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**A NOVEL MODE SELECTION ALGORITHM FOR DEVICE-TO-DEVICE COMMUNICATION SYSTEMS TO ENHANCE THE SYSTEM THROUGHPUT**

A NOVEL MODE SELECTION ALGORITHM FOR DEVICE-TO-DEVICE COMMUNICATION SYSTEMS TO ENHANCE THE SYSTEM THROUGHPUT

By

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Thesis submitted in partial fulfillment of the requirements for the degree of M.Sc. in Computer Science

At

The Faculty of Graduate Studies

Jordan University of Science and Technology

April, 2017

**A NOVEL MODE SELECTION ALGORITHM FOR DEVICE-TO-DEVICE COMMUNICATION SYSTEMS TO ENHANCE THE SYSTEM THROUGHPUT**

By

**Islam Shaker AL Husban**

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April, 2017

**تفويض**

نحن الموقعين أدناه، نتعهد بمنح جامعة العلوم والتكنولوجيا الأردنية حريةالتصرف في نشر محتوى الرسالة الجامعية، بحيث تعود حقوق الملكية الفكريةالرسالة الماجستير إلى الجامعة وفق القوانين والأنظمة والتعليمات المتعلقةبالملكية الفكرية وبراءة الاختراع.

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**DEDICATION**

Getting through my dissertation required more than academic support, and I have many, many people to thank for listening to and, at times, having to tolerate me. To my family, none of this could have happened without their efforts. My mother Fadwa, who offered the support and the chance to fulfill my passion for learning. My father Shaker, who offered love, and encouragement throughout my entire life. Also, I am truly grateful to my beloved brothers (Safwan, Sofyan and Mohammed) and one and only sister (Salsabeel ) for supporting me spiritually throughout writing this thesis and my life in general.

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TABLE OF CONTENTS

[DEDICATION i](#_Toc489984314)

[ACKNOWLEDGEMENT ii](#_Toc489984315)

[TABLE OF CONTENTS iii](#_Toc489984316)

[LIST OF ABBREVIATIONS viii](#_Toc489984317)

[ABSTRACT ix](#_Toc489984318)

[Chapter One : Introduction 1](#_Toc489984319)

[1.1. Era of The Mobile Internet 1](#_Toc489984320)

[1.2. Implications for Mobile Stakeholder and Operators 2](#_Toc489984321)

[1.3. Toward 5G 3](#_Toc489984322)

[1.4. Thesis Structure 4](#_Toc489984323)

[Chapter Two : Device to Device Communications 5](#_Toc489984324)

[2.1. The Deﬁnition of D2D Communications 5](#_Toc489984325)

[2.2. Classification of D2D Communication Scenario 6](#_Toc489984326)

[2.2.1 Based on Spectrum Resources 6](#_Toc489984327)

[2.2.2 Based on The Offered Services Type 9](#_Toc489984328)

[2.2.3 Based on Network Control 10](#_Toc489984329)

[2.3. Performance Gains of D2D Communications 11](#_Toc489984330)

[2.4. Advantages of D2D Compared to Other Technology 11](#_Toc489984331)

[2.4.1 D2D Compared to Short Range Wireless Technology 12](#_Toc489984332)

[2.4.2 D2D Compared to FemtoCell /PicoCell / Relay 12](#_Toc489984333)

[2.4.3 D2D Compared to Traditional 4G Cellular Networks 12](#_Toc489984334)

[2.4.4 D2D Compared to Cognitive Radio Networks (CRN) 13](#_Toc489984335)

[2.4.5 D2D Compared to Mobile Ad-Hoc Networks (MANETs) 13](#_Toc489984336)

[2.4.6 D2D Compared to Machine to Machine communication (M2M) 14](#_Toc489984337)

[2.5. Applications and Use Cases of D2D Communication 14](#_Toc489984338)

[2.6. Challenges and Limitation of D2D Communications 15](#_Toc489984339)

[Chapter Three : Thesis Focus, Theoretical Background, and Research Problem 16](#_Toc489984340)

[3.1. Thesis Scope and Focus 16](#_Toc489984341)

[3.2. Literature Review 18](#_Toc489984342)

[3.3. Thesis Research Problem and Contribution 20](#_Toc489984343)

[Chapter Four : System Model and Problem Formulation 21](#_Toc489984344)

[4.1. Simulation System Model 21](#_Toc489984345)

[4.2. Problem Formulation for Communication Modes 21](#_Toc489984346)

[4.2.1 Cellular Mode: 22](#_Toc489984347)

[4.2.2 Dedicated Mode: 23](#_Toc489984348)

[4.2.3 Reuse Mode: 24](#_Toc489984349)

[4.3. Problem Formulation for Mode Selection 27](#_Toc489984350)

[4.4. Problem Formulation for Channel Assignment 27](#_Toc489984351)

[4.5. Problem Formulation for Power Control 28](#_Toc489984352)

[4.6. Problem Formulation for The Optimization Joint Mode Selection, Resource Allocation, And Power Control 30](#_Toc489984353)

[4.7. The Optimization Joint Mode Selection, Resource Allocation, and Power Control Based on The Network Load 33](#_Toc489984354)

[4.8. Proposed Schemes and Algorithms 33](#_Toc489984355)

[Chapter Five : Simulation environment, Results, and Analysis 37](#_Toc489984356)

[5.1. Users Distribution in Simulation Network 37](#_Toc489984357)

[5.2. Simulation Tools 38](#_Toc489984358)

[5.3. Simulation Procedure: 38](#_Toc489984359)

[5.4. Simulation Parameters: 39](#_Toc489984360)

[5.5. Result and Analysis 40](#_Toc489984361)

[5.5.1. Impact of Maximum Transmit Power on Overall System Throughput 40](#_Toc489984362)

[5.5.2. Impact of Maximum D2D Distance on Overall System Throughput 43](#_Toc489984363)

[5.5.3. Impact of the D2D Pairs Number on Overall System Throughput 46](#_Toc489984364)

[5.5.4. Number of iterations 50](#_Toc489984365)

[Chapter Six : Conclusion and Future Work 51](#_Toc489984366)

[References 52](#_Toc489984367)

[Abstract in Arabic Language 56](#_Toc489984368)

**LIST OF FIGURES**

**Figure** **Description** **Page**

[Figure 1: The evolution of HetNets architecture [14]. 3](#_Toc489985552)

[Figure 2: Traditional cellular mode vs. D2D mode in a cellular system. 6](#_Toc489985553)

[Figure 3: Type of D2D communication based on spectrum [9]. 7](#_Toc489985554)

[Figure 4: Inband D2D communication scenarios. 7](#_Toc489985555)

[Figure 5: Outband D2D communication scenario. 8](#_Toc489985556)

[Figure 6:Types of D2D communications based on the provided service. 10](#_Toc489985557)

[Figure 7: A sample of D2D communications concept and applications [15]. 15](#_Toc489985558)

[Figure 8: D2D communication modes [23] 18](#_Toc489985559)

[Figure 9: Snapshot from the algorithm code step 1. 34](#_Toc489985560)

[Figure 10: System model for the various distances in the two user topologies 37](#_Toc489985561)

[Figure 11: A snapshot of the cellular system and generated users 38](#_Toc489985562)

[Figure 12: Overall system throughput for different algorithms using different maximum power (where NU = ND = 2, r=20 m, K = 8, M = 18,18-24 dBm) (a) Overall system throughput using different maximum power in slow rayleigh fading(SRF) (b) Overall system throughput using different maximum power in fast rayleigh fading (FSF) 41](#_Toc489985565)

[Figure 13: Overall system throughput for proposed Optimal algorithm and Algorithm 2 from [23] using different maximum power in both fast and slow Rayleigh fading (where NU = ND = 2, r=20 m, K = 8, M = 18,18-24 dBm) 42](#_Toc489985566)

[Figure 14: Overall system throughput for proposed Optimal algorithm compared with algorithms from [23] using different maximum power in both fast and slow Rayleigh fading (where NU = ND = 2, r=20 m, K = 8, M = 18,18-24 dBm) 43](#_Toc489985567)

[Figure 15: Overall system throughput for different algorithms using different maximum D2D distance (where NU = ND = 2, r=20-100 m, K = 8, M = 18,24 dBm) (a) Overall system throughput using different maximum D2D distance in slow rayleigh fading (SRF) (b) Overall system throughput using different maximum D2D distance in fast rayleigh fading (FSF) 44](#_Toc489985568)

[Figure 16: Overall system throughput for proposed Optimal algorithm and Algorithm 2 from [23] using different D2D distance in both fast and slow Rayleigh fading (where NU = ND = 2, r=20-100 m, K = 8, M = 18,24 dBm) 45](#_Toc489985569)

