algedir and Hazem H. Refai (2019) published on IEEE Wireless Communication and Networking conference provided a review on energy-efficient scheme in terms of a joint resource block and power allocation.

The research work carried out on energy efficient resource allocation in energy harvesting based D2D heterogeneous networks by Zhufang Kuang, Gang Liu, Gongqiang Li and Xiaoheng Deng provided a novel approach to maximize the average energy efficiency of all D2D links by guaranteeing quality of service.

The research on Spectral and Energy efficient D2D Communication: A mixed strategy approach carried out by Selmi Sawsan and Bouallegue Ridha (2020) published on the Journal of Communications Software and Systems provided an approach which maximizes the total spectrum efficiency by using a joint spectrum and energy efficient resource allocation algorithm.

2.2 MATHEMATICAL PRELIMINARIES

2.2.1 KKT CONDITIONS:

KKT conditions are also known as Karush-Kuhn-Tucker conditions. As per KKT condition, the derivative of the Lagrangian has to vanish at the optimal. KKT conditions are used to solve optimization problems. These conditions are used for optimal power allocation for communication.

Consider a set of parallel channels. These channels are arranged in decreasing order of gains. Channel 1 has higher gain. Hence, it is the strongest channel. Channel n has lower gain. Hence, it is the weakest channel. This is called parallel channel communication.

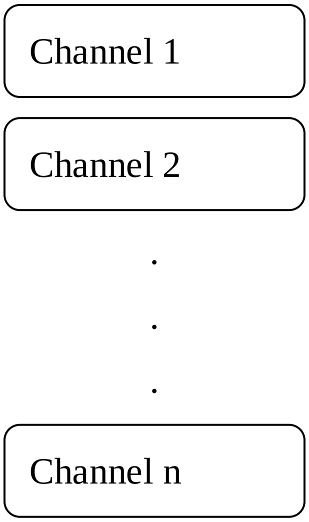


Fig. 2.1 Channels with decreasing Gain

The inputs of these channels are P_1, P_2,…, $P_n$which are powers. The gains of these channels are α_1,α_2,…, α_n. The output of these channels will be the product of power and gain which is $P_1\alpha_1$, $P_2\alpha_2$, …, $P_n\alpha_n$. These are the received powers.

Transmission can be done at a certain bitrate over each of these communication channels and bitrates depends on the power that is allocated to that particular channel. There will be thermal noise or Gaussian noise at the receiver for every communication which is taken as additive white Gaussian noise.

$$y_i = \sqrt{\alpha_i} * x_i + n_i \qquad \text{-------------------------} \ (2.1)$$

where n_i is additive white Gaussian noise. For additive white Gaussian noise, Mean = 0 and Variance =σ^2.

$$\text{SNR for channel i} = \frac{\alpha_i P_i}{\sigma^2} \text{-------------------------}(2.2)$$

Shannon's formula is used to find the bit rate at which one can transmit over these channels which is also called as maximum information rate.

Maximum rate at which information can be transmitted over channel i is given by

$$\text{Max. Rate} = log_2 \ (1+\text{SNR})$$

$$= log_2(1+\frac{\alpha_i P_i}{\sigma^2}) \qquad \text{------------------------}(2.3)$$

Sum rate corresponding to powers P_1, P_2,…, P_n is

$$=\sum_{i=1}^{n} log_2(1 + \frac{\alpha_i P_i}{\sigma^2})$$

$$= \sum_{i=1}^{n} log_e(1+\frac{\alpha_i P_i}{\sigma^2}) * log_2\text{e}$$

$$= \max(\sum_{i=1}^{n} \log(1+\frac{\alpha_i P_i}{\sigma^2})) \text{ --------------(2.4)}$$

Two constraints are assumed here which are as follows:

- There is no unlimited power. Total transmitted power is a fixed quantity i.e., sum of powers across all channels has to be fixed.

  $\sum_{i=1}^{n} P_i$ = P where P is maximum transmit power of transmitter.
- Power has to be non-negative. Thus, all powers P_1, P_2,…, P_n are greater than or equal to zero.

  $P_i \geq 0$ (or) $-P_i \leq 0$

Since the log function is concave, it is converted to convex function for easy solving.

$$\equiv \min (- (\sum_{i=1}^{n} \log(1+\frac{P_i\alpha_i}{\sigma^2})) \text{ -------------------------(2.5)}$$

$$\text{s.t. } \sum_{i=1}^{n} P_i = P,\ P_i \geq 0$$

\` This is a convex optimization problem for optimal power allocation i.e., powers are allocated optimally to n channels.

$$L(\bar{P},\bar{\lambda},\gamma) = \sum_{i=1}^{n} -\log(1+\frac{P_i\alpha_i}{\sigma^2}) + \gamma(\sum_{i=1}^{n} P_i - P) - \bar{\lambda}^T\bar{P} \text{ -----------(2.6)}$$

There is one Lagrange multiplier for each power i.e., $\lambda_1, \lambda_2, \dots, \lambda_n$ for P_1, P_2,…, P_n.

There is a situation called complementary slackness where either the constraint is slack or the lagrange multiplier is slack.

$\lambda_i P_i$ = 0

Case 1: If non-negative power is allocated to a channel i.e.,$P_i \geq 0$, then λ_i=0.

$P_i = \frac{1}{\gamma} - \frac{\sigma^2}{\alpha_i}$

$\Rightarrow \; \frac{1}{\gamma} \geq \frac{\sigma^2}{\alpha_i}$

where $P_i$is optimal power allocated to i^{th}channel.

Case 2: If lagrange multiplier is slack i.e.,$\lambda_i \geq 0$, then P_i =0.

$\lambda_i = \gamma - \frac{\alpha_i}{\sigma^2}$

$\Rightarrow \gamma > \frac{\alpha_i}{\sigma^2}$

$\Rightarrow \frac{1}{\gamma} < \frac{\alpha_i}{\sigma^2}$

Thus, P_i = max $\left\{\frac{1}{\gamma} - \frac{\sigma^2}{\alpha_i}, 0\right\}$

In the equation$\frac{1}{\gamma} - \frac{\sigma^2}{\alpha_i}$,when $\alpha_i$increases$\frac{\sigma^2}{\alpha_i}$decreases. Hence, $\frac{1}{\gamma} - \frac{\sigma^2}{\alpha_i}$increases. Thus, more power is allocated to stronger channel i.e., channel with high gain (channel 1).

2.2.2 DINKELBACH TECHNIQUE

Consider a fractional programming problem,

P1

$$\max_{P} \frac{X(p)}{Y(p)}$$

$$s.t. \; p \in \mathcal{P}$$

Based on Dinkelbach method, P2 is transformed into,

P2

$$\max_{p} \quad X(p) - z\,Y(p)$$

$$s.t.\ p \in \mathcal{P}$$

Where, z is a new auxiliary variable and P3 is a convex optimization problem for a constant z. The problem of finding the optimum p, is then solved by updating the auxiliary variable z iteratively until convergence as,

$$z(l+1) = \frac{X(p\,(l))}{Y(p\,(l))}$$

Where, l is the iteration index.

2.2.3 ENERGY EFFICIENCY

The common definition of Energy Efficiency (EE) is the ratio between the Spectral Efficiency (SE) and the total power consumption. For D2D users, the sum EE over j^{th}subcarrier is expressed as,

$$EE = \frac{R^{D2D}}{P_{total}}\ bits/joule/Hz \qquad (2.7)$$

where, P_{total} is the total power consumed and $P_{total} > 0$. $R^{D2D}$is the sum rate of SUs over n^{th} subcarrier.

