Resource Allocation in Device to Device Communication for 5G Cellular Network

Wayu Berry Dubiso

A Thesis Submitted to

The Department of Electronics and Communication Engineering
School of Electrical Engineering and Computing

Presented in Partial Fulfillment of the Requirement for the Master's of Science Degree in Electronics and Communication Engineering

Office of Graduate Studies

Adama Science and Technology University

September,2021

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DECLARATION

I hereby declare that this Master Thesis entitled "**Resource Allocation in Device to Device Communication for 5G Cellular Network**" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Wayu Berry Dubiso	________________________	________________
Name of the student	Signature	Date

RECOMMENDATION

We, the advisors of this thesis, hereby certify that we have read the revised version of the thesis entitled "Resource Allocation in Device to Device Communication for 5G Cellular Network" prepared under our guidance by Wayu Berry submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Electronics and Communication Engineering (Communication Engineering). Therefore, we recommend the submission of revised version of the thesis to the department following the applicable procedures.

______________________	______________________	______________
Major Advisor	Signature	Date
______________________	______________________	______________
Co-advisor	Signature	Date

APPROVAL PAGE OF M.SC. THESIS

We, the advisors of the thesis entitled "**Resource Allocation in Device to Device Communication for 5G Cellular Network**" and developed by **Wayu Berry Dubiso**, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Major Advisor	Signature	Date
Co-advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by **Wayu Berry Dubiso** have read and evaluated the thesis entitled "**Resource Allocation in Device to Device Communication for 5G Cellular Network**" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in **Electronics and Communication Engineering**.

Chairperson	Signature	Date
Internal Examiner	Signature	Date
External Examiner	Signature	Date

Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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School Dean	Signature	Date
Office of Postgraduate Studies, Dean	Signature	Date

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ABSTRACT

The increased usage of smart devices and mobile applications has resulted in a tremendous increase in mobile traffic demand over the previous decade. As a result, efficiency and availability are important criteria for the development of future cellular networks, with device-to-device (D2D) communication being one of the most promising technologies. In contrast to communication through Base Station, D2D communication allows mobile users in close proximity to interact directly with each other, avoiding the base station. Some of the potential benefits and problems of D2D communication in cellular networks are explored in this thesis. This thesis is primarily concerned with resource allocation approaches for direct D2D communication and Communication through Base Station over cellular spectrum. The main contributions are in the area of resource allocation mechanisms, which are widely recognized as critical strategies for realizing the technology's promises.

The incorporation of D2D communication in cellular network is first explored to see if it may improve their energy efficiency. Energy efficiency of d2d shows better result than that of through base station for short distance communication. in the simulation, we fixed distance to 100m. for the given distance, D2D communication shows better result in energy efficiency and spectral efficiency. but as distance increases, communication via base station resulted in better performance since BS covers more distance. so we can conclude that, for shorter distance d2d is more preferable than BS. The transmission energy consumption is reduced by optimizing mode selection, downlink transmission period, and power allocation together.

Second, D2D's performance in LTE and 5G networks is compared. Moreover, we have evaluated the effect of instantaneous SNR on the data rate at different sub-carrier spacing or numerology. Unlike 4G LTE which has only 15 kHz sub carriers spacing on a resource block, for a single resource element, 5G has a varieties of numerology which ranges from 15 kHz to 120 kHz. For all SNR values, the data rate has increasing function despite the value of the carrier frequency.

Keywords: Capacity, Cellular Communication, Direct D2D, Resource Allocation, Spectral Efficiency

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LIST OF ACRONYMS

1G	First Generation
2G	Second Generation
3G	Third Generation
3GPP	Third generation partnership project
4G	Fourth Generation
5G	Fifth Generation
B5G	Beyond Fifth Generation
BS	Base Station
BW	Bandwidth
CSI	Channel State Information
CoMP	coordinated multipoint
D2D	Device-to-device
DL	Downlink
eNB	Enhanced Node B
FDD	Frequency Division Duplexing
ITU	International Telecommunication Union
LTE	Long Term Evolution
LoS	Line of sight
NLoS	None-line of sight
IoT	Internet of things
QoS	Quality of service
M2M	Machine-to-Machine
MIMO	Multiple input multiple output
IP	Internet Protocol
RRM	resource management
SINR	Signal to Interference & Noise Ratio
P2P	Peer-to-peer
UE	User Equipment

CHAPTER ONE

1 INTRODUCTION

1.1 Background of the Study

The mobile communications industry has grown at an incredible rate over the previous decade, both in terms of mobile user numbers and data traffic demands. For many years, voice traffic dominated mobile networks. However, the widespread use of smart devices and the widespread use of mobile applications caused data traffic to increase. According to a survey published in[1], global monthly data traffic is now more than seventeen times that of voice traffic.

As a result, D2D communications underlying a cellular network infrastructure has gotten a lot of attention in recent years for increasing cellular capacity, improving user throughput, and extending the battery life of UEs by facilitating physical proximity of communicating devices and reuse of spectrum resources [2]. D2D allows a user equipment (UE) to connect with another neighboring UE directly through a D2D link using cellular network channel resources, eliminating the need for extra hops via the central base station (BS), resulting in improved service guarantee in a regulated environment. In general, D2D communication allows for speedy access to the radio spectrum with minimum interference and promises four types of gain: proximity gain, reuse gain, hop gain, and paring gain [3]. Peer-to-peer (P2P) file sharing, local call service, video streaming, and content-aware programs are examples of common D2D communication applications.

The communication efficiency in 5G systems will be improved by incorporating techniques such as coordinated multipoint (CoMP) joint transmission and reception, network-assisted interference cancellation and suppression, spectrum reuse, and three dimensional or full dimensional MIMO [4]. The density of heterogeneous node deployments in 5G systems will be significantly higher than that of today's conventional single-tier (e.g., macro cell) networks. The heterogeneity of various classes of BSs (for example, macrocells and small cells) provides flexible coverage area and improves spectral efficiency. By shrinking the cell, the area spectral efficiency is increased due to increased spectrum reuse. Furthermore, by deploying small cells indoors, coverage can be improved (such as home, office buildings, public vehicles etc.). Wireless P2P communication, which is at the heart of cellular architecture, has the potential to significantly increase the network's overall spectrum and energy efficiency. Furthermore, network-controlled P2P communications in 5G systems will allow other nodes (such as relay or M2M gateway) to control communications among P2P nodes rather than the macro cell BS [5].

The cellular network has now been in operation for four generations. The primary motivation for this forward journey has been the need for fast multimedia-rich data exchange as well as high quality voice calls. As newer and more demanding applications emerge, and the subscriber base grows at an exponential rate, there is an urgent need for more novel techniques to boost data rates and reduce latency. In cellular networks, D2D communication is a new paradigm [6]. It enables user equipment (UEs) in close proximity to communicate via a direct link rather than having their radio signals travel all the way via the base station (BS) or the core network. One of its primary advantages is the ultra-low latency in communication as a result of the shorter signal traversal path. D2D communication can be enabled using a variety of short-range wireless technologies such as Bluetooth, Wi-Fi Direct, and LTE Direct (as defined by the Third Generation Partnership Project (3GPP) [7]. Data rates, distance between 1-hop devices, device discovery mechanisms, and typical applications are the main differences. For example, Bluetooth 5 has a maximum data rate of 50 Mbps and a range of close to 240 m, WiFi Direct has a rate of up to 250 Mbps and a range of 200 m, and LTE Direct has a rate of up to 13.5 Mbps and a range of 500 m [8].

D2D connectivity will give operators more flexibility in offloading traffic from the core network, increase spectral efficiency, and lower energy and cost per bit. D2D communication did not appear to be financially viable to cellular network providers until recently. However, the current boom in context-aware and location-based services is causing a rapid shift in this situation [9].

The majority of existing work on D2D communications relies on centralized resource allocation, in which the eNB allocates resources to both cellular and D2D users. However, because of their high complexity, centralized schemes may not be suitable for large networks. As a result, resources should be allocated to D2D links in a distributed manner. Each D2D link must sense the network environment and use resources adaptively without causing harmful interference to cellular users. In distributed schemes, either a fully distributed model or a message-passing model can be used. In the first case, each D2D link will access the spectrum solely through local measurement, with no communication with other nodes [10].

Multiple antennas and MIMO schemes can be used by D2D transceivers to increase data throughput and link coverage without increasing transmit power or bandwidth. The MIMO technique distributes transmit power across transmission antennas to achieve a higher rate array gain and a diversity gain to mitigate the effect of fading. The main issue with using MIMO technology in D2D communications is the development of efficient precoders (i.e., how the multiple data streams should be independently emitted from the transmission antennas and properly weighted at the receivers to achieve the maximum link throughput). The transmit power of the precoder should be kept as low as possible to avoid interfering with neighbors while still meeting QoS requirements (e.g., SINR). Recent research in this field has concentrated on advanced signal-processing techniques used at transceivers to reduce and cancel out perceived interference. However, these proposed techniques necessitate channel information and are complex, making them unsuitable for D2D communications [11].

1.2 Statement of the problem

5G networks are expected to provide 1000 times the mobile data volume per area, 10 to 100 times the user data rate, and 10 to 100 times the number of connected devices as current cellular systems. Designing wireless networks capable of meeting these lofty goals while accounting for cost, energy, and radio spectrum constraints is a difficult task for both industry and academia. With the increase number of smart cell phone users and development of new technologies the users demand higher data rates and capacity with fair price and the operators has to provide QoS and earn their profit, so, in order to enhance QoS and gain profit, either they have to increase either bandwidth or deploy a number of antennas in a given area, which is costly from the operator side. Increasing bandwidth is also not best solution since bandwidth is scarce resource we have. So the operators have to optimize their profit with good QoS.to tackle the above problems, D2D with proper resource allocation is best solution.

1.3 Objective

1.3.1 General Objective

- The General objective of this proposed thesis is to evaluate energy efficiency by resource allocation using device to device of 5G cellular network.

1.3.2 Specific Objectives

- To Evaluate Spectral Efficiency of D2D and communication through BS.
- To Evaluate Energy Efficiency of D2D and standard cellular communication
- To Evaluate the performance of D2D at different new radio numerologies.
- To Compare resource allocation based performance of D2D mode and Cellular communication through BS.

1.4 Significance of the study

A significant shift in architecture, as well as an increase in the number of wireless devices and technologies, will place a massive traffic load on the Base Station. Such a huge platform will require the Base Station to manage and control. Connection establishment, session setup, and transmissions will become more complicated and time-consuming as a result of this. The future 5G network, which is set to replace today's 4G in order to create next-generation cellular networks capable of managing and meeting the demands of a huge number of devices and applications that 4G can't manage, should also discover a solution to offload the Base Station from the traffic load. As a result, network capacity is increased. Peer to Peer communication, also known as Device to Device communication, is one such promising and effective technology. This thesis significant for operators and users because it evaluates the performance of device to device communication with efficient technique with different spectral spacing or new radio numerology.

1.5 Scope and Limitations of the Study

Smart radio resource management (RRM) techniques including mode selection, power control, and time or frequency resource allocation can offer the opportunity to deploy D2D communication in cellular networks. The path loss gain (and hence the physical distance) between the users is the simplest and easiest way to select the communication mode for a pair and mitigate interference. This method can be used to give the result a geometric interpretation. Distance-based solutions, on the other hand, does not guarantee the effective quality of the links, which is influenced by factors such as shadowing and interference. As a result, in the context of RRM techniques, CSI and perceived SINR are recommended as decision metrics. The performance of a system improves when solutions based on optimization formulations are used. However, because of their complexity and associated signaling overhead, they are usually less practical. This proposed thesis work is only focused on improving the energy efficiency of D2D communication through frequency spectrum allocation. The modeled system is simulated through Matlab software only.

1.6 Main Contributions

This thesis aims to enhance capacity and the energy efficiency of D2D communication by efficient allocation of frequency in new radio numerology.

1.7 Thesis Organization

This thesis organizes into the following five chapters. Chapter 1: Presents introduction of the research work, statement of the problems, objectives, significance, and scope of the research. Chapter 2: Includes a literature review on the introduction of Device to device communication, use cases Energy efficiency, mode selection, power control in D2D communication and also it introduces the D2D technology and discusses its potential advantages and the possible challenges that must to be dealt with. Chapter 3: Describes the methodology followed in this research thesis. Chapter 4: Presents the proposed results and discussions. Chapter 5: Discusses the conclusions and recommendations.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Introduction of Device to device communication

Wireless communication has grown in popularity over the last two decades. Over the previous decade, the number of mobile users, mobile broadband traffic, and user demand for faster data access all increased at unprecedented rates [1]. Applications such as 3D holography, machine-to-machine communication, virtual reality, e-learning and e-health, video-based applications, and augmented reality necessitate higher bandwidth. While current 4G cellular technology cannot meet the growing data demands of existing mobile users, allocating resources to support such applications with newer technology is more difficult. As a result, there is a clear demand for next-generation wireless cellular connectivity that can handle a greater number of smart devices and a broader range of applications than 4G can. As a result, research on 5G wireless communication emerges, necessitating the development of new technologies to transform traditional cellular communication [12].