[Figure 17: Overall system throughput for proposed Optimal algorithm compared with algorithms from [23] using different D2D distance in both fast and slow Rayleigh fading (where NU = ND = 2, r=20 -100 m, K = 8, M = 18,24 dBm) 46](#_Toc489985570)

[Figure 18: Overall system throughput for different algorithms using different number of K pairs (where NU = ND = 5, r=20 m, K = 1-15 pair, M = 15,24 dBm) (a) Overall system throughput using different number of K pairs in slow rayleigh fading (SRF) (b) Overall system throughput using different number of K pairs in fast rayleigh fading (FSF) 48](#_Toc489985573)

[Figure 19: Overall system throughput for proposed Optimal algorithm and Algorithm 2 from [23] using different number of K D2D in both fast and slow Rayleigh fading (where NU = ND = 5, r=20m, K = 1-15, M = 15,24 dBm) 49](#_Toc489985574)

[Figure 20: Overall system throughput for proposed Optimal algorithm and proposed algorithms from [23] using different number of K D2D in both fast and slow Rayleigh fading (where NU = ND = 5, r=20 m, K = 1-15, M = 15,24 dBm) 49](#_Toc489985575)

[Figure 21: Overall system throughput for different algorithms using different maximum power (where NU = ND = 2, r=20 m, K = 8, M = 18,18-24 dBm) 50](#_Toc489985576)

**LIST OF TABLES**

**Figure** **Description** **Page**

[Table 1 : A comparison between D2D communications based on spectrum utilization. 9](#_Toc489977041)

[Table 2 : D2D communications schemes based on network control. 11](#_Toc489977042)

[Table 3 : Simulation parameter 39](#_Toc489977043)

LIST OF ABBREVIATIONS

|  |  |
| --- | --- |
| **3G/4G/5G** | **G**enerations of mobile telecommunications technology |
| **AWGN** | **A**dditive **W**hite **G**aussian **N**oise |
| **BS** | **B**ase-**S**tation |
| **CRN** | **C**ognitive **R**adio **N**etworks |
| **CSI** | **C**hannel **S**tate **I**nformation |
| **CUs** | **C**ellar **U**sers |
| **D2D** | **D**evice-**to**-**D**evice |
| **DUs** | **D**evice-to-Device **U**sers |
| **E2E** | **E**nd-**T**o-**E**nd |
| **eNB** | **E**volved **N**ode **B**ase **S**tation |
| **FRF** | **F**ast **R**ayleigh **F**ading |
| **HetNets** | **H**eterogeneous **N**etwork |
| **IoT** | **I**nternet **o**f **T**hings |
| **LTE** | **L**ong **T**erm **E**volution |
| **LTE-A** | **L**ong **T**erm **E**volution-**A**dvanced |
| **MANET** | **M**obile **A**d-**H**oc **N**etworks |
| **ProSe** | **P**roximity **S**ervice |
| **QoS** | **Q**uality-**o**f-**S**ervice |
| **QoE** | **Q**uality **o**f **E**xperience |
| **RRM** | **R**adio **R**esource **M**anagement |
| **SINR** | **S**ignal-to-**I**nterference-**P**lus-**N**oise **R**atio |
| **SNR** | **S**ignal-to-**N**oise **R**atio |
| **SRF** | **S**low **R**ayleigh **F**ading |
| **VoIP** | **V**oice **o**ver **IP** address |
| **WiFi** | **W**ireless local area networking with devices based on the IEEE 802.11 standards |

ABSTRACT

**A NOVEL MODE SELECTION ALGORITHM FOR DEVICE-TO-DEVICE COMMUNICATION SYSTEMS TO ENHANCE THE SYSTEM THROUGHPUT**

By

**Islam Shaker AL Husban**

The recent evolution of mobile systems, such as smartphones and tablets in cellular network systems, increases the demands for new technological trends and services that can support the mobile operators and satisfy mobile user’s expectations even with spectrum limitations. However, due to its potential capability to improve spectral efficiency, power, delay, and network capability without increasing infrastructure cost; mobile stakeholders and researchers have examined the Device-to-Device (D2D) underlying communications technology. D2D underlying communication, can be defined as two devices communicate directly using the cellular resources without the involvement of the base station (BS). Nevertheless, the decision when the direct communication mode (D2D) is preferred over the other communication modes is still one of the open research problems. In this thesis, dynamic joint mode selection and resource allocation low-complexity algorithms for D2D systems are developed. Our algorithms can directly select the optimal communication mode using uplink and downlink channels by considering the network load and the received information from the BS. The algorithms were evaluated numerically via Matlab-based simulations and the result showed that our novel joint mode selection, channel assignment, and power control in D2D communication underlying networks-assisted cellular system maximized the overall system throughput, while guaranteeing high signal-to-noise-plus-interference ratio (SINR) for both cellular and D2D links.

1. Introduction

The recent evolution of mobile system increases the demands for new technological trends and services that can support the mobile operators and accommodate the massive mobile data traffic in the network despite the spectrum scarcity. In this chapter, a description on the main perspective of this growth and discuss the reasons behind it is briefly introduced.

1. Era of The Mobile Internet

In the past five decades, the world has witnessed an evolution in mobile systems, a shift from the traditional mobiles that are used just for calling, texting and content creation to smart terminals (*i.e., smartphones, tablets, sensor devices, laptops etc…),* that are used also for web browsing, and handling much more important tasks. Consequently, a fast-growing competitive market of reachable low-cost mobile device arises where the retails of smartphones and tablets beat the sales of PCs, laptops, and notebooks [1]. For example, 20% of the world’s population owned tablet devices in 2014 [2], and more than 1,423.9 million unit of smartphones were sold worldwide in 2015 [3].

This recent proliferation of new generation of terminals led to an impressive diverse sets of mobile internet applications such as (*i.e., social network, video on demand, Voice over IP address(VOIP), live TVs, gaming, Internet of Things(IoT), etc.*). These most popular applications are a live example of how the internet has become an important aspect of the daily life of a mobile user:

* Facebook (*Social Networking Application*) has more than 1.04 billion daily active users; and more than 934 million of them access their accounts from mobiles [4].

Thus, that mobile devices users are twice as active on their Facebook account compared to non-mobile users [5].

* YouTube (Mobile Video Application), reports that more than half of YouTube views come from mobile devices [6] where the average mobile viewing session is more than 40 minutes.
* Skype (Mobile Communication Application) aVoIP leader already has more registered users than any global carrier [5].
* Whats-App, (Mobile Texting Application), reports that it has over one billion active users globally [7].

Each one of these applications has at least more than a billion active users on their mobiles, which is almost one third of all connected people to Internet daily [6]. Mobile users are likely to accelerate the growth of mobile data usage. Thus, the increased demand for low-cost Internet bandwidth anytime and anywhere which points to the fact that we are in a new chapter of life called the IoT or more specific “*Era of the Mobile Internet*”.

1. Implications for Mobile Stakeholder and Operators

The Mobile system witnessed a new generation of devices and applications with no time, and its evolution places mobile Stakeholder/Operators in deadlock because of the boom in demands for higher transmission data rates, which is challenging because of the spectrum limitation [8-12]. In fact, regardless of many existing Wi-Fi deployments and 4G/3G mobile phone generations; there is an ongoing challenge to fulfill high expectations of mobile user’s regarding faster data rates and shorter delay with better quality-of-service (QoS) for data communications at various times and locations, especially in hotspots and indoor areas where the heterogeneous network (HetNets) is needed [8]. Therefore, there is an emerging need for new technological solutions, trends, and services that can live up to future communication services requirements as well as help mobile operators to accommodate higher data rates while reducing the delay time and the consuming energy at reasonable cost [9] [13] can be more beneficial than using the existing technologies.

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| --- |
| 1. The evolution of HetNets architecture [14]. |

1. Toward 5G

Many research efforts have been focusing on the issues mentioned in the earlier sections, to solve them by enhancing the communication capacity, introducing new trends and so on. A recent research shows the potential of 5G in supporting these recent market trends, accommodating the mobile data traffic explosion as well as improving spectral efficiency. 5G will be far superior to traditional 4G and go beyond expectation with 1000 times improvement on system capacity, 25 times improvement on average cell overall throughput, and 10 times higher spectral efficiency. It can provide the cell center users with higher data rates that reach 10 Gbps and up to 5 Gbps for cell edge users. In addition, it can support more connected devices with an end-to-end (E2E) latency that is up to 5 times lower [15].

1. Thesis Structure

In this section, the thesis organization is presented as follow: An overview of the definition, classification, and the potential achievement of the D2D communication technology to cellular networks are introduced in chapter 2. In Chapter 3, the thesis focus and contribution is explained briefly and a review of the recent related work is presented. Chapter 4 is dedicated to present the details of simulation system model and problem formulation of our proposed algorithm studied in this thesis. In Chapter 5, the performance results of our proposed algorithms using Matlab-based simulations are introduced. Finally, in Chapter 6 the thesis conclusion and the future research are illustrated.