CHAPTER 3

SYSTEM MODEL

3.1 SYSTEM MODEL

In the proposed system model, it is assumed that$D$ D2D pairs are co-located with C cellular users. The D2D pairs share the downlink channel of cellular users. A single macro cell with a base station at the centre is considered for the analysis (Fig. 3.1).

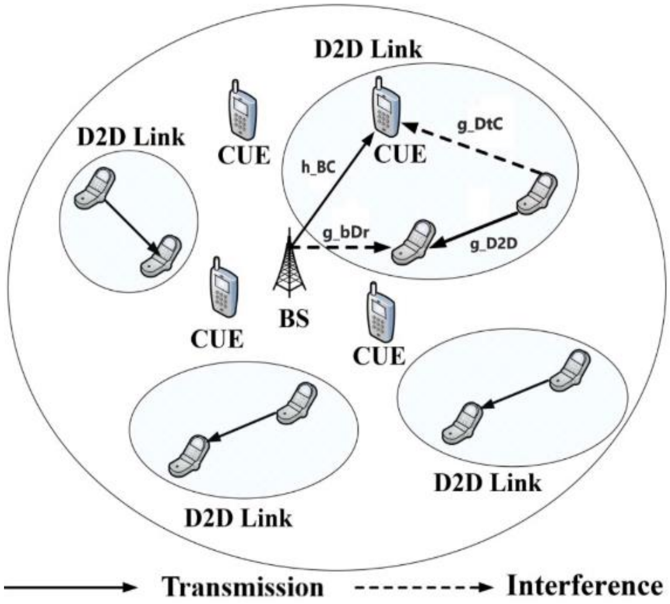


Fig. 3.1 System Model

Fig.3.1 shows the system model. The continuous line represents the desired signal transmission and the dotted line represents interference. The following naming conventions are followed,

BS - Base Station

CUE - Cellular User Equipment

D2D Link - Device to Device Link

h_BC_j - Channel Gain between the base station and j^{th} cellular user.
g_DtC_{ij} - Interference channel Gain between i^{th} D2D transmitter and j^{th} CUE.
g_D2D_{ij} - Channel Gain of i^{th} D2D user using j^{th} channel
g_bDr_{ij} - Interference channel Gain from BS to i^{th} D2D receiver through j^{th} channel.

3.2 DEVICE DISCOVERY:

In the discovery phase, the BS has to discover a UE which needs to interact with another UE i.e., it must also discover a receiving UE. This phase also includes the messages that have to be exchanged between UEs and between UE and base station. The information about this link between UEs and the link between UE and BS are provided to the network by these messages.

The criteria for mode selection are applied if the discovered pair is a D2D candidate pair. This criterion will decide whether or not the new pair can communicate in D2D mode. If the mode selection criterion determines that D2D mode is not advantageous for the new pair, cellular mode is assigned. D2D mode is assigned if the new pair meets all of the requirements for D2D communication. Device discovery can be done in two methods namely,

- Centralized approach
- Distributed approach

In centralized approach, a UE notifies the base station of its intention to communicate with another UE. The base station then initiates a series of message exchanges between the devices and acquires information about the link between them. In distributed approach, probe messages are broadcasted by a UE which wants to communicate with another UE and these messages are received by other UEs. The base station is then notified of the results of its inquiry, and the base station makes the final decision.

A link discovery is considered successful only when the following criteria are satisfied:

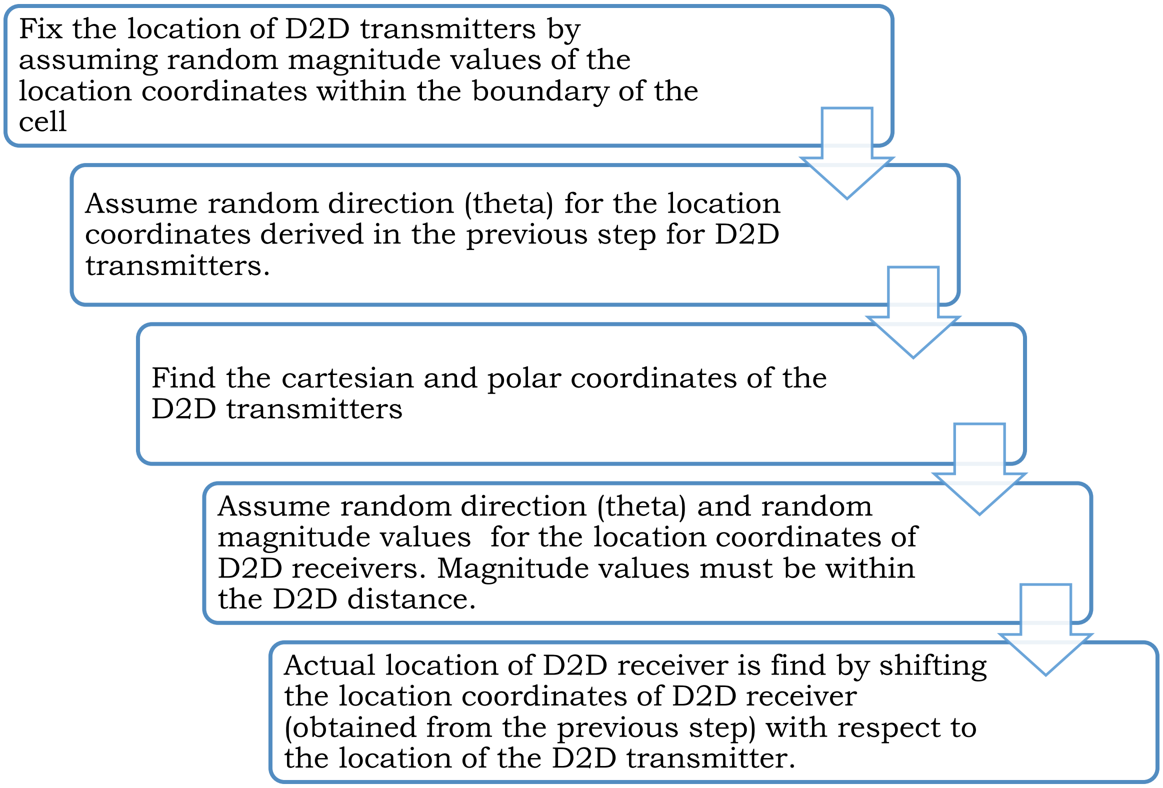
- The sender device knows the receiver device’s ID.
- The receiver device knows the sender device’s ID and that the sender wants to communicate with it.
- The new pair meets the proximity requirement.

The network is then in charge of assigning resources to the new pair. The discovery phase's final stage is resource assignment. The discovery phase is then completed. Following the completion of the discovery process, the UEs that make up the new D2D pair may begin exchanging data. The new pair is now a fully integrated part of the cell, exchanging data through a bidirectional connection rather than relaying data via the base station.

3.2.1 ALGORITHM FOR D2D PAIR DISCOVERY:

Fig.3.2 shows the algorithm steps for locating D2D pairs within the cell.

- In the derived system model, the BS is assumed to be at the centre of the cell.
- Random values for magnitude and theta of D2D transmitter are assumed and from which the location of the D2D transmitter in the Cartesian coordinates is determined.
- The same procedure is repeated for the D2D receiver as well.
- The D2D pairs are assumed to be placed at the calculated Cartesian coordinates.



Fix the location of D2D transmitters by assuming random magnitude values of the location coordinates within the boundary of the cell

Assume random direction (theta) for the location coordinates derived in the previous step for D2D transmitters.

