DESIGN AND ANALYSIS OF RESOURCE SHARING TECHNIQUE BASED ON MODE SELECTION AND POWER CONTROL FOR D2D COMMUNICATION

A Thesis
Submitted in partial fulfillment of the requirements for the
award of the degree of

DOCTOR OF PHILOSOPHY
in
Electronics & Electrical Engineering

By
Koushik Barman
(41400752)

Supervised by **Co-supervised by**
Dr. Ajay Roy **NA**

LOVELY PROFESSIONAL UNIVERSITY
PUNJAB
2021

DECLARATION

I declare that the thesis entitled **“Design and Analysis of Resource Sharing Technique Based on Mode selection and Power Control for D2D Communication”** has been prepared by me under the guidance of **Dr. Ajay Roy,** Associate Professor, School of **Electronics and Electrical Engineering** at **Lovely Professional University, Punjab, India.** No part of this thesis has been included in or has formed the basis for the award of any Degree or Diploma or Fellowship of any institution or university anywhere previously.

I further declare that there is no falsification or manipulation in terms of research materials, equipment or processes, experiments, methods, models, modelling, data, data analysis, results, or theoretical work.

I have checked the thesis using Turnitin for ensuring that there is no plagiarized material in my thesis and wherever any copyrighted material has been included, the same has been duly acknowledged.

Koushik Barman
KOUSHIK BARMAN
School of Electronics and Electrical Engineering
Lovely Faculty of Technology and Sciences
Lovely Professional University
Phagwara, -144411 (Punjab)

We endorse the above declaration of Ph.D. student

(Signature of the Ph.D. Supervisor)

Date: 20/4/21

(Signature of the Ph.D. Co-Supervisor)

Acknowledgment

I would like to first say a huge thank you to my supervisors, Dr. Ajay Roy and Late Dr. Mritunjay Kumar Rai, Lovely Professional University, Jalandhar. This research work would not have been possible without their support, supervision, and inspiration. Under their guidance, I successfully overcame many difficulties and learned a lot. I could see the journey over the five years as the most memorable one in terms of learning, knowledge, and taking up a challenge with confidence.

I am grateful to the School of Research Degree Programme (RDP) members for being in my entire research progress review panel, providing useful suggestions during the period. I am indeed thankful to all anonymous reviewers of my research papers submitted to various International Journal and International conferences.

I am indebted to the Honorable Chancellor, Worthy Pro-Chancellor, the Vice-Chancellor, and the successive Deans, LPU, to facilitate the administrative issues involved and encourage me.

I was indeed able to improve upon the work containing herein. My deep appreciation goes out to my LPU colleagues. Their encouragement helped me to come to this level. I enjoyed working with wonderful people like Dr. Gulshan Kumar, Dr. Gurpreet Kumar, Mr. Rajeev Patial, Mr. Dushyant Kumar, Mr. Gurpreet Singh Saini, Mr. Sujit Karmaker, etc.

I would also like to say a heartfelt thanks to my father, Shri Tikendra Nath Barman, my mother, Smt. Sita Rani Barman, my wife Smt. Arundhati Barman and my son Shri. Abhinandan Barman for always believing in me and encouraging me to follow my dreams.

At the end of my thesis, I would like to thank everyone who made this thesis possible and an unforgettable experience for me.

Koushik Barman

Date Koushik Barman

Certificate

I certify that **KOUSHIK BARMAN** has prepared his thesis entitled "**Design and Analysis of Resource Sharing Technique Based on Mode Selection and Power Control for D2D Communication**" to award the Ph.D. degree of the Lovely Professional University, under my guidance. He has carried out the work at the **School of Electronics and Electrical Engineering**, Lovely Professional University.

(Signature of the Ph.D. Supervisor)

Dr. Ajay Roy
Associate Professor
School of Electronics and Electrical Engineering
Lovely Faculty of Technology and Sciences
Lovely Professional University,
Phagwara, Kapurthala-144411 (Punjab)

ABSTRACT

Worldwide deployment of standalone 5G NR network started in early 2020. One of the significant objectives of 5G NR is to provide very low latency interaction and very high reliability communication among proximity devices. Device-to-device communication plays a crucial role in achieving this objective. The area of D2D communication is undergoing exponential growth in the past few years due to versatile applications such as social networking[1], proximity-based services in public safety[2], health care[3], Ultra-Reliable Low-Latency Mobile Communication[4], etc. Device to device communication allows direct communication between two user equipment under licensed band or under ISM band. It allows to share spectrum between cellular users and non-cellular users.[5]. A conventional one-tier mobile network where a mobile user equipment (UE) communicates with another mobile user equipment (UE) through a base station is no longer valid in 5G NR. A multi-tier network where direct communication among multiple mobile UEs in the device tier will replace conventional cellular tier network[6]. It provides a direct link between two UEs or several UEs; therefore, high-speed transmission of data, voice, multimedia is possible. It uses a cellular licensed band for D2D news; therefore, it is more secure than other unlicensed band communication like WiFi, Bluetooth, or NFC[7]. This multi-tier architecture introduces new challenges such as resource allocation and interference control between device tier and cellular tier links, device discovery and service discovery protocol[8] for device tier links, new pricing strategy[9] for spectrum allocation in device tier D2D link, etc. In this thesis, firstly resource allocation problem has been investigated. While allocating cellular uplink and downlink resources to the device tier D2D link for D2D communication, it raises interference among cellular link and D2D link. A detail analysis of interference problem has been addressed initially and an orthogonal precoding scheme has been proposed to overcome interference problem in device tier D2D links. The proposed orthogonal precoding technique is a novel technique and it can drastically reduce interference in device tier. Codebook based precoding has been utilized in LTE-A downlink and 5G cellular standard[10] The proposed technique has been evaluated analytically in single link and multiple link scenario and compared with traditional precoding-based techniques in terms of various performance parameter like

ergodic capacity and link outage probability. In all scenarios proposed technique outperforms as compare to conventional precoding technique. The research work further extended by proposing a join mode selection and resource allocation algorithm where optimum resource allocation depends on mode of operation. Three modes are considered for the algorithm i.e. cellular mode, Reuse Mode and D2D dedicated link mode. Selection of mode will be depended on location of UEs in the cell, amount of interference, transmitted power and required throughput. The proposed mode selection-based resource sharing algorithm along with orthogonal precoding-based interference control has been jointly evaluated in single cell two tier scenario and performance of resource sharing scheme has been presented in terms of link outage probability in different interference region. The research work is further extended by applying two service discovery protocols (i.e. reactive and proactive protocol) for investigation of dependency of proposed resource sharing technique on number of D2D service request in device tier. A comparative control overhead analysis of proactive and reactive protocols under power control-based interference management scenario has been carried out. It has been observed that for increasing number of D2D link request proactive protocols performs better than reactive protocols. Application of service discovery protocol depends on D2D mode of operation and interference management schemes because number of D2D link request varies in different modes i.e. dedicated mode, reuse mode and cellular mode. The research work is further extended by proposing pricing strategy for device tier D2D network. The proposed pricing strategy is based on the concept where operator provides incentive to the device which acts as a relay node and provides D2D communication to other devices by sharing its cellular spectrum. The proposed technique has been simulated for operator-controlled device relaying scheme under relay aided D2D scenario. The proposed technique will encourage a greater number of users to participate in D2D communication and thus improve the operator’s revenue.

The objective of the Present Research Work

The present study carried out under the following’s objectives:

1. Performance analysis of an algorithm for optimal Mode selection prioritizing the quality of the D2D link in terms of throughput
2. Control overhead analysis of service discovery protocol for D2D communication
3. Performance analysis of joint resource allocation and interference management based on power control technique for D2D communication
4. Design and formulate a spectrum sharing portability-based pricing model for service providers in the device-to-device communication scenario.

The analysis carried out to fulfill the above objectives explained below section.

A. Performance analysis of an algorithm for optimal Mode selection prioritizing quality of D2D link in terms of throughput

The existing cellular network has limited resources. A resource block(RBs) in LTE consists of a time-frequency slot. Each slot unit is 0.5 ms long in a time domain and 180 kHz in the frequency domain. The sub carrier spacing between each space is 15 kHz. In the LTE-A system, SC-FDMA directs an uplink communication from mobile to a base station. But downlink from a base station to mobile follows OFDMA. A limited number of RBs sets up D2D connections that need to share with D2D users in such a way that other UEs communicating in cellular mode do not suffer from a lack of resources. If the same RB is assigned for D2D link and cellular link, then there will be interference. The objective here is to propose the best optimal way of selecting these RBs for providing seamless D2D connection without compromising the existing cellular connections UEs can be communicated among themselves using different modes.

A UE may or may not opt for D2D communication. Base station or eNodeBs can assign dedicated links for D2D connection. Also, D2D communication is possible through eNodeB. UEs can reuse the same RB for D2D. Therefore, there are several modes or options available for establishing a D2D link. The research intention is to provide an optimal algorithm for selecting the best and optimal modes for a D2D connection based on the distance between UEs and eNodeBs, the position of UEs in the cell, the length among several UEs who want to connect through the D2D link and available power for transmission from D2D transmitting node without effecting ongoing cellular communication. The proposed algorithm works based on three modes, i.e., cellular modes, dedicated mode, and reuse mode. The cellular mode Base station acts as a relay node, and UE uses the uplink channel and downlink channel for communication with another UE similar to traditional cellular communication. In this case, there will be no separation between cellular resources and D2D resources. In dedicated mode, 50% of total resources are reserve for D2D communication purposes, and the rest 50% are for traditional cellular communication purposes. In Reuse mode, D2D and cellular users utilized the same resources. The operating mode which provides the highest throughput is considered as an optimal mode at an instant. Then the available resource block will be assigned to the D2D user by activating that optimal mode.

B. Control overhead analysis of service discovery protocol for D2D communication

A service discovery protocol allows mobile users to search for D2D service from the nearby base station or any other D2D transmitter node. UEs themselves search for neighbour UE to establish a D2D link. An eNodeB or base station can broadcast messages to UEs for D2D connection. A UE can request eNodeB for a D2D connection without getting any notice from eNodeB. Therefore, it is a real challenge for the researcher to make a proper service discovery protocol that can work under the above said conditions and provide the optimal solution for D2D service requests based on their location in the cell. Commercially available service discovery protocols are best suitable for one tier (i.e., cellular tier) network. Service discovery protocol for two-tier networks (i.e., cellular tier and device tier) is still an ongoing research topic. In the device tier, millions of devices communicate among themselves using license band spectrum. Control overhead calculation and comparative analysis of reactive and proactive service discovery for device tier D2D communication network under power control-based interference management scenario is the objective of this research. It has been observed that for an increasing number of D2D link requests, proactive protocols perform better than reactive protocols. Application of service discovery protocol depends on D2D mode of operation and interference management schemes because several D2D link request varies in different modes, i.e., dedicated mode, reuse mode, and cellular mode.

C. Performance analysis of joint resource allocation and interference management based on power control technique for D2D communication

This research aims to provide a precise solution for joint resource allocation and power control for D2D communication. As we know, the 3GPP group has taken the initiative to add D2D service for the LTE-A, which will also be the promising feature of 5th generation mobile communication in 2020; it is the essential requirement to have a cost-effective and efficient solution for resource allocation and power control. Allocation of resource block introduces interference. The objective of interference management is to provide a solution so that interference should not degrade link quality during resource allocation. Optimum power transmission strategies can control interference of cellular link on Device to device link. Binary power control technique, retransmission of interference signal and then canceling it at the receiver side, allocation of separate resource for D2D are some techniques that can solve this problem. If the same resource has been allocated to cellular and D2D users, it is known as frequency reuse mode. In the case of frequency reuse mode, chances of link degradation are more because, at the receiver end, the required signal to interference plus noise ratio needs to be maintained so that it should not fall below the threshold value of accepted SINR. Otherwise, due to high interference, link outage probability will increase. The major challenge comes when SINR for both, i.e., cellular link and D2D link, are below the threshold value of SINR. It may happen due to the same time-frequency bock allocation. In this research work, a cooperative mode selection and interference control scheme has been proposed.

The code book-based precoding technique has been considered to overcome interference challenge during frequency reuse mode in this scheme. Precoding allows the generation of a precoding matrix index (PMI) that contains the channel state information. Typically base station sends a standard reference signal (CRS) during downlink to the mobile user equipment. CRS holds channel state information, and this information is shared with the D2D transmitter for D2D communication. Performance analysis of traditional precoding and orthogonal precoding has been reported in this thesis. The interference region is divided into three-part. Low interference region is that region where interference to signal ratio is less than 0.5. Moderate interference is defined as the region where the interference to signal ratio is 0.5 to 1. Finally, the worst interference region is one where the interference to signal ratio is more than 1. The analysis and simulation result illustrated in this thesis report shows that orthogonal precoding provides less outage probability than the conventional precoding

while allocating the same resource block to D2D link underlying downlink cellular communication.

D. Design and formulate a spectrum sharing portability-based pricing model for service providers in the device-to-device communication scenario.

The fourth objective of this research work is to design and formulate a pricing model of spectrum sharing portability among service providers for the device to device communication. Spectrum sharing among operators is a big challenge. The objective of this research is to design a novel pricing model for operator assist D2D communication. The model is based on incentive opportunities for the mobile devices willing to serve as a relay node for establishing a D2D communication link. The proposed pricing strategy is based on the concept where the operator provides incentive to the device, which acts as a relay node and provides device communication to supplementary nodes by sharing its cellular spectrum. The proposed technique will encourage many users to participate in D2D communication and thus improve the operator's revenue. The novelty of the proposed technique is that a new utilization function has been defined for spectrum sharing among service providers, and user equipment act as D2D relays. The proposed technique has been evaluated in the case of relay assist two-tier D2D scenarios. Analysis of the proposed model has been done under the following conditions. The total number of users of equipment assisted by the base station was taken as N=2. Assigned bandwidth, B_i was 5 MHz, SNR range (γ_i) remained 5 dB to 25 dB and spectral efficiency K=0.2. In the case of the awarded spectrum of the relaying node, the assigned bandwidth was 2.5 MHz, and the SNR range was 2.5 to 12.5 dB. A fixed unit price of the spectrum (p_i) has been considered. Device's revenue and Operators revenue's revenue in operator control device relay scenario has been observed for SNR range of 5 to 25 dB. The number of participants increases in device tier D2D operator's revenue increases automatically. Incentive benefit to the relay nodes enhances D2D participants in the network.

List of Publications

1. Barman K., Roy A. (2021) An Operator-Controlled Incentive Distribution Model for Device Relaying D2D Communication. In: Sherpa K.S., Bhoi A.K., Kalam A., Mishra M.K. (eds) Advances in Smart Grid and Renewable Energy. ETAEERE 2020. Lecture Notes in Electrical Engineering, vol 691. Springer, Singapore. https://doi.org/10.1007/978-981-15-7511-2_29 (**SCOPUS INDEXED**)
2. K. Barman and A. Roy, "A combine mode selection based resource allocation and interference control technique for D2D communication," IEEE 2020 7th International Conference on Signal Processing and Integrated Networks (SPIN), Noida, India, 2020, pp. 284-289, doi: 10.1109/SPIN48934.2020.9070968. (**SCOPUS INDEXED**)
3. K. Barman and A. Roy, "Investigation of Interference Management Mechanism for D2D Communication in Licensed Band Spectrum," 2020 International Conference on Emerging Smart Computing and Informatics (ESCI), Pune, India, 2020, pp. 193-197, doi: 10.1109/ESCI48226.2020.9167600. (**SCOPUS INDEXED**)
4. K. Barman, M.K Rai, G. Kumar and H. Kim "Resource Sharing Technique for Device to Device Link in License Band LTE-A" International Journal of Grid and Distributed Computing, Vol. 11, No. 4 (2018), pp.145-156 (**SCOPUS INDEXED**)
5. Koushik Barman, Ajay Roy, "Optimum service discovery and resource sharing technique for D2D communication in Two Tier network" International Journal of Advanced Science and Technology, 1st Jun 2020.
6. K. Barman and A. Roy, "Comparative performance analysis of service discovery protocol and interference management schemes for device to device communication in 5G network", presented in *International Conference on Intelligent Circuits and Systems ICICS 2020*, LPU and considered for publication as Book Chapter by Taylor & Francis(**Scopus)**. ISBN 9781003129103.

TABLE OF CONTENTS

Chapter 1 Introduction

Chapter 2 Resource allocation technique based on a mode selection algorithm

Chapter 3 Performance analysis of service discovery protocols for D2D communication

Chapter 4 Performance analysis of joint resource allocation and interference management for D2D communication

Chapter 5 The pricing model for spectrum sharing portability in the device to device communication

5.2.2 Device Controlled Device Relaying (DCDR)

5.2.3 Device control direct communication (DCDC)

5.2.4 Operator control direct communication (OCDC)

Chapter 6 Outage probability Analysis of Relay based D2D Network

Chapter 7 Conclusion and Scope of Future Research

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

1G,2G,3G,4G,5G	First Generation, Second Generation, Third Generation, Fourth Generation, Fifth Generation
3GPP	Third Generation Partnership Project
AMPS	Advance Mobile Phone Service
AWGN	Additive White Gaussian Noise
ACK	Acknowledgement
BS	Base Station
BW	Bandwidth
CDMA	Code Division Multiple Access
CDF	Cumulative Distribution Function
CPM	Conventional MIMO Precoding
CSI	Channel State Information
D2D	Device to Device
DL	Downlink
FDMA	Frequency Division Multiple Access
FDM	Frequency Division Multiplexing
GSM	Global System for Mobile
HSPA	High Speed Packet Access

IC	Interference Cancellation
Kbps	Kilobit per second
LAN	Local Area Network
LTE	Long Term Evolution
LTE-A	Long Term Evolution-Advanced
MAC	Media Access Control
MANET	Mobile Ad-hoc Networks
Mbps	Megabit per second
MIMO	Multiple Input Multiple Output
NFC	Near Field Communication
NR	New Radio
OFDM	Orthogonal Frequency Division Multiplexing
PSK	Phase Shift Keying
QoS	Quality of Service
RAN	Radio Access Network
TDM	Time Division Multiplexing
Wi-Fi	Wireless Fidelity
Wi-MAX	Worldwide Interoperability for Microwave Access
Wireless LANs	Wireless Local Area Network

Chapter-1

1. Introduction

Device-to-device communication has been considered as the most promising technology to satisfy the exponentially increasing demand of heterogenous mobile data of futuristic two-tier cellular networks [11]. It has been reported as the most apparent feature of Long-Term Evolution (LTE) and 5G New Radio (NR) standard. This chapter discussed mobile communication history, motivation of the research, need, and application area of the device to device communication underlying mobile network. Many challenges and unsolved questions exist to design a device-to-device communication architecture under the existing cellular network. This research work addressed some specific challenges and proposed solutions to overcome those challenges. The significance and objectives of this research work are also outlined in this chapter.

1.1 Background and Motivation

Mobile communication technology has shown incredible growth within the last four decades in terms of speed of adoption and the extent of the global transformation. This technology has ensured its position as a significant triumph within a brief period[12]. G. Marconi reveals wireless communication pathways by experimenting with the transmission of three-dot morse code using electromagnetic waves across 3 km[13]. The massive growth in the telecommunication sector begins with the contribution of Claude Shannon for the theoretical foundation of information theory in 1948 and the successful development of low-power analog electronic ICs[14]. The evaluation of mobile communication is broadly classified in different generations. The First Generation (1G) of mobile communication started in the 1980s. Advanced Mobile Phone System (AMPS), Total Access Communication System (TACS) and Nordic Mobile Telephone (NMT) ware publicly available 1G networks during that time. 1G system was capable to provide data rate up to 2.4 kbps. There were several challenges like hand off, security and low capacity[15]. The era of the cellular 2G system started in the late 1990s. Global Systems for Mobile communications (GSM), CDMA, IS95[16] were well-known 2G systems.2G supports data rate up to 64kbps[17]. 2G mobile phones last longer due to low power requirements and longer battery life. 2G was famous for Short Message Service (SMS) and email[13]. There was another generation known as 2.5G, which was famous for supporting General Packet Radio Services (GPRS), Enhanced Data Rate for GSM Evolution (EDGE)[18], and Code Division Multiple Access (CDMA) 2000. It was an amendment to 2G, which supports up to 144kbps using packet and circuit switching[19]. 3G system introduced. The 3G cellular system was introduced in the late 2000s. 3G infrastructure supports 2Mbps of data transmission rate and supports IP mobile services. Some of the famous 3G technologies are Wideband Code Division Multiple Access (WCDMA), Universal Mobile Telecommunications Systems (UMTS), etc. The 3.5G support enhanced data rate 5 to 50 Mbps using advanced technologies like High-Speed Uplink or Downlink Packet Access (HSUPA or HSDPA), Evolution-Data Optimized (EVDO), etc. 4G systems started its journey in the mid-2010s [13]. Long Term Evolution (LTE) Advanced is well known 4G standard by a 3rd generation partnership project group. 4G system supports high-speed IP-based solution for multimedia and voice-over Intermate service[20]. Worldwide Interoperability for Microwave Access (WIMAX) is another 4G wireless broadband communication standard based on IEEE802.16. Deployment of 5G system started in early 2020s and still going on[21]. 5G supports millimeter wave communication, beam division multiple access, massive MIMO technology[13]. In 2017, ITU prepared draft report of 13 minimum requirements for 5G[22]. Low latency and high reliability interaction among devices which are in proximity is the main prospect from new generation. The 3rd Generation Partnership Project (3GPP), a consortium with seven national or regional telecommunication standards organizations has taken initiative to develop standard for standalone 5G NR in release 15 (5G Phase-1) and release 16(5G Phase 2) as per IMT-2020 requirement[23]. Table1.1 presents a summary of evaluation from 1G to 5G. Mobile data traffic has been increased drastically in past decades[24]. It has been reported in CISCO VNI Mobile white paper[25] that exponential growth of mobile data traffic will remain continue as illustrated in Figure 1.1 This report illustrated that a smart device generated 10 times more data than a non-smart device in 2017 whereas in 2022 it will increase to 15 times.

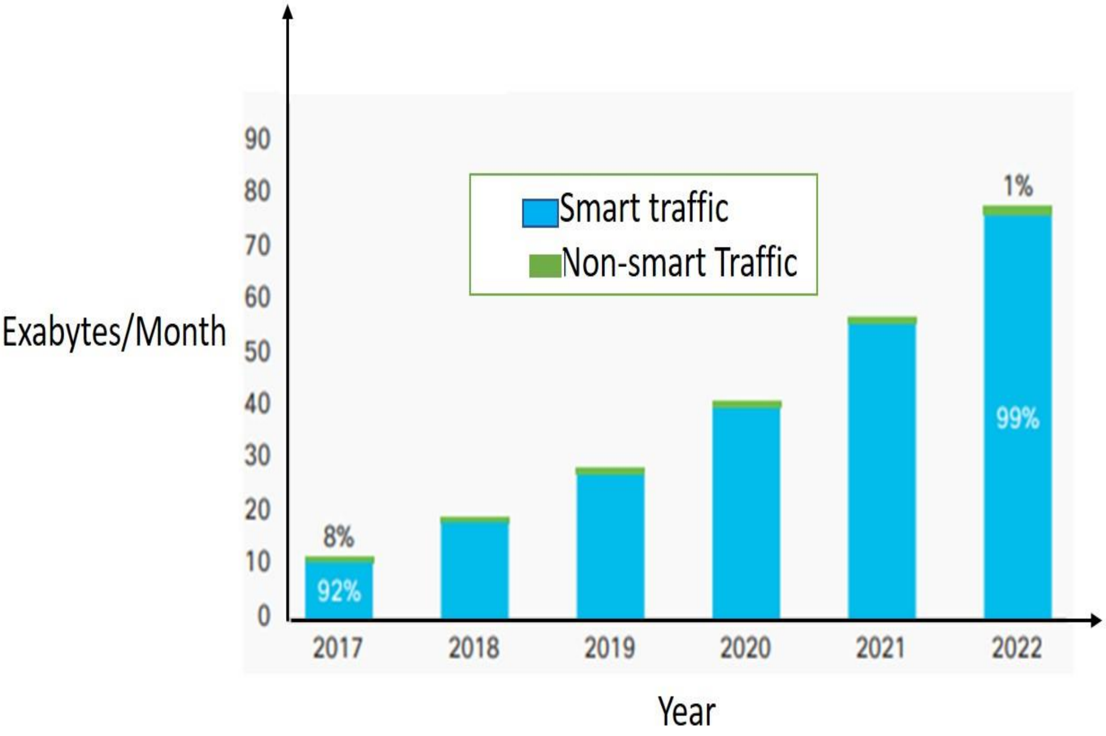


Figure 1.1 Estimation of data traffics of Mobile devices[25].

Table 1.1 Generations of mobile communication [25]

Year	Generation	Technology /Access Scheme	Highest Modulation scheme	Avg. Throughput /user	Channel bandwidth	Approx. Latency (ms)	Applications
1980s	1G	AMPS (Analog) / FDMA	NA	2.4kbps	30 kHz	NA	Circuit switched Voice
1990s	2G	GSM /TDMA+FDMA	GMSK	10 kbps	200 kHz	650	Circuit switched Voice and basic data+packet switching, call conference
	2G	IS95 /CDMA	QPSK	10 kbps	1.25 MHz	550	
	2.5G	GPRS		50 kbps	200 kHz	550	
	2.5G	EDGE	8 PSK	200 kbps	200 kHz	550	
2000s	3G	WCDMA/UMTS		384 kbps	5 MHz	200	Voice, High speed data and video calling, Circuit +IP based Packet switching, call conference, low speed online gaming and IP TV
	3G	CDMA2000	QPSK	384 kbps	1.25 MHz	300	
	3.5G	HSDPA/HSUPA	64QAM	5-30Mbps	5 MHz	100	
	3.5G	1 EVDO Rev A, B, C/ CDMA+TDMA+CA	16QAM and 64QAM	5-30Mbps	1.25 X 3CA MHz	100	
2010s	4G	WiMAX /SOFDMA (3.5 GHz and 5.8 GHz frequency band)	64QAM	100 Mbps	3.5 MHz, 7MHz, 10 MHz	50	All IP mobile broadband applications, High speed Online Gaming, HDTV streaming
	4G	LTE(FDD) /OFDMA, SCFDMA+TDMA	64QAM	100-200Mbps	1.4-20MHz	50	IP based gaming and HD content delivery
	4G	LTE-A, VoLTE /OFDMA, SCFDMA	64QAM	1.5Gbps for UL and 3Gbps for DL	1.4-20MHz	50	IP based multimedia service, Live conference
2020s	5G	New Radio, MMwave, BDMA		UL 10 Gbit/s DL 20Gbps	Minimum: 100MHz, Maximum: 1GHz	4 ms for eMBB and 1 ms for URLLC	Cloud based Mobile IOT applications

1.2Device to device communication

Device to device (D2D) communication is a novel technique where direct interaction occurs between two mobile user equipment (UEs) under cellular network coverage using a licensed cellular spectrum or unlicensed spectrum. Some examples of unlicensed band D2D are Bluetooth, WiFi Direct[26], etc., whereas LTE Direct is a licensed band D2D. UEs communicate through a base station in a traditional mobile network. D2D allows direct communication between two UEs or a relay node performs data offloading in two tier[27]. In Figure 1.2 illustrates concept of D2D communication and its various modes. [28].