1. Device to Device Communications

The essential knowledge of D2D communications technology in cellular networks is provided in this chapter. Section 2.1, provides the D2D communications definition. The classification scenarios of the D2D communications are introduced in Section 2.2. In Section 2.3, the main performance gains are provided. In Sections 2.4 and 2.5, we discuss the importance of the proposed schema compared to the existing technologies and a sample of use cases and applications. The main challenges of the D2D communication are presented in the Section 2.6. Finally, the focus and motivation behind this thesis is addressed in last section 2.7.

1. The Deﬁnition of D2D Communications

The concept of D2D technology can be very fruitful in terms of proximity service (ProSe) and applications [8] [16] [17] comparing with current traditional cellular mode. In this recent technology, the devices in proximity can get a chance to communicate with each other directly without going through any core network or any other infrastructure [16], while in the traditional cellular mode the first device should pass on data to a core network or any other infrastructure (i.e., *BS*) using uplink, and then the core network should send the data back to the target device using downlink [9]. And this not the only benefit as studies show that this concept can grant higher flexibility with variety of options in choosing the proper communication scenario starting by setting the involvement level of the BS in the process as well as the proper type of spectrum (i.e., *licensed*, *unlicensed*) [12].The concept of D2D communication against the traditional cellular mode in Figure 2.

|  |
| --- |
| 1. Traditional vs D2D Traditional cellular mode vs. D2D mode in a cellular system. |

1. Classification of D2D Communication Scenario

Researchers classify the D2D communication scenario into categories based on various aspects such as network resource control, the type of spectrum resources, the type of service and so on; in this section, three of them are presented as follow: 1) Based on the type of spectrum resources, 2)Based on the offered services type, 3)Based on the network resource control.

1. Based on Spectrum Resources

In this subsection, the D2D communication classification based on the spectrum where the communication occurs in cellular networks into two categories identified as in band (*licensed part*)and outband (*unlicensed part*) [9] [20]. Furthermore, this form can be further divided based on the used method to share the spectrum resources into two categories identified as underlay and overlay. This classification is illustrated in Figure3.

|  |
| --- |
| 1. Type of D2D communication based on spectrum [9]. |

1. **Inband D2D Communication**

In this communication mode, both of D2D users (DUs) and cellular users (CUs) use licensed part of the spectrum for data communication (i.e., *LTE, LTE-A, etc*.). This form of deployment further divided into two categories identified as underlay and overlay based on the way used to share the spectrum resources. In the underlay scenario, the D2D devices use the same cellular resources at the same frequency /time of another cellular user simultaneously. On the other hand, in the overlay scenario, the D2D devices use a dedicated cellular resource at the same frequency /time of another cellular user but not simultaneously. The motivation behind choosing this kind of communication is high reliability since it occurs in the licensed part of the spectrum. Figure 4 shows the two types of the inband D2D communication.

|  |
| --- |
| 1. ***underlay_overlay***Inband D2D communication scenarios. |

1. **Outband D2D Communication**

In this communication mode, DUs use the unlicensed spectrum resources (*i.e., industrial, scientific, or medical(ISM))* and a second interface (*i.e., ZigBee, Bluetooth, wifi-direct, etc*.) to communicate while the CUs use their licensed spectrum resources and both cellular and D2D communications can take place simultaneously. This form of deployment further divided into two categories identified as controlled and autonomous based on the BS way used to control for both D2D and cellular spectrum resources. In the controlled scenario, the BS controls both the CU's and the DU's. On the other hand, in the autonomous scenario, the users control all the DUs and the BS controls the CU's.The motivation behind choosing outband is usually to avoid the interference problems that occur between D2D and cellular links in the inband category. Figure 5showsthe two types of the outband D2D communication.

|  |
| --- |
| 1. Outband D2D communication scenario. |

In Table 1, an overview to the main advantages and disadvantages for both *inband/outband* D2D communications based on spectrum utilization is demonstrated [9 -10] [12] [20].

1. A comparison between D2D communications based on spectrum utilization.

|  |  |  |
| --- | --- | --- |
|  | **Inband** | **Outband** |
| **Benefits** | * QOS guaranteed due to the BS control to cellular spectrum. * High transmission data rates up to 1 Gbps with distance up to 1km. * No need of new interface any device can use *inband* communication. | * No interference issue since they are using different band and infrastructure. * DUs and CUs can work both simultaneous. |
| **Weakness** | * Interference problem since both DUs and CUs are using same band and infrastructure. * Computational overhead on the BS and complex algorithm for radio resource management (RRM). | * Two interfaces are required and QoS is not guarantee. * Not power efficient with Low data rate and transmission distance. |

1. **Based on The Offered Services Type**

In this classification, the type of the service is taken into consideration when the D2D communication scenario occurred **[10].**

* **Emergency Services:** In this scenario, the D2D devices can make a connection using both cellular resources and unlicensed resources if needed and this can be very fruitful in terms of safety.
* **Commercial Services:** In this category, the D2D connections take place in cellular resources only and this makes it easy to control.

Figure 6 shows the two types of D2D communications scenario based on the provided service as we can see that in the emergency scenario when we lose the licensed resources we can always use a third party (unlicensed) to make a connection. On other hand, the commercial service gives us an example of regular use for the licensed resources.

|  |
| --- |
| 1. Types of D2D communications based on the provided service. |

1. Based on Network Control

In this category, the D2D networks configuration is built based on the control level of the BS in the communication process [9] [16]:

* **Stand-Alone D2D:** This model is similar to ad-hoc network where the devices communicate with each other in a distributed manner without the help of cellular system BS. Moreover, in this model, fixed infrastructure such as access points or BS is not a prerequisite the devices rely on local hardware capabilities, hence the use of the term “stand-alone D2D.” [18-19].
* **Network Control D2D:** In this model, the cellular system BS has the full control of the D2D connection [18].in this model, fixed infrastructure such as access points or BS is a requirement the devices do not rely on local hardware capabilities and that’s why it called network control D2D [18-19].
* **Network Assisted D2D:** In here, we can see a balance between the past two categories where the cellular system BS has a partial control of the D2D connection which is the coordination between the cellular users and the DUs operate in self-organized way [16] [18]. To illustrate the impact of network control level, we depict the D2D Communications schemes and compare them based on the level of the BS control and how they make their RRM

Moreover, the advantages and disadvantages of each schema based on network control are illustrated in Table 2.

1. D2D communications schemes based on network control.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Stand-Alone** | **Network-Control** | **Network-Assisted** |
| **BS** | No control | Full control | Partial control |
| **RRM** | Based on both node local information | Based on global information from cellular BS | Based on both node local information and BS global information they make their RRM decisions separately |
| **Benefits** | High ﬂexibility | High performance | High coordination |
| **Difficulties** | No coordination between nodes | Insufficient scalability since everything must pass by the BS | Computational overhead of the BS |

1. Performance Gains of D2D Communications

Additional performance gain such as a higher data rates, with low latency and consume less power can be added by D2D communication technology to what already exists in the traditional way of communication [21-24].First, the hop gain which denotes the ability of using one direct link instead of using two links uplink/downlink via BS, which happens when we set a D2D communication by allowing devices to communicate using direct link without BS. Second, the proximity gains which depends on the location of user and denotes the ability of nearby devices to communicate [22]. The last one is the reuse gain which denotes the DUs ability of reusing the same CUs link[21-24].

1. Advantages of D2D Compared to Other Technology

At the present time, many devices can communicate with each other either using the licensed band like the traditional way of communication using the BS or else using different short-range communication technologies such as wireless short-range technologies. Moreover, several studies have proposed the integration between the licensed and unlicensed band such as mobile Ad-hoc networks (MANET) and cognitive radio networks (CRN) [25]. In next following subsections, the potential to choose the D2D technologies over these technologies is presented.

1. D2D Compared to Short Range Wireless Technology

D2D technology outperforms short-range wireless technologies, as it can offer higher data transmission rates up to 1 Gbps, compared to 250 Mbps [15][20], plus D2D can offer 1Km range, compared to 200m only. In addition, D2D communication is more robust and much more suitable for public safety applications [5]. Moreover, D2D can offer uniform service for users with a guaranteed QoS since it works in licensed part beside the licensed part of the spectrum [5] [10] [15] [20] [34].

1. D2D Compared to FemtoCell /PicoCell / Relay

D2D communication can also outperform FemtoCells, relays, and PicoCells with lower cost and less traffic. Since these technologies need the data to be transmitted from the sender user via a centralized node such as (*FBS/Pico/Relay*), then this node sends the data back to target device which is the Receiver User, which can increase the traffic on these nodes as well as increasing the cost of installing new infrastructure [15 -16] [34].