Find the cartesian and polar coordinates of the D2D transmitters

Assume random direction (theta) and random magnitude values for the location coordinates of D2D receivers. Magnitude values must be within the D2D distance.

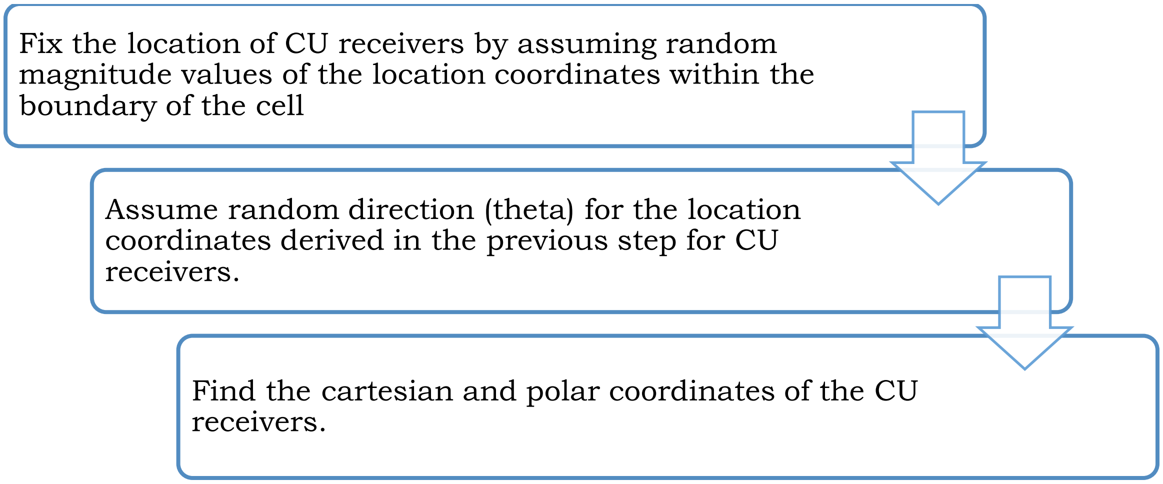
Actual location of D2D receiver is find by shifting the location coordinates of D2D receiver (obtained from the previous step) with respect to the location of the D2D transmitter.

Fig. 3.2 D2D pair discovery – Algorithm

3.2.2 ALGORITHM FOR CUE DISCOVERY:

Fig. 3.3 shows the algorithm steps for locating cellular user equipment (CUE receivers) within the cell.

- In the derived system model, the BS is assumed to be at the centre of the cell.
- Random values for magnitude and theta of CU are assumed and from which the location of the CU receiver in the Cartesian coordinates is determined.
- The CU and BS are placed at the calculated Cartesian coordinates within the cell.



Fix the location of CU receivers by assuming random magnitude values of the location coordinates within the boundary of the cell

Assume random direction (theta) for the location coordinates derived in the previous step for CU receivers.

Find the cartesian and polar coordinates of the CU receivers.

Fig.3.3 CUE discovery – Algorithm

3.3 WIRELESS CHANNEL GAIN:

The channel gain of a wireless channel is defined by the equation,

$$Y = HX + Z \qquad \text{-----------------------} \ (3.1)$$

Here,

Y – Signal received by the receiver

X – Signal transmitted by the sender

Z – Noise term

H – Channel gain of the Wireless channel

In order to design a high-performance communication scheme in a wireless network, the knowledge of channel gains is very essential. Due to mobility, fading and power instability, channel gains usually vary with time. Hence estimating the channel gain of the wireless channel and tracking it is, fundamentally important.

3.3.1 ALGORITHM FOR FINDING CHANNEL GAIN:

The fading channel gain between the users is computed based on the 3GppUMi path loss model. The path loss in dB for a hexagonal cell, NLOS communication with carrier frequency f_c is given by,

$$PL\ (dB) = 36.7\ log_{10}\ d + 22.7 + 26\ log_{10}\ f_c \text{ ----------------------- (3.2)}$$

Where, d distance between the concerned transmitter and receiver. The standard deviation of the shadowing component is assumed as 4 (based on standard). The detailed procedure for finding the channel gain is explained in this section.

- The absolute distance between the transmitter and the receiver is calculated based on their location information.
- The path loss is computed using eq. 3.2. The shadowing parameters of different users are assumed to be Gaussian distributed with a standard deviation of 4.
- Random fading channel gain matrix ‘h’, which is of iid Gaussian, is generated. The size of the matrix depends on the number of transmitters, number of receivers and the number of possible shared channels.
- The actual channel gain is given by,

$$Channel\ gain = abs\ (h)^2 * pathloss\ and\ shadowing\ effect \text{ ------ (3.3)}$$

Fig. 3.4 explains the procedure to find the channel gain. The same procedure is followed for the finding the channel gains between,

- Base Station & jth Cellular User
- ith D2D transmitter and jth Cellular User
- ith D2D transmitter and receiver, using jth Channel

- Base Station and ith D2D receiver, through jth Channel

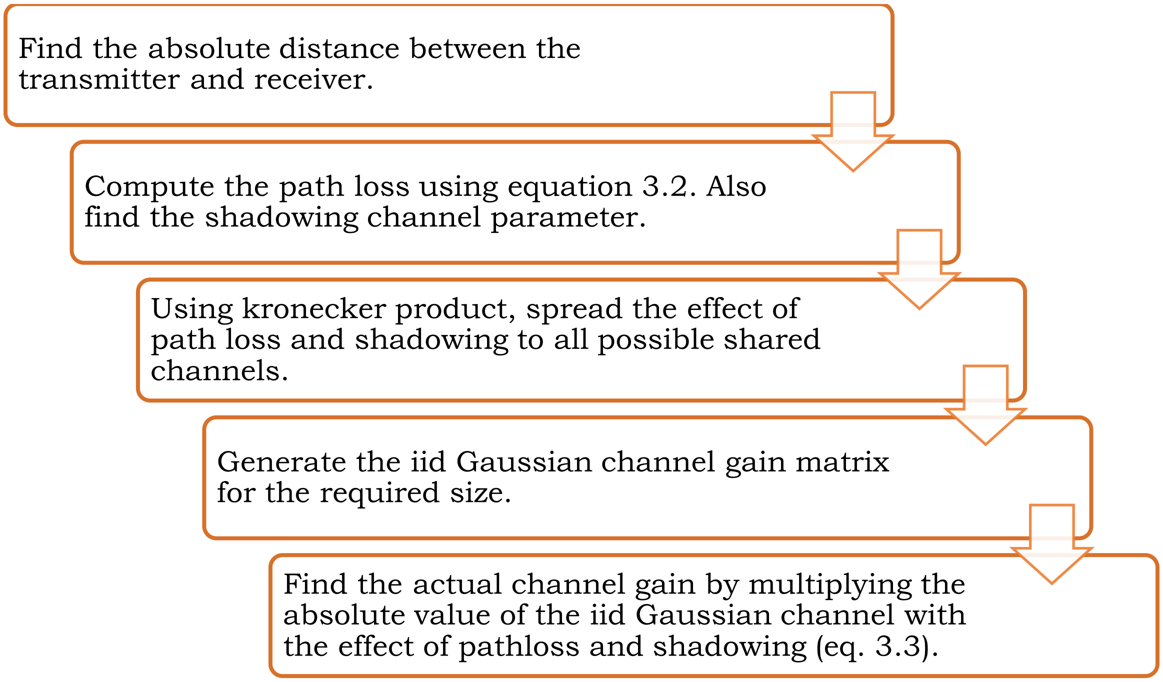


Fig. 3.4 Finding Channel Gain

3.4 PERFORMANCE METRICS:

The rate of ith D2D user, using the channel of jth CU is given by,

$$r_{ij} = log_2\left(1 + \frac{Pd_{ij}g\_d2d_{ij}}{N_o + P_j g\_bdr_{ij}}\right) - - - - - - - - (3.4)$$

where,

Pd_{ij}→ Power of ith D2D user on jth CU channel

P_j→ Power of jth CU i.e., power transmitted from BS for jth CU.

