Social Aware Information Dissemination

for

Device to Device Communication

by

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ABSTRACT

Due to ever increasing demanding for higher data rates, a lot of work is being done on 5G. Device to Device (D2D) communication, a paradigm of 5G, is a technology in which devices can communicate directly with each other bypassing the Base Station (BS). D2D is an efficient scheme to improve spectral efficiency, energy efficiency, offload data from BS and to increase network capacity. However there are many challenges associated with this vital technology including efficient resource allocation and interference management. Particularly, in underlay communication, where cellular and D2D users share the same spectrum, it becomes critical to devise a technique in order to ensure efficient radio resource utilization while catering interference issues. Recent works have been focusing on physical domain constraints however our aim is to utilize the social human behaviors to resolve the D2D resource allocation problems. This thesis proposes a framework for effective resource allocation by leveraging social networks and forming social communities. The suggested technique is likely to improve the D2D rate and coverage probability at the same time. Numerical simulations are also illustrated to show the effectiveness of our proposed scheme as compared to the existing ones. Some applications of D2D are:

- Public safety services
- Content sharing/ local multicasting
- E-health

DEDICATION

I dedicate this report to my parents, and my supervisor, Dr. Syed Ali Hassan for their prayers and encouragement.

ACKNOWLEDGMENT

I am appreciative to Allah Almighty who gave me with the strength to fulfill this postulation and I am grateful to Him for His benevolence. Without His consent I couldn't have indulged myself with this undertaking.

Upon the completion of my thesis, I am grateful to my supervisor Dr. Syed Ali Hassan and Co-Supervisor Dr. Muhammad Imran who mentored and guided me towards my goal. I would also like to thank my committee members Brig Dr. Imran Rashid and Col Dr. Abdul Ghafoor for their valuable support and time.

Lastly, I am highly thankful to my friends and family who encouraged and helped me despite all the circumstances.

ACRONYMS

1G	1st Generation
2G	2nd Generation
3G	3rd Generation
4G	4th Generation
5G	5th Generation
BS	Base Station
D2D	Device to Device
SMS	Short Message Service
MMS	Multimedia Message Service
AMPS	Advanced Mobile Phone Systems
GSM	Global System for Mobile Communication
TDMA	Time Division Multiple Access
GPRS	General Packet Radio Service
EDGE	Enhanced Data rates for GSM Evolution
UMTS	Universal Mobile Telecommunication System
HSPA	High Speed Packet Access
LTE	Long Term Evolution
IP	Internet Protocol
Kbps	Kilobits per second
Mbps	Megabits per second
Gbps	Gigabits per second
3D	3 Dimensional
IoT	Internet of Things
M2M	Machine to Machine
V2V	Vehicle to Vehicle
MIMO	Multiple Input Multiple Output
NOMA	Non-Orthogonal Multiple Access
UE	User Equipment
SINR	Signal to Interference plus Noise Ratio

QoS	Quality of Service
CUE	Cellular user equipment
DUE	D2D user equipment
CM	Cellular Mode
DM	Dedicated Mode
SM	Shared Mode
SINR	Signal to Interference plus Noise Ratio
FEC	Forward Error Correction
FDMA	Frequency Division Multiple Access
RB	Resource Block

Table of Contents

List of Figures

List of Tables

CHAPTER 1

1 INTRODUCTION

1.1 Cellular Evolution

1G refers to the First Generation wireless technology that used analog transmission for speech services. It was introduced in 1980s and included Advanced Mobile Phone Systems (AMPS) with data rates around 2 Kbps.

2G refers to the Second Generation of mobile systems that used digital communication. It came in the end of 1980s and provided services like Short Message Service (SMS), Multimedia Message Service (MMS) and picture messages along with phone call and message encryption. Global System for Mobile Communication (GSM) is a popular 2G standard that was launched in 1991 and used Time Division Multiple Access (TDMA) technology giving data rates around 9.6Kbps. The benefits of 2G over 1G include better roaming facilities, spectral efficiency and cost effectiveness.

General Packet Radio Service (GPRS) is a packet oriented mobile data service which when combined with 2G is described as 2.5G. Enhanced Data rates for GSM Evolution (EDGE) is digital mobile technology that is considered pre-3G and gives data rates up to 384 Kbps.
3G refers to the Third Generation of wireless technology that came in 1998 and enabled high data speed services like mobile internet, video calling etc. Universal Mobile Telecommunication System (UMTS) is a 3G system capable of providing data rates as high as around 2Mbps. High Speed Packet Access (HSPA) is termed as 3.5G technology developed to provide better performance and enhanced upload and download speeds.Long Term Evolution (LTE) is termed as pre-fourth generation or 3.9G having a different air interface than that of 2G and 3G. It was developed with a purpose to redesign the network architecture to an IP based system thereby achieving higher data rates and reduced latency as compared to 3G. 4G or Fourth Generation wireless technology which was introduced in

2008 can deliver speeds up to 100 Mbps. It provides mobile broadband internet access thus enabling applications like video conferencing, IP telephony, 3D television, etc. LTE Advanced is a 4.5G standard that provides better performance than 4G in terms of improved coverage and capacity.

In order to overcome the demand for extremely high data rates (1 Gbps and more), reduced latency, high spectral efficiency, improved coverage and long battery life, Fifth Generation or 5G wireless standard is currently under development. 5G will be an all IP based model that will enable the availability of very high bandwidth and will support the simultaneous connectivity of massive number of devices like Internet of Things (IoT), Machine to Machine (M2M), Vehicle to Vehicle (V2V) and Device to Device (D2D) communications.

1.2 Motivation

The demand for high speed data transfer with minimal delay along with the evolution of different multimedia applications like virtual reality hardware, self-driving cars, gaming, vlogging, etc. led to the evolution of cellular network. As the spectrum below 5GHz is congested so there is a need to use the bandwidth in an efficient manner. As the number of subscribers go on increasing, the mobile systems need to provide high capacity and become more cost effective and energy efficient. In order to incorporate these constraints, many techniques are being developed and incorporated e.g. Multiple Input Multiple Output (MIMO), milli-meter wave communication, Non-Orthogonal Multiple Access (NOMA), D2D [1] etc.

In a traditional cellular network as shown in figure 1.1, the signal is first sent to the BS which acts as relay and transfers it to the end user even if source and destination are closer to each other than to the BS. In such networks, it is comparatively easy to manage interference and spectral resources however the radio resources are not utilized efficiently.

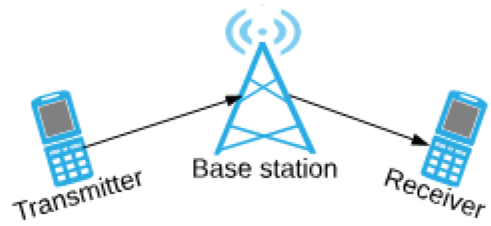

Figure 1.1 Traditional Cellular network

Device-to-Device (D2D) communication is a promising concept in next generation cellular networks [2] in which direct link is established between devices in close proximity thus by-passing the BS (see figure 1.2). D2D offers many advantages [3] like reduced latency, high data rates, enhanced spectral efficiency, wider coverage, energy efficiency, etc. Moreover, it finds numerous applications in e-health, local advertising, location based services, content sharing, disaster relief, data offloading, video dissemination, etc.

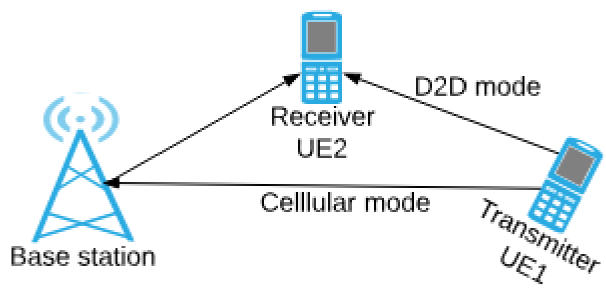

Figure 1.2 D2D Communication

D2D underlay communication also offers various gains like proximity gain that lowers delays, reuse gain that allows both CUE and DUE to simultaneously use the spectral resources [4] and hop gain that allows direct link between devices instead of communication via BS.

1.2.1 Types of D2D

D2D is basically divided into two types [5]:

1.2.1.1 Outband:

Communication occurs in unlicensed part of the spectrum. It aims to eliminate the interference between D2D and cellular links and requires an extra interface, usually Wi-Fi direct or Bluetooth. If control of second interface is under cellular network then it is called Controlled D2D otherwise it is called Autonomous communication. In Controlled D2D, security and mobility management, etc. are done with the help of BS. Autonomous communication, on the other hand, is helpful in situations like network failure. The data transfer rate of outband is lower than that of in-band.

1.2.1.2 Inband:

Communication occurs under licensed spectrum. Cellular spectrum is used for both cellular link and D2D communication. If cellular and D2D users are given dedicated cellular resources then it is called Overlay and if cellular and D2D users share same radio resources then it is called Underlay [6]communication.

In Underlay D2D, when D2D UEs share the spectrum resources of cellular users, there is a high chance of interference. So it becomes a challenge to manage resources and interference effectively which is the main motivation behind this thesis.

1.3 Problem Definition/ Statement

Nowadays human beings are linked via social networks like Facebook, Twitter, etc. so the question arises whether it is possible to leverage the human behaviors appearing in the social networks to solve the D2D resource sharing problem?

Uptil now no radio resource management schemes exist that utilize the concept of social networks and social communities along with frequency re-use concept to cater interference issues thereby increasing system coverage rate.

1.4 Thesis Contribution/Methodology

The primary objective of this thesis is to use the information of social ties strength to form social communities among users and to allocate resources effectively using this social relationship information. We consider social aware D2D communication underlaying cellular networks which is projected onto two domains i.e. physical domain and social domain. In the physical domain, radio transmission distance between UEs is calculated to determine proximity users while social domain incorporates social relationships among devices.

We derive the Signal to Interference plus Noise Ratio (SINR) expressions for cellular and D2D UEs and find system coverage rate and total D2D rate. We further form social communities among devices that satisfy distance and social tie strength threshold. Overall, the technique uses social information to allocate resources effectively and reduce interference (by forming communities) in order to enhance spectral efficiency and capacity.

1.5 Thesis Outline

This thesis is separated into five parts:

Chapter 1: In this chapter, basics of the topic are introduced along with the scope, motivation and problem statement of this work.

Chapter 2: This chapter incorporates all the literature review highlighting the challenges of underlay D2D communication along with existing techniques like game theory etc. to cater the issues of social aware resource allocation in D2D networks.

Chapter 3: This chapter consists of our proposed technique to cater resource management issues thereby enhancing D2D rate.

Chapter 4: This chapter includes the results of proposed algorithm along with comparison with previous techniques and simulations that aim at achieving the required coverage rate.

Chapter 5: Future works and Conclusion are presented in this section.

CHAPTER 2

2 LITERATURE REVIEW AND BACKGROUND

2.1 D2D and its Challenges

Integration of D2D in 5G networks finds numerous applications however there also many challenges [7] associated with it.

2.1.1 Peer Discovery

Before establishing a D2D connection, devices first need to discover their peers i.e. they need to find whether nearby devices can possibly communicate with each other. There are two approaches to device discovery: 1) Network controlled and 2) Autonomous [8]. In network controlled/assisted approach [9], the network uses signaling to know about the approximate location of devices. This is a convenient approach but results in high signaling overhead. In the latter approach, the peers are discovered autonomously by D2D UEs by transmitting a known sequence or beacon. This ad hoc network [10] approach results in low signaling overhead however, the discovery process also results in draining of the battery as the peer devices need to be in the same time and space for efficient discovery. Therefore information about mobility of devices is critical in effective peer discovery.

2.1.2 Mode Selection

Mode Selection problem [11] refers to identifying the right mode: cellular or D2D between two UEs i.e. whether UEs communicate directly or via BS. It is mostly done either by UEs or by the network in order to achieve some performance objectives like high channel gain, low transmit power, reduced latency, high spectral efficiency, etc. For example, if direct channel is noisy then to ensure better QoS, cellular mode may be preferred. On basis of sharing of bandwidth, there are three main modes:

Cellular Mode (CM):

It refers to the traditional cellular communication where there is an indirect exchange of data between UEs via BS. This mode is preferred when UEs are either farther part or the channel is not suitable for direct communication. Although CM results in low spectral efficiency however it results in efficient interference management by the BS.

Dedicated mode (DM):

It refers to the direct communication between UEs without involving the BS however the BS allocates dedicated resources for this communication between DUEs. As the transmission becomes one directional (either uplink or downlink) therefore, spectral efficiency is higher in case of DM. This mode is also sometimes called the Orthogonal mode as both CU and D2D transmissions are given dedicated orthogonal radio resources thereby resulting in lesser interference issues. This scheme has the benefit that the interference between cellular and D2D users does not need to be handled by the BS.

Shared Mode (SM):

Shared mode is also called Non-orthogonal or underlay mode in which CUEs and D2D UEs share the same radio resources. This mode gives the highest spectral efficiency as compared to CM or DM, however, it also results in significantly higher interference levels between CUEs and DUEs. In order to cater such interference, advanced techniques need to be developed which increases the overall complexity of the system.

A comparison [12] of these modes is shown in table 2.1.