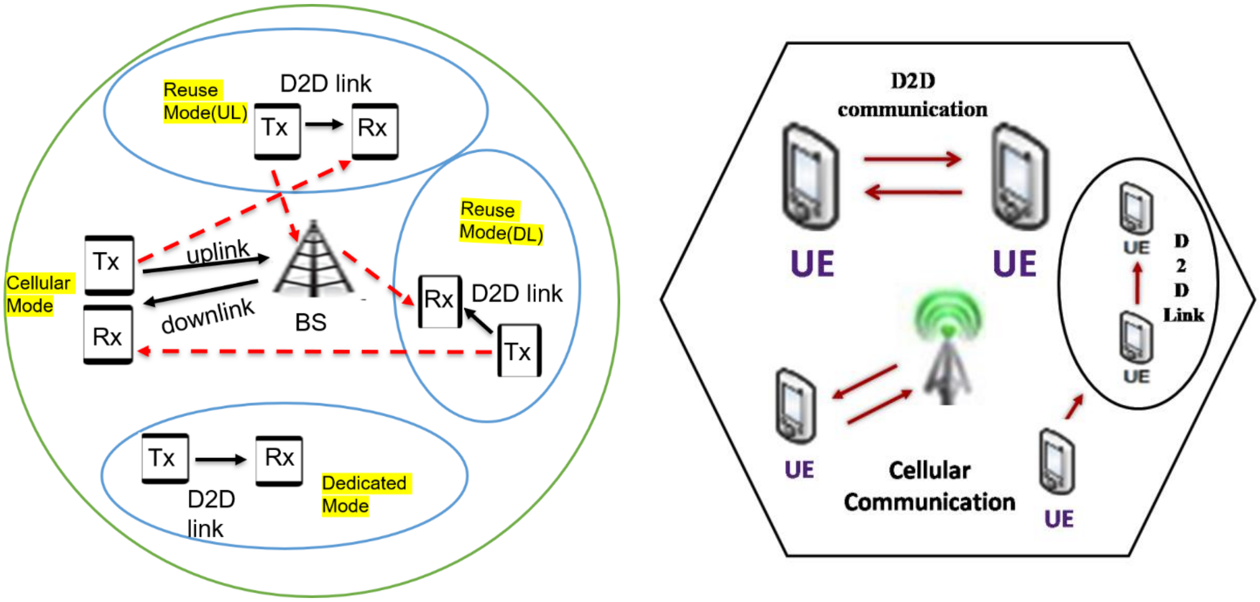


Figure 1.2 Concept of D2D and its various modes

1.2.1 Various Types of D2D scenario

Device-to-device communication can be classified into two categories based on the utilization of spectrum. They are (a) Outbound D2D and (b) Inband D2D. In the case of Outbound D2D interaction among UEs accomplished using unlicensed band (ISM band). WiFi, Direct, NFC, Bluetooth, Adhoc Computer Network, Adhoc Sensor network, etc., are an example of out-band D2D. The primary concern in this type of D2D communication is a security issue and quality of service guarantee.

On the other hand, Devices that use the license band spectrum for communication are known as Inband D2D. LTE Direct is an example of licensed band D2D communication where devices use cellular range for direct contact under the supervision of a mobile base station. Due to centralized control, this type of D2D communication is more secure, and it ensures a better quality of service guarantee. Inband D2D is further classified into two categories, i.e., overlay D2D and underlay D2D[29]. Overlay D2D does not allow to reuse same resource block for cellular and D2D communication simultaneously.

On the other hand, underlay inbound D2D allows reusing time-frequency resource block among D2D links and cellular links. The major challenge in under lay D2D is that it introduces interference to the existing cellular users. Therefore, intracellular interference limits D2D communication. Figure 1.3 presents a classification of D2D communication.

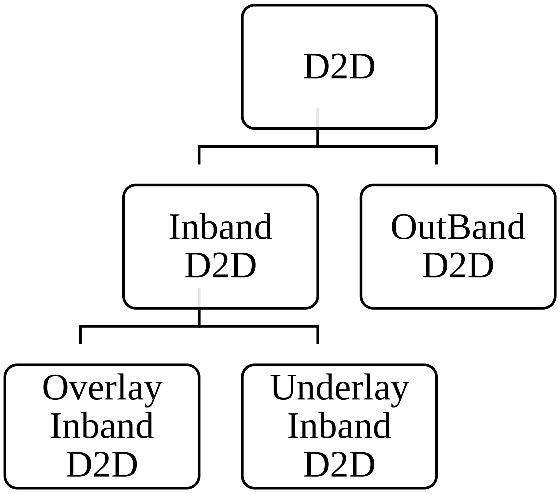


Figure 1.3 Classification of D2D communication

1.2.2 Research Issues and Challenges

There are several challenges for D2D communication. In this section, relevant challenges have been discussed in detail.

a. Resource allocation – The first challenge in D2D is to allocate proper time frequency resources that is required for D2D communication. This resource utilization depends on availability and the D2D mode of operation. Efficiency of the resource allocation depends on various factors such as throughput requirement, mode of operation, availability of resources, D2D user density, etc.. [30]. In most of the literature three operating modes of D2D communications has been mentione. Cellular mode is that mode where a best station works a relay and the UE communicates with another UE through the base station. In case of dedicated mode direct communication between two UE occurs but the resources are reserved separately for this purpose. Therefor it is not an efficient mode in terms of bandwidth utilization. Reuse mode is also very important as it allows to reuse the cellular uplink or downlink spectrum for D2D link establishment. There is a requirement to control the interference because same spectrum shared between cellular and D2D [31] Orthogonal resources may be utilized for allocation with higher efficiency.

b. Interference management and mode selection: Another challenge is to manage interference while allocating resources for D2D. Interference can be classified in various category. Conventional cellular link causes interference to the D2D link in reuse mode of operation. Precoding technique with channel state information can be used to control such interference. There may be interference of D2D link on cellular link. A proper power control can help to minimize such interference. Another possibility is the interference of D2D link on another D2D link. This can be minimizing by allocation resources with efficient algorithm and threshold value of receiver SINR can be used to calculate probability of link outage which is a parameter to manage the interference.

There are three different interference management schemes as mentioned below-

i) **Power control schemes-** in this scheme, cellular mode communications are not degraded while resource blocks are assigned to D2D users and cellular users. It set uplink or downlink resource blocks to D2D user. Thus, it controls transmitted power for D2D communication, so the cellular links are not affected. One issue in this technique is that the outage probability of breaking D2D link is high.

ii) **Retransmission schemes-** In this technique interference is calculated by D2D receiver and that interference information is retransmitted to the D2D transmitter so that the information can be shared to overcome the problem. Channel state information plays very important role in such kind of technique.

c. Optimum Resource control schemes- In this technique only a limited resource utilized by proper reuse algorithm for D2D as well as cellular link. This technique ensure that all resources need to be utilized in a specific time and all users need to be served as per the requirement in network.

d. Service discovery Protocols: Device to device communication requires optimum service discovery protocols. A service discovery protocol enables users to find D2D service and initiates end-to-end D2D contact**.**

e. D2D pricing models: D2D is a novel technique, and so such pricing models available to increase the number of D2D users. The D2D use cases may hamper the profitability of existing cellular services if the number increases. In such a scenario, there is a need to develop new pricing schemes for D2d deployment scenarios.

1.3 Literature Review

Telecommunication Network is approaching at fifth generation. In early 2012, International Telecommunication Union (ITU), a well-known radio interface standard developing agency at the United Nations, initiated a program known as “IMT for 2020 and beyond (IMT-2020)”. In 2017, ITU prepared a draft report of 13 minimum requirements for 5G, as shown in Table 1.3[23]. In new era of 5G the goal is a very highly reliable system design that provide low latency communication. The 3rd Generation Partnership Project (3GPP), a consortium with seven national or regional telecommunication standards organizations, has taken the initiative to develop a standard for standalone 5G NR in release 15 (5G Phase-1) and release 16(5G Phase 2) as per IMT-2020 requirement. Criteria for device communication (D2D) were first introduced by 3GPP in release 12 as part of LTE standards, especially for public safety applications[32]. Researchers have admired that D2D communication is a new paradigm that can fulfill user expectations from the 5G mobile network.

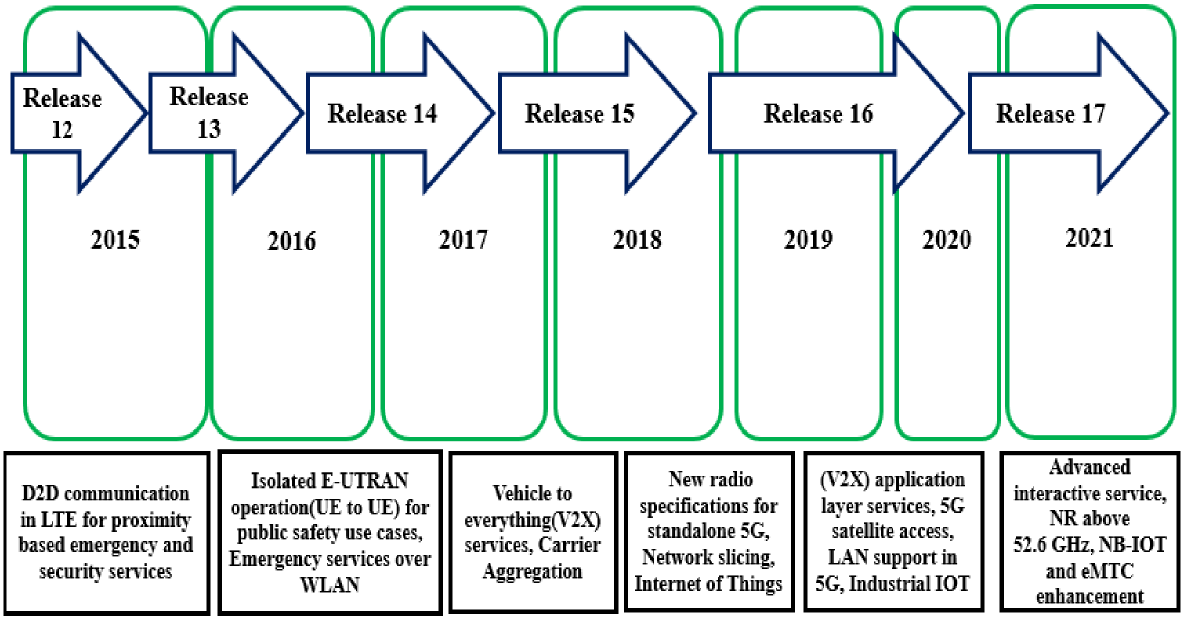


Figure 1.4 Timeline for 3GPP releases related to mobile network standardization

Table 1.3 5G requirement of various parameters and their specifications

1. Peak data rate	Downlink	20 Gbit/s	
	Uplink	10 Gbit/s	
2. Peak spectral efficiency	Downlink	30 bit/s/Hz	
	Uplink	15 bit/s/Hz	
3. User experienced data rate	Downlink	100 Mbit/s.	
	Uplink	50 Mbit/s.	
4. 5th percentile user spectral efficiency	Test Environment	Downlink (bit/s/Hz)	Uplink (bit/s/Hz)
	Indoor Hotspot – eMBB	0.3	0.21
	Dense Urban – eMBB (Note 1)	0.225	0.15
	Rural – eMBB	0.12	0.045
5. Average spectral efficiency	Test Environment	Downlink (bit/s/Hz)	Uplink (bit/s/Hz)
	Indoor Hotspot – eMBB	9	6.75
	Dense Urban – eMBB (Note 1)	7.8	5.4
	Rural – eMBB	3.3	1.6
6. Area traffic capacity	10 Mbit/s/m^2 (Downlink: Indoor Hotspot–eMBB)		
7. Latency	User plane latency	4 ms for eMBB	
		1 ms for URLLC	
	Control plane latency	20 ms	
8. Connection density	one million devices per km^2		
9. Energy efficiency	Efficient data transmission in a loaded case		
	Low energy consumption when there is no data		
10. Reliability	1-10^{-5}		
11. Mobility	Stationary: 0 km/h, Pedestrian: 0 km/h to 10 km/h Vehicular: 10 km/h to 120 km/h High speed vehicular: 120 km/h to 500 km/h.		
12. Mobility interruption time	0 ms.		
13. Bandwidth	Minimum: 100MHz, Maximum: 1GHz		

Figure 1.4 presents 3GPP releases and a timeline for next-generation wireless protocol standards. D2D provides a way to communicate directly instead of cellular base stations intervention[13]. Short-range D2D communication using unlicensed band like transferring of files between two UEs using blue tooth, exchanging information among UEs with the help of mobile applications and WiFi, Mobile hotspot applications, NFC applications are not secure and not manageable centrally by the base station. It has been reported[33] There are several techniques for mode selection based on power control that has been proposed to date. It has been reported in the **literature**[34], [35][36] that spectrum sharing is possible between licensed cellular networks and infrastructure-less wireless networks. Moreover, D2D users can communicate using the same resource spectrum as the cellular user to communicate with the base station. In this research paper, two realistic models for D2D communication have been proposed. They are the cell-wide D2D user distribution model and clustered D2D user distribution model. Here both classes of users (cellular user and D2D user) are distributed uniformly in the cells. In a cluster model, the D2D transverse is placed randomly and distributed uniformly in the cell. It has been claimed that the second model is more realistic in modern urban environments with densely populated cellular users. However, it has been observed that D2D users can be communicated during the uplink frame of the network causes less interference than making the connection during the downlink. During uplink, D2D users are affected by the interference of their signal as there will be only one receiver that is fixed Base station. Still, if they communicate during the down link, there is a probability of interfering with every cellular user in the system. To establish a D2D connection, the D2D user needs to determine available channels for use and required power on each track to be sent on those respective channels. They should determine the amount of power in each channel without crossing the allowed interference level at the base station. Let N is the number of orthogonal channels, D= the distance between the D2D transmitter and the eNodeB. α is path loss exponent, k is the margin in the SINR at the base station P_{TDD} is the transmitted power of D2D user, P_{TBS} is the eNodeB, and P_{RDD} is the received power of D2D user. Total path loss can be calculated by equation (1.1), and P_{TDD} can be obtained from equation (1.2)

$$D^{\alpha} = \frac{P_{TBS}}{P_{TDD}} \qquad (1.1)$$

$$(k-1)\ N\ D^{\alpha} \geq P_{TDD} \qquad (1.2)$$

Equations (1.1) and (1.2) have been used in the literature[34] for obtaining the minimum power requirement for establishing D2D link in both the proposed model named as a cell-wide model and clustered model. The probability of a single-hop Device to device link that does not causes a cellular link to break is much higher in the case of the D2D model. However, the results do not show how to do optimum power allocation for the considered scenarios. It also does not tell about the upper limit on the maximum transmission rate of all available D2D links. **In literature**[37], using an appropriate power control method, the interference between cellular and D2D communications can be avoided and gives the eNodeB to select modes of communication, i.e., whether the D2D or cellular. Therefore, two power control cases have been discussed in[31]. Firstly, both cellular and D2D communications are considered opposing services without any priority. The greedy sum-rate maximization technique is applied for the calculation under the supreme transmit power restriction. In the second case, priority to the cellular users has been considered with a minimum approved transmission. Moreover, three different resource allocation modes has been illustrate as per the Figure 1.5. They are (1) Non-orthogonal resource sharing mode (NonMod), (2) Separate resource sharing mode (SepMod) and (3) Cellular mode (CellMod). In cellular mode Communication between UEs to BS uses 25% of the resources whereas BS to UEs uses 25% for D2D transmission. Rest 50% remain reserved for cellular communication. Separation mode is another name of dedicated mode. In this half of the resources are reserve for D2D and half is reserved for cellular. In non-orthogonal mode same resources are used for D2D and cellular. Interface schemes are important in this case.

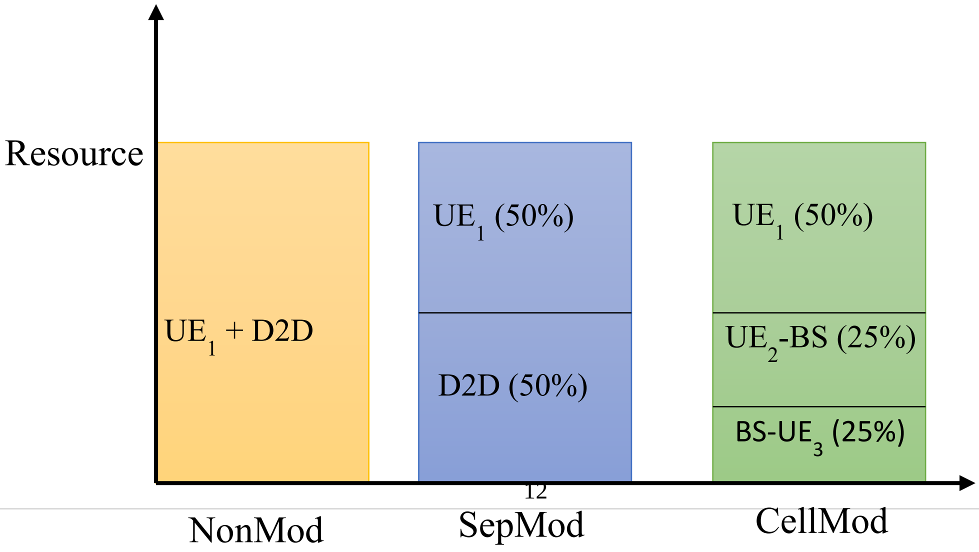


Figure 1.5 Illustration of Three Possible Resource Allocation Mode[31]

It has been reported in[31] that if RULre is the sum rate for NonMod in the uplink, RDLre is the sum rate for NonMod in the downlink, RSepMod is the sum rate of SepMod and RcellMod is the sum rate of CellMod, then the resource allocation mode which gives the maximum sum rate for uplink and down link is given by equation (1.3) and (1.4) respectively.

$$R_{ULmax} = \max (R_{ULre} , R_{SepMod} , R_{cellMod}) \tag{1.3}$$

$$R_{ULmax} = \max (R_{ULre} , R_{SepMod} , R_{cellMod}) \tag{1.4}$$

The literature results [31] provides an idea of prioritized communication between cellular and D2D for three different modes of operation by controlling the power. But the result does not provide a clear idea of direct communication between UEs without the base station's involvement, which means here the mode selection is the task of the base station; UEs cannot select an appropriate mode of operation. **Literature** [38][39] has been focused on reusing cellular bands to establish D2D links. With the help of a proper power control scheme, it is possible to reuse the uplink or downlink resources for D2D communication with minimum interference between cellular UEs and D2D UEs. A good D2D link SINR can be achieved by properly defining the maximum power on the D2D link. The SINR of the UL cellular transmission is given by equation (1.5)

$$\xi=\frac{P_1C_1}{P_2C_2+\sigma^2} \tag{1.5}$$

P_1 and P_2 denote the transmit powers of the cellular and D2D UEs respectively, C_1 and C_2 are corresponding link gains. σ^2 is the AWGN power. In addition to SINR, authors of [39] also illustrated resource allocation scheme-based mode selection with the help of calculating maximum sum rate as mentioned in[31]and [40]. The result shows that using proper power control interference can be managed between D2D UEs and cellular UEs. Furthermore, it has been reported in the **literature**[37] that an algorithm for mode selection can be developed for selecting three different modes based on received RF power and the distance among several UEs. The mode selection procedure has been illustrated in the single-cell scenario and multi-cell scenario. There are three different modes. They are Reuse mode, dedicated user mode, and Cellular User mode. There may be the reuse of uplink resources and reuse of downlink resources [36]. In dedicated mode, dedicated resources are allocated to the UEs for D2D communication.

In Cellular mode, D2D communication is established with the help of the base station, and transmission of data is through the base station. The authors of [37] have focused on the measurement of SINR for providing the limiting parameter of rate guaranty to prioritize the cellular user for the mode selection. A normalized cell of radius one and a path loss model with a path loss exponent of 4 has been considered for a single cell scenario. The received power at distance d has been given by equation (1.6)

$$P(d) = \frac{P_t}{d^4} \tag{1.6}$$

The sum rate of cellular and D2D communication has been calculated similarly as mentioned in the literature [37].In the case of multi-cell scenarios, optimal model selection depends not only on interference from the other cell but also on the load condition of the cell. The data rate for the D2D link in cellular mode will be lesser when the cell is overloaded, and the base station or eNodeB will assign fewer dedicated RBs to the D2D connection. **In** [41]**,** the projected algorithms take care of three basic kinds of stuff- (1) whether the D2D gets devoted resources or not, (2) reclaims the same resources of cellular or not, and (3) functions in cellular mode. **In literature** [42]**,** Mixed-Integer Nonlinear Programming (MINLP) has been formulated for optimum resource allocation between D2D link and cellular link. A greedy heuristic algorithm has been illustrated for sensing the interference to the primary cellular network by utilizing channel gain information. If the downlink channel resource is shared for the D2D link establishment, it creates interference to other mobile users receiving a signal from the base station doing cellular downlink.

Uplink channel sharing generates interference to the base station as it is utilized for D2D link establishment. Cellular interference problem during uplink and downlink has been reported in [43]**. Literature** [30]focused on three different modes of operations, Nonorthogonal mode, orthogonal mode, and Cellular mode. The concept of Sum rate optimization has been illustrated for the best possible mode selection. The analysis is focused on the optimization of sum rate subject to spectral efficiency limits and maximum transmit power restrictions. In cellular mode, the constraint is maximum energy transfer, and the optimum RB allocation between D2D and the cellular connection is in closed form. The proposed resource sharing method has been compared with the path loss-based selection method, and the result shows that the proposed method provides gain over the path loss-based selection method. **In**[43]**,** joint resource allocation and power control based on an iterative algorithm have been submitted. Fractional programming has been reported, and the help of the iterative approach obtains it. The authors noted that the proposed technique converges fast and can be the optimal solution for resource allocation. In [44], downlink resource sharing between cellular and multiple D2D users has been discussed. The power control technique has been considered for downlink interference management. In[45], a relay-based system has been proposed where mobile users at the cell edge can transmit data to the base station during a relay node. The authors presented that the resource sharing technique best of relay selection can be implemented in the 5G system. It has been reported in [10] that the Precoding technique can be used for interference control. From various literate, it has been observed that although different methods of D2D communication have been proposed, the main focus is given on power control and resource allocation issues. Several challenges are found for providing a proper algorithm of mode selection for D2D links with a higher value of throughput. The dedicated mode is required to compromise the allocation of resource bocks between D2D UEs and Cellular UEs. In contrast, in Reuse mode, the spectral efficiency reduces, and in-band interference arises between D2D UEs and cellular UEs.

Table 1.4A, Table 1.4B, and Table 1.4C present a comparison among different power control-based interference management schemes reported in the literature.

Table 1.4A: Comparison of various power control-based interference management schemes for D2D communication

First Author, year	**Interference Management Scheme**	**Objective fulfilled**				**Proposed Method/ Algorithm/ Contributions**	**D2D Scenario**	**Evaluation Parameter /performance metric**
		Minimization of Cellular Interference on nearby cellular link	Minimization of Cellular Interference on D2D link	Minimization of D2D interference on cellular link	Minimization of D2D interference on nearby D2D link			
Anders Gjendemsjø, 2008	Power Control	Yes. (Interference from multiple BS-DL to a single UE Rx)	No	No	No	Binary power control (BPC) algorithm	multiple interfering link	sum of link capacities, optimum throughput for N ≤ 2
Chia-Hao Yu, 2011	Power Control	No	No	Yes (Priority given to cellular link not to break)	No	Greedy sum-rate maximization algorithm	Single hop and Clustered D2D Link	Data rate, Outage Probability
Brett Kaufman, 2015	Power Control	No	No	Yes (priority given to cellular link links)	No	Geometrical approach based algorithm	Single link intracellular	Attenuation and Probability of D2D link (distance based approach)
H. Min,2011	Power Control	No	No	Yes	No	Limiting Maximum D2D transmit power	Single cell scenario	sum rate or throughput calculation for different modes, SINR
W. Zhao **2015**	Power Control	No	No	Yes	No	BS knows CSI for RB allocation in three modes.	Single cell and Multi-cell environment.	Throughput

Table 1.4B: Comparison of various power control-based interference management schemes for D2D communication

First Author, year, Ref No	Interference Management Scheme	Objective fulfilled				D2D Scenario	Evaluation Parameter /performance metric/Remarks
		Minimization of Cellular Interference on D2D link	Minimization of D2D interference on cellular link	Minimization of D2D interference on nearby D2D link	Proposed Method/ Algorithm/ Contributions		
T.Huynh et al. 2016, [41]	Power Control	NA	Yes	NA	Fractional programming iterative approach Interference from D2D communication does not affect to the cellular communications	Single link, Downlink and Uplink	Throughput of D2D pair and CU in both UL and DL phases
Y.Yang et al. 2017, [29]	Power Control	YES	NA	NA	D2D transmission capacity can be enhanced by relay transmission	Relay based scenario	Transmission capacity, user density, power, the D2D link distance
Y. Jiang et al. 2017, [40]	Power Control	NA	Yes	NA	Mixed Integer Nonlinear Programming Greedy Heuristic Algorithm Power optimized for maximization of the energy efficiency (EE) of D2D communications	Uplink and downlink resource sharing scenario	Iterative resource allocation and power control scheme.

Table 1.4C: Comparison of various power control-based interference management schemes for D2D communication

First Author, year, Ref No	**Interference Management Scheme**	**Objective fulfilled**	**Proposed Method/ Algorithm/ Contributions**	**D2D Scenario/cellular scenario**	**Evaluation Parameter** **/performance metric/Remarks**
P.K. Mishra et al. 2016 [43]	Power Control	Minimizes packet loss, upload time, and number of resource blocks, whereas it increases the throughput of the network	Relay selection scheme is used in two-hop communication strategy	Uplink D2D	BS measures link capacity between the cell edge device to Selected relay and the selected relay to BS.
N.T Nguyen et al. 2017[57]	Precoding	Significant coverage gains over the space-time coding scheme despite with low feedback overhead.	A precoding matrix consisting of orthogonal vectors is employed at the transmitter to enhance the maximum signal-to-interference-plus-noise ratio of the user	Cellular downlink	Cellular cell coverage extension
E.Sourour 2019 [10]	Precoding	Full channel state information at the transmitter	Code book-based precoding at transmitter side	Cellular	Applicable in spatial modulation (SM) and generalized spatial modulation (GSM) systems
S.S. Thoota 2019 [59]	Precoding	Codebook based multiuser (MU) multiple input multiple output (MIMO) systems.	Square-root-MM (SMM) and inverse-MM (IMM) algorithms	Cellular downlink	Throughput maximization

1.4 Objectives of Research Work

The area of device-to-device (D2D) communication is undergoing exponential growth in the past few years due to versatile applications such as social networking, proximity-based services in public safety, health care, Ultra-Reliable Low-Latency mobile Communication, etc. [4], [46]. The work presented in this thesis is focused on resource allocation challenges for two tiers of mobile D2D networks. In a traditional mobile web, mobile user equipment (UE) communicates with other mobile user equipment (UE) through the base station using the uplink and downlink channels. On the other hand, traditional one-tier mobile networks (UE-BS-UE) cannot fulfill increasing mobile traffic demand, especially multimedia and real-time data, due to several limitations such as inadequate network coverage and high outage probability. In addition, it suffers from distance constrain, power limitations, and low throughput at the cell edge. Therefore, designing the two-tier mobile network is essential. Two-tier network architecture consists of a traditional cellular network (UE-BS-UE) and a device tier (UE-UE) network. Device tier network allows traffic offloading from cellular tier under the supervision of base station or a D2D relay node which works as a gateway between cellular tier and device tier. Resource allocation is a process in which time-frequency resource blocks (RBs) are allocated to D2D users for direct communication in the device tier network.

Allocation of RBs depends on various conditions and circumstances such as availability of RBs, location of D2D user, interference from cellular tier, etc. Therefore, optimum resource allocation in two-tier networks depends on the mode selection technique where each mode satisfies a predefined or adaptive network condition. The present research work is focused on performance analysis of RB allocation technique for proposed D2D device tier scenarios considering single link and multiple link channels. Mode selection-based interference control technique has been examined while allocating the same resource block to the cellular user and D2D user. An orthogonal precoding technique has been introduced in the device tier to mitigate the interference problem. The parameters studied were outage probability, signal to interference plus noise ratio (SINR), and throughput. The research work is further extended by applying two service discovery protocols (i.e., reactive and proactive protocol) to investigate the dependency of the proposed resource sharing technique on several D2D service requests in the device tier. A comparative control overhead analysis of proactive and reactive protocols under a power control-based interference management scenario has been carried out. It has been observed that for an increasing number of D2D link requests, proactive protocols perform better than reactive protocols. Application of service discovery protocol depends on D2D mode of operation and interference management schemes because several D2D link request varies in different modes, i.e., dedicated mode, reuse mode, and cellular mode. The research work is further extended by proposing a pricing strategy for device tier D2D networks. The proposed pricing strategy is based on the concept. The operator provides an incentive to the device, which acts as a relay node and provides D2D communication to other devices by sharing its cellular spectrum. The proposed technique has been simulated for an operator-controlled device relaying scheme under relay aided D2D scenario. The proposed approach will encourage many users to participate in D2D communication and improve the operator's revenue.