N_o→ Noise power spectral density

g_d2d_{ij}→ Channel gain of ith D2D user on jth CU channel

g_bdr_{ij}→ Interference channel gain at the d2d receiver due to the signal transmitted from BS to jth CU.

In the system model assumed, the channel of each cellular user is shared with only one D2D users and no two channels of cellular users are allotted to a D2D user. In order to ensure this type of channel sharing, a channel control parameter ρ is introduced. ρ is a matrix of size, no. of D2D users x no. of available channels for sharing. The elements of ρ matrix assumes either 1 or 0. If $\rho_{ij} = 1$, then the j^{th} CU channel is shared with i^{th} D2D user. Thus, the actual rate of i^{th} D2D user is given by,

$$R_i = \sum_{j=1}^{C} \rho_{ij}\, r_{ij} \qquad (3.5)$$

Similarly, the rate of j^{th} CU is given by,

$$R_j = log_2\left(1 + \frac{P_j \quad h\_bc_j}{N_o + Pd_{ij} \quad g\_dtc_{ij}}\right) \qquad (3.6)$$

where,

h_bc_j→ Channel gain between the BS and jth CU

g_dtc_{ij}→ Interference channel gain seen at the j^{th} CU receiver. The interference is due to the i^{th} D2D transmitter using the j^{th} CU channel

The expression for Energy Efficiency of i^{th} D2D user is given by,

$$EE_i = \sum_{j=1}^{C} \frac{\rho_{ij}\, r_{ij}}{\varepsilon\left(\rho_{ij}\, Pd_{ij} + P_s\right)} \qquad (3.7)$$

where,

ε → Drain efficiency of the power amplifier

P_s→ Circuit power

Since the cellular users share their channel with the D2D user in underlay mode, the resource allocation process carried out must guarantee a minimum QoS for the cellular users. Let, Rth_jbe the minimum data rate to be guaranteed for j^{th} cellular user, i.e. the QoS constraint is written as,

$$R_j^{CU} \geq Rth_j \tag{3.9}$$

Assume that the j^{th} resource block is allotted for spectrum sharing with the i^{th}D2D user, then, from eq. (3.6) and (3.9), the transmission power required by the base station for transmitting over the j^{th} resource block is written as,

$$P_j \geq \left(2^{Rth_j} - 1\right) \frac{\left(Pd_{ij} g_{dtc_{ij}} + N_o\right)}{h_{bc_j}} \tag{3.10}$$

Since energy efficiency increases with the decrease in P_j , let, $P_j$assumes its minimum value, i.e.,

$$P_j = \alpha \frac{\left(Pd_{ij} g\_dtc_{ij} + N_o\right)}{h\_bc_j} \tag{3.11}$$

Where, $\alpha = \left(2^{Rth_j} - 1\right)$, Substituting P_j (eq. (3.11)) in the data rate expression for i^{th}D2D user is,

$$r_{ij}^{D2D} = log_2\left(1 + \frac{Pd_{ij} g\_d2d_{ij}}{\frac{\alpha\left(Pd_{ij} g\_dtc_{ij} + N_o\right) g\_bdr_{ij}}{h\_bc_j} + N_o}\right) \tag{3.12}$$

$$\Rightarrow r_{ij}^{D2D} = log_2\left(1 + \frac{Pd_{ij} a_{ij}}{N_o e_{ij} + Pd_{ij} f_{ij}}\right) \tag{3.13}$$

Where, $a_{ij} = g\_d2d_{ij} h\_bc_j$, $e_{ij} = \psi\, g\_bdr_{ij} + h\_bc_j$ and $f_{ij} = g\_dtc_{ij} g\_bdr_{ij}$.

CHAPTER 4

ENERGY EFFICIENT RESOURCE ALLOCATION

The capacity shortage problem can be avoided by D2D communication, as it allows the cellular spectrum resource reuse among many D2D communication pairs. D2D communication can be initiated when UEs of the source and the destination are in a close proximity, so that they can establish a direct communication link between each other rather than being routed through the BS.

In the proposed system, when a CUE shares the spectrum resource with a D2D pair, the other adjacent D2D pairs and the CUEs will interfere with it and hence resource allocation and interference are crucial issues.

In our scenario, the problem of resource allocation for D2D communication underlying cellular networks, is formulated and analysed, in order to maximize the energy efficiency considering the number of CUEs is the same as that of the D2D pairs.

4.1 ENERGY EFFICIENT RESOURCE ALLOCATION IN D2D:

The problem for energy efficient power and sub-channel allocation in a D2D underlying communication for the system model formulated in chapter 3 is defined as,

P3:

$$\max_{\{Pd_{ij},\ \rho_{ij}\}} \quad EE = \sum_{i=1}^{D} EE_i = \frac{\sum_{i=1}^{D}\sum_{j=1}^{C}\rho_{ij} r_{ij}^{D2D}}{\sum_{i=1}^{D}\epsilon\sum_{j=1}^{C}\rho_{ij} Pd_{ij} + \ P_s} \qquad (4.1\,a)$$

$$s.t.$$

$$\sum_{j=1}^{C}\rho_{ij} \leq 1\,, \qquad \forall i \qquad (4.1b)$$

$$\sum_{j=1}^{C} \rho_{ij} Pd_{ij} \leq Pd\_max_i \qquad \forall i \tag{4.1c}$$

where, (4.1b) ensures that, a D2D users reuses only one cellular users resource block, (4.1c) states that, the power allocated to the i^{th} D2D user for transmission must not exceed Pd_max_i. Substituting, r_{ij}^{D2D} from eq. (3.13), in the objective function of P3, the modified problem statement is written as,

P4:

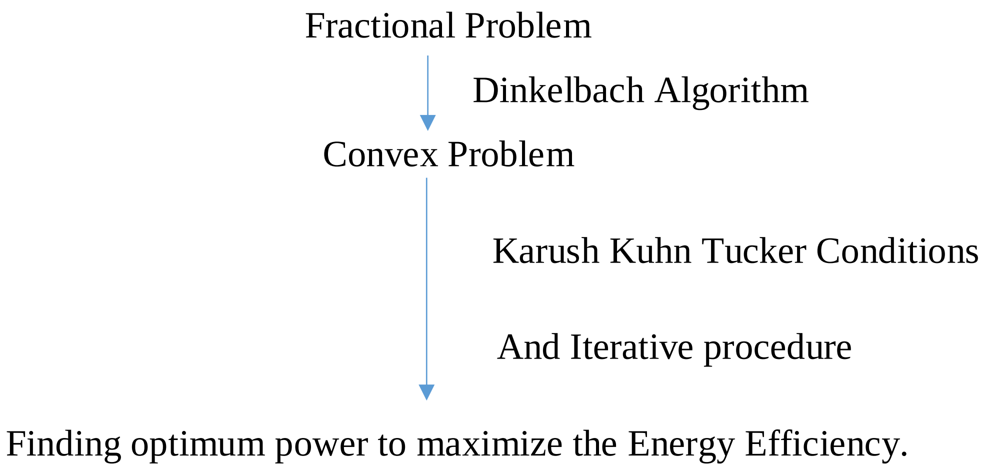
$$\max_{\{Pd_{ij},\ \rho_{ij}\}} \quad EE = \frac{\sum_{i=1}^{D} \sum_{j=1}^{C} \rho_{ij} log_2 \left(1 + \frac{Pd_{ij} a_{ij}}{N_o e_{ij} + Pd_{ij} f_{ij}}\right)}{\sum_{i=1}^{D} \epsilon \sum_{j=1}^{C} \rho_{ij} Pd_{ij} + \ P_s} \tag{4.2a}$$

$$s.t.$$

$$\sum_{j=1}^{C} \mathcal{S}_{ij} \leq 1\ , \qquad \forall i \tag{4.2b}$$

$$\sum_{j=1}^{C} \mathcal{S}_{ij} Pd_{ij} \leq Pd\_max_i \qquad \forall i \tag{4.2c}$$