Type of D2D mode	CM	DM (DUEs use dedicated resources)	DM (DUEs use shared resources)	SM (DUEs use dedicated resources)	SM (DUEs use shared resources)
Spectral efficiency	Low	Medium	High	High	Very high
Interference among CUEs and DUEs	No	No	No	Yes	Yes
Interference among DUEs	No	No	Yes	No	Yes
Implementation complexity	Low	Low	Medium	Medium	High

Table 2.1 Comparison of D2D Communication Modes [6]

2.1.3 Interference Management

Although D2D communication provides many benefits however the introduction of D2D enabled communication in traditional cellular networks also results in high levels of interference especially in underlay communication, when D2D users share the spectrum of CUEs, then, due to the SM, a lot of interference issues occur which need to be resolved for efficient communication. For example intra-cell interference occurs between cellular and D2D users along with the possibility of inter-cell interference. Figure 2.1 illustrates the scenario of underlay D2D communication.

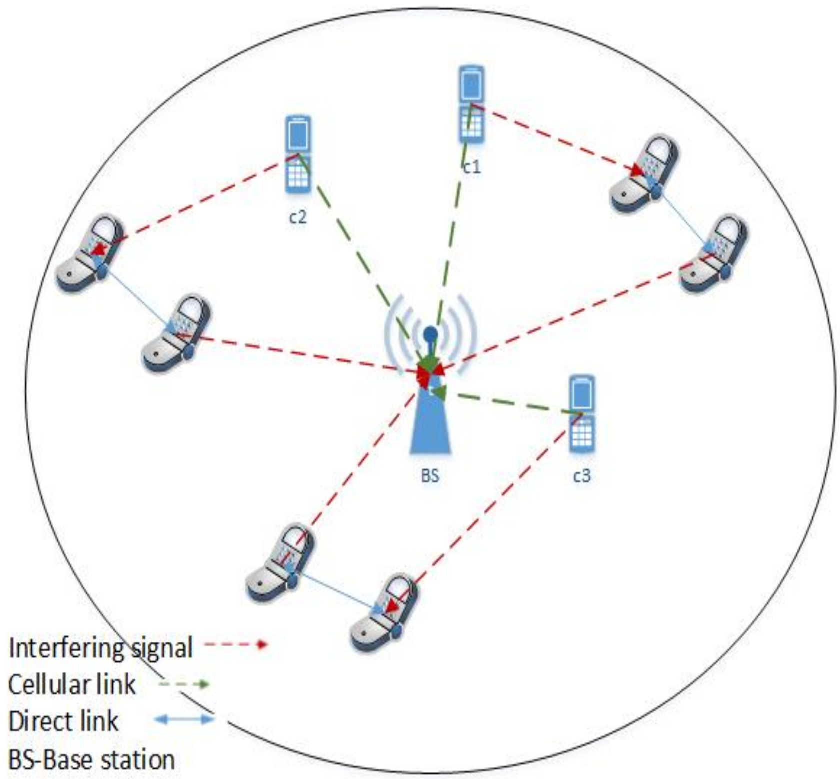

Figure 2.1 Underlay D2D communication

As it can be seen in the figure, the uplink transmission of CUEs is interfered by DUE while transmission from D2D transmitter to D2D receiver is interfered by CUE. To mitigate interference, different approaches are proposed which are divided into following categories: interference avoidance schemes, interference coordination schemes and interference cancellation schemes. Among these schemes, mode selection, power control and optimum resource allocation are among some of the popular techniques to cater interference issues.

There are two levels of interference coordination i.e. intra-cell and inter-cell however inter-cell is more difficult to manage as it involves multiple cells. Moreover, among D2D 'connected' and 'opportunistic' communications, interference coordination is easier for 'connected' communication because the BS has all the required information (and computing power) to centrally manage the power control. On the other hand, in case of 'opportunistic' communication, interference is mostly managed by mobile handsets whose limited computing power and mobility makes it difficult to handle interference coordination.

Mode selection is an important approach to avoid interference. In[13], MIMO techniques are introduced for interference avoidance which also result in improved SINR. In [14],cooperative communication has been exploited as an interference mitigation technique as without proper interference management, performance of cellular networks gets affected. Advanced coding and decoding techniques like Forward Error Correction (FEC) coding have been proposed in [15] for interference cancellation.

2.1.4 Resource Management

Radio Resource Management involves allocating the spectrum resources effectively such that QoS is maintained along with the achievement of required network capacity and system throughput [16]. Resource distribution depends upon the employed scheme to access the channel e.g. among the two techniques called Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA), the resources are ‘time slots’ and ‘frequency bands’ respectively. The two schemes are shown in figure 2.2.

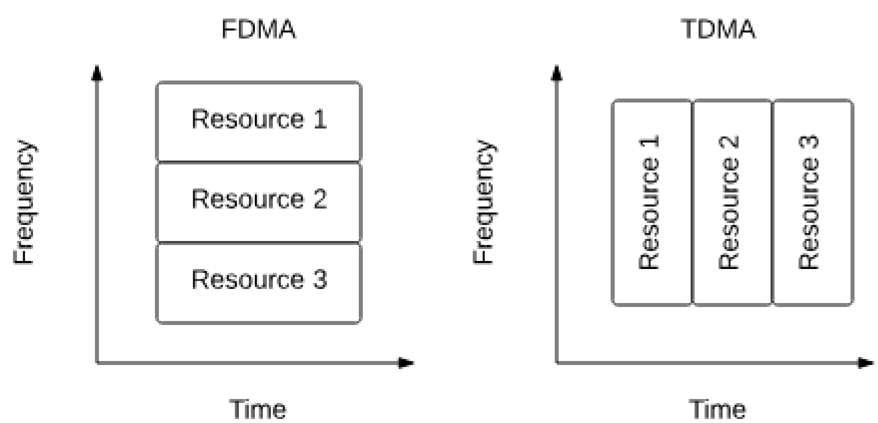

Figure 2.2 FDMA and TDMA radio resources

In this thesis, the focus is on Inband D2D where cellular and D2D users utilize the same licensed spectrum. As discussed earlier, there are two are two main resource allocation strategies i.e. orthogonal and non-orthogonal. In orthogonal approach, different frequency channels are allotted for cellular and D2D communication. On the other hand, in non-orthogonal approach, cellular and D2D users share the same radio resource leading to maximum resource utilization but higher interference.

Resource Block:

The physical transmission resource/resource allocation unit in LTE technology is time-frequency resource block (RB). A resource block is a time frequency grid consisting of mostly 84 resource elements and occupies 0.5 ms in the time domain and 180 kHz in the frequency domain as shown in figure 2.3. In this thesis, the transmission resource is RB. For both cellular or D2D link, we need to allocate sufficient RBs and the number of required RBs depends on the particular application. Further, in order to avoid inter-cell interference, we consider that initially all cellular users have orthogonal RBs.

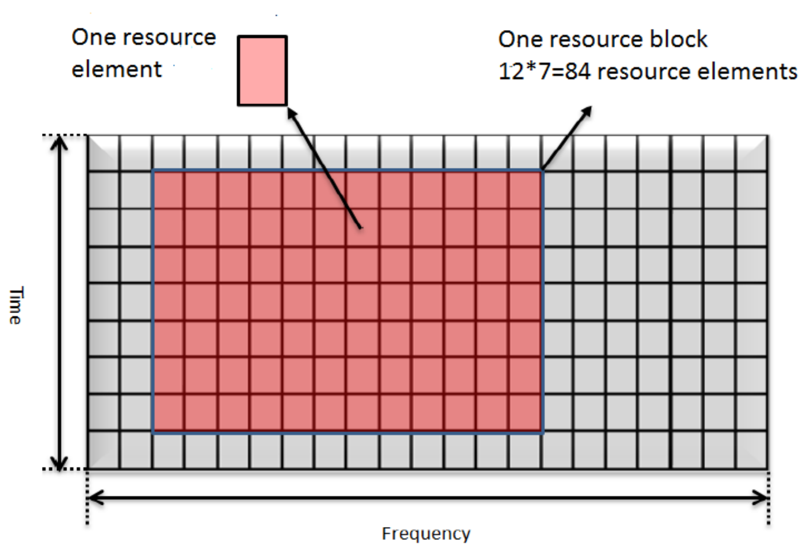

Figure 2.3 Resource Block

In order to mitigate interference, different resource allocation algorithms have been proposed. For example, in [17] a graph based resource allocation scheme has been proposed in order to cater interference and increase capacity of the network. In the proposed approach, resource allocation for D2D underlay cellular communication is considered a non-linear problem that needs to be optimized. In the graph, vertices represent links while edges represent interference. The simulations show the efficiency of the proposed scheme in terms of higher throughput. In [18], Xu et al. presents a reverse iterative combinatorial auction scheme to allocate resources in downlink for D2D underlay cellular network. The auction algorithm assumes resources as bidders whereas D2D packages/links are the goods to be auctioned off. Overall the scheme has low complexity and aims to reduce interference while improving system sum rate. In the solution proposed by Janis et al. in [19], the power values of cellular users are sent to the BS by D2D users which in turn, stops allocating same resource blocks to cellular and D2D users in order to minimize interference. The results show that this interference aware resource allocation approach is better than random allocation in terms of achieving higher system capacity. In [20], game theory has been introduced to allocate spectral resources in uplink for D2D underlay cellular systems. The resource allocation problem is presented as a coalition formation game and utility function is optimized in order to enhance the system sum rate.

Human beings form social ties and social communities with each other. In [21], social networks are leveraged to solve the problem of resource allocation. An optimal social community-aware resource allocation algorithm is proposed to maximize system throughput by minimizing transmission time. Zhao et al. proposes a social group utility maximization game in [22] to solve the problem of resource allocation. Utilizing the two domains i.e. physical and social domain, a distributed resource allocation algorithm is presented that achieves Nash equilibrium thus reducing complexity and enhancing sum utility rate of the system. The authors of [23] have proposed a two-step coalition game i.e. cooperative game theory has been used to form coalition of communities whereby DUEs use the spectral resources of CUEs belonging to the same coalition. This results in maximizing the utility of communities participating in the coalition. A cluster based approach has been proposed by authors of [24] in which D2D multicast clusters are formed. An algorithm is developed to choose a DUE as cluster head of each community which in turn disseminates the information to the members of the cluster thereby reducing the load of the BS. The proposed scheme offers an energy efficient scheme of resource allocation and power control that helps in improving the network performance. In order to cater resource management and interference problems, the idea of formation of small social communities has been presented by authors of [25]. A bipartite graph matching algorithm is presented to optimize resource allocation in the scenario of varying number of D2D users. The scheme offers lower complexity and increased system throughput.

CHAPTER 3

3 SOCIAL NETWORKS/CHARACTERISTICS

In this chapter, the system model and proposed technique has been explained. Nowadays mobile social networking [26] has penetrated into our lives due to the rapid growth in information and communication technology particularly ubiquitous mobile communications and online social networking. Social networking applications like Facebook, Watsapp, Skype, Instagram, etc. have led to an increase in the amount of people involved in online social interactions. That is why social domain [27] is an important feature to be considered while designing communication systems. For example, while data forwarding, relaying and file dissemination [28] in a network, those users which are in proximity or have strong social relationships with each other, will be more willing to cooperate with each other resulting in an efficient system. Similarly, in a scenario where a video is to be shared among socially familiar devices, load on network operator can be significantly reduced. This is because devices which have social trust [29]-[30] will easily cooperate and share data directly among each other.

3.1 Social Characteristics

Some important social characteristics include social ties, community [31], centrality and bridges.

Ties: The strength of a relationship between two individuals is regarded as social tie. In communication networks, social ties between mobile users are built on the basis of friendship, altruism, colleague-ship, etc. and their strength can greatly influence the system efficiency.

Community: A community is basically group of individuals sharing same interests, social relations/trust, etc. In communication networks, different mobile devices with similar interests, close proximity or strong social ties can form a community resulting in effective data dissemination among users and increased system throughput.

Bridge: A bridge is a connection between two communities that allows information flow between the nodes of respective communities.

Centrality: Centrality refers to the relative importance of a node in a network e.g. in a socially familiar community of users, a cluster head [32] or central user is selected that is further connected to all the devices in that community. Then in this scenario, this central node can easily share content with its members on the basis of social trust.

3.2 Social Meets D2D

The performance of D2D underlaying cellular networks [33] can be monitored via proximity patterns and social behaviors. In this thesis, the challenges encountered in D2D communication have been tackled by exploiting physical domain as well as social domain [34]. In scenarios like conferences, university, offices, disasters, etc. the idea of social awareness can be exploited to enable devices to cooperate and directly communicate with each other. In mobile networks, devices are carried by users that are mostly connected via multiple social media applications like Facebook, Twitter, etc. We can use the social relationships [35] with friends, colleagues, neighbors, etc. and exploit social trust to enable cooperative D2D communication e.g. a trusted user can act as a relay by leveraging social trust and social reciprocity. Therefore, the purpose of this research is to exploit the social ties and construct a D2D connectivity environment by focusing on social interactions and distance constraints.