The objective of the Present Research Work

The present study has been carried out under the following's objectives:

1. Performance analysis of an algorithm for optimal Mode selection prioritizing the quality of the D2D link in terms of outage probability and throughput
2. Performance analysis of joint resource allocation and interference management based on power control technique for D2D communication
3. Control overhead analysis of service discovery protocol for D2D communication
4. Design and formulate a spectrum sharing portability-based pricing model for service providers in the device-to-device communication scenario.

To fulfill the above objectives, the analysis is carried out as follows:

A. Performance analysis of an algorithm for optimal Mode selection prioritizing the quality of the D2D link in terms of throughput.

The existing cellular network has limited resources. In LTE (Long Term Evaluation), system resources are divided into RBs. For D2D connection setup, a limited number of RBs need to share with D2D users so that the other UEs communicating in cellular mode do not suffer from a lack of resources. If the same RB is assigned for the D2D link and cellular link, there will be interference. The objective here is to propose the best optimal way of selecting these RBs for providing seamless D2D connection without compromising the existing cellular connections UEs can be communicated among themselves using different modes. A UE may or may not opt for D2D communication. Base station or eNodeBs can assign dedicated links for D2D connection. Also, D2D Communication can be done via eNodeB. UEs can reuse the same RB for D2D. Therefore, there are several modes or options available for establishing a D2D link. The research intention is to provide an optimal algorithm for selecting the best and optimal modes for a D2D connection based on the distance between UEs and eNodeBs, the position of UEs in the cell, the distance among several UEs who want to be connected through the D2D link and available power for transmission from D2D transmitting node without effecting ongoing cellular communication. The proposed algorithm works based on three modes, i.e., cellular modes, dedicated mode, and reuse mode. The cellular mode Base station acts as a relay node, and UE uses the uplink channel and downlink channel for communication with another UE similar to traditional cellular communication. In this case, there will be no separation between cellular resources and D2D resources. In dedicated mode, 50% of total resources are reserve for D2D communication purposes, and the rest 50% are for traditional cellular communication purposes. In Reuse mode, the same resources will be utilized for D2D and cellular users. The operating mode which provides the highest throughput is considered as an optimal mode at an instant. Then available resource block will be assigned to the D2D user by activating that optimal mode.

B. Control overhead analysis of service discovery protocol for D2D communication

Service discovery protocol provides direct services to the nearby user equipment utilizing establishing D2D link [47]. A UE can its selves search for neighbor UE to establish a D2D link. An eNodeB or base station can broadcast messages to UEs for D2D connection. A UE can request eNodeB for a D2D connection without getting any message from eNodeB. Therefore, it is a real challenge for the researcher to make a proper service discovery protocol that can work under the above-said conditions and provide the optimal solution for D2D service requests based on their location in the cell. To date, commercially available service discovery protocols are best suitable for one tier (i.e., cellular tier) network where service discovery protocol for two-tier networks (i.e., cellular tier and device tier) is still an ongoing research topic. In the device tier, millions of devices communicate among themselves using license band spectrum. Control overhead calculation and comparative analysis of reactive and proactive service discovery for device tier D2D communication network under power control-based interference management scenario is the objective of this research. It has been observed that for an increasing number of D2D link requests, proactive protocols perform better than reactive protocols. Application of service discovery protocol depends on D2D mode of operation and interference management schemes because several D2D link request varies in different modes, i.e., dedicated mode, reuse mode, and cellular mode.

A. Performance analysis of joint resource allocation and interference management based on power control technique for D2D communication

This research aims to provide a precise solution for joint resource allocation and power control for D2D communication. Here a precoding-based technique has been proposed to minimize the effect of interference at the D2D receiver. Furthermore, the proposed method has been compared with the traditional precoding technique in terms of outage probability. The simulation result presented in this thesis states that proposed orthogonal precoding provides less outage probability than the conventional precoding technique.

D. Design and formulation of a spectrum sharing portability-based pricing model for service providers in the device-to-device communication scenario.

The fourth objective of this research work is to design and formulate a pricing model of spectrum sharing portability among service providers for the device to device communication. Spectrum sharing among operators is a big challenge. This research aims to design a novel pricing model for base station-supported D2D communication. The model is based on incentive opportunities for the mobile devices willing to serve as a relay node for establishing a D2D communication link. The proposed pricing strategy is based on the concept. The operator provides an incentive to the device, which acts as a relay node and provides D2D communication to other devices by sharing its cellular spectrum. The proposed technique will encourage many users to participate in D2D communication and improve the operator’s revenue. The novelty of the proposed method is that a new utilization function has been defined for spectrum sharing among service providers, and user equipment act as D2D relays. The proposed technique has been evaluated in the case of a relay assist two-tier D2D scenario. Analysis of the proposed model has been done under the following conditions. The total number of devices served by the operator was taken as N=2. Assigned bandwidth, Bi was 5 MHz, SNR range stood 5 dB to 25 dB, and spectrum efficiency K =0.2. In the given spectrum of the relaying node, the assigned bandwidth was 2.5 MHz, and the SNR range was 2.5 to 12.5 dB. A fixed unit price of the spectrum (pi) has been considered. Device's revenue and Operators revenue's revenue in operator control device relay scenario has been observed for SNR range of 5 to 25 dB.

1.5 Research Methodology and Tools

This research work has been conducted in various stages. After a thorough review of relevant system models, we have described our system models in the following chapters of this thesis report suitable for proposed research analysis purposes. The system models that have been used for analysis are downlink resource sharing model, uplink resource sharing model and relay-based resource sharing model. The methodology that has been followed is based on mathematical derivation and simulation. One of the proposed two-tier models is shown in Figure 1.6. Tier I represent a conventional cellular network operating in frequency division duplex mode, where BS is serving three UEs, e.g., UE_1, UE_2, and UE_3 using H_{01}, H_{02}, and H_{03}, respectively. These are narrow band quasi-static and frequency flat fading channel responses corresponding to cellular downlinks. W is the available bandwidth for cellular downlink. Tier II represents the device tier where UE_1 acts as a relay node.

In tier II, UE_1 provides proximity services to UE_2 and UE_3. Consider UE_1 is providing two types of D2D services, e.g., BS data offloading service to UE_2 and device-to-device context-aware services to UE_3. Data offloading service such as voice over IP holds a constant bit rate whereas context-aware services like video streaming, social networking, etc. are possible using variable bit rate. Therefore, we defined C_{12} as the guaranteed consistent throughput of channel H_{12}, and C_{13} is the minimum targeted bit rate of channel H_{13}. The relay UE, e.g., UE_1 is the gateway for the transition from tier I to tier-II, must fulfill specific specifications. It must have isolated receive and transmit antenna and loopback interference cancellation capability. HL denotes loopback interference channel response between receive and transmits antenna port of relaying UE.

Moreover, UE_1 directly communicates with UE_3 and performs BS data receive and forward to UE_2 operation using the same frequency band. Therefore, we consider UE_1 a highly capable UE that relays data from base station and performs underlay D2D communication simultaneously. A separate analysis of pricing strategy for providing incentives to UE_1 has been discussed in a later chapter. On the other hand, UE_3 suffers from cellular downlink interference while receiving data from UE_1 because BS is using the same frequency band for downlink transmission. Therefore, we have proposed a codebook-based orthogonal precoding technique for revoking interference. As a result, orthogonality has been maintained between cellular link and D2D link while selecting precoding vector. Table 1.5 summaries objective-wise research methodology.

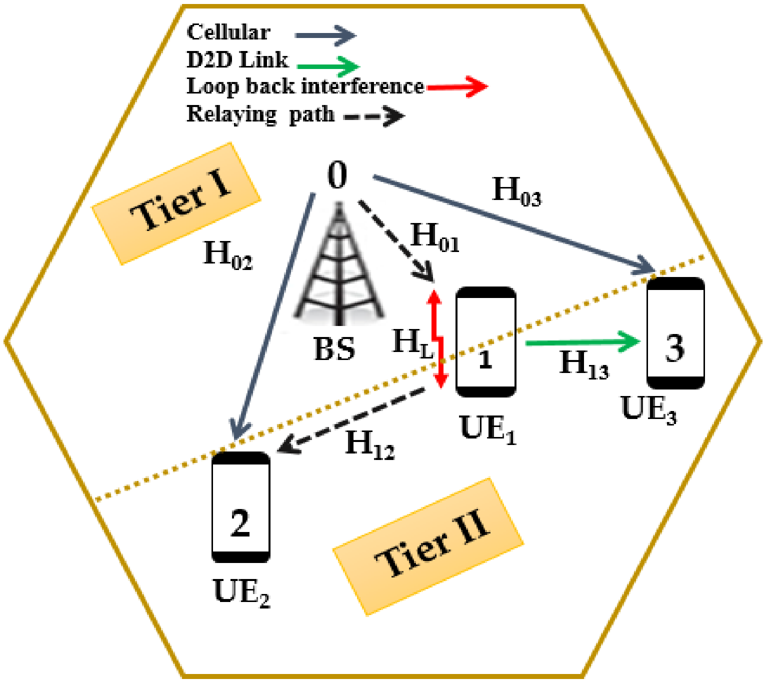


Figure 1.6 Relaying based downlink resource sharing scenario.

Table 1.5 Methodology/ Tools/ Instruments

Objective	Analysis to be under taken	Instruments/ processes/ software to be used	In house availability (Yes/ No)	Organization/ Institute (where the facility is available)
1	Analysis of Mode Selection Algorithm based on the location of UEs in the cell, amount of interference, transmitted power, and required throughput.	MATLAB	Yes	LPU
2	Stochastic modeling and time frame-based analysis of Service discovery protocol	MATLAB	Yes	LPU
3	Analysis of outage probability for joint mode selection and interference management based on precoding technique.	MATLAB	Yes	LPU
4	Analysis of service utilization factor for Operator controlled D2D incentive distribution model	MATLAB	Yes	LPU

1.6 Thesis Organization

This thesis is organized into six chapters. Chapter 1 provides the significance, background, and objectives of the proposed research work. In chapter 2, mode selection-based resource allocation techniques have been discussed. It also presented an analysis of the power control-based mode selection algorithm. In chapter 3, a common mode selection and interference technique based on precoding have been proposed, and the proposed method has been compared with conventional precoding reported in the literature. Chapter 4 introduced a time frame-based analysis of Service discovery protocol for D2D link in device tier network. Detail analysis of control overhead calculation has been reported. Chapter 5 presents an investigation of various two-tier network and pricing schemes for

D2D users. A pricing scheme has been proposed for relaying cellular tier network traffic to the device tier users where relay nodes benefit from bandwidth incentives from the operator for providing data offloading service to the D2D users. The pricing scheme not only increases the participation of D2D user as well as increase operator's revenue. Chapter 6 deals with the evaluation of the proposed interference control technique in a relay-based D2D scenario. The relay-based method is applicable where the base station offloads data to the cell edge user equipment through a relay device. This chapter outage probability has been calculated for relay-based two-tier networks in various modes of operation. It enhanced the through put and link quality of the cellular UE located at the cell edge. Chapter 7 provides a brief conclusion and future work for the presented research.

1.7 Summary

Device-to-device communication is an integral part of LTE-A and 5G NR. There are several challenges to developing the architecture of D2D communication, such as interference of existing cellular users to D2D link in the two-tier network, development of optimum resource allocation algorithm, service discovery protocol design, pricing scheme development for encouraging participation of D2D user, and also improve the profitability of the operator. This chapter summarizes research challenges, thesis objectives, background works, research methodology, and thesis organization in detail.

Chapter-2

Resource allocation technique based on a mode selection algorithm

2.1 Introduction: Resource allocation is a process to allocate time-frequency block to the cellular link and Device to device (D2D) link in an optimum way so that each of the links is not suffered from the interference challenges. A proper resource allocation technique increases spectrum efficiency and accommodates many users in the network. This chapter describes the principle of resource allocation technique. Also, an optimum mode selection algorithm based on the power control technique has been proposed, and simulation results are presented based on the designed D2D scenario.

2.2 Resource Allocation: A resource is a time-frequency block**.** The traditional cellular network base station allocates resource block for uplink and downlink communication to the mobile user equipment that falls under its coverage area. The literature survey found that D2D communication provides proximity services in licensed band spectrum using uplink and downlink resources of LTE-A, which is more secure and reliable than unlicensed band communication[13]. WiFi, Bluetooth are examples of unlicenced band communication because they use the ISM band for D2D communication [26]. In an LTE-A system, the total bandwidth is divided into equal size physical Resource Blocks. These RBs physically occupy one slot of 0.5 ms in the time domain and 180 kHz in the frequency domain with sub carrier spacing of 15 KHz[48]. LTE-A uses OFDMA for down link and SC-FDMA for uplink. Figure 2.1 presents LTE-A resources as per 3GPP release 10. These uplink and downlink resources can be shared for D2D communication. The presence of a D2D link in the existing cellular network has been shown in Figure 2.2. Sharing of licensed band resources introduced interference between D2D users and cellular users. The problem of interference can be avoided by defining modes and selecting the appropriate method using the optimum algorithm.

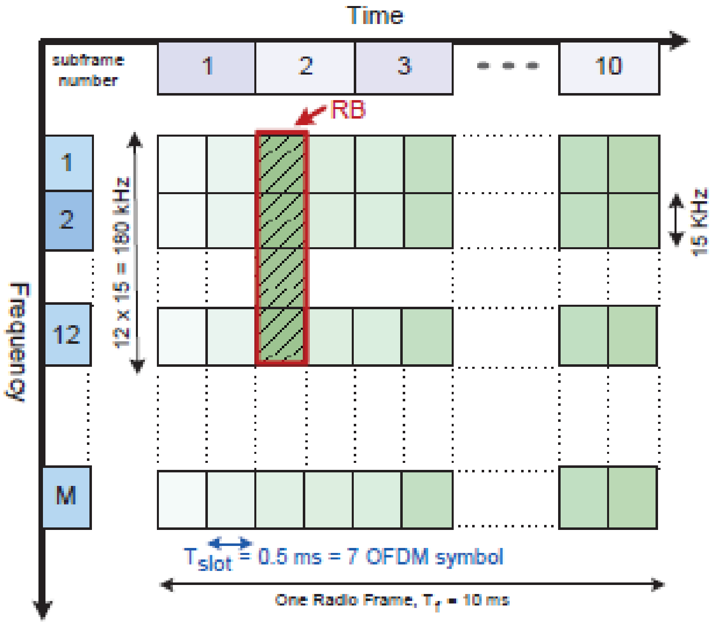


Figure 2.1. LTE-A Resources[49]

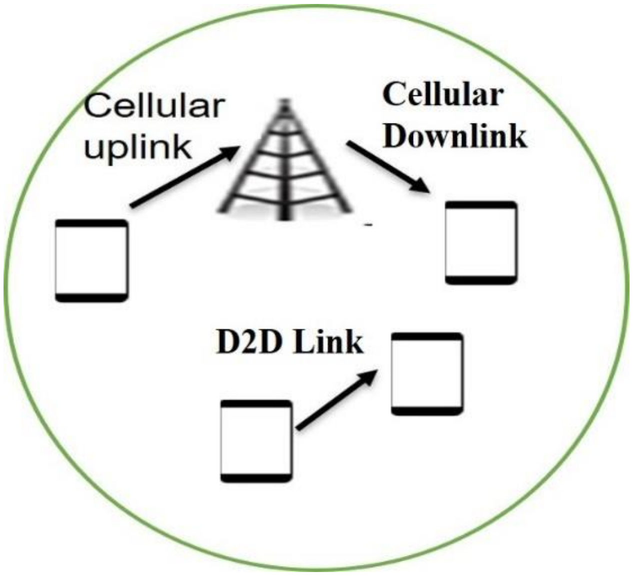


Figure 2.2. D2D link in a cellular network.

In most of the literature [30][34][50], the designing of optimum mode selection algorithms is based on the position of UEs in cell area and availability of resource block. Mode choice contracts decide whether a mobile user pair should connect straight or through the base station, whereas resource distribution deals with a suitable selection of mobile resource blocks to be shared. There are two possibilities. Firstly, during downlink communication, there is a chance that the D2D receiver gets interference from the base station. Also, during uplink, mobile user equipment gets interference from the D2D transmitter. In [31], it has been proposed that resource allocation can be done by defining various modes of operation. Figure 2.3 shows Operating Modes for the resource block sharing technique mentioned in[31]. Here, the authors describe three methods named as NorMode, SepMode, and CellMode.All nodes use orthogonal resources, and communication between UEs to BS uses 25% of the resources, whereas BS to UEs uses 25% for D2D transmission. Rest 50% remain reserved for cellular communication. The main problem in this mode selection technique was that authors compromise with the D2D link quality. Therefore, the cellular link has been given more priority as compared to the D2D connection. Also, there was a distance constrain to establish a good quality D2D link. In[51], the multicell spectrum sharing approach has been presented based on two modes, and also an effect of densification of D2D users on D2D performance has been illustrated. The author explained that the overlay scenario provides a worst performance than the underlay scenario.

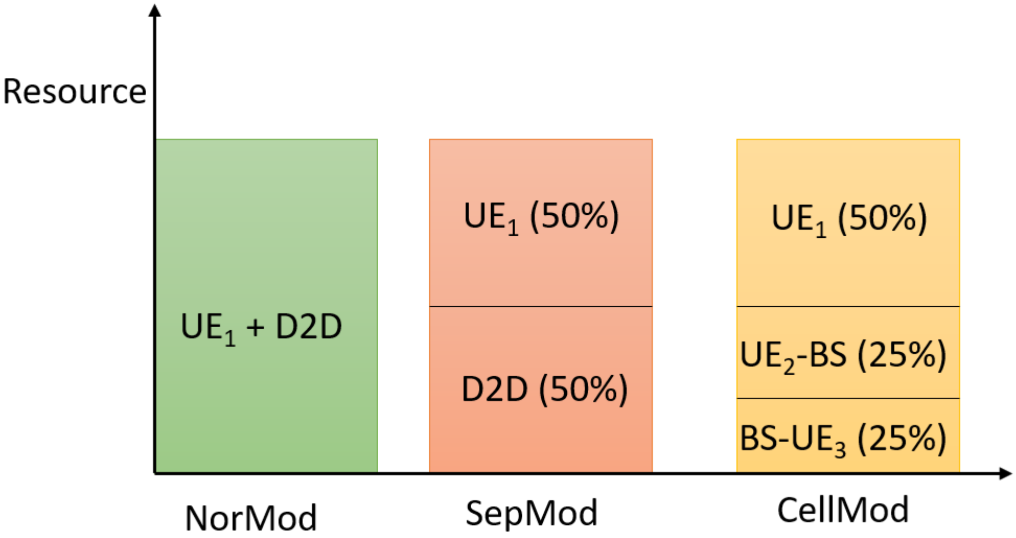


Figure 2.3. Operating Modes for resource block sharing technique[31]

2.2.1 Mode Selection parameters

Mode selection parameters are defined as the decision-making variables for a resource allocation algorithm to decide which is the based suitable mode for assigning resource blocks to mobile user equipment. In most of the literature, distance from the base station, signal to noise plus interference ratio, outage probability, path loss, and throughput have been considered the mode selection parameter.

Let P_1 and P_2 denote the transmit powers of the cellular and D2D UEs. Then, respectively, C_1 and C_2 are corresponding link gains. Then SINR for uplink cellular communication is given by,

$$\text{SINR}= \frac{P_1 C_1}{P_2 C_2+\sigma^2} \tag{2.1}$$

Here σ^2 is the Additive White Gaussian Noise power. Now the base station has complete control over the power P_1 and P_2. The above equation implies that in the case of ideal UL power control without the presence of a D2D transmitter (P_2=0) and a target SNR of P/σ^2, the cellular power control target is P_1C_1=P. BS can control the power of the D2D link to avoid interference due to the same resource allocation to the cellular UE for uplink. When there is no D2D link, optimum SINR will be achieved for cellular UL, whereas more no of D2D link causes degradation of SINR value of cellular UL. Therefore, a threshold level needs to be maintained for the resource allocation of D2D users. It has been observed that D2D user communication during the uplink frame of the network causes less interference than making the connection during the downlink. During uplink, D2D users only need to be concerned with the interference of their signal on one other uses as there will be only one receiver that is the concern fixed Base station. Still, if they communicate during the down link, there is a probability of interfering with every cellular user in the system. To establish a D2D connection, D2D users need to determine available channels for use and required power on each track that needs to be sent on those respective channels. D2D users need to determine how much power they can transmit in each channel without crossing the allowed interference level at the base station. Figure 2.4 illustrates the concept of interference during uplink and downlink resource sharing.

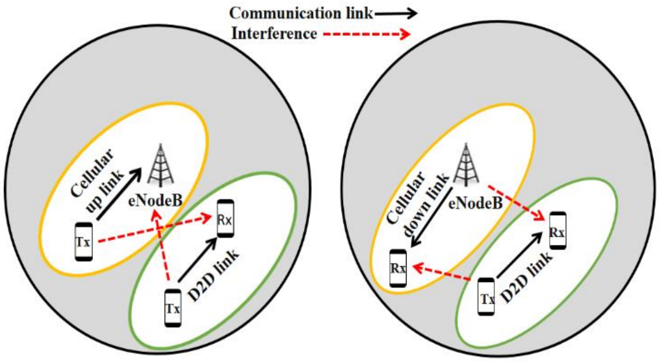


Figure.2.4. (a) Downlink and (b) Uplink interference

2.2.2 Path loss calculation

Let N is the number of orthogonal channels available in the system, D is the distance between the D2D transmitter and the base station. α is the path loss exponent, k is the margin in the SINR at the base station, which determines the power control of the cellular link to compensate for the interference from the D2D user, P_{TDD} is the transmitted power of D2D user, $P_{T_{BS}}$ is the transmitted power of the Base station and $P_{R_{DD}}$ is the received power of the D2D user, then total path loss can be calculated by equation (2.2), and P_{TDD} can be obtained from equation (2.3)

$$D^{\alpha} = \frac{P_{T_{BS}}}{P_{R_{DD}} - N} \tag{2.2}$$

$$(K-1)ND^{\alpha} \geq P_{TDD} \tag{2.3}$$

2.2.3 Throughput calculation

Let $R_{ULre}$is the sum rate for Non-orthogonal Mode (NonMod) in the uplink, $R_{DLre}$is the sum rate for NonMod in the downlink, $R_{SepMod}$is the sum rate of Separation mode (SepMod) and $R_{cellMod}$is the sum rate of Cellular Mode (CellMOD), then the resource allocation mode which gives the maximum sum rate for uplink and down link is given by equation (2.4) and (2.5) respectively.

$$R_{ULmax} = \max (R_{ULre}, R_{SepMod}, R_{cellMod}) \tag{2.4}$$

$$R_{DLmax} = \max (R_{DLre}, R_{SepMod}, R_{cellMod}) \tag{2.5}$$

2.3 Proposed algorithm for mode selection

Based on various literature surveys mentioned in previous sections, a mode selection algorithm has been proposed. Precisely, there are three modes in the proposed algorithm named as (1) cellular mode, (2) Reuse Mode, and (3) Dedicated mode. The mode selection will depend on UEs' location in the cell, amount of interference, transmitted power, required throughput, and D2D scenario. The novelty of the proposed algorithm is that it is adaptive and modify itself as per the D2D scenario. Figure 2.5 presents a generalized flow chart of the algorithm. Firstly, it collects various parameters like the location of UEs, SINR value, outage probability, throughput, and D2D scenario. Then it compares the values with predefined threshold levels. Then it sends the compared result to various check points, and finally, it assigns the appropriate mode for the intended UE. To establish a D2D link, resource blocks (RBs) need to be available at the D2D communication request. However, each base station or eNodeB has a limited no of RBs. eNodeB will decide how many RBs are available for a D2D connection.

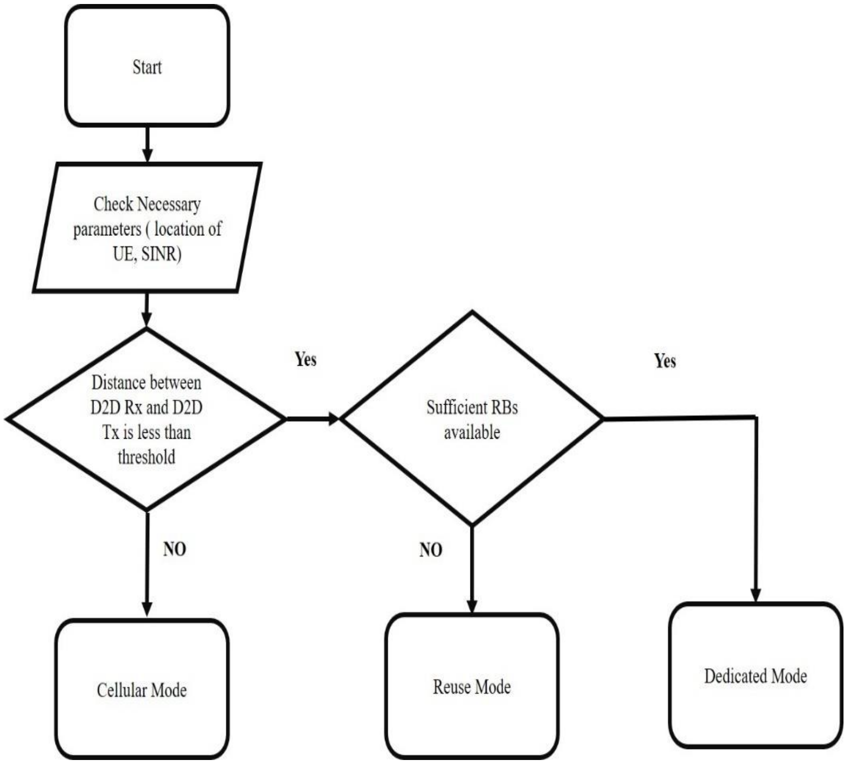


Figure 2.5. Flow chart for mode selection algorithm

The algorithm works as follows-

1. Firstly, the D2D terminal sends searching signals to each other with power set by the base station or eNodeB and estimates the received signal powers (P_{ij} and P_{ji}).
2. Secondly, D2D terminals estimate interference plus noise power with/without their own base station signal present in the downlink.
3. Thirdly, D2D terminals estimate interference plus noise power in uplink with/without terminals transmitting in their cell.
4. Fourthly, D2D terminals send the found information to the base station to support the mode selection.
5. After the fourth step, the corresponding base station or eNodeB decides on the number of dedicated and cellular mode resources allocated to the D2D terminals in uplink/downlink based on cellular load.
6. After this process, eNB decided on the maximum transmitted power the D2D terminal can use for several direct modes.
7. Then it estimates the SINR for each communication mode and estimates the throughput based on SINR.
8. Finally, it selects the mode which provides height throughput

2.4 Model description for algorithm testing

In this section, two different system models are presented for simulation of the proposed mode selection technique.

2.4.1 Single-cell general model

First of all, a single cell scenario has been considered for designing the algorithm. Then, a single base station (eNode-B in LET-A, or BS) is evaluated at the center of the cell, and multiple UEs are considered for D2D communication and cellular communication. Figure 2.6 shows the single-cell system model for designing the mode selection algorithm.