As the fractional form of the energy efficiency equation of the system is a non-convex optimization problem, it is hard to solve it. But by transforming the fractional problem into a solvable convex problem using Dinkelbach algorithm, the convex optimization problem is solved by employing Karush Kuhn Tucker (KKT) conditions. Then an iterative procedure is formulated to find the optimum power which will maximize the energy efficiency.



4.2 DINKELBACH ALGORITHM:

P4 can be transformed into a corresponding subtractive form according to the theory of nonlinear fractional programming

P5:

$$\max_{\{Pd_{ij},\rho_{ij}\}} \sum_{i=1}^{D}\sum_{j=1}^{C}\rho_{ij}log_2\left(1+\frac{Pd_{ij}a_{ij}}{N_o e_{ij}+Pd_{ij}f_{ij}}\right)-\sum_{i=1}^{D}\eta_i\epsilon\sum_{j=1}^{C}\rho_{ij}Pd_{ij}+P_s \quad (4.3a)$$

$$s.t.$$

$$\sum_{j=1}^{C}\rho_{ij}\leq 1\,, \qquad \forall i \qquad (4.3b)$$

$$\sum_{j=1}^{C}\rho_{ij}Pd_{ij}\leq Pd\_max_i \qquad \forall i \qquad (4.3c)$$

4.3 LAGRANGIAN FUNCTION:

The Lagrangian of (4.3a) of P5 can be formulated as,

$$\mathcal{L}\left(Pd_{ij},\ \rho_{ij}, \lambda_i, \mu_i\right)$$

$$= -\left[\sum_{i=1}^{D}\sum_{j=1}^{C}\rho_{ij}log_2\left(1+\frac{Pd_{ij}a_{ij}}{N_o e_{ij}+Pd_{ij}f_{ij}}\right) - \sum_{i=1}^{D}\eta_i\epsilon\sum_{j=1}^{C}\rho_{ij}Pd_{ij} + P_s\right] + \sum_{i=1}^{D}\lambda_i\left(\sum_{j=1}^{C}\left(\rho_{ij}-1\right)\right) + \sum_{i=1}^{D}\mu_i\left(\sum_{j=1}^{C}\rho_{ij}Pd_{ij} - Pd\_max_i\right) \quad (4.4)$$

Solving the above Lagrangian equation,

$$\frac{\partial\mathcal{L}}{\partial Pd_{ij}} = -\frac{\rho_{ij}}{log\ 2}\frac{N_o b_{ij}a_{ij}}{\left(N_o e_{ij}+Pd_{ij}c_{ij}+Pd_{ij}a_{ij}\right)\left(N_o b_{ij}+Pd_{ij}f_{ij}\right)} + \eta_i\epsilon\,\rho_{ij} + \mu_i\rho_{ij} = 0 \quad (4.5)$$

$$\frac{\partial L}{\partial\rho ij} = -\log_2\left(1+\frac{Pdij*aij}{No*eij+Pdij*fij}\right) + \eta_i\varepsilon P_{dij} + \lambda_i + \mu_i P_{dij} = 0 \quad (4.6)$$

$$\frac{\partial L}{\partial\lambda i} = \rho_{ij} - 1 = 0$$

$$\frac{\partial L}{\partial\mu i} = \rho_{ij}*P_{dij} - P_i^{max}$$

From Eq. (4.5),

$$\eta_i\varepsilon + \mu_i = \frac{No*\rho ij*aij}{log_2((No*\rho ij)^2 + No*\rho ij*Pdij*fij + No*\rho ij*Pdij*aij + Pdij*fij*No*\rho ij + (Pdij*fij)^2 + Pdij*Pdij*fij*aij)} \quad (4.7)$$

$$\log_2(\eta_i\varepsilon+\mu_i)(P_{dij}^2(f_{ij}^{\ 2}+f_{ij}a_{ij}) + P_{dij}(2N_o\rho_{ij}f_{ij}+N_o\rho_{ij}a_{ij}) + N_o^2\rho_{ij}^2) = N_o\rho_{ij}a_{ij}$$

$$P_{dij}^2(f_{ij}^{\ 2}+f_{ij}a_{ij}) + P_{dij}(2N_o\rho_{ij}f_{ij}+N_o\rho_{ij}a_{ij}) + N_o^2\rho_{ij}^2 - \frac{N_o\rho ija_{ij}}{log2(\eta i\varepsilon+\mu i)} = 0 \quad (4.8)$$

The above equation seems to be a quadratic equation, with,

$$A^{(0)} = f_{ij}^2 + f_{ij}a_{ij}$$

$$A^{(1)} = 2N_o e_{ij} f_{ij} + N_o e_{ij} a_{ij}$$

$$A^{(2)} = N_o^2 e_{ij}^2 - \frac{N_o e_{ij} a_{ij}}{\log 2\,(\eta_i \epsilon + \mu_i)}$$

The roots of the quadratic equation is obtained as below,

$$Pd_{ij} = -\frac{A^{(1)}}{2A^{(0)}} \pm \sqrt{\frac{A^{(1)} * A^{(1)}}{4 * A^{(0)} * A^{(0)}} - \frac{4 * A^{(0)} * A^{(2)}}{4 * A^{(0)} * A^{(0)}}}$$

$$Pd_{ij} = -\frac{A^{(1)}}{2A^{(0)}} \pm \sqrt{\frac{A^{(1)} * A^{(1)}}{4 * A^{(0)} * A^{(0)}} - \frac{A^{(2)}}{A^{(0)}}}$$

$$Pd_{ij} = \left(-\frac{A^{(1)}}{2\,A^{(0)}} + \sqrt{\frac{(A^{(1)})^2}{4(A^{(0)})^2} - \frac{A^{(2)}}{A^{(0)}}} \right)^{+} \tag{4.9}$$

where, $(x)^{+} = \max\ (x, 0)$, Upon solving Eq. (4.6),

$$\lambda_i + (\eta_i \varepsilon + \mu_i) \mathrm{P}_{\mathrm{dij}} = log_2\left(1 + \frac{Pdij * a_{ij}}{N_{o*} \rho ij + Pdij * f_{ij}}\right)$$

$$\lambda_i = log_2\left(1 + \frac{Pdij * a_{ij}}{N_{o*} \rho ij + Pdij * f_{ij}}\right) - (\eta_i \varepsilon + \mu_i) * \mathrm{P}_{\mathrm{dij}}$$

$$\lambda_i = log_2\left(1 + \frac{Pdij * a_{ij}}{N_{o*} \rho ij + Pdij * f_{ij}}\right) - \frac{N_o * \rho ij * a_{ij} * Pdij}{log2\,(N_o * \rho ij + Pdij * f_{ij} + Pdij * a_{ij})\,(N_o * \rho ij + Pdij * f_{ij})} \tag{4.10}$$

