Relay Assisted Device to Device Communication underlaying Cellular Networks

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Relay Assisted Device to Device Communication underlaying Cellular Networks

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by

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under the guidance of

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This is to certify that the work presented in the dissertation entitled *Relay Assisted Device to Device Communication underlaying Cellular Networks* submitted by *Ganta Rajan*, Roll Number *214EC5187*, is a record of original research carried out by her under my supervision and guidance in partial fulfillment of the requirements of the degree of *Master of Technology* in *Electronics and Communication Engineering.* Neither this thesis nor any part of it has been submitted earlier for any degree or diploma to any institute or university in India or abroad.

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Dedicated to my Family and Friends

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Declaration of Originality

I, ***Ganta Rajan***, Roll Number ***214EC5187*** hereby declare that this dissertation entitled ***Relay Assisted Device to Device Communication underlaying Cellular Networks*** presents my original work carried out as a postgraduate student of NIT Rourkela and, to the best of my knowledge, contains no material previously published or written by another person, nor any material presented by me for the award of any degree or diploma of NIT Rourkela or any other institution. Any contribution made to this research by others, with whom I have worked at NIT Rourkela or elsewhere, is explicitly acknowledged in the dissertation. Works of other authors cited in this dissertation have been duly acknowledged under the sections "Reference" or "Bibliography". I have also submitted my original research records to the scrutiny committee for evaluation of my dissertation.

I am fully aware that in case of any non-compliance detected in future, the Senate of NIT Rourkela may withdraw the degree awarded to me on the basis of the present dissertation.

May 31, 2016 Ganta Rajan
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Abstract

Device-to-Device (D2D) communication underlaying cellular networks is a latest technology of advanced wireless communication which allows two nearby devices to communicate without assistance of Base Station (BS) in cellular network. Device-to-Device (D2D) communication improves Spectral Efficiency , Energy Efficiency ,link reliability and overall system throughput by permitting nearby devices to communicate directly in licensed spectrum.In this thesis , two device discovery protocols are presented ,one reactive protocol and other proactive protocol which helps in discovering the D2D pairs which intend to communicate with each other.In addition, we propose a mode selection algorithm that decides the mode in which the devices can communicate either through traditional cellular mode or D2D mode. This optimum mode selection maximizes the overall throughput.

The benefits of D2D communication are limited practically when the distance between D2D users is long and poor channel environment between the D2D users. To overcome these drawbacks, a relay-assisted D2D communication is introduced where additional relay mode is proposed along with existing modes (i.e) cellular mode and D2D mode. A joint mode and relay selection scheme based on Hungarian algorithm is proposed to improve the overall system throughput. The Hungarian algorithm proposed, selects a suitable communication mode for each transmission and also select the relay device that acts as a relay between transmitting user and receiving user for relay mode communication.D2D devices sharing the same spectrum with cellular users results in interference, which requires to be managed in the resource allocation algorithm. A graph theory based resource allocation method for D2D users is proposed to improve the overall system capacity and extend the network coverage area.

Contents

List of Acronyms

Acronym	Description
ACK	Acknowledgement
AWGN	Additive White Gaussian Noise
BS	Base Station
BW	Bandwidth
CDF	Cumulative Distribution Function
CSI	Channel State Information
CU	Cellular User
D2D	Device to Device
EE	Energy Efficiency
LOS	Line of Sight
MWBM	Maximum Weighted Bipartite Matching
M2m	Machine to Machine
NLOS	Non Line of Sight
NOS	Non-orthogonal sharing
OFDM	Orthogonal Frequency Division Multiplexing Access
OS	Orthogonal sharing
PDF	Probability Density Function
QoS	Quality of Service
SINR	Signal-to-Interference Noise Ratio
SNR	Signal to Noise Ratio
SE	Spectral Efficiency
TDD	Time Division Duplex
UE	User Equipment

Nomenclature

Nomenclature	**Description**
B	Bandwidth
C	Channel Capacity
CH_k	k^{th}Channel
r	Cell Radius
L	Time slots available
D	Targeted Distance
P_c	Transmit power for Cellular user
P_d	Transmit power for D2D pair
P	Transmit power
OH_{re}	Control Overhead for the Reactive algorithm
OH_{pr}	Control Overhead for the Proactive algorithm
$\mathbb{W}$	Weight Matrix of size $p \times r$
$\mathbb{U}$	Index set of UEs ,$\mathbb{U} = \{1, 2, ..., N_u\}$
$\mathbb{U}_c$	Index set of UEs in Cellular mode
$\mathbb{U}_d$	Index set of UEs in D2D mode
ρ_{ij}	Mode indicator
ξ_{th}	SINR threshold
N_u	Number of UEs in cell
$\|h_{ij}\|$	Channel gain of $p - q$ link
$\xi_{pq}^{c/d}$	SINR of cellular link/D2D link from UE_p to UE_q
$\xi_{r,k}^{DP,CH}$	SINR from the Transmitter UE to Receiver UE utilizing CH_k
$\xi_{ij}^{DT,DR}$	SNR from the Transmitter UE to Receiver UE
$\xi_{r}^{DP,BS}$	SINR from the Receiver UE to BS
N_0	Noise Power Spectral Density
ϱ^c	Maximum transmit power of Cellular user
ϱ^d	Maximum transmit power of D2D user

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1

Introduction

1.1 Background

Wireless communication networks have seen a tremendous growth in the past decades. This trend might grow exponentially in the next decade. The technologies improved to meet the increasing demand for wireless communication are far from satisfying the expectations.The achievement of wireless networks depends on network spectral efficiency (SE) and energy efficiency (EE) [1]. Radio Spectrum must be efficiently used for assisting ever increasing wireless traffic growth and quality of services (QoS) demands from users.

In order to meet capacity demands from the data traffic growth, network with base stations (BSs) are expected to achieve a higher spectral efficiency and energy efficiency. A typical network model consists of Macro-Base Station (M-BS), Pico-Base Station(P-BS), Femto-Base Station (F-BS) and relay base-stations (R-BS).

An M-BS transmits high power, serves a larger coverage area; while other types of BSs transmit at a relatively lower power so their coverage area is smaller .A network with base station can improve the wireless link quality since the BSs are now much closer to UEs. Due to the existence of BSs with diverse transmit powers, the network can be more energy efficient and spectral efficient.

1.2 D2D Communication

Tremendous increase in demand for wireless communication technologies lead to overcrowding of radio spectrum. So efficient utilizing of radio spectrum is the important task and new innovative technologies are required. A new paradigms to revolutionize the existing wireless networking technologies is Device-to-device communication. Device-to-Device (D2D) communications in the wireless network are used to facilitate proximity-aware services and data traffic offloading, especially in local area communication services[2]. Device-to-device communication is a new technique in advanced wireless communication to improve the spectral efficiency of cellular systems. In D2D communication, devices in near proximity can communicate directly with each other without assistance of BS and can provide performance gain. The demand for higher data rates increased worldwide during the past few years. Todays user applications need higher data rates for services like video sharing and gaming, offloading the data transfer from base station. Other application of D2D are machine-to-machine (M2M) communication and relaying[3].

D2D is classified into inband and outband. In case of outband ,D2D users utilize unlicensed radio spectrum for communication,Wi-fi or ZigBee are some examples of outband D2D .While in case of inband, D2D users utilize licensed radio spectrum (cellular spectrum). To establish a connection in outband,D2D uses the assistance of BS known as controlled outband or autonomous outband. Inband D2D can be further categorised into overlay inband and underlay inband.In overlay inband D2D users can have either dedicated radio resources for communication. In underlay inband D2D users share the resources allocated for cellular users. Figure 1.1 shows the categorization of D2D communications. The decision on how D2D users communicate either through BS (cellular mode) or directly

(D2D mode) should be taken sensibly.Further in case of D2D mode, BS should choose among controlled outband, overlay inband or underlay inband.Figure 1.1 shows the classification of D2D communications.

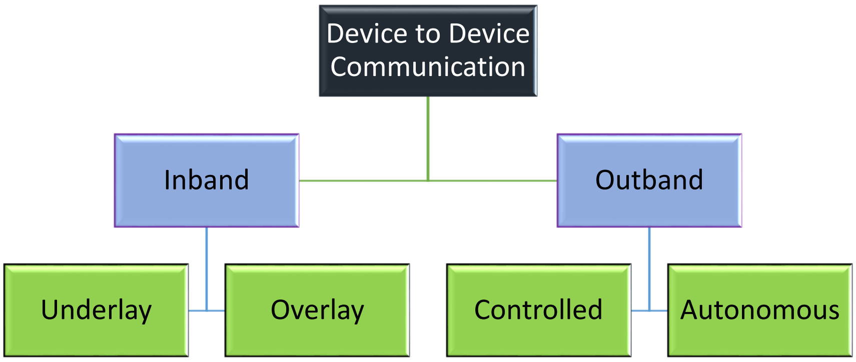

Figure 1.1: Classification of D2D Communication

1.2.1 Outband

In general ,D2D communication use unlicensed spectrum in which users establish the D2D connection.The BS doesn't have the control over the D2D communication established between the devices which is not useful for cellular networks. But in case of controlled outband, BS has control on the D2D communication [4, 5].The advantage of this scheme as it uses unlicensed spectrum there is no chance of interference from cellular communications. The major disadvantage is the interference on D2D connections by other users accessing unlicensed spectrum.These disadvantages restrict user from using the outband in D2D communication .

1.2.2 Inband

Overlay Inband provides energy efficiency but doesnt provide spectral efficiency because it needs dedicated radio spectrum [6].Underlay Inband is the best mode which provides spectral efficiency [3, 7]. The main disadvantage in this method is sharing of the same radio resources for both D2D and cellular users, this will cause interference among the users.In uplink scenario when the D2D link shares the resources,BS experiences interference from D2D transmissions as well as from others D2D users accessing the uplink.In downlink scenario when the D2D link shares the resources,cellular users experience interference from D2D transmission and D2D recievers will experience interference from users communicating with BS.

To enhance the communication capacity and capabilities and to introduce new services research is performed on device-to-device (D2D) communications device-to-device (D2D) communications as an underlay to cellular networks [8]. A D2D link is a direct connection between two communicating devices, using the spectrum provided for cellular networks. The D2D communication is recognized as one of the technology that enable User Equipments (UEs) to facilitate high data rate local communication without an infrastructure of Base Station (BS) [3, 9] (i.e) a UE can communicate with other UEs in the range using cellular network resources without involvement of base station.

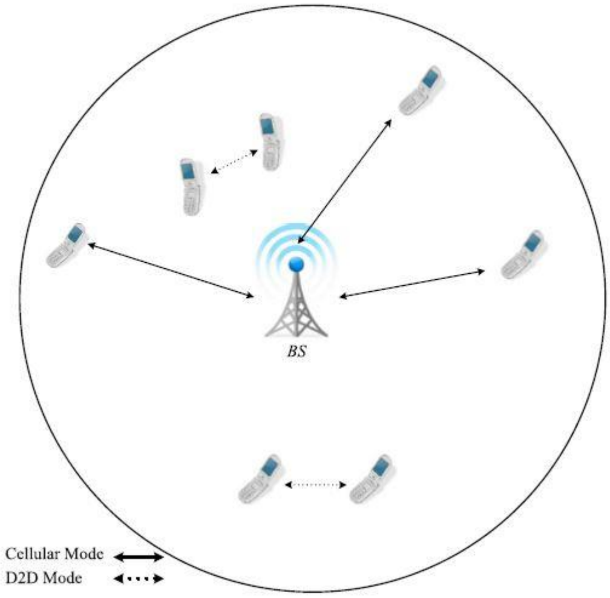

Figure 1.2: D2D and Cellular mode of communication

The concept of D2D communication is shown in Figure 1.2.The UEs communicating through direct links refers to D2D Mode and UEs communicating through the BS refers to cellular mode. The direct device communications, for example Bluetooth and Wi-Fi direct, use unlicensed spectrum for communication. The D2D communication uses licensed spectrum which improves the QoS and provides better coverage.The D2D communication underlying cellular network operates in a licensed spectrum allocated to the cellular users, the D2D users can access the licensed spectrum in two modes either in a dedicated mode or in a shared mode [10].