Social Ties and D2D:

The strength of social ties [36] reflects the degree of trustworthiness between users and users with strong social ties are often expected to contact more frequently and share more data. The links between devices having strong social ties will have higher communication demands and need to be allocated higher spectral resources. Strong social ties can help in solving D2D challenges [37] of peer discovery and resource allocation thereby increasing system throughput, coverage rate and spectral efficiency.

Social Communities and D2D:

D2D underlaying cellular networks can benefit from social communities [38] as they assist in resolving challenges of mode selection, interference management, resource allocation and peer discovery. In networks where devices are socially aware [39], they may have interest in similar data and may want to contact more frequently. In order to assist communication over such links, appropriate resource management is required. Forming social communities is an efficient way to assist in spectrum allocation thus reducing network load, decreasing interference issues and increasing spectral efficiency. For example, in a community of researchers, the users interested in similar topics can easily share files amongst each other directly. In such scenarios, community assisted D2D helps in effective resource allocation thereby increasing system throughput.

Community formation also helps in the peer discovery process of D2D candidates by reducing time and energy which, otherwise, is quite a tedious and energy consuming task due to randomized scanning of beacons. Furthermore, the problem of mode selection can also be effectively resolved by forming social communities. Mode selection requires channel knowledge and network load information which can be easily detected via social communities thus helping in deciding which mode to select. Table 3.1 shows qualitative analysis of socially aware in-band D2D.

3.3 System Model

In this thesis, we consider social aware underlay D2D communication which is projected onto two domains i.e. physical domain and social domain. In D2D underlaying cellular networks, the physical domain caters distances between UEs while social domain incorporates social relationships among devices. The wireless devices, having similar interests, may want to share similar contents directly with each other. Such users, also being in close proximity, strengthen their relationships by forming strong social ties and ultimately by forming social communities. This type of direct communication leads to effective D2D communication resulting in offloading the burden of BS along with enhancing spectral efficiency, coverage and system capacity.

	Ties	**Community**	**Centrality**	**Bridge**
Peer discovery	Beacon rate adjustment	Peer density Encounter patterns	Proactive beacons Communication demands	/
Mode selection	/	Community density Community interests	Cellular preferential Bottleneck detection	Inter-community demands
Resource allocation	Communication demands Security and privacy	Communication oriented sharing Communication demands	Resource demands Bottleneck prediction	Dissemination dominant Bottleneck prediction
Interference management	Relay selection Spectrum allocation	Resource partition Distributed coordination	/	/

Table 3.1 Analysis of social structures in underlay D2D communication [7]

Thus devices which are physically close to each other (at a predefined distance) form direct links and those having strong social ties form social communities in social domain. In physical domain, there are two types of UEs i.e. regular cellular users and D2D users. The CUEs are connected to the BS and are transmitting in uplink in the considered scenario. The devices which are at a particular distance i.e. 5m apart may form D2D link. In order to explain the in-band scenario, we consider that CUEs are allocated channels by the BS and the allocated bandwidth is in turn used by the D2D pairs connected to this CUE. We assume that cellular users are assigned orthogonal resource blocks so that interference in minimum. Our focus is to allocate these resources to the D2D users in a way that results in higher social group utility.

We further assume that a D2D user cannot be sharing more than one cellular user's spectrum at a time however, multiple D2D users can be sharing the radio resources of the same CUE. The spectrum resource usage relationship is explained by a factor $x_{c,d}$ whose value ranges between 0 to 1. If $x_{c,d}$=1, then a D2D user is using the resources of that CUE and if $x_{c,d}$ = 0 then D2D user is not using the resources of that particular CUE.

This spectrum reuse, on one hand, enhances spectral efficiency but on the other hand, leads to severe interference issues. For example, in Figure 3.1, it can be seen that when CUE transmits a signal in uplink then its transmission is interfered by the D2D users which share its spectrum. Similarly, in a D2D link, when a D2D transmitter sends the intended signal to the D2D receiver, then this signal is interfered by two types of interferences. One interference comes from the CUE and the other comes from the D2D links, which share the same spectrum. Thus all user equipments, sharing the same spectrum, will interfere each other. To cater such issues of D2D underlay cellular communication, we introduce the concept of social ties and social communities with the objective to increase overall D2D rate and enhance system coverage and capacity.

Proposed Scenario:

We consider a single cell scenario as shown in figure 3.2 in which radius of cell is assumed to be 500 meters and BS lies at the center of this cell. Then N number of users are randomly deployed in this cell. Some of the users are regular CUEs while some are DUEs having constant transmit powers. The transmitter and receiver of a D2D link are 5m apart. We assume there are C cellular users and D D2D links. In the physical domain, the D2D users can choose the spectral resource of any cellular user c, $\forall c \in C$ where the spectrum usage depends on the factor $x_{c,d}, \forall c \in C \ and \ d \in D$. The indicator $x_{c,d}$ is given by the following constraints:

$$x_{c,d} \in \{0,1\} \forall c \in C, d \in D \quad (3.1)$$

$$\sum_{c \in C} x_{c,d} \leq 1, \forall d \in D \quad (3.2)$$

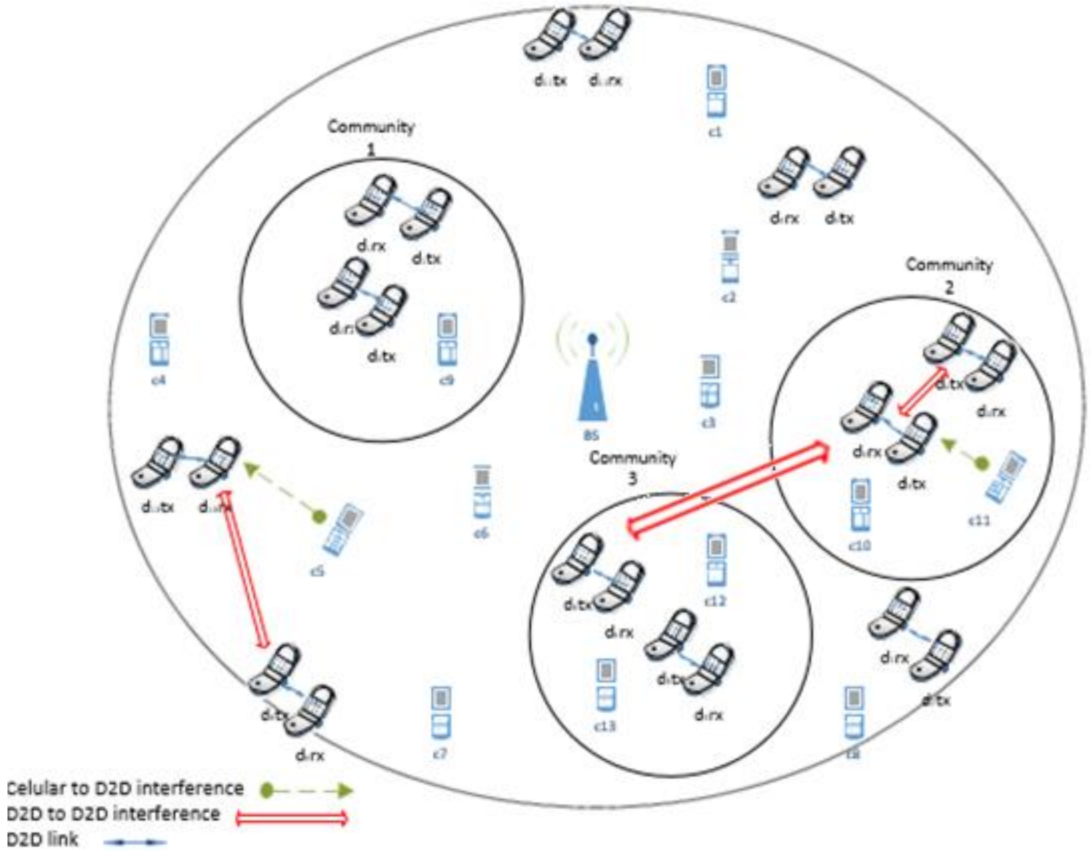

Figure 3.1 Proposed Scenario

The next step is to incorporate user's social behaviors by forming social communities.

Community Formation:

The formation of communities relies on two factors. One is the physical distance between UEs and second is the strength of social ties among them. First there is a random selection of DUE items and then we apply a distance threshold. For a particular DUE *d* (transmitter part), suppose it has set of *K* neighbor D2D links. All the DUE items which satisfy the distance threshold (distance from DUE *d's* transmitter to *K* neighbors' transmitters) will be its potential neighbors. We consider a factor $e_{d,k}\ \forall\ d\ \in D, k\ \in K$ to describe the distance constraint i.e. $e_{d,k}\ = 1$ only if *k* lies in the transmission range of *d.* Next we check the social constraint by first assigning weights to each of the edges between D2D links. For example, in the social domain shown in figure 3.3, edge value of 1 between Alice and Smith represents strong social tie and edge value of 0.5 between Smith and Mike represents a weaker social tie.

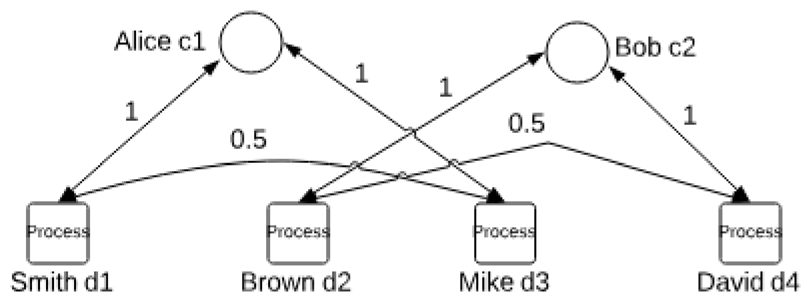

Figure 3.2. Graph showing weights of edges in social domain

In our system model, the weight coefficient $w_{d,k}$ is assigned randomly on the basis of number of neighbors such that the sum of weights is equal to 1. Other factors that may be considered in assigning this weight coefficient are time and interactivity factor.

We can summarize our community formation strategy in two steps:

1. Firstly there is a selection of potential D2D neighbors on basis of distance threshold
2. Secondly the potential D2D neighbors are assigned weights depicting the strength of their social ties. If the weight is below a certain social threshold I then that D2D link is removed from the set of potential neighbors and the remaining D2D links form a community. Here I is the mean of weight coefficients between selected DUE and its neighbors i.e. $\sum_{i=1}^{L} w_{d,k} /L$ where L is the neighbor count.

After the formation of communities, we find the rate of cellular users and D2D users with the goal to optimize D2D rate and overall system coverage. The channel is assumed to be Rayleigh fading channel where $|h_o|^2$ represents the power of the channel. The received power between any two nodes *i* and *j* is given:

$$P_{i,j} = P_i * |h_{i,j}|^2 = P_i * {\zeta_{i,j}}^{-\alpha} * |h_o|^2 \qquad (3.3)$$

Where ζ is the distance between nodes *i* and *j*, α is the path loss exponent, h_o is the complex channel coefficient that follows Gaussian distribution and P_i is the transmitted power. The SINR is given by:

$$p_j = \frac{P_i * \zeta_{i,j}{}^{-\alpha} * |h_o|^2}{P_{int,j} + N_o} \qquad (3.4)$$

where $P_{int,j}$+N_o are the interference power and terminal noise at receiver respectively.

The uplink channel rate of regular cellular user *c* is given by:

$$R_c = \log_2 \left(1 + \frac{P_c * \zeta_{c,b}{}^{-\alpha} * |h_o|^2}{\sum_{d \in D} x_{c,d} * P_d * \zeta_{d,b}{}^{-\alpha} * |h_o|^2 + N_o} \right) \qquad (3.5)$$

where P_c is transmit power of cellular user and $\zeta_{c,b}$ is the distance from cellular user to the BS. In the denominator, $x_{c,d}$ shows spectrum usage indicator, P_d is the transmit power of DUE and $\zeta_{d,b}$ is the distance from interfering D2D transmitter *d* to the BS.

Similarly, the channel rate of D2D user *d* is given by:

$$R_d = \log_2 \left(1 + \frac{P_d * \zeta_{d,d}{}^{-\alpha} * |h_o|^2}{P_{int,d} + N_o} \right) \qquad (3.6)$$

where $\zeta_{d,d}$ is the distance between two DUEs (transmitter and receiver) and $P_{int,d}$ is the interference power received by D2D receiver *d* from the cellular user *c* and other D2D transmitters sharing the same spectrum.

This is represented as follows:

$$P_{int,d} = \sum_{c \in C} x_{c,d} * P_c * \zeta_{c,d}{}^{-\alpha} * |h_o|^2 + \sum_{d\prime \in D \setminus \{d\}} x_{d,d\prime} * P_{d\prime} * \zeta_{d\prime,d}{}^{-\alpha} * |h_o|^2 \qquad (3.7)$$

The first part of summation shows interference from cellular user while second part of summation represents interference from other D2D UEs. In the above equation, $P_{d\prime}$ is the transmit power of other D2D transmitters and $\zeta_{d\prime,d}$ is the distance from other D2D transmitters to current D2D receiver. $x_{d,d\prime}$ indicates the interference among D2D links sharing same resources. If $x_{c,d'} = 1$ and $x_{c,d} = 1$ then $x_{d,d\prime}$=1 otherwise it is equal to zero.