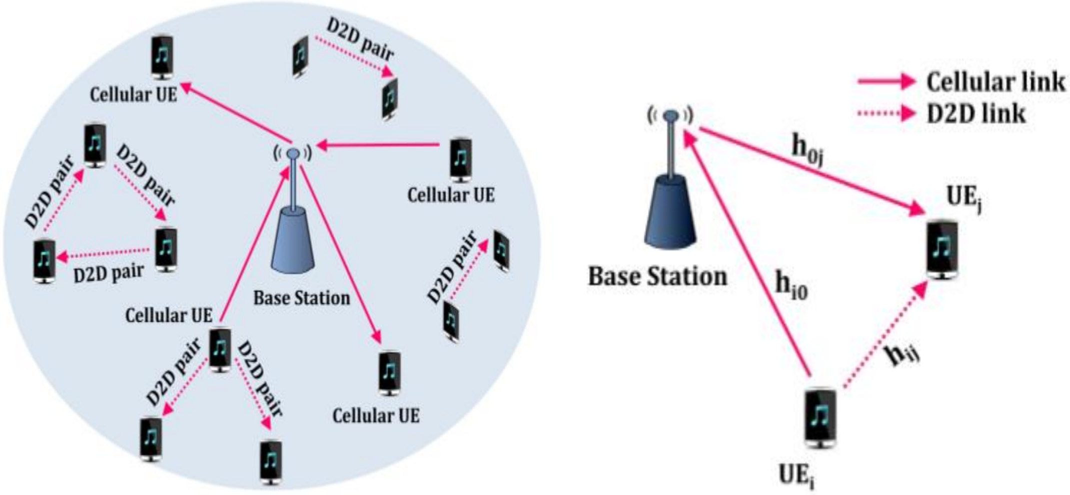


Figure 2.6 System model for mode selection

Let N_u is the total number of active UEs in the cell which are uniformly distributed. A communication link has been named a cellular link when a UE communicates with another UE via the base station or eNode-B. A direct link between UEs has been known as D2D direct link, and such UEs are called D2D UE. It also has been. Consider that cellular resources are shared with D2D resources. The selection of mode depends on link quality and SINR value at the receiver. The cellular UEs can be affected by interference due to sharing the same resources to the D2D UEs. The minimum value of SINR with minimizing outage of cellular link for which a link can exist between UE_i to UE_j in cellular mode is given by,

$$\gamma_{ij}^{c}=\text{arg min } \{\gamma_{i0}, \gamma_{0j}\} \quad \forall\, i, j = \{1,2, \ldots N_u\} \tag{2.6}$$

Where γ_{i0} is SINR for uplink UE_i to BS and γ_{0j} is the SINR for downlink BS to UE_j. Considering intra-cell interference, γ_{i0} and γ_{0j} can be calculated as

$$\gamma_{i0} = \frac{p_{io} \, \| h_{io} \|^2}{\sum_{k=1, k\neq i}^{Nu} p_{int,k} + N_0} \forall\, i \tag{2.7}$$

$$\gamma_{0j} = \frac{p_{oj} \, \| h_{oj} \|^2}{\sum_{k=1, k\neq j}^{Nu} p_{int,k} + N_0} \forall\, j \tag{2.8}$$

Where p_{ij} is the transmitted power and h_{ij} is channel gain of the i-j link.

$p_{int,k}$ is the interference power from UE$_k$ N$_0$ is the AWGN power spectral density in watts/Hz. Similarly, for D2D direct mode from UE$_i$ to UE$_j$, minimum SINR is given by,

$$\gamma_{ij} = \frac{p_{ij} \parallel h_{ij} \parallel^2}{\sum_{k=1,k\neq i}^{Nu} p_{int,k} + N_0} \forall\, i,j \tag{2.9}$$

2.4.2 Problem formulation for single-cell general model

Let selection of UEs are defined as a finite index set U with N$_u$ elements.

U= {1,2,…,N$_u$ }. UE$_i$, i ∈ U will communicate with UE$_j$, j ∈ Ueither in cellular mode or in D2D direct mode. The end-to-end throughput of the cellular link is half of the minimum value between the uplink and the downlink throughput since the BS relays data from UE$_i$ to UEj, the same resources are used for both uplink and downlink transmissions.

Therefore, the overall throughput of the system model can be formulated as

$$T_{max}=\text{Max}\ \{\sum_{i,j\in U} [\tfrac{1}{2}\alpha_{ij} log_2(1+\gamma_{ij}^c)+(1-\alpha_{ij}) log_2(1+\gamma_{ij}^d)]\} \tag{2.10}$$

The SNR values for both the modes are higher than or equal to its threshold value assigned by the BS. Here $\alpha_{ij} \in \{0,1\}$ is mode indicator. $\alpha_{ij} = 1$ for cellular UEs and $\alpha_{ij} = 0$ for a D2D User equipment. Now let us define a cluster. A cluster is defined as a collection of links that share mutual resources underlying the cell. Consider total L links in a cluster sharing the same resources of cellular uplinks or downlinks UE$_k$ in U$_c$. Reuse of resource indicator, ε_k^{ij} can be defined for each section in L such that ε_k^{ij} = 1 if an i-j link in L reuses the resource of UE$_k$ in Uc. Clustering will introduce cochannel interference, which can be formulated as

$$\gamma_{k0}^c = \frac{p_{ko} \parallel h_{ko} \parallel^2}{\sum_{i=1,i\neq k}^{L} p_{i,k} \parallel h_{ik} \parallel^2 + N_0} \tag{2.11}$$

Where $\gamma_{k0}^c$is the SINR of the UE$_k$-BS link for an uplink time slot.

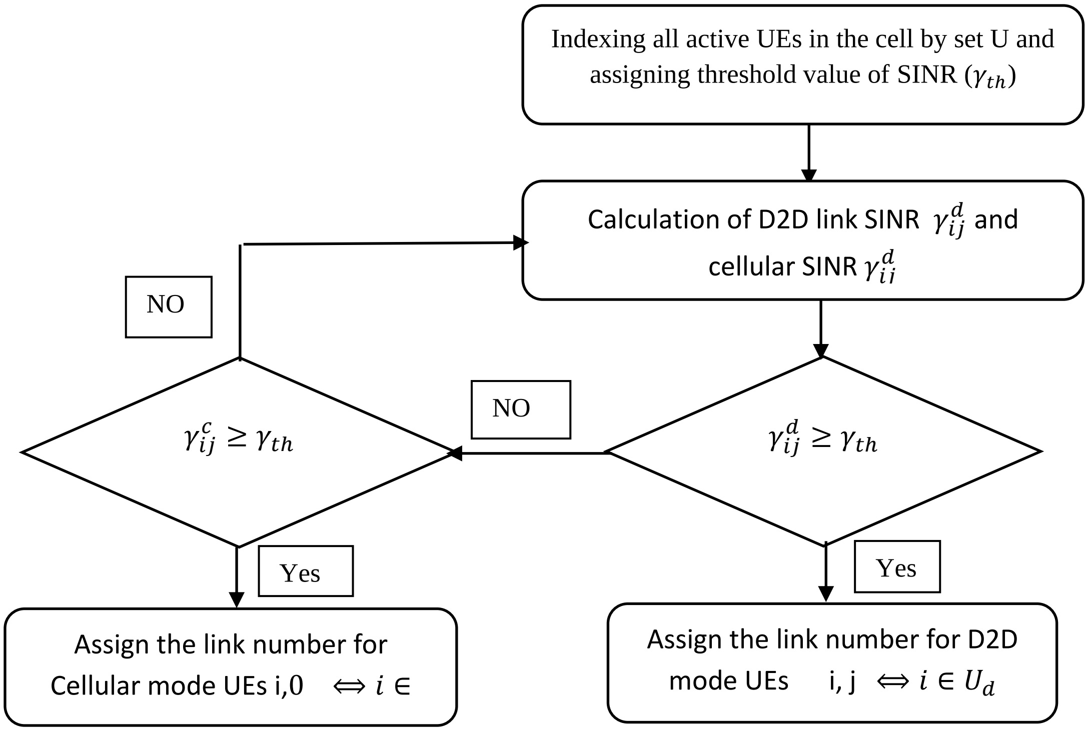


Figure 2.7. Flow chart for Reuse mode of operation

The number of essentials in set Uc is Nc, and the number of elements in the set U_d is N_d. Now a UE can be allied with a single mobile link or multiple D2D links, or a grouping of both. Clustering allows the reuse of the same radio resource for the entire group of UEs. It improves the utilization of radio resources and hence improves spectral efficiency. Figure 2.7 shows a flow chart for the reuse mode of operation.

2.4.3 Problem formulation for Uplink Resource Sharing model

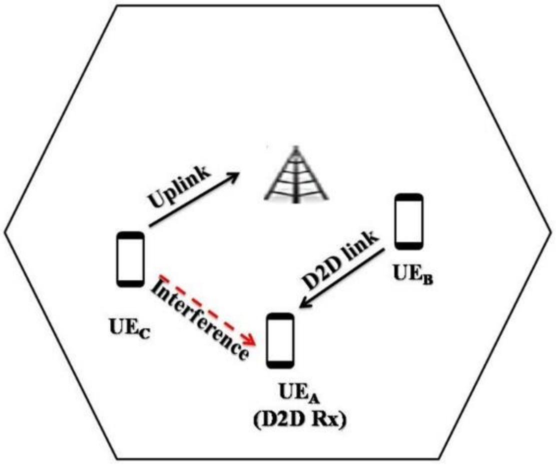


Figure 2.8 Uplink resource sharing scenario

Figure 2.8 illustrates a scenario where a cellular uplink resource has been shared to establish a D2D link using a spectrum reuse mode of operation. Consider, UE$_C$ is communicating with eNB using the uplink cellular channel at time instant $T_{1,}$ and eNB has assigned resource block RB$_1$ to UE$_C$ for this purpose. At the same time, instant T_1, UE$_B$ is communicating with UE$_A$ using the same resource block RB$_1$. Sharing of uplink resource block introduces interference to UE$_{A,}$ which receives a signal from UE$_B$ during time interval T_1. If the distance between UE$_C$ and UE$_A$ is dC$_A$ and the initial transmitted power from UEc is Pc then received interference power can be expressed as

$$\text{Pint} = c\,.\,(\,d_{CA}\,)^{-\alpha}\,P_c \qquad (2.12)$$

Here c and α are representing path loss constant and path loss coefficient, respectively. If the initial transmitted power of UE$_B$ is P_d and the distance between UE$_B$ and UE$_A$ is dB$_{A,}$ then the received signal power of the D2D link at UE$_A$ can be expressed as

$$P_{sig} = c\,.\,(\,dB_A)^{-\alpha}\,P_d \qquad (2.13)$$

Consider, h_C is the channel coefficient of interference channel and h_D is the channel coefficient of D2D channel, σ^2 is the Additive White Gaussian Noise power,

Hence, Signal to noise plus interference ratio of D2D link at UE$_A$ can be expressed as

$$\gamma_D = \frac{|h_D|^2\ \text{Psig Pd}}{|h_C|^2\text{Pint} + \sigma^2} \qquad (2.14)$$

$$\text{Or, } \gamma_D = \frac{c.|h_D|^2 d_{BA}^{-\alpha}}{c.|h_{C|2}\,P_C\ d_{CA}^{-\alpha} + \sigma^2}$$

Suppose h_D and h_C are independently following an exponential distribution.

$x=|h_D|^2$ Psig, $y= |h_C|^2$ Pint$+ \sigma^2$, a=Psig, b=Pint, $\delta=\frac{1}{\sigma^2}$

Therefore, probability density function of x and y can be formulated as

$$f(x) =\frac{1}{a}\exp\left(\frac{-x}{a}\right) U(x)$$

$$f(y) = \frac{1}{b}\exp\left(\frac{-y}{b} + \frac{1}{b\delta}\right) U\left(y- \frac{1}{\delta}\right)$$

Therefore, the probability density function of $z = \frac{x}{y}$ can be formulated as

$$f(z)=\int_{\sigma^2}^{\infty} yf(yz, y)dy=\left[\frac{\sigma^2}{(a+bz)} + \frac{ab}{(a+bz)^2}\right]\exp\left(-\frac{z\sigma^2}{a}\right)$$

CDF can be expressed as $F(z)=\int_0^z\left[\frac{\sigma^2}{(a+bt)} + \frac{ab}{(a+bt)^2}\right] \exp\left(-\frac{t\sigma^2}{a}\right)dt$

$$=\int_0^z \frac{\sigma^2}{(a+bt)} \exp\left(-\frac{t\sigma^2}{a}\right) dt + \int_0^z \frac{ab}{(a+bt)^2} \exp\left(-\frac{t\sigma^2}{a}\right)dt$$

$$=\int_0^z \frac{\sigma^2}{(a+bt)} \exp\left(-\frac{t\sigma^2}{a}\right) dt+ \left[\frac{-a\exp\left(-\frac{t\sigma^2}{a}\right)}{a+bt}\right]_0^z -\int_0^z \frac{\sigma^2}{(a+bt)} \exp\left(-\frac{t\sigma^2}{a}\right) dt$$

$$=1 - \frac{a}{a+bz} \exp\left(-\frac{z\sigma^2}{a}\right) \qquad (2.15)$$

Replacing values of a, b, z in eq. (2.15) and using eq. (2.12) & eq. (2.13),

$$F(z)=F(\gamma_D)= 1- \frac{P_d d_{BA}^{-\alpha}}{P_d d_{BA}^{-\alpha}+\gamma_D P_C d_{CA}^{-\alpha}}\exp\left\{- \frac{\sigma^2\gamma_D}{P_d d_{BA}^{-\alpha}}\right\}$$

Therefore, the outage probability of the D2D link at UE_A can be calculated as

$$Pout=Pr\,[\gamma_D<\gamma_{th}] =1- \frac{P_d d_{BA}^{-\alpha}}{P_d d_{BA}^{-\alpha}+\gamma_{th} P_C d_{CA}^{-\alpha}}\exp\left\{- \frac{\sigma^2\gamma_{th}}{P_d d_{BA}^{-\alpha}}\right\}$$

$$\cong 1- \frac{P_d d_{BA}^{-\alpha}}{P_d d_{BA}^{-\alpha}+\gamma_{th} P_C d_{CA}^{-\alpha}}\left[1- \frac{\sigma^2\gamma_{th}}{P_d d_{BA}^{-\alpha}}\right] =\frac{\gamma_{th}[P_C d_{CA}^{-\alpha}+ \sigma^2]}{P_d d_{BA}^{-\alpha}+\gamma_{th}P_C d_{CA}^{-\alpha}} = \frac{\gamma_{th}[I_r+\frac{1}{\gamma}]}{1+\gamma_{th}I_r} \qquad (2.16)$$

Here γ_{th} is the threshold value of SINR for the D2D link. Outage probability signifies the probability of the nonexistence of a D2D link due to cellular interference. It shows the probability of the D2D link SINR value falling below the predefined threshold. It projects D2D link-breaking probability under cellular uplink interference. Ir is defined as the interference power ratio at the receiver, and γ is the SNR value at the receiver for the D2D transmission link.

Consider dmax is the maximum allowable distance between UE_B and UE_A for which D2D link has threshold outage probability, Pout_th

Therefore, the condition for a successful D2D link is

$$\mathrm{Pout} < \mathrm{Pout\_th}$$

Or, $\frac{\gamma_{\mathrm{th}}[\,\mathrm{P_C}\,\mathrm{d}_{\mathrm{CA}+\,\sigma^2}^{-\alpha}\,]}{\mathrm{P_d}\mathrm{d}_{\mathrm{BA}+}^{-\alpha}\gamma_{\mathrm{th}}\mathrm{P_C}\,\mathrm{d}_{\mathrm{CA}}^{-\alpha}} < \mathrm{Pout\_th}$

In case, dBA=dmax then, $\frac{\gamma_{\mathrm{th}}[\,\mathrm{P_C}\,\mathrm{d}_{\mathrm{CA}+\,\sigma^2}^{-\alpha}\,]}{\mathrm{P_d}\mathrm{d}_{\mathrm{max}+}^{-\alpha}\gamma_{\mathrm{th}}\mathrm{P_C}\,\mathrm{d}_{\mathrm{CA}}^{-\alpha}} = \mathrm{Pout\_th}$

Or, $\mathrm{Pout\_th}\ \mathrm{P_d}\mathrm{d}_{\mathrm{max}}^{-\alpha} + \mathrm{Pout\_th}\ \gamma_{\mathrm{th}}\mathrm{P_C}\ \mathrm{d}_{\mathrm{CA}}^{-\alpha} = \gamma_{\mathrm{th}}[\ \mathrm{P_C}\ \mathrm{d}_{\mathrm{CA}}^{-\alpha} \quad + \ \sigma^2]$

Or, $\mathrm{Pout\_th}\ \mathrm{P_d}\mathrm{d}_{\mathrm{max}}^{-\alpha} = \gamma_{\mathrm{th}}[\ \mathrm{P_C}\ \mathrm{d}_{\mathrm{CA}+\,\sigma^2}^{-\alpha}\ ]$ - $\mathrm{Pout\_th}\ \gamma_{\mathrm{th}}\mathrm{P_C}\ \mathrm{d}_{\mathrm{CA}}^{-\alpha}$

Or, $\mathrm{d}_{\mathrm{max}}^{-\alpha} = \frac{\gamma_{\mathrm{th}}\mathrm{P_C}\ \mathrm{d}_{\mathrm{CA}}^{-\alpha}\ [1-\mathrm{P_{out\_th}}] + \sigma^2\ \gamma_{\mathrm{th}}}{\mathrm{P_d}\ \mathrm{Pout\_th}}$

Or, $\mathrm{d}_{\ \mathrm{max}} = [\frac{\mathrm{P_d}\ \mathrm{P_{out\_th}}}{\gamma_{\mathrm{th}}\mathrm{P_C}\ \mathrm{d}_{\mathrm{CA}}^{-\alpha}\ [1-\mathrm{P_{out\_th}}] + \sigma^2\ \gamma_{\mathrm{th}}}]^{\frac{1}{\alpha}}$ (2.17)

Equation (2.16) provides outage probability of D2D link, and Equation (2.17) offers maximum allowable D2D link distance for a given signal to interference plus noise threshold (γ_{th}) under cellular coverage without applying any interference cancelation technique.

The objective of the interference cancellation technique is to minimize cellular interference on the D2D link. During demodulation, the receiver interference signal can be identified and canceled to enhance the quality of the D2D link. If the outage probability before applying interference cancelation is P_{BIC} and outage probability after applying interference cancelation technique is P_{AIC}, then the overall outage probability at the receiver can be calculated as,

$\mathrm{Pout} = 1-(1-P_{BIC})\ (1-P_{AIC})$ (2.18)

Here, P_{BIC} signifies the probability of not able to detect the interference signal at the receiver. If P_{BIC} increases chances of success of the detector to detect interference reduces.

Let the ratio of interference power to the signal plus noise at UE_A is given by,

$\gamma_{\mathrm{int}} = \frac{|\mathrm{h}_{\mathrm{C}|2}\ \mathrm{Pint}}{|\mathrm{h}_{\mathrm{D}|2\ \mathrm{Psig}} + \sigma^2} = \frac{|\mathrm{h}_{\mathrm{C}|2}}{|\mathrm{h}_{\mathrm{D}|2\ \mathrm{I_r}} + \sigma^2/\mathrm{P_{int}}} = \frac{|\mathrm{h}_{\mathrm{C}|2}}{|\mathrm{h}_{\mathrm{D}|2\ \mathrm{I_r}} + 1/\gamma}$ (2.19)

Therefore, the outage probability of detection of interference at UE_A before the interference cancelation process can be calculated as

$P_{BIC} = \Pr\ [\gamma_{\mathrm{int}} < \gamma_{\mathrm{th}}] = 1 - \frac{\mathrm{I_r}}{\mathrm{I_r}+\gamma_{\mathrm{th}}}\exp\{-\frac{\gamma_{\mathrm{th}}}{\mathrm{I_r}\gamma}\} \cong 1 - \frac{\mathrm{I_r}}{\mathrm{I_r}+\gamma_{\mathrm{th}}}(1 - \frac{\gamma_{\mathrm{th}}}{\mathrm{I_r}\gamma})$ (2.20)

Outage probability of detection of interference at UE_A after interference cancelation process can be calculated as

$$P_{AIC} = 1\text{-}\exp\left(-\frac{\gamma_{th}}{\gamma}\right) \cong 1\text{-}\left(1\text{-}\frac{\gamma_{th}}{\gamma}\right) = \frac{\gamma_{th}}{\gamma} \qquad (2.21)$$

$$\text{Therefore, Pout} = 1\text{-}\frac{I_r}{I_r+\gamma_{th}}\left(1 - \frac{\gamma_{th}}{I_r\gamma} - \frac{\gamma_{th}}{\gamma}\right) \qquad (2.22)$$

2.5 Simulation result

The simulation setup parameters are given below in table 2.1. Figure 2.9 shows the simulation result for the single-cell general model. It represents the D2D distance vs. path loss plot for cellular mode and D2D mode of communication. The simulation result shows a D2D link distance up to 40meter D2D-LOS link maintains less than 80 dB path loss underlying cellular networks. Figure 2.10 shows maximum transmit power vs. distance between D2D Tx and BS plot, whereas Figure 2.11 presents a signal to interference plus noise ratio vs. normalized base station power plot. Simulation parameters are taken as per 3GPP macro cell propagation model mentioned in 3GPP TR 36.931 version 9.0.0 Release 9 and reference [52] .

Table 2.1: Simulation parameters for single cell general model

Parameter	Specification
Channel Bandwidth	10 MHz
Noise Power Density	-174 dBm/Hz
Simulation Runs	250
Path-loss Models	Cellular mode: 128.1+37.6 log10(d[km]) D2D mode: 148 + 40 log10(d[km])
Maximum UE transmit power	Cellular mode :24 dBm D2D mode : 21 dBm
Shadow fading standard deviation.	Cellular mode:10 dB D2D mode: 12 dB
SNR threshold	10 dB

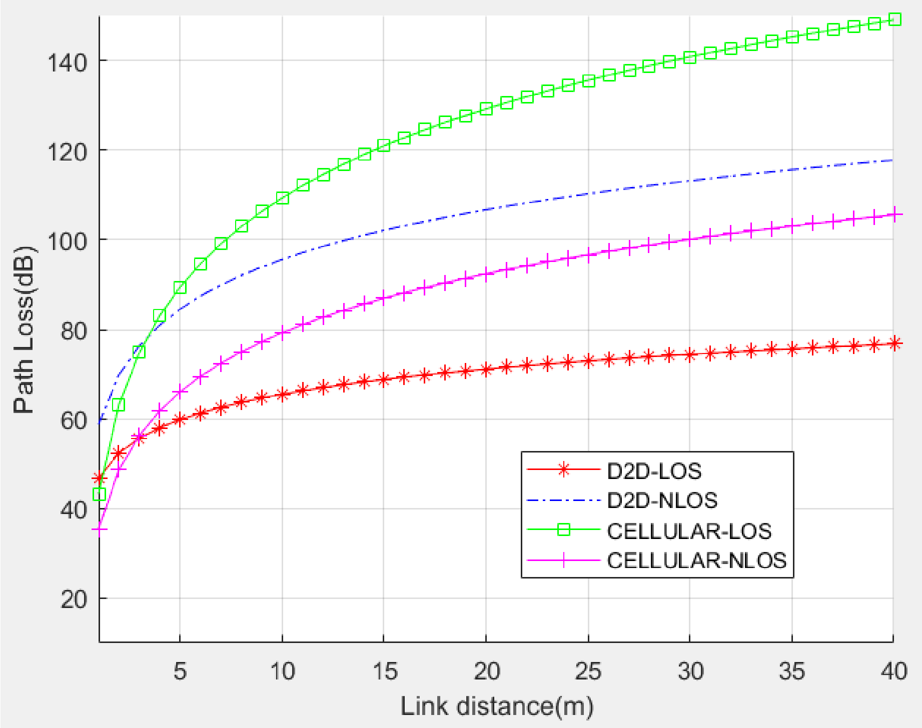


Figure 2.9 Pathloss vs. D2D Link distance

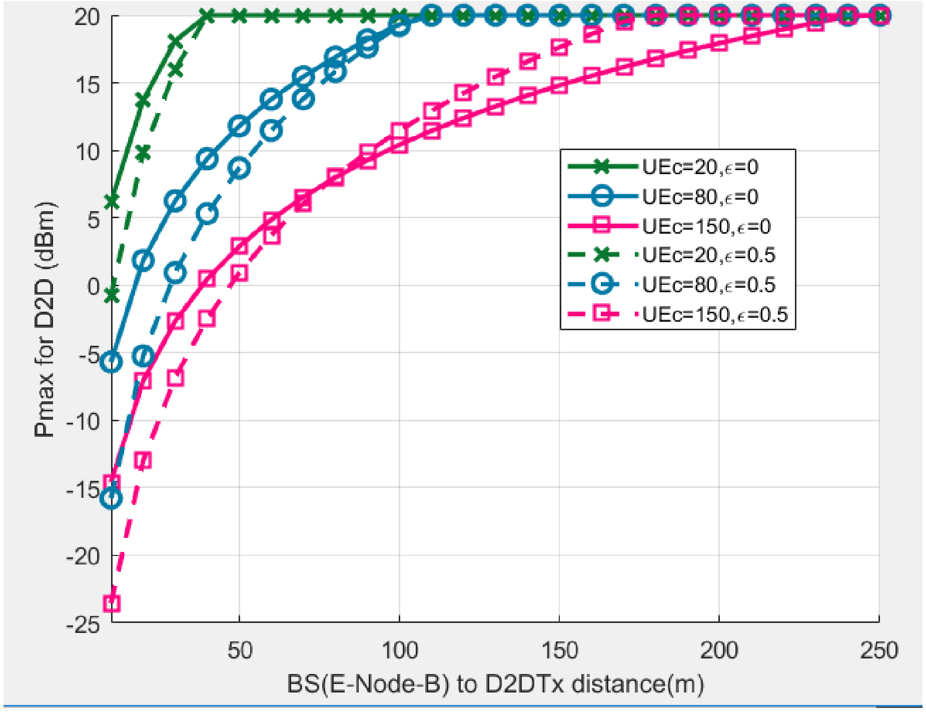


Figure 2.10 Maximum transmit power vs distance between D2D Tx and BS.

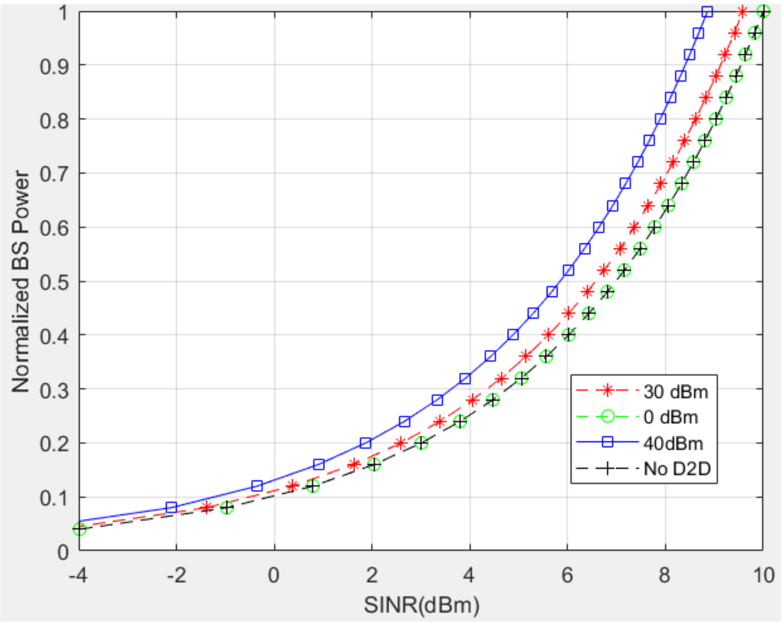


Figure 2.11: Normalized base statin power vs. SINR

Figure 2.12 shows the simulation result for the Uplink Resource Sharing model. It offers a comparison of outage probability for the traditional link and a link with an interference control approach.