The main aim of D2D communication is to

1. Increase the spectral efficiency
2. Reduce the traffic load
3. Increase the system overall throughput

In D2D communications the improvement in spectral efficiency is achieved because in a D2D transmission session is established using one direct wireless link, while in cellular transmission session uses two wireless links with assistance of BS.The spectral efficiency is especially improved when multiple D2D links use the same resources simultaneously.As the D2D communication takes place in the licensed frequency band interference occurs between the D2D links and the cellular communication links, so there is a chance that D2D communication may interrupt cellular communication, and in addition to this D2D links interfere with each other. These interference problems are to be addressed when facilitating D2D communication.

1.2.3 Technical Challenges

There are many challenges that are to be concentrated while designing the concept of D2D communication. The main challenges are Device discovery and session setup, communication mode selection, resource allocation and Quality of service, interference coordination and management, power allocation.An outline of the technical challenges in D2D communications is shown in Figure 1.3.

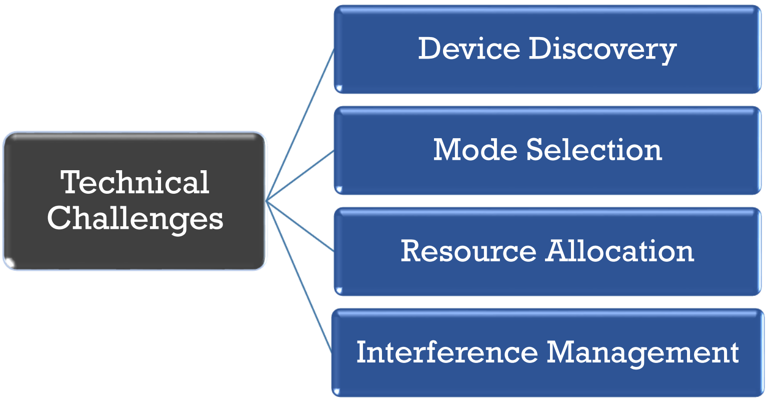

Figure 1.3: Technical Challenges in D2D Communication

Device discovery is the first step of D2D link establishment, in which the UEs or the BS discover the presence of D2D candidates and identify whether the D2D pairs need to communicate with each other [2]. A D2D communication is a pair of UEs, a transmitter and a receiver, which are in the proximity of each other.

In D2D communication underlying cellular network, a UE can operate either in the cellular or D2D mode [6]. The mode selection can be done by taking various criteria such as distance, channel quality of D2D and cellular links, interference, load of the BS and energy efficiency. Proper mode selection plays an important role in D2D communication to increase the spectral efficiency of the system [1].

Allocation of cellular resources to the D2D transmission is a critical issue. There are two resource sharing modes in the network: (i) Non-orthogonal sharing (NOS) mode: In this case D2D links and cellular links reuse the same resources, and (ii) Orthogonal sharing (OS) mode: In this case D2D links use part of the resources while the other resources are allocated for cellular communication [11]. In order to utilize resources efficiently NOS mode of cellular communication is desired for D2D communication.

1.3 Motivation

In traditional cellular communication, the Cellular Users (CU) have to communicate with each other through the Base Station (BS). In contrast, D2D communication allows direct communication between two devices without assistance of a BS. D2D communication with its accompanying challenges is a viable option to provide wireless communication services, spectrum utilization and address the huge mobile traffic from large number of devices. The spectral efficiency will be maximised when multiple UE2UE links use the same cellular channel resources simultaneously. This improves spectral efficiency but there is more chance of interference from UEs. Network-assisted transmissions through relays could efficiently enhance the performance of D2D communication when the D2D UEs are far away from each other or if the channel quality is not suitable for direct communication. The radio resources at the relays are shared between the D2D communication links and the two-hop cellular links using these relays[12]. Relay-aided D2D communication is a smart solution to provide consistent transmission and also improve overall network throughput. The advantages of D2D communication can be realized with negligible interference between UE2UE and BS2UE links. Hence resource allocation, interference co-ordination and management plays a vital role in modelling D2D communication underlaying cellular network.

1.4 Thesis Structure

This section presents the structure of the thesis work.

- **Chapter 1 :** In this chapter ,an introduction to D2D communication, the major technical challenges and related work carried out so far are presented.
- **Chapter 2 :** In this chapter, two algorithms are proposed for device discovery. These algorithms are explained and analyzed.The mathematical analysis of the proposed methods is carried out in terms of control overhead.

- **Chapter 3 :** In this chapter , mode selection algorithm is proposed to select among cellular and D2D modes.Also, the resource allocation Algorithm is proposed based on Hungarian algorithm.The mathematical analysis of the proposed algorithm is carried out in terms of overall system throughput.

- **Chapter 4 :** In this chapter, a joint mode and relay selection algorithm is proposed.A new mode is introduced to the existing communication modes which in turn increases the overall system throughput.

- **Chapter 5 :**In this chapter ,finally the conclusion is discussed and future work scope in this topic is presented .

2

Device Discovery in D2D Communications

In this chapter, we focus on the Device Discovery method for D2D communication described in [13].This method finds a D2D pair if that pair requests for resources to participate in D2D communication.We propose two Discovery Algorithms,their performance is evaluated and examined.

2.1 D2D Communication in Cellular Networks

In traditional method of cellular communication,two UEs communicate by relaying through BS.BS controls link establishment, resource allocation in a specific range served by that cellular system.If two UEs are in the proximity D2D communication can be established.If distance between two UEs can satisfy the constraints,then the UEs can form a D2D pair.This is first step in the method of

Device Discovery.The conditions for mode selection will conclude whether D2D pair can communicate.The conditions include aspects like distance between the pairs in the cell,availability of resources for sharing,etc.

The D2D communication can be implemented in three stages,the first stage deals with discovery of D2D candidates,the second deals with the mode selection and resource allocation and finally third stage is the communication of two UEs.

2.1.1 Device Discovery and Communication

In this device discovery stage, base station discovers a UE that wants to connect with another UE. During this discover phase UEs exchange lot of messages with BS and among themselves (i.e) UE and UE. These messages will provide the information about the links established among the UEs and the links between the UEs and the BS to the network. If a new D2D candidate is confirmed to be a D2D pair , then mode selection condition is applied. This condition decides whether a new D2D pair can communicate in D2D mode. If the pair satisfies conditions for D2D communication, D2D mode is assigned. If this D2D pair fails to satisfy the conditions, cellular mode is assigned to the pair.BS allocates the resource to the new D2D pair. After device discovery,mode selection and resource allocation ,the D2D can communicate and exchange information with each other without the assistance of BS [14].

2.2 Device Discovery Process

In this section we suggest two protocols for device discovery in which the exchange of messages is set up by BS or UE based on information provided in [15].These outline of the protocols is described as following,

- Reactive protocol:In this scenario, a UE notifies the BS that It want to communicate with another UE. Then base station communicates with the devices to obtain information regarding the link.

- Proactive protocol:In this scenario,BS multi-casts request from time to time to all UEs, even if there is no request for service from UEs.

In these two cases, the BS assists for discovery of UEs. The entire process is controlled by BS. In this thesis we consider network assisted device discovery method, because BS can control the interference and entire process will be efficient and we can expect considerably better results.We compare these two protocols in terms of the performance computed from numerical simulations.

This conditions for successful discovery of D2D candidates can be summarized as:

- If the transmitting device has the details of the receiving device,
- If the receiving device has the details of the transmitting device and if they want to communicate with each other,
- If the pair satisfies the proximity condition.

2.3 System Model

The system model consists of number of uniformly distributed UEs in the cell.The system model is shown in the Figure 2.1 .We assume a D2D communication in cellular networks coordinated by a BS.We also assume that the BS is positioned at the center with radius in the cell.BS coordinates traditional and D2D communications in the cell.UEs in the proximity can communicate with each by a direct D2D link.BS decides if the direct communication between the UEs can be established by observing the location of UEs. BS allocates the resource to the new D2D pair. After device discovery,mode selection and resource allocation ,the D2D can communicate and exchange information with each other without the assistance of BS.

2.4 Protocols for Device Discovery

We propose two protocols termed as reactive and proactive.In reactive protocol the process of device discovery is started by a UE,where as in proactive protocol BS starts the process of device discovery [16].

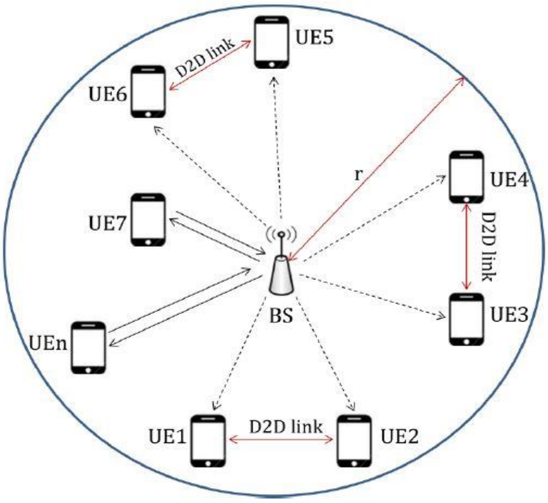

Figure 2.1: System model for Device Discovery

2.4.1 Reactive Protocol For Device Discovery

In this protocol a UE which wants to establish communication starts the device discovery process.But before starting the process the UE contacts the BS regarding the link information about the remaining UEs in the cell.Even if the process is initiated by UE it is coordinated by BS for device discovery. Figure 2.2 shows the exchange of signaling messages for reactive device discovery method.The discovery is described in the following steps:

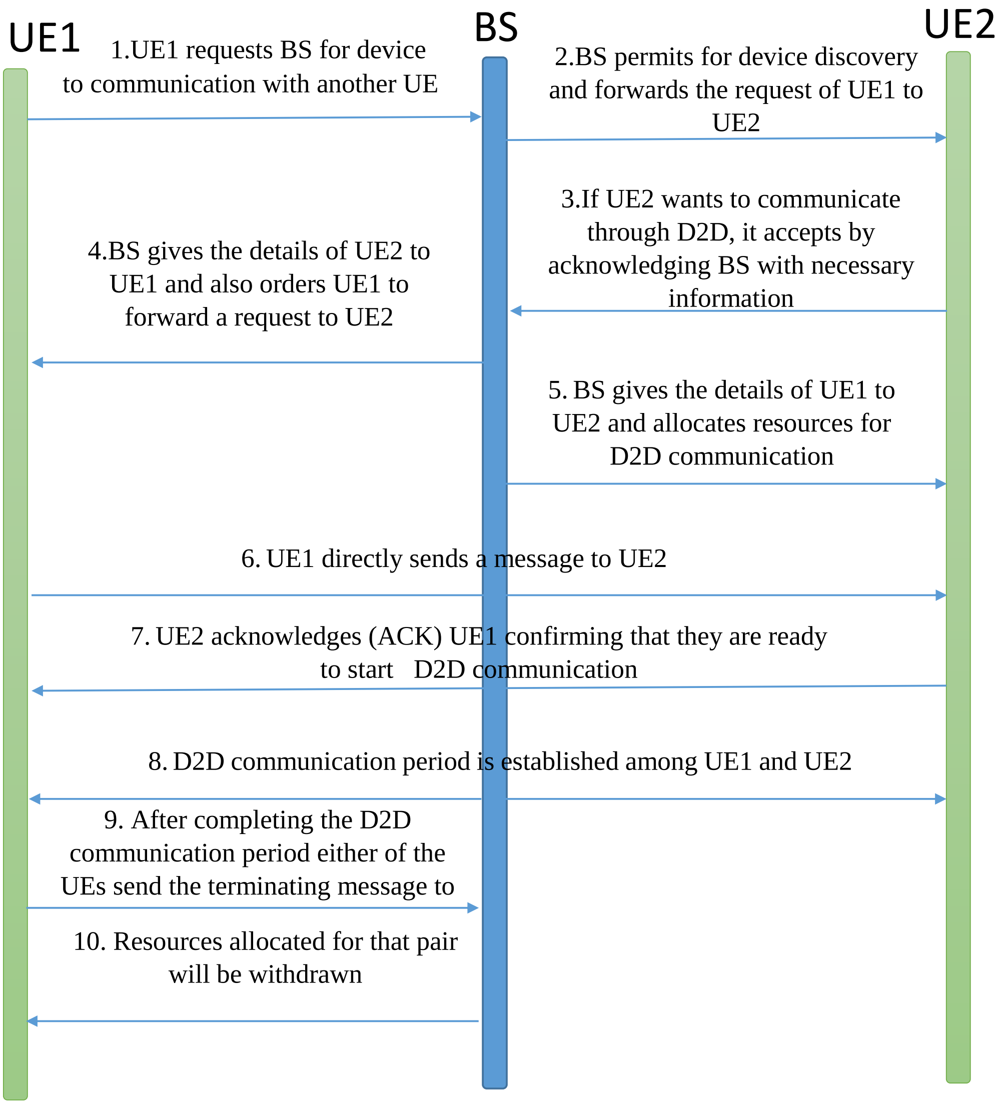

Figure 2.2: Device Discovery messages using the Reactive Algorithm

	Reactive Protocol for Device Discovery
Step 1:	UE1 requests BS for device discovery to communication with , another UE providing its own details to the BS.
Step 2:	BS permits for device discovery and forwards the request of UE1 to UE2.
Step 3:	If UE2 wants to communicate through D2D, it accepts by acknowledging BS with necessary information.
Step 4:	BS gives the details of UE2 to UE1 and also orders UE1 to forward a request to UE2.
Step 5:	BS gives the details of UE1 to UE2 and allocates resources for D2D communication.
Step 6:	UE1 directly sends a message to UE2.
Step 7:	UE2 acknowledges (ACK) UE1 confirming that they are ready to start D2D communication.
Step 8:	D2D communication session is established among UE1 and UE2.
Step 9:	After completing the D2D communication session,either of the UEs send the terminating message to BS.
Step 10:	And finally resources allocated for that pair will be withdrawn.