The first-generation cellular devices could only transmit voice calls and had a battery life of only a few hours and a transmission speed of only 2.4 kbps. 2G was a digital cellular technology that allowed users to send and receive voice and text messages (voice services and data) at a speed of 64 kbps. In addition, 2G provided a secure and reliable communication system. In the year 2001, commercial 3G cellular networks were launched. In the third generation, smartphone technology features such as email, online browsing, multimedia downloading, and image sharing were offered. At a minimal price, 3G enables a wide range of applications, higher capacity, and increased data throughput. 4G was developed with the goal of providing high speed and quality, enhanced security, multimedia, internet over IP, and very low-cost voice and data services. Fourth-generation wireless communication networks support mobile web access, IP telephones, high-definition television, online gaming, 3D television, videoconferencing, and cloud computing. Despite the fact that 4G wireless networks have far more applications and benefits than 3G wireless networks, there is a need to upgrade to the next generation wireless technology [13].

All 4G applications are bandwidth demanding, and there are only a limited number of bandwidth resources available. Aside from this constraint, the increasing number of wireless users and their demand for high-speed services has created a strong demand for next-generation improvements. As a result, the existing cellular 4G network has been studied, and a transition from an architectural to a conceptual approach, resulting in next-generation 5G networks, has occurred. 5G is intended to combine several of the 4G technologies with several new ones. 5G includes heterogeneous networks, Massive MIMO, millimeter-wave spectrum (30-300GHz), cognitive radio networks, D2D communication, and other technologies [14].

Device-to-device communication was introduced in 4G LTE. D2D communication is defined as the direct transmission of data between two devices in cellular networks without the use of a central Base Station or Access point. Device to Device communication, also known as P2P or D2D, enables direct communication between devices that are close to one another. As a result, D2D enables data traffic to be offloaded from the Base Station, increasing network capacity and reducing transmission delays [15]. D2D services include peer-to-peer communication, relaying, and proximity services. Online gaming, content sharing (multimedia-images, audio, and video clips), traffic dumping, disaster relief, and other D2D applications are just a few examples.

This thesis area has been dragged by a rapidly developing and promising technology with numerous applications. Some resource allocation strategies for D2D communication in 5G and B5G have been analyzed and discussed in this thesis with the goal of evaluating spectrum efficiency and throughput and improving system performance. Despite the fact that various review works have contributed more to research on resource allocation approaches in D2D wireless communication, there is a gap in the literature for a comprehensive studies on resource allocation techniques in 5G. The thesis begins by presenting the principles of D2D communication, laying the groundwork for a deeper understanding of D2D's history and assisting users in better understanding the challenges that must be overcome when incorporating D2D into wireless communication systems. The primary goal of all research projects has always been to improve system performance, which is entirely dependent on resource management strategies. A complete and modern study of resource allocation and management is required to understand and identify the research gap to work on, as well as to develop methods to improve system performance using modern and recent technologies. The majority of current Peer-to-Peer communication research management effort is focused on the implementation of D2D communication using algorithms that become mathematically complex when used repeatedly in a dynamic wireless communication system.

As a result, it is necessary to identify Distributed resource allocation techniques that can automatically allocate resources using trendy Learning techniques with a promising future in the world of machines and devices. Although wireless communication learning techniques have received more attention, they are still not widely used in current practical applications. In order to make readers aware of this emerging method, the need for it is discussed in this thesis, promising remarkable results and assisting in achieving an efficient and automatic allocation of resources.

2.1.1 D2D Architecture

Following the introduction of D2D communication, the network is divided into two tiers: the macro tier and the device tier [7]. The macro tier is traditional cellular communication, while the device tier is D2D communication. D2D communication, as previously stated, is defined as direct communication between mobile devices that are closer to each other, with data transmission occurring without or with only a partial involvement of the Base Station. Figure 2.1 depicts the D2D integrated Cellular communication system model. The image depicts D2D network communication applications such as content sharing, online gaming, and multimedia content delivery. As a result, the massive data traffic of next-generation wireless communication that would otherwise be laid on the base station can be off-loaded, improving overall network performance and capacity [5] . Because of the short communication range between two devices that make up a D2D pair, there is a significant improvement in spectrum and energy efficiency, end-to-end delay, and throughput [6]. The classification of D2D communication, its benefits, uses, concerns, and obstacles are discussed in the following subsections.

2.1.2 D2D communication classification

D2D communication can be implemented as either self-organized D2D communication or network-assisted D2D communication, depending on the involvement of the cellular infrastructure in the direct communication setup. Self-organized D2D communication, like standard ad-hoc networks, makes use of unlicensed spectrum. Because of its low overhead and ease of implementation, this method is frequently used. As a result, it can be used even when the cellular infrastructure is down, as in the case of a natural disaster. Network-assisted D2D communication, on the other hand, occurs when the BS facilitates D2D communication through control signaling and resource management. As a result, the network can coordinate D2D and cellular communications while minimizing mutual interference. Coordination, on the other hand, may necessitate a high level of signaling and complex centralized resource management. As a result, different levels of network support can be expected in order to achieve an appropriate trade-off between complexity/signaling overhead and guaranteed performance. D2D users, for example, can be assisted by the network during the discovery phase before managing radio resources and scheduling transmissions on their own [16].

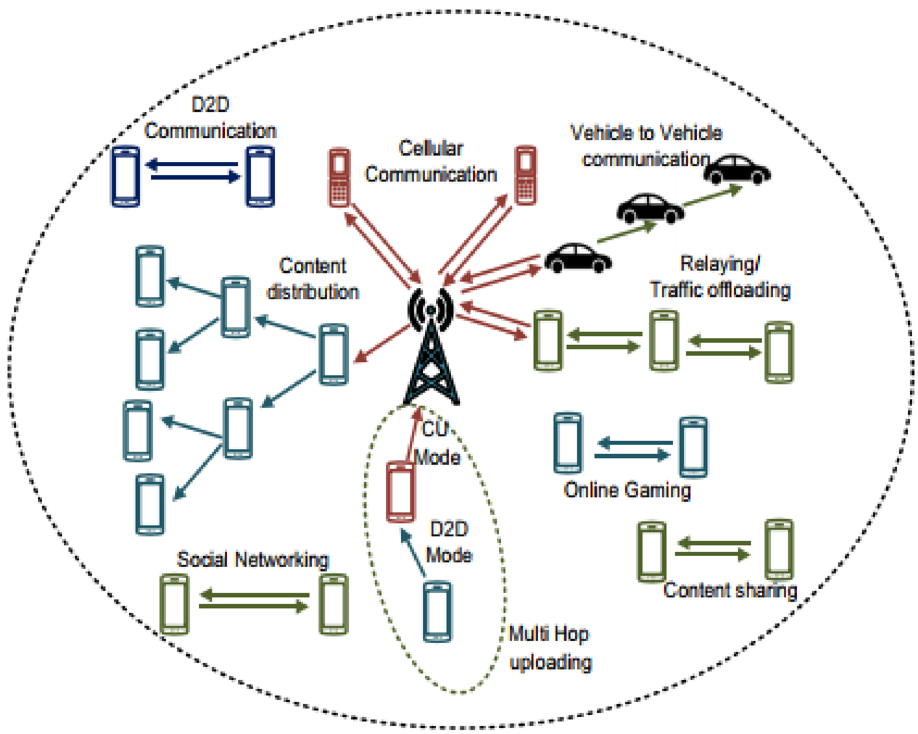

Figure 2.1 D2D integrated cellular communication system model [12]

D2D communications can be further classified into the following categories based on how users access the spectrum:

Inband D2D: Inband D2D, as the name implies, defines cellular communication as communication between devices operating within the licensed spectrum. To put it another way, both D2D and cellular devices use the same licensed spectrum. Inband D2D communication is preferable to Outband D2D communication because it has more control over the licensed spectrum, allowing for better interference management, whereas uncontrollable unlicensed spectrum degrades the system's Quality of Service (QoS). There are two types of inband D2D communication: D2D communication underlay and overlay [17]. The concept of Underlay D2D is based on spectrum sharing. The spectrum allocated to cellular users is also allocated to D2D users. Because D2D and cellular users share the same spectrum, the main concern with Underlay D2D is interference generated by the D2D user to the cellular user.

Overlay D2D communication does not use spectrum sharing. The licensed spectrum, is divided into two non-overlapping sections, one for cellular communication and the other for D2D transmission. Overlay D2D eliminates interference concerns by allocating a separate dedicated spectrum to D2D users, but it also results in spectrum waste because different resources are allocated for D2D transmission. One section of the band that cannot be used or shared by the other group, even when idle, results in wasting scarce spectrum resources [18].

Out-band D2D: Out-band D2D communication, like Ad-hoc networking, occurs in an unlicensed band (Eg: Bluetooth, Wi-Fi direct). Two devices in close proximity exchange data at an unlicensed frequency, avoiding interference with cellular connectivity in the licenced band. This means that while out-band D2D communication helps to eliminate interference between cellular and D2D users, there is still the risk of interference between devices operating on the same unlicensed frequency (2.4 GHz ISM band). These services provide local services as well as faster internet access in the unlicensed ISM band at a very low cost and in an extremely convenient manner. Interference management is extremely difficult in the uncontrollable unlicensed spectrum, so this type of interference is a threat. As a result, connection control and interference management become difficult in the unlicensed band. Wi-Fi direct, Zigbee, and Bluetooth are just a few examples of Out-band D2D [9].

Out-band D2D communication is classified into two types: controlled and autonomous. The interface is managed by the cellular network, which is also in charge of managing the parameters that control D2D communication in the managed D2D type. D2D with control improves spectrum efficiency, system performance, and dependability. In the autonomous D2D type, communication is controlled by the users or devices involved in the communication, whereas cellular communication is controlled by the network.

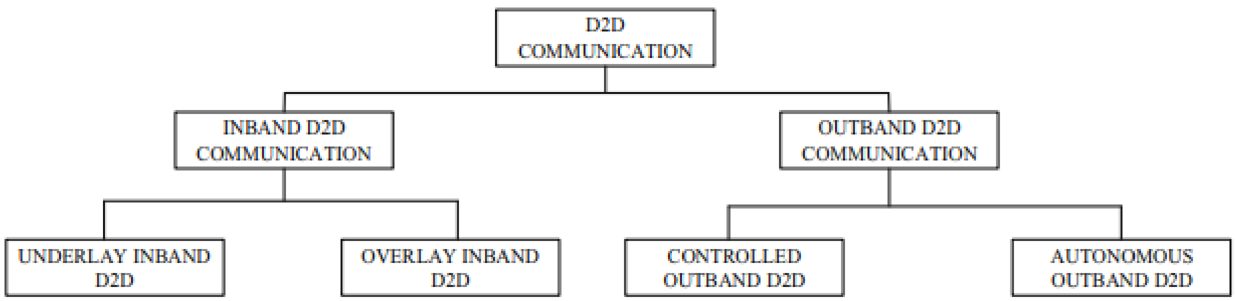

Figure 2.2 Classification of D2D [19].

Table 2.1 D2D Technologies [19].

Feature	***In-band D2D***	***Wi-Fi Direct***	***Bluetooth***
Standardization	3GPP LTE	IEEE 802.11	Bluetooth SIG[a]
Frequency band	Licensed band for LTE-A	Unlicensed ISM band	Unlicensed ISM band
Interference control	yes	no	no
Max transmission distance	1000 m	200 m	10-100 m
Max data rate	1 Gbps	250 Mbps	24 Mbps

2.2 D2D use cases

Peer-to-Peer (P2P) and direct transmission and relaying D2D are the main use cases of D2D communication. In the P2P type, D2D users are both the transmitting source and the receiving destination. Communication or data transmission occurs directly between terminals, without the use of any central access points. Wireless cellular communication benefits from D2D communication in a variety of ways. D2D integrated Internet of Things (IoT) services, Local data services, and Disaster Management are examples of D2D application services.

2.2.1 D2D integration with IoT services

In the near future of wireless communication, a communication link will be formed between terminals, which are most likely machines. The Internet of Things relies heavily on communication between machine terminals. An interconnected wireless network can be formed by combining the D2D and IOT characteristics [20]. Vehicle-to-vehicle (V2V) connectivity and other smart devices can benefit from D2D-enhanced IOT. A vehicle network is constructed to ensure that a vehicle can communicate with adjacent vehicles in order to avoid road accidents during lane transmissions, as well as to notify other nearby drivers about the accident or any other road hazard.

Vehicles communicating via V2V can also update the traffic status of a specific path, allowing for real-time traffic updates to online Maps services. In the event of an emergency, IoT and D2D can collaborate to clear traffic as quickly as possible. D2D communication is also advantageous in the field of Wireless Sensor Networks. The Internet of Things (IoT), a major concept in the future sensor world, allows for greater connectivity between objects without the use of a base station as an intermediary node [21].

