Improving spectral efficiency in intra-inter-cell underlay Device to Device (D2D) communication

A Thesis submitted in partial fulfillment of the requirements for the Degree of Master of Engineering in Software Engineering

By

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I hereby recommend that the thesis, entitled **"Improving spectral efficiency in intra-inter-cell underlay Device to Device (D2D) communication"** prepared by **Mohit Mahata** (Examination Roll Number: M4SWE19018, Registration Number: 140971 of 2017-2018), under my supervision, be accepted in partial fulfillment of the requirements for the Degree of **Master of Engineering** in **Software Engineering** from the **Department of Information Technology** under **Jadavpur University**.

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Abstract

Device to Device (D2D) communication is now becoming a promising technology for most of the applications as it enables devices to communicate with each other without traversing the base station or core network. D2D communication reduces latency and increases spectral efficiency (SE) of the network. But in underlay D2D intra-cell and inter-cell interference significantly affect the spectral efficiency. Most of the cases we have seen that communicating devices are static in nature. In this paper we are considering a scenario where some of the devices are dynamic, i.e. they can move from one cell to adjacent cell. Then we propose a method based on intra and inter-cell communication changing probability to mitigate the interference (intra and inter-cell) and to improve the overall spectral efficiency for different schemes. Here we consider a minimum signal-to-interference plus noise ratio (SINR) for cellular users. Simulation result shows that our proposed method outperforms in terms of spectral efficiency.

Keywords: Device to device (D2D) communication, intra-cell interference, inter-cell interference, signal-to-interference plus noise ratio (SINR), spectral efficiency.

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Chapter 1

Introduction

Nowadays, wireless communication has become extremely important in every field of our daily life. Because of the ever increasing data demand of the users and wide variety of applications wireless communications are expected to be provided in a more effective and efficient way. Internet of things (IoT) is an application that connects a lot of devices and users to each other [1]. If we communicate through a base station (cellular network) in IoT based applications, it imposes a huge load on the network which in turn increases the latency of the communication and decreases the overall quality of service (QoS). To overcome these problems device to device (D2D) communication appears as a promising and demanding technology. It is expected to provide an improvement in network throughput and spectral efficiency as it can offload traffic at the base station (BS). It can also improve quality of service for some local area services.

In this chapter we present basic concepts of D2D communication, some existing scheduling techniques which are used in cellular networks, some resource allocation techniques in D2D communication and their problems and scope of our thesis.

1.1 Basics of D2D Communication

In recent years, we have seen exponential growth of wireless communication along with data traffic and also high demands for broadband mobile wireless communications. New wireless multimedia applications and services are increasing rapidly day by day. These are the key drivers to the development of the Long Term Evolution-Advanced (LTE-A) network.

LTE-A has carrier aggregation feature which enables it to be three times faster than the previous generation of Long Term Evolution (LTE). It is more reliable than LTE and it also offers better quality of service (QoS) than traditional LTE network. But LTE-A has some limitations also. They are discussed below.

- One of the main challenges of LTE-advanced is to recover the local-area services and enhance spectrum efficiency. Technical capabilities are required to achieve this.
- As it uses multiple antennae and transmitters, so users would experience much poorer battery life on their devices, while on this network. This would mean that they would have to use larger devices with more battery power, if they want to stay online for longer periods of time.

To overcome these limitations D2D communication comes into picture. It is a new technology that offers wireless peer-to-peer communications and improves spectrum utilization in LTE-Advanced network. D2D communications was initially proposed in cellular network as a new paradigm to improve network performance of the system.

Device to device (D2D) communication refers to technology that enables the direct communication between two or more devices or users without traversing the base station or intermediary devices on a network.

D2D communication may be categorized [2] in three types:

- Peer-to-peer communication: This is almost like conventional point-to-point (P2P) communication. A point-to-point connection refers to a communication where connection is in between two communication endpoints or nodes.
- Cooperative communication: Cooperative communication allows communication terminals in a network to hear and help the information transmission of each other. It is done by using extra relay nodes (RNs) to assist the communications between sources and their corresponding destinations. In a relay system, source nodes first transmit their data to the RNs. Each RN then processes and forwards its received data information to the destination nodes following some cooperation protocols. By relaying cell coverage is extended for a network and reliability is also improved in the system.
- Multiple-hop communication: This is like an extension of cooperative communication. Here multiple devices form an ad-hoc mesh network to enable data routing between devices. It has some application areas like mobile ad-hoc networks (MANETs) and multi hop cellular networks.