Therefore the channel selection parameter ρ_{ij} is formulated as,

$$\rho_{ij} = \begin{cases} 1 & j = \underset{j}{argmax}\, y_{ij} \\ 0 & otherwise \end{cases} \tag{4.11}$$

Where,

$$y_{ij} = log_2\left(1 + \frac{Pd_{ij} a_{ij}}{N_o b_{ij} + Pd_{ij} c_{ij}}\right) - \frac{N_o b_{ij} a_{ij} Pd_{ij}}{log\,2\,(N_o b_{ij} + Pd_{ij} c_{ij} + Pd_{ij} a_{ij})(N_o b_{ij} + Pd_{ij} c_{ij})}$$

(4.12)

Thus, (4.11) provides the optimum channel allocation of j^{th}cellular user channel to the i^{th}D2D user based on the parameter $y_{ij}$and (4.9) provides the D2D user transmission power obtained by solving the convex optimization problem P5. However, according to Dinkelbach technique, an iterative procedure is followed to find the optimum D2D transmission power which will maximize the energy efficiency.

4.4 ITERATIVE ALGORITHM:

The inputs for Joint power control and D2D-CU matching algorithm are

$g\_d2d_{ij}, g\_bdr_{ij}, g\_dtc_{ij}, a_{ij}, e_{ij}, f_{ij} \forall\ i, j$;

$h\_bc_j \forall j$;$Pd\_max_i \forall i$

R_C, ϵ, P_s

Steps:

1. Set the initial value of auxiliary variable as$\eta_i = 0.1, \forall i$, the maximal tolerance,$diff = 10^{-7}$ and the step size parameter$\beta =$
2. Initialize the Lagrange variables$\lambda_i = 1\ and \mu_i = 1\ \forall i$
3. Compute Pd_{ij} based on (4.9)
4. Compute $y_{ij} \forall i, j$ according to (4.12) and find optimum selection matrix ρ_{ij}
5. **While**$(4.3a) > diff$
    a. Update the Lagrange variable as,

$$\mu_i(l+1) = \left(\mu_i(l) - \beta\left(Pd\_max_i - \textstyle\sum_{j=1}^{C} \rho_{ij} Pd_{ij}\right)\right)^+ \quad (4.13)$$

```
    b. Repeat steps 3 and 4 to find $Pd_{ij}$ and $\rho_{ij}$
    c. Update $\eta_i(l+1)\ as,$
       $\eta_i(l+1) = \frac{\sum_{i=1}^{D}\sum_{j=1}^{C}\mathcal{S}_{ij} log_2\left(1+\frac{Pd_{ij}a_{ij}}{N_o b_{ij}+Pd_{ij}c_{ij}}\right)}{\sum_{i=1}^{D}\epsilon\sum_{j=1}^{C}\mathcal{S}_{ij}Pd_{ij}+P_c}$   (4.14)

End While

6. Compute $P_j$ according to (3.11)
7. End
Output : Optimum, $\eta_i$, $P_j$, $Pd_{ij}$ and $\rho_{ij}$
```

CHAPTER 5
RESULTS AND DISCUSSION

This chapter provides the simulation results and discuss the performance of the energy efficient resource allocation in heterogeneous D2D networks. In the simulations, it is considered that the D2D users coexist with the cellular users in a cellular network area and they are distributed randomly which follows uniform distribution.

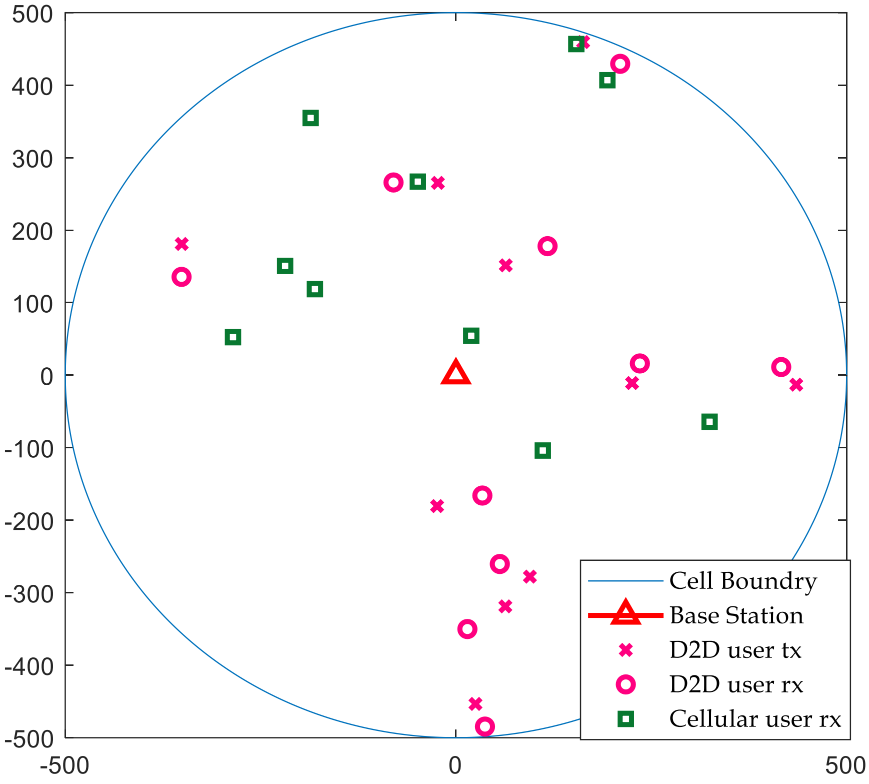


Fig. 5.1 Simulation environment

Fig. 5.1 shows a single cell simulation environment with10 D2D users and 10 cellular users. The base station is located at the centre of the cell. The radius of the cell is 500 meters. All channel gains including the interference channel gains are considered as Rayleigh distributed incorporating the effects of path loss and shadowing. The path loss exponent is assumed as 3.5 for all channel gains and the shadowing effect is assumed to be Gaussian distributed with mean zero and a $4\ dB$ standard deviation. The construction of D2D cellular network and the modelling of channel gains between all the users are explained elaborately in chapter 3. Table 5.1 lists the other different simulation parameters used in this study.

Table 5.1: Simulation Parameters

Description	Notation	Value
Noise power spectral density	N_o	$-174\ dBm/Hz$
Static circuit power	P_s	$50\ mW$
Maximum power of D2D user	Pd_max_i	$20\ dBm$
Drain efficiency of power amplifier	ϵ	0.38
Minimum threshold data rate of cellular users	Rth_j	$15\ bps/Hz$
Radius of the cell		$500\ m$
Path loss exponent		3.5
Standard deviation of shadowing effect		$4\ dB$

Fig. 5.2 compares the performance of energy efficient resource allocation algorithm in terms of its energy efficiency ($bits/Joule/Hz$) for the cellular user threshold data rate of 15 bps/Hz and 12 bps/Hz. The total number of cellular users and D2D users is assumed to be10. The maximum D2D power is20 dBm. It can be seen from the graph that, as the distance between D2D users increases, the energy efficiency decreases. The reason is, as the D2D distance increases, the fading effect on channel gains increases and more power is required by D2D users for their transmission which leads to decrease in total energy efficiency of D2D links. Moreover, comparing the QoS of cellular users in terms of their threshold data rates, the total D2D energy efficiency obtained with $Rth = 12\ bps/Hz$is more when compared to that with$Rth = 15\ bps/Hz$. The reason is, with$Rth = 12\ bps/Hz$, only less transmit power is required for downlink transmission to cellular user

receivers in order to maintain this QoS. Therefore, the interference caused due to this transmission to the D2D users is less. This results in increase in total D2D energy efficiency for the scenario with $Rth = 12\ bps/Hz$ compared to $Rth = 15\ bps/Hz$.