2.2.2 Local data services

Local services are provided based on proximity. The three primary applications of D2D local services are proximity-based transmission, in which data is communicated directly between two nearby terminals, traffic offloading, and social applications, in which the device is discovered, the connection is established, and data or online gaming is transmitted. Because the number of devices and network density in future 5G and B5G networks is expected to increase, traffic offloading is the most important local service [22]. As multimedia services such as video streaming and HD video transmissions become more popular, a large amount of traffic is placed on the central base station and spectrum resources [23]. The network's downlink traffic can be offloaded by locating media services in a hotspot area that provides popular media content to users. Because the multimedia content is served locally by the local server, traffic at the Base Station is reduced. The popular culture of exchanging large amounts of multimedia content such as photographs, movies, and voice notes may be offloaded from the base station by enabling D2D communication.

2.2.3 Disaster management

In the event of a natural disaster, D2D communication must be capable of providing network access in the absence of cellular communication [24]. Communication becomes impossible in disaster-stricken areas. This constraint is more severe in the case of wireless communication. Tsunamis, earthquakes, cyclones, volcanoes, and other unpredictability disrupt communication networks. Despite the fact that disasters strike in various parts of the world, the problems that arise are nearly identical. Damage to communication network infrastructure, energy and power constraints, resource scarcity, network availability, and limited services are the major challenges.

A damaged system takes a long time to repair and manage, so it cannot be fixed right away. As a result, rescue efforts are affected. Damage to disaster-affected areas can be partial or total, but a telecommunications system failure delays emergency responses, resulting in the unavoidable loss of many lives. The solution to this problem is to use D2D communication to connect two terminals wirelessly. In other words, this concept entails establishing an ad-hoc network in areas where there are network gaps. Users in disaster-affected areas can use single and multi-hop communication to connect with devices in the coverage area that are linked by wireless networks, easing the rescue effort.

2.2.4 D2D in rural areas in the absence of base stations

D2D has enormous potential for linking rural and urban areas. D2D communication has the potential to connect rural areas that lack access to the internet or other facilities capable of supporting 5G and beyond B5G. Because of the network's low density or capacity, rural areas benefit from low latency. The greater the number of machines and sensors installed to support the Internet of Things concept, the better the facilities in rural and remote areas. One of the most common examples is remote surgery, which is performed by a more responsive surgical robot that responds to the surgeon's instructions from thousands of miles away from the patient in the remote location. Another application of D2D communication is autonomous farming, in which D2D facilitates communication between farm sensors and farm equipment. This type of connection between sensor devices and farm equipment does not necessitate the use of a Base Station as an intermediate communication structure for efficient operation [25]. As a result, D2D communication can be established in remote areas without the use of a base station.

2.3 Benefits of D2D communication

2.3.1 Power efficiency and Spectral efficiency

Because data is communicated directly between devices rather than being routed through a central entity, D2D communication exhibits three types of gains: Hop gain, Proximity gain, and Reuse gain. Direct data transmission in P2P or D2D results in Hop gain because no central entity or base station is involved in communication between two devices in close proximity to each other. Because the devices are so close together, very little power or energy is required for transmission, resulting in increased power or energy efficiency [26]. Because of the short-distance transmission between the peers, the end-to-end delay during transmission is also minimized, resulting in increased throughput and proximity gain. D2D communication devices opportunistically access radio resources that are occupied by cellular communication. Because resources are shared across cellular and D2D communication, the scarce and expensive spectrum resources are efficiently utilized [27]. The spectrum sharing characteristic of D2D communication induces reuse gain. As a result, D2D communication has a significant advantage in terms of spectral efficiency.

2.3.2 Reduced latency

Short-distance communication between devices requires a real-time and faster network, which D2D communication can provide, for data exchange, online gaming, smart traffic monitoring systems, and emergency services during natural disasters. Because of the shorter distance communication, the time required for data transfer for P2P or one-to-many content distributions is reduced. As a result, D2D has lower latency, which allows it to be used in real-time applications where delays are undesirable.

2.3.3 Fairness

The devices near the cell edge, far from the Base Station, have very low signal and channel quality, but the devices closest to the Base Station benefit from all of the network's benefits, as illustrated in Fig.2.3 D2D alleviates this problem by allowing cell edge devices to transmit data to the base station via a nearby device with high signal quality and coverage [28]. As a result, D2D provides fairness in communication [29], ensuring that devices that are closer to the Base Station and in coverage with strong signal quality, as well as devices that are out of coverage and far away from the Base Station, have the same communication quality.

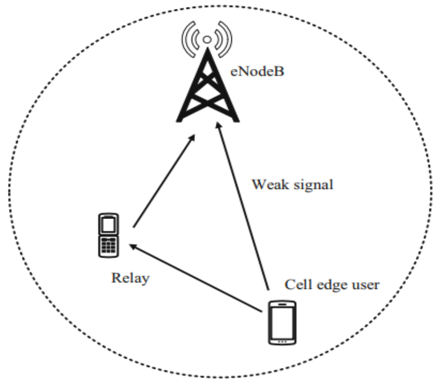

Figure 2.3 Fairness in D2D communication [29]

2.3.4 Flexible infrastructure

Traditional wireless communication requires a comprehensive architectural arrangement to function. Any type of disaster that causes damage or failure in this infrastructure can completely disrupt wireless connectivity. Fortunately, D2D allows for communication by enabling wireless communication by establishing an Ad-hoc network even when the infrastructure is unavailable. As a result, D2D does not rely solely on a structured architecture that cannot guarantee continuous operation. It instead creates a theoretical framework for wireless communication.

2.4 Challenges in D2D

D2D communications via wireless cellular connection will be extremely beneficial due to their numerous advantages. D2D communication, on the other hand, introduces significant challenges and design issues [30], which are discussed in greater detail below.

2.4.1 Device discovery

The first stage in establishing D2D communication is device discovery, also known as peer discovery. The device wishing to establish a D2D connection must be capable of locating other nearby devices in a reasonable amount of time [31]. Only if the devices are close enough together and choose to be discoverable can they be found. In this case, devices that want to communicate send beacon signals to nearby network devices [32]. Devices that are ready to join a D2D network respond to the beacon signal by providing information about their position, channel state, and distance. The two types of device discovery are centralized and distributed.

Centralized Discovery: Two devices in a D2D pair discover each other with the assistance of a central Access Point or a Base Station. The devices that are intended to send data to neighboring devices notify the Base Station. The Base Station gathers information on the Channel State quality, location, availability, interference, and power control qualities by initiating a message exchange between the two devices. The level of Base Station involvement can be used to categorize the centralized discovery further. The involvement of the Base Station can be complete or partial. If the Base Station becomes completely involved in the process, the devices are prevented from starting device discovery. The Base Station is also the only site where device discovery messages are sent and received between devices. As a result, the Base Station is responsible for locating nearby devices, collecting data on channel connection efficiency, and initiating D2D communication. Without the approval of the central Entity or Base Station, the device that wishes to communicate initiates device discovery in the partially involved Base station type of device discovery.

The Base Station's involvement is described as partial because it is not involved in the initial discovery phase but is later involved in message exchange to gather information about the Signal to Interference plus Noise Ratio (SINR) and Channel quality, as well as the D2D connection establishment process.

Distributed Discovery: The devices conduct all device searches and connection establishment on their own, with no interference from the Base Station. The device that wants to connect starts looking for other devices in its vicinity. Beacon signals are sent, and messages about the location, channel state information, and device availability status are sent between the devices for D2D communication. There is a risk of interference and synchronization because there is no management from the central entity or Base Station.

To locate other nearby devices, a pilot or beacon signal is sent out. The pilot signal sends out scheduling information, which can be problematic if the information is incorrect. The beacon signals are broadcast frequently and repeatedly unless a suitable device is found. As a result of the repeated beacon signals, other devices in the network may experience interference. Because the state of surrounding devices is constantly changing due to device movement, the frequency of beacon transmissions cannot be low, as this will cause the discovery process to be delayed.

Another significant challenge in D2D communication is synchronization. The Base Station synchronizes all of the network's devices. The base station determines the schedule time. When two devices are engaged in data transmission and one of them is discovered to be out of range of the base station, the network must continuously search for other nearby devices.

2.4.2 Mode selection

Traditional wireless communication operates in cellular mode, which means that devices only communicate with one another via the base station. However, since the development of D2D communication, the communication modalities have expanded to include cellular, D2D, and hybrid communication [33], as illustrated in Fig. 2.4.

Cellular Mode: In the past, wireless communication was accomplished in this manner. The Base Station is the hub through which the devices communicate with one another. The Base Station acts as a go-between for the two communicating devices. Only devices in cellular mode consume all of the resources. As a result, there is no concept of direct communication in this modality.

D2D Mode: The devices communicate with one another without requiring the use of a Base Station. Depending on the spectrum used, D2D mode can be classified as Reuse mode or Dedicated mode [34].

Reuse D2D mode: Reuse mode, also known as Underlay D2D mode, reuses the spectrum currently employed by cellular transmission. The devices that use this mode transmit data directly using the cellular radio spectrum's uplink and downlink resources.

Dedicated D2D mode: Overlay D2D mode, also referred to as Dedicated D2D mode, operates in a dedicated spectrum. The data is transmitted directly between the devices via a separate or dedicated radio band designated for D2D communication.

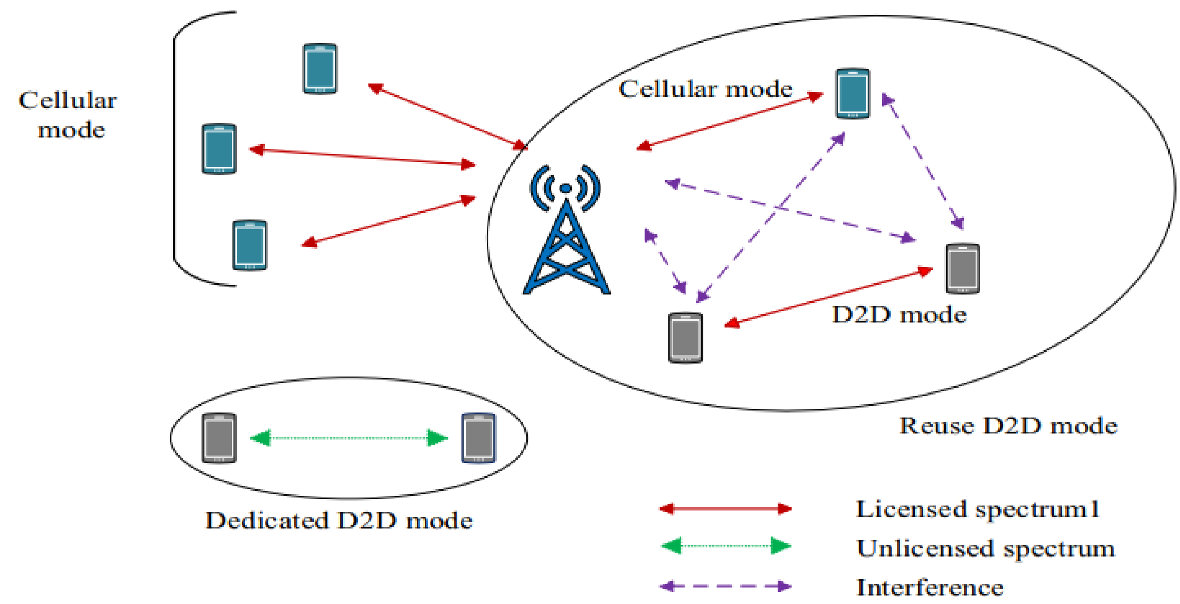

Figure 2.4 Mode selection in D2D [34]

A network's multiple modes of operation complicate network administration, add to the network's weight, and make resource management more difficult. The manner of communication is influenced by the distance between the devices, channel gain, QoS, and transmission power. If the channel gain and QoS of a given mode are greater than those of all other feasible modes, that mode is selected as the operating mode. Choosing a mode adds to network overload and complexity. The frequency with which a network's modes are changed is also an issue. The frequency with which modes are changed is unavoidable as the number of devices in a network and the number of channels increases.

2.4.3 Security and Privacy

As previously stated, D2D communication devices operate in a variety of modes. Since the introduction of D2D communication, the operation of the cellular network has been a hybrid of cellular and ad-hoc communication. As a result, D2D faces the same security and privacy issues as cellular and ad-hoc communications [35]. The most common are malware attacks, eavesdropping, relay attacks, message alteration, node impersonation, and other security issues. There is a significant difficulty because there is no single entity to monitor the network's security and privacy. As a result, D2D necessitates a more secure and trustworthy data transport method. The cryptographic method of securing data from third parties is not possible with D2D communication due to the lack of a structured traditional cellular infrastructure. Key generation in the cryptography scheme consumes power as well. It is not advisable to spend a significant amount of time and money solely on improving the system's security and privacy. As a result, a better trade-off between security and energy consumption must be maintained. In D2D communication, multiple devices join and leave the network. Devices connecting to a network for the first time must adhere to the network's privacy policy in order for the network to perform better in terms of security and privacy [8].