1.2 Configurations of D2D Communication

There are different configurations [2] of the D2D networks discussed below:

- Network-controlled D2D: Here the base station and the core network control the signaling setup and resource allocation for both cellular users (CUs) and D2D pairs. Resource allocation done by base station can be static or on demand. This kind of centralized control can result in efficient interference management and resource allocation.
- Self-organized D2D: This configuration is distributed in nature. D2D users sense the spectrum holes, collect channel state information (CSI) and possible interferences and communicate in a self-organizing way to other D2D pairs. Thus, it reduces signaling overhead but may create instability due to lack of centralized control.
- Network-assisted D2D: In this scenario, the BS only allocates resources to the D2D users and thereafter users communicate between themselves directly in a self-organizing way. It has low signaling overhead and partial centralized control. Here security of the network can be a potential issue.

1.3 Classification of D2D Communication

Based on the used spectrum by D2D users and their impact on cellular users D2D communication can be classified into two groups namely inband D2D and outband D2D communication [3]. Inband D2D can be further classified into underlay and overlay D2D. Outband D2D can also be classified into two groups namely controlled and autonomous. Classification of D2D communication is shown in Figure 1.1.

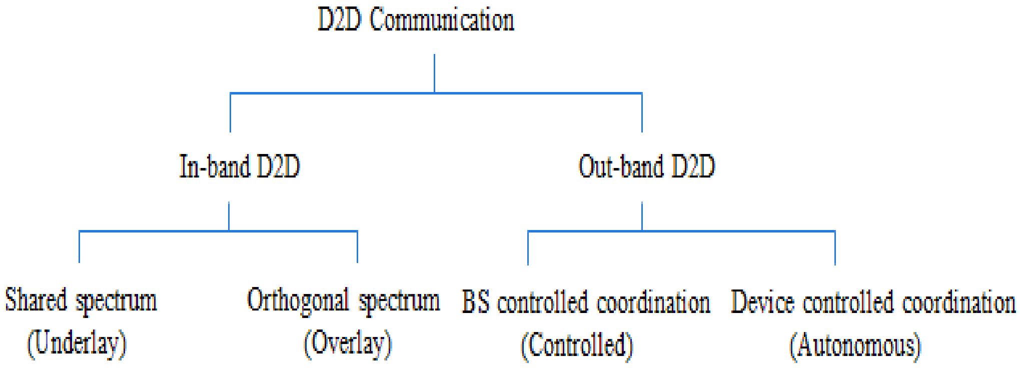

Figure 1.1: Classification of D2D communication.

1.3.1 Inband D2D Communication

Here, cellular communication and D2D communication use the same spectrum licensed to the cellular operator. The motivation for choosing inband communication is the high control over licensed spectrum. The most disadvantage of inband D2D is the severe interference caused by D2D users to cellular communications .This interference can be mitigated using some efficient resource allocation methods.

- Undelay Inband D2D: In underlay inband mode, cellular and D2D communications share the same radio resources during the communication. Underlay D2D can improve spectrum efficiency, energy efficiency and cellular coverage by the use of different techniques including interference reduction, resource allocation and others.
- Overlay Inband D2D: In this mode, resource blocks (the smallest unit of resources that can be allocated to a user) is divided into two groups, one is for cellular users and another for D2D users to eliminate interference for the D2D communications on cellular transmissions.

1.3.2 Outband D2D Communication

Nowadays, outband D2D is gaining attentions by the researchers. Here, D2D communication uses unlicensed spectrum (e.g., the free 2.4 GHz ISM band or 38 GHz mm Wave band) where cellular communication does not occur. Outband D2D may suffer from the uncontrolled nature of unlicensed spectrum. To exploit the unlicensed spectrum it is necessary to have another extra interface that implements WIFI-Direct, Zig-Bee or Bluetooth.

- Controlled mode: In this category of D2D communications, the coordination between radio interfaces is controlled by the base station (BS).
- Autonomous mode: Nowadays, there are very few works on this category. In autonomous D2D communication the coordination between radio interfaces is controlled by the users themselves. So, it is motivated by reducing the overhead of cellular network. It does not require any changes at the BS and can be deployed easily.

Pictorial representations of inband and outband D2D and their classification is illustrated in Figure 1.2.