The system sum rate is given by the following equation:

$$\Re = \sum_{c \in C} \left(R_c + \sum_{d \in D} x_{c,d} * R_d \right) \quad (3.8)$$

For our system model, we form non-overlapping communities containing both CUEs and DUEs. We then assign different bandwidths to users inside and outside communities and find D2D rate for all DUEs both inside and outside communities by modifying R_d equation. Here we assume that a DUE within community can share bandwidth from a cellular user of any community. Also, DUEs outside the community can share the spectral resources of any CUE lying outside the community. Finally using game theory we find optimal D2D rates and coverage probability thereby optimizing our results.

3.4 Game Theory

A game is general interaction between two or more people where the outcomes of interaction depend on what everybody does and everybody has different levels of happiness for the different outcomes. The idea of game theory [40] is thought to have initiated by Von Neumann' s paper published in 1928. In this paper he proved the existence of mixed strategy equilibria by focusing on two player zero sum games. In 1944, Neumann wrote a book along with Oskar Morgenstern named *Theory of Games and Economic Behavior*, in which the idea of expected utility theory was introduced proposing that a rational player will always take actions to maximize his utility. This concept was later extended by economists to solve problems dealing with uncertainties. John F. Nash gave the idea of Nash Equilibrium by focusing on non-zero sum games and was awarded a Nobel Prize in Economics in 1994. However, now, game theory finds numerous applications in other disciplines as well like computer science, politics, biology, engineering and philosophy.

Game theory [41] is the study of mathematical models of conflict and cooperation between intelligent rational decision-makers. It helps in decision making processes as it deals with the study of mathematical modeling of situations of conflict or cooperation by predicting how a certain individual will behave in a particular situation.

3.4.1 Fundamental Elements of a Game

There are three basic elements of a game [42], namely *players, strategies and utilities.*

Players:

A player can be regarded as a participant or a decision maker in a game e.g. governments, people, etc. A **rational player** is one who always makes a decision that maximizes his own profit/utility e.g. if strategy 1 gives better profit than strategy 2 then a rational player will take a decision in favor of strategy 1.

Strategies:

Strategies are a set of actions from which a player can select his own choice e.g. while tossing a coin whether to select head or tail, whether to vote in an election or not, etc.

Utilities:

Utility is the payoff/outcome that a player gets on deciding a particular strategy given other player's strategies e.g. a person earning a profit on investing in a stock market.

3.4.2 Representation of Games

Normal Form:

It is also known as strategic/matrix form as the game is represented by a matrix showing the utilities, actions and players. Generally it assumes that players are moving simultaneously and can be represented by a function that maps a player's payoff to all sets of actions. For example, in figure 3.4, a game is shown in normal form where there are two players, each having two strategies. Player 1 can either move up or down. Similarly, player 2 can either move left or right.

Further, there is a payoff associated with each strategy e.g. if player 1 chooses down and player 2 chooses right then player 1 will get a payoff of 3 and player 2 will receive 4.

	Player2 chooses Left	Player2 chooses Right
Player1 chooses up	4,3	-1,-1
Player1 chooses down	0,0	3,4

Figure 3.3 Payoff matrix of a 2-player, 2-strategy game

Extensive Form:

It is mostly used to represent games with time sequencing of player's moves, depicting their decision at every point, the payoffs associated with those decisions and the information a player has about the other player's moves while making a decision e.g. chess, poker, etc. The game is shown as a decision tree where every node represents a point of decision. The lines out of the node specify a player's strategy/move and the utilities are shown at the bottom of the tree.
An extensive form game is shown in figure 3.5 where there are two players: player 1 and player 2. The initial node represents player 1 who can choose between F (fair) and U (unfair). Next the player 2 makes a decision between A or R after watching player 1's move. After this the game terminates and every player gets his respective payoff as shown at the bottom of the tree. Suppose player 1 chooses U then player 2 will make a decision to get the maximum payoff thereby choosing A. At the end, player 1 gets '8' and player 2 gets '2' as payoff.

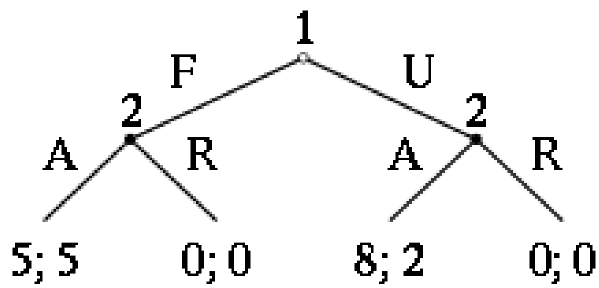

Figure 3.4 An extensive form game

3.4.3 Types of Games

Games are classified into many categories [43], however cooperative and non-cooperative games are the most popular ones.

3.4.3.1 Cooperative Games

Cooperative Games also known as coalitional games [44] focus on groups of agents rather than individuals where the players are externally enforced to form groups and there is a competition between these groups/coalitions to get the maximum payoff. Cooperative game theory [45] is used to analyze such games by predicting which groups will form, what strategies will be played by every group and what will be the resultant utilities.

Definition:

Transferable utility assumes that each coalition receives some value as its payoff and this payoff is divided among the members of that coalition. A coalitional game with transferable utility is a pair (N, v) where N consists of a finite set of players called the grand coalition, and $v: 2^\wedge N \longmapsto \mathbb{R}$ associates with each coalition $S \subseteq N,$ a real valued payoff $v(S)$ that the coalition's members can distribute among themselves.

The game is also called profit game as the function describes how much payoff the players can get by forming a coalition. Cooperative games have a lot of applications e.g. in politics, different political parties can form a coalition to run a government and then divide the payoffs amongst themselves.

Core:

Depending on what the coalition is trying to achieve, a coalition needs to consider how it ought to divide the payoff among its members. The players will prefer a grand coalition if the payment profile is from a set called core.

Definition: Let v be a game. The core of v is the set of payoff vectors

$$C(v) = \{x \in \mathbb{R}^N : \sum_{i \in N} x_i = v(N); \sum_{i \in S} x_i \geq v(S), \forall S \subseteq N\} \quad (3.9)$$

A payoff vector is in core if the sum of payoffs of all the members in the sub-coalition is at least as much as they could earn on their own i.e. there does not exist any coalition where the agents could have gotten better payoff on their own. Thus, there is no incentive to leave the grand coalition otherwise the core will be empty.

3.4.3.2 Non-Cooperative Games

Non cooperative games are those in which there is no forced cooperation among players; the alliances can only be self-enforced and the individual players compete with each other with the purpose to maximize their payoffs. They have wide range of applications particularly in wireless networks where they are used to solve the resource allocation problem. These games are usually defined by Normal and Extensive form. Non-cooperative game theory is used to analyze such games by predicting actions and utilities of individual players and finding Nash Equilibrium.

Nash Equilibrium:

Nash Equilibrium, named after American mathematician John Forbes Nash Jr., is an important concept in game theory and is used in predicting the outcome of strategic interaction of several players by taking into consideration the decision making of others. If every player in a game has chosen its strategy and no player has any incentive to change his current strategy provided the other players' strategies remain unchanged then such a strategy profile constitutes a Nash Equilibrium.

By definition: Let ($\boldsymbol{S}$,U) be a game with n players, where $\boldsymbol{S}$ is the set of strategy profiles and $U(x)$ is its payoff function. Let S_i' be a strategy profile of player i and S_{-i} be a strategy profile of all players except for player i. The payoff depends on the strategy profile chosen, i.e., on the strategy chosen by player i as well as the strategies chosen by all the other players. A strategy profile $S^* \in \boldsymbol{S}$ is a Nash equilibrium (NE) if no unilateral deviation in strategy by any single player is profitable for that player, that is

$$\{U_i(S_i^*, S_{-i}^*) \geq U_i(S_i', S_{-i}^*) \forall S_i' \in \boldsymbol{S}_i, \forall i \in N\} \quad (3.10)$$

Prisoner's Dilemma:

Prisoner's Dilemma was developed by Albert Tucker and is the most popular example of non-cooperative games. The game as shown in figure 3.6 involves:

Players: Two prisoners kept in separate rooms and unable to communicate with each other
Strategies: Both can choose either to cooperate or defect.
Payoffs: U1= [-1,-3,0,-2]   and U2= [-1, 0, -3,-2]

It is assumed that players are rational and will act to maximize their payoffs. According to the figure, if both prisoners cooperate then each will serve one year in prison. However, if A chooses to cooperate and B chooses to defect then A will serve three years and B will go free. As going free is better than serving one year, therefore, player B's best response to player A's action is to defect (betray). Similarly, if A chooses to defect then player B serves three years on cooperating but 2 years on defecting. So again player B's best response to A's action is to defect. By similar pattern, if B defects then A should also defect and if B chooses to cooperate then again A's best response will be to defect. Thus, choosing to defect is the best response and results in a better payoff, no matter what the other player decides. Defect can be regarded as the dominant strategy and is the Nash Equilibrium of this game. The game is a dilemma in the sense that cooperation by both players results in one year of imprisonment however it does not give a rational outcome.

Prisoner A \ Prisoner B	Prisoner B stays silent (*cooperates*)	Prisoner B betrays (*defects*)
Prisoner A stays silent (*cooperates*)	Each serves 1 year	Prisoner A: 3 years Prisoner B: goes free
Prisoner A betrays (*defects*)	Prisoner A: goes free Prisoner B: 3 years	Each serves 2 years

Figure 3.5. Matrix form of prisoner's dilemma

CHAPTER 4

4 EXPERIMENTS AND RESULTS

In this chapter we analyze the results of our proposed model through various simulations. The system model is implemented by varying number of users in a single cell. All the analysis is done in MATLAB R2014a by varying different simulation parameters like cell radius, path loss exponent, number of communities, etc.

We consider a single cell scenario with 500 meter radius and BS at its center as shown in figure 4.1.

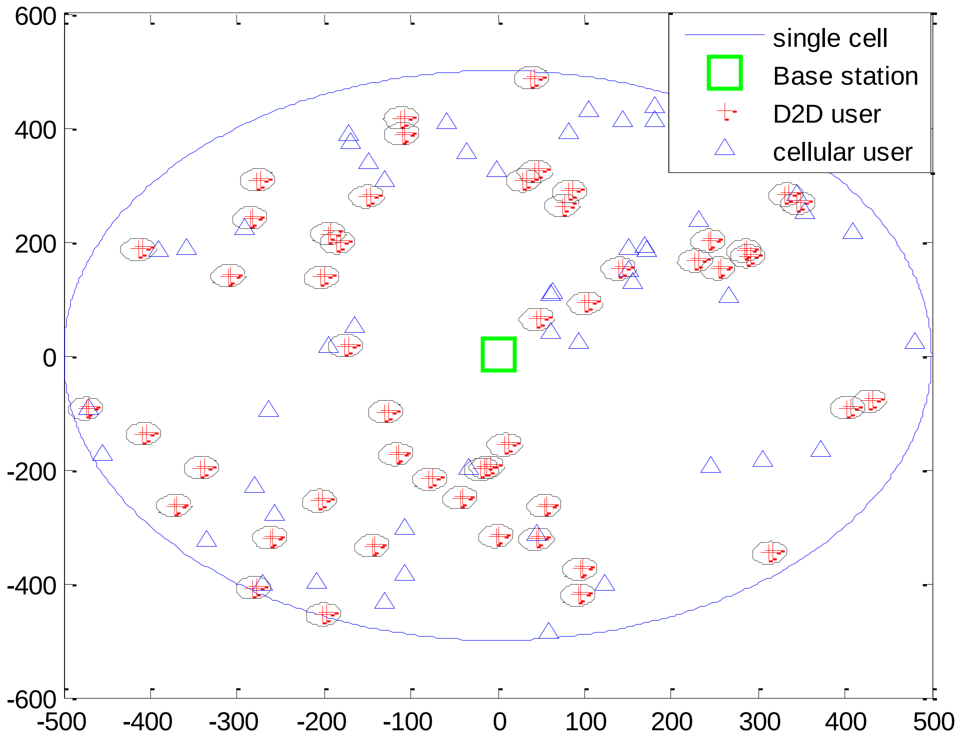

Figure 4.1. Single cell scenario with BS at center, CUE=50 and DUE=50

Initially number of D2D and cellular users are assumed to be 50 each. The simulation parameters are described in Table 4.1.

Parameter	Value
Cellular layout	Isolated cell, 500 m coverage
D2D and cellular user distribution	Random and distributed
Community radius	90 m
Distance between D2D transmitter and receiver	5 m
Path loss exponent	2
Noise power spectral density	-174 dBm/Hz
D2D transmit power	10 dBm
CU transmit power	23 dBm

Table 4.1 Simulation Parameters

Next we select potential DUEs for the formation of communities. As the community radius is considered to be 90 meter therefore for non-overlapping communities, we take the potential DUEs that are 90 meter apart. Next we find all the distances i.e. distances of CUEs from BS, distances of D2D transmitters from CUEs, distances of CUEs from D2D receivers and distances of D2D transmitters from other D2D receivers. The UEs that lie within the threshold distance and also conform to the social threshold become part of a community. We then divide the 180 kHz bandwidth between DUEs within community and those outside the community and then find the D2D rate.