This reactive protocol process needs a total of ten messages should be exchanged between two UEs and the BS, and out of which seven handshakes are compulsory for successful D2D communication session.

2.4.2 Proactive Protocol For Device Discovery

In this protocol BS notifies all the D2D enabled UEs about the discovery by a multi cast message sent time to time.If a UE wants to communicate with other UE, it responds to the multi casting message and informs the BS about device discovery. Fig 2.2.shows the exchange of signaling messages for proactive device discovery method.The discovery is described in the following steps:

	Proactive Protocol for Device Discovery
Step 1:	The BS time to time multicasts information to all UEs regarding discovery .
Step 2,3:	The UEs that intend to communicate through D2D , communication respond to the BS and give the details of the UEs.
Step 4:	BS updates the details check if the D2D communication condition is satisfied. If yes, the BS forwards a message about the location of UE to anyone of those two UEs
Step 5:	One among the UEs, responds to the BS that they are interested in starting a D2D period
Step 6:	The BS forwards the message to UE2 that is received from UE1 and also allocates resources for D2D communication.
Step 7:	UE2 forwards an acknowledgement message to UE1 and BS, confirming that they are ready to start D2D communication.
Step 8:	D2D communication session is established between UE1 and UE2.
Step 9:	After completing the D2D session,either of the UEs send the terminating message to BS.
Step 10:	And finally resources allocated for that pair will be withdrawn.

This Proactive protocol process needs seven handshakes for successful D2D session.But this protocol differs from reactive protocol in the first step of the process where BS multicasts to all UE without considering the traffic.The last three handshakes are the similar in both the cases, hence not considered for overhead computation.

2.5 Overhead Analysis

We calculate the control overhead of the suggested protocols as number of messages required to set up a D2D session.We assume there are$N$ UEs in the system out of which $M - N$participate in D2D communication which need device discovery. As discussed in the earlier section in reactive algorithm that we need 7 handshakes for successful D2D communication, then for M D2D pairs we need$7 * M$ handshakes. While in case of proactive algorithm we just need 6 handshakes,

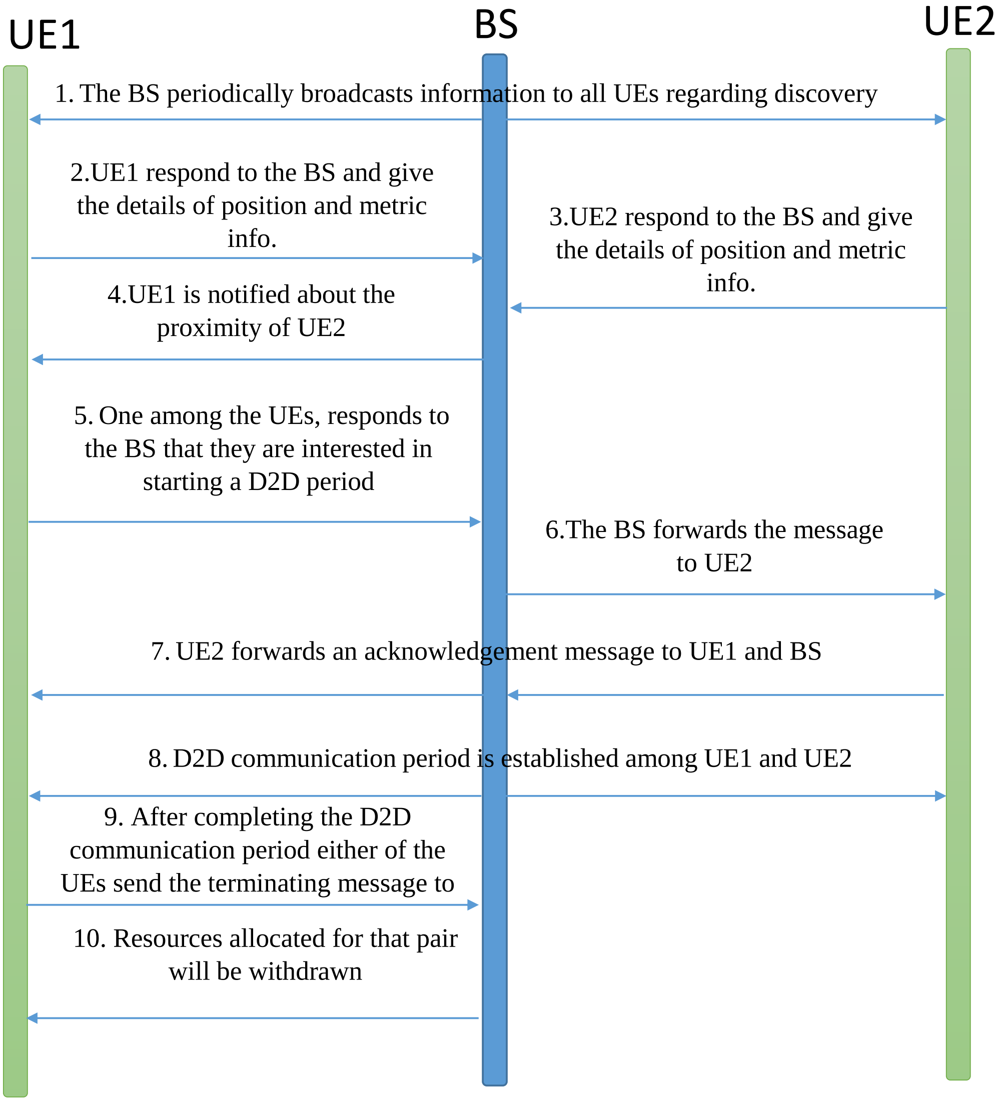

Figure 2.3: Device Discovery messages using the Proactive Algotihm

but in addition to this, as BS multicasts the message to all the UEs, results in a total of$(T + 6 * M)$ handshakes for M D2D pairs. The total duration is divided into$T$timeslots and control overhead is calculated. The D2D pairs in respective timeslot varies from 0 to M.

In our analysis, we find the number of D2D pairs in the area. Then we calculate control overhead for single D2D request scenario and multiple D2D requests scenario. we compare our results for reactive and proactive algorithms in these scenarios. Our analysis is carried out in terms of number of handshakes in specified timeslot. The neighborhood and k can be calculate for specified node density λ with in coverage area of the cell [17].

The Probability that two nodes form a D2D pair can be formulated as [18]:

$$P\left(d \leq D\right) = 1 - e^{\lambda * \pi * D^2} \tag{2.1}$$

where D is the distance between the two UEs that form a D2D pair. λ is the node density.

The probability if k users are with in the distance D from a preferred node can be realized from a binomial distribution[19].

$$P(k) = 1 - \sum_{j=0}^{k} \binom{n}{j} (1-p)^j p^{n-j} \tag{2.2}$$

where $j = 1, 2, 3.....k$ and $p = 1 - P\left(d \leq D\right)$ is the probability that the UE are not present in D meters range from the certain node.

Single D2D Pair Request:

We consider that D2D pairs request for device discovery in a specific timeslot.Out of T time slots device discovery appeal can occur in $L \leq T$ timeslots. Hence, the control overhead for the reactive and proactive Algorithms can be obtained as shown.

$$OH_{re} = \frac{7 * L * 1}{T} \tag{2.3}$$

$$OH_{pr} = \frac{T + 6 * L * 1}{T} \tag{2.4}$$

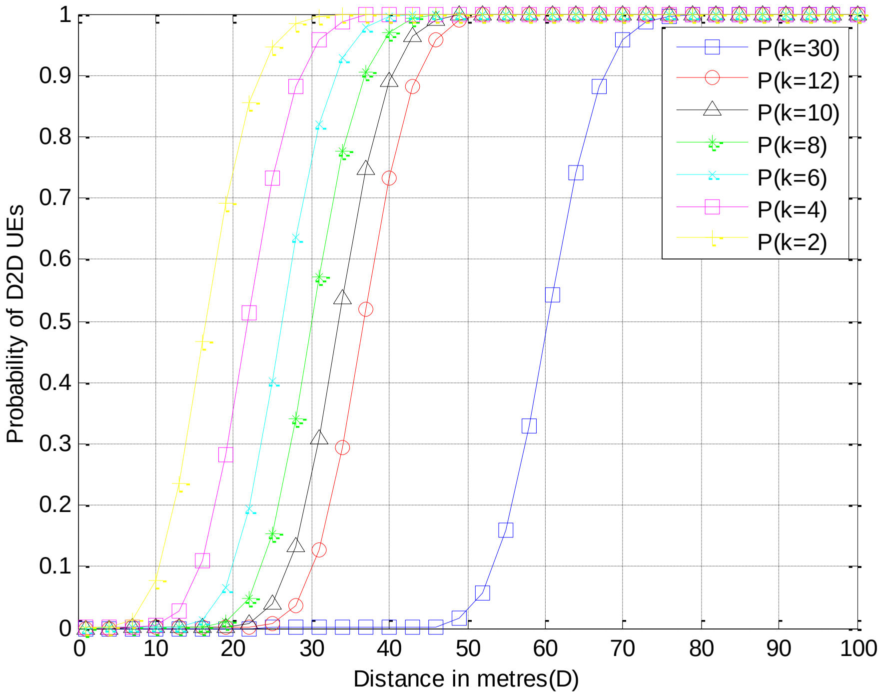

Figure 2.4: Probability of finding k D2D UEs as a function of Distance.

Multiple D2D Pairs Request:
We assume that in specific timeslot $0, 1, 2, 3.....M$ D2D pairs may request for device discovery. The control overhead for the reactive and proactive Algorithms can be obtained as shown.

$$OH_{re} = \frac{7 * L * M}{T} \tag{2.5}$$

$$OH_{pr} = \frac{T + 6 * L * M}{T} \tag{2.6}$$

where M is the number of D2D pairs.

2.6 Simulation Results and Disscusion

We compare the performance of the two proposed protocols based on the Matlab simulations.The parameters considered for simulation are in Table 2.1. The probability thats indicates how many D2D UEs can be found within varying targeted distances is shown in Fig 2.6 .

Table 2.1: Simulation Parameters for Protocol Overhead Analysis

Symbol	Parameter	Value
n	Number of UE pairs	100
k	Number of D2D UEs	2, 4, 6, 8, 10, 12....30
r	Cell radius	1000m
D	Targeted Distance	0 to 100 m
L	Time Slots available	0, 1, 2, ..., 20
M	Number of D2D pairs	1, 2, 3, 4, 5, 6.....15
T	Total no.of Time slots	20
j	Number of observations	1 to k

Results for Single D2D Pair request:
The simulations were carried out for single D2D pair request per specific time slot .The result is shown in the Fig 2.5.

Results for Multiple D2D Pairs request:
The simulations were carried out for Multiple D2D pairs requests over increasing

number of time slots .The result is shown in the Fig 2.6 .