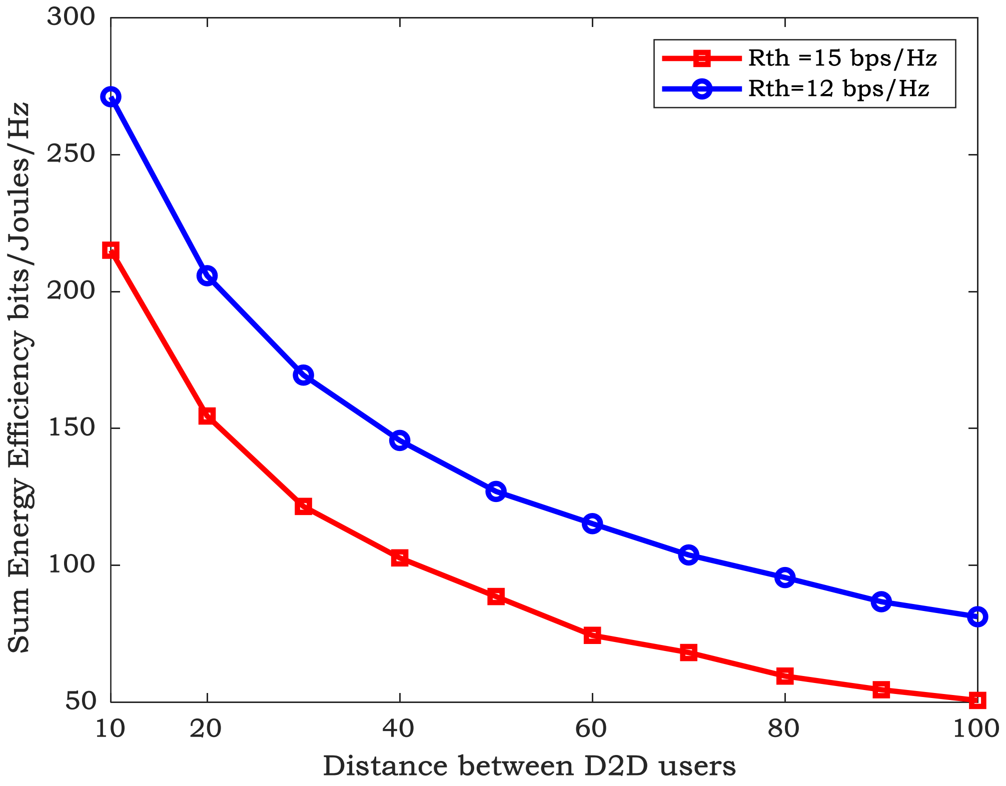


Fig. 5.2 Sum Energy Efficiency of D2D users Vs. Distance between D2D users

From Fig. 5.2 for a maximum D2D distance of $30\ m$, the total D2D energy efficiency obtained is around $125\ bits/Joule/Hz$ with $Rth = 15\ bps/Hz$and $175\ bits/joule/Hz$ with $Rth = 12\ bps/Hz$. Fig. 5.3 compares the total D2D energy efficiency for different number of D2D users. The maximum D2D power is fixed as $20\ dBm$. As the number of D2D users increases, the total energy efficiency also increases. For 20 D2D users with a maximum D2D distance of $50\ m$ and $Rth = 12\ bps/Hz$, the sum energy efficiency obtained is around $100\ bits/Joule/Hz$. Whereas, with a maximum D2D distance of $30\ m$, the sum energy efficiency obtained for the same QoS constraint is around $140\ bits/Joule/Hz$.

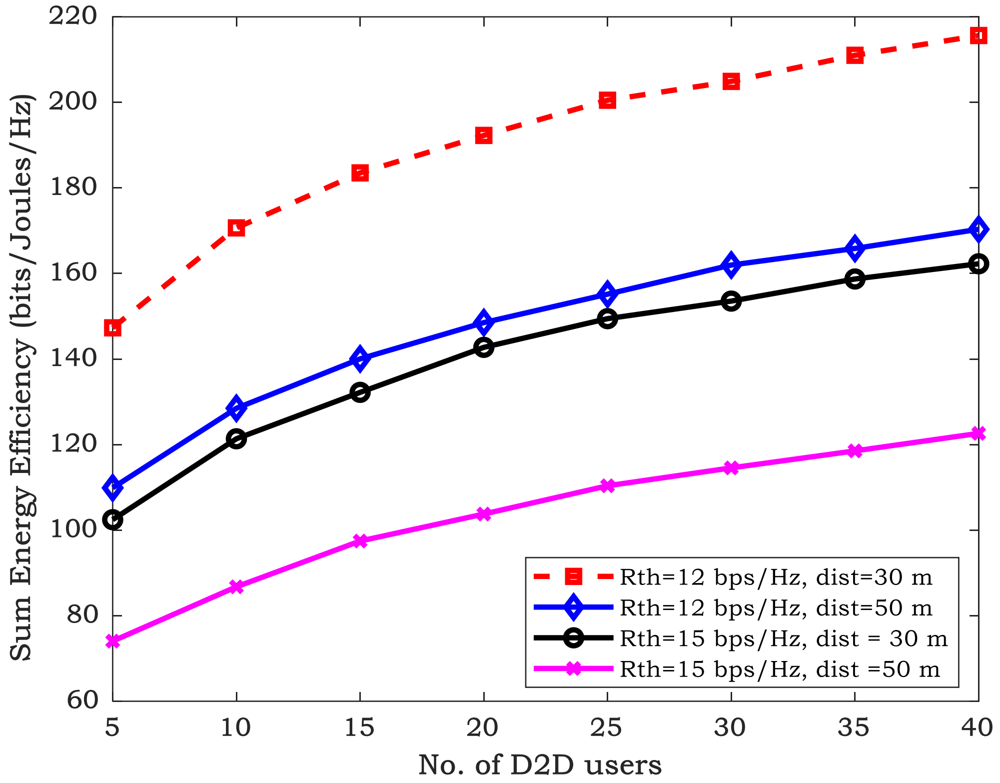


Fig. 5.3 Sum Energy Efficiency of D2D users Vs. Number of D2D users with $Rth = 12\ bps/Hz, 15\ bps/Hz$ and D2D distance = $30\ m, 50\ m$

Fig. 5.3 compares the sum energy efficiency for different number of D2D users with respect to the maximum D2D transmission powers of 20 dBm, 14 dBm and 8 dBm. It can be seen from the chart that, even if the maximum D2D transmission power is changed, the sum energy efficiency remains almost the same for a fixed number of D2D users. The reason is, the energy aware algorithms practically take only the minimum required power for transmission, even though the available power is much larger. This helps in maintaining maximum energy efficiency. It can be seen from Fig. 5.4 that, a sum energy efficiency for 10 D2D users is maintained around 142 $bits/Joule/Hz$ for different maximum D2D powers of 20 dBm, 14 dBm and 8 dBm. Similar effect can be seen even if the number of D2D users is increased.Also, since the energy aware algorithms take the minimum power for transmission, the data rate obtained also remains constant. From Fig. 5.5, it can be seen that, the data rate of 20 D2D users is around 7.2 bps/Hz and 30 D2D users is around 7.7 bps/Hz for different maximum D2D powers of 20 dBm, 14 dBm and 8 dBm.