When number of communities is 3:

In the simulation, we keep the D2D density fixed i.e. 50 and with the number of communities equal to 3 and parameters shown in the table 4.1, we vary the bandwidth between community and non-community users. Figure 4.2 shows this scenario and figure 4.3 shows the corresponding D2D rate.

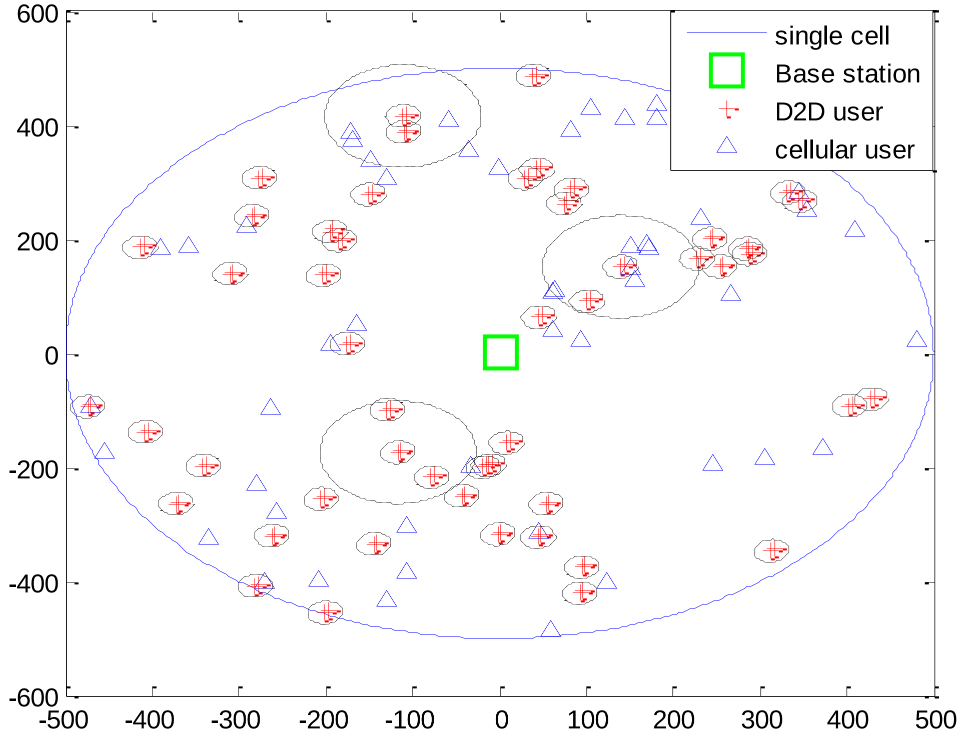

Figure 4.2. Scenario for cell radius=500m and no of communities=3

It can be seen in figure 4.2 that as the number of communities is only 3, therefore, there are only a few D2D users that are lying within the communities. As a result, it can be seen in figure 4.3 that D2D rate of community users is increasing at a very slow rate even though the bandwidth assigned is increasing. On the other hand, the rate of non-community D2D users is highest when full bandwidth is assigned to them but keeps on decreasing as assigned bandwidth decreases. The total D2D rate is decreasing overall as more DUEs are out of community. Moreover, D2D rate is more when higher bandwidth is assigned to non-community D2D users. The point of intersection in the figure highlights the point where at a particular bandwidth, the rate of both community and non-community D2D users becomes the same.

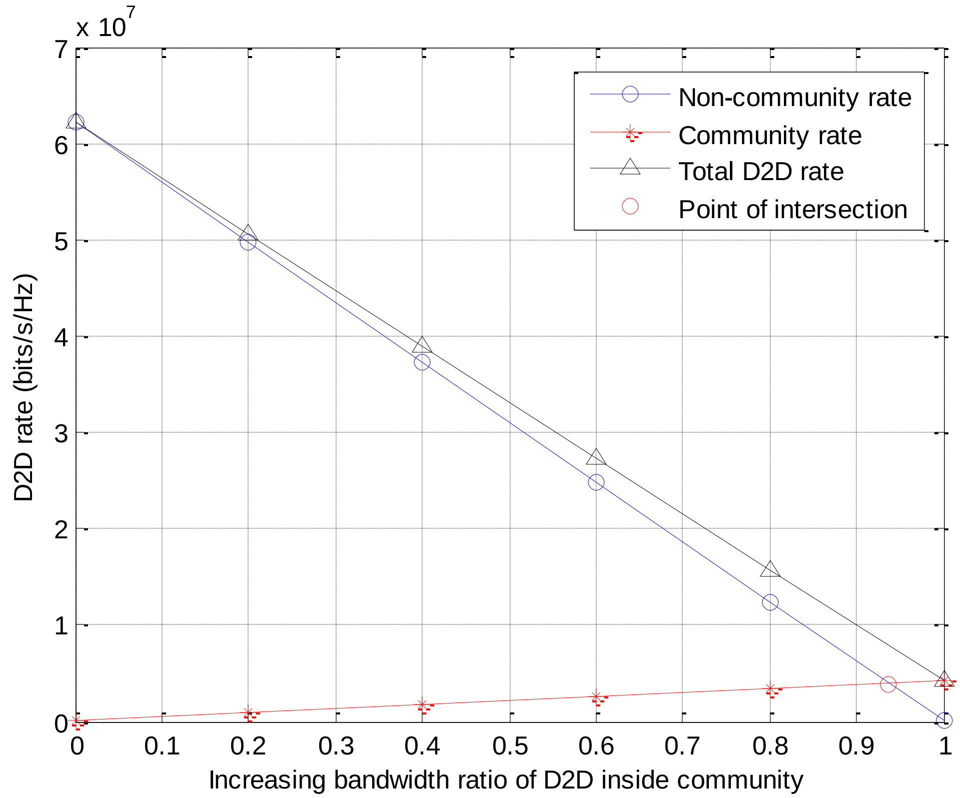

Figure 4.3. Community, non-community and total D2D rate when no of communities is 3

The area besides this point reflects a greedy approach however at the point of intersection, we get a fairness point where bandwidth division is optimal such that both community and non-community DUEs get the same rate.

As we increase the number of communities, the point of intersection keeps on moving to the left side reflecting the optimal division of bandwidth as more DUEs become part of the communities thus contributing to higher D2D rate. This is illustrated in figure 4.4 that shows the comparison when number of communities is three versus the case when number of communities is twelve.

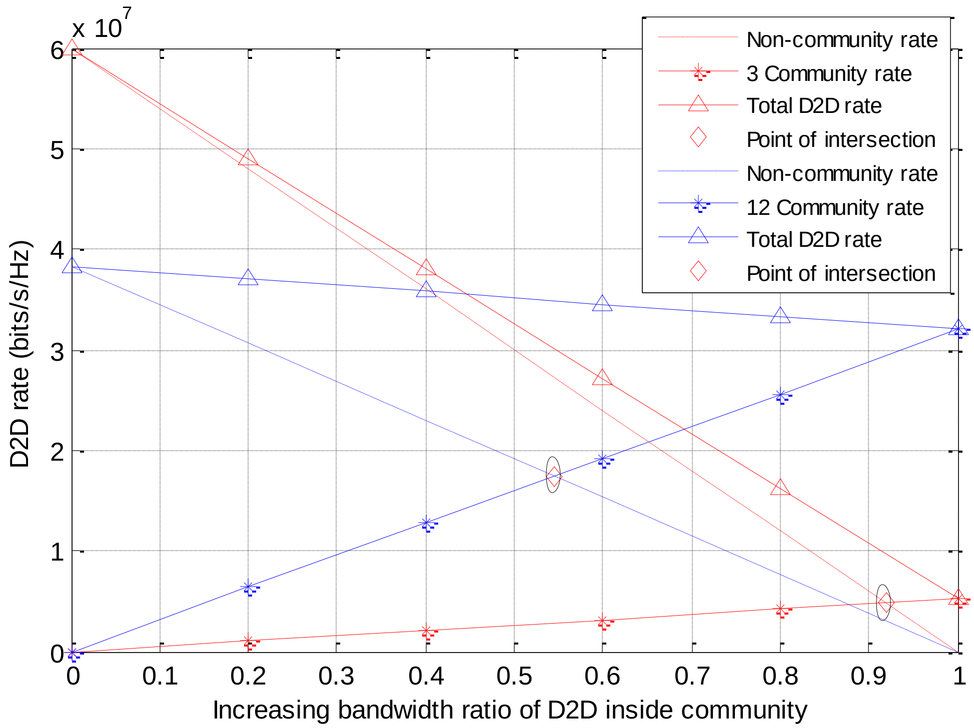

Figure 4.4 Comparison of D2D rate when no of communities is 3 versus 12

The results indicate that as we increase the number of communities, the rate of community DUEs and the total D2D rate also increases with increase in bandwidth of community users. The point of intersection i.e. the point at which community and non-community users have the same rate shifts from extreme right to left side indicating that when number of communities is less, total D2D rate value is decreasing, however, when number of communities increases, rate of community DUEs increases ultimately increasing the total D2D rate. Here the point of intersection moves from 0.91 to 0.54 showing that when number of communities is equal to twelve, then the same rate (community as well non-community) is achieved when optimal bandwidth division between community and non-community users is almost 54% and 46% respectively. Moreover, total D2D rate value is higher when more bandwidth is assigned to community users.

Figure 4.5 shows that as the number of communities increase gradually from three to eleven, the total D2D rate increases correspondingly. This is because as communities increase, more CUEs and DUEs become part of the communities and the bandwidth division is such that overall rate increases.

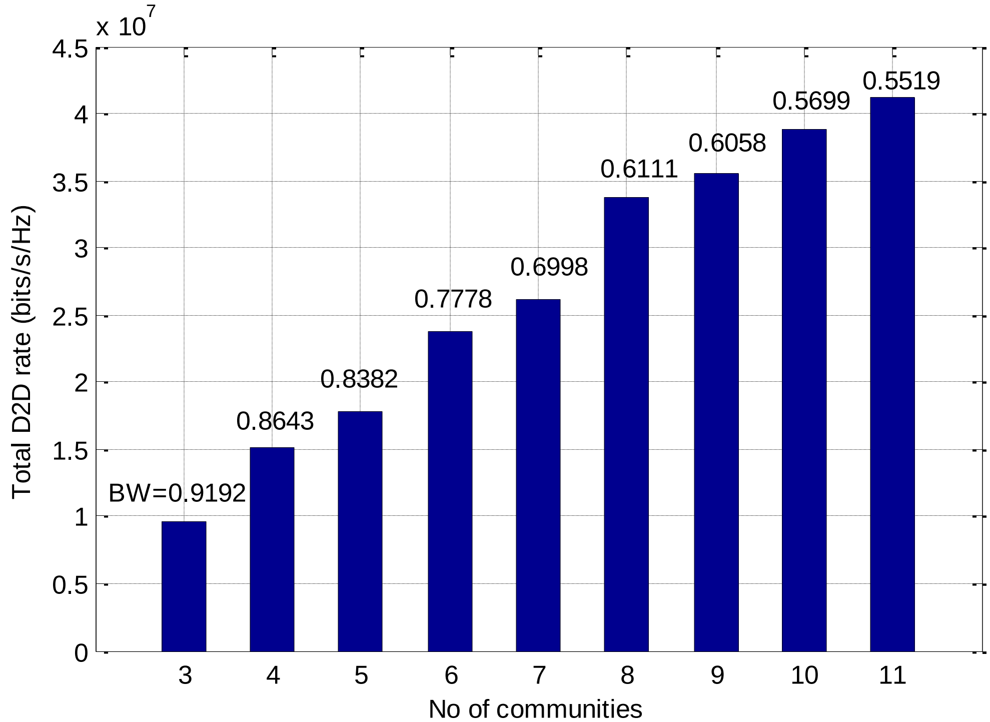

Figure 4.5 Graph showing increase in total D2D rate as communities vary from 3 to 11

Varying Path loss exponent:

The reduction in power density or attenuation in the signal of an electromagnetic wave is termed as path loss. In wireless communication, the path loss maybe due to refraction, diffraction, absorption effects and depends on factors like distance between transmitter and receiver, environment (rural or urban), etc. The term is usually represented by path loss exponent whose value ranges from 2 to 4. Path loss is usually given by:

$$L = 10 * n * \log_{10}(d) + C$$

C is a constant, d is the distance, n is the path loss exponent and L is the path loss measured in decibels. In our work, we keep the cell radius equal to 500 m and simulation parameters as given by table 4.1 and vary the path loss exponent β from 2 to 3 and compare the results. It can be seen in figure 4.6 that as the value of β changes from 2 to 3, then, for a particular number of communities, the data rate for DUEs decreases comparatively. For example, when the number of communities is 4, then D2D rate for $\beta = 3$ is almost half to that of $\beta = 2$. This is because SINR decreases with increase in value of β however, for a particular value of β, say 3, the overall trend shows that D2D rate increases with increase in number of communities.