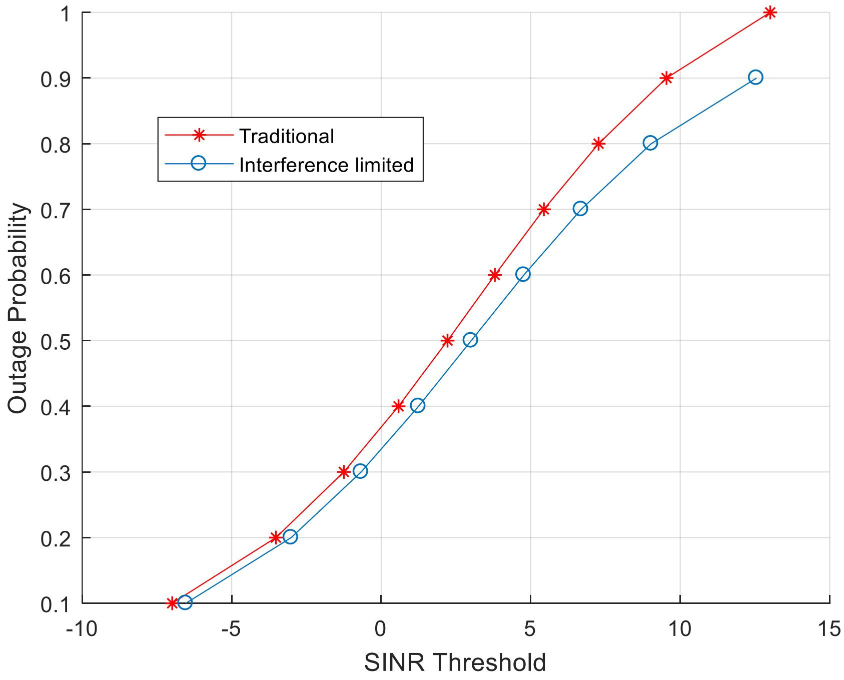


Figure 2.12: SINR vs. outage probability curve for Traditional mode and interference-limited mode

2.6 Summary

This chapter describes the resource allocation technique based on model selection. It has been proposed that three modes, i.e., cellular, Reuse, and dedicated mode, can be considered for optimal model selection algorithm. Furthermore, mathematical calculation of outage probability for two different scenarios, i.e., single-cell general and uplink sharing scenario, has been illustrated. Finally, simulation results are presented for the proposed mode selection technique.

Chapter-3

Performance analysis of service discovery protocols for D2D communication

3.1 Introduction

Service discovery protocols are a set of rules for searching nearby devices and establishing communication links among them. There are two types of service discovery protocols, e.g., distributed network protocols and centralized network protocols. Examples of distributed network protocols are reactive protocol and proactive protocol. An example of centralized network protocols is the Push mechanism-based direct discovery protocol and Network assistance-based EPC level protocol. Faustin Ahishakiye et al. in[53] reported two types of service discovery protocol, i.e., reactive and proactive. The main idea of the reactive protocol is that User Equipment that proposes to begin Device to device communication with another User's equipment initiates proximity service discovery requests utilizing a pull service detection process.

In contrast, the proactive protocol is originated by the base station or eNodeB, which is serving user equipment before any device-to-device tier requests have been established[53]. This method is known as push service discovery. Here base station transmits periodic messages to all user types of equipment to register in device-to-device service discovery application. The intended UE gives replies for establishing a D2D service. Table 3.1 shows a comparison of existing service discovery protocols. Device to Device communication using a licensed cellular spectrum band is a novel approach in LTE-A standard, introduced in March 2011 by 3GPP release 12 [54]. D2D is going to be an integral part of the 5G cellular network. Short-range D2D communication using unlicensed band already exists and also commercially available. For example, transferring of files between two UEs using blue tooth, exchanging information among UEs with the help of mobile apps and Wi-Fi, Mobile hotspot applications, NFC applications already exist [55]. Popular mobile application ‘Whatsapp’ can use Near Field Communication (NFC)[56] which is available in all smartphones for peer discovery. But all these techniques belong to unlicensed band communication; they do not use the existing cellular spectrum for resource sharing. Therefore they are not secure and also not manageable centrally by the base station or eNodeB. It has been reported in [14] that spectrum sharing is possible between licensed cellular networks and infrastructure-less wireless networks. Moreover, D2D users can communicate using the same resource spectrum as the cellular user uses to communicate with the base station. It is possible to overcome interference challenges by sharing the same resources with D2D and cellular user through power control technique[53], [57].

Table3.1. Existing service discovery protocol

Network Types	**Distributed Networks** **(MANETs/ WLAN/WiFi-Direct)**	**Centralized Networks(LTE-A)**
Device Discovery Mechanism	Proactive and Reactive	Direct discovery EPC assist discovery
Operating Frequency Band	Unlicensed ISM band	Licensed Band
Service Discovery protocol types	Carrier Sense Multiple Access	Direct discovery: Push mechanism based protocol EPC level discovery: Network assistance based protocol(Ref:ITU 3GPP release 12)
Limitations	1. Security Challenges 2. Resource allocation and management challenges 3. Protocol Overhead problems	Protocol design challenges in case of out of coverage area of eNodeB

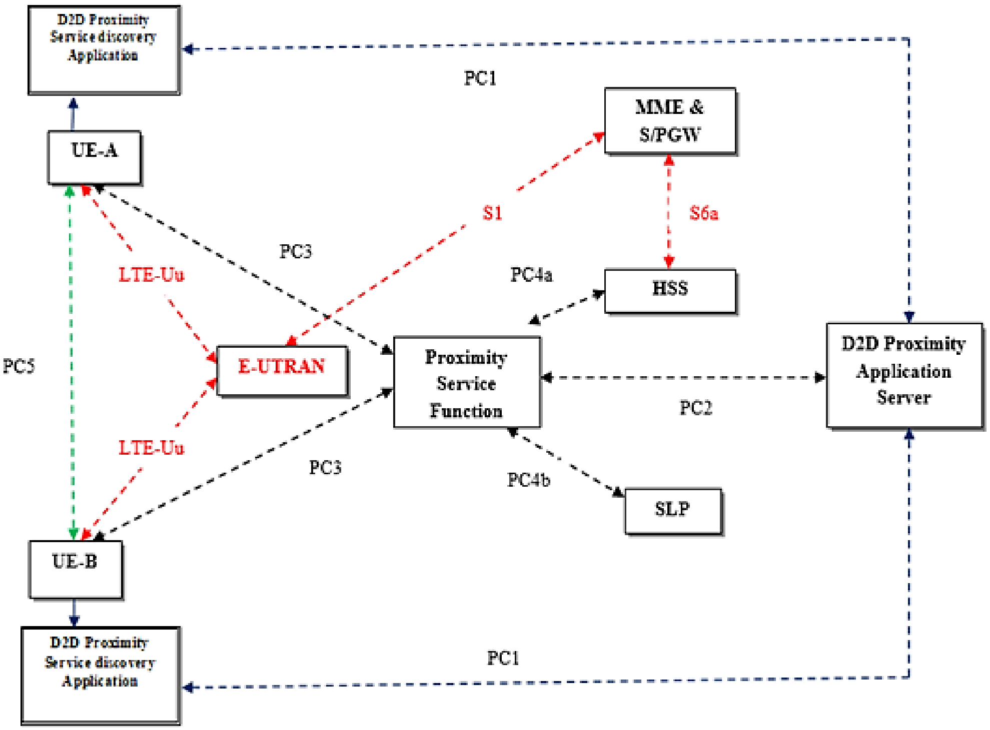


Figure 3.1. LTE-A architecture for supporting service discovery D2D communication.

Figure 3.1 shows the Non-Roaming Reference Architecture mentioned in 3GPP release 12. The development of 3GPP release 12 was focused on public safety communications[58]. According to this architecture, direct proximity discovery is possible if the UEs are under radio coverage of E-UTRAN. In the case of Direct discovery, any mobile user equipment discovers all other mobile users who are sounding. It is possible utilizing proximity service function, proximity application server, and proximity service find application. All UEs have an application known as the D2D proximity service discovery application, through which they can connect to the D2D proximity application server. A server that handles clients' requests to discover nearby devices can only respond if there are available D2D services that can be ensured by proximity service function. According to 3GPP release 12, two different models for proximity service discovery is possible. Model-A has been shown in Figure 3.2, and Model-B has been illustrated in Figure 3.3.

Model-A ("I am here"): This model consists of announcing user equipment and monitoring user equipment. The announcing device sends a message to the neighbor devices that it can provide proximity services. A monitoring device immediately responds to the announcing device using acknowledge only if it wants to get that service. A proximity function is used to establish a connection between announcing device and the monitoring device[32].

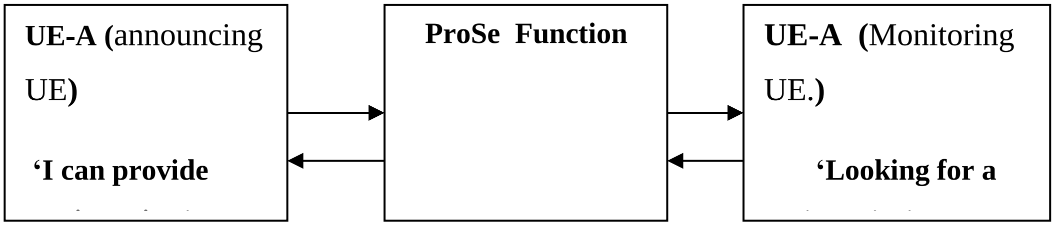


Figure.3.2. Concept of model A

Model-B ("who is there?" / "are you there?"): This model consists of a Discoverer device and a Discovery device. A discoverer device searches for proximity services, whereas a Discovery device reacts on a request provided by a discoverer device only if it is interested in providing a service. A proximity function is used to establish a connection between the Discoverer device and the discovery device [7].

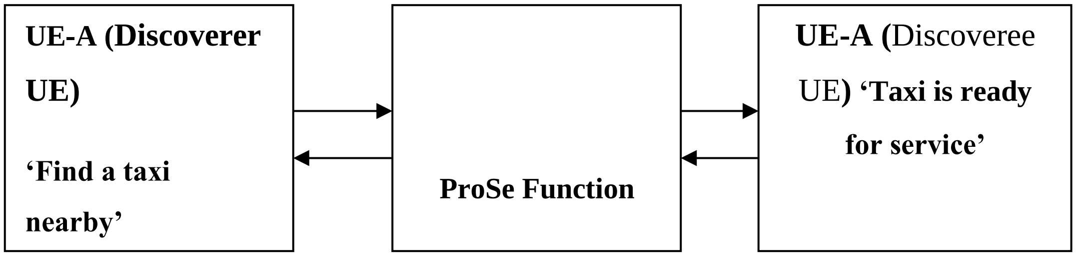


Figure. 3.3 Concept of Model B.

3.2 Proposed design of service discovery protocol.

UEs that want service discovery may be under the coverage area of UTRAN. Also, it is possible that They are not in coverage of UTRAN. If they are not in coverage, there must be some alternatives like WLAN or WiFi to be connected. Architecture has been proposed for the same in Figure 3.11.

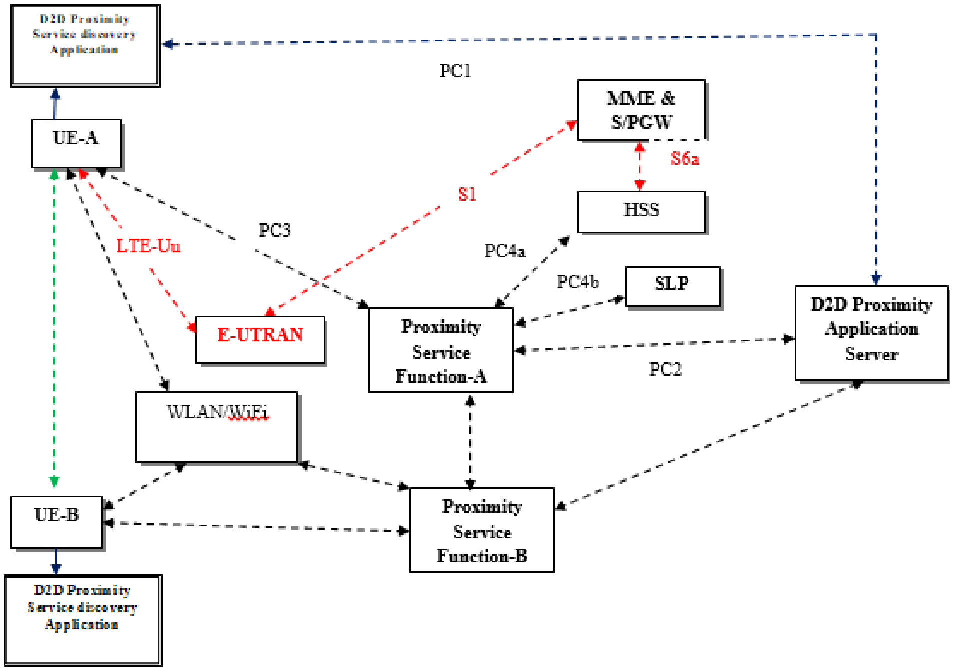


Figure 3.4. D2D service discovery with WLAN support in case of out of E-UTRAN coverage

Figure 3.4, UE-B represents a mobile user under WLAN coverage but out of the range of E-UTRAN or conventional mobile network. In contrast, another mobile user defined by UE-A is under the capacity of a mobile network. For D2D service discovery, the model will follow the following steps.

1. In the first step, UE-A initiates a proximity service request for communication with UE-B through the proximity service function-A. Some essential parameters need to be provided to the proximity service function for this service request to be performed. These parameters are the location of UE-A and UE-B, EPC ProSe user ID, Third-party application ID, WLAN link layer ID, Application layer User ID of UE-A, Window parameter, and Session ID. This request of proximity service discovery remains valid for the entire window or the session time mentioned. After the session time, the corresponding UE needs to retransmit the request if the previous request was failed or a new request needs to be initiated.
2. Proximity service Function-A communicates with the Proximity Application Server my means of MAP request in the second step. This MAP request is a search

request which verifies the records of the intended service and requests the user’s authenticity.

3. Once the proximity application server's authenticity of UE-A and UE-B is verified, it sends a MAP response to the proximity application function-A and conforms authenticity of UE-B.
4. Proxy Function-A sends a request to Proxy Function-B to recovers subscriber B's record in the fourth step. Then Proxy-Function-B checks the present status, locations, and permissions of UE-B. Again, WLAN ID plays a crucial role for this task to complete.
5. Finally, communication occurs between UE-A and UE-B after successful handshaking between Proxy function- A and Proxy function-B.

3.3 Algorithm for Service discovery Protocols

In this section, an algorithm has been proposed for reactive service discovery, and proactive service discovery and calculation of control overhead are also discussed in detail. As discussed in the earlier section, a D2D proximity service request remains valid for a session window; therefore, a timeframe-based analysis is more appropriate for the calculation of control overhead. Furthermore, control overhead depends on the required number of service discovery messages to successfully establish a D2D proximity service session window between Two UEs.

The scenario presented in Figure 3.4 present only two UEs that communicates for D2D proxy service. The communication steps mentioned in the earlier section are valid for any number of mobile users who want proximity service. We discuss reactive and proactive service discovery procedures separately to analyze the required number of service discovery messages.

3.3.1 Reactive procedure for service discovery (UE-A to UE-B)

Step-1: UE-A wants reactive service discovery. So, it activates the proxy application available in the device and sends a request to the base station by proximity service function-A. The request consists of various parameters like UE-A, ID of targeted D2D pair, Window parameter, etc.

Step-2: Now, the request will only be entertained if UE-A has permission for that proximity service. Therefore, it is forwarded to the D2D proximity application server to verify the authenticity of the request. If it is a valid request, it sends a response to proxy function -A, which requests proxy function -B for D2D service to be initiated with UE-B.

Step-3: If UE-B is available and willing to communicate with UE-A, it sends the acknowledgment through proxy function B.

Step-4: Once confirmation is received base station informs UE-A about the proximity location of UE-B and instructs UE-A for initialization of communication.

Step-5: UE-A sends a Direct invitation to UE-B for the device-to-device communication and the resource allocated by the base station.

Step-6: UE-B sends an acknowledgment to UE-A and confirms that they can start D2D communication. Therefore a D2D session starts between UE-A and UE-B

Step-7: Once the session over, a D2D termination message is transmitted by the base station to corresponding UEs.

In this reactive protocol total, seven handshakes are required in each session for D2D proximity service discovery.

3.3.2 Proactive procedure for service discovery (UE-A to UE-B)

In proactive protocol base station periodically broadcast a message regarding the availability of proxy services. This message is received only by authenticating user equipment that is registered in the network for proximity service. Any active UE running proxy service application can respond immediately to such a message if it requires that service. The steps are mentioned below-

Step-1: The base station broadcast all available proximity service information to all active UEs registered for proximity service.

Step-2: UEs that want to do D2D communication or have proximity service requirements immediately reply to the base station to message that they want that service. This reply message consists of information of their present location, targeted D2D pair, and other related information.

Step-3: The base station updates the position information and checks D2D communication criteria, available resource block, channel condition, and then if all requirements are fulfilled, sends the notification about the proximity of D2D peer to one of the UE who wants D2D communication.

Step-4: After getting a notification from base station UE-A or UE-B, send an acknowledgment to a base station that it wants to start the D2D session.

Step-5: The base station starts the session and sends the session ID to another UE.

Step-6: Another UE also accept it, and the session started

Step-7: Once the session over, a D2D termination message is transmitted by the base station to corresponding UEs.

Proactive service discovery also required a total of seven handshake signals to establish a proxy service discovery process. Out of these seven handshakes, one is reserved for broadcasting all available proxy services to UEs by the base station.

3.3.3 Analysis of protocol overhead for proactive and reactive process

Control overhead depends on the required number of service discovery messages for starting the D2D session between active UEs. Let us consider that there are total N numbers of active UEs in a two-tier network at a specific time. Out of these N UEs, only M numbers of D2D requests present at a particular time. That means M D2D session requests have existed where $M \leq N$. Therefore, if these pairs use the reactive protocol to establish a D2D session, there will be 7M handshakes, whereas, in the case of proactive protocol, it will be T+6M handshakes. Here, T represents time slots for a multicast message transmitted by the base station to all active UEs. Let us consider that the number of D2D requests within a one-time slot is identical over different time slots. Here N numbers of UEs that produce M numbers of D2D requests per time slot have a pdf expressed by the following expression.

$$\rho = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(M-\mu)^2}{2\sigma^2}\right) \tag{3.12}$$

Here μ is the mean of device request σ is the Standard deviation of a Gaussian random process. A Gaussian process has been considering representing the D2D proximity request generation by different UEs in the two-tier network.

D2D can send proximity service discovery requests to the base station in any time slots out of T time slots, but the request doesn't have to happen in all time slots.

Protocol overhead for proactive is given by

$$(PO)_P = (T+6KM)/T \tag{3.13}$$

Protocol overhead for reactive is given by

$$(PO)_R = (K*7*M)/T \tag{3.14}$$

Here K represents the time slot of the actual generation of D2D proximity service request. T is the total number of observation time slots.

3.3.4 Simulation setup parameters

For simulation purposes, we have considered that UEs are randomly distributed in a two-tier network. Also, two different modes reuse mode, and dedicated mode of resource allocation schemes, are considered for analysis. Table 3.2 presents the various parameters and their values used for simulation setup. Simulation parameters are taken as per reference[53]

Table 3.2 Parameters for simulation setup.

Symbol	Parameter	Value
N	Total active UE	200
R	Cell radius	1 km
K	Active D2D pair	2, 4, 6,8,10
M	No of time slot with Nonempty D2D request	0,1,2,3,4,5…T
T	Total number of time slot per observation window	20
γ	SINR	0 to 10 dBm
D	Max distance for D2D communication	200m

3.3.5 Result and discussion

The result presented in Figure 3.5 compares reactive and proactive protocol in two-tier D2D networks. The presence of a total 200 active UEs has been considered, and a variable number of D2D proxy discovery requests (i.e., 2,4,6,8, and 10) has been taken per session window. The result shows that reactive protocol is a decent choice for fewer D2D proxy service requests (<5). In contrast, for an increasing number of D2D proximity service requests (>5), proactive protocol performs better than reactive. Both protocols are evaluated for dedicated mode and reuse mode of resource allocation technique discussed in the previous chapter with SINR threshold level of 0 to 10 dBm.

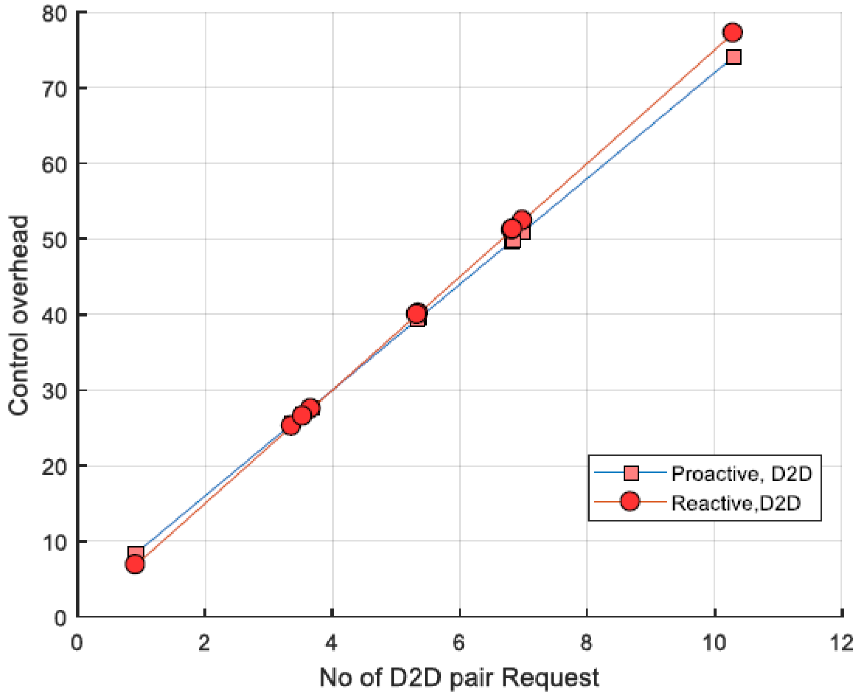


Figure 3.5 D2D request vs. Control overhead plot for reactive and proactive protocol

3.4 Summery

This chapter provides an analysis of the protocol for handling proximity service requests in the two-tier network. Different Models based on 3GPP have been presented in detail. Furthermore, control overhead analysis of reactive and proactive protocol has been discussed in the D2D scenario. Finally, a simulation has been conducted for 200 active UEs in reuse and dedicated mode of operation. Simulator result shows that for fewer D2D requests, the reactive protocol may be a decent choice. Still, as the number of D2D proximity requests increases, proactive protocol outperforms reactive protocol.

Chapter-4

Performance analysis of joint resource allocation and interference management for D2D communication

4.1 Introduction

It is essential in a two-tier network to manage the power of cellular link and D2D link so that D2D link outage probability should not increase or cellular connection is also not affected by D2D link while allocating same resources to the cellular link and D2D link. This chapter has reported a common resource sharing technique based on orthogonal precoding during downlink resource sharing. Also, comparative performance analysis of orthogonal precoding and traditional precoding for the proposed interference management technique has been illustrated in the chapter.

4.2 Resource block

A resource block is defined as the smallest unit of time-frequency slot that can be allocated to a mobile user. In Long Term Evaluation (LTE) standard, a resource block is 0.5 ms long in time and 180 kHz wide in frequency with 12 fixed subcarriers. In the 5G New Radio (NR) standard, one resource block contains 12 subcarriers like LTE, but depending on subcarrier spacings, the length of the resource block varies in the frequency domain. Table 4.1 shows the numbers of resource blocks and subcarriers for different bandwidths in LTE standard. In contrast, Table 4.2 shows the minimum and maximum resource blocks for other carrier spicing and channel bandwidth in the 5G NR standard.

Table 4.1 LTE resource block specification

BW (MHz)	**No of RB**	**UL Subcarriers**	**DL Subcarriers**
1.4	6	72	73
3	15	180	181
5	25	300	301
10	50	600	601
15	75	900	901
20	100	1200	1201

Table 4.2 5G NR resource block specification

μ	**Subcarrier spacings(kHz)**	**Minimum RBs**	**Maximum RBs**	**Minimum Channel Bandwidth (MHz)**	**Maximum Channel Bandwidth (MHz)**
0	15	24	275	4.32	49.5
1	30	24	275	8.64	99
2	60	24	275	17.28	198
3	120	24	275	34.56	396
4	240	24	138	69.12	397.44

4.3. Resource allocation

Resource allocation is a technique that involves the distribution of RBs to mobile users for uplink or downlink commination. In a traditional network, a base station allocates resources to the UEs under its network coverage. In a Two-tier network, the same RBs are shared for D2D link communication and cellular link communication. This type of resource allocation involves frequency reuse which introduces interference between cellular link and D2D link. Furthermore, the same resources are allocated among multiple D2D links in the device tier network, which generates interferences with each other. Precoding is the most proposing technique to tackle such interference challenges in the two-tier network.

4.4 Precoding

Precoding is defined as a technique where a transmitter sends coded information to a receiver through which the receiver can estimate the channel condition. Precoding technique can be used in downlink frame or uplink frame which includes channel state information generated by the various parameter of a channel state vector-like Channel Quality Indicator(CQI), rank indication (RI), precoding matrix indicator (PMI), and precoding type indicator (PTI)[59]. In various literature, it has been found that precoding techniques control interference problems and extend cell coverage[60], [61]. Orthogonal random precoding and codebook-based precoding with known CSI information are popular techniques for interference control in cellular downlink communication[60]. Codebook-based precoding techniques for cellular downlink sum-rate maximization in MU-MIMO have been illustrated in [62]. Orthogonal precoding can be a perfect choice in a two-tier network for device-to-device and cellular link interference control. LTE downlink utilized a precoding technique to control interference. In[63] concept of distributed precoding has been illustrated, and it has been claimed that precoding drastically improves the quality of the downlink by reducing adjacent cell interference in LTE.

4.5 Interference problem

Device-to-device communication enhances the overall system capacity of a two-tier network, but at the same time, it enables interference in the cellular tier and device tier. Resource blocks are limited, so the same resources are assigned to the cellular user link and device-to-device user link. This mode of resource allocation is called frequency reuse mode. Frequency reuse mode enhances the spectrum efficiency and accommodates more significant numbers of UEs. Still, it introduces interference while sharing the same downlink or uplink channel resource with the D2D channel. In most of the literature, binary power control technique has been considered for interference control[64][36]. In binary power control technique, the base station controls the transmitted power of cellular link and D2D link so that an acceptable throughput can be maintained for both the link, i.e., D2D link and cellular link. The prime limitation of the binary power control technique is that it compromises the performance of D2D links while cellular links are given more priority. Cell edge or UEs in remote places require D2D as the main priority compared to a traditional cellular connection. In some literature, geometrical location-based power control approaches have been mentioned as an interference control technique. The geometric approach-based procedure is also said to indicate that cellular link should not break while allocating resources for D2D connection. Therefore, priority has been given to the cellular link. The main disadvantage of the binary power control scheme and geometric approach based power control scheme is that there is more probability to break D2D link as compare to cellular uplink or downlink because these schemes are focused on how to improve cellular uplink or downlink quality while the same resource is allocated to D2D link. Interference can be avoided if channel state information is available to the base station. In the LTE system, the base station uses a precoding matrix to get channel state information, and then during downlink, it sends precode data to the receiving UE. This concept can also be implemented in device-tier networks to avoid interference challenges. In this chapter precoding-based technique has been proposed for joint resource allocation and interference control.

4.6 Analysis of interference scenario

An interference scenario is important for the analysis of the D2D system model. Signal to interference and noise ratio (SNIR) is the basic parameter for any system model based on interference scenario. Figure 4.1 presents a multicell single-hop D2D scenario. According to the scenario, UE_i acts as a D2D transmitter, and UE_j is a D2D receiver. Consider UE_i transmits average power P_i. The distance between UE_i and UE_j is d_i. Received signal power at UE_j is given by $P_j = \frac{P_i}{|U_i - U_j|^{\alpha}} = p_i/(d_i)^{\alpha}$. Here, α (>2) is the path loss coefficient. It is also known as the power decaying factor. U_i is the location of UE_i, and U_j is the location of UE_j. D2D receiver UEj suffers from two different types of interference, i.e., Cellular uplink/downlink interference and neighbor D2D link interference. Therefore received interference power at D2D receiver location U_j due to uplink/downlink interference or other D2D link interference located at U_k can be presented by $\sum_{k \neq i,j} \frac{P_k}{|U_k - U_j|^{\alpha}}$. Therefore, signal to interference plus noise ratio(SINR) at U_j , $SINR_j = \frac{\frac{P_i}{|U_i - U_j|^{\alpha}}}{N_0 + \sum_{k \neq i,j} \frac{P_k}{|U_k - U_j|^{\alpha}}}$. Here N_0 denotes ambient noise power level. The quality of the D2D link depends on $SINR_j$. A higher value of SINRj ensures that the D2D link is stronger enough to provide device tier service. $SINR_j$ may degrade in case interference signal power from neighbor D2D link or cellular uplink /downlink increases. In joint resource allocation and interference control technique, it is very important to decide which link needs to be given the highest priority. Therefore, there are two different cases in terms of link priority as per the following.