2.4.4 Interference management

Interference control is a critical challenge in a cellular network with interference due to the inclusion of D2D communication. While device-to-device communication can be done in a separate dedicated spectrum, scarce resources will be wasted, and the primary goal of the transition from 4G to 5G will be overlooked. D2D communication is required to offload data traffic at the base station while also increasing spectral efficiency through spectrum sharing. As a result, spectrum sharing is the most efficient way for D2D communication to use spectrum resources. Simultaneous spectrum sharing by cellular and D2D communication will almost certainly result in unwanted interference. Interference is discovered between the two tiers of the previously mentioned novel cellular design. Interferences found in the new two-tiered architecture include co-tier and cross-tier interferences [36].

Co-tier interference: Co-tier interference occurs when two devices in the same tier interfere with each other. Interference occurs between two D2D devices in a communication system that includes both cellular and D2D communication. Interference occurs when a transmitting D2D device and a receiving D2D device share spectrum resources and are close to each other. In other words, co-tier interference occurs when neighboring D2D devices share the same spectral resources [37].

***Cross-tier interference*:** Cross-tier interference occurs when devices in two different tiers interfere with each other. In other words, when D2D communication and cellular communication are combined, the devices in both modes of communication interfere with each other. The source and destination of cross-tier interference differ depending on whether the cross-tier interference occurs in an uplink or downlink scenario. In the uplink scenario, the cellular device in the macro-tier transmits data to the Base Station, whereas the D2D device in the device-tier transmits data to the D2D receiver. Because the uplink frequency is shared by the D2D pairs, interference occurs between the cellular transmitter and the D2D receiver, as well as between the D2D transmitter and the Base Station. Interference at the Base Station is insignificant because the power of the Base Station is greater than that of the interfering signal. When a cellular user receives data from the Base Station, this is referred to as a downlink situation [15]. The downlink spectrum is used by D2D users to communicate. As a result, there is macro-tier interference between the sending Base Station and the receiving D2D, as well as between the broadcasting D2D user and the receiving cellular user.

These interferences degrade system performance and QoS, wasting energy and bandwidth. As a result, interferences in cellular communication combined with D2D communication will lower system performance and spectrum efficiency, which is one of the primary characteristics of D2D communication in 5G. As a result, any undesired interference in the communication system should be managed or minimized [38]. When it comes to sharing spectrum resources, improper resource allocation is the primary cause of interference in the communication system. Correct resource management and allocation can improve the performance of the communication system.

2.4.5 Resource management

Two aspects of resource management are interference management and power control. The allocation of resources can be centralized, distributed, or semi-distributed [11]. In the centralized method, the base station is in charge of resource distribution and administration. The centralized solution is more difficult to implement because the Base Station, which is in charge of system monitoring, SINR and channel quality computation, connection construction, and call setup, must also allot resources and control interference in the system. As the number of network users increases, so does the complexity, because the Base Station must obtain critical information from the devices and measure channel quality and network performance without assistance.

As a result, the centralized strategy is only suitable for small cell networks and is difficult to implement in larger networks. The distributed strategy, on the other hand, excludes the Base Station from resource management. The devices handle resource allocation and management.

This type is also suitable for networks with a greater number of devices. The devices exchange messages more frequently in order to learn more about their peers. Devices that intend to communicate in D2D mode monitor cellular resources and, when available, use licensed cellular communication resources. The devices collect data on channel quality, SINR, and cellular resource availability while monitoring cellular communication. In a communication network, resource allocation is another method of reducing unwanted interference. Interference is reduced by allocating resources efficiently, such as spectrum and power, which is the most difficult issue in D2D communication [39]. The following sections provide a detailed discussion and comparison of the various resource allocation strategies used in D2D communication.

2.5 Related Works

2.5.1 Mode selection

The most difficult aspect of mode selection is deciding whether two users should connect directly, using dedicated or shared resources, rather than via the BS. The best mode is determined by the performance measure to be improved (e.g., sum rate, transmit power, energy consumption, and system capacity), as well as the state information available at the time of the decision (e.g, physical distance, channel quality of the links, interference level).

The simplest and most intuitive mode selection algorithms use the path loss, which is directly related to the physical distance between the nodes. In [40], for example, the D2D mode is active if the path loss of the users forming the D2D pair is less than a certain threshold. A mode selection approach that accounts for both D2D link distance (r_d) and cellular distance (r_c) is proposed in [17]. Here, D2D mode is selected if $T_d r_d^{-\alpha} > r_c^{-\alpha}$, where α is the path loss exponent and T_d is a bias factor to control the traffic offloading from the cellular infrastructure to the D2D communication. In fact, by using large values of T_d more user pairs are forced to communicate in D2D mode. Authors in [41] provides another example of distance-dependent mode selection in a slightly different scenario in which many fixed relay nodes are used to aid cellular connectivity and the D2D pair's mode option is between underlay and overlay D2D communication. Different D2D spectrum sharing technologies and cellular uplink servers (BS or relay nodes) result in a variety of communication modalities. The mode with the highest sum rate is chosen by the algorithm.

Authors in [33] proposes that mode selection be based on channel quality rather than just link distance. When the D2D pair shares the uplink or downlink resource with a cellular transmission, the algorithm takes into account both the quality of the connected links and the varied amounts of interference that occur. This scheme's goal is to optimize the total rate while keeping SINR limitations on active cellular links in mind. The authors also look at expanding their method to a multi-cell scenario, where other cells' interference could affect the outcome. However, the scheme's signaling load increases dramatically.

Several mode selection studies assume a single antenna system and limitations that prioritize cellular users. The authors of [39], on the other hand, take into account the effect of many antennas at the BS and offer all users the same priority, regardless of their communication mode. They analyze two approaches to mode selection optimization: maximizing rate for a given transmit power and the dual challenge of decreasing power while maintaining a given rate. They obtain closed-form solutions and demonstrate that, despite their close relationship, the two problems behave differently depending on the communication mechanism employed.

Most of the work focuses on the simplified case of an isolated cell assuming that inter-cell interference is controlled by various interference management mechanisms in order to deal with more tractable problems. The mode selection problem becomes more complicated in a multi-cell system not only because of increased interference, but also because the BS-user association may be involved. Author in [16] recently investigated the problems of mode selection and BS association in parallel. so, the author's goal is to maximize apparent SINR at receivers while limiting the maximum number of users that each BS can support.

To solve the integer programming problem to its optimality, a graph-based strategy is used. When dealing with the mode selection problem, it's important to remember that there are several design considerations to consider, such as how frequently the communication mode should be updated, what channel state information is required, and how frequently this information should be supplied. In fact, the mode selection timeframe cannot be too coarse because the wireless channel may vary rapidly, and the necessary signaling overhead, on the other hand, should be kept to a minimum.

2.6 Time or frequency resource allocations

Assigning specific time or frequency resources to system users is critical not only for taking advantage of available channel frequency variety, but also for enhancing spectrum efficiency and system capacity through intelligent resource reuse. [26] present frequency resource allocation algorithms based on distance constraints between likely interfering users (cellular and D2D), with the basic idea being to avoid cellular and D2D users coexisting on the same resource when they are too close to each other.

Nonconvex and mixed integer formulations are common when approaching the spectrum reuse problem from an optimization standpoint, and finding an optimal solution, even for small networks, is difficult. Optimal solutions are found in highly specific cases, such as [29]. A simplified model with only one cellular user and one D2D pair is used for joint power and resource allocation that maximizes throughput.

Other studies limit resource allocation analysis to a single cell instance, accounting for distinct objectives and system constraints. Both [42][15] consider the sum rate maximization problem. [42] proposes a resource sharing technique that enables a single D2D pair to use all available cellular resources while still maintaining cellular communications. The resource allocation problem is stated as a power control problem. Despite the fact that the problem appears to be nonconvex at first, the authors show how it can be transformed into a convex one and solved optimally. [15], on the other hand, formulates the resource allocation problem as a mixed integer nonlinear programming problem. The authors also propose an alternate heuristic algorithm because it is difficult to solve during the short scheduling intervals required by current systems (such as LTE). According to this algorithm, the resources to be shared in uplink or downlink are simply those with the lowest cross gain across interfering users.

Authors in [17][41] present recent research on the joint resource and power allocation challenge for energy efficient D2D communication. The goal of [17] is to optimize the minimum weighted energy efficiency of D2D linkages, where the weights are used to determine the relative priorities between the D2D links. Each D2D link allows multiple cellular users to share resources. Each cellular resource can only be reused by one D2D link at a time to limit interference to cellular communications. The authors approach the problem by breaking it down into goals: first, they characterize the optimal power allocation for cellular links, and then they transform the original resource allocation problem into a joint resource and power allocation problem for only D2D links. The brunch-and-bound strategy is used to find the best solution to the resource allocation problem, which is a mixed integer nonlinear programming problem. There are alternatives with a lower level of complexity and limited message exchange. [41] formulates an energy-efficient resource allocation problem as a nonconvex combinatorial programming problem with resource reuse constraints similar to [17]. The authors, on the other hand, use the properties of fractional programming to obtain a tractable solution using an iterative technique. They also propose a two-layer iterative solution strategy in which the original joint formulation of power and resource allocation is divided into two independent optimization problems in each iteration.

Finally, resource distribution in multi-cell networks is a topic that is rarely discussed in the literature. Most studies, on the other hand, assume that a sophisticated inter-cell interference mitigation method runs alongside the per-cell resource allocation algorithms. There are two exceptions: [43]. The authors of [43] use a fractional frequency reuse technique in which cellular and D2D users use different downlink frequency resources depending on where they are in the cell area. The process proposed in [44] is also based on the positions of the users, as well as a significant exchange of information between the users and the BSs, as well as between the BSs themselves.

[24] proposed two sub channel allocation strategies and an ideal power allocation scheme for numerous D2D pairs underlay in an uplink mmWave cellular network. They developed an algorithm for allocating subchannels and transmit power in order to optimize the sum rate of D2D transmitters. They divided the problem into two parts: subchannel allocation and power allocation. They investigated two heuristic approaches to the subchannel allocation problem: greedy max SINR and minimal interference. In contrast to the greedy max SINR scheme, which requires global CSI, the minimum interference scheme relies solely on the location of each node, which is more practical. Following sub channel allocation, we used DC programming to perform transmit power allocation.

Authors in [45] proposed a novel distributed system in which D2D devices can choose between data transmission in the millimeter and microwave bands. D2D users must detect LOS links and their corresponding directions in order to execute accurate beam alignment when developing a distributed mmW band communication protocol for D2D communications. They have employed stochastic geometry to create a comprehensive framework for analyzing the suggested mechanism's performance in terms of D2D users' received SINR coverage probability, for which closed-form analytical formulas have been derived.

[28] proposed an optimal power allocation technique for OFDM-based cognitive radio networks that is computationally simple. Because they use some aspects of the water-filling procedure, power increment and power decrement water-filling algorithms have significantly lower computing complexity than typical water-filling algorithms. As a result, the technique can be used to handle the power allocation problem efficiently.

[29] proposes techniques for reducing interference in the 3GPP-LTE cellular network and the underlying D2D communication network. They conducted numerous simulations using real-world scenarios and LTE-standard parameters. Simulation results showed that the proposed greedy heuristic approach improves network performance in terms of sum of cell and D2D throughput without causing significant harm to the core cellular network for all typical scheduling algorithms of the primary network. During the DL phase, the proposed heuristic algorithm selects the optimal shared radio resource with lower channel gain between the UE receiver and D2D transmitter, and during the UL phase, the proposed heuristic algorithm selects the optimal shared radio resource with lower channel gain between the D2D transmitter and the eNodeB.

The Authors [32] proposes that mode selection should based on channel quality rather than just link distance. When the D2D pair shares the uplink or downlink resource with a cellular transmission, the algorithm considers both the quality of the connected links and the various levels of interference that may occur. This scheme's goal is to optimize the total rate while keeping SINR limitations on active cellular links in mind. The authors also look at expanding their method to a multi-cell scenario, where other cells' interference could affect the outcome. However, the scheme's signaling load increases dramatically.

CHAPTER THREE

3 METHODOLOGY

3.1 Introduction

In this thesis, secondary data sources such as LTE books, past research studies, Institute of Electrical and Electronics Engineers (IEEE) articles, and resource allocation of device-to-device communication for LTE and 5G cellular networks are examined. The approach of this study is designed as follows, based on the inputs obtained from a review of related literatures and the statement of the problem in consideration.;

3.2 Materials

In this research work, software such as MATLAB/R2017a, is used. MATLAB is the computing software which consists of technical toolboxes and Simulink.