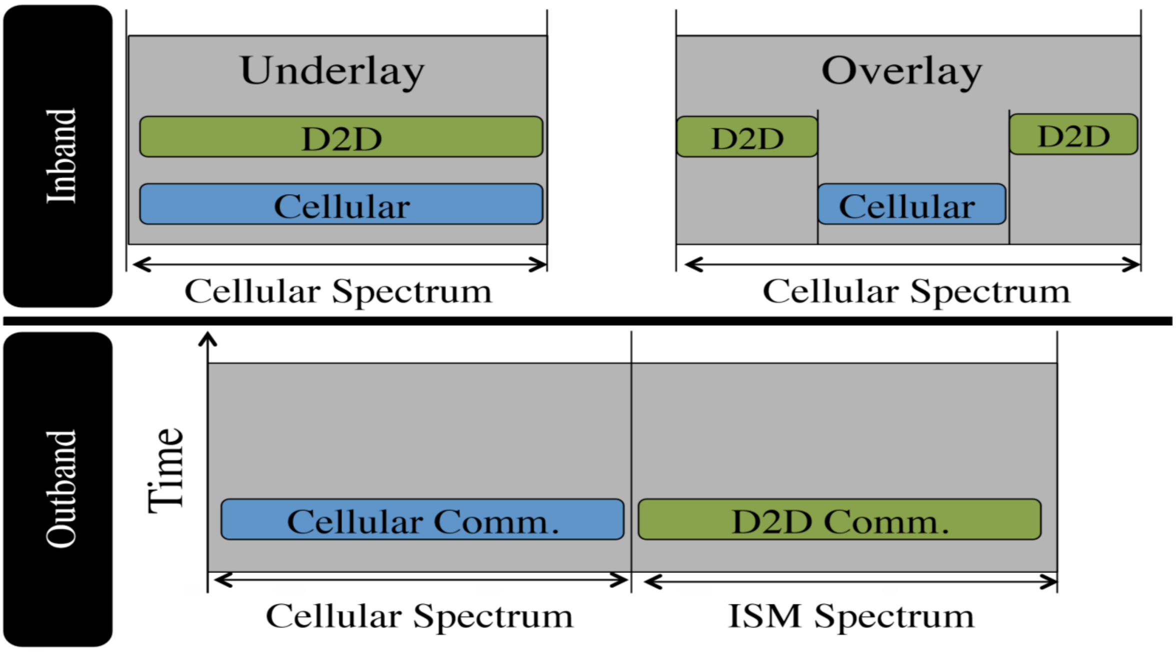

Figure 1.2: Inband and outband D2D

1.4 Application areas of D2D

In the future 5G systems, we can predict that network-controlled direct D2D communication offers the opportunity of short-distance communication [4]. Device to device (D2D) communication can be extremely important for communication services in adjacent areas due to the transfer of data without going through the base station or core network. For example, by using the regional transmission more neighboring devices may connect with multimedia services, they can find a nearby friend, they are allowed for real-time communications conversations. It also has the potential to be applied in emergency medicine and disaster situations where patients are far from healthcare providers and the outreaching communication bandwidth is limited. D2D communication also allows separating local traffic from the global network. This is known as local traffic offloading. By doing this, it will not only remove the load burden on the backhaul and core network caused by data transfer, but also reduce the necessary effort for managing traffic at central network nodes. Thus direct D2D communication extends the idea of distributed network management as it incorporates the end devices into the network management concept. In this way, the wireless user device with D2D capability can have a dual role: they can either act as an infrastructure node and/or as an end-user device in a similar way as a traditional device.

As in direct D2D, there is local communication link between nearby devices; it provides low-latency communication. Direct D2D has been seen as one of the necessary and important features to support real-time services in the future. Another important aspect of D2D communication is it's reliability. Sometimes additional D2D links can be employed to increase reliability. The device power consumption can be reduced significantly in case of D2D communication due to the short distance transmission.