Case A: D2D is the primary link, and the cellular link is the secondary link.

In this case, the D2D link is the prime focused link that needs to be maintained during the allocation of the same resources, i.e., cellular uplink or downlink resources to the D2D link. According to the scenario of figure 4.1, successful reception of the signal at U_j is only possible if $SINR_j > \beta$, where β denotes predefined threshold value.

Case B: Cellular link is the primary link, and D2D is the secondary link. Let base station located at $\mathrm{U_k}$. It transmits a signal to a cellular UE at $\mathrm{U_c}$ during its downlink communication. Due to this transmission, it suffers from interference from a D2D transmitter located at $\mathrm{U_i}$ because it also initiates D2D transmission with the same resource block. In this situation, $\mathrm{SINR_c}$ at cellular UE receiver is given by,

$$\mathrm{SINR_c} = \frac{\frac{P_k}{|U_k - U_c|^{\alpha}}}{N_0 + \sum_{i \neq c,k} \frac{P_i}{|U_i - U_c|^{\alpha}}}.$$

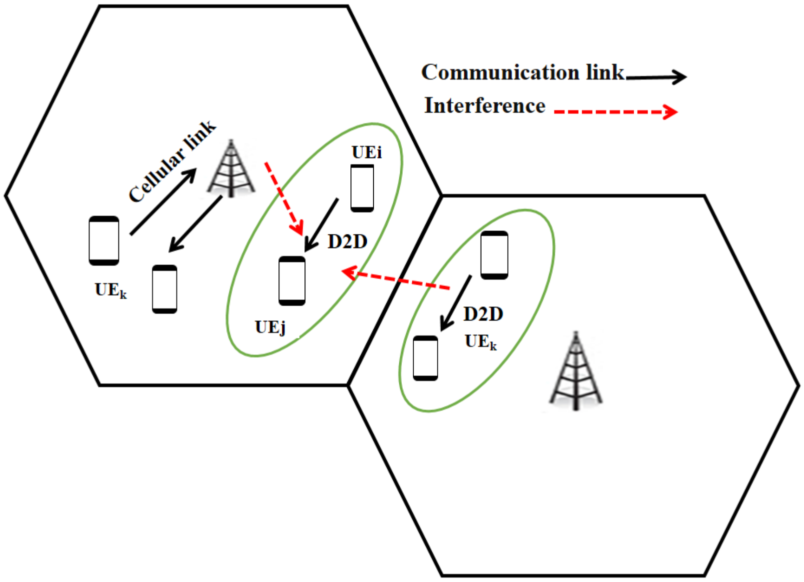


Figure 4.1. Interference scenario in a two-tier network

4.7 Proposed Interference Control technique

In this section, a joint resource allocation and interference control technique has been illustrated based on combined power control and codebook-based orthogonal precoding technique. Cellular downlink or uplink resources can be allocated for D2D link communication based on priority link analysis and calculated outage probability of an intended link at a given instant of time. The precoding technique ensures the quality of the channel. The base station sends a common reference signal (CRS) to the D2D transmitter. Then it extracts channel state information from CRS and feeds back precoding matrix index. According to the precoding matrix index, the D2D transmitter applies precoding data on the transmitted signal vector. PMI can be modified in an adaptive manner so that it can be synchronized with the instantaneous change of channel condition.

4.7.1 System model for downlink resource sharing scenario

Figure 4.2 presents an inbound two-tier scenario where the base station allocates downlink resources to the D2D transmitter. In this case, resources that are used for cellular downlink, i.e., base station to UE communication link, have been shared with D2D link transmission. It generates interference at the receiver of the D2D link. Let us assume that Intercellular interferences are controlled by inter-cell interference control (ICIC) mechanisms. Only intra cellular interference will be considered for analysis.

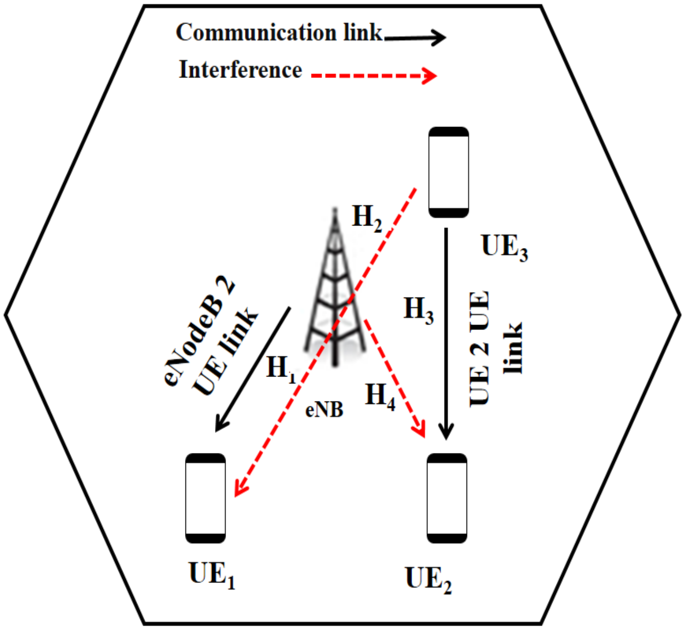


Figure 4.2. Intracellular single link scenario for D2D communication.

Consider a downlink eNB to UE_1 uses the same resources of a D2D link UE_3 to UE_2. In this scenario, UE_1 receives interference from UE_3 because eNB sends a downlink signal to UE_1, and during the same time, UE_3 sends a D2D link signal to UE_2 using the same downlink resource. Similarly, UE_2, which is acting as D2D receiver encountered by interference from eNB.

Mathematical expression of received signal at UE_1 is given by

$$Y_1=\sqrt{P_1}\,H_1S_1PC_1+\sqrt{P_2}\,H_2S_3PC_3+n_1 \qquad (4.1)$$

Mathematical expression of received signal at UE_3 is given by

$Y_2=\sqrt{P_3}H_3\,S_3PC_3+\sqrt{P_4}H_4S_1PC_1+n_2$ (4.2)

P_1, P_2, P_3, and P_4 denote average transmitted power through H_1, H_2, H_3, and H_4, respectively. n_1 and n_2 represent additive white gaussian noise at UE_1 receiver and UE_3 receiver, respectively. S_1 is the transmitted signal by the base station (eNB) in the downlink, and PC_1 is the precoding matrix-vector for channel H_1. Similarly, S_3 is the signal transmitted by the D2D transmitter PC_3 is the precoding matrix-vector assigned by UE_3.

A maximal ratio combiner (MRC) has been used for decoding the received signal at the receiver. A simplified block diagram of the transmitter and receiver side has been shown in figure 4.3.

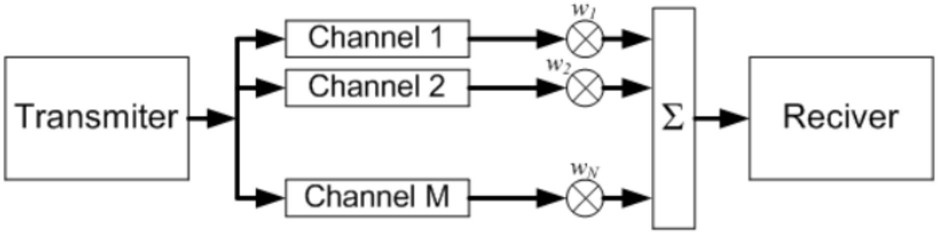


Figure 4.3. Concept of Maximal ratio combiner

MRC uses a linear combiner to add received signals from channels. The weights of the linear combiner at UE_1 is $W_1 = H_1PC_1$. Similarly, the weight of the linear combiner at UE_3 is given by $W_3 = H_3\,PC_3$. The output of the linear combiner at UE_1 is expressed as $\gamma_1= Y_1\,W_1^H$. Similarly, output at UE_3 is given by $\gamma_3= Y_3\,W_3^H$. $SINR_1$ at UE_1 and $SINR_3$ at UE_3 can be then expressed as

$$SINR_1 =\frac{\| H_1PC_1PC_1^HH_1^H\|^2}{I_r^1\| H_2PC_3pc_1^HH_1^H\|^2+\frac{1}{\varepsilon_1}I} \qquad (4.3)$$

$$SINR_3 =\frac{\| H_3PC_3pc_3^HH_3^H\|^2}{I_r^2\| H_4PC_1PC_3^HH_3^H\|^2+\frac{1}{\varepsilon_3}I} \qquad (4.4)$$

Here in orthogonal precoding pc_1 and pc_3 are orthogonal to each other. Therefore we have following conditions.

$$pc_3pc_1^H = 0 \text{ and } pc_1pc_3^H = 0$$

4.7.2 Simulation Setup and Result Analysis

The objective of this analysis is to compare the performance of conventional precoding and proposed orthogonal precoding to control interference in cellular downlink resource sharing scenarios presented in figure 4.2. Analysis of the outage probability of the D2D link has been obtained at the receiver side. Outage probability is an evaluation parameter that is widely used in various literature for the quality of service guarantee of a communication link. It is defined as breaking the probability of communication link. Mathematically it is the probability that SINR falls below the predefined threshold. More the outage means more the probability to break the communication link. In a downlink resource sharing, the scenario base station shares the downlink resource block to the D2D transmitter for establishing a direct communication link. The interference may vary depending on the position of UEs in the cell. Therefore, for the simulation purpose, interference control ratio (Ir) has been considered for defining high interference zone and low interference zone. Ir defines the ratio of interference power and signal power. Based on the Ir value interference region can be defined as shown below.

Region 1	Interference power< D2D link signal power
Region 2	Interference power = D2D link power
Region 3	Interference power > D2D link power

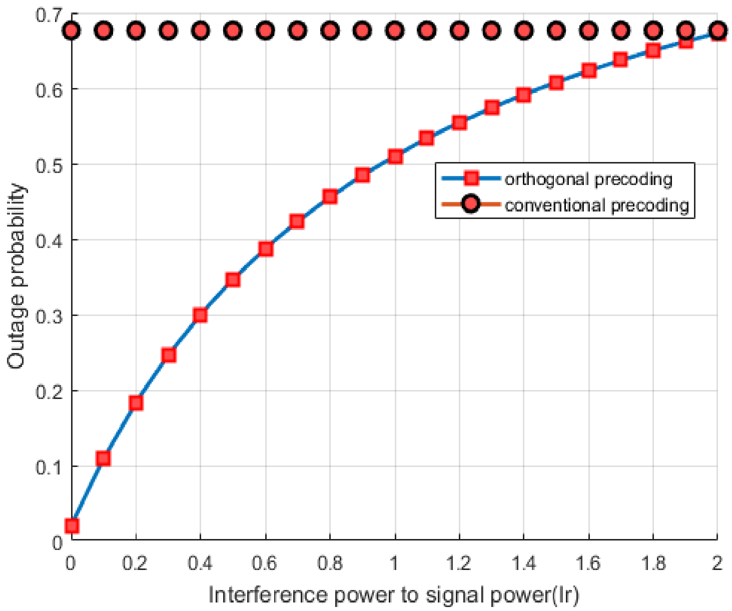


Figure 4.4 Interference power ratio vs. outage probability

Figure 4.4 shows the simulation result of the scenario mentioned in Figure 4.2. It compares the outage probability of D2D link underlying cellular network while applying conventional precoding mentioned in literature [65] and orthogonal precoding for interference control in different interference regions. In Region 1 (Ir<1), the outage probability of orthogonal precoding is in the range of 0 to 0.5, whereas in the same region outage probability of the conventional precoding technique is 0.7. In Region 2 (Ir=1) outage probability of conventional precoding is 1.4 times more than that of orthogonal precoding. In region 3(Ir>1), where interference on the D2D link is maximum, orthogonal precoding shows better results than conventional precoding. Figure 4.5 presents a D2D link outage comparison between conventional precoding and orthogonal precoding for SINR threshold rang -20db to 30 dB. It is clearly visible that orthogonal precoding outperforms compare to conventional precoding in a wide range of SINR thresholds. Table 4.3 shows comparative data analysis of outage probability and SINR threshold for different Ir values. Figure 4.6 shows SNR vs. outage probability plot for the D2D link underlying cellular network. Orthogonal precoding can be applied to get a better result in terms of link quality guarantee for an SNR up to 20db

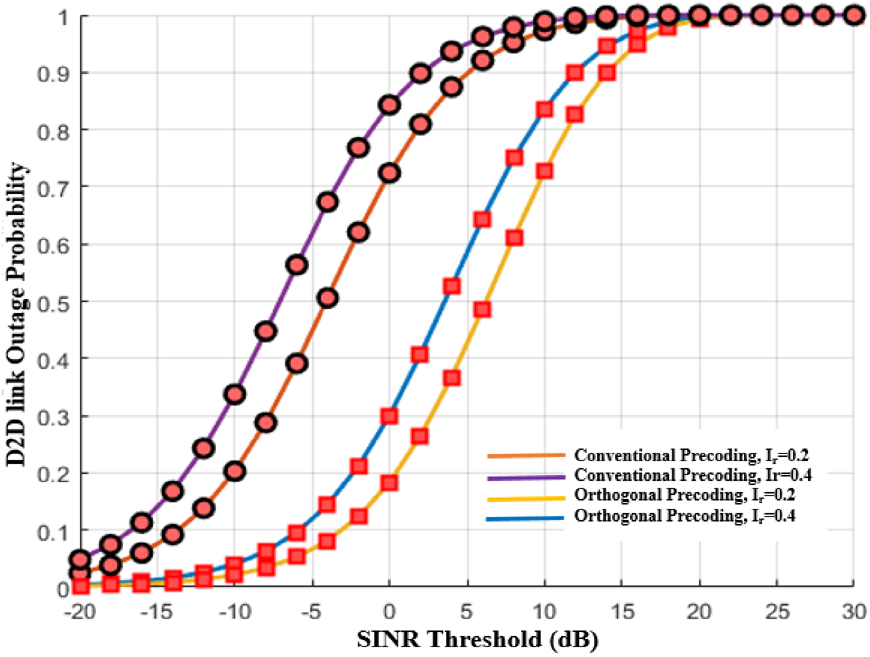


Figure 4.5 Signal to Noise plus interference vs. D2D link Outage probability

Table 4.3 Comparison of Conventional precoding and orthogonal precoding for different interference and SINR threshold.

Conventional Precoding	**Orthogonal Precoding**	**SINR Threshold**	**I_r**
0.85	**0.3**	**0 dB**	**0.4**
0.95	**0.65**	**5 dB**	**0.4**
0.7	**0.2**	**0 dB**	**0.2**
0.9	**0.49**	**5 dB**	**0.2**

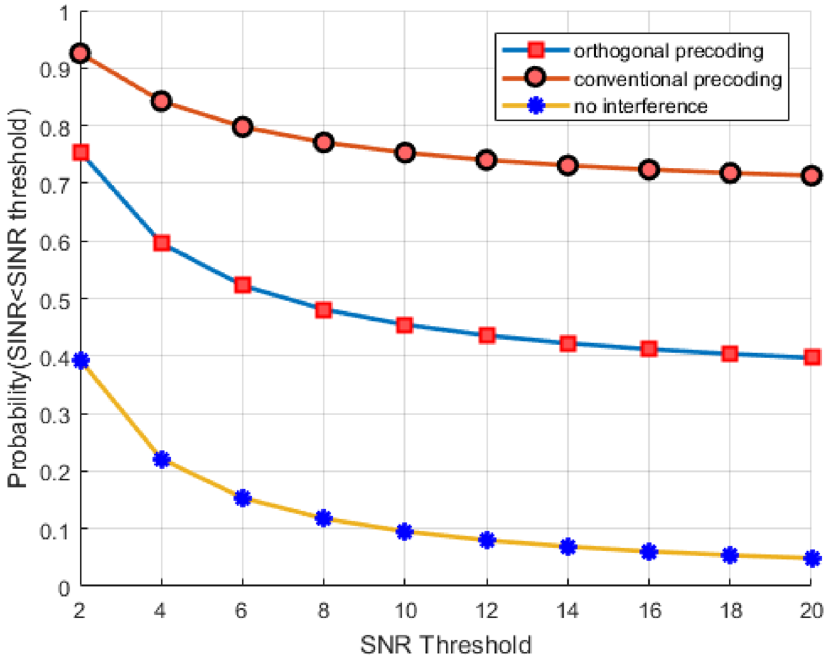


Figure 4.6 Signal to Noise Threshold vs. D2D link Outage probability

4.8 Summery

In this chapter, a joint resource sharing and interference technique has been presented. The proposed technique is based on defining interference regions and the calculation of outage probability. The interference in the D2D link can be controlled by the precoding technique. Results show that orthogonal precoding outperforms compare to traditional precoding. Inbound D2D communication allows the reuse of up-link or down-link spectrum of cellular users who are in a good quality channel state. However, D2D links suffer from interference of cellular links. The quality of the D2D link reduces as the received interference power increases. To solve this problem, we have analyzed and compared the outage probability of D2D link in the presence of a cellular link in three different interference regions using a downlink resource sharing scenario. The simulation result shows that the proposed orthogonal precoding method enhances the signal quality and improves the reliability of D2D link by means of reducing outage probability compare to the traditional precoding technique

Chapter-5

The pricing model for spectrum sharing portability in the device to device communication

5.1 Introduction

The design of an optimal pricing model for the two-tier network is an ongoing challenge for the researchers. In the traditional model, the operator charges to the mobile users as per their subscription, i.e., data speed and data used for a specific duration of time. But in the two-tier model, the device tier users may share their resources to nearby devices which are getting poor data speed from the operator due to several reasons such as low speed from the operator at the cell edge, poor network coverage, etc.[66]. Operator control schemes are also more secure as it uses centralized monitoring of mobile user equipment [67]. This chapter is focused on designing of appropriate pricing model for a two-tier network. The proposed model depends on the mode of operation and device to device network scenario. The proposed model can be applied to various power control [68], [69] based D2D scenario. This chapter illustrates an incentive-based pricing scheme in various possible scenarios of the D2D network.

5.2 Device relaying Scenarios

There is four possible device delaying scenario in the two-tier network. Figure 5.1 illustrates a block diagram of this scenario. It has been reported in the literature that spectrum trading is possible between cellular users and D2D users in frequency reuse mode. In a spectrum trading problem primary users, i.e., cellular user sells their bandwidth to the D2D link for their mutual benefits. This kind of problem can be solved by bandwidth auction games, as mentioned in [70]. But the participation of users in spectrum trading games is a big challenge.

5.2.1 Operator Control Device Relaying (OCDR): There is a possibility that some of the UEs are suffering from low data speed or out of the operator's network coverage. It happens while the UEs are traveling through the cell edge. In this scenario, a device that is under the network coverage can serve as a gateway or relay to provide data offloading service to the other UEs to fulfill the data speed requirement. This is known as Operator Control Device Relaying.[71] In a two-tier network, the pricing of D2D service depends on various factors. It is the prime requirement that the relay device needs to be in a position to serve the rest of the UEs. The measurement parameters for the same are channel throughput, signal to noise ratio, and D2D link outage probability. If all the requirements are met by the relay device, the operator must address that how that UEs are going to be controlled and charged for providing the D2D service. In this case, it also needs to be taken care of the opinion of the UEs, i.e., whether they want a traditional low-speed link with no additional price or switches to D2D relaying with higher speed and quality of service guarantee.

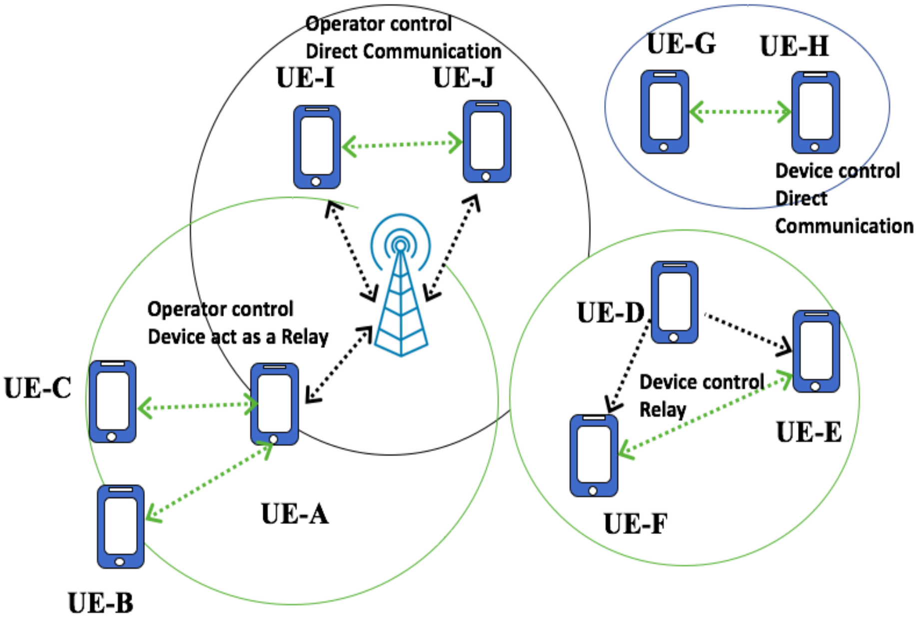


Figure 5.1. Possible device relaying D2D scenarios in device tier network.

OCDR architecture has been formed in Figure 5.1 by UE-A, UE-B, UE-C, and the base station. Here UE-A is the relaying node while UE-B and UE-C are the serving nodes. UE-B and UE-C are located at the cell edge and safer from poor data speed and network coverage. Therefore UE-A, which has the capability to work as a relay node, may provide data offloading service to UE-B and UE-C on a charge basis. The base station or servicing operator has full control of UE-A and can provide incentives to UE-A for working as a relay node. Wi-Fi direct and LTE-Direct are examples of operator-controlled licensed band D2D peer-to-peer communication[72].

5.2.2 Device Controlled Device Relaying (DCDR)

In two-tier networks, there are possibilities that the device tier is independent of the network tier. Here network tier is the traditional mobile communication network where UE communicates with other UE in the network coverage area through the base station. In case the base station is out of service or all the UEs are out of the network area, then these devices are not able to communicate among themselves in the traditional network tier model. In a two-tier DCDR model, devices that are out of network area form an Adhoc mesh network and start communication between themselves without the involvement of the base station. This type of architecture is known as Device Control Device Relaying architecture.[71] In Figure 5.1, UE-D, UE-E, and UE-F form DCDR architecture. The mesh network can be formed by using unlicensed spectrum like Wi-Fi, Blue tooth, etc. To establish a successful D2D link in this scenario, there is a need for mutual understanding among the UEs where they want to be part of the same network or not.

5.2.3 Device control direct communication (DCDC)

DCDC is defined as direct communication between multiple UEs using a relay, and the controlling is also based on a device tier network. The base station does not have any control over devices under this architecture. UE-G is communicating with UE-H using the DCDC model in Figure 5.1. Operation independent scenario has been shown where network operator not responsible for D2D connection establishment. In this kind of situation, cooperative game theory-based approach, bargaining game theory-based approach, the double auction-based technique can be considered for the pricing model as mentioned in[73]–[75].

5.2.4 Operator control direct communication (OCDC)

In this architecture, direct communication between two UEs is possible only if the operator allows to establishment D2D link. UE-I and UE-J form this network in Figure 5.1. Here base station actively supports establish and monitoring the direct connection. In this case, it is the prime requirement that both the UEs need to be under the coverage of the cellular network. There might be a predefined policy for spectrum allocation based on the mode of operation. The pricing policy also depends on the operator. Here these UE directly communicate through assigned channel and speed by the Operator. Spectrum can be traded between seller and buyer for this kind of model [66]. A spectrum buyer wants a spectrum with less price, but the seller wants to get more benefits by providing maximum spectrum with the optimal costing. Therefore, it introduces a conflict situation between buyer and seller. The probability of a successful deal depends on the agreement between buyer and seller. Action theory can be considered for solving such situations[76], [77].

5.3 Analysis of proposed model for operator-controlled incentive distribution

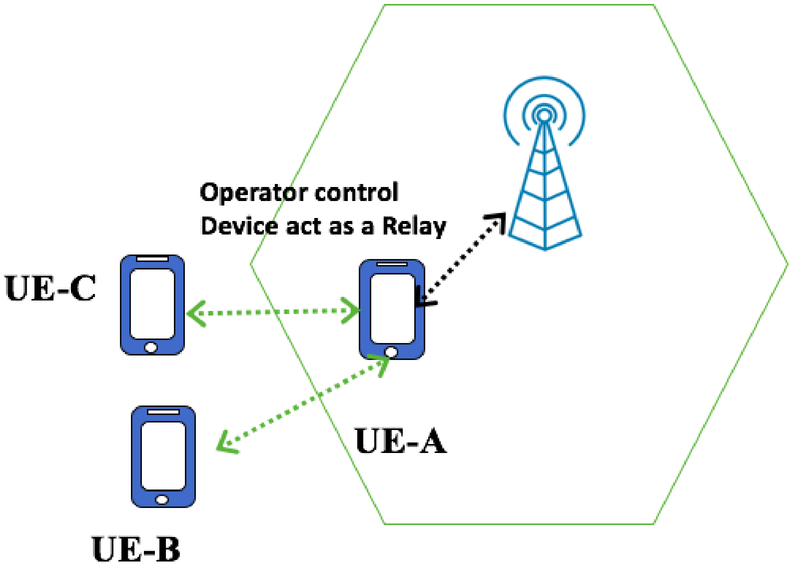


Figure 5.2. Operator controlled device relay scenario

The proposed model is based on incentive policy for the D2D uses. According to the policy, a D2D user that acts as a relay to provide data offloading service to nearby devices is eligible for getting incentives from the operator. In Figure 5.2, UE-A is a relay device that provides data offloading service to UE-B and UE-C. To understand the need for incentive policy, let us solve the following questions.

(1) Why UE-B and UE-C will take service from UE-A?

(2) Why will UE-A provide service to UE-B and UE-C?

UE-B and UE-C will take service when they are out of network coverage of the registered operator. It is also possible that UE-B and UE-C are getting very low data speed due to several constraints like poor network signal at the cell edge, channel bandwidth restrictions, poor signal to noise ratio, high outage probability, etc. UE-A will provide service to UE-B and UE-C to get incentives from the network operator. The network operator will allow this to increase the profitability as the number of users increases, profitability also increases. An incentive may be in the form of extra data or monetary benefit on the monthly bill.