By observing the simulation results,we can conclude that when the number of D2D requests are less the reactive protocol performance is better than the proactive protocol since a very few handshakes were exchanged among the UEs and BS,as shown in the figure 2.5 . In contrast when the when the number of D2D requests increase the proactive protocol exhibits a better performance than reactive algorithm.From the figure 2.6 we can observe that when the D2D happen in less than 7 out of 20 the proactive has low control overhead than reactive so reactive protocol performs better.And if more than 7 proactive surpass the reactive protocol performance.It can be generalized as if $L \leq T/M$ reactive protocol performs better,else proactive protocol performs better. The graph shows when D is very less,we cannot find any D2D candidate in the range. So,the control overhead in this case is zero since D2D communication cannot be enabled under this situation. In case of proactive algorithm an amount of overhead is necessary for proactive algorithm to start discovery process.

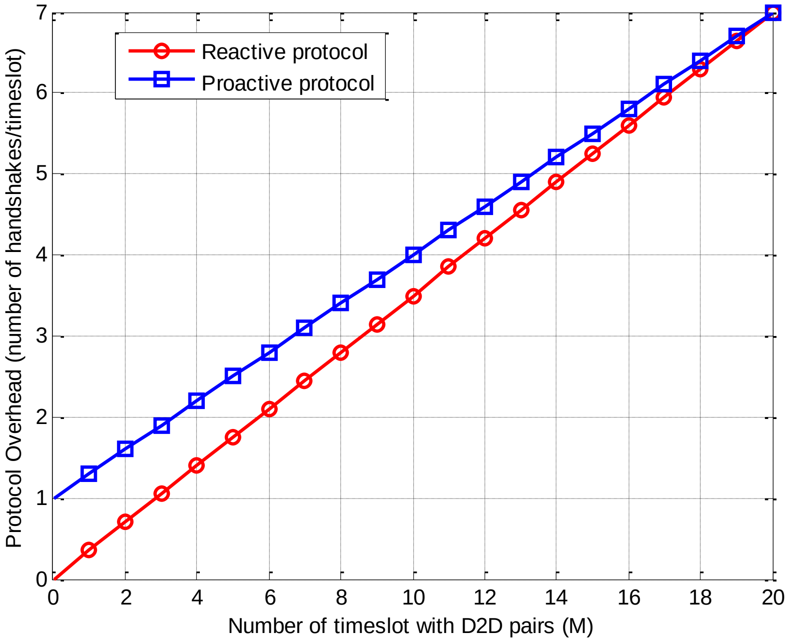

Figure 2.5: Protocol overhead for single D2D request

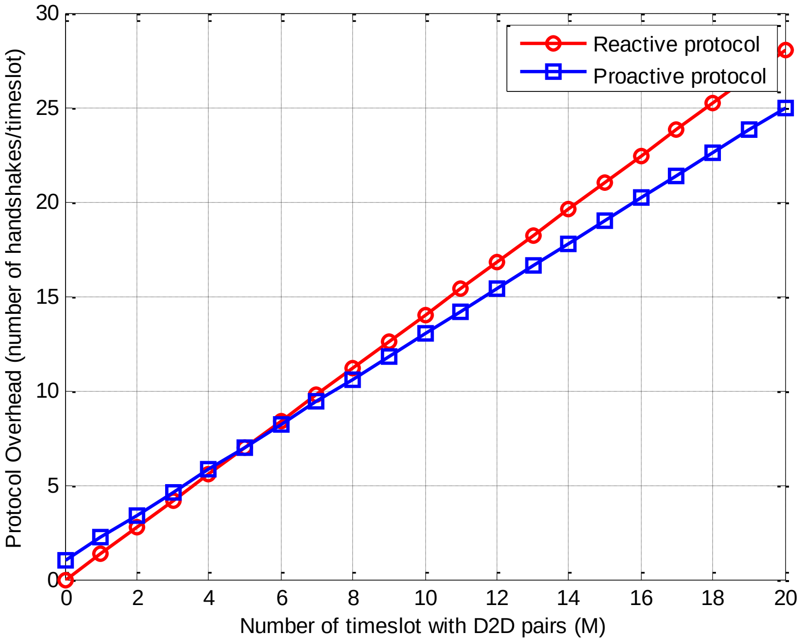

Figure 2.6: Protocol overhead for Multiple D2D requests

2.7 Summary

In this chapter,two protocols are proposed to discover the devices in the proximity which intend to communicate through D2D communication in cellular network.Each method has individual advantages.The simulation results show that reactive performs better if the D2D request traffic is less and if the D2D requests increase proactive is opted as it shows better performance than the reactive protocol.

3

Joint Mode and Relay selection

3.1 Introduction

The D2D communications underlaying cellular network includes appropriate mode selection.Mode selection selects the mode in which mode a UE pair should communicate either directly or through the BS. Our main objective is to improve the spectrum utilization efficiency and overall system throughput by ensuring quality-of-service (QoS) to both cellular and D2D UEs [20].

A mode selection Algorithm is proposed to choose the appropriate mode of communication for each UEs in the cell. The proposed algorithm ensures the QoS, interference level among D2D and cellular connection need to satisfy the minimum SINR threshold constraints of the network for mode selection.We consider an indoor office scenario according to the WINNER II A1 office model to perform our study[21].

In D2D communication the basic modes through which the devices (UEs) can communicate are either cellular mode or D2D mode. But we cannot depend on these modes for long distances which limits the D2D communication practically. In order the increase the handling capacity of D2D communication we introduce a new mode of communication known as relay mode. The Hungarian Algorithm is proposed for the selection of suitable mode for respective UE depending upon the constraints so as to achieve maximum overall system throughput.

Long distances and poor radio conditions between D2D UEs limit the benefits of D2D communication practically[12].Thus the idea of UE relaying is present in which the D2D UEs act as relays between the base station and cellular(UEs) when these UES are positioned near the cell edges or in poor coverage region[22]. This communication relayed through a UE is stated as relay mode of communication. We consider the relay transmission mode as an extra mode of transmission with the current cellular and D2D modes. In this chapter cellular mode refers to communication between two UEs through BS and D2D mode refers to direct communication between the two UEs.

A Joint mode and relay selection algorithm is suggested to maximize the system throughput, Hungarian algorithm is used in getting the maximum throughput [23]. The goal of proposed method is to select an appropriate mode from D2D mode, relay mode and cellular mode of communication, for every communication and selection of a appropriate relay UE which acts as a relay node for relay mode communication. The simulation results exhibit that our proposed algorithm increases the performance of system throughput when compared with the traditional D2D communication scheme as in [8].

3.2 Hungarian Algorithm

The Hungarian Algorithm is an algorithm which finds an optimal assignment for a linear assignment problem[24].We will manage the assignment problem with the Hungarian algorithm . Two different implementations of this algorithm are illustrated, both are graph theoretic, one with $O(n^4)$ complexity, and the other one with $O(n^3)$ complexity.Hungarian algorithm can also be implemented without using graph theory.Description of the steps of this algorithm, adapted from [25].

3.2.1 $O(n^4)$ Algorithm

This algorithm deals with bipartite graph. The main objective of the following method is to find the perfect matching using edge weights. The solution for the assignment problem will be these edges. If we are not able to find the perfect matching in the existing step, then the Hungarian algorithm modifies weights of the edges.so that all the existing edges get new weights and these alterations do not effect the optimal solution.A description of the steps of this algorithm is given below:

	$O(n^4)$ **Algorithm**
Step 1:	Find the 0-weight edges for each vertex.
Step 2:	Find if L the perfect matching ,then L is the maximum weight matching. Or else find the minimum vertex cover F.
Step 3:	Let $\psi = \min\left(c_{ij}\right) : i \notin F, j \notin F$. Update the weights: $c_{ij} = \begin{cases} c_{ij} - \psi, i \notin F \wedge j \notin F \\ c_{ij}, i \in F \vee j \in F \\ c_{ij} + \psi, i \in F \wedge j \in F \end{cases}$
Step 4:	Reiterate until **Step 1** is solved.

In this case we have issues while finding the matching in the step 2, for every repetition this causes our Algorithm to $O(n^5)$ operations which increases the complexity. In order to avoid the increase in complexity we alter the matching in the previous step, which reduces to$O(n^2)$ operations.

3.2.2 $O(n^3)$ Algorithm

This algorithm deals with the maximum-weighted matching problem[26]. The theorem states that If $L^*$is a perfect matching in the equality sub graph l_g, then

$L^*$is a maximum-weighted matching in l shows the connectivity between the equality sub graphs and maximum-weighted matching.A description of the steps of this algorithm is given below:

	$O(n^3)$ **Algorithm**
Step 1:	Find initial matching and initialise vertex labelling.
Step 2:	Find if L is perfect matching, then L is maximum weight matching. Otherwise, set $S = \{x_i\}, T = \{\emptyset\}$such that$x_i \in X$.
Step 3:	If $H_l(S) \neq T$ then calculate $\psi = \min\{x_i + y_j - w_{i,j} : x_i \in S, y_j \notin T\}$ and update the existing labels as follows: $v_i'(v) = \begin{cases} v_i - \psi, x_i \in S \\ v_i + \psi, y_j \in T \end{cases}$
Step 4:	If $H_l(S) = T$.Select a new vertex $y \in \{H_l(S) - T\}$. • If y is an unmatched node, $x - y$ is an augmenting path.Augment matching along this path and go to **Step 2**. • If y is a matched node to z, then $S = S \cup \{z\}$, $T = T \cup \{y\}$ And go to**Step 3**

3.3 System Model

Let us consider a WINNER A1 office model scenario in which UEs in the cell are represented by a set $\mathbb{U}$ with N_u elements, i.e, $\mathbb{U} = \{1, 2, ..., N_u\}$ for traditional D2D communication. Communication can be established between UE$_i$ and UE$_j$,either through the cellular or D2D link.The overall throughput optimization problem can be expressed as:

$$C = \max \left\{ \sum_{i,j \in \mathbb{U}} \left[\frac{1}{2} \rho_{ij} \log_2 \left(1 + \xi_{ij}^{c} \right) + (1 - \rho_{ij}) \log_2 \left(1 + \xi_{ij}^{d} \right) \right] \right\} \tag{3.1}$$

subject to

$$\xi_{ij}^{c} \geqslant \xi_{th}, \ \forall \ i, j \in \mathbb{U} \tag{3.2}$$

$$\xi_{ij}^{d} \geqslant \xi_{th}, \ \forall \ i, j \in \mathbb{U} \tag{3.3}$$

$$\sum_{i \in \mathbb{U}} \sum_{j \in \mathbb{U}} \rho_{ij} \leqslant 1 \tag{3.4}$$

where $\rho_{ij} \in \{0, 1\}$ is the mode indicator, $\rho_{ij} = 1$ indicates a cellular link and $\rho_{ij} = 0$ in case of D2D link. ξ_{th}, is the minimum SINR required to set up ij link for both cellular and D2D links.

We consider a single cell scenario for joint relay and mode selection.This model consists of a BS and N_u randomly distributed UEs in the cell. A communication between two UEs i.e from UE_p to UE_q is indicated as (p, q) where $p \in \mathbb{P} = \{1, 2, ..., p\}$ and $q \in \mathbb{Q} = \{1, 2, ..., q\}$. In this model set $\mathbb{P}$ indicates transmitting UEs and set $\mathbb{Q}$ indicates receiving UEs respectively.We assume Time Division Duplex (TDD) mode of operation ,in which a UE can receive or transmit data in the specified timeslot, i.e., $\mathbb{P} \cap \mathbb{Q} = \emptyset$. A set $\mathbb{R} = \{1, 2, ..., r\}$ denotes the set of receivers and idle UEs in the cell such that $\mathbb{R} \cap \mathbb{P} = \emptyset$ and $\mathbb{Q} \subseteq \mathbb{R}$.A system with D2D UEs,Cellulars UEs and Relay UEs in the cell is shown in Figure 3.1.

For establish a communication between (p, q) one among the following modes should be selected as shown in the figure

1. **Cellular mode** :This mode refers to a communication between UE_p and UE_q with the assistance of BS.
2. **D2D mode** :This mode refers to a direct communication between UE_p and UE_q.
3. **Relay mode** :This mode refers to a communication between UE_p to UE_q through UE_r which acts as the device relay.