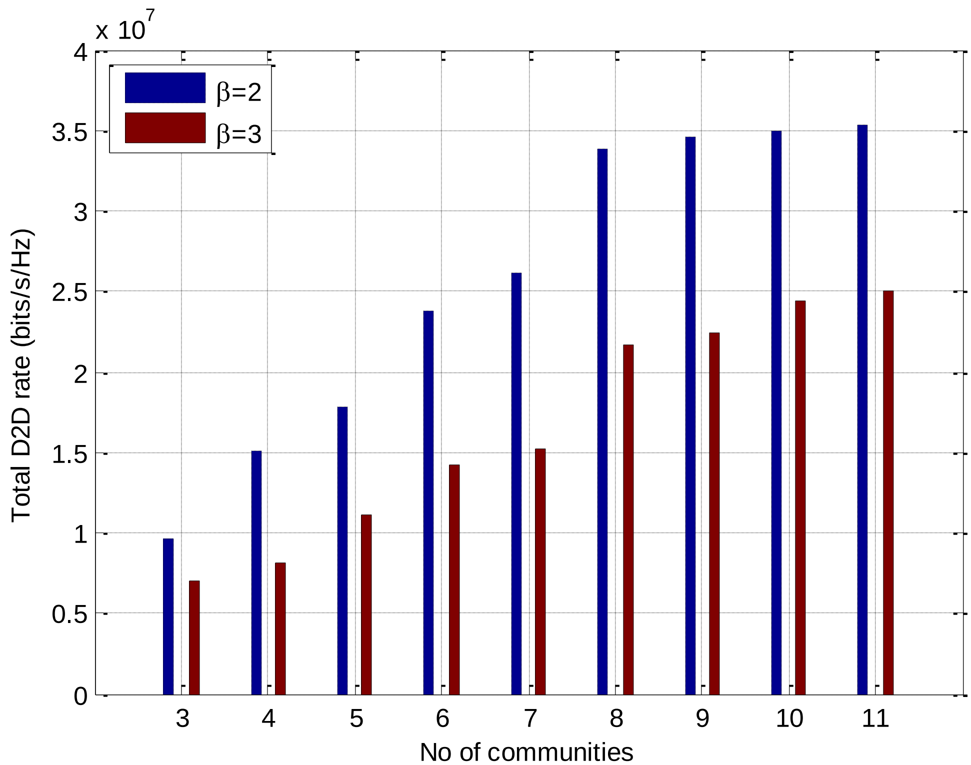

Figure 4.6 Comparing D2D rate for $\beta = 2$ versus $\beta = 3$

Rural versus Urban Scenario:

In the proposed scenario, the D2D density is kept to 50 and CUEs are also 50 in number in a 500 meter cell radius. However, if we consider the urban cell scenario and vary the cellular users and D2D density to 250 in a 1000 meter cell radius as shown in figure 4.7 then due to increase in number of UEs, there will be multipath effect and significant propagation path losses ultimately leading to a decrease in signal strength and D2D rate. Figure 4.7 also depicts the case where there are three communities in the cell showing that as compared to the cell with 500 meter radius that can accommodate around 13 communities, this cell can accommodate around 26 communities i.e. more the cell radius, more the number of non-overlapping communities.

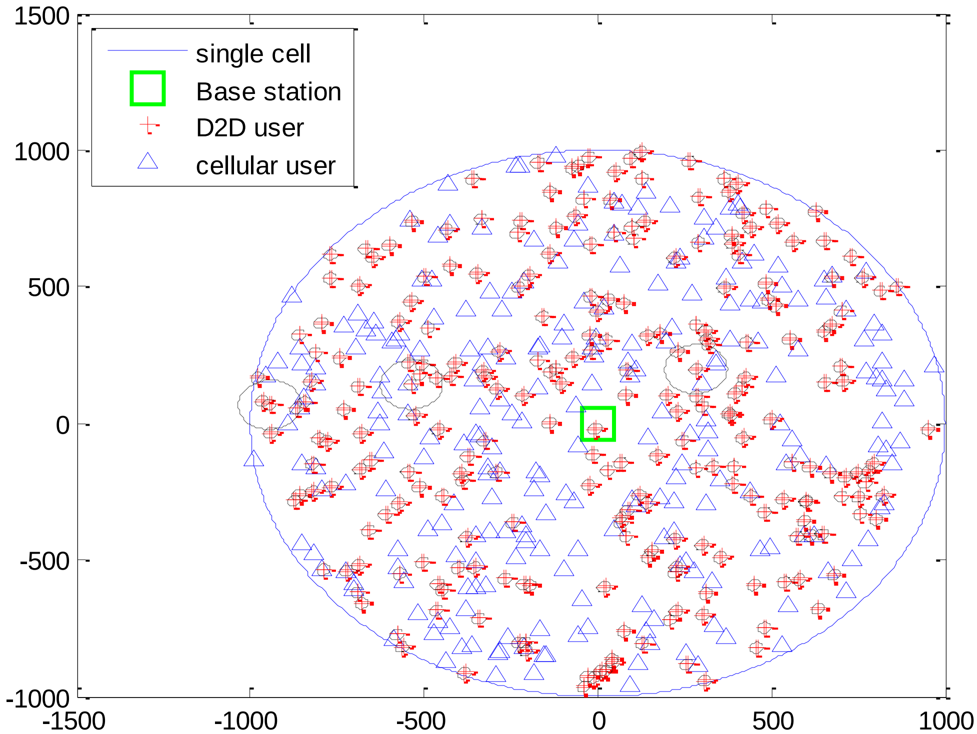

Figure 4.7 Scenario for cell radius=1000m and no of communities=3

From figure 4.8, it is evident that with the simulation parameters shown in table 4.1, cell radius 1000 m, D2D density equal to 250, β=2 and number of communities=3, D2D rate of community users does not increase significantly with increase in assigned bandwidth as compared to rural cell scenario. As more users are out of community, therefore they result in decrease of overall D2D rate because lesser bandwidth is assigned to them gradually. We can see that lines for total D2D rate and rate of non-community users overlap because the contribution to total D2D rate by community users is almost minimal. To improve this, we increase the number of communities and see further results.

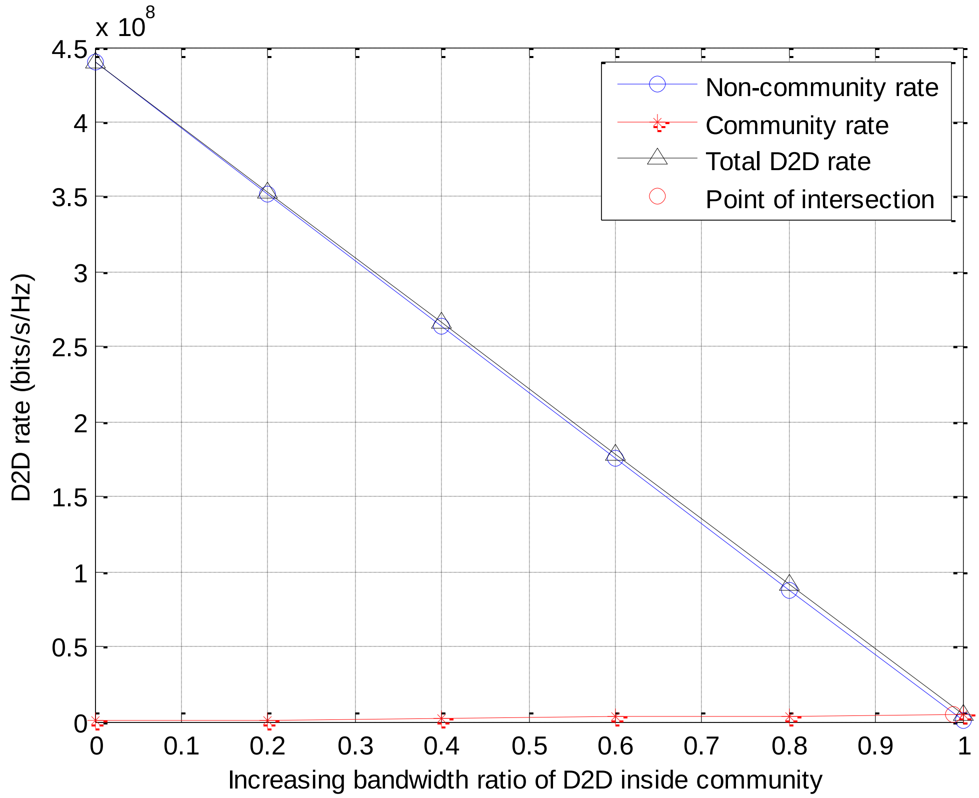

Figure 4.8 D2D rate when cell radius=1000m, $\beta = 2$, DUE=250, No of communities=3

In the 1000 m cell radius with 250 users, if we increase the number of communities from 3 to 25, the rate of community users increases and ultimately total D2D rate also increases as shown in figure 4.9. The point of intersection also moves to the left showing the optimal bandwidth division between community and non-community users to be around 73% and 27% respectively. Moreover, when compared to the rural cell scenario, the achieved D2D rate is also greater for the same number of communities.

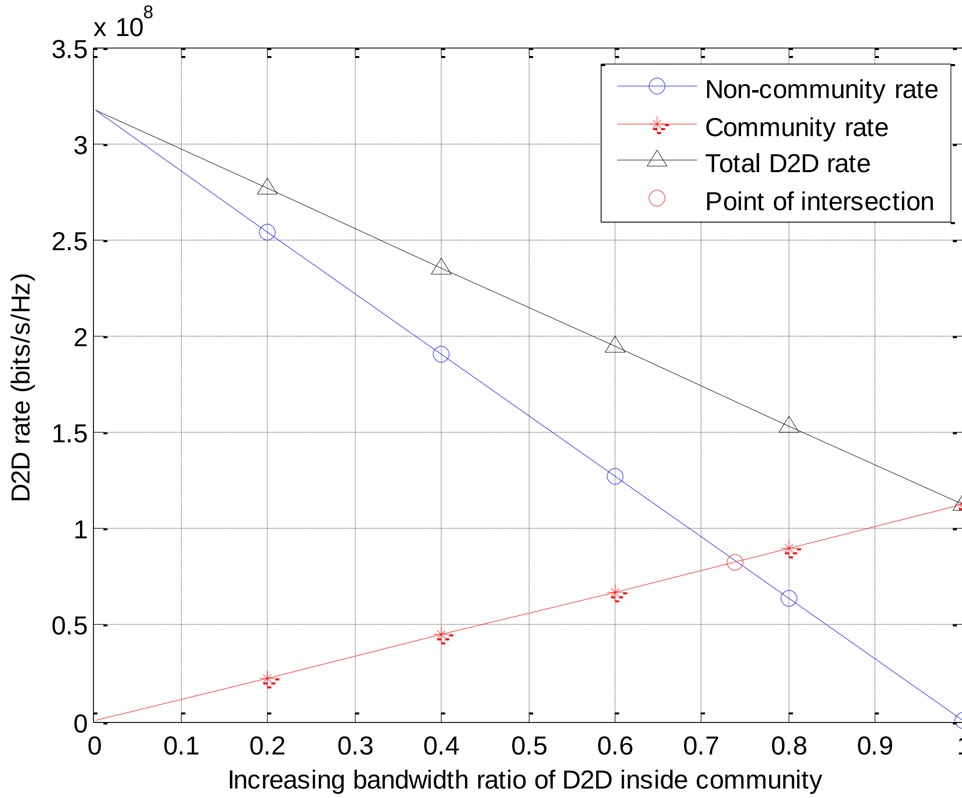

Figure 4.9 D2D rate when cell radius=1000m, $\beta = 2$, DUE=250, No of communities=25

Analyzing the D2D rates for cell radius 1000 m by varying the number of communities from 3 to 11, figure 4.10 shows increase in D2D rate with increase in community number.

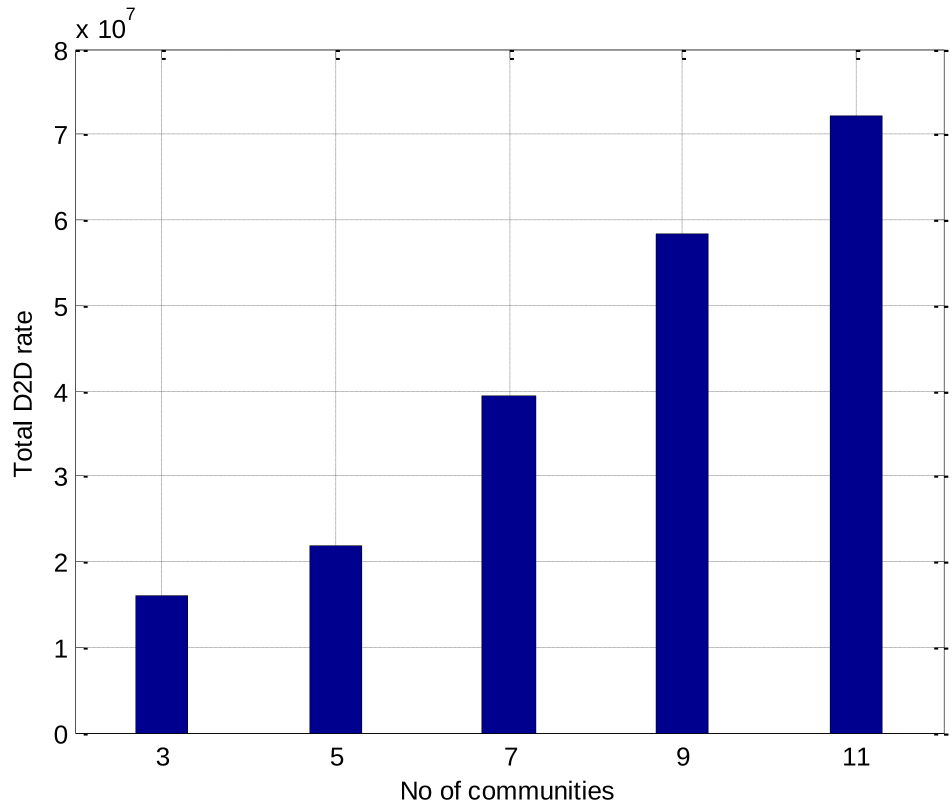

Figure 4.10. Effect of community number on D2D rate (Cell radius=1000, $\beta = 2$, DUE=250)

We now compare the results when cell radius is varied from 500 to 1000 meter and D2D density is increased from 50 to 250. Figure 4.11 shows that for the two mentioned scenarios, the D2D rates significantly rise as we vary the community number. Moreover, for a particular community number, say 9, D2D rate for 1000 m radius is almost double to that of 500 m radius.