3.3 System Model

A concept of D2D communications underlying a cellular network is addressed in this thesis, in which UE1 wishes to share information with UE2. As illustrated in Fig. 1.a, there are various transmission methods for this task, The first one is Communication as direct D2D between UE_1 and UE_2 which is considered as Mode A and Communication as cellular UEs via base station (Mode B) .The distance of devices from the base station is considered as a decision parameter for mode selection. The transmitter's transmission and circuit power consumption are also taken into account. The transmission power from UE_i, $i = 1; 2$, is defined as P_{D_i} There is also a maximum transmission power threshold for UEs, i.e., $P_{D_i} \leq P_{D_i,max}$. The transmission power of the BS is P_{BS}. The circuit power is the same for all UEs, defined as $P_{c,D}$; while BS's circuit power is written as $P_{c,BS}$.

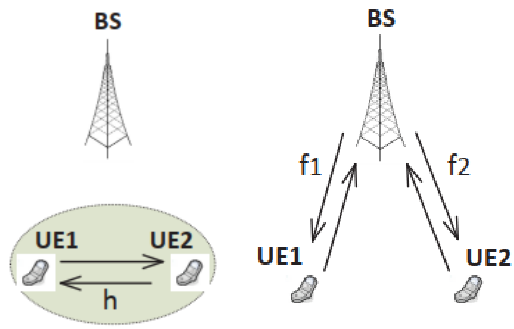

Figure 3.1 D2D Mode(a) and Cellular Mode(b) c

Mode A: Direct D2D between UE_1 and UE_2

The reciprocal channel gains between two nodes are assumed and represented as follows: f_i , $i = 1; 2,$ states the channel gain between UE_i and BS, h is the channel gain between UE_1 and UE_2.

In the direct D2D mode, within two time slots, UE1 and UE2 will exchange information via a direct one-hop D2D link. The signals received at UE1 and UE2 are

$$y_1 = \sqrt{P_{D1}} h x_1 + n_1 \tag{3.1}$$

$$y_2 = \sqrt{P_{D2}} h x_2 + n_2 \tag{3.2}$$

where x_i is the data sent by UE_i; and n_i, $i = 1,2,$ is the additive white Gaussian noise (AWGN). For the consideration of same received SNR at UE_1 and UE_2, we set $P_{D1} = P_{D1} = P_D$

For each UE, the maximum attainable transmission data rate in bits/s is

$$r_{A_1} = r_{A_2} = \frac{W}{2} log\left(1 + \frac{P_D |h|^2}{W N_0}\right) \tag{3.3}$$

where W represents the channel bandwidth and N_0 represents AWGN power spectral density. The channel coefficient $|h|^2 = |h_0|^2 / \mathcal{PL}_A$, where h_0 follows a complex normal distribution $\mathcal{CN}(0,1)$; $\mathcal{PL}_A$ is the path loss for mode A is modeled, where

$$\mathcal{PL}_A = \mathcal{PL}_{A0} . d_D^{\alpha_A} \quad 3.4$$

Where $\mathcal{PL}_{A0}$ is pass loss constant and α_A is path loss exponent for mode A.

The total power consumption during two-time-slot transmission of Mode A is

$$P_{total,A} = 2P_D + 2P_{C,D} \quad 3.5$$

Let

$$SNR_A \triangleq \frac{P_D}{WN_0 . \mathcal{PL}_A} \quad 3.6$$

The overall instantaneous energy-efficiency and spectral efficiency of Mode A in a single round of communications can be represented as

$$ee_A = \frac{r_{A_1} + r_{A_2}}{P_{total,A}} = \frac{W \, log_2(1 + SNR_A|h_0|^2)}{2P_D + 2P_{c,D}} \quad 3.7$$

$$se_A = \frac{r_{A_1} + r_{A_2}}{W} = log_2(1 + SNR_A|h_0|^2) \quad 3.8$$

Mode B: Cellular UE's through BS

UE1 and UE2 will exchange information across the BS in two time slots in this manner. Let d1, d2 be the distances between UE1 and BS, respectively, where d1, d2 can be configured properly within the cell coverage. UE1 and UE2 transmit to BS at the same time in the first time slot. BS will use an amplify-and-forward technique and broadcast at a power scaling factor of

$\beta_c = \sqrt{\frac{1}{P_{D1}|f_1|^2 + P_{D2}|f_2|^2}}$ in the second time slot. Note that

$$|f_1|^2 = \frac{|f_{1,0}|^2}{\mathcal{PL}_{B0}.d_1^{\alpha_B}} \quad 3.9$$

$$|f_2|^2 = \frac{|f_{2,0}|^2}{\mathcal{PL}_{B0}.d_2^{\alpha_B}} \quad 3.10$$

where $f_{1,0}$ and $f_{2,0}$ follow complex normal distribution $\mathcal{CN}(0,1)$; $\mathcal{PL}_B$ is the constant path loss for Mode B; α_B is the path loss exponent for Mode B. Then, the transmission rate r_{B1} can be derived as

$$r_{B1} \triangleq \frac{W}{2} log_2\left(1 + \frac{\mu_{B1}|f_{1,0}|^2|f_{2,0}|^2}{v_{c1}|f_{1,0}|^2 + |f_{2,0}|^2}\right) \quad 3.11$$

Where

$$\mu_{B1} \triangleq \frac{P_{BS}}{WN_0.\mathcal{PL}_A.d_1^{\alpha_B}}\ , \quad 3.12$$

$$v_{B1} \triangleq \frac{P_{BS} + P_{D1}}{P_{D2}}\left(\frac{d_2}{d_1}\right)^{\alpha_B} \quad 3.13$$

At UE2, we can derive the transmission rate r_{B2} as

$$r_{B2} \triangleq \frac{W}{2} log_2\left(1 + \frac{\mu_{B2}|f_{1,0}|^2|f_{2,0}|^2}{v_{B2}|f_{1,0}|^2 + |f_{2,0}|^2}\right) \quad 3.14$$

Where

$$\mu_{B2} \triangleq \frac{P_{BS}}{WN_0.\mathcal{PL}_A.d_1^{\alpha_B}}\ , \quad 3.15$$

$$v_{B2} \triangleq \frac{P_{BS} + P_{D1}}{P_{D1}} \left(\frac{d_1}{d_2}\right)^{\alpha_B} \quad 3.16$$

During Mode B's two-time-slot transmission, the total power usage is

$$P_{total,B} = P_{BS} + P_{D1} + P_{D2} + P_{c,BS} + 2P_{c,D} \quad 3.17$$

Where $P_{c,BS}$ is the circuit power of BS. The average energy-efficiency and average spectral-efficiency of this communication through base station cellular mode B can also be calculated.

$$ee_B = \mathbb{E}_{f1,0\,,f2,0}\left\{\frac{r_{B1} + r_{B1}}{P_{total,B}}\right\} \quad 3.18$$

$$se_B = \mathbb{E}_{f1,0\,,f2,0}\left\{\frac{r_{B1} + r_{B1}}{W}\right\} \quad 3.19$$

3.4 Resource Allocation

The bandwidth and frequency spectrum of wireless communication determine the data rate that can be achieved and are referred to as communication resources. From 1G to 4G generations , the need for faster data rates and a larger number of users drove the evolution of communication. Similarly, the fifth generation must meet the growing demand for higher data rate services in areas such as vehicular communication, data relaying, live video streaming, local advertisement broadcasting, video streaming, and so on. Figure 3.1 depicts resource allocation with multiplexing and channel bandwidth modification from 1G to 4G. 5G's goal is to provide lower-latency services, which necessitate channel state information, a minimum data rate, and the type of traffic used to distribute resources to users.

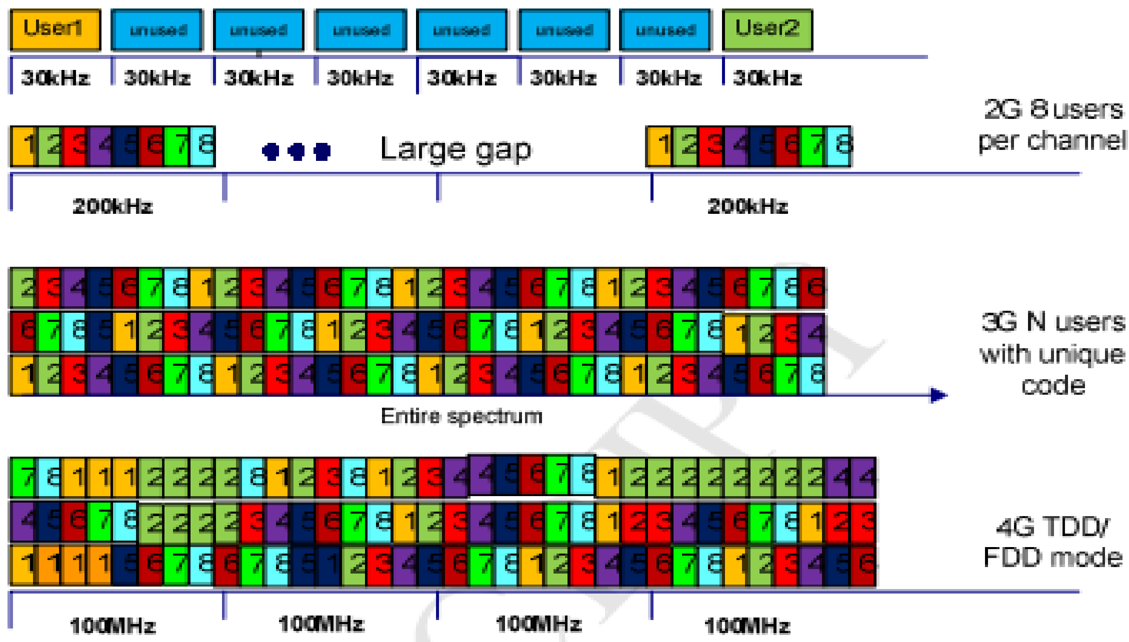

Figure 3.2 Resource allocation from 1G to 4G [58]

3.4.1 Device discovery in D2D communication

The detection of devices in close proximity is the first step in resource assignment. In order to establish a device pair, user equipment must scan for peer devices. Beacon broadcast and device searching use a lot of power in the device finding process. There are two ways to enable power conservation: network assisted mode and no network assistance mode [46]. Devices emit beacons at regular intervals using device discovery zones with a predefined number of RBs. If a collision occurs, the device switches off for an unknown amount of time, with a beacon transmission limit set. The random back off strategy improves device detection by 20- 50%. Network traffic is identified or dedicated signaling device discovery is performed during network assistance. A-priori and a- posteriori approaches are utilized in traffic identification. A-priori, the network detects D2D pairs before the communication begins, whereas a- posteriori, the network identifies devices as a pair after the connection has already begun [46].

3.4.2 Resource allocation for D2D in 5G

When neighboring devices begin to connect, the eNB allows direct communication between them without going through it. Because D2D user equipment (DUE) communicates over short distances, it uses little power to transmit, allowing cellular user equipment (CUE) to reuse frequency or resource blocks. Interference is created when multiple users' equipment uses the same resource, emphasizing the importance of efficient resource allocation. The distance between the D2D transmitter and the CU receiver for downlink, as well as the distance between the D2D receiver and the CU transmitter for uplink, are not taken into account when assigning the RB to users, which is a violation of admission control [47]. Resource allocation to the D2D user equipment and cellular user equipment requires various aspects to be considered as:

1. The distance between the D2D transmitter and the D2D receiver (D2D Rx), as well as the distance between the D2D users and the BS.
2. Downlink interference from the eNB to the D2D Rx, and uplink interference from cellular user equipment to D2D user equipment and vice versa.
3. Cellular user equipment, D2D user equipment, and overall network data rate or throughput
4. For resource reuse, the interference matrix is used to pair cellular user equipment and D2D user equipment.
5. The D2D devices' mode of operation.
6. Single Cellular user resources to be reused by single D2D user or multiple D2D users, single D2D user to reuse single cellular user resources or multiple cellular user resources.

The resources are shared as a one-to-one mapping between CUE and DUE, which means that only one DUE can reuse CUE resources, or as a one-to-many mapping between CUE and DUE, which means that one cellular user resource can be consumed by numerous DUEs and one DUE can reuse resources from multiple CUEs. Some researchers have employed RB assignment in relation to the OFDMA [47].Prior to DUE, eNB assigns resources to CUE in the resource allocation process. This priority is due to the fact that D2D communication is less important than cellular communication. The next step is to enable resource scheduling for down-link at the eNB based on the location or channel quality indicator for each D2D user's channel state information (CSI) processes, in accordance with the Release 11 standard. The distance between the D2D transmitter and D2D receiver is an important consideration in determining the mode of resource allocation. In general, dedicated resources are good for the shortest distance between the eNB and DUEs, whereas longer distances to satisfy higher throughput necessitate the DUE employing a greater number of CUEs resources [48].