1. D2D Compared to Traditional 4G Cellular Networks

D2D has numerous benefits over traditional 4G cellular, several studies have showed that D2D can be very fruitful from different perspectives [8-9] [12] [15-16][20][22][26-33] such as:

* Higher spectral efficiency, network capacity up to double due to the replacement of uplink-downlink transmission in the traditional cellular mode and consumes half of resources (one link) in D2D communication mode, which can boom the availability of resources to use in reuse gain.
* Higher network coverage without increasing the infrastructure cost since users are using the same terminals.
* Higher data-rates, battery savings, and lower delay due to proximity.
* Higher reliability, since it can communicate locally between particularly if the LTE network has failed for any reason.

1. D2D Compared to Cognitive Radio Networks (CRN)

Cognitive radio networks (CRN) and D2D communication are similar from architectural perspective. However, the D2D is superior to the CRN since CRN suffers from a lack of coordination, and this leads to spectrum sensing which can cause a battery drain and consume lots of power. The same lack of coordination in underlay CRN makes it a very difficult task to manage interference, which can cause unguaranteed QoS [5] [9].

1. D2D Compared to Mobile Ad-Hoc Networks (MANETs)

MANETs and outband D2D technology are also the same from architectural perspective, where both have the ability of direct communication. Moreover, they can be identical in the case of network failure, where the DUs can act autonomously [35]. However, the key difference between them is the full control of the BS especially in the network assisted D2D communications scenario. This gives D2D advantage over MANETs and solves the lack of coordination issues that occur in MANETs and manages the security challenges that may arise [5]. Furthermore, D2D communications technology gives us better QoS compared to MANETs technology, as a result of working under licensed spectrum. In addition, D2D works in the licensed and unlicensed spectrum in single-hop manner, while MANETs woks only on the unlicensed spectrum in single and multi-hop manner [35].

1. D2D Compared to Machine to Machine communication (M2M)

Both D2D and M2M have a focus on exchanging data between nodes or devices [35]. However, they have several differences: first, the data path direction as in D2D communication the data use a direct way of communicating without going through any infrastructures, while M2M remote devices communication through a centralized node (BS) [9-10], [12], [35]. Second, the work method as in D2D communication the nodes work in a dependent manner to achieve ProSe, while M2M is application-oriented technology and that works in independent manner where the set of terminals exchange data with the BS. Third, the location in D2D communication is very important and depends on the device location to communicate, while M2M location is not important since they communicate using main server or BS. Finally, the number of connected devices in D2D communication can be between two devices or few numbers in proximity, while in M2M many nodes can connect to main server or BS [9].

1. Applications and Use Cases of D2D Communication

D2D is a simple, powerful approach that offers many advantages over conventional approaches in addition to various use cases, and applications such as local data service (*i.e. bit torrent, online gaming, proximity services, streaming services, social networking, community services*), local voice traffic, Multiuser cooperative communication (MUCC) and public safety [8][15][20][31]. Figure 7 shows a sample of D2D use cases and applications [15].

|  |
| --- |
| 1. A sample of D2D communications concept and applications [15]. |

1. Challenges and Limitation of D2D Communications

Behind the potential gains of the D2D communications that mentioned before still there are some main technical challenges that need to be emphasized. Yet, the connection setup between DUs and CUs is not optimal as it requires like any other communication technology key functions to work for example:

* Designing new peering and service discovery methods (*i.e. defining network role, synchronization, and designing reference signal*) [22][14].
* Designing physical layer techniques (*i.e. Encoding, Signaling, Data transmission and reception, etc.*) [22] [14].
* Solving the RRM algorithms (*i.e. mode selection, scheduling, resource allocation, power control, and interference management problem*) [17] [22] [29] [31] [36-37].

1. Thesis Focus, Theoretical Background, and Research Problem

This chapter provides provide brief information about thesis scope and contribution. In section 3.1 the thesis scope and focus with a brief overview on the D2D communications modes definition, advantages, and disadvantages is addressed. Then after that in section 3.2 the literature work in the D2D communications in cellular networks are reviewed. Finally, in section 3.3, in the last section the objective of the thesis is presented.

1. Thesis Scope and Focus

Previous chapters present a detailed introduction about the D2D communications importance in increasing the spectrum efficient and by reviewing all the benefits and drawbacks of both the inband and outband D2D communications. In the inband D2D communication the underlay inband D2D communication shows a good potential to be promising topic. Therefore, the scope of this thesis is on underlay inband technical challenges. However, there are many technical challenges, in this thesis our work considered the RRM problem particularly, the mode selection, resource allocation, and power optimization problems since till now there are no direct factors and methods to decide when the direct communication mode is preferable [9] [17]. Therefore, the attention in such problem increased in the last decade as a concept, it refers to the decision whether communicating devices in proximity should communicate via BS, like the traditional way or using a direct communication link [12] [22].

Many researchers classify these communication methods into three modes [23] [38]:

1. **Cellular Mode:** This mode is the traditional mode where the users communicate as conventional CUs through a BS using two orthogonal channels one from both (uplink and downlink) channels that are not currently used by any other devices without interference. Pair number (1) in Figure 8 is to illustrate this concept as it shows the D2D transmitter sends the data to the BS and then the BS send it back to the D2D receiver. However, due to the spectrum limitation and to achieve better performance, this mode should not be used unless the other two modes are not available.
2. **Dedicated Mode**: In here, the D2D users communicate directly using only one of the cellular users unused channels the uplink channel, or downlink channel. Pair number (2) in Figure 8 illustrates this concept where it shows the D2D transmitter sending data to the D2D receiver directly without sending it to BS which can reduce channel consumption to half if we compare it cellular mode. Though, spectrum utilization is not always rich, sometimes it can be very poor and we cannot find available resource due to different factors such as network load, channel conditions, and the distance between the devices so that the availability of free resource can be a problem.
3. **Reuse Mode:** In this mode, the spectrum utilization could be maximize by allowing two D2D users to make a direct connection by reusing one of the current cellular user channels (downlink/uplink).Pair number (3) in Figure 8 illustrates this concept where it shows an example of uplink reuse channel as it shows it cause an interference and thus since when using same channel at the same time can cause a serious interference problem needs to be solved with an efficient mechanism.

|  |
| --- |
| 1. D2D communication modes [23] |

However, the decision itself is not the only challenge, there are two other critical challenges arise the first one, how can we select the optimal transmission mode and the second one is when can we select the optimal transmission mode. In fact, many factors should be considered when this decision is made for example the aims and the type of the application can play a key role in this decision to guarantee the QoS, or quality of experience (QoE). Moreover, network load, resources availability, distance between the devices themselves and BS since this give an insight how much the interference situation can be managed [12].

1. Literature Review

From the above, it is intuitive that mode selection is very important in the D2D communications setup since there is still no known general method to determine when to select the optimal communication mode in various contexts [9]. Several studies have examined the mode selection problem such as [9] [11] [17] [20] [23] [25] [28] [38] [40 - 43] the literature describes several techniques that study a set of mode selection scenarios such as interference management [38], power efficiency [30] [40-42], and resource allocation [23] [29] [36] [40] [43]. For example, Doppler et al. in [38] proposed a heuristic mode selection algorithm based on the quality of the cellular and D2D links taking into account the different interference situations when sharing cellular uplink /downlink resources. In case of multi-cell, it also considers the inter-cell interference impact on the sum-rate of the D2D users. They studied two cellular network scenarios: namely, single cell environment, and multi-cell environment. The authors proposed a strategy that assumed a BS with full channel state information (CSI) of all users’ links, and calculate the throughput of the three D2D modes based on path loss model and distance. Then after that, their algorithm selects the mode with highest sum-rate that fulfills the cellular signal to interference plus noise ratios (SINR) constraint. Their study shows that the location of the devices can be very influence and the optimal mode can largely depend on it not only on the links quality or interference situation. In a simulated setting, they achieved 50% more gain on system throughput compared to the traditional cellular communications. Similarly, in [40] Hakola et al. examined the mode selection by proposing comprehensive system equations to indicate the optimal mode for all devices. The proposed algorithm uses abstract information from the network to define the system equations such as the quality of link, the interference and noise levels. They assumed that DUs use the uplink resources only of the cellular network and BS with full CSI. In their study, they compared the performance gain of proposed algorithm with three other modes: cellular mode, forced D2D mode and path loss mode. Their theoretical analysis concludes that the performance gain of D2D communication is largely depends on mode selection algorithm and distance between the devices. However, these methods, did not consider power control or resource allocation for more realistic results many algorithms tried to solve the combined mode selection problem with power optimization, and resource allocation[11] [17] [23] [41]. For instance, in [41] Jung et al. the authors proposed a two-step algorithm using uplink resource sharing for the D2D communications in a single-cell environment where the BS has the full CSI. In simulation setting, their algorithm achieved up to 100% gain and minimized the overall transmission power compared to forced D2D mode, forced cellular mode, and the algorithm proposed in [40]. One of the drawback of this algorithm is executing using the brute-force algorithm for searching in all mode combinations for all devices and thus, computationally intractable. Moreover, in [23] Yu et al. proposed another joint algorithm based on network loads also in a single-cell environment where the BS has the full CSI. The numerical simulations show that, their algorithm can perform very closely to the optimal solution which is branch and bound method.