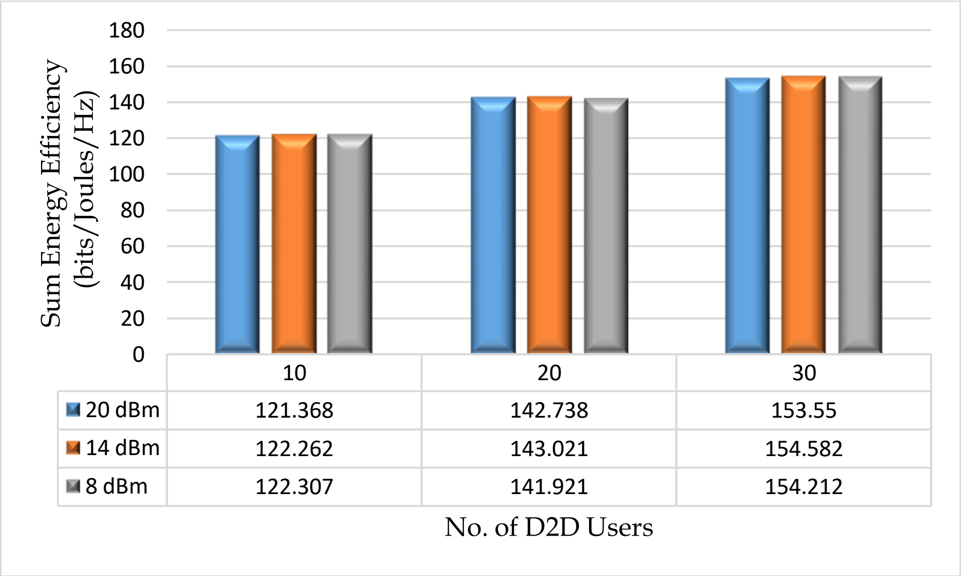


Fig. 5.4 Sum Energy Efficiency of D2D users Vs. Number of D2D users with $Pd\_\max = 20\ dBm\ ,\ 14\ dBm, 8\ dBm$

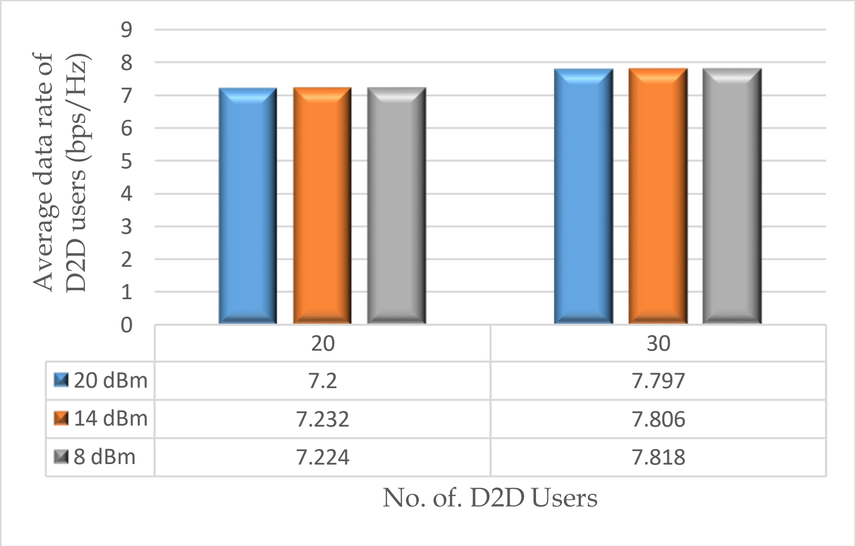


Fig. 5.5 Average data rate of D2D users Vs. Number of D2D users with $Pd\_\max = 20\ dBm\ ,\ 14\ dBm, 8\ dBm$

Analysing the performance of the cellular users from the simulation results, it can also be seen that, the data rate of cellular users is maintained at the assumed Rth(as specified in the constraint equation). Therefore, the outage probability of cellular users is zero. Table 5.2 shows the average power required by cellular users with $Rth = 12\ bps/Hz$.

Table 5.2: Average power of cellular users

Number of cellular users	**Average cellular user power**
10	$48.28\ dBm$
20	$50.87\ dBm$
30	$52.43\ dBm$

CHAPTER 6
CONCLUSION

The proposed method for maximizing the average energy efficiency in Device-to-Device Communication is being developed using the iterative algorithm based on the Dinkelbach and Lagrangian constrained optimization. It’s being simulated using MATLAB software. The resource allocation problems in D2D communication were successfully overcome by the formulation of energy efficient approach, and later the non-convex problem was converted into convex optimization problem. The KKT conditions were used for solving optimization problem and helped in optimal power allocation for communication. In the simulations results obtained, the system model is considered that the D2D users coexist with the cellular users in a cellular network area and they are distributed randomly which follows uniform distribution. Further the following graphs on Sum Energy Efficiency of D2D users Vs. Distance between D2D users, Sum Energy Efficiency of D2D users Vs. Number of D2D users with the variation in the parameters like R_{th} and Distance were obtained. The system was able to improve capacity shortage problem and hence we arrived at the optimum D2D transmission power which will maximize the energy efficiency.

REFERENCES

1. K. Doppler et al.,” Device-to-device communication as an underlay to LTE-advanced networks”, IEEE Commun. Mag., vol. 47, no. 12, pp. 42- 49, Dec. 2009.
2. C. H. Yu et al.,” Resource Sharing Optimization for Device-to-Device Communication Underlaying Cellular Networks,” IEEE Trans. Wireless Commun., vol. 10, pp. 2752-2763, 2011.
3. Wang, F., Song, L., Han, Z., Zhao, Q., and Wang, X., Joint Scheduling and Resource Allocation for Device-to-Device Underlay Communication, Wireless Communication Networking Conference (WCNC), 2013 IEEE, pp. 134–139, 2013.
4. Ye, Q., Al-shalash, M., Caramanis, C., Andrews, J.G., May, I.T., 2015. Distributed resource allocation in device-to-device enhanced cellular networks. Commun. IEEE Trans. 63 (2), 441–454
5. S. Liu, Y. Wu, L. Li, X. Liu and W. Xu, "A TWO Stage Energy-Efficient Approach for Joint Power Control and Channel Allocation in D2D Communication," in IEEE Access, vol. 7, pp. 16940-16951, 2019, doi: 10.1109/ACCESS.2019.2894003.
6. Z. Kuang, G. Liu, G. Li and X. Deng, "Energy Efficient Resource Allocation Algorithm in Energy Harvesting-Based D2D Heterogeneous Networks," in IEEE Internet of Things Journal, vol. 6, no. 1, pp. 557-567, Feb. 2019, doi: 10.1109/JIOT.2018.2842738.
7. M. Zeng, Y. Luo and H. Jiang, "Energy Efficient Resource Allocation for Wireless Power Transfer-Supported D2D Communication with Battery," in IEEE Access, vol. 7, pp. 185666 185676, 2019, doi: 10.1109/ACCESS.2019.2960529.

8. Shen, K. and Yu, W., 2018. Fractional programming for communication systems—Part I: Power control and beamforming. IEEE Transactions on Signal Processing, 66(10), pp.2616-2630.