In general, the structure of an eNB cell is divided into two regions: near field strength and far field strength [49]. Equipment in the high field region would transmit at a low power level, whereas equipment in the far field would require a higher power level. Because far field equipment causes more interference with neighboring cell equipment, the analysis necessitates a multi-cellular structure. To assign RBs to DUEs, soft or hard fractional frequency reuse (FFR) was used. Prior to RB assignment, DUEs were arranged in an array in descending order based on the parameter selected from Table 3.1.

3.4.3 Resource Allocation Scenarios:

S1: RBs from a single CUE are reused by a single DUE.

S2: RBs from a single CUE are reused by several DUEs.

S3: RBs from many CUEs are reused by a single DUE.

S4: RBs from numerous CUEs have been reused by several DUEs.

S5: Numerous DUEs reuse multiple CUE's RBs, each with a different mode.

3.4.4 Resource allocation parameters

Resource allocation (RA) must take into account system information such as channel gain as shown in Table 3.1. When allocating resources, system information such as channel gain, user number, and SINR measurements must be considered. RA will be inaccurate unless it is considered.

Table 3.1 Resource allocation parameter

Resource Allocation Parameters				
P1: Quality of service	P2: Channel gain	P3: SINR threshold	P4: fractional frequency reuse(soft/hard)	P5: sum rate and throughput

3.4.5 Basic Resource Allocation Algorithm

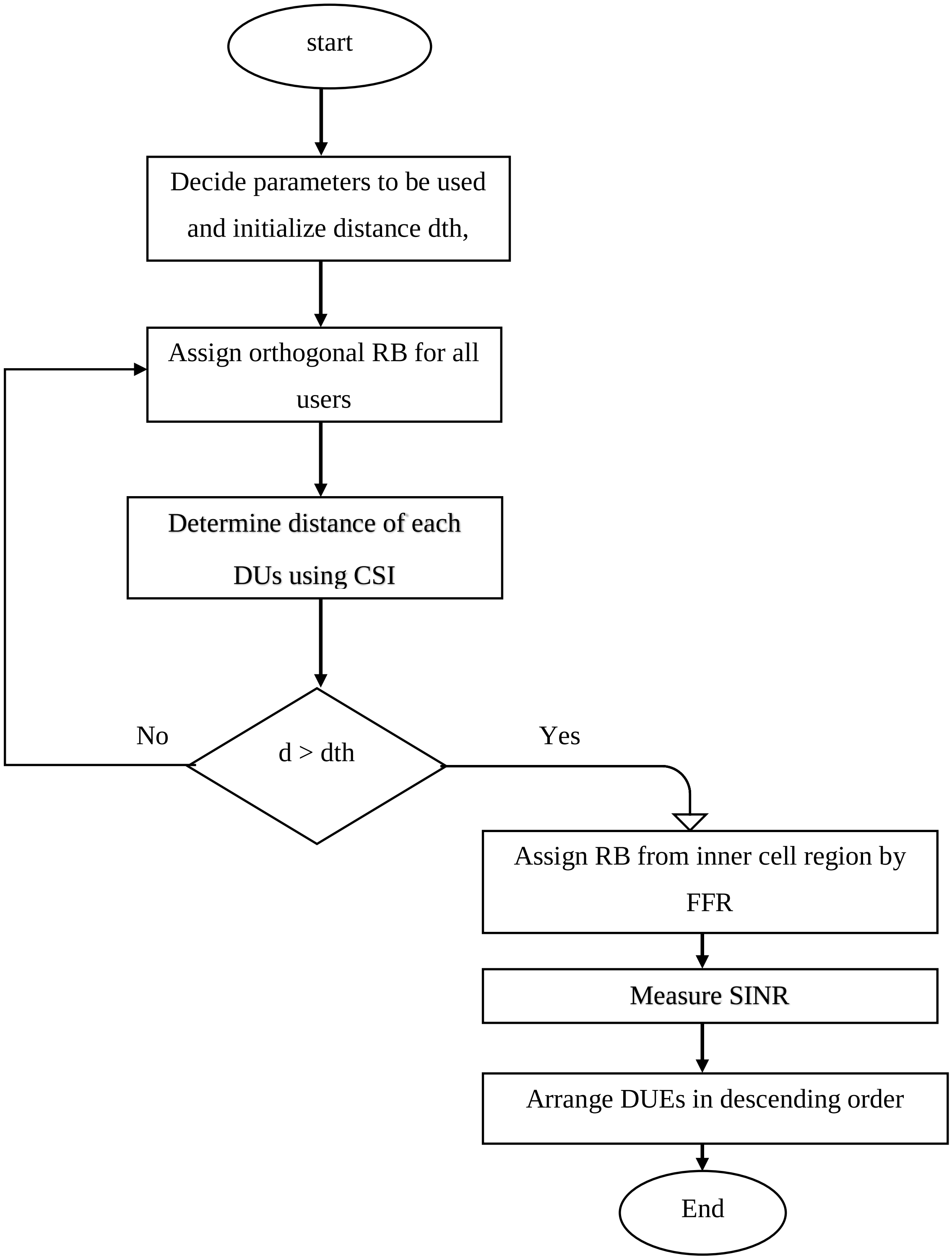

Figure 3.3 Basic algorithm for resource allocation [5]

Table 3.2 Simulation Parameters

List	Input parameters	Value
1	Base Station circuit power, $P_{c,BS}$	10W
2	Base Station power, P_{BS}	30W
3	Maximum UE Tx power, $P_{D,max}$	250mW
4	UE circuit power $P_{c,D}$	100mW
5	Channel Bandwidth W	10MHz
6	Path loss for cellular link	$128.1 + 37.6\ log_{10}(d[km])\ dB$
7	Path loss for D2D link	$148.1 + 40\ log_{10}(d[km])\ dB$
8	Noise Figure	$7dB$
9	Thermal noise density N_0	$-174\ dBm$

3.4.6 Modes of operation in D2D communication

To achieve the system's goal, devices in in-band D2D communication use the cellular user's resources in underlay mode. D2D users have the option of working in one of three modes: distributed, centralized, or mixed. When operating in distributed mode, all devices compete for the same goal. Individual target attainment varies due to interference from cellular users and other D2D pairings. In contrast to distributed mode, the base station (BS) acts as the controller in centralized mode, allocating resources to D2D pairs and cellular users to achieve a system goal. The BS manages resource allocation in mixed mode, but each D2D pair seeks to achieve its own goal in addition to the system's.

[27]recommends distributed mode by distributed energy efficient resource allocation algorithm to optimize energy efficiency of each user equipment subject to spectral efficiency and power transmission requirements to maximize energy efficiency of each user equipment. A trade-off between spectrum efficiency and energy efficiency was investigated for distributed RA in D2D communication. The broadcast sounding message evaluates the interference caused by resource reuse and proposes a distributed algorithm for power and RA using an identical interest game. It was discovered that the algorithm converges at local maximum points. The transmission of interference information from each user to the BS via a distributed iterative method is proposed in [49] for the interference issue. The weighted sum rate is maximized when using the graph

coloring approach to assign resources to users for asynchronous D2D communication, resulting in a global optimum solution.

The interference from the D2D transmitter is priced at the BS controlling the distributed power at the D2D transmitter end using mixed mode using the Stackelberg game theoretic model. Dual updating performance algorithms at the D2D transmitter and BS are presented to converge to the local optimal solution for sum rate maximization based on the interference cost from resource reuse. However, because continuous message passing incurs an overhead for interference measurement, the overhead of message sending must be reduced. [50] discusses the application of Stackelberg game theory to a network-centric and user-centric strategy. A user-centric method for utility function optimization places cellular users as leaders and D2D couples as followers.

The network centric approach, like the user centric approach, employs a pricing strategy to maximize the system's total energy efficiency, exposing the same local optimal point. When the three approaches are compared, it is clear that the central allocation strategy loses ground to the distributed allocation scheme as the number of devices increases. The centralized approach handles interference much better than the distributed scheme, but the message passing through sounding reference signals adds overhead. While distributed allocation degrades system performance as each device strives to achieve its goal, the convergence of distributed schemes to the optimal goal varies with different algorithms. As the number of users increases and the overhead for frequent communication with the BS decreases, the mixed mode algorithms become more adaptive.

3.5 Techniques of D2D resource allocation

To name a few, the game approach, graph coloring method, column generation method, auction algorithm, iterative approach, greedy water filling, FFR, or heuristic algorithm have all been used in the literature to assign RBs. The color represents the RB in the first stage of the graph coloring method, and two nodes connected by an edge do not have the same color. The second stage entails the selection of resources. Before graph coloring, a previously established neighbor graph is used to complete the resource selection of all devices. The radius of the node is critical for constructing the neighbor graph. A wide radius that encompasses a large number of devices makes it difficult to assign resources to all of them; on the other hand, a short radius causes all of the devices to share the same RB.

Using the column generation approach, the optimization problem was divided into a restricted master problem and a pricing problem, and then solved iteratively until the improvement was achieved. The master problem provides dual variables in order to obtain the best solution, and the pricing problem is addressed for the new variables in the column as the most feasible access pattern based on their value. These new values represent a discount on the current objective value of the master problem. Before RB assignment, all D2D link channels were tested for interference level. The slot with the most interference is removed from the assignment, and the D2D connection with the highest weight is processed first [29]. Because it is a centralized solution, the processing overhead is extremely substantial, making it only suitable for small-scale networks.

The greedy water filling algorithm sorts D2D pairs [51][68], in descending order for a given constraint and then allocates resources, but fairness is not guaranteed. While in the auction-based algorithm, the BS allocates resources to users such as DU and CU through a proportionally fair auction with a pricing mechanism. In contrast, in an iterative algorithm, resources are allocated to users while optimizing throughput or data rate and changing the power level in each iteration until the algorithm converges.

The Stackelberg game [52] is used in the game method to address the non-linear problem of resource distribution while accounting for interference and power, with BS acting as the leader and CU and DU competing for resource allocation. The FFR-based technique divides the cell into an inner and outer cell, with the frequency band divided into four bands and the cell sectored into three sections. With the overall network sum throughput constrained, CUEs in the inner cell and DUEs in sector 1 allowed for resource reuse. Similarly, CUEs in sector 1 and DUEs in sectors 2, 3, and the inner cell can share the same resources based on the overall sum throughput. In this design, all resources are assumed to have equal power. The handset's movement causes vertical or horizontal handover. It employs mode switching (cellular/D2D) within the cell during vertical handover, either in the presence of significant interference or handset movement that prevents communication. For horizontal handover, consider switching from one cell to another.

Inadequate channel knowledge, high computational complexity, heterogeneous user conditions, limited backhaul capacity, transceiver impairments, and a restricted level of coordination between base stations are all indicators of non-idealities in the real-time performance of multi-cell systems.

3.6 Access technique

Long-term evolution (LTE) employs orthogonal frequency division multiple access (OFDMA) and its variant, single carrier FDMA (SC-FDMA), for signal transmission. Multipath fading channel reliability, high spectral efficiency, low implementation complexity, and flexible transmission bandwidths are all features of these systems. Advanced features include frequency-selective scheduling, multiple input multiple output (MIMO) transmission, and interference cooperation. Because OFDMA is backward compatible, it is one of the preferred multiplexing techniques in 5G.

Power fluctuation is a problem with OFDMA signals, which affects the efficiency of power amplifiers that consume more power. The use of expensive and efficient power amplifiers by Enhanced Node B (eNB) raises the cost of the UE's handset. As a result, SC-FDMA is a better option for UE uplink. SC-FDMA has the advantage of not having a problem with power fluctuation, and each data symbol is practically distributed across the entire assigned bandwidth, lowering the mean transmission power. While SC-FDMA is unsuitable for the downlink at the eNB due to an additional forward FFT throughout the downlink band, resulting in power fluctuations and data spreading across the entire band, SC-FDMA is ideal for the uplink at the eNB.

In OFDMA, a sub channel is a subset of a subcarrier allotted to a user for modulation. A resource block (RB) is the smallest element in OFDMA, with each frame consisting of ten sub-frames. A sub-frame is made up of two slots. The resource block occupies a 0.5ms time slot in the frequency domain, with twelve subcarriers separated by 15 kHz for a total bandwidth of 180 kHz. Fig.2.2. LTE spectrum allocation ranges from 1.4 to 20 MHz. Transmission from 6-110 RBs is possible over a single carrier frequency, allowing for variable spectrum bandwidths.

OFDMA divides the available spectrum into frequency and time slots. These slots were assigned to users using the demand and supply concept. Seven users are allotted slots at the same time, referring to data traffic. Because of the high volume of real-time voice traffic, user 5 is assigned continuous slots, whereas user 4 is assigned data bursts. The frequency and time slot assignment in the resource block are determined by the required data rate and data type (real-time or non-real-time). In 5G, the OFDM method was used to allocate resources for multiple access [11]. A filter bank multicarrier (FBMC) is recommended for asynchronous transmission.

CHAPTER FOUR

4 RESULT AND DISCUSSION

In this section we evaluate the performance of d2d communication modes with given parameters.