1. Thesis Research Problem and Contribution

The aim behind this thesis is to propose a novel joint mode selection and resource allocation scheme for the ‎network-assisted D2D communication underlying cellular network optimization problem, and to provide an insight on the algorithm behavior and its effect on the system performance. The performance of the proposed algorithm is evaluated through simulations using Matlab. To achieve this goal, basically, we extend the work introduced in [23] to examine additional generic and realistic scenarios. We expand the work to the case where, a dynamic decision based on the network load for both uplink and downlink channels since the reuse mode can give us the maximum spectrum utilization [9] [23-25], unlike the work in [23], where they study the case of reusing only uplink channels when the reuse mode is preferred. In our proposed algorithm, a dynamic low-complexity algorithm directly selects the optimal mode of the communication modes from (Cellular mode, dedicated mode, and Reuse mode) for DUs and CUs immediately when connection request arrives based on the received information from the BS about the network load and user’s location. By considering joint mode selection, resource allocation, and power control for uplink and downlink channels our approach ‎aims to improve D2D system performance in terms of the overall throughput, the proposed algorithms are numerically evaluated via Matlab-based simulations.

1. System Model and Problem Formulation

In this chapter, the simulation system model is presented in section 4.1. In section 4.2 a brief explanation about the communication modes problem formulation is clarified. Then after that the problem formulation for the mode selection, channel assignment, and power control is provided is sections 4.3, 4.4, and 4.5, respectively. Then later on, in section 4.6 and section 4.7 the optimization problem of the joint mode selection, resource allocation, and power control is addressed. Finally, in section 4.8 the proposed algorithm procedure is provided.

1. Simulation System Model

In this thesis, the simulation scenario is modeled as a single-cell system with radius ***R***, that ‎consists of potential multi DUs, which denote as ***K*** pairs, , and potential CUs, which denote as , where the number of ***K*** pairs is less than users. Each one of the CUs will communicate using orthogonal channels one uplink, and one downlink. On the other hand, the DUs will communicate using one of the three communication modes (cellular, dedicated, or reuse) based on the number of the available uplink links (**NU**), and available downlink links (**ND**) channels. All this happened in the signal coverage of the BS that has a full instantaneous CSI of all users’ links.

1. Problem Formulation for Communication Modes

The channel capacity formula for D2D user ***k*** and cellular user ***m*** can be expressed as:

|  |  |
| --- | --- |
| **C** = B **= Bits/s/Hz** | **(4.1)** |

Where

|  |  |
| --- | --- |
|  | **(4.2)** |

Subject to:

* ***B***: stands for the bandwidth
* and : stand for the power, and the interference power, respectively.
* is stands for the power of the additive white Gaussian noise (AWGN).
* **:** stands for **t**he instantaneous channel gain between the sender and receiver is expressed as:

|  |  |
| --- | --- |
|  | **(4.3)** |

Subject to:

* stands for the path loss constant.
* is stands for the channel fading component between the sender and receiver D2D pair. In this thesis, the channel is modeled using two channels fading the slow rayleigh fading and fast rayleigh fading.
* **:** stands for the distance between the transmitter and receiver and is the path loss exponent.

1. Cellular Mode:

As mentioned before, theD2D users communicate like the traditional way through BS using two free orthogonal channels that are not currently used by any other devices one uplink channel (***NU***) and one downlink channel (***ND***). No interference happened here since the cellular mode use free orthogonal channels, and for QoS reasons both uplink, and downlink should be larger than a given threshold,. In this work, the focus on the D2D power so as assumption the will be always the minimum. The cellular mode channel capacity denotes a ***K*** dimensional indication vector:

|  |  |
| --- | --- |
| **,** where | **(4.4)** |

Where the cellular can be expressed as:

|  |  |
| --- | --- |
|  | **(4.5)** |

Subject to:

* andstand for the power between D2D pair number ***k*** and the power fromD2Dpair number ***k*** to BS, respectively.
* stands for the channel gain between D2Dpair number ***k*** and BS.
* isstands for the power of the additive white Gaussian noise (AWGN).

1. Dedicated Mode:

Similar to first mode, from interference perspective where the user in here adds no interference to the system, since all channels are orthogonal to each other. In this mode, one free orthogonal channel either uplink or downlink channel (***NU***,***ND***) is needed. The dedicated mode channel capacity denotes a ***K*** dimensional indication vector:

|  |  |
| --- | --- |
| where) | **(4.6)** |

Where the dedicated can be expressed as:

|  |  |
| --- | --- |
|  | **(4.7)** |

Subject to:

* stands for the power between D2D pair number ***k***.
* is stands for channel gain between D2Dpair number ***k***.
* stands for the power of the additive white Gaussian noise (AWGN).

1. Reuse Mode:

In this mode unlike, the earlier modes from the interference perspective, since two devices one D2D users and one cellular user are using the same channel simultaneously the users in the reuse mode will add an interference to the system. In this mode, one channel (uplink or downlink) only needed from the cellular user channels. However, for QoS reasons since the CUs have the higher priority for both uplink and downlink the DUs are not allowed to reuse the channel if cellular user less than a given threshold. The reuse mode channel capacity of the D2D pair number ***k*** which is reusing an active channel that currently being used by cellular user number ***m*** denote as ***K***× ***M*** dimensional indication matrix:

|  |  |
| --- | --- |
| , where**)** | **(4.8)** |

However, as mentioned earlier since D2D pair number ***k*** is reusing an active channel of a cellular user number ***m***. the channel capacity of the cellular user number ***m*** will be affected by this interference. The channel capacity of reusing channel is denoted as K × M dimensional indication matrix:

|  |  |
| --- | --- |
| where**)** | **(4.9)** |

In this mode, there are three scenarios as follows:

1. **Reusing Uplink Channel:**

In this case, the D2D pair number ***k*** is reusing an active uplink channel that is currently being used by cellular user number ***m*** and the channel capacity of reusing uplink channel is denoted as ***K***× ***M*** dimensional indication matrix:

|  |  |
| --- | --- |
| **, where)**  **, where)** | **(4.10)** |

The can be expressed as:

|  |  |
| --- | --- |
|  | **(4.11)** |

Subject to:

* and :stand for the power from D2Dpair number ***k*** to cellular user number ***m****,* and the power from the cellular user number ***m*** to the receiverD2Dpair number ***k***, respectively.
* : stands for the channel gain between D2Dpair number ***k***. similar, :is the channel gain betweenD2Dpair number ***k*** cellular user number ***m***. Also,:  stands for the channel gain between cellular user number ***m*** and the BS. And finally, is the channel gains between theD2Dpair number ***k***, and BS.
* is stands for the power of the additive white Gaussian noise (AWGN).

1. **Reusing Downlink Channel:**

In this case, the D2D pair number ***k*** is reusing an active downlink channel that is currently being used by cellular user number ***m*** and the channel capacity of reusing downlink channel is denoted as ***K***× ***M*** dimensional indication matrix:

|  |  |
| --- | --- |
| , where**)**  , where**)** | **(4.12)** |

The can be expressed as:

|  |  |
| --- | --- |
|  | **(4.13)** |

Subject to:

* and : stand for the power from D2Dpair number ***k*** to cellular user number ***m****,* and the power from the cellular user number ***m*** to the receiver D2D pair number ***k***, respectively.
* is stands for the channel gain between D2Dpair number ***k***. similar, : is the channel gain betweenD2Dpair number ***k*** cellular user number ***m***. Also : stands for the channel gain between the BS and cellular user number ***m***.
* is the channel gains between the D2Dpair number ***k***, and BS.
* is stands for the power of the additive white Gaussian noise (AWGN).

1. **No Channel Is Reused**

|  |  |
| --- | --- |
| where**)** | **(4.14)** |

The can be expressed as

|  |  |
| --- | --- |
|  | **(4.15)** |

Subject to:

* stands for the power of cellular user number ***m***.
* stands for the channel gain between the BS and cellular user number ***m***.
* is thestands for power of the additive white Gaussian noise (AWGN).