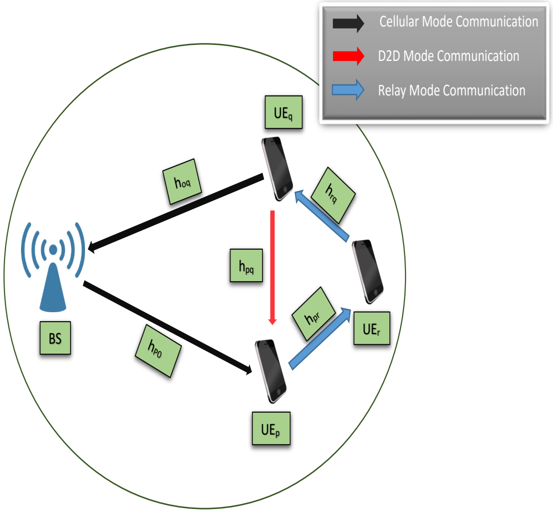

Figure 3.1: System model for Relay assisted D2D Communication

Signal-to-Interference-Noise-Ratio (SINR) is taken into consideration that indicates the Quality of Service (QoS) to maximize the network capacity. The Cellular mode can also be realised as two hop relay link ,since the communication between two UEs is established with the assistance of BS acting as a relay node.

Then SINR for (p, q) transmission for cellular mode, can be written as:

$$\xi_{pq}^{c} = \min\{\xi_{p0}, \xi_{0q}\} \quad p \in \mathbb{P}, q \in \mathbb{Q} \tag{3.5}$$

where ξ_{p0} and ξ_{0q} represent the SINR of at BS for UE$_p$-BS link and SINR at UE$_q$ for BS-UE$_q$ link respectively. SINR of uplink ξ_{p0} and downlink ξ_{0q} are calculated as [27]:

$$\xi_{p0} = \frac{P_{p0}|h_{p0}|^2}{\sum_{i \in P, i \neq P} P_{int,i} + N_0} \quad p \in \mathbb{P} \tag{3.6}$$

$$\xi_{0q} = \frac{P_{0q}|h_{0q}|^2}{\sum_{i \in P, i \neq P} P_{int,i} + N_0} \quad n \in \mathbb{Q} \tag{3.7}$$

where P_{pq} and $|h_{pq}|$ represent the transmit power and channel gain of link between UE$_p$ to UE$_q$ and$p/q = 0$ denotes the BS.$P_{int,i}$ denotes the interference power and N_0 is the power spectral density of the Additive White Gaussian Noise (AWGN) at the receiver.

The relay mode can also be realized as two hop relay link ,since the communication between two UEs is established with the assistance of UE acting as a relay node. UE$_r$ act as the relay for (p, q) transmission.Then SINR for (p, q) transmission for relay mode, can be written as:

$$\xi^r_{pq} = \min\{\xi_{pr}, \xi_{rq}\} \quad p \in \mathbb{P}, q \in \mathbb{Q} \tag{3.8}$$

where ξ_{pr} and ξ_{rq} represent the SINR at UE$_r$ for (p, r) transmission and SINR at UE$_q$ for (r, q) transmission.

The SINR for (p, q) transmission for D2D mode, can be written as:

$$\xi^d_{pq} = \frac{P_{pq}|h_{pq}|^2}{\sum_{i \in P, i \neq P} P_{int,i} + N_0} \quad p \in \mathbb{P}, q \in \mathbb{Q} \tag{3.9}$$

To mitigate the interference among users in D2D communications the maximum allowed transmit power is limited to ϱ^c for a cellular link and ϱ^d for a D2D link[28].

3.3.1 Problem Formulation

The quality of communication depends on type of channel, propagation medium and interference from nearby UEs. The constraints limit D2D communications when the D2D UEs are far away from each other and substantially reduces the overall system performance. Under these adverse conditions the communication assisted through relay network can improve the performance [12].The main goal of this work is to maximise the overall system channel capacity by selecting a appropriate mode of communication for every transmission in the cell. The overall system channel capacity maximizing problem is formulated as:

$$C = \max \left\{ \sum_{p \in P, q \in Q} a_{pq} \log_2 \left(1 + \xi_{pq}^{c}\right) + b_{pq} \log_2 \left(1 + \xi_{pq}^{r}\right) + o_{pq} \log_2 \left(1 + \xi_{pq}^{d}\right) \right\} \tag{3.10}$$

The problem in (3.10) need to satisfy the following constraints:

$$\begin{aligned} \xi_{pq}^{c} &\geq \xi_{th}, \quad p \in \mathbb{P}, q \in \mathbb{Q} \\ \xi_{pq}^{r} &\geq \xi_{th}, \quad p \in \mathbb{P}, q \in \mathbb{Q} \\ \xi_{pq}^{d} &\geq \xi_{th}, \quad p \in \mathbb{P}, q \in \mathbb{Q} \end{aligned} \tag{3.11}$$

$$\begin{aligned} &\sum_{q \in \mathbb{R}} a_{pq} \leq 1, \quad a_{pq} \in \{0,1\}, \quad p \in \mathbb{P} \\ &\sum_{q \in \mathbb{R}} b_{pq} \leq 1, \quad b_{pq} \in \{0,1\}, \quad p \in \mathbb{P} \\ &\sum_{q \in \mathbb{R}} o_{pq} \leq 1, \quad o_{pq} \in \{0,1\}, \quad p \in \mathbb{P} \end{aligned} \tag{3.12}$$

$$a_{pq} + b_{pq} + o_{pq} = 1, \quad \forall\, p \in \mathbb{P} \tag{3.13}$$

where a_{pq}, b_{pq} and o_{pq} are the communication mode indicators.$a_{pq} = 1$ indicates cellular mode of communication, otherwise $a_{pq} = 0$. $b_{pq} = 1$ indicates D2D mode of communication , otherwise $b_{pq} = 0$.$o_{pq} = 1$ indicates relay mode of communication, otherwise $o_{pq} = 0$.SINR threshold, ξ_{th}, is the minimum SINR necessary to establish the (p, q) transmission.

The constrain (3.11) shows the QoS requirements for the cellular, relay and D2D communication modes. The constraint shows that every element in $\mathbb{P}$ should have a maximum of one partner in $\mathbb{R}$. The constraint indicates that a every transmission is assigned with any one of the three communication modes. The main objective is to develop a mode selection algorithm such that the overall throughput is maximised.

3.4 Proposed Algorithm

We proposed two algorithms in this section , mode selection Algorithm and Joint mode and relay selection Algorithm.

3.4.1 Mode Selection Algorithm

In this section we select appropriate communication mode i.e, D2D or cellular communication,which satisfies the QoS requirement and maximizes the overall system throughput. By selecting the mode we imply that the network chooses whether the UEs should communicate directly or through the BS. Each UE can operate either in Cellular mode or D2D mode of communication. In the proposed mode selection scheme, D2D link maximizes the throughput than cellular link.

To establish a communication from UE$_i$ to UE$_j$, the BS compares the ξ_{ij}^c and ξ_{ij}^d with xi_{th} $.UE_i$ is assigned in $\mathbb{U}_c$ or $\mathbb{U}_d$ upon the decision of comparison.If the minimum SNR requirements are not met in both the cases ,then neithe the mode is assigned to UE$_i$

3.4.2 Joint Mode and Relay Selection Algorithm

We suggest a mode selection algorithm to solve the problem stated. The suggested algorithm is Hungarian algorithm which achieves maximum weighted matching for bipartite graph.We further assume that the BS has acquisition SINR at UEs and the channel state information (CSI) of transmissions and this method can be executed at the BS.

To assign the communication modes for every transmission we consider a weighted bipartite graph, $G(X, Y, E)$, as shown in Figure 3.2. Our main motivation is to select a appropriate partner for every element in $\mathbb{P}$ corresponding to $\mathbb{R}$ so that the overall system throughput is maximised with selecting the appropriate mode of communication. In bipartite graph X vertices denotes the transmitting UEs in $\mathbb{P}$ and Y vertices denotes the remaining users inside the cell , i.e., $\mathbb{R}$ (UEs other than the transmitters in cell).

SINR is the important parameter in maximizing the overall system through-

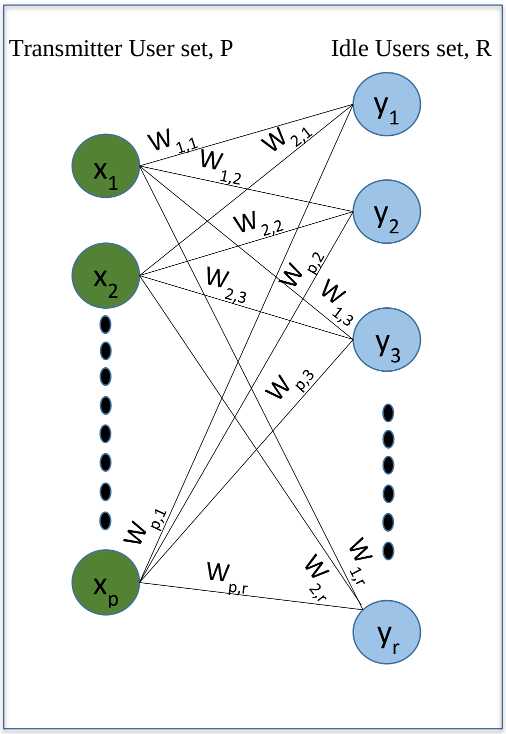

Figure 3.2: Weighted Bipartite graph matching scenario

put.As shown in the figure the weights of the edges are the SINR values for particular transmission between the nodes.The weight of the each edge between a user x_i in X and user y_j in Y for (p, q) transmission, $w_{i,j} = \xi_{ij}, \forall i \in \mathbb{P}$ if $q = j$. Else, i.e.,$q \neq j$, the SINR of relay mode, (p, j, q) is calculated and assigned as weights, $w_{i,j} = \min\left(\xi_{pj}, \xi_{jq}\right), \forall i \in \mathbb{P}$.

The corresponding weight matrix for edge weight for each vertex in X for the corresponding vertex in Y is:

$$\mathbb{W} = \begin{array}{c} \\ x_1 \\ x_2 \\ x_3 \\ \vdots \\ x_p \end{array} \begin{array}{c} \begin{array}{ccccc} y_1 & y_2 & y_3 & \cdots & y_r \end{array} \\ \begin{pmatrix} w_{1,1} & w_{1,2} & w_{1,3} & \cdots & w_{1,r} \\ w_{2,1} & w_{2,2} & w_{2,3} & \cdots & w_{2,r} \\ w_{3,1} & w_{3,2} & w_{3,3} & \cdots & w_{3,r} \\ \vdots & \vdots & \ddots & \vdots & \\ w_{p,1} & w_{p,2} & w_{p,3} & \cdots & w_{p,r} \end{pmatrix} \end{array} \tag{3.14}$$

```
Algorithm   Mode Selection Algorithm
Step 1:     Initialization: Given $(m, n)$ transmissions and $\xi_{th}$
Step 2:     Form $\mathbb{P}, \mathbb{Q}, \mathbb{R}$ sets
Step 3:     Construct the weight matrix, $\mathbb{W}$, with weights generated
            as follows:
            for $i = 1$ to length($\mathbb{P}$)
              for $j = 1$ to length($\mathbb{R}$)
                if $\mathbb{Q}$(i) = $\mathbb{R}$(j) then
                $w_{ij} = \xi_{ij}$
                else
                $w_{ij} = \min(\xi_{i,j}, \xi_{j,q})$
                end if
              end for
            end for
Step 4:     Construct the bipartite graph, $G = (X, Y; E)$, where $X = \mathbb{P}$,
            $Y = \mathbb{R}$ and $E = \mathbb{W}$
Step 5:     [P,W]= Hungarian-function ($\mathbb{W}$)
Step 6:     for $i = 1$ to length(P)
              if W(i) $< \xi_{th}$ then
              Assign cellular mode of transmission
              else if P(i) = $\mathbb{Q}$(i) then
              Assign direct link D2D mode of transmission
              else
              Assign relay mode of transmission with UE$_{P(i)}$
              as the relay UE
              end if
            end for
```

The proposed Hungarian algorithm is used to compute the maximum weighted bipartite matching for the corresponding elements in X and Y.After perfect matching, the corresponding communication modes are assigned to each UEs in $\mathbb{P}$.

A Step by Step process of mode selection method is presented in Algorithm I. Our mode selection algorithm starts with initialisation of transmission and SINR threshold value. Then we initialise the sets for transmitter UEs set, Idle UE set and relay UE.Then the corresponding weight matrix is generated by satisfying conditions in **Step 3**. **Steps 4** constructs the bipartite graph and followed by maximum weighted matching based on the Hungarian algorithm in **5**. The matching is done by satisfying the following constraints:

$$\max \sum_{i=1}^{|\mathbb{P}|} \sum_{j=1}^{|P|} w_{ij} e_{ij} \tag{3.15}$$

$$\sum_{i=1}^{|\mathbb{P}|} e_{ij} = 1 \quad \forall j = \{1, 2, ..., |P|\} \tag{3.16}$$

$$\sum_{j=1}^{|P|} e_{ij} = 1 \quad \forall i = \{1, 2, ..., |\mathbb{P}|\} \tag{3.17}$$

$$e_{ij} \in \{0, 1\} \tag{3.18}$$

In **Step 6** depending upon the matching the corresponding communication modes are assigned to every transmission in the cell.