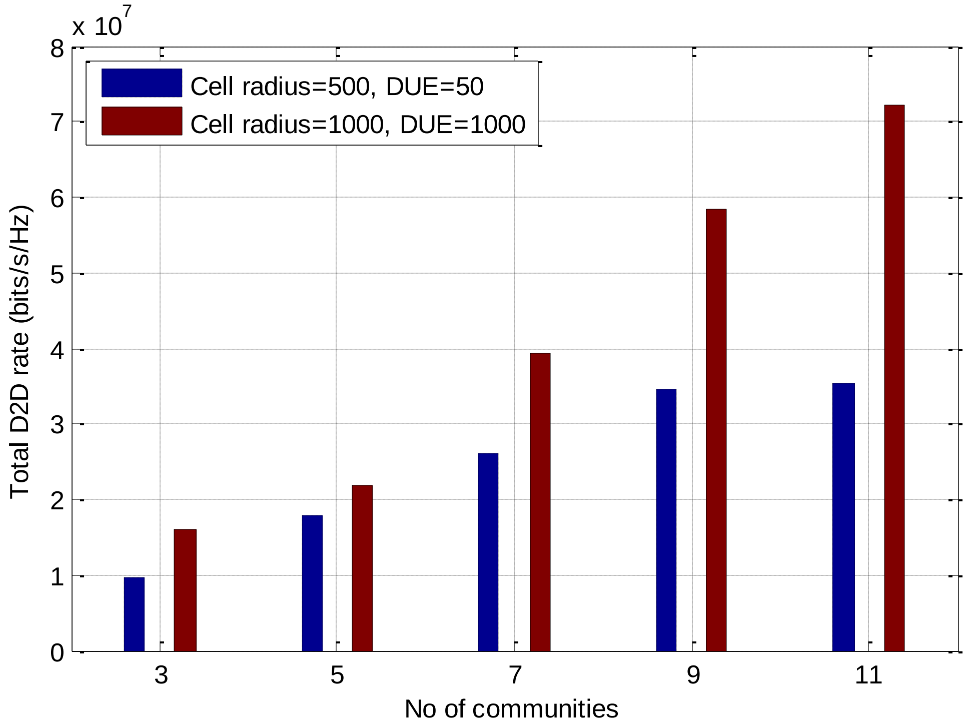

Figure 4.11 Comparison of D2D rates for different cell radii and D2D densities

Coverage probability:

Next we analyze the coverage rate for various cell radii and number of communities.

When Beta=2, cell radius= 500 m, DUE=50

Number of communities=3

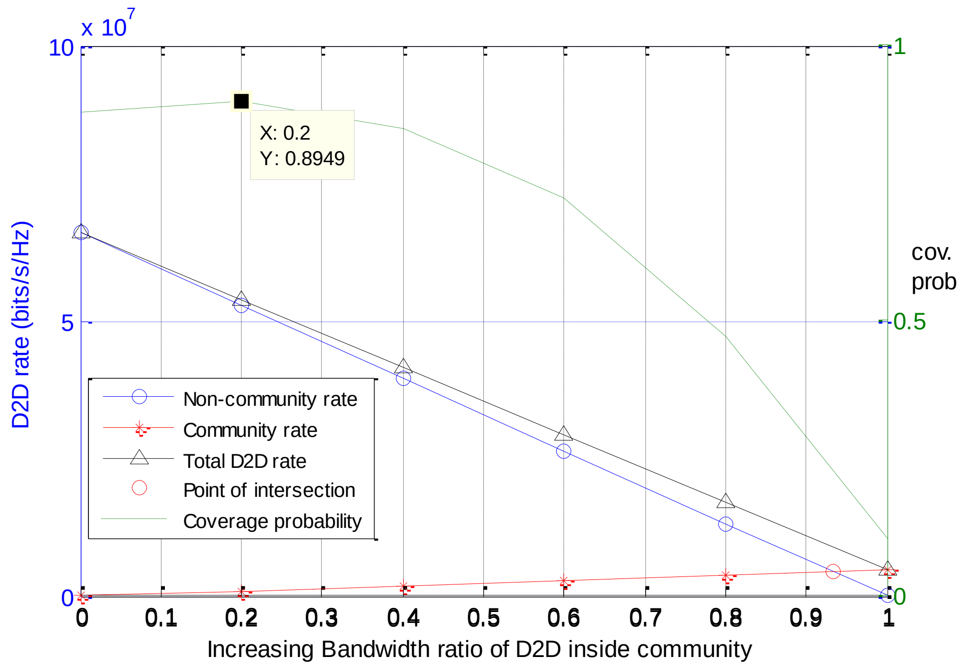

Figure 4.12 Coverage probability for DUE=50, no of communities=3

Number of communities=7

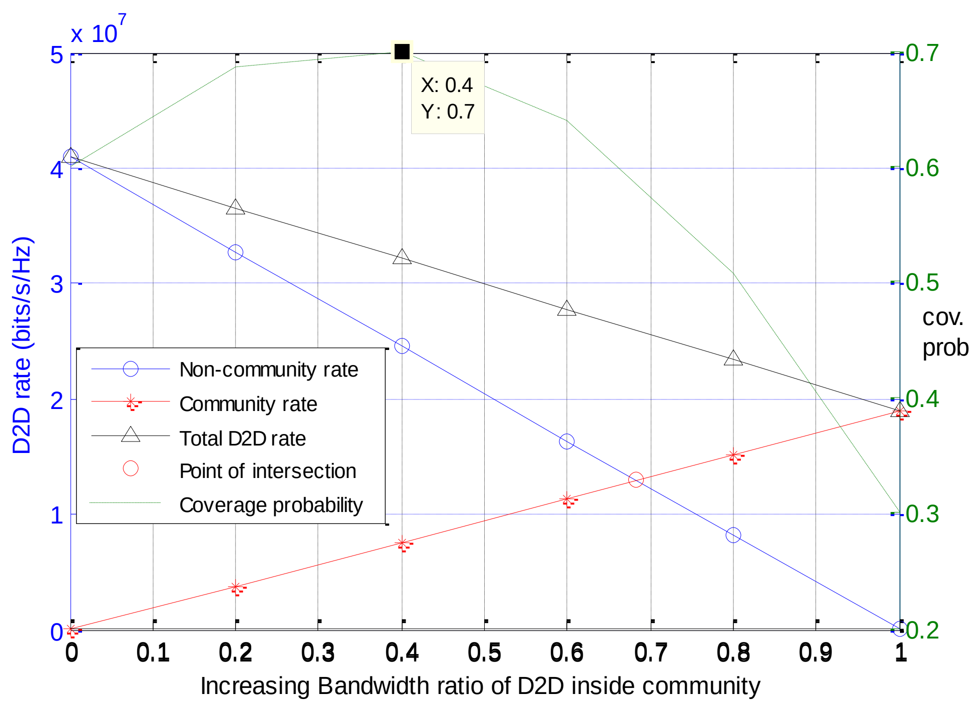

Figure 4.13 Coverage probability for DUE=50, no of communities=7

Number of communities=11

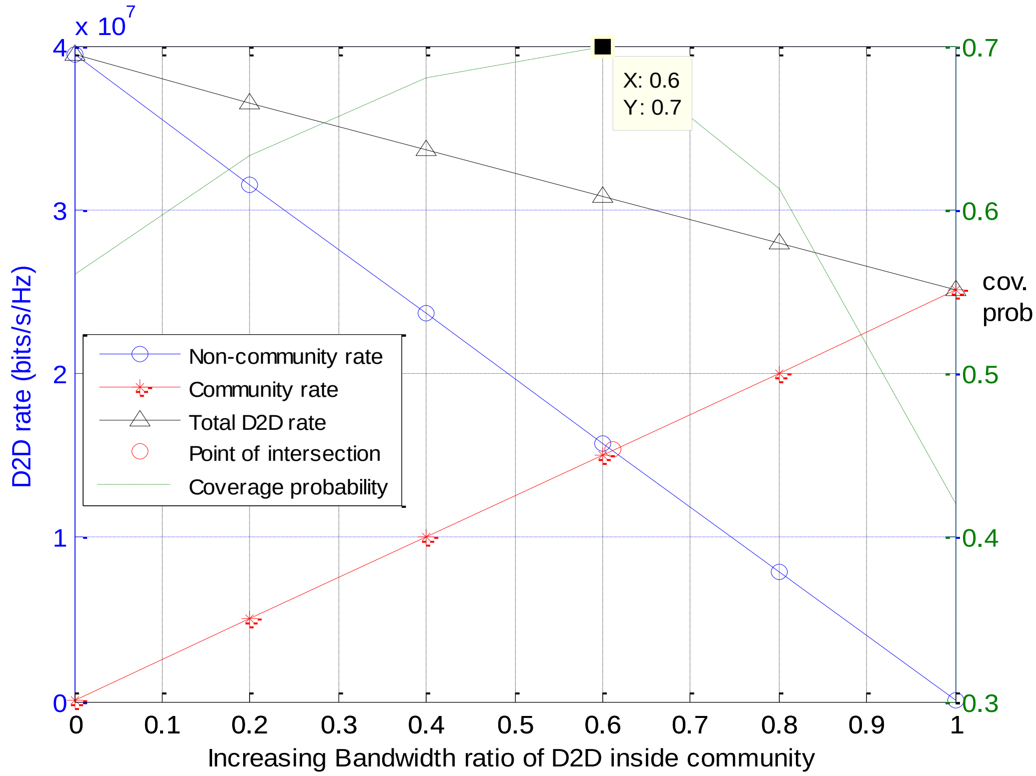

Figure 4.14 Coverage probability for DUE=50, no of communities=11

Figures 4.12, 4.13 and 4.14 show the coverage probability for the cases when DUE=50 and number of communities are 3, 7 and 11 respectively. As number of communities is increased, more DUEs items become part of the communities and thus require greater bandwidth. The graphs of coverage probability indicate that point of maximum coverage shifts thereby changing the bandwidth ratio assigned to community versus non-community members. Fair bandwidth division requires that more the communities, more the bandwidth assigned to community users.

Next we analyze the results when we plot the ergodic rate.

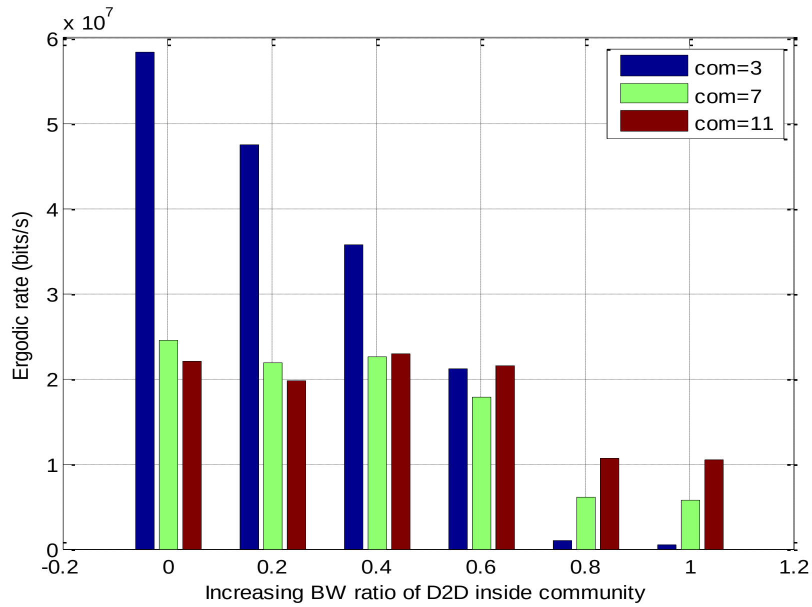

Figure 4.15 Ergodic rate when no of communities is 3,7 and 11

From figure 4.15, it can be seen that as we increase the BW ratio of community DUEs, then for a particular no of communities, ergodic rate decreases.