1. Problem Formulation for Mode Selection

The, which is an indication matrix describes the DUs choice from the three communication modes:

|  |
| --- |
| **= {}** |

Where:

* ***,:*** stands for th**e Cellular Mode,** and this happened only if**=1**, **= 0** , and.
* , stands for the ‎**Dedicated‎ Mode,**and this happened only if **=1**, **= 0**, , and.
* , stands for the **Uplink Reuse Mode,** and this happened only if **=1**, **=0**,, and .
* , stands for the **Downlink Reuse Mode,** and this happened only if**=1**, **=0**,, and .

1. Problem Formulation for Channel Assignment

In here, indications vectors are created to indicated the status of channel assignment and mode selection for each D2D pair number ***k*** and the cellular user number ***m***:

* For the cellular and the dedicated mode, a ***K*** dimensional indications vector is created:, respectively.
* For the uplink reuse mode and downlink reuse mode a ***K*** × ***M*** indication matrixes are created: **,** , respectively.

1. Problem Formulation for Power Control

Similar to mode selection, the power matrix is denoted as, which is an indication matrix:

|  |
| --- |
| **= {, , , }** |

Where

* : stand for the power of the DUs when the cellular mode and the dedicated mode are used, respectively. In here they are always equal to which is maximum power of the DUs since both are using orthogonal channels, there is no co-channel interference in both modes, so the maximum throughput could be achieved when both DUs and CUs with their maximum powers.
* ***,*** : represent the power of the D2D pair number ***k*** is reusing an active uplink channel that is currently being used by cellular user number ***m***, and the power of this cellular user number ***m***, respectively. However, in here the problem is little bit different, the cannot have the which is maximum power of the DUs due to the fact of exciting of a co-channel interference. Similarly and for the same reason the cannot have the which is maximum power of the CUs. So, we need to find the optimal power. In this thesis, to obtain optimal power control vector (), we use the algorithm discussed in [13]:

|  |  |
| --- | --- |
|  | **(4.16)** |

Subject to

* : cannot be less than zero and above .
* : cannot be less than zero and above .
* : the power will be equal toonly in the case of no reuse for the CU.

However, for QoS reasons the D2D pair number ***k*** is allowed to reuse the channel only if the larger than a given threshold

* ***,*** : represent the power of the D2D pair number ***k*** is reusing an active downlink channel that is currently being used by cellular user number ***m***, and the power of this cellular user number ***m***, respectively. However, in here the same problem in the uplink reusing is happened, the cannot have the and cannot have the due to the fact of exciting of a co-channel interference. So, we need to find the optimal power. In here the algorithm used before with the reusing the uplink channel cannot being used without modification since in paper [13] they propose it for the uplink channels only, in this thesis one of the contribution is modified the algorithm mentioned in [13] to consider also finding the optimal power for the downlink channel:

|  |  |
| --- | --- |
|  | **(4.17)** |

Subject to

* : cannot be less than zero and above .
* : cannot be less than zero and above .
* **:** the power will be equal toonly in the case of no reuse for the CU.
* : stands for the power of the cellular user number ***m*** and there are two cases to define the right value:
* The cellular user number ***m*** Not **reused** by any D2D pair number ***k*** then the power will equal to
* The cellular user number ***m*** is **being reused** by any D2D pair number ***k*** then the power will equal one of or depending on the reusing case if it uplink or downlink. Moreover, Equation (4.15) will be used to calculate the value of (. Similar, Equation (4.16) will be used to calculate the value of ( )

1. Problem Formulation for The Optimization Joint Mode Selection, Resource Allocation, And Power Control

To find the optimal power for D2D pair number ***k*** and he problem formulation for the joint mode selection, resource allocation, and power control can be represented as follows [23]:

|  |
| --- |
| **(4.17)** |

Subject to:

|  |  |  |
| --- | --- | --- |
|  |  | **(4.17. a)** |

This equation describes the D2D users in the cellular mode, where:

* + : stands for the cellular mode when it equal to 1 that means it has been selected by the D2D pair number ***k***.
  + **:** stands for the channel capacity when the D2D pair number ***k*** is in the cellular mode.

|  |  |  |
| --- | --- | --- |
|  |  | **(4.17. b)** |

This equation describes the D2D users in the cellular mode, where:

* + : stands for the dedicated mode when it equal to 1 that means it has been selected by the D2D pair number ***k***.
  + : stands for the channel capacity when the D2D pair number ***k*** is in the dedicated mode.

|  |  |  |
| --- | --- | --- |
|  |  | **(4.17.c)** |

This equation describes the D2D users in the uplink reuse mode, where:

* + : stands for the uplink reuse mode when it equal to 1 that mean the D2D pair number ***k*** is reusing the uplink of cellular user number ***m.***
  + : stands for the channel capacity uplink reuse mode when the D2D pair number ***k*** is reusing the uplink of cellular user number ***m.***
  + ***:*** stands for the channel capacity of cellular user number ***m*** when interfered byD2D pair number ***k.***

|  |  |  |
| --- | --- | --- |
|  |  | **(4.17.d)** |

This equation describes the D2D users in the uplink reuse mode, where:

* + : stands for the downlink reuse mode when it equal to 1 that mean the D2D pair number ***k*** is reusing the downlink of cellular user number ***m.***
  + : stands for the channel capacity downlink reuse mode when the D2D pair number ***k*** is reusing the downlink of cellular user number ***m.***
  + : stands for the channel capacity of cellular user number ***m*** when interfered by D2D pair number ***k.***

1. The Optimization Joint Mode Selection, Resource Allocation, and Power Control Based on The Network Load

As mentioned in the earlier chapter each one of the three communication mode needs resources/channels to communicate. Thus, selecting the optimal mode largely depends on the number of free resources (). However, the number of free resources cannot be an accurate measurement to network status and we cannot depend on it to set the optimal mode since the network status can be affected by the number of active device to device users, thus the communication scenario can be categorized as follow [23]:

1. **Light Load ()**

Where The number of the available links () is more than or equal the number of active device to device users, which means that there is at least one empty resource for each D2D pair and thus, makes the cellular and the dedicated mode are the optimal modes in this case.

1. **Medium Load ()**

In here the number of the available links () is less than the number of active device to device users, which means the empty resource is not enough for all the D2D pair and thus makes the dedicated mode and the reuse are the optimal modes in this case.

1. **Heavy Load()**

This case is a little difficult since no empty resource is available for any D2D pairs which means the only way to communicate is to use the reuse mode.

1. Proposed Schemes and Algorithms

To maximize the overall system throughput while guarantee the SINR for both cellular users, and D2D pairs links, we need to solve the optimization problem in (4.17) and find the optimal solution, we will consider the base problem considered in [23]. We proposed a low-complexity, dynamic algorithm that reuse the uplink and downlink channels of a cellular user unlike the approach discussed in [23], which reused only the uplink.

Our algorithm will directly select the optimal communication mode bearing in mind the availability from both uplink and downlink channels comparing with number of D2D ***k*** pairs. It will then find the optimal power to reach optimal solution and maximize achievable throughput. In Figure 9 a pseudo code for the main selection process is declared. Our **Optimal Algorithm** will dynamically select one of these three cases:

|  |
| --- |
| 1. Snapshot from the algorithm code. |

1. There are no orthogonal empty resources in the network. In this case the reuse mode will be directly selected. However, in our algorithm the reuse mode will have two reusing cases: reusing the uplink channel and reusing the downlink channels. First our ***optimal algorithm***will calculate the channel capacity for all K pairs in both cases.

*For all* ***K*** *pairs*

*T3\_UL(k,m) = Channel capacity for reusing uplink channel(k,m)*

*T3\_DL (k,m) = Channel capacity for reusing downlink channel(k,m)*

Then after that, the proposed algorithm for the reuse mode will take the maximum value for each D2D pair number k and cellular user number m and set the proper mode based on the available information.

*If highest value form T3\_UL then,the uplink reuse mode will be selected.*

*If highest value form T3\_DL then,the downlink reuse mode will be selected.*

1. There are orthogonal empty resources in the network. In this case we will go to the dedicated mode or reuse mode and thus due to the fact that there are resources but not for all DUs. Simply our algorithm willdistribute the all the resources on the ***K*** pairs and for the ones who couldn’t have the chance to have one of the empty orthogonal resources the reuse mode in both cases will be selected. The question is how ?Our algorithm will assume that there is no empty resources and do the same procedure in (**Case 1**), then after that the algorithm will take the result of (**Case 1**)for the all ( ***K*** - (***NU*** + ***ND***)) and for the rest of ***K*** pairs the dedicated mode will be selected.
2. There are orthogonal empty resources in the network for all ***K*** pairs.In this case we will go to the dedicated mode or cellular mode. First our optimal algorithm will calculate the channel capacity for all ***K*** pairs in both cases, then after that based on the result the algorithm will set the proper mode by taking into consideration the number of ***K*** pairs and the number of the available links without forget that the cellular mode needs two emptyresources.