The flow chart for the proposed model has been shown below

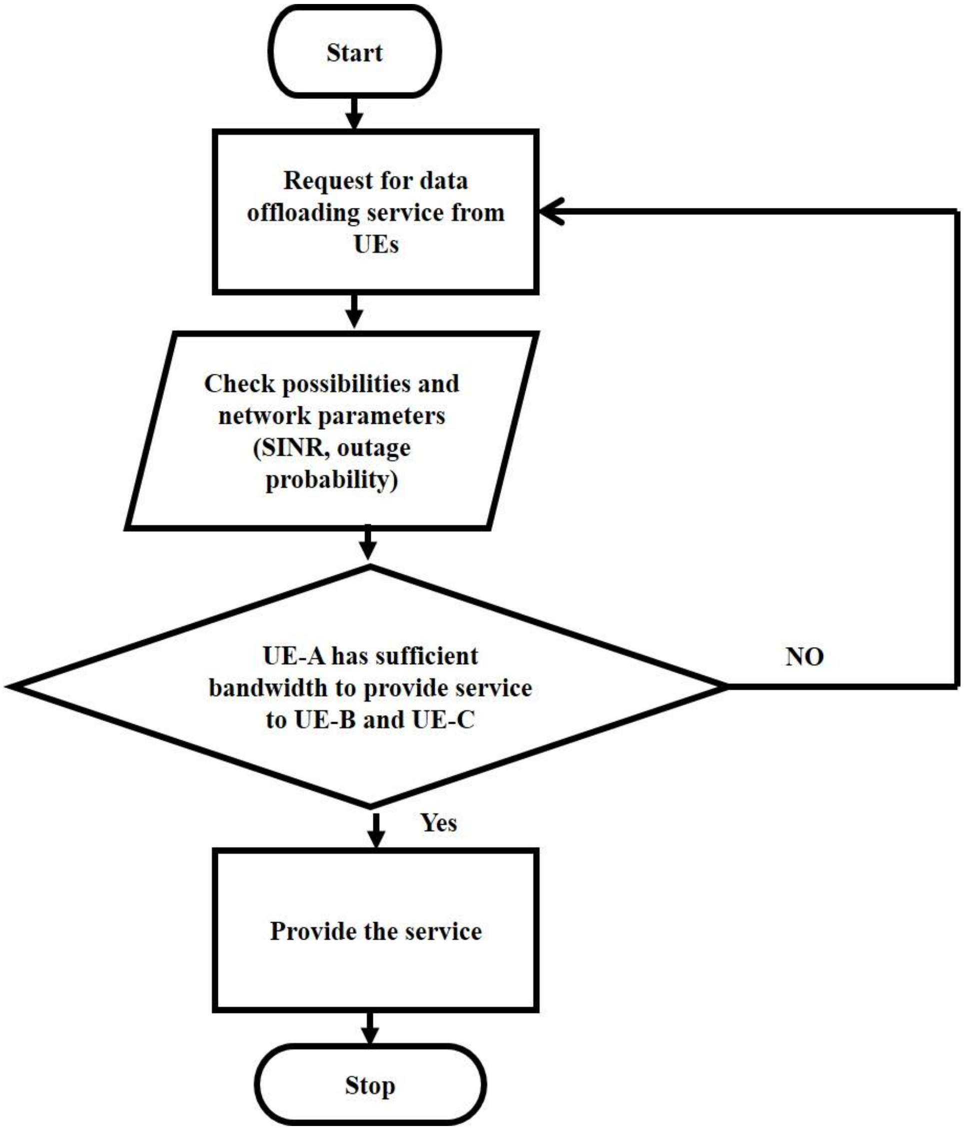


Figure 5.3. Flow chart of proposed data offloading service model.

In Figure 5.3, a flowchart has been shown for the understanding of data offloading service In this proposed model, UE-A receives a request for data offloading service from UE-B and UE-C. Then it checks possibilities of data service by means of essential parameters. It estimates the necessary Signal to interference plus noise ratio, outage probability, and throughput for establishing a D2D link. Then it checks whether sufficient bandwidth is available for sharing resources with UE-B and UE-C or not. If sufficient bandwidth is available, then it initiates necessary steps to provide the service with a predefined pricing model.

A utility function U calculated as[66]

$$U = B\,log_2(1 + k\gamma) - MBP + \overline{B}\,log_2(1 + k\bar{\gamma}) \qquad 5.1$$

Equation 5.1 defined the utility function applicable to the proposed model. B is the bandwidth provided by the operator to any user equipment under its coverage area. k is the Spectrum efficiency and it can be calculated as k = 1.5/ln(0.2/BERtar). M is defined as the number of hops between the base station and the targeted device. $\overline{B}$ is incentive awarded to relay device. γ is signal to noise ratio of concern link and $\bar{\gamma}$ is the signal to noise ratio of incentive bandwidth awarded link. Revenue generated by each cellular user can be calculated from the 1st term of equation 5.1, whereas any device in the cellular network will pay charges to the serving operator as per the calculated value from the 2nd term of equation 5.1.

Revenue of operator can be calculated as

$$R=\sum_{i=1}^{N} MB_iP_i - M\,\overline{B}\,log_2(1 + k\bar{\gamma}) \qquad 5.2$$

Here $\overline{B}$ is awarded bandwidth for relay node. It is the incentive for providing offloading service.

5.3.1 Simulation Setup

Consider that operator provides a fixed pricing scheme for all mobile user equipment under its service. Simulation parameters have been selected as per reference [71].

Number of active UEs in a cell of cellular network at a given instant of time = 100

Bandwidth assigned for each active device (B_i)=5 MHz

Incentive Awarded Bandwidth ($\overline{B}$)= 2.5 MHz

Spectral efficiency(k)=0.2

SNR range(γ_i): 5 to 25 dB

Number of relay device =1

Number of the device taking service from relay device in OCDR network =2

The unit price of spectrum for cellular network 1 unit and for OCDR network 1.2 unit.

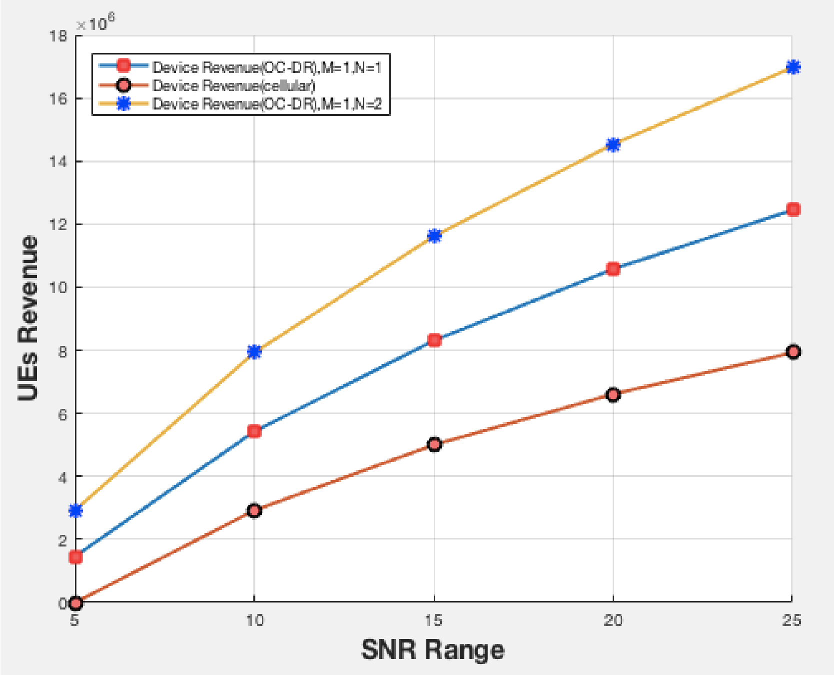


Figure 5.4. Comparison of UEs revenue in OCDR and cellular network

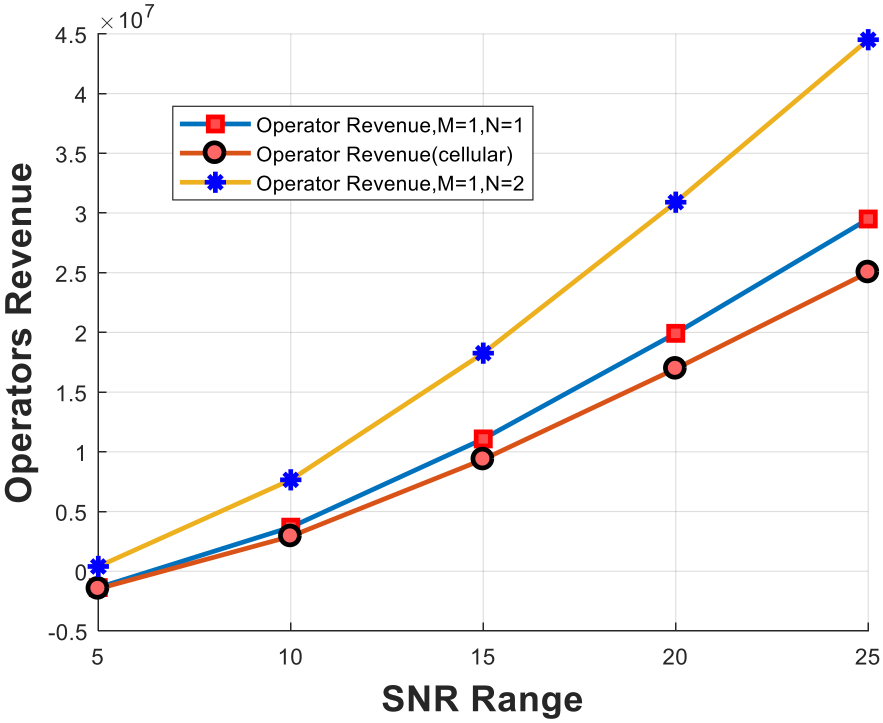


Figure 5.5. Comparison of operator's revenue in OCDR and cellular network.

5.3.2 Simulation Result

The proposed model has been simulated under an operator-controlled device relaying scenario (OCDR). Figure 5.4 presents simulation results in terms of UEs revenue for a specific range of signal-to-noise ratio. UEs revenue increases drastically while the number of participations increases in device tier network as compare to traditional cellular tier network. The result shows that in the OCDR network with two serving UEs and one relay node, UEs revenue is two times of the cellular network. Figure 5.5 illustrates the operator’s revenue for the SNR range of 5 to 25 dB. Operators' revenue enhances drastically in the OCDR network as compare to the cellular network while the number of participants increases for data offloading service.

5.6 Summery

In this chapter, a pricing model has been presented for spectrum sharing between cellular tier and device tier network. The proposed model has been investigated for the data offloading scenario. A relay device has been considered as a mediator between the cellular network and the D2D network. The function of the relay device is to offload data from the base station to the D2D link. The devices which are at the cell edge can get the maximum benefit from the relay device. Due to poor network at the cell edge, it is better to switch from a conventional network to a device tier network where service has been provided by a relay device. Thus, the operator's benefit increases and the relay device gets incentive benefits from the base station in terms of extra bandwidth and additional services. This new concept of incentive distribution for the mobile users who work as relay devices not only increases the participation of D2D users but also enhances the operator’s profitability.

Chapter-6

Outage probability analysis of Relay based D2D Network

6.1 Introduction

Device to Device link quality depends on link outage probability. More the outage means poor link quality. Network throughput or data transmission speed will drastically fall if the outage probability increases. Therefore it is very important to analyze these two parameters for the proposed mode selection-based resource sharing technique. In this chapter, a detailed mathematical analysis has been done for cellular mode and Operator Control Device Relaying (OCDR) mode considering downlink resource sharing scenario in a two-tier network.

6.2 Two-tier network

Figure 6.1 shows a two-tier network. Tier-I provides a traditional cellular architecture where communication between two devices takes place through the base station, whereas Tier-II provides the architecture for direct communication among devices. Mobile user equipment, UE-1, is considered a relaying device. UE 1 provides data offloading service to the mobile neighbor users, i.e. UE-2 and UE-3 in Tier-II.

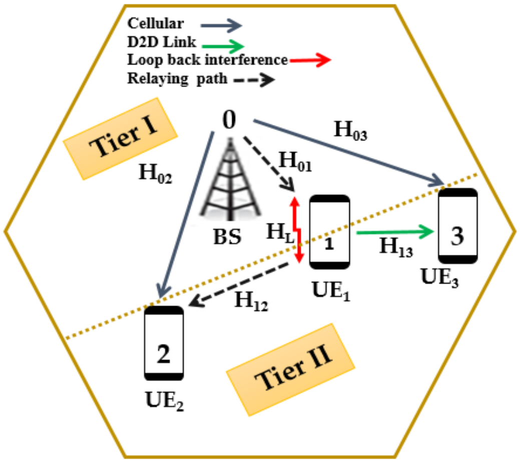


Figure 6.1. Relaying based downlink resource sharing scenario

6.3 Cellular mode

Cellular mode is the traditional mode where BS transmits data to UE_1, UE_2, and UE_3 using H_{01}, H_{02}, and H_{03}, respectively. It allows UEs to communicate with each other only through the base station, i.e., the Tier-I network of Figure 6.1. Consider P_{01}, P_{02}, P_{03} are transmitted signal power from the base station to UE_1, UE_2, and UE_3, respectively. In cellular mode, $P_{01}=0$ and $P_{02} + P_{03} = P$, where P is the transmit power constraint for BS. Let BS is transmitting signal S(i) at i^{th} time instant through UE_2 and UE_3 respectively using downlink. The received signal at UE_2 and UE_3 can be expressed as,

$$Y_{02}=\sqrt{P_{02}}H_{02}\, S(i)+ n(i) \tag{6.1}$$

$$Y_{03}=\sqrt{P_{02}}H_{03}\, S(i)+ n(i) \tag{6.2}$$

Here n(i) is zero-mean additive white Gaussian noise at an i^{th} time instant. Let $\boldsymbol{\sigma^2}$ is the variance of n(i). Therefore, channel power to noise ratio and achievable throughput in full-duplex mode at UE_2 and UE_3 are given as follows,

$$\boldsymbol{\gamma_{02}}= \frac{|\, H_{02}|^2}{\sigma^2} \text{ and } \boldsymbol{\gamma_{03}}= \frac{|\, H_{03}|^2}{\sigma^2} \tag{6.3}$$

$$C_{02} = \frac{1}{2}\boldsymbol{W * log_2}(1+\boldsymbol{P_{02}} \frac{|\, H_{02}|^2}{\sigma^2}) \tag{6.4}$$

$$C_{03} = \frac{1}{2}\boldsymbol{W * log_2}(1+\boldsymbol{P_{03}} \frac{|\, H_{03}|^2}{\sigma^2}) \tag{6.5}$$

Here W is the channel bandwidth. Therefore, minimum transmission power to fulfill constant throughput in cellular mode can be obtained from (6.4) and (6.5) as follows,

$$\boldsymbol{P_{02}} = \frac{\frac{1}{W}\ (2^{2C_{o2}})-1}{\gamma_{02}} \tag{6.6}$$

$$\boldsymbol{P_{03}} = \frac{\frac{1}{W}\ (2^{2C_{o3}})-1}{\gamma_{03}} \tag{6.7}$$

Outage probability can be calculated as

$$P_{out,\,02} = 1- \exp\,(-\boldsymbol{\gamma_{th}/\gamma_{02}}) \tag{6.8}$$

$$P_{out,03} = 1 - \exp(-\gamma_{th}/\gamma_{03}) \tag{6.9}$$

Cellular mode is preferred when the channel condition is good between BS and UE. In case UE is at the cell edge and suffering from far fading, then it is difficult to achieve guaranteed constant throughput. At the cell edge, as the channel to noise ratio falls below the threshold level, transmit power need to be increased at BS to fulfill throughput requirement, but it introduces power constraint challenges[50], [78].

6.4 Operator Control Device Relaying (OCDR) mode

In relaying mode, UE_1 receives a BS signal and forwards it to UE_2. At the same time, UE_1 transmits a signal to UE_3 using the same frequency band, which is accomplished by D2D direct communication mode. Relaying Mode and D2D direct communication mode may occur simultaneously using the same radio resources, so it introduces loopback channel interference. HL denotes loopback interference channel response, as shown in Figure 6.1. Let signal transmitted by BS is $S_{1,}$ and the same signal is forwarded to UE_2 by D2D relay UE_1. P_{01} is the transmitted power by the base station, and P_{11} is the loopback interference power. Let s(i) is the transmitted signal from a base station at ith time instant, and d(i) is the transmitted signal by D2D relay at an ith time instant. Received signal at transmitting port of relay UE_{01} can be expressed as,

$$Y_{01}=\sqrt{}P_{01}H_{01}S\,(i) + \sqrt{}P_{11}\,H_L\,d(i)+ n(i) \tag{6.10}$$

At the same time, instant received signal at D2D receiver UE_3 can be formulated as

$$Y_{03}=\sqrt{}P_{03}\,H_{03}\,S\,(i) + \sqrt{}P_{11}H_{13}\,d\,(i) + n\,(i) \tag{6.11}$$

Signal to interference plus noise ratio at UE_1 and UE_3 is formulated as follows.

$$\boldsymbol{\gamma_{01}}=\frac{P_{01}|\ H_{01}|^2}{P_{11}|H_L|^2+\sigma^2} \tag{6. 12}$$

$$\boldsymbol{\gamma_{03}}=\frac{P_{11}|\ H_{13}|^2}{P_{03}|H_{03}|^2+\sigma^2} \tag{6.13}$$

Consider precoding technique has been applied and after precoding, received signal at D2D receiver UE_3 can be formulated as

$$Y_{03}=\sqrt{P_{03}}\,H_{03}\,PC_{03}S\,(i) + \sqrt{P_{11}}H_{13}\,PC_{13}\,d\,(i) + n\,(i) \qquad (6.14)$$

Where PC_{03} and PC_{13} are precoding vectors for BS to UE_3 transmission and UE_1 to UE_3 transmission, respectively. Maximal ratio combiner (MRC) has been used at the receiver to process Y_{03}. The weight of the linear combiner at UE_3 is $W = H_{13}\,PC_{13}$. Therefore, the output of the linear combiner at UE_3 after the MRC process is expressed as $\boldsymbol{Y'_{03}} = Y_{03}\,\boldsymbol{W^H}$.

In (6.13) $\boldsymbol{P_{03}}$ is the transmitted power of BS to UE_3 using cellular downlink and $\boldsymbol{P_{11}}$is the transmitted power of UE_1 to UE_3

Let, interference to signal ratio, $I_r = \frac{\boldsymbol{P_{03}}}{\boldsymbol{P_{11}}}$ and signal to noise ratio $\boldsymbol{\gamma} = \frac{\boldsymbol{P_{11}}}{\boldsymbol{\sigma^2}}$ therefore equation (6.13) can be rearranged as, $\boldsymbol{\gamma_{03}} = \frac{|\,\boldsymbol{H_{13}}\mathbf{pc_{13}pc_{13}^{H}H_{13}^{H}}|^2}{\mathbf{I}_r|\boldsymbol{H_{03}}\mathbf{pc_{03}pc_{13}^{H}H_{13}^{H}}|^2+\frac{1}{\gamma}}$ (6.15)

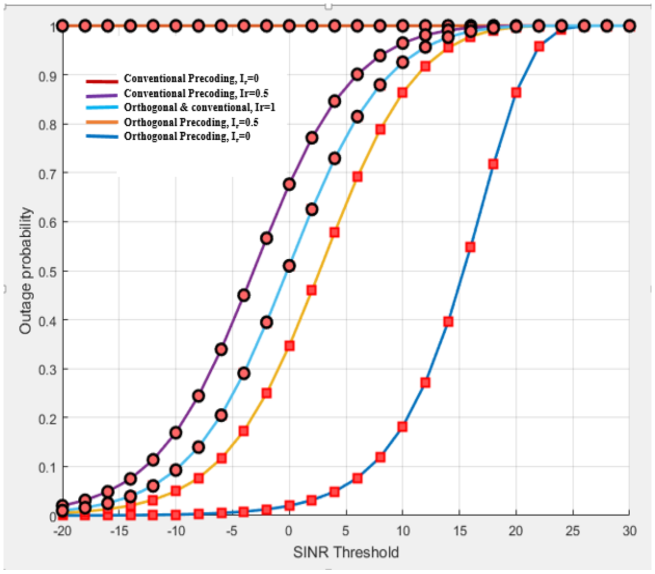


Figure 6.2 Downlink resource sharing case: SINR vs. outage probability curve for Conventional Precoding and Orthogonal precoding with Ir=0, Ir=0.5, Ir=1

Analysis of outage probability for conventional precoding and orthogonal precoding in the relay-based scenario has been shown in figure 6.2. Outage probability has been calculated for an SINR range -20 dB to 30dB. It shows that in a relay based D2D network, orthogonal precoding provides a better result than conventional precoding in terms of less probability of link break down.

6.5 Summery

In this chapter, a relay based D2D scenario has been discussed. This scenario is appropriate in data offloading applications where a UE works as a relay device to provide data offloading service to other UEs. In a data offloading case the relay UE need to take care of self-interference. An analysis of outage probability has been shown based on mathematical derivations. Results show that orthogonal precoding provides less probability of outage compared to conventional precoding in the relay-based scenario.

Chapter-7

Conclusion and Scope of Future Research

7.1 Summary of thesis

The overall contributions have been summarized in this section. This research work is focused on resource allocation technique, interference management methods, service discovery mechanism, and pricing strategy development of a two-tier device-to-device communication network. Conventional Single tier network has several limitations such as high link outage probability at the cell edge, unsuitable for proximity-based services and mission-critical applications where ultra-low latency with high reliability is the main concern. Therefore researchers are working to develop a two-tier network model where a device tier and cellular tier both exist and share resources among themselves. In the device tier network, two or more devices can communicate directly. Cellular resource blocks (uplink and downlink) can be shared in an optimum way for such D2D communication in frequency reuse mode. This two-tier model provides low latency and high reliable licensed band communication. In this thesis, firstly, a mode selection-based resource sharing technique has been proposed. The research is further extended to provide a suitable interference control mechanism for a two-tier network. Orthogonal precoding has been proposed to control interference in the frequency reuse mode of operation. The proposed orthogonal technique has been compared with conventional precoding techniques in different D2D scenarios such as downlink resource sharing scenarios, relay-based data offloading scenarios. Result analysis shows that in all possible scenarios, orthogonal precoding provides less outage probability than conventional precoding. Also, an analysis of service discovery protocol has been presented in this research. Reactive and proactive service discovery protocols are suitable in D2D proximity-based service scenario. A comparative control overhead analysis of proactive and reactive protocols has been shown under a power control-based interference management scenario. It has been shown that for an increasing number of D2D link requests, proactive protocols perform better than reactive protocols. Application of service discovery protocol depends on D2D mode of operation and interference management schemes because a number of D2D link request varies in different modes, i.e., dedicated mode, reuse mode, and cellular mode. A pricing model has been proposed where a UE, which acts as a relay device to provide data offloading service to the other UEs, will get incentives in terms of extra bandwidth. The proposed model has been evaluated in a two-tier operator-controlled device relaying scenario. Simulation results show that operators' profitability increases in the proposed model as the number of participants in D2D communication increases. There is a “Win-Win” situation for operators and D2D UEs. A UE which provides data relaying service gets extra benefit from a service provider, and it increases the number of participation. Hence operator's profit increases as compared to the existing pricing model.

7.2 Future scope of research

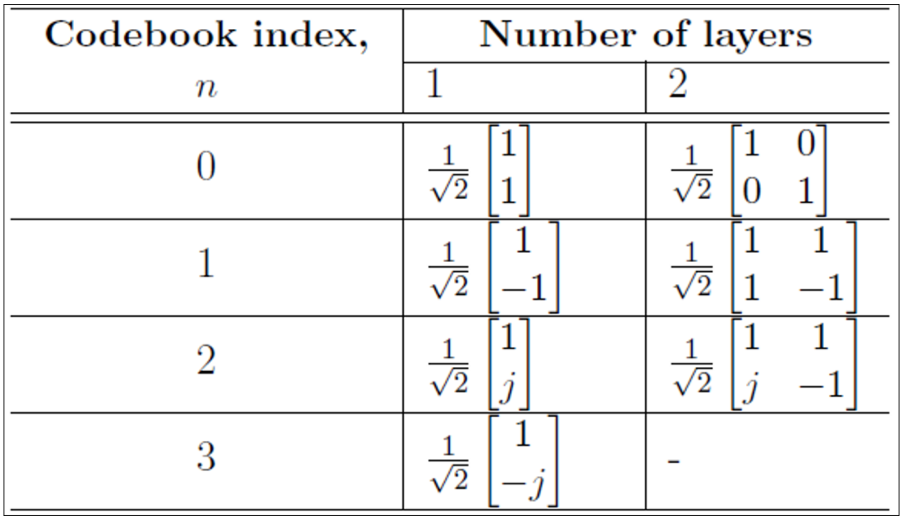
The resource management technique based on mode selection is limited to the two-tier scenario. There is a scope to do further analysis of modes in the multi-tier heterogeneous mobile-IoT network. The proposed model of interference control based on orthogonal precoding in the D2D scenario needs further investigation in the dynamic network where mobile users are moving at high speed, for example, inside a train. Also, the investigation needs to be done for the intercellular cluster-based scenario. The pricing model has been analyzed only for operator-controlled device relaying networks. There is a need for an analysis pricing model in another scenario like device control device relaying network.

Appendix I

Precoding Code book

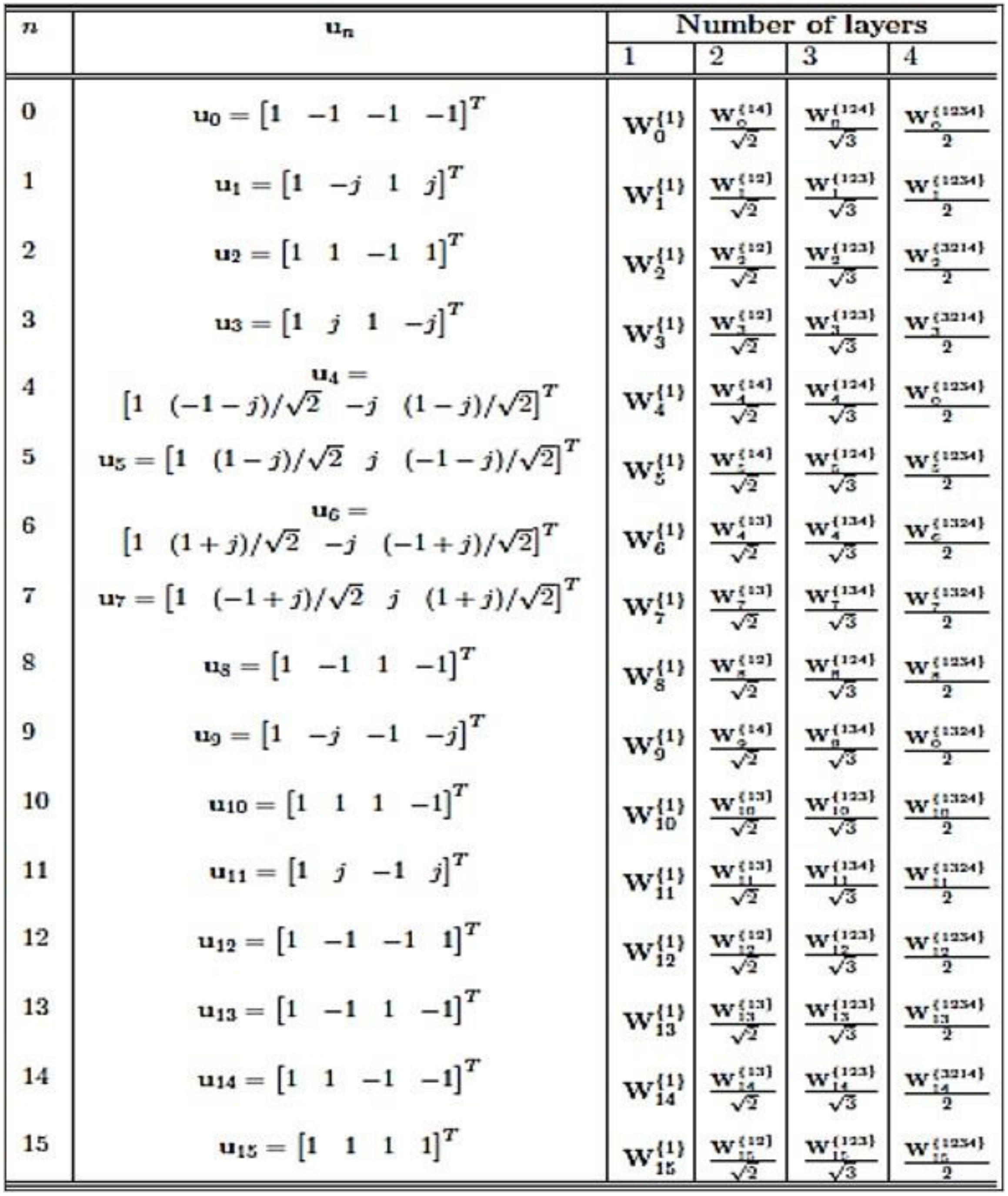
Codebook used for transmission in two antenna ports and four antenna ports has been shown in Table A.1 and Table A.2, respectively.