Moreover, the point of fair division i.e. the point where all communities have almost same ergodic rate lies around center of x-axis thus highlighting the bandwidth division among community and non-community members.

CHAPTER 5

5 CONCLUSION AND FUTURE WORK

5.1 Conclusion

Rapid advancement in modern communication systems has led to an increase in the demand of higher data rates. Device to device communication is an emerging paradigm of 5G that can help in solving this issue by providing direct connectivity between devices. Besides this, it also provides better coverage, spectral efficiency and lower latency.

D2D communication underlaying cellular networks is a type of D2D in which devices share the spectrum resources of regular cellular users thus enhancing spectral efficiency. However it also offers many challenges such as resource allocation, mode selection, interference management, etc. We know that mobile devices are carried by human beings and those having strong social relationships tend to have higher trust and thus are able to contact more easily and frequently to exchange data. The aim of the research is to exploit social characteristics like social ties and social communities to enhance D2D communication.

In the proposed approach D2D underlay cellular communication is projected onto two domains i.e. physical and social domain. The physical domain determines the distances between devices to ensure which devices are in close proximity. The social domain determines the nature of social ties between devices. If the devices are sufficiently close and are socially aware then this integration with social domain can lead to formation of social communities.

The proposed technique simulation results show that the proposed system model leads to enhanced coverage rate and optimal bandwidth division thus enhancing spectral efficiency.

5.2 Future Work

In our system model, we have proposed a single cell scenario whereas in future, we can extend this idea to multiple cells. As social mobile networks continue to grow, we can exploit the idea of social D2D paradigm further to solve other challenges of D2D like peer discovery as well as power control resulting in energy efficient communications. However, as mobile networks continue to grow, security issues in D2D underlay cellular networks also arise which need to be catered as well because mostly the transmissions occur directly between devices without the involvement of core network. In such scenarios, the social domain can be exploited to enable faster and trustworthy communication between devices. In ultra-dense networks, when in-band D2D communication occurs, there is a high probability of jamming attack over direct links thereby creating a hurdle in information exchange. Other security risks include spoofing, eavesdropping and denial of service attack. In this regard, the idea of forming social coalitions based on game theory can be exploited in D2D networks to ensure secrecy and physical layer security.

Further, in this thesis, we have worked with D2D communication underlaying cellular networks considering the uplink scenario. We can extend the proposed model to downlink scenario as well to aid resource management and increase coverage rate. The idea of frequency reuse can be exploited along with social characteristics to help in resolving interference and resource allocation issues. For example, in reverse frequency allocation the cell is divided into multiple regions like macro-cell and femto-cell and each region is assigned frequency in such a way that helps in avoiding interference issues and assigning spectrum efficiently. Similarly, we can extend the idea in both link and downlink transmission of our proposed model such that if one social community uses one frequency band in uplink then another community can use the same frequency band in downlink thereby limiting interference and enhancing spectral efficiency.

REFERENCES

1. Pimmy Gandotra et al. “A survey on Device to Device communication: Architecture and security issues”, Journal of Network and Computer Applications, 2016.
2. U. N. Kar and D. K. Sanyal, “An overview of device-to-device communication in cellular networks,” *ICT Express*, 2017.
3. S. Hakola, T. Chen, "Device-to-Device Communication in Cellular Network-Performance Analysis of Optimum and Practical Communication Mode selection," WCNC 2010.
4. S. A. R. Naqvi, H. Pervaiz, S. A. Hassan, L. Musavian, Q. Ni, M. A. Imran, X. Ge, R. Tafazolli, “Energy-Aware Radio Resource Management in D2D-Enabled Multi-Tier HetNets”, *IEEE Access*, vol. 6, pp. 16610-6622, March 2018.
5. K. Doppler, M. Rinne, C. Wijting, C. Ribeiro, and K. Hugl, “Device-to-device communication as an underlay to LTE-advanced networks,” IEEE Commun. Mag., vol. 47, no. 12, pp. 42–49, Dec. 2009.
6. Mach, Pavel, Becvar, Zdenek, Vanek, Tomas, 2015. “In-band device-to-device communication in OFDMA cellular networks: a survey and challenges”. *IEEE Commun. Surv. Tutor.* 17.4, 1885–1922.
7. Y. Li, T. Wu, P. Hui, D. Jin, and S. Chen, “Social-aware D2D communications: Qualitative insights and quantitative analysis,” *IEEE Commun. Mag*., vol. 52, no. 6, pp. 150–158, Jun. 2014.
8. F. Baccelli et al., “On the design of device-to-device autonomous discovery,” in *Proc. 4th Int. Conf.* COMSNETS, 2012, pp. 1–9.
9. G. Fodor et al., “Design aspects of network assisted device-to-device communications,” IEEE Commun. Mag., vol. 50, no. 3, pp. 170–177, Mar. 2012.
10. R. I. Ansari, S. A. Hassan, C. Chrysostomou, "RANC: Relay-Aided Network-Coded D2D Network", *IEEE International Conference on Information, Communications and Signal Processing (ICICS),* Dec, 2015, Singapore.
11. F. Malandrino, C. Casetti, C. F. Chiasserini, and Z. Limani, “Uplink and downlink resource allocation in D2D-enabled heterogeneous networks,” in Proc. IEEE WCNC Workshop, Apr. 2014, pp. 87–92.

12. R. I. Ansari, C. Chrysostomou, S. A. Hassan, M. Guizani, S. Mumtaz, J. Rodrigues , “5G D2D Networks: Techniques, Challenges, and Future Prospects”, *IEEE Systems Journal*, Vol. to appear, Jan, 2018.

13. Jänis, Pekka, et al. "Interference-avoiding MIMO schemes for device-to-device radio underlaying cellular networks." *Personal, Indoor and Mobile Radio Communications*, 2009 IEEE 20th International Symposium on. IEEE, 2009.

14. Shin, Wonjae, Kyung Hun Jang, Hyun-Ho Choi, 2013. “Device-to-device communication assisted interference mitigation for next generation cellular networks”. In: Proceedings of the 2013 IEEE International Conference on Consumer Electronics (ICCE).

15. Halperin, Daniel, et al., “ Interference Cancellation: Better Receivers for a New Wireless MAC”. 2007.

16. U. Saleem, S. Janghser, H. K. Qureshi, S. A. Hassan, “Joint Subcarrier and Power Allocation in Energy Harvesting-aided D2D Communication”, *IEEE Transactions on Industrial Informatics*, to appear, pp. , Jan, 2018.

17. R. Zhang, X. Cheng, L. Yang, and B. Jiao, “Interference-aware graph based resource sharing for device-to-device communications underlaying cellular networks,” in *Proceedings of IEEE WCNC*, 2013, pp. 140–145.

18. C. Xu *et al.*, “Efficiency resource allocation for device-to-device underlay communication systems: A reverse iterative combinatorial auction based approach,” *IEEE J. Sel. Areas Commun.*, vol. 31, no. 9, pp. 348–358, Sep. 2013.

19. P. Janis, V. Koivunen, C. Ribeiro, J. Korhonen, K. Doppler, and K. Hugl, “Interference-aware resource allocation for device-to-device radio underlaying cellular networks,” in *Proceedings of IEEE VTC Spring*, 2009, pp. 1–5.

20. Y. Li, D. Jin, J. Yuan, and Z. Han, “Coalitional games for resource allocation in the device-to-device uplink underlaying cellular networks,” *IEEE Trans. Wireless Commun.*, vol. 13, no. 7, pp. 3965–3977, Jul. 2014.

21. Y. Li, S. Su, and S. Chen, “Social-aware resource allocation for device-to-device communications underlaying cellular networks,” *IEEE Wireless Communications Letters,* vol. 4, no. 3, pp. 293–296, June 2015.

22. Y. Zhao, Y. Li, Y.Cao, T. Jiang, and N.Ge, "Social-aware resource allocation for device to-device communications underlaying cellular networks," *IEEE Transactions on Wireless Communications*, vol. 14, no. 12, pp. 6621–6634, Dec. 2015.
23. F.Wang *et al.*, "Social Community Aware Resource Allocation for D2D Communications Underlaying Cellular Networks," *IEEE Trans. Vehic. Technol.*, in press, May 2016.
24. Jiang, F., et al., "Energy-Efficient Multicast Transmission for Underlay Device-to-Device Communications: A Social-Aware Perspective", Mobile Information Systems, 2017.
25. Feng, Z., Z. Feng, and T.A. Gulliver, "Effective Small Social Community Aware D2D Resource Allocation Underlaying Cellular Networks", IEEE Wireless Communications Letters, **6**(6): p. 822-825, 2017.
26. K. C. Chen, M. Chiang, and H. V. Poor, "From technological networks to social networks," *IEEE J. Sel. Areas Commun.*, vol. 31, no. 9, pp. 548–572, Oct. 2013.
27. P. Hui et al., "Selfishness, altruism and message spreading in mobile social networks," in Proc. IEEE INFOCOM Workshops, Apr. 2009, pp. 1–6.
28. Z. Zheng, T. Wang, L. Song, Z. Han, and J. Wu, "Social-aware multi-file dissemination in device-to-device overlay networks," in *Proc.INFOCOM WKSHPS*, Toronto, ON, Canada, Apr. 2014, pp. 219–220.
29. A. Ometov *et al.*, "Toward trusted, social-aware D2D connectivity: Bridging across the technology and sociality realms," *IEEE Wireless Commun. Mag.*, vol. 23, no. 4, pp. 103–111, Aug. 2016.
30. X. Chen, B. Proulx, X. Gong, and J. Zhang, "Social trust and social reciprocity based cooperative D2D communications," in *Proc. MobiHoc*, Bangalore, India, Aug. 2013, pp. 187–196.
31. G. Palla, I. Derényi, I. Farkas, and T. Vicsek, "Uncovering the overlapping community structure of complex networks in nature and society," Nature, vol. 435, no. 7043, pp. 814–818, Jun. 2005.
32. B. Peng, T. Peng, Z. Liu, Y. Yang, and C. Hu, "Cluster-based multicast transmission for device-to-device (D2D) communication," in *Proceedings of the IEEE 78th Vehicular Technology Conference (VTC Fall '13)*, pp. 1–5, Las Vegas, Nev, USA, September 2013.
33. Y. Cao, X. Chen, T. Jiang, and J. Zhang, "So Cast: Social ties based cooperative video multicast," in *Proc. INFOCOM*, Toronto, ON, Canada, Apr. 2014, pp. 415–423.

34. X. Wang, M. Chen, T. T. Kwon, L. Jin, and V. C. Leung, “Mobile traffic offloading by exploiting social network services and leveraging opportunistic device-to-device sharing,” *IEEE Wireless Commun.*, vol. 21,no. 3, pp. 28–36, Jun. 2014.
35. Y. Zhang, L. Song, W. Saad, Z. Dawy, and H. Zhu, “Exploring social ties for enhanced device-to-device communications in wireless networks,” in Proc. IEEE Globecom, Dec. 2013, pp. 4597–4602.
36. X. Chen, B. Proulx, X. Gong, and J. Zhang, “Exploiting social ties for cooperative D2D communications: a mobile social networking case,” IEEE/ACM Transactions on Networking, vol. 23, no. 5, pp. 1471–1484, 2015.
37. G. Zhang, K. Yang, and H. Chen, “Socially aware cluster formation and radio resource allocation in D2D networks,” *IEEE Wireless Communications*, vol. 23, no. 4, pp. 68–73, 2016.
38. E. Datsika, A. Antonopoulos, N. Zorba, and C. Verikoukis, “Green cooperative device–to–device communication: a social–aware perspective,” IEEE Access, vol. 4, pp. 3697–3707,2016.
39. M. Zhang, X. Chen, and J. Zhang, “Social-aware relay selection for cooperative networking: an optimal stopping approach,” in *Proceedings of the 1st IEEE International Conference on Communications (ICC ’14)*, pp. 2257–2262, Sydney, Australia, June 2014.
40. Z. Han, D. Niyato, W. Saad, T. Basar, and A. Hjoungnes, Game Theory in Wireless and Communication Networks: Theory, Models and Applications, Cambridge, U.K.: Cambridge Univ. Press, 2011.
41. Beibei Wang, Yongle Wu, and K.J. Ray Liu., “Game theory for cognitive radio networks: An overview. Computer Networks”, 2010.
42. G. Bacci, L. Sanguinetti, M. S. Greco, M. Luise, "A game-theoretic approach for energy-efficient detection in radar sensor networks", *Proc. IEEE 7th Sensor Array Multichannel Signal Process. Workshop (SAM)*, pp. 157-160, Jun. 2012.
43. L. Song, D. Niyato, Z. Han, and E. Hossain, “Game-theoretic resource allocation methods for device-to-device (D2D) communication,” *IEEE Wireless Commun.*, vol. 21, no. 3, pp. 136–144, Jun. 2014.

44. K. R. Apt and A.Witzel, “A generic approach to coalition formation,” Int. Game Theory Rev., vol. 11, no. 3, pp. 347–367, Sep. 2009.
45. G. Chalkiadakis, E. Elkind, M. Wooldridge, "Cooperative game theory: Basic concepts and computational challenges", *IEEE Intell. Syst.*, vol. 27, no. 3, pp. 86-90, May/Jun. 2012.