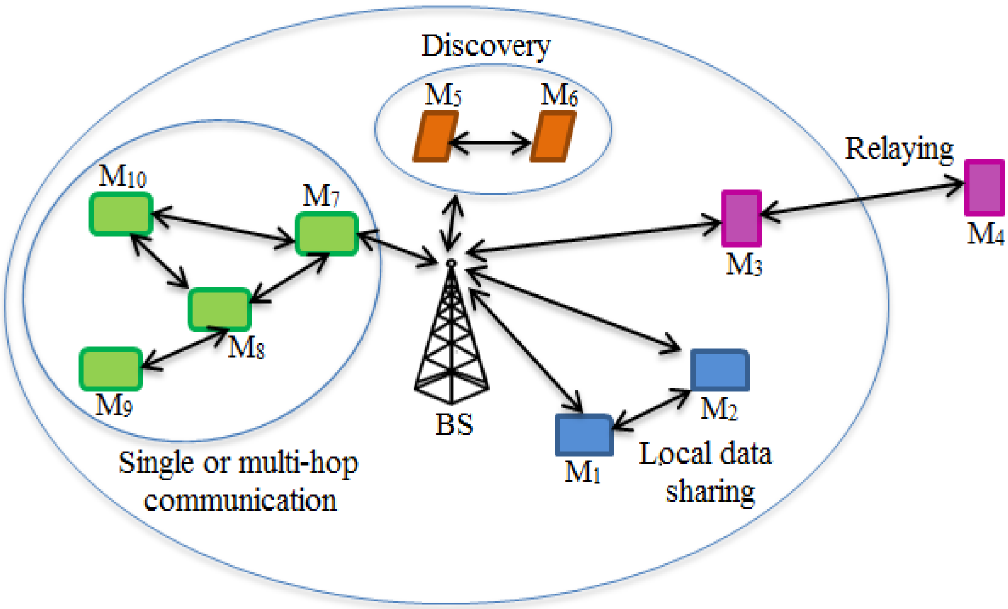

Figure 1.3: Typical use cases of D2D communication.

Figure 1.3 shows typical use cases of D2D communication. Here BS represents the base station. M1, M2, M3,…, M9, M10 are the devices present in the network. Four scenarios are shown in the figure. They are discussed below.

Local Data Sharing (Offloading)

The first one is about local data sharing (between M1 and M2) where data caching in one device can be shared with other devices in proximity, which is also known as offloading.

Relaying

In the second scenario, called relaying (between M7 and M8), D2D communication can play a key role to improve availability of the network to extend the coverage area via a D2D based relay. This is especially important for the use cases related to public safety which includes both indoor and outdoor devices.

Single or Multi-hop local Proximity Communication

The third scenario, known as single or multi-hop local proximity communication (among M1, M2, M3 and M4), is the one use cases considered in the 3rd Generation Partnership Project (3GPP) Release 12. Here in this case, the devices within proximity can set up a peer-to-peer link or multicast link that does not use the cellular network infrastructure. One of the particular applications for this kind of links is the public safety service.

D2D Discovery

The last scenario is about D2D discovery (considered in 3GPP Release 12 as well), which refers to a process that identifies whether a user equipment (UE) is in proximity of another UE (between M5 and M6).

1.5 Scope of the Thesis

In this thesis paper, we propose an effective method for resource allocation to maximize the spectral efficiency (SE) of the network. Here we consider the interference from adjacent cells (inter-cell interference) and also consider the intra and inter-cell communication changing probability while calculating the total interference. We calculate the spectral efficiency of the network for both the traditional underlay D2D communication and optimal resource sharing scheme in two cases, one for static devices and another for dynamic devices. Then we compare them with respect to SE. Numerical results show that our proposed method outperforms in terms of spectral efficiency. A minimum signal to interference plus noise ratio (SINR) for the cellular devices is guaranteed. Also, there is no restriction on the number of D2D devices that can share a resource block with a cellular user.

Chapter 2

Literature Review

In underlay D2D communication, spectrum is used efficiently, but there is interference between the communications who share the same resource blocks. For this, importance of efficient interference management and effective resource allocation is increased day by day. Interference mitigation results better spectral efficiency (SE) of the network.

In the thesis, we have done a significant effort related to the resource allocation and interference mitigation in underlay D2D communication [5-20].

2.1 Bisection-based Method for Resource Allocation

In [5], energy-efficient and fair resource allocation is investigated in a downlink orthogonal frequency-division multiplexing (OFDM)-based mobile communication system. Here they propose bisection-based optimal power allocation (BOPA) and a two-step subcarrier assignment is designed to avoid unaffordable computational complexity of exhaustive search. A comparison between the energy-efficient solution and the traditional spectral-efficient method is made here and it is observed that they are similar with each other in the low channel-gain-to-noise ratio (CNR) regime but in high-CNR regime proposed method is more energy efficient than the traditional method.

2.2 Resource Allocation based on Graph Theory

In [6], to avoid the dominant interference among D2D pairs graph-coloring theory is introduced for resource allocation. Here they provide a feedback method and a resource allocation algorithm to avoid interference by utilizing the graph-coloring theory. The theory centers on some practical issues such as the feedback overhead and the computational complexity.