For comparison reasons and to provide an insight on the algorithm behavior and its effect on the system performance also we examine the behavior of the proposed heuristic algorithms in [23]:

* **Algorithm 1**: This algorithm proposed to solve the light load scenario, ‎where we can find enough orthogonal empty resources for all D2D pairs. That is ‎make cellular and dedicated modes are the only applicable choice.
* **Algorithm 2**: In here, this algorithm proposed to solve the medium load ‎scenario, where we can find orthogonal empty resources but not enough for all ‎D2D pairs. That is make the ‎dedicated mode and reuse mode are applicable options. ‎However in [23] the DUs can only reused the uplink channel only.
* **Algorithm 3**: This algorithm is the conventional cellular mode and it has been used for declaring the difference between using the traditional way of communication all time and using D2D technology when applicable.

1. Simulation environment, Results, and Analysis

In this chapter, the simulation environment is set and the main parameters are introduced. In section 5.1 the user’s distribution inside the network cell is introduced. Then after that in section 5.2 simulation tools is discussed. Later on, the simulation procedure and the main parameters that used to run the simulation are presented in sections 5.3 and 5.4, respectively. Finally, in section 5.5 the impact of changing the transmit power, distance between the D2D users, number of ***K*** pairs and number of simulation iteration is discussed.

1. Users Distribution in Simulation Network

Cellular *CUs* are randomly scattered with uniform distribution in the cell. The *Tk* and *Rk* denote to the transmitter and the receiver of D2D pair *k*, respectively. The *Tk* are randomly spread with uniform distribution in the cell. The cell network is represented with radius *R* and *r* represent the maximum distance between the *Tk* and *Rk*. In Figure 10, we consider a single cellular user and ***Tx*** has full information to send to a single ***Rx***.

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| 1. System model for the various distances in the two user topologies |

In Figure 11, a snapshot of the cellular system and the generated CUs and DUs is shown. Cells with one cellular user and one D2D pairs in each cell. Red dots represent CUs, blue dots represent D2D transmitters, while green dots are D2D receivers.

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| 1. A snapshot of the cellular system and generated users |

1. Simulation Tools

To prove the efficiency of our algorithm, the performance is evaluated compared to conventional cellular network and the proposed algorithm in [23] via numerical simulations. These simulations were conducted using simple network simulator tool developed in Matlab/Simulink software package environment were scripts and functions are added to integrate the D2D communication functions into the MATLAB environment.

1. Simulation Procedure:

Due to many random components in the system model, Monte Carlo simulation is performed to obtain statistically reliable results. In each Monte Carlo iteration, cell is created, and then CUs and DUs are randomly placed within the cell. Path gains for all links are then calculated, and power control and resource allocation are executed. After the last Monte Carlo iteration is executed, parameters of interest (e.g. SINR, consumed power, throughput) can be evaluated.

1. Simulation Parameters:

In this thesis, all the links assumed to experience independent block fading. Some simulation parameters, e.g. the number of DUs/CUs and the number of available links, are set divergently according to the intended simulation scenario. However, some parameters are always kept at the same values. Our Simulation parameters are inspired from [13] [23]. Table 6 summarized all the parameters.

1. Simulation parameter

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| **Parameter** | **Value** |
| Cell Radius, ***R*** | 500 *m* |
| D2D Distance, ***r*** | 20….100 *m* |
| Uplink Bandwidth | 3 *MHz* |
| Noise Spectral Density | -174 *dBm /Hz* |
| Shadowing Standard Deviation | 10 *dB* |
| SINR Threshold, () | 10 *dB* |
| Maximum Number of Uplink Channels | 20 |
| Maximum Number of Downlink Channels | 20 |
| **Cellular** | |
| Number of Cellular Users, ***M*** | 10-20 |
| Maximum ***Tx*** power of CU, | 18-27 *dBm* |
| Path Loss Model | 128.1+37.6 log (*d[****km****]*) |
| SINR Minimum Threshold, ( | Uniformly Distributed in [0, 25] *dB* |
| **D2D** | |
| Number of D2D Pairs*,* ***K*** | 1-15 |
| Maximum Tx Power of DU, | 18-27 *dBm* |
| Path Loss Model | 148+40 log (*d[****km****])* |
| SINR Minimum Threshold,( | Uniformly Distributed in [0, 25] *dB* |

1. Result and Analysis
2. Impact of Maximum Transmit Power on Overall System Throughput

This section studies the impact of changing the transmit power on the overall system throughput. The goal of this scenario is to illustrate the impact of increasing the maximum powers ( on the overall performance for the uplink and downlink D2D underlay with different channel fading. The x-axes represent**,** where the maximum powers of both DUs and CUs is increased from 18 dBm to 27 *dBm*. Similarly, y-axis represents the total system throughput [bits/sec/Hz].

In Figure 12the Slow Rayleigh Fading (SRF), and Fast Rayleigh Fading (FRF) are shown **a**, and **b**, respectively. As the figures show, the performance of (**Algorithm 3**) in both figures is the worst, which is intuitive since it indicates only the cellular mode in which the users use the maximum power and consumes a lot of power to communicate with BS. Moreover, for (**Algorithm 1**) in both figures it shows a better performance than the (**Algorithm 3**) which is obvious since the dedicated mode is used here plus the cellular which is the one that already used in (**Algorithm 3**). Also, (**Algorithm 2**) shows a superior performance in all the earlier algorithms and thus due to the fact of using the reusing mode. However, our proposed algorithm (**Optimal Algorithm**) superior all the algorithm since it selects the proper mode directly and reuse the not only the uplink channels also the downlink as well.

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| **(a)** | |
| **(b)**   1. Overall system throughput for different algorithms using different maximum power (where *NU = ND = 2, r=20 m, K = 8, M = 18,18-24 dBm)***(a)**Overall system throughput using different maximum power in slow rayleigh fading(SRF) **(b)**Overall system throughput using different maximum power in fast rayleigh fading (FSF) |

Moreover, our (**Optimal Algorithm**) outperform the other algorithm even with low transition power. Figure 13give us a close look on our (**Optimal Algorithm**)comparing with (**Algorithm 2**), in both channel fading (SRF,FRF).

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| 1. Overall system throughput for proposed **Optimal algorithm** and **Algorithm 2** from [23] using different maximum power in both fast and slow Rayleigh fading(where *NU = ND = 2, r=20 m, K = 8, M = 18,18-24 dBm)* |

As well, Figure 14 gives us a general look on all the algorithms outperform with different channel fading. As a summary, from the simulation results, it shows that our proposed scheme (**Optimal Algorithm**) in all figures scenarios has the best performance.

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| 1. Overall system throughput for proposed **Optimal algorithm** compared with algorithms from [23] using different maximum power in both fast and slow Rayleigh fading(where *NU = ND = 2, r=20 m, K = 8, M = 18,18-24 dBm)* |

1. Impact of Maximum D2D Distance on Overall System Throughput

This section studies the impact of changing the distance between the DUs. The aim of this scenario is to show the effect of the maximum distance between the D2D pairs on the overall performance of the uplink and downlink. The ***x-***axes represent ***r (m)***, which is the mean distance between the D2D pair where the distance increases from 20 -100 meters. Similarly, y-axis represents the total system throughput in [bits/sec/Hz].

In Figure 15 the SRF, FRF are shown **a**, and **b**, respectively. As the figures, shows our (**Optimal Algorithm)** and (**Algorithm 2)** from [23] have the best performance which is intuitive, since the D2D ***K*** pairs more than the available orthogonal links, the cellular mode by itself like in (**Algorithm 3**)will not solve the problem and also the combination of the cellular mode and dedicated mode like in (**Algorithm 1**) will not makes us reach the optimal solution. However, only the reuse mode will help us in this case and since our (**Optimal Algorithm)** and (**Algorithm 2)** from [23] they are only one who have this mode they outperform the others.

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| **(a)** |
| **(b)**   1. Overall system throughput for different algorithms using different maximum D2D distance (where *NU = ND = 2, r=20-100 m, K = 8, M = 18,24 dBm)* **(a)** Overall system throughput using different maximum D2D distance in slow rayleigh fading (SRF) **(b)** Overall system throughput using different maximum D2D distance in fast rayleigh fading (FSF) |

As Figure 16 our algorithm (**Optimal Algorithm)** superior all algorithm even with the distance increasing between the D2D transmitter which can cause more pathloss but even with that our proposed algorithm showed that it can dynamically change the mode and take the advantage form all of the exist modes cellular, dedicated, and reuse in it both cases (uplink reuse /downlink reuse) unlike (**Algorithm 2)** from [23].