3.5 Simulation Results and Discussion

In this section, we consider WINNER II A1 model [21] where both the BSs and active UEs are distributed inside the buildings.A line-of-sight (LOS) scenario in which the transmitter and the receiver are either in the same corridor or in the same room. Non-LOS (NLOS) scenario is in which room-to-room (NLOS1) or corridor-to-room (NLOS2) communication cases. We use MATLAB software for our simulation.

The figure 3.3shows the analysis of throughput versus distance in cse of LOS and NLOS paths with heavy walls and light walls.It is evident from the plot that as the distance increases in case of NLOS the throughput decreases.where as in case of LOS the D2D case has more coverage than cellular

we also calculate the performance of proposed joint mode and relay selection algorithm through simulation. We use MATLAB software for our simulation.We

Table 3.1: Simulation Parameters for Traditional and Realy assisted D2D Communication

Parameter	Value
Path loss model for LOS	18.7 log10(d) +46.8 + $20log_{10}(fc/5)$
Path loss model for Room-to-room (NLOS1)	$20log_{10}(d)$ + 46.4+ $20log10(f_c/5)$ + χ_1
Path loss model for Corridor-to-room (NLOS2)	$36.8log_{10}(d)$ + 43.8+ $20log10(f_c/5)$ + χ_2
Path loss model for cellular link	128.1 + $37.6log_{10}(d[km])$
Path loss model for D2D link	127+$30log_{10}(d[km])$
Wall atenuation[dB] χ_1 χ_2	 $5n_w$ $5(n_w-1)$
Shadow fading standard deviation	6 dB for D2D users 8 dB for cellular users
Cell radius	500m
Noise spectral density	-174 dBm/Hz
Bandwidth	10MHz
BS transmit power	46dbm
SNR threshold, ξ_{th} D2D and cellular communication	 10dB
Maximum transmit power of cellular user ϱ^c	24dbm
Maximum transmit power of D2D user ϱ^d	20dbm

consider a single cell scenario with one BS and 20 UEs and we also assume that the UEs are randomly distributed. We consider $P = (4, 5, 9, 10, 13, 18, 20)$ as transmitters to communicate with corresponding receivers $Q = (2, 3, 7, 12, 15, 17, 19)$.the UEs other than transmitter can be represented by set

$R = (1, 2, 3, 6, 7, 8, 11, 12, 14, 15, 16, 17, 19)$.

The parameters considered for our simulation are shown in the Table3.1.

We compare our proposed algorithm overall system throughput with the traditional D2D communication. In traditional D2D communication we have only two modes cellular mode and D2D mode. The communication modes are selected upon satisfying the SINR constraints.

Fig 3.5 shows the throughput per UE different values of d with the proposed

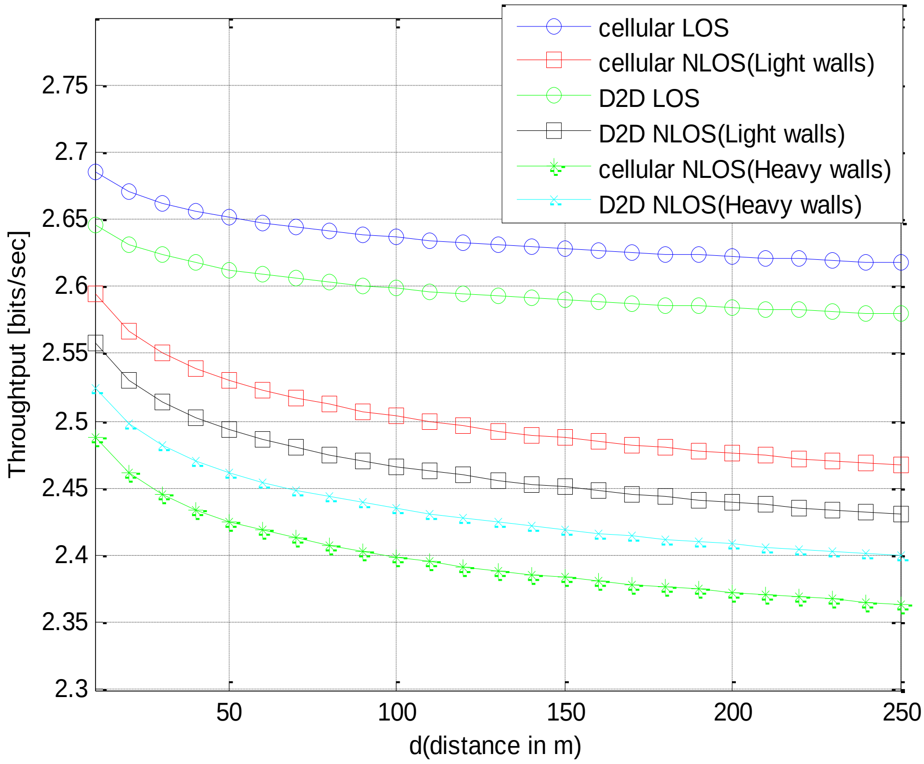

Figure 3.3: Throughput vs distance d

algorithm for $\xi_{th} = 5$dB and 10 dB is where d is the distance between the transmitter and receiver.The figure shows the comparison between our proposed method traditional D2D communication in terms of performance. We can conclude from the figure that if the distance between the transmitter and receiver increases the throughput gradually decreases in both the cases.

In case of traditional D2D communication, the throughput value meets to the cellular transmission mode throughput value at d = 80 m for ξ_{th} = 10 dB and d = 110 m for ξ_{th} = 5 dB. But the proposed algorithm provides a D2D coverage upto d = 130 m for ξ_{th} = 10 dB and d = 160 m forξ_{th} = 5 dB.The extended coverage area can be show in the figure

The proposed algorithm improves the overall throughput in a specific region

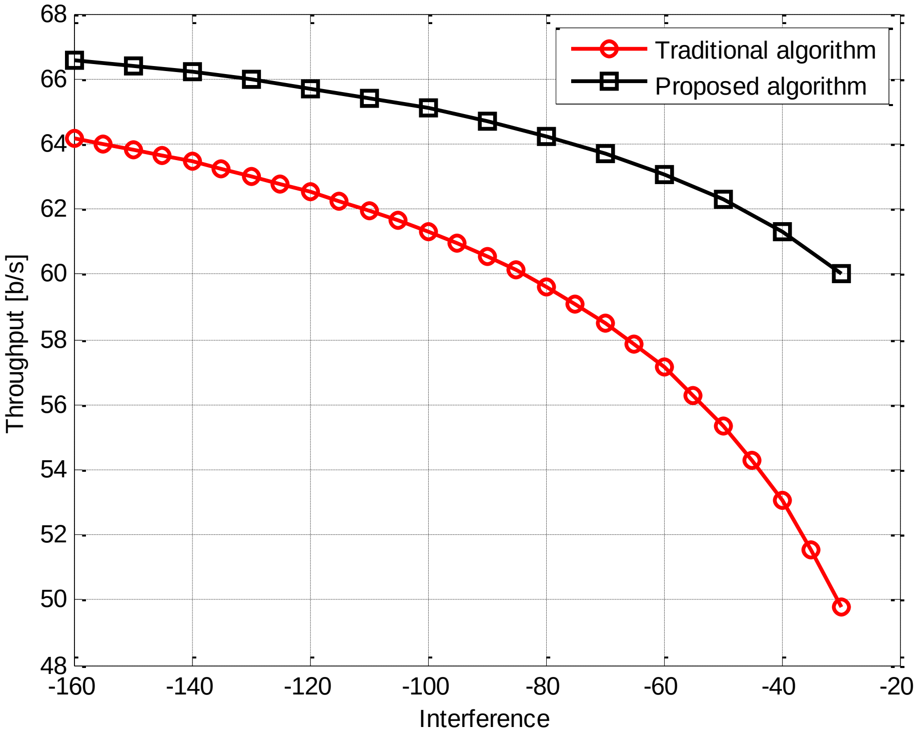

Figure 3.4: Throughput vs interference plot

where transition takes place from D2D to cellular occurs, when compared to the existing methods.

A comparison between the traditional D2D communication and our proposed algorithm is shown in the figure 3.4. The throughput is plotted with different interference power values. The throughput of the traditional D2D communication method without relay mode is lesser when compared to the proposed algorithm.

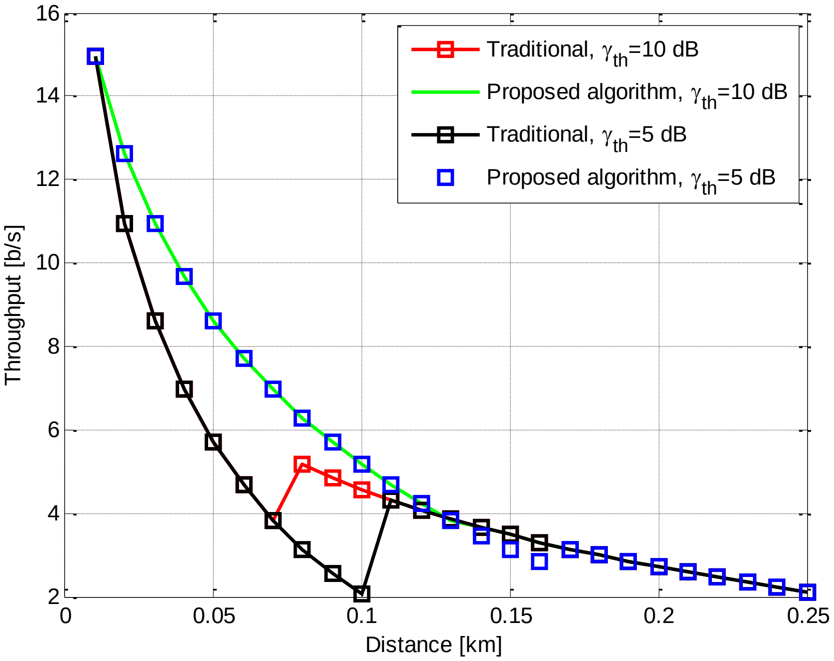

Figure 3.5: Throughput vs distance d for$\xi_{th} = 5$dB,10dB

3.6 Summary

In this chapter, we suggest an additional mode of communication to the existing cellular mode and D2D mode to overcome the drawbacks in case where the distance between the transmitting devices and receiving devices is large.We proposed a joint mode and relay selection algorithm based on Hungarian Algorithm for relay assisted D2D communication.This proposed algorithm provides better throughput compared to the existing methods.

4

Resource Allocation:A Graph-based Approach

4.1 Introduction

The D2D communications underlaying cellular network includes appropriate channel allocation.In channel allocation we consider each D2D pair will share the independent frequency allocated to one cellular user whose channels can be shared. Our main objective is to improve the spectrum utilization efficiency and overall system throughput by ensuring quality-of-service (QoS) to both cellular and D2D UEs [7]. This chapter has important Objective:

- Spectral Efficiency of cellular spectrum can be improved by sharing cellular links with multiple D2D links. In this article ,we construct a bipartite graph for cellular users and D2D users.We introduce Hungarian algorithm to achieve MWBM for bipartite graph [26], and perform channel allocation for users.Graph theory has been widely used to solve the channel management problems[29].

4.2 System Model

A system with a one BS and N cellular UEs, L idle UEs ,also we consider there are M UEs close to the cell experiencing shadowing is shown in the figure 4.1.The UEs that are experiencing shadowing cannot directly communicate with BS,so the idle users in the cell act as a relay to communicate with BS and form D2D pairs with the UEs near the cell which improves the throughput and also network coverage area .We represent the idle UEs which acts as receivers by $DR$and transmitting UEs by DT .We represent the cellular UEs by CU and channels available by CH.The individual UEs in the sets CU,DR,DT, CH are represented by CU_n where $1 \leq n \leq N$, DR_j where $1 \leq j \leq L$, DT_i where $1 \leq i \leq M$,CH_k where $1 \leq k \leq K$.Here CH_k represents the k^{th} channel . We use Orthogonal Frequency Division Multiplexing Access(OFDMA) technique for multiple access in both D2D and cellular communication.In this cell we consider that every UE in the cell has transmit power denoted by P.