In [7], Resource sharing problem is investigated to optimize the system performance. They formulate the interference relationships among different D2D communication links and cellular communication links as an interference-aware graph, and propose an interference-aware graph based resource sharing algorithm that can effectively obtain optimal resource assignment solutions.

Hyper graph theory is discussed in [8] for wireless communication. An interference graph based channel assignment algorithm is proposed in [9].

2.3 Speed Sensitive Algorithm

Speed sensitive algorithm with multiple users is studied and analyzed in Long Term Evaluation (LTE) network in [10]. Here distance and speed has been considered as important parameters. The speed has been detected using the Gauss Markov Mobility Model. They calculate received signal power (RSP) for various users with respect to base stations at various time intervals and the path loss between transmitter and receiver.

In [11], a novel speed and service-sensitive algorithm and analytical model for cellular networks is proposed. They use the Gauss-Markov mobility model to predict the speeds of mobile stations, and divide mobile stations into three classes based on the predicted speeds: fast, medium-speed, and slow. An analytical model is also developed to evaluate the performance of this system with different speed classes and service types. Simulations and analytical results show that the proposed algorithm can significantly improve the network performance in terms of network throughput and other parameters comparing with the traditional algorithms.

2.4 Power Control and Resource Scheduling Scheme

D2D power control schemes including stochastic optimization, robust optimization, and a game theoretic approach are proposed in [12]. These schemes aim to maximize the achieved rate of an underlay D2D pair while satisfying a given transmit rate for a cellular user. The effectiveness of the proposed schemes are proved by numerical results. The game theoretic approach is also extended here for the case of multiple D2Dpairs. Power allocation under imperfect channel information is also done here. They also give an idea of interference channel gain for underlay D2D communication. Simulation results demonstrate the performance degradation of the cellular user with the increase in the number of D2D pairs.

[13] Proposes a joint power control and resource scheduling scheme to enhance both the network throughput and the users' fairness of the underlay D2D communication. Their scheme aims to maximize the sum of all users' proportional fairness functions while simultaneously taking into account factors such as fairness, signal-to-interference-plus-noise ratio requirements, and severe interference. They also take into consideration the time-varying feature of user's channel condition. Numerical results confirm that their proposed scheme not only improves the system throughput, but also boosts the system fairness. It also guarantees the QoS levels of all D2D users and cellular users.

2.5 Genetic Algorithm based Method

In [14], they propose to use K-Means clustering to locating a user equipment (UE) around the cluster center as the UE Owner of the cluster. The process of K-Means clustering is described below.

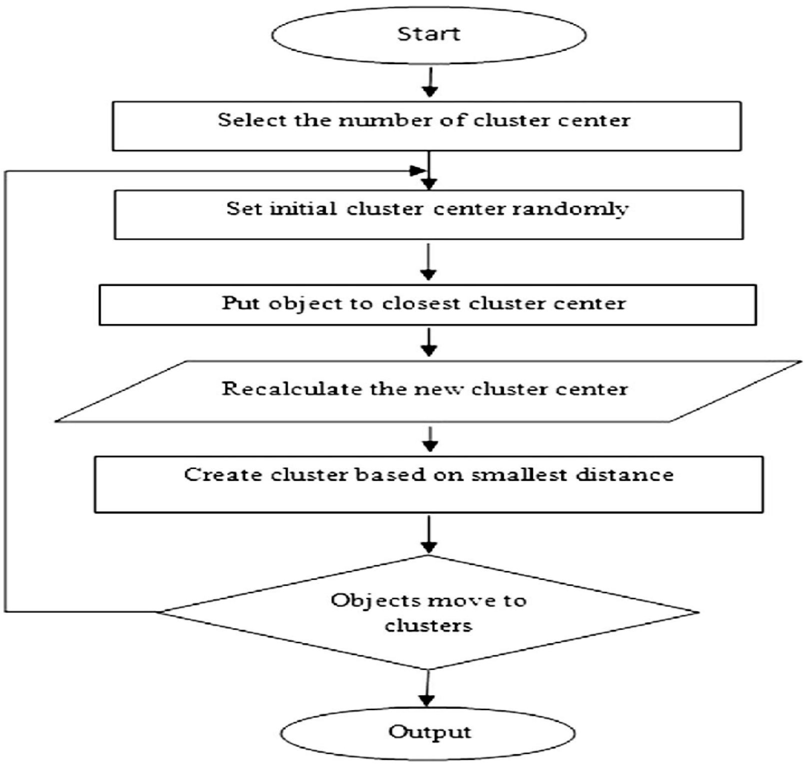

Figure 2.1: Flow Chart of K-Means Clustering Method.