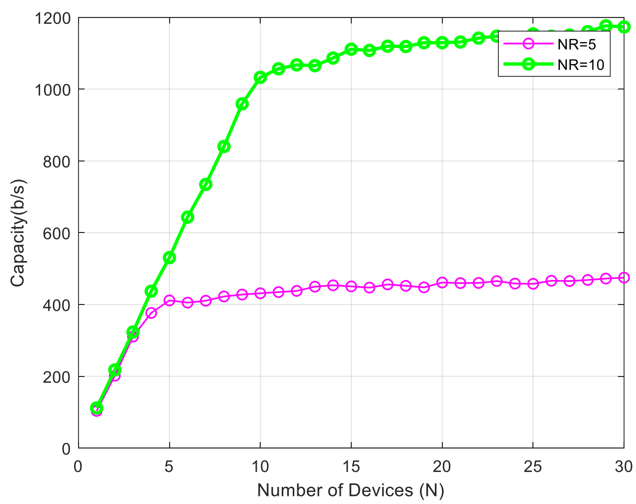

Figure 4. 1 Capacity vs number of Cellular user equipment(CUE)

Fig. 4.1 shows the relationship of capacity and number of devices. As shown in the figure, capacity increases with the number of devices and receivers or end terminals. For example, the capacity when the number of receivers set to ten is got better than that of five. In addition, considering only when the number of users is ten at different points, it is shown that the capacity linearly increases up to almost 1000bps and then logarithmic-ally increases for all devices. Moreover, the capacity linearly increases for both number of users up to when the number of devices equals to three and it logarithmically increases for the rest number of devices in the case of five users.

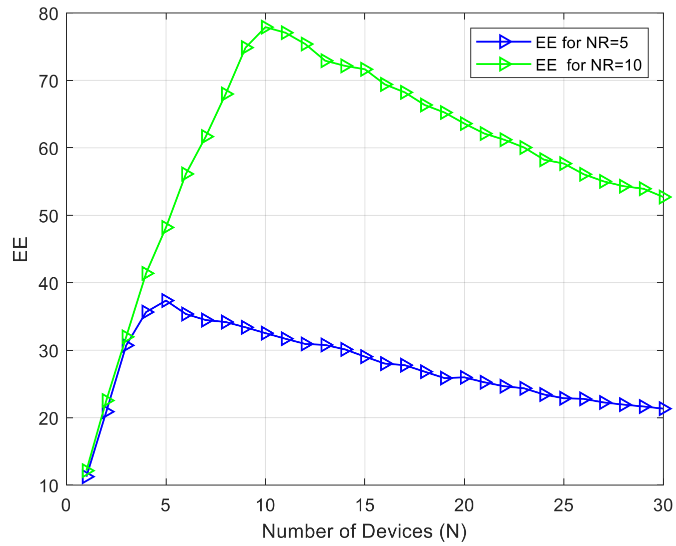

Figure 4. 2 Energy Efficiency vs Number of Devices of via BS

Fig 4.2 shows show the relationship of the number of devices and energy efficiency of communication via base station. As the number devices increase the energy efficiency also increase up some optimal points. Next we evaluate the energy efficiency for different number of devices at different number of user terminals or user end receivers. Though EE increases with the number of devices logarithmically, while considering only ten receivers, it tends to increase up to optimal and then starts declining. The maximum point at which the EE starts to decline is what we call the optimal point. Therefore, the optimal point for ten receivers is shown to be around 79 b/s/J and 37b/s/J which is achieved when the number of devices are 10 and five respectively. After the optimal point, EE curve declines for both number of receivers.

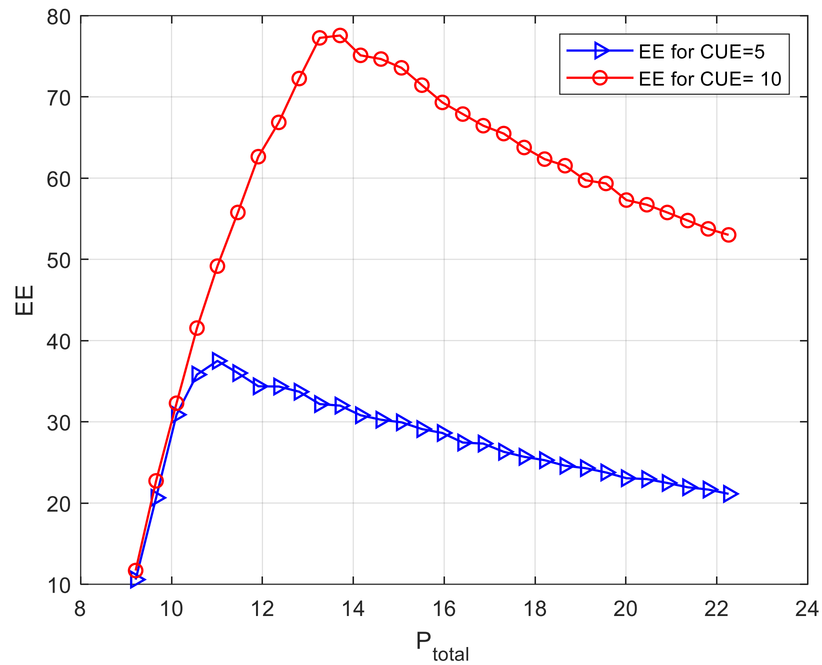

Figure 4. 3 Effect of Energy Efficiency Vs Device total power via BS

Fig. 4.3 depicts the effect of total power on energy efficiency for different number of devices. As we can see from the figure above, the EE increases, with the increase of total power but after some point it starts to decline. This is because, increasing transmit power affects both capacity and total power positively up to optimal point. but when increase in transmit power more affects total power than capacity, the graph starts declining after the optimal point. Generally, we can elucidate the graph by dividing in two portions. In the first portion, which is before the optimal point, increase in transmit power affects the capacity more than the total power. Which means increase in transmit power favors both the capacity and the total power positively. But, in the second portion, the increase in transmit power affects the total power than the capacity which lead to the condition at which the change of increase in total power exceeds the change in capacity.

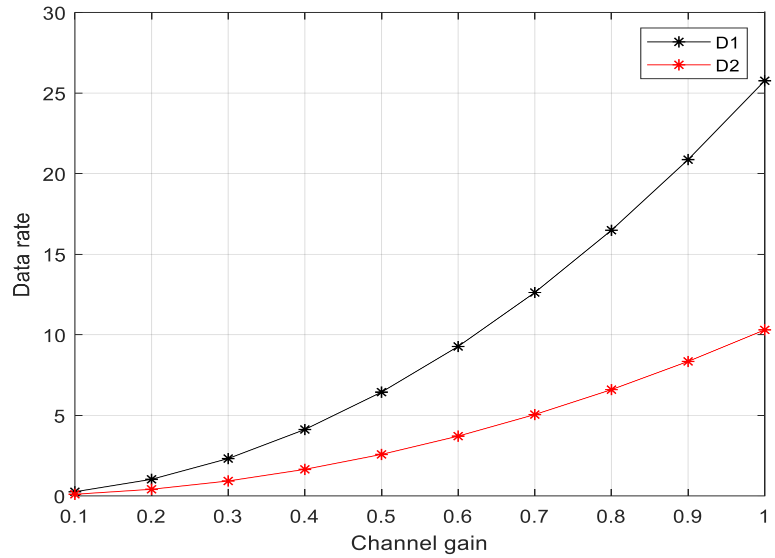

Figure 4. 4 Data rate vs channel gain

The contribution of channel gain for data rate is illustrated in figure 4.4. Since increase in the channel gain increases SNR, and one of the inputs for the data rate is SNR, the data rate is affected by channel gains in general and the data rate of devices is affected based on their distances from each other or from a base station in particular. In this scenario, two devices with different distances from the base station have been considered. Device one and two are located at a distance of ten meters and twenty meters from the BS respectively. As the separation distance increases, the data rate decreases due to increase in path loss which directly affects the received signal. If the received signal decreases, the data rate also decreases.

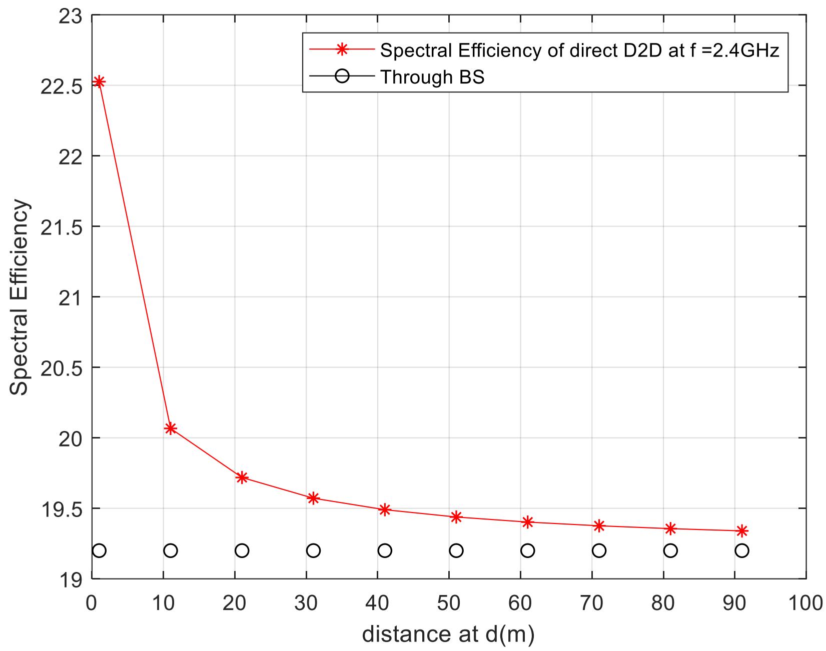

Figure 4. 5 Spectral efficiency vs distance of users in D2D mode

In figure 4.5, we illustrated how distance of users from a base station affects the overall data rate and spectral efficiency. Since increase in distance lowers the total rates, the spectral efficiency be also affected in one or other ways. For instance, the users near the center of the cell achieves better spectral efficiency than the users at the outskirt of the cell as observed from the figure. For this particular scenario, the spectral efficiency becomes zero at distance of 90m due almost the loss of data rate at the point.

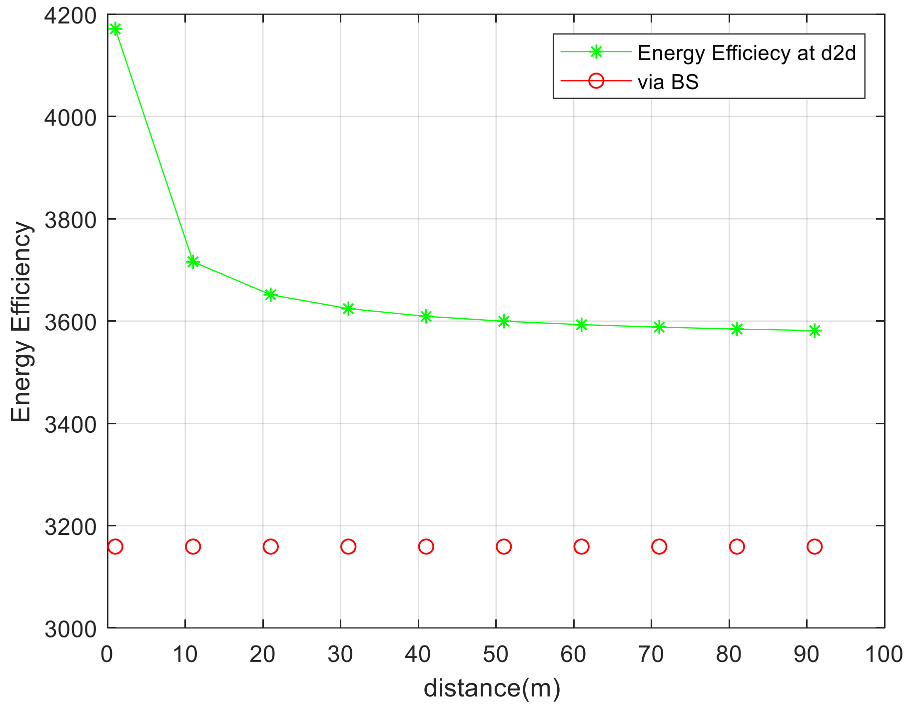

Figure 4. 6 Energy Efficiency of d2d vs cellular

Fig 4.6 illustrate the Effect of d2d as distances.as simulation result shows, EE energy efficiency of d2d is better than that of base station for the above result, in the above simulation distance is fixed to 100*m*. but as distance increases more, traditional base station would cover more distance, so we can conclude that, for shorter distance d2d is more preferable than BS.