Table A.1 Codebook for two antenna port



Codebook index, n	Number of layers	
	1	2
0	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\1\end{bmatrix}$	$\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 0\\0 & 1\end{bmatrix}$
1	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-1\end{bmatrix}$	$\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 1\\1 & -1\end{bmatrix}$
2	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\j\end{bmatrix}$	$\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 1\\j & -1\end{bmatrix}$
3	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-j\end{bmatrix}$	-

Table A.2 Codebook for four antenna port



n	$\mathbf{u}_n$	Number of layers			
		1	2	3	4
0	$\mathbf{u}_0 = \begin{bmatrix}1 & -1 & -1 & -1\end{bmatrix}^T$	$\mathbf{W}_0^{\{1\}}$	$\mathbf{W}_0^{\{14\}}/\sqrt{2}$	$\mathbf{W}_0^{\{124\}}/\sqrt{3}$	$\mathbf{W}_0^{\{1234\}}/2$
1	$\mathbf{u}_1 = \begin{bmatrix}1 & -j & 1 & j\end{bmatrix}^T$	$\mathbf{W}_1^{\{1\}}$	$\mathbf{W}_1^{\{12\}}/\sqrt{2}$	$\mathbf{W}_1^{\{123\}}/\sqrt{3}$	$\mathbf{W}_1^{\{1234\}}/2$
2	$\mathbf{u}_2 = \begin{bmatrix}1 & 1 & -1 & 1\end{bmatrix}^T$	$\mathbf{W}_2^{\{1\}}$	$\mathbf{W}_2^{\{12\}}/\sqrt{2}$	$\mathbf{W}_2^{\{123\}}/\sqrt{3}$	$\mathbf{W}_2^{\{3214\}}/2$
3	$\mathbf{u}_3 = \begin{bmatrix}1 & j & 1 & -j\end{bmatrix}^T$	$\mathbf{W}_3^{\{1\}}$	$\mathbf{W}_3^{\{12\}}/\sqrt{2}$	$\mathbf{W}_3^{\{123\}}/\sqrt{3}$	$\mathbf{W}_3^{\{3214\}}/2$
4	$\mathbf{u}_4 = \begin{bmatrix}1 & (-1-j)/\sqrt{2} & -j & (1-j)/\sqrt{2}\end{bmatrix}^T$	$\mathbf{W}_4^{\{1\}}$	$\mathbf{W}_4^{\{14\}}/\sqrt{2}$	$\mathbf{W}_4^{\{124\}}/\sqrt{3}$	$\mathbf{W}_0^{\{1234\}}/2$
5	$\mathbf{u}_5 = \begin{bmatrix}1 & (1-j)/\sqrt{2} & j & (-1-j)/\sqrt{2}\end{bmatrix}^T$	$\mathbf{W}_5^{\{1\}}$	$\mathbf{W}_5^{\{14\}}/\sqrt{2}$	$\mathbf{W}_5^{\{124\}}/\sqrt{3}$	$\mathbf{W}_5^{\{1234\}}/2$
6	$\mathbf{u}_6 = \begin{bmatrix}1 & (1+j)/\sqrt{2} & -j & (-1+j)/\sqrt{2}\end{bmatrix}^T$	$\mathbf{W}_6^{\{1\}}$	$\mathbf{W}_4^{\{13\}}/\sqrt{2}$	$\mathbf{W}_4^{\{134\}}/\sqrt{3}$	$\mathbf{W}_6^{\{1324\}}/2$
7	$\mathbf{u}_7 = \begin{bmatrix}1 & (-1+j)/\sqrt{2} & j & (1+j)/\sqrt{2}\end{bmatrix}^T$	$\mathbf{W}_7^{\{1\}}$	$\mathbf{W}_7^{\{13\}}/\sqrt{2}$	$\mathbf{W}_7^{\{134\}}/\sqrt{3}$	$\mathbf{W}_7^{\{1324\}}/2$
8	$\mathbf{u}_8 = \begin{bmatrix}1 & -1 & 1 & -1\end{bmatrix}^T$	$\mathbf{W}_8^{\{1\}}$	$\mathbf{W}_8^{\{12\}}/\sqrt{2}$	$\mathbf{W}_8^{\{124\}}/\sqrt{3}$	$\mathbf{W}_8^{\{1234\}}/2$
9	$\mathbf{u}_9 = \begin{bmatrix}1 & -j & -1 & -j\end{bmatrix}^T$	$\mathbf{W}_9^{\{1\}}$	$\mathbf{W}_9^{\{14\}}/\sqrt{2}$	$\mathbf{W}_9^{\{134\}}/\sqrt{3}$	$\mathbf{W}_9^{\{1324\}}/2$
10	$\mathbf{u}_{10} = \begin{bmatrix}1 & 1 & 1 & -1\end{bmatrix}^T$	$\mathbf{W}_{10}^{\{1\}}$	$\mathbf{W}_{10}^{\{13\}}/\sqrt{2}$	$\mathbf{W}_{10}^{\{123\}}/\sqrt{3}$	$\mathbf{W}_{10}^{\{1324\}}/2$
11	$\mathbf{u}_{11} = \begin{bmatrix}1 & j & -1 & j\end{bmatrix}^T$	$\mathbf{W}_{11}^{\{1\}}$	$\mathbf{W}_{11}^{\{13\}}/\sqrt{2}$	$\mathbf{W}_{11}^{\{134\}}/\sqrt{3}$	$\mathbf{W}_{11}^{\{1324\}}/2$
12	$\mathbf{u}_{12} = \begin{bmatrix}1 & -1 & -1 & 1\end{bmatrix}^T$	$\mathbf{W}_{12}^{\{1\}}$	$\mathbf{W}_{12}^{\{12\}}/\sqrt{2}$	$\mathbf{W}_{12}^{\{123\}}/\sqrt{3}$	$\mathbf{W}_{12}^{\{1234\}}/2$
13	$\mathbf{u}_{13} = \begin{bmatrix}1 & -1 & 1 & -1\end{bmatrix}^T$	$\mathbf{W}_{13}^{\{1\}}$	$\mathbf{W}_{13}^{\{13\}}/\sqrt{2}$	$\mathbf{W}_{13}^{\{123\}}/\sqrt{3}$	$\mathbf{W}_{13}^{\{1234\}}/2$
14	$\mathbf{u}_{14} = \begin{bmatrix}1 & 1 & -1 & -1\end{bmatrix}^T$	$\mathbf{W}_{14}^{\{1\}}$	$\mathbf{W}_{14}^{\{13\}}/\sqrt{2}$	$\mathbf{W}_{14}^{\{123\}}/\sqrt{3}$	$\mathbf{W}_{14}^{\{3214\}}/2$
15	$\mathbf{u}_{15} = \begin{bmatrix}1 & 1 & 1 & 1\end{bmatrix}^T$	$\mathbf{W}_{15}^{\{1\}}$	$\mathbf{W}_{15}^{\{12\}}/\sqrt{2}$	$\mathbf{W}_{15}^{\{123\}}/\sqrt{3}$	$\mathbf{W}_{15}^{\{1234\}}/2$

References

[1] C. Xu, C. Gao, Z. Zhou, Z. Chang, and Y. Jia, “Social Network-Based Content Delivery in Device-to-Device Underlay Cellular Networks Using Matching Theory,” *IEEE Access*, vol. 5, pp. 924–937, 2017, doi: 10.1109/ACCESS.2016.2621010.

[2] A. Alnoman and A. Anpalagan, “On D2D communications for public safety applications,” in *2017 IEEE Canada International Humanitarian Technology Conference (IHTC)*, 2017, pp. 124–127, doi: 10.1109/IHTC.2017.8058172.

[3] B. Mohanta, P. Das, and S. Patnaik, “Healthcare 5.0: A Paradigm Shift in Digital Healthcare System Using Artificial Intelligence, IOT and 5G Communication,” in *2019 International Conference on Applied Machine Learning (ICAML)*, 2019, pp. 191–196, doi: 10.1109/ICAML48257.2019.00044.

[4] A. Kumar, J. Eldho, S. Pandey, R. Bajpai, and N. Gupta, “Outage Analysis of D2D-based Ultra-Reliable Low Latency Communication System under Nakagami-m Fading Channel,” in *2020 IEEE International Conference on Advanced Networks and Telecommunications Systems (ANTS)*, 2020, pp. 1–4, doi: 10.1109/ANTS50601.2020.9342835.

[5] M. Condoluci, L. Militano, A. Orsino, J. Alonso-Zarate, and G. Araniti, “LTE-direct vs. WiFi-direct for machine-type communications over LTE-A systems,” in *2015 IEEE 26th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, 2015, pp. 2298–2302, doi: 10.1109/PIMRC.2015.7343681.

[6] E. Hossain, M. Rasti, H. Tabassum, and A. Abdelnasser, “Evolution toward 5G multi-tier cellular wireless networks: An interference management perspective,” *IEEE Wirel. Commun.*, vol. 21, no. 3, pp. 118–127, 2014, doi: 10.1109/MWC.2014.6845056.

[7] M. Li, “Soft Frequency Reuse-Based Resource Allocation for D2D Communications Using Both Licensed and Unlicensed Bands,” in *2019 Eleventh International Conference on Ubiquitous and Future Networks (ICUFN)*, 2019, pp. 384–386, doi: 10.1109/ICUFN.2019.8806044.

[8] K. W. Choi and Z. Han, “Device-to-Device Discovery for Proximity-Based Service

in LTE-Advanced System," *IEEE J. Sel. Areas Commun.*, vol. 33, no. 1, pp. 55–66, Jan. 2015, doi: 10.1109/JSAC.2014.2369591.

[9] J. Wang, C. Jiang, Z. Bie, T. Q. S. Quek, and Y. Ren, "Mobile Data Transactions in Device-to-Device Communication Networks: Pricing and Auction," *IEEE Wirel. Commun. Lett.*, vol. 5, no. 3, pp. 300–303, Jun. 2016, doi: 10.1109/LWC.2016.2547395.

[10] E. Sourour, "Codebook-based precoding for generalized spatial modulation with diversity," *Eurasip J. Wirel. Commun. Netw.*, vol. 2019, no. 1, 2019, doi: 10.1186/s13638-019-1545-7.

[11] R. I. Ansari *et al.*, "5G D2D Networks: Techniques, Challenges, and Future Prospects," *IEEE Syst. J.*, vol. 12, no. 4, pp. 3970–3984, Dec. 2018, doi: 10.1109/JSYST.2017.2773633.

[12] H. Viswanathan and M. Weldon, "The Past, Present, and Future of Mobile Communications," *Bell Labs Tech. J.*, vol. 19, pp. 8–21, 2014, doi: 10.15325/BLTJ.2014.2335491.

[13] A. Gupta and R. K. Jha, "A Survey of 5G Network: Architecture and Emerging Technologies," *IEEE Access*, vol. 3. Institute of Electrical and Electronics Engineers Inc., pp. 1206–1232, 2015, doi: 10.1109/ACCESS.2015.2461602.

[14] C. E. Shannon, "A Mathematical Theory of Communication," *Bell Syst. Tech. J.*, vol. 27, no. 4, pp. 623–656, 1948, doi: 10.1002/j.1538-7305.1948.tb00917.x.

[15] K. R. Santhi, V. K. Srivastava, G. SenthilKumaran, and A. Butare, "Goals of true broad band's wireless next wave (4G-5G)," *IEEE Veh. Technol. Conf.*, vol. 58, no. 4, pp. 2317–2321, 2003, doi: 10.1109/vetecf.2003.1285943.

[16] A. F. Molisch, "IS95 and CDMA 2000," in *Wireless Communications*, IEEE, 2011, pp. 621–634.

[17] R. D. Yates and N. B. Mandayam, "Challenges in low-cost wireless data transmission," *IEEE Signal Process. Mag.*, vol. 17, no. 3, pp. 93–102, May 2000, doi: 10.1109/79.841734.

[18] S. Hamiti, M. Hakaste, M. Moisio, N. Nefedov, E. Nikula, and H. Vilpponen, "EDGE circuit switched data-an enhancement of GSM data services," in *WCNC. 1999 IEEE Wireless Communications and Networking Conference (Cat.*

No.99TH8466), 1999, vol. 3, pp. 1437–1441 vol.3, doi: 10.1109/WCNC.1999.796975.

[19] T. Halonen, J. Romero, and J. Melero, *GSM, GPRS and EDGE Performance: Evolution Towards 3G/UMTS*. Wiley, New York, 2003.

[20] U. Varshney, “4G Wireless Networks,” *IT Prof.*, vol. 14, no. 5, pp. 34–39, 2012, doi: 10.1109/MITP.2012.71.

[21] M. Agiwal, H. Kwon, S. Park, and H. Jin, “A Survey on 4G-5G Dual Connectivity: Road to 5G Implementation,” *IEEE Access*, vol. 9, pp. 16193–16210, 2021, doi: 10.1109/ACCESS.2021.3052462.

[22] ITU, “Minimum requirements related to technical performance for IMT-2020 radio interface(s),” *Work. Party 5D*, vol. November, no. 5D/TEMP/300(Rev.1), pp. 1–148, 2017.

[23] “(No Title).” [Online]. Available: https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2410-2017-PDF-E.pdf. [Accessed: 01-Mar-2021].

[24] K. Barman and A. Roy, *A combine mode selection based resource allocation and interference control technique for D2D communicationin **. .

[25] Cisco, “Cisco visual networking index (VNI) global mobile data traffic forecast update, 2017-2022 white paper,” *Ca, Usa*, pp. 3–5, 2019.

[26] L. Militano, M. Condoluci, G. Araniti, A. Molinaro, and A. Iera, “When D2D communication improves group oriented services in beyond 4G networks,” *Wirel. Networks*, vol. 21, no. 4, pp. 1363–1377, May 2015, doi: 10.1007/s11276-014-0860-5.

[27] G. Fodor *et al.*, “Design aspects of network assisted device-to-device communications,” *IEEE Commun. Mag.*, vol. 50, no. 3, pp. 170–177, Mar. 2012, doi: 10.1109/MCOM.2012.6163598.

[28] U. N. Kar and D. K. Sanyal, “An overview of device-to-device communication in cellular networks,” *ICT Express*, vol. 4, no. 4, pp. 203–208, 2018, doi: 10.1016/j.icte.2017.08.002.

[29] Y. Yang, Y. Zhang, L. Dai, J. Li, S. Mumtaz, and J. Rodriguez, “Transmission Capacity Analysis of Relay-Assisted Device-to-Device Overlay/Underlay Communication,” *IEEE Trans. Ind. Informatics*, vol. 13, no. 1, pp. 380–389, Feb.

2017, doi: 10.1109/TII.2016.2617921.

[30] D. Kumar *et al.*, “Mode Switching for Energy-Efficient Device-to-Device Communications in Cellular Networks,” *IEEE Trans. Wirel. Commun.*, vol. 64, no. 8, pp. 6993–7003, 2016, doi: 10.1109/TWC.2015.2463280.

[31] C. H. Yu, O. Tirkkonen, K. Doppler, and C. Ribeiro, “Power optimization of device-to-device communication underlaying cellular communication,” in *IEEE International Conference on Communications*, 2009, doi: 10.1109/ICC.2009.5199353.

[32] D. Astely, E. Dahlman, G. Fodor, S. Parkvall, and J. Sachs, “LTE release 12 and beyond,” *IEEE Commun. Mag.*, vol. 51, no. 7, pp. 154–160, 2013, doi: 10.1109/MCOM.2013.6553692.

[33] D. Feng, L. Lu, Y. W. Yi, G. Y. Li, S. Li, and G. Feng, “Device-to-device communications in cellular networks,” *IEEE Commun. Mag.*, vol. 52, no. 4, pp. 49–55, 2014, doi: 10.1109/MCOM.2014.6807946.

[34] B. Kaufman and B. Aazhang, “Cellular networks with an overlaid device to device network,” in *Conference Record - Asilomar Conference on Signals, Systems and Computers*, 2008, pp. 1537–1541, doi: 10.1109/ACSSC.2008.5074679.

[35] B. Kaufman, J. Lilleberg, and B. Aazhang, “Spectrum Sharing Scheme Between Cellular Users and Ad-hoc Device-to-Device Users,” *IEEE Trans. Wirel. Commun.*, vol. 12, no. 3, pp. 1038–1049, Mar. 2013, doi: 10.1109/TWC.2012.011513.120063.

[36] B. Kaufman *et al.*, “Device-to-Device Communication Underlaying Cellular Communications Systems,” *IEEE Commun. Mag.*, vol. 64, no. 8, pp. 5750–5762, 2016, doi: 10.1109/TWC.2011.060811.102120.

[37] A. Gjendemsjø, D. Gesbert, G. E. Øien, and S. G. Kiani, “Binary power control for sum rate maximization over multiple interfering links,” *IEEE Trans. Wirel. Commun.*, 2008, doi: 10.1109/TWC.2008.070227.

[38] V. K. N. Lau, Yan Chen, and Kaibin Huang, “Spectrum sharing between cellular and mobile ad hoc networks: transmission-capacity trade-off,” *IEEE J. Sel. Areas Commun.*, vol. 27, no. 7, pp. 1256–1267, Sep. 2009, doi: 10.1109/JSAC.2009.090921.

[39] P. JANIS *et al.*, “Device-to-Device Communication Underlaying Cellular

Communications Systems," *Int. J. Commun. Netw. Syst. Sci.*, vol. 02, no. 03, pp. 169–178, 2009, doi: 10.4236/ijcns.2009.23019.

[40] W. Zhao and S. Wang, "Resource Allocation for Device-to-Device Communication Underlaying Cellular Networks: An Alternating Optimization Method," *IEEE Commun. Lett.*, vol. 19, no. 8, pp. 1398–1401, Aug. 2015, doi: 10.1109/LCOMM.2015.2444403.

[41] K. Akkarajitsakul, P. Phunchongharn, E. Hossain, and V. K. Bhargava, "Mode selection for energy-efficient D2D communications in LTE-advanced networks: A coalitional game approach," in *2012 IEEE International Conference on Communication Systems, ICCS 2012*, 2012, doi: 10.1109/ICCS.2012.6406196.

[42] Y. Jiang, Q. Liu, F. Zheng, X. Gao, and X. You, "Energy efficient joint resource allocation and power control for D2D communications," *arXiv*, vol. 65, no. 8, pp. 6119–6127, 2017.

[43] T. Huynh, T. Onuma, K. Kuroda, M. Hasegawa, and W. J. Hwang, "Joint downlink and uplink interference management for device to device communication underlaying cellular networks," *IEEE Access*, vol. 4, no. c, pp. 4420–4430, 2016, doi: 10.1109/ACCESS.2016.2603149.

[44] L. Ma, X. Deng, J. Wang, Y. Huang, and F. Shi, "Downlink Resource Sharing in Multichannel Device-to-Device Communication," *IEEE Wirel. Commun. Lett.*, vol. 8, no. 3, pp. 741–744, Jun. 2019, doi: 10.1109/LWC.2018.2890599.

[45] P. K. Mishra, S. Pandey, and S. K. Biswash, "Efficient Resource Management by Exploiting D2D Communication for 5G Networks," *IEEE Access*, vol. 4, pp. 9910–9922, 2016, doi: 10.1109/ACCESS.2016.2602843.

[46] Z. Kaleem, N. N. Qadri, T. Q. Duong, and G. K. Karagiannidis, "Energy-Efficient Device Discovery in D2D Cellular Networks for Public Safety Scenario," *IEEE Syst. J.*, vol. 13, no. 3, pp. 2716–2719, Sep. 2019, doi: 10.1109/JSYST.2019.2899922.

[47] R. A. Martins, I. Sousa, M. P. Queluz, and A. Rodrigues, "Techniques for Device-to-Device Discovery in Out-of-Coverage Networks," *IEEE Access*, vol. 9, pp. 10291–10303, 2021, doi: 10.1109/ACCESS.2021.3050256.

[48] D. Lopez-Perez, A. Ladanyi, A. Juttner, H. Rivano, and J. Zhang, "Optimization method for the joint allocation of modulation schemes, coding rates, resource blocks

and power in self-organizing LTE networks," in *2011 Proceedings IEEE INFOCOM*, 2011, pp. 111–115, doi: 10.1109/INFCOM.2011.5934888.

[49] M. Zulhasnine, C. Huang, and A. Srinivasan, "Efficient Resource Allocation for Device-to-Device.pdf," *IEEE 6th Int. Conf. Wirel. Mob. Comput. Netw. Commun. Effic.*, pp. 368–375, 2010.

[50] Z. Lin, L. Huang, Y. Li, H. C. Chao, and P. Chen, "Analysis of transmission capacity for multi-mode D2D communication in mobile networks," *Pervasive Mob. Comput.*, vol. 41, pp. 179–191, Oct. 2017, doi: 10.1016/j.pmcj.2017.07.012.

[51] M. I. Poulakis, A. G. Gotsis, and A. Alexiou, "Multi-cell Device-to-Device communication benefits in the presence of densification," in *2017 IEEE International Conference on Communications Workshops (ICC Workshops)*, 2017, pp. 1335–1340, doi: 10.1109/ICCW.2017.7962844.

[52] W. Chen, T. Li, Z. Xiao, and D. Wang, "On mitigating interference under device-to-device communication in macro-small cell networks," in *2016 International Conference on Computer, Information and Telecommunication Systems (CITS)*, 2016, pp. 1–5, doi: 10.1109/CITS.2016.7546431.

[53] F. Ahishakiye and F. Y. Li, "Service discovery protocols in D2D-enabled cellular networks: Reactive versus proactive," *2014 IEEE Globecom Work. GC Wkshps 2014*, pp. 833–838, 2014, doi: 10.1109/GLOCOMW.2014.7063536.

[54] S. Doumiati, H. Artail, and D. M. Gutierrez-Estevez, "A framework for LTE-A proximity-based device-to-device service registration and discovery," *Procedia Comput. Sci.*, vol. 34, pp. 87–94, 2014, doi: 10.1016/j.procs.2014.07.054.

[55] and H. Y. Mohsen Nader Tehrani, Murat Uysal, "Overview of D2D Communication Types and Main Technical Challenges," *IEEE Communications Magazine*, pp. 86–92, 2014.

[56] R. Want, "Near field communication," *IEEE Pervasive Comput.*, vol. 10, no. 3, pp. 4–7, 2011, doi: 10.1109/MPRV.2011.55.

[57] U. N. Kar and D. K. Sanyal, "An overview of device-to-device communication in cellular networks," *ICT Express*, vol. 4, no. 4. Korean Institute of Communications Information Sciences, pp. 203–208, 01-Dec-2018, doi: 10.1016/j.icte.2017.08.002.

[58] M. Höyhtyä, O. Apilo, and M. Lasanen, "Review of Latest Advances in 3GPP

Standardization: D2D Communication in 5G Systems and Its Energy Consumption Models,” *Futur. Internet*, vol. 10, no. 1, p. 3, Jan. 2018, doi: 10.3390/fi10010003.

[59] B. Fang, Z. Qian, W. Zhong, W. Shao, and H. Xue, “Coordinated precoding for D2D communications underlay uplink MIMO cellular networks,” in *2015 IEEE/CIC International Conference on Communications in China (ICCC)*, 2015, pp. 1–5, doi: 10.1109/ICCChina.2015.7448661.

[60] N. T. Nguyen and K. Lee, “Cell Coverage Extension With Orthogonal Random Precoding for Massive MIMO Systems,” *IEEE Access*, vol. 5, pp. 5410–5424, 2017, doi: 10.1109/ACCESS.2017.2693023.

[61] R. Chithra, R. Bestak, and S. K. Patra, “Orthogonal MIMO precoding schemes for device-to-device communication in LTE networks,” in *2015 38th International Conference on Telecommunications and Signal Processing, TSP 2015*, 2015, doi: 10.1109/TSP.2015.7296480.

[62] S. S. Thoota, P. Babu, and C. R. Murthy, “Codebook-Based Precoding and Power Allocation for MU-MIMO Systems for Sum Rate Maximization,” *IEEE Trans. Commun.*, vol. 67, no. 12, pp. 8290–8302, Dec. 2019, doi: 10.1109/TCOMM.2019.2940959.

[63] W. Fu, F. Shi, and N. Liu, “Distributed precoding technology of reducing inter-cell interference in LTE downlink,” in *2011 IEEE 3rd International Conference on Communication Software and Networks*, 2011, pp. 369–372, doi: 10.1109/ICCSN.2011.6013614.

[64] Q. Wang, C. Lai, Y. Dong, Y. Shu, and X. Xu, “Joint user clustering and resource allocation for device-to-device communication underlaying MU-MIMO cellular networks,” *Eurasip J. Wirel. Commun. Netw.*, 2015, doi: 10.1186/s13638-015-0358-6.

[65] H. Min, W. Seo, J. Lee, S. Park, and D. Hong, “Reliability improvement using receive mode selection in the device-to-device uplink period underlaying cellular networks,” *IEEE Trans. Wirel. Commun.*, vol. 10, no. 2, pp. 413–418, 2011, doi: 10.1109/TWC.2011.122010.100963.

[66] E. Hossain, D. Niyato, and Z. Han, *Dynamic spectrum access and management in cognitive radio networks*, vol. 9780521898. Cambridge University Press, 2009.

[67] J. Yue, C. Ma, H. Yu, and W. Zhou, “Secrecy-Based Access Control for Device-to-Device Communication Underlaying Cellular Networks,” *IEEE Commun. Lett.*, vol. 17, no. 11, pp. 2068–2071, Nov. 2013, doi: 10.1109/LCOMM.2013.092813.131367.

[68] S. Sharifi and M. Fathi, “Price-based device-to-device communication underlying cellular networks,” in *2016 8th International Symposium on Telecommunications (IST)*, 2016, pp. 309–313, doi: 10.1109/ISTEL.2016.7881831.

[69] W. Gu and Q. Zhu, “Stackelberg game based social-aware resource allocation for NOMA enhanced D2D communications,” *Electron.*, vol. 8, no. 11, pp. 1–14, 2019, doi: 10.3390/electronics8111360.

[70] M. K. Farshbafan, M. H. Bahonar, and F. Khaiehraveni, “Spectrum Trading for Device-to-Device Communication in Cellular Networks using Incomplete Information Bandwidth-Auction Game,” in *2019 27th Iranian Conference on Electrical Engineering (ICEE)*, 2019, pp. 1441–1447, doi: 10.1109/IranianCEE.2019.8786475.

[71] M. Tehrani, M. Uysal, and H. Yanikomeroglu, “Device-to-device communication in 5G cellular networks: Challenges, solutions, and future directions,” *IEEE Commun. Mag.*, vol. 52, no. 5, pp. 86–92, 2014, doi: 10.1109/MCOM.2014.6815897.

[72] A. Asadi and V. Mancuso, “WiFi Direct and LTE D2D in action,” in *2013 IFIP Wireless Days (WD)*, 2013, pp. 1–8, doi: 10.1109/WD.2013.6686520.

[73] K. Zhu, E. Hossain, and D. Niyato, “Pricing, spectrum sharing, and service selection in two-tier small cell networks: A hierarchical dynamic game approach,” *IEEE Trans. Mob. Comput.*, vol. 13, no. 8, pp. 1843–1856, 2014, doi: 10.1109/TMC.2013.96.

[74] A. Perrig, J. Stankovic, and D. Wagner, “Security in wireless sensor networks,” *Communications of the ACM*, vol. 47, no. 6. pp. 53–57, Jun-2004, doi: 10.1145/990680.990707.

[75] D. Kumar, D. Manjunath, and J. Nair, “Spectrum sharing: How much to give,” in *2016 8th International Conference on Communication Systems and Networks, COMSNETS 2016*, 2016, doi: 10.1109/COMSNETS.2016.7439962.

[76] C. S. Hyder, T. D. Jeitschko, and L. Xiao, “Bid and Time Truthful Online Auctions in Dynamic Spectrum Markets,” *IEEE Trans. Cogn. Commun. Netw.*, vol. 3, no. 1, pp. 82–96, Mar. 2017, doi: 10.1109/TCCN.2017.2669997.

[77] N. Tadayon and S. Aissa, “Radio Resource Allocation and Pricing: Auction-Based Design and Applications,” *IEEE Trans. Signal Process.*, vol. 66, no. 20, pp. 5240–5254, Oct. 2018, doi: 10.1109/TSP.2018.2862398.

[78] C. Hoymann, W. Chen, J. Montojo, A. Golitschek, C. Koutsimanis, and X. Shen, “Relaying operation in 3GPP LTE: Challenges and solutions,” *IEEE Commun. Mag.*, vol. 50, no. 2, pp. 156–162, 2012, doi: 10.1109/MCOM.2012.6146495.