$h_n^{CU,BS}$,$h_{ij}^{DT,DR}$,$h_j^{DR,BS}$,$h_i^{DT,BS}$,$h_{ni}^{CU,DR}$ represent the channel gains of the Cellular UE to BS link,Transmitting UE to Receiver UE link,Receiver UE to BS link and interference from Transmitting UE to BS ,interference from Cellular UE to Receiver UE respectively.

The SINR of the link at receiver is given by

$$\xi_1^{i,j,k} = \frac{Ph_{ij}^{DT,DR}}{N_0 B + s_{jl}^k P_{jl} h_{jl}^{DT,DR} + x_n^k P_n h_{nj}^{CU,DR}} \tag{4.1}$$

As we assumed that transmitting UEs suffers path loss and shadow fading, we neglect the interference. Then, the SINR at the BS can be written as:

$$\xi_j^2 = \frac{Ph_j^{DR,BS}}{N_0 B} \tag{4.2}$$

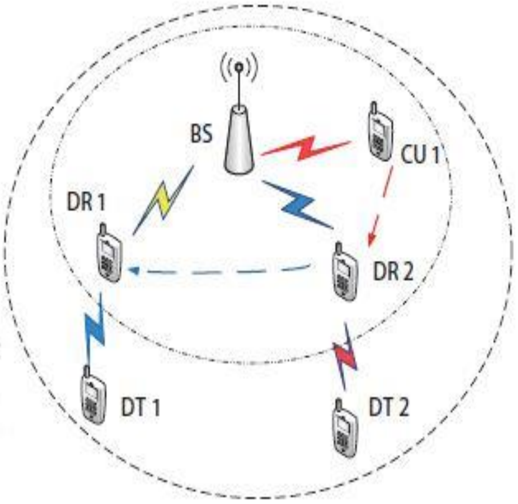

Figure 4.1: System model for D2D Communication underlaying Cellular networks

Therefore the total SINR from DT_i to BS can be expressed as

$$\xi_{il}^{k} = \frac{\xi_1^{i,j,k} \xi_j^2}{\xi_1^{i,j,k} + \xi_j^2 + 1} \tag{4.3}$$

where P_c^j and P_d^i denote the transmit power for D2D pair and cellular user , $h_c^j$and h_c^j denote channel gains of D2D communication ans cellular communication of $i-j$ link. N_0 is the power spectral density of the Additive White Gaussian Noise (AWGN) at the receivers.

$$\xi_{ij}^{d} = \frac{P_d^i h_d^i}{N_0 B + P_c^i h_{c2d}^{ij}} \ \forall\ i, j \tag{4.4}$$

The capacity of this link R_{ij}^k is given as:

$$R_{ij}^{k} = B.\log_2\left(1 + \xi_{il}^{k}\right) \tag{4.5}$$

The signals from transmitting UE experience path loss and shadow fading interference at BS is neglected , SINR at the BS is expressed as :

$$\xi_n^k = \frac{Ph_N^{CU,BS}}{N_0 B} \tag{4.6}$$

The capacity of the link R_n^k is

$$R_n^k = B.\log_2\left(1+\xi_n^k\right) \tag{4.7}$$

where B is the bandwidth.N_0 is the power spectral density of the (AWGN).

In this article, we consider D2D UEs can reuse the available channels if the interference among D2D and cellular communication is acceptable [30]. The BS can decide which cellular users can share channel with minimum interference and identify those users as channel sharing users. The number of the users in the cell is denoted by S .The channel sharing condition should satisfy the minimum SINR requirements of both cellular and D2D users.

4.2.1 Problem Formulation

In this section, we suggest method for D2D pair formation and channel allocation algorithm to enhance the throughput of the system.We define a matrix such that $S = [s_{ij}^k]$, the values of the variable s_{ij}^k is assigned as follow

$$s_{ij}^k = \begin{cases} 1, \text{channel k is assigned to the path} \\ \text{from transmitter to reciever} \\ 0, \text{others} \end{cases} \tag{4.8}$$

Matrix $X_{K*N} = x_n^k$ represents the channel allocation matrix for cellular users set CU,and x_n^k is assigned as follows

$$x_n^k = \begin{cases} 1, \text{if channel k is allocated to } CU_n \\ 0, \text{others} \end{cases} \tag{4.9}$$

Our main objective is to improve the cell coverage area and let the users in the poor coverage area to communicate with the BS.The resource allocation problem can be expressed as

$$\max\left\{\sum_{k=1}^{K}\sum_{i=1}^{M}\sum_{j=1}^{L} s_{ij}^{k}R_{ij}^{k} + \sum_{n=1}^{N}\sum_{k=1}^{K} x_{n}^{k}R_{n}^{k}\right\} \tag{4.10}$$

$$s.t\begin{cases}\sum_{j=1}^{L}\sum_{k=1}^{K} s_{ij}^{k} \leq 1, 1 \leq i \leq M\\ \sum_{i=1}^{M}\sum_{k=1}^{K} s_{ij}^{k} \leq 1, 1 \leq j \leq L\\ \sum_{i=1}^{M}\sum_{j=1}^{L} s_{ij}^{k} \leq 1, 1 \leq k \leq K\\ \sum_{k=1}^{K} x_{n}^{k} = 1, 1 \leq n \leq N\end{cases} \tag{4.11}$$

The constraints 4.11 should be satisfied as per our considered scenario.The first constraint ensures that a transmitting UE uses at most one channel with only one receiving UE.The second constraint ensures that the receiving UE pairs with only one transmitting UE and also use only one channel for communication. The third constraint ensures that one transmitting UE can use only one channel.The fourth constraint ensures that only one channel is engaged by respective link from the cellular UE to the BS.

4.3 Proposed Algorithm

In this section we proposed algorithm for D2D pair formation and Resource Allocation for newly formed D2D pair.

4.3.1 D2D Pair Forming and channel Allocation Algorithm

A D2D pair forming and channel allocation scheme is proposed for D2D communications in a single cell scenario.A bipartite graph is constructed between transmitting UEs and receiving UEs .A matching by MWBM between the transmitter UEs and receiving UEs forms a D2D pair.A bipartite graph is constructed between D2D pairs and channels CH. A Hungarian Algorithm is presented to resolve the MWBM for D2D pair forming and channel allocation or channel allocation . The MWBM gives a solution for allocating channels in the cell. This algorithm maximizes the overall system throughput.

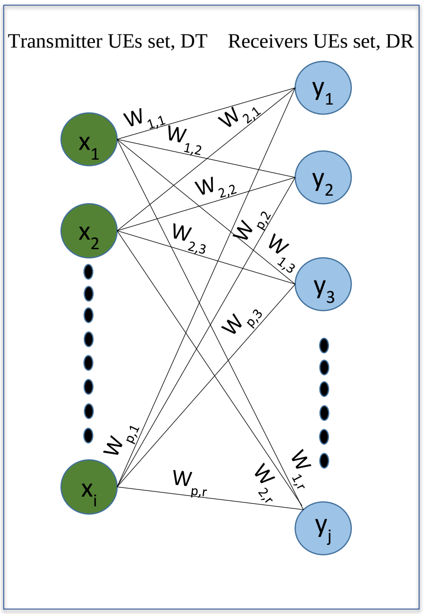

Figure 4.2: Matching scenario between Transmitter and Receive UEs

A . D2D Pair Formation

We construct a bipartite graph denoted by $G = (X, Y, W)$, each vertex in X represents the set of transmitting devices V_i^{DT}, ,each vertex in Y represents the set of receiving devices V_j^{DR}, W connects one vertex in transmitter set and other in receiver set. We calculate the total capacity of the system to study the performance. The edge weight of individual path is the value of SNR of D2D link.The weight is given by

$$W_{ij} = \log_2 \left\{ 1 + \frac{\xi_{ij}^{DT,DR} \xi_j^{DR,BS}}{1 + \xi_{ij}^{DT,DR} + \xi_j^{DR,BS}} \right\} \tag{4.12}$$

where $\xi_{ij}^{DT,DR}$and $\xi_j^{DR,BS}$ represent the SNR values at receiver and BS .

We assume that number of users near the cell M are less than the idle users L in the cell. The number of D2D pairs that can be formed is restricted by the size of sets DR, DT, CH and CU.R represents total number of D2D pairs with available channels ,$R \leq min\,(K - N, M, L).DP_r$ represent the r^{th} pair in D2D pairs set DP where $1 \leq r \leq R$.The D2D users having better capacity are selected

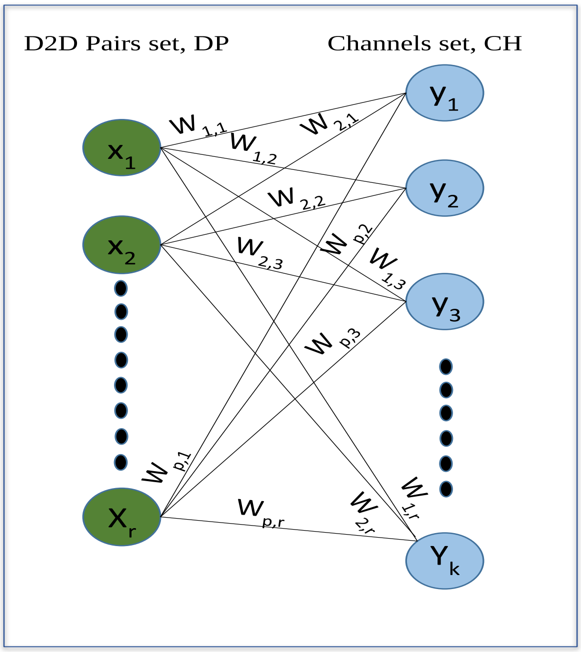

Figure 4.3: Matching scenario between D2D pairs and channels

when the available channels are less.

The Hungarian algorithm proposed based on maximum weighted bipartite matching (MWBM)forms D2D pairs .Then we compute the capacity and SNR for every D2D pair and from the computed values we find the least value. Then we compute the capacities of links from individual transmitting UEs to individual receiving UEs. On comparing the capacities of all the D2D pairs, the minimum capacity is replaced with a better capacity D2D pair.

B . Resource Allocation

The available channels are alloted to the links from transmitting UEs to BS and from cellular UEs to BS.D2D pairs set and channels set are represented by DP and CH .To find the matching between these two sets we employ MWBM to solve the channel allocation problem.Similar to the case in D2D pair formation we construct a bipartite graph in this case $G = (X, Y, W)$ each vertex in X represents the set of D2D pairs DP,each vertex in Y represents the set of channels CH, Wconnects one vertex in D2D pair set and other in channels set.

The weight of a individual edge in the bipartite graph can be given as

$$W_{rk} = \log_2(1 + \xi_{r,k}^{DP,CH}) + \log_2(1 + \xi_{r}^{DP,BS}) - \log_2(1 + \xi_{r,k}^{DP,CH} + \xi_{r}^{DP,BS}) \quad (4.13)$$

where $\xi_{r,k}^{DP,CH}$ is the SINR from the Transmitter UE to Receiver UE in DP_r utilizing CH_k. $\xi_{r}^{DP,BS}$ is the SINR from the Receiver UE in DP_r to BS.

A Hungarian Algorithm is presented to resolve the MWBM of the bipartite graph , so as to increase matching efficiency.

C . Analysis

In this section, we discuss on the performance of our proposed algorithm. We represented our size of the sets by X and for first set and Y for the second set.In the proposed algorithm ,to find the augmented path it alters the path to maximum of X times for the worst case scenario. And for each vertex in the X set we alter the path X times.So there are maximum of X^2 alterations.Each alteration have to cross all the edges in the graph which is defined as complexity of the system.the complexity of each alteration is $O(XY)$ and the total complexity for all the alteration is $O(X^3Y)$.

In case of D2D pair formation the complexity is $O(M^3L)$ when $M \leq L$ or $O(L^3M)$ when $L \leq M$.We compute capacity L times for every DT and categorize once.The complexity is $O(ML + M^2log_2(M))$.The complexity for channel allocation to R D2D pairs is $O(R^3K)$.The total complexity is $O(R^3K + M^3L)$ or $O(R^3K + L^3M)$.

The system performance can be effected by total number of devices .We have three cases for estimating the performance.