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| 1. Overall system throughput for proposed **Optimal algorithm** and **Algorithm 2** from [23] using different D2D distance in both fast and slow Rayleigh fading(where *NU = ND = 2, r=20-100 m, K = 8, M = 18,24 dBm)* |

Similarly, Figure 17 shows that (**Optimal Algorithm)** outperforms other algorithms under the two types of considered fading channels. As a summary, the distance between the D2D users can play a significant role in selecting the proper mode not only the number of available links as it can be seen from the results, when the distance between the D2D transmitter and the D2D receiver is very big the possibility for losing the connection is increased due to the interference factor for example. Also, the location of the CUs can play an important role and give us the chance to take advantage of reuse downlink channel not only the uplink one so that reusing the downlink channel can be fruitful in some cases.

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| 1. Overall system throughput for proposed **Optimal algorithm** compared with algorithms from [23] using different D2D distance in both fast and slow Rayleigh fading(where *NU = ND = 2, r=20 -100m, K = 8, M = 18,24 dBm)* |

1. Impact of the D2D Pairs Number on Overall System Throughput

This section studies the impact of changing the number of D2D pairs comparing to exist resources on the overall system performance. The aim of this scenario is to show the effect of the network load on the overall system throughput. The x-axes represent ***K***, which is the number of D2D pairs while y-axis represents the total system throughput.

The performance under Slow Rayleigh fading and Rayleigh Fast fading is depicted in Figure18.a and Figure18.b, respectively. In this scenario by comparing the number of the available channels (network load) and K pairs, the result is divided into:

1. **Light Network Load**, as in previous sections show in this model the dedicated and cellular modes are preferable since the number of the available links is more than the ***K*** pairs. In our scenario, the light mode is activated for K pairs from 1 to 5 pairs, where the total number of empty resources is 10. In here as the figures show that **(Algorithm 3)** performance keeps increasing until K=5, then it exhibits a fixed performance after that it faces a stable performance and this occurs as a result of having two empty resources required for each of ***K*** pairs and in our scenario, there is only 10.While **(Algorithm 2)**and our proposed algorithm **(Optimal Algorithm)** have the best performance, which is intuitive since the dedicated mode exploits the spectrum resource better than the cellular mode only since it uses only one resource for each ***K*** pair **(Algorithm 3)**. One can see this clearly in the figures.
2. **Medium Network Load, in** this case, both the dedicated and the reuse are preferable since, the number of empty channels is less than the D2D pairs. In our scenario, the medium mode is activated for ***K*** from 5 to 10 pairs, where the total number of empty resources is 10. In here as the figures show that **(Algorithm 3)** as mentioned it will face a stable performance and this is stand for a reason which two empty resource is required for each of K pairs and in our scenario, there is only 10. While **(Algorithm 1)**, **(Algorithm 2)** and our proposed algorithm **(Optimal Algorithm)**have the best performance. Which is intuitive since, these algorithms have in common the dedicated mode where the users will use only one resource and since there is 10 available resource, each one of them will take one.
3. **Heavy Network Load, where**in this case, the reuse is preferable since, there are no empty resources in this case. In our scenario, the heavy mode is activated for ***K*** from11 to 15 pairs, where the total number of empty resources is 10. In here as the figures show that **(Optimal Algorithm)** has the best performance since we are reusing not only the uplink channel but also the downlink channel as well.

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| (a) |
| (b)   1. Overall system throughput for different algorithms using different number of ***K*** pairs (where *NU = ND = 5, r=20m, K = 1-15 pair, M = 15,24 dBm)* **(a)** Overall system throughput using different number of ***K*** pairs in slow rayleigh fading (SRF) **(b)** Overall system throughput using different number of ***K*** pairs in fast rayleigh fading (FSF) |

Moreover, Figure 19 gives us a close look on the **(Optimal Algorithm)** outperforms **(Algorithm 2)*.*** As well, Figure 20 gives us a general look at all the algorithms outperform with different channel fading.

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| 1. Overall system throughput for proposed **Optimal algorithm** and **Algorithm 2** from [23] using different number of ***K*** D2D in both fast and slow Rayleigh fading(where *NU = ND = 5, r=20m, K = 1-15, M = 15,24 dBm)* |
| 1. Overall system throughput for proposed **Optimal algorithm** and proposed **algorithms** from [23] using different number of ***K*** D2D in both fast and slow Rayleigh fading(where *NU = ND = 5, r=20m, K = 1-15, M = 15,24 dBm)* |

1. Number of iterations

In this section, a set of experiments using different maximum powers for both DUs and CUs is presented. The aim of this is to observe the simulation as it happens over different number of simulation, and collect performance measures to provide an accurate understanding and draw conclusions on the overall performance of the network. where the number of available links = = 2, the maximum distance between the D2D pairs is fixed to ***20meters***, the number of DUs pairs ***K*** = 8, and the number of CUs ***M*** = 18. The x-axes represent**,** which is the average power for the CUs and DUs. Similarly, y-axis represents the total system throughput.

This simulation is illustrated in Figure 21. As it shows, our algorithm gives different result upon different iteration since each iteration create a new scenario with new user’s location with respect to the scenario fixed parameters and thus effect many things such as channel conditions, the interference situation and power. However, as mentioned before, mode selection as mentioned effect by many factors.

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| 1. Overall system throughput for different algorithms using different maximum power (where *NU = ND = 2, r=20 m, K = 8, M = 18,18-24 dBm)* |

2. Conclusion and Future Work

In this thesis, a new novel method of joint mode selection and resource allocation to set up optimal mode for network assisted D2D communications underlying cellular networks using uplink and downlink resources is introduced. Our scheme maximized the spectrum utilization efficiency and the system throughput while at the same time minimizing the impact of interference and guaranteeing the target SINR of both cellular and D2D links. The objective of this thesis is providing an insight on the algorithms behavior and their effect on the system performance. To achieve this purpose, we design a dynamic algorithm considers the network load, the algorithm directly should decide about the optimal mode selection (Cellular mode, Dedicated mode, and Reuse mode) for DUs and CUs and the best resource to be shared immediately when connection request arrives based on the received information from the BS. Then, the algorithm combines the mode selection and channel assignment. The algorithm’s practicality and performance enhancement were exhibited through numerical evaluations via Matlab-based simulations.

As a result, a significant improvement to overall system throughput was achieved by using this smart mode selection and considering reusing the uplink and downlink channels. Moreover, one of the main outcome of this thesis is the low complexity code implementation which can play a real role in increasing the performance of algorithm. However, studying a single-cell scenario can be unrealistic scenario from real-world perspective. Thus, studying multi-cell scenario with more than one D2D pair can reuse the CUs users can be more realistic and promising future research direction. Though, these additions can make the optimization problem be more difficult and complex.

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Abstractin Arabic Language

**خوارزمية مبتكرة تسمح لجهازين خلويين لإختيار طريقة الأتصال المباشر بينهما بحيث تزيد كمية المعلومات الممكن تداولها في النظام الخلوي ككل**

**إعداد: إسلام شاكر الحسبان**

**الملخص**

إن التطور الأخير في أنظمة الاتصالات واختراع الهواتف والألواح الذكية التي يمكن إستخدامها للوصول للأنترنت في أنظمة الشبكات الخلوية زاد الطلب على البحث عن تكنولوجيا وخدمات جديدة ممكن أن تساعد مشغلي شبكات الهاتف النقال لتلبية توقعات مستخدمي هذه الأجهزة الذكية من وجود سرعة أنترنت أعلى مع أدنى معدل تأخير للوصول لهذه البيانات، من دون الزيادة في إستهلاك الطاقة في أقل تكلفة ممكنة. لإستيعاب هذا الطلب الضخم للولوج إلى شبكة الإنترنت حتى مع محدودية القدرة الإستيعابية للشبكة. قام الباحثون في دراسة تكنولوجيا جديدة تسمح بإتصال جهازين مباشرة بدون الحاجة للرجوع للقاعدة الرئيسية. ولكن يبقى السؤال الأكثر أهمية ماهية الطريقة المستخدمة لإتخاذ قرار الأتصال المباشر. هذا السؤال لا يزال من المشاكل البحثية المفتوحة فحتى الأن لم يتم العثور على عامل أو سبب مباشر ممكن أن يساعد في تحديد طريقة الأتصال. في هذا البحث تم تقديم خوارزمية مبتكرة تسمح لجهازين خلويين لإختيار طريقة الاتصال المباشر بينهما بحيث تزيد من كمية المعلومات الممكن تداولها في النظام الخلوي ككل. ولكي يتحقق أقصى قدر من الإنتاجية الإجمالية للنظام الخلوي تم تطوير خوارزمية في هذه الرسالة تستخدم طريقة مرنة لتحديد الطريقة الأمثل للتواصل بين الجهازين بناءاً على المعلومات الواردة من القاعدة الرئيسية عن حالة الشبكة. وهذه الخوارزمية تم تقييمها عدديا عن طريق تطوير برنامج محاكاة بإستخدام برنامج MATLAB.