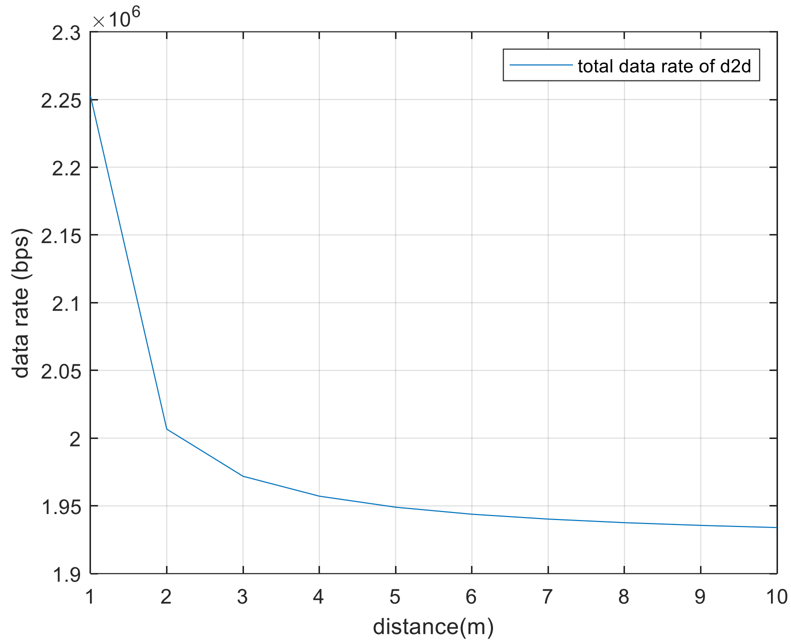

Figure 4. 7 Data rate of d2d devices

Fig.4.7 shows the effect of distance on data rate, as the distance between devices increases the the data rate will be affected, i.e data rate will decrease, this is because the data rate depends on distance and as the distance increases path loss will also increases which results in attenuation of signal.so in order to enjoy the full benefits of d2d, the distance between devices must be kept below the threshold.

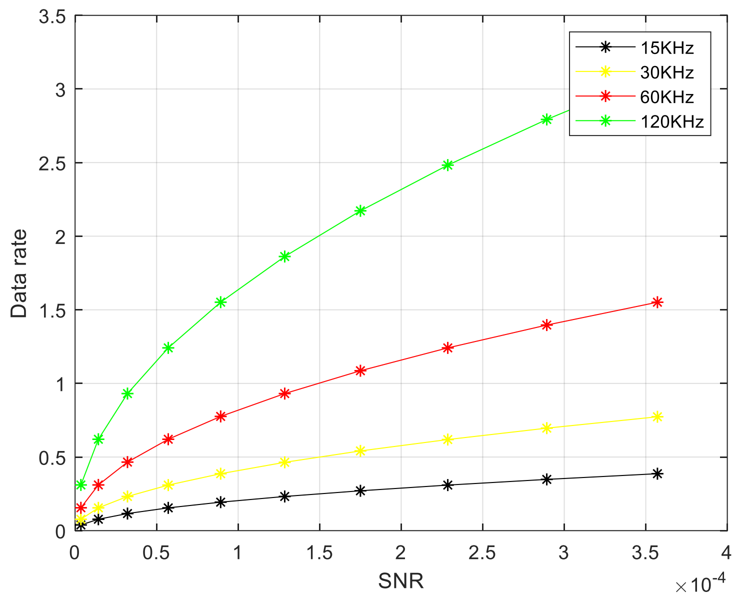

Figure 4. 8 Comparison of LTE and 5G at different numerology.

Figure 4.6 presents the effect of instantaneous SNR on the data rate at different sub-carrier spacing or numerology. Unlike 4G LTE which has only 15 kHz sub carriers spacing on a resource block, for a single resource element, 5G has a varieties of numerology which ranges from 15 kHz to 120 kHz. For all SNR values, the data rate has increasing function despite the value of the carrier frequency. Since high frequency carries transports more data than lower frequencies, the data rate increases as sub-carrier spacing value increases.

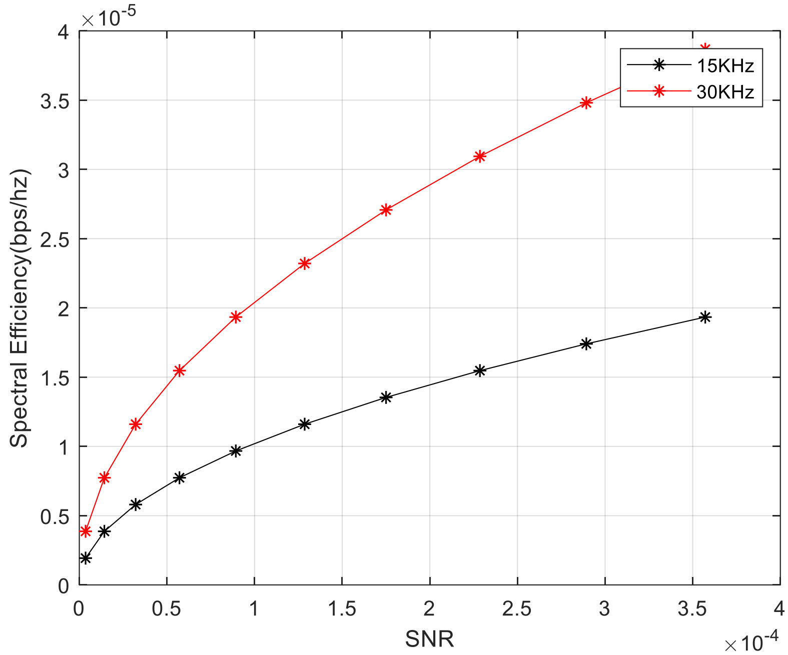

Figure 4. 9 Spectral efficiency vs SNR at 15kHz and 30kHz sub-carriers for D2D UE

In figure 4.7, spectral efficiency (SE) at different SNR levels is shown for both 15 and 30 kHz frequencies. For this case we have used system bandwidth of 20MHz and so that spectral efficiency increases with all SNR values in both sub-carriers. As a change in BW can affect SE directly for the same sub-carrier spacing, it increases all over the values of SNR for a fixed BW. From the above figure we can compare that spectral efficiency at a given instantaneous SNR value, for SNR value of 0.5 spectral efficiency at 15kHz is 0.7bps/Hz where as for 30KHz it is 1.4bps/Hz,so we from this we can conclude that increasing BW as well as using different the advantage of using different subcarrier spacing has in 5G technologies.

CHAPTER FIVE

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this thesis, we have evaluated the performance of D2D communication in two possible modes. As the connection can be made through the base station and the relays, it can be categorized as cellular and direct D2D. For both cases the mathematical formulations are analyzed based on the parameters and possible requirements. Accordingly, the capacity of the system has been evaluated from the perspective of number of devices and users and EE has been evaluated for the perspective users and devices. Hence, Though EE increases with the number of devices logarithmically, while considering only ten receivers, it tends to increase up to ten devices and then starts declining. The maximum point at which the EE starts to decline is what we call the optimal point. Therefore, the optimal point for ten receivers is shown to be around 79 b/s/J and 37b/s/J which is achieved when the number of devices are 10 and five respectively. Furthermore, we evaluated the effect of channel gain on the system data rates and the results shown that the data rate decreases due to increase in path loss which directly affects the received signal. If the received signal decreases, the data rate also decreases.

Moreover, we have evaluated the effect of SNR on the data rate at different sub-carrier spacing or numerology. Unlike 4G LTE which has only 15 kHz sub carriers spacing on a resource block, for a single resource element, 5G has a varieties of numerology which ranges from 15 kHz to 120 kHz. For all SNR values, the data rate has increasing function despite the value of the carrier frequency. Finally the achievements show that the average spectral and energy efficiency of D2D is better than that of via base station and the spectral efficiency is almost double as well while stepping from one numerology to other due to increase in frequencies.

Generally, it can be concluded that, for short distance, d2d performs almost better than via BS. But as the distance increase communication via BS performs better than d2d.This is because, d2d operates on certain protocols which depends distance between devices.

5.2 Recommendations

1. D2D with offloading and numerology should be done
2. Less complex and adaptive hybrid (traditional and D2D) communication is left as an open research issues in the current state-of-the-arts.
3. Nearby device searching(scanning) with a minimum power consumption of the devices should be done.

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Appendix

Code for D2D VS Communication through Base Station

```
clear all;
close all;
clc;
pd1=250;
pd2=pd1;
B=10*10^4
N=7;
N0 =-174
d1=1:1:10; %distance of ue by keeping d2 constant
d2 = 100
d11 = 40
d21 = 1:10:100 %by keeping d1 constant for vc2
f= 2.4e9 %frequency 1
f1 = 5e9 %frequency 2
f2 = 28e9 %frequency 3
lamda = 3e8/f %lamda
lamda1 = 3e8/f1 %lamda
lamda2 = 3e8/f2 %lamda
PL1 = (4*pi.*d1/lamda).^2 %pathloss of device one
PL2 = (4*pi.*d21/lamda).^2 %pathloss of device two
%pathloss for f1
PL12 = (4*pi.*d1/lamda1).^2 %pathloss of device one
PL22 = (4*pi.*d21/lamda1).^2 %pathloss of device two
%pathloss for f2
PL122 = (4*pi.*d1/lamda2).^2 %pathloss of device one
PL222 = (4*pi.*d21/lamda2).^2 %pathloss of device two
pbs_ckt=30;
pbstx=10; %power for base station transmitter
pueckt1=250; % user equipment circuit power
```

```
pue_pt1=1:10:100; %
% puetx = 0.1:0.1:1;
pueckt2=150;
pue_pt2=200;
p_tot = pbstx + pd1+ pd2 + pbs_ckt
%calcultating mc1 starts here
mc1 = pbstx/B*N0*PL1
mc2 = pbstx/B*N0*PL2
%mc1 for f1
mc12 = pbstx/B*N0*PL12
mc22 = pbstx/B*N0*PL22
%mc1 for f2
mc122 = pbstx/B*N0*PL122
mc222 = pbstx/B*N0*PL222

%calculating vc1 and vc2 starts here
vc1 = ((pbstx + pd1)/pd2)*(d21/d11).^2
vc2 = ((pbstx + pd1)/pd2)*(d1/d2).^2

%SNR for f
SNR11 = mc1./vc1 %signal to noise ratio for device one
SNR22 = mc2/vc2 %signal to noise ratio for device two
%SNR for f1
SNR112 = mc12./vc1 %signal to noise ratio for device one
SNR222 = mc22/vc2 %signal to noise ratio for device two
%SNR for f2
SNR1122 = mc122./vc1 %signal to noise ratio for device one
SNR2222 = mc222/vc2 %signal to noise ratio for device two
%rc for f
rc11 = B/2*log2(1+SNR11); %Data rate for device one
%rc for f1
```

```
rc112 = B/2*log2(1+SNR112); %Data rate for device one
%rc for f2
rc1122 = B/2*log2(1+SNR1122); %Data rate for device two

xx=real(rc11) %real part of rcc1
%real part for f at f1
xx_1 =real(rc112)
%real part for f2
xx_2 = real(1122)
%data rate for device two a f
rc22 = B/2*log2(1+SNR22); % data rate for  device two
%data rate for device two a f1
rc221 = B/2*log2(1+SNR222); % data rate for  device two
%d----------data rate for device two a f2---------------%
rc222 = B/2*log2(1+SNR2222); % data rate for  device two
%---------real part of device two starts here at f----------%
yy = real(rc22) %real of rc22
%---------real part of device two at f1---------------------%
yy1 = real(rc221) %real of rc22
%---------real part of device two at f2---------------------%
yy2 = real(rc222) %real of rc22
rc_1 = xx/p_tot
rc_12 = xx/p_tot
rc_13 = xx/p_tot
%------------rc for device two---------%
rc_2 = yy/p_tot
rc_21 = yy/p_tot
rc_22 = yy/p_tot
%----------rc_tot for devices
rc_tot= xx + yy
rc_tot= xx + yy
```

```
rc1_tot= xx_1 + yy1
rc2_tot= xx_2 + yy2
Energy_efficiency = rc_tot/p_tot
Energy_efficiency1 = rc1_tot/p_tot
Energy_efficiency2 = rc2_tot/p_tot
Spectral_efficency = rc_tot/B

zzx= 19.2
figure
plot(rc_tot)
legend('total data rate')
grid
figure
plot(d1,Energy_efficiency,'r-*')
text(d1,Energy_efficiency,'max point')
xlabel('distance at d')
ylabel('Energy Efficiency')
legend('Energy Efficiency at d')
figure
plot(d21,Energy_efficiency,'g-*')
xlabel('distance at d2')
ylabel('Energy Efficiency')
legend('Energy Efficiecy')
grid
figure
plot(d1,Spectral_efficency,'g-*')
xlabel('distance at varying d1')
ylabel('Spectral Efficiency')
legend('Spectral Efficiecy at f=2.4GH')
grid
figure
```

```
plot(d21,Spectral_efficency,'r-*');hold on
plot(d21,zzx,'k-o');hold on

xlabel('distance at d(m)')
ylabel('Spectral Efficiency')
legend('Spectral Efficiency of direct D2D at f =2.4GHz','Through BS')
grid
```