- $R \leq minKN, M, L = M$: In this scenario the number of available channels and receivers are more but the number of receivers limit the number of D2D pairs formed.Every D2D pair is allocated a separate channel when $R \leq (KN)/2$ so there is no interference among the devices.If $R \geq (KN)/2$ the D2D pairs reuse the channel in the cell.

- $R \leq minKN, M, L = L$: In this case DR are less so available DT cannot form a D2D pairs.To improve the capacity more users should be served, we find the DTs which can get into the network .

- $R \leq minKN, M, L = KN$: In this case the available channels are less and cannot be served for every user.This also happens when there are more CUs that reuse the frequency.We find the suitable CUs that get the service in the network.

Algorithm I:Hungarian Algorithm for MWBM

```
Step 1:  Initialisation :Given $W$, label=0
Step 2:  Initialise $X' = [0]_{M \times L}$
Step 3:  Set $l_x(i) = \max(w_{ij}), l_y(j) = 0, i, j \in \{1, 2, 3, .....S\}$
         while label=0
           for $(i = 1; i \leq M; i = i + 1)$
             for $(j = 1; j \leq L; j = j + 1)$
                 $w_{ij} = l_x(i) + l_y(j) - w_{ij}$
             end for
           end for
Step 4:  Update the matrix.Set $n$=number of lines,$n_s$ = uncovered elements.
           if (n!=0)
           for $(i = 1; i \leq M; i = i + 1)$
             for $(j = 1; j \leq L; j = j + 1)$
                 $w_{ij} = l_x(i) + l_y(j) - w_{ij}$
             end for
             if (the row $i$is uncovered)
               $l_x(i) = l_x(i) - n_s$;
               end if
             if (the row $i$is covered)then
               $l_y(j) = l_y(j) + n_s$;
               end if
             end for
           else
             label=1;
           end if
         end while
```

4.3.2 Hungarian Algorithm of MWBM

A weighted bipartite graph [11] is constructed for D2D pair formation and denoted by $G = (X, Y, W)$ as shown in Figure 4.2(a).Each vertex in X represents the set of transmitting devices V_i^{DT}, ,each vertex in Y represents the set of receiving devices V_j^{DR}, W connects one vertex in transmitter set and other in receiver set.

The matching in bipartite graph is done in such a way that two identical end points in sets DT and DR have only one line.

Similar to the case in D2D pair formation ,a weighted bipartite graph [26] is constructed for channel allocation and denoted by $G = (X, Y, W)$ as shown in Figure 4.3(a).Each vertex in X represents the set of D2D pairs DP,each vertex in Y represents the set of channels CH, W connects one vertex in D2D pair set and other in channels set.

The matching in bipartite graph is done in such a way that two identical end points in sets DP and CH have only one line.

We get the maximum capacity by finding the MWBM of the bipartite graph ,thereby the problem of channel allocation is changed into a MWBM problem.The weight matrix is defined as shown in 4.14

$$W = \left\{ \begin{array}{ccccc} w_{1,1} & w_{1,2} & w_{1,3} & \cdots & w_{1,L} \\ w_{2,1} & w_{2,2} & w_{2,3} & \cdots & w_{2,L} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ w_{M,1} & w_{M,2} & w_{M,3} & \cdots & w_{M,L} \end{array} \right\} \tag{4.14}$$

4.4 Simulation Results and Discussion

We carry out out simulation to check the performance of our proposed MWBM Algorithm.We use Matlab software for simulations.We compare our proposed algorithm with traditional algorithm.

In Fig 4.5, for the scenario with 10 CUs and 20 channels, only 10 channels can be assigned to D2D pairs. When M = 5,increase in M value increases the system capacity.The capacity increases with increase in number of DRs until D2D pairs

Table 4.1: Simulation Parameters for Resource Allocation

Parameter	Value
Path loss model for cellular link	128.1 + 37.6log10(d [km])
Path loss model for D2D link	127+30log10(d [km])
Shadow fading standard deviation	6 dB for D2D users 8 dB for cellular users
Cell radius	500m
Transmission Distance	100m
Noise spectral density	-174 dBm/Hz
Bandwidth,BW	5MHz
Transmit power P	23dbm

formed reaches 5.

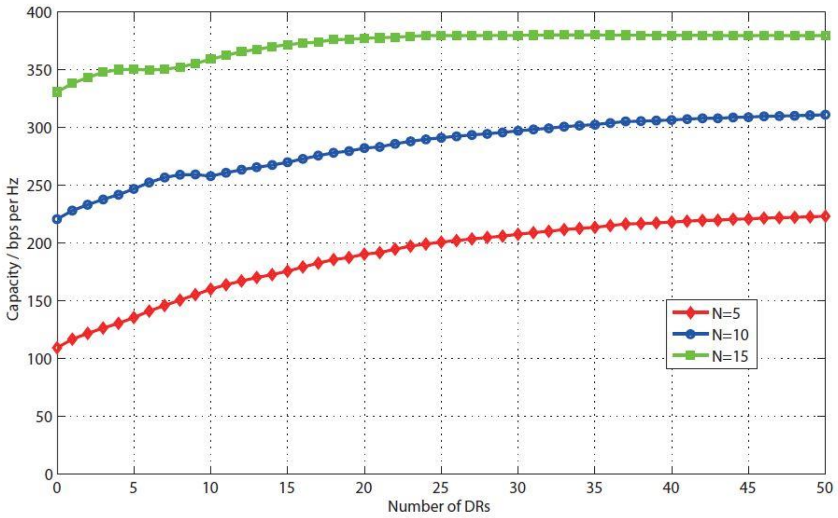

Figure 4.4: System capacity with the number of DR.

In Fig 4.6, for the scenario with 20 channels and 10 CU devices. The plots in these two cases are nearly the same. With M = 5, The rate of growth of capacity is less because D2D pairs cannot be formed on reaching 5(number of D2D pairs).The same happens in the case for M=10 and M=15 as shown in Fig4.3.

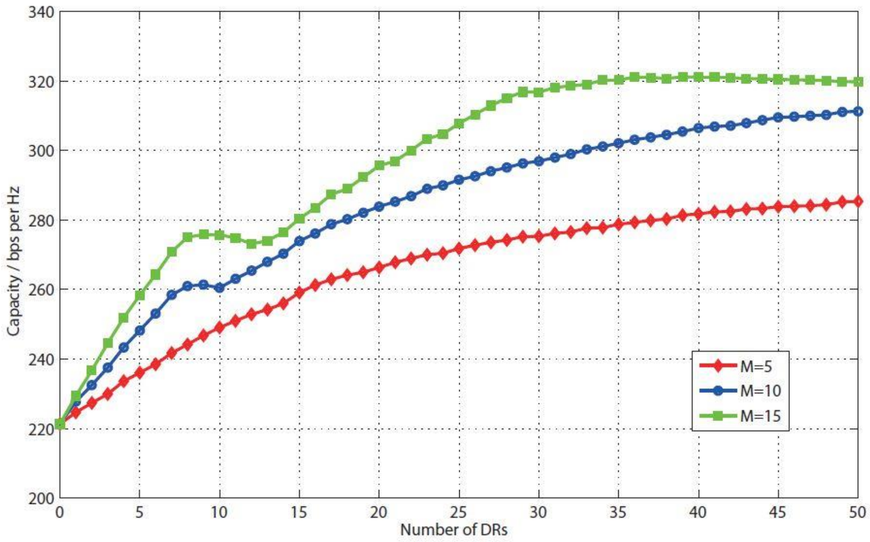

Figure 4.5: System capacity varying with DRs

In Fig 4.4, for the scenario with 10 DTs and 20 channels. When the CUs increase the channels available for D2D pairs decrease.When N=5,5 channels are used by CUs and remaining 15 channels are available for D2D pairs. When N = 10 and N = 15,it is evident from the plot that the capacity increases ,decreases and again increase moderately and with increasing DR UEs system capacity combine at the end.

We consider D2D users and cellular users are uniformly distributed in the cell. We also assume that both the cellular users and D2D users have fixed transmission powers.We use different path-loss models and shadowing values for cellular links and D2D links.We define our simulation parameters in table 4.1

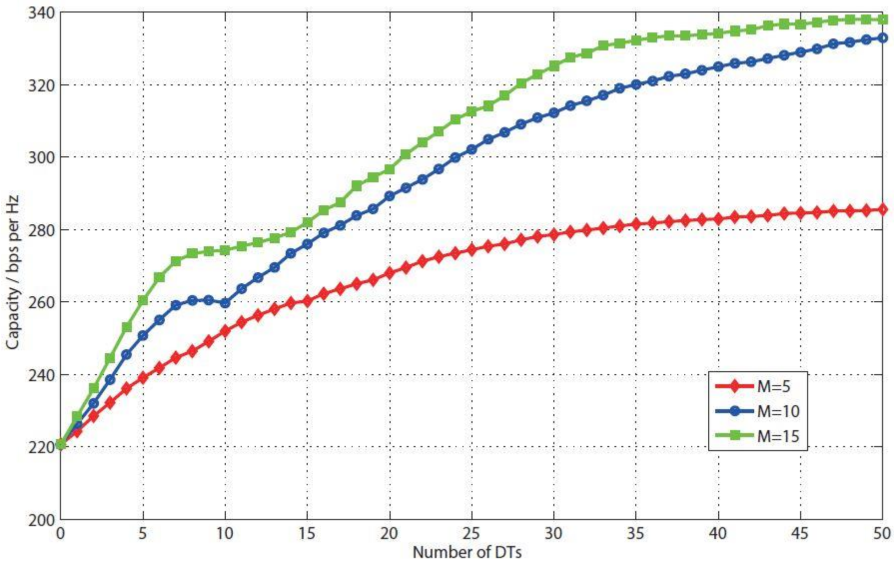

Figure 4.6: System capacity with the number of DT

4.5 Summary

In this chapter, D2D pair development and channel allocation based on Hungarian algorithm is proposed.We consider a single cell scenario for channel allocation. We convert the D2D pair development and channel allocation problem into MWBM matching problem, and execute the MWBM algorithm to attain maximum matching.Our proposed resource allocation algorithm improves the spectral efficiency and also the system throughput.

5

Conclusion

D2D communication as an underlay to cellular networks can be advanced technique to improve the system throughput and spectrum efficiency by reusing resources of cellular networks. The sharing of the resources by the D2D users and cellular users addressing the interference issues improves the spectral efficiency.

Two methods are proposed to discover the devices in the proximity which intend to communicate through D2D communication in cellular network.The simulation results show that reactive performs better if the D2D request traffic is less and if the D2D requests increase proactive is opted as it shows better performance than the reactive algorithm.So,when we have a request from only one D2D pair we prefer reactive algorithm and if the number of requests from the D2D pairs are more we prefer proactive algorithm which gives better results.

A mode selection algorithm is proposed and a WINNER A1 office model scenario is considered.The algorithm decides in which mode the users can communicate satisfying the minimum threshold conditions for communication and also show that D2D communication can enhance the throughput when compared with traditional cellular communication.

A relay mode of communication is suggested as an additional mode to the existing cellular and D2D modes to overcome the drawbacks in case where the distance between transmitting devices and receiving devices is large. We proposed a joint mode and relay selection algorithm based on Hungarian Algorithm for relay assisted D2D communication.This method can improve the coverage area of the D2D communication through relaying.Simulations results show that the proposed algorithm can enhance the throughput compared to existing methods.

A graph-based algorithm is proposed for D2D pair forming and for resource allocation based on Hungarian algorithm.We consider a single cell scenario for resource allocation. We formulate the D2D pair forming and resource allocation problem as a two-step matching problem, and apply the MWBM algorithm in graph theory to achieve maximum matching.Maximum weighted bipartite matching method based on Hungarian algorithm is used to allocate resources for users in cell.Our proposed resource allocation algorithm improves the spectral efficiency and also the system throughput guaranteeing the quality of service.

Scope for Further Research

We considered a single cell scenario for our simulation so far in this thesis work.The performance can be evaluated through simulations in multiple cells scenario.

Interference among the D2D users and also from cellular users should be managed as throughput of users may be reduce due to the resource sharing.

In maximum weighted matching scenario ,we assumed that the CSI is available at the BS to calculate the weights in the bipartite graph.A scenario with imperfect channel state information can be considered and performance can be evaluated.

A joint mode and relay selection is carried out only for single relay that can be extended to multiple relays which can improve the overall throughput compared to a single relay.

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