Frequency hopping technique is considered here to mitigate the co-channel interference. Genetic Algorithm (GA) with frequency hopping technique is used here to optimally select the number of frequency channels required in the system and then they allocate these frequency channels to the UE clusters for their D2D communications.

A genetic algorithm-based method is proposed in [15] to minimize the interference and maximize the spectral efficiency. Here they give a brief idea about different stages of genetic algorithm like crossover, mutation, fitness function and others. Flow chart of genetic algorithm is given below.

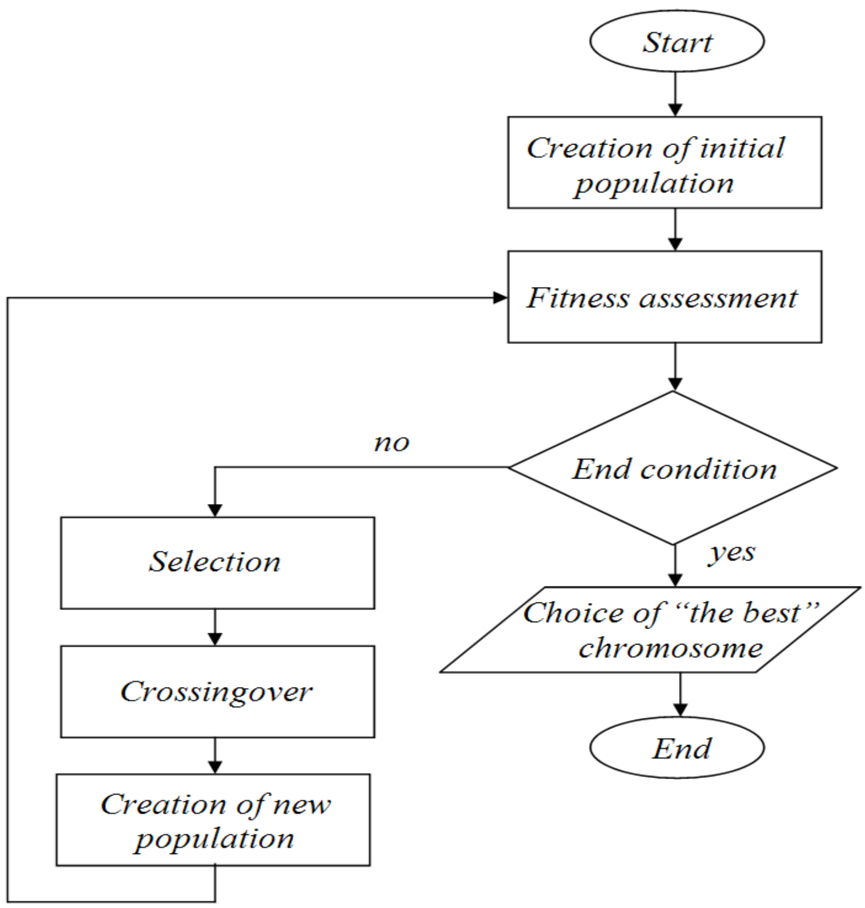

Figure 2.2: Flow Chart of Genetic Algorithm

Since D2D underlay cellular network degrades the signal-to-interference plus noise ratio (SINR), they consider a minimum SINR for cellular devices. We have seen the superior performance of the proposed method in terms of spectral efficiency and interference mitigation with respect to other methods from numerical evaluations. In this paper, they consider only devices in one cell and assume that there is no interference from adjacent cells.

2.6 Other Resource Allocation Methods

Various interference mitigation techniques, concepts and expressions of SINR for different cases, distance-constrained outage probability analysis for D2D communication is done in [16-19]. Concepts of next generation wireless communication system are discussed in [20]. They have done performance analysis of wireless networks, when circuit switching is used as the primary method of channel allocation. They also provide an overview of the issues and problems in mobility.

Chapter 3

Proposed Methodology

3.1 Optimal Resource Sharing Scheme

Here we consider a scenario in a cellular network, in which there are two types of communications, namely cellular communication and the D2D communication, where the D2D communication is treated as an underlay to the traditional cellular communication. We assume that there are X cellular UEs, Y D2D pairs in the network, where A_x, x = 1, 2, . . . , X, denotes a traditional cellular UE, and $D_{y,t}$ and $D_{y,r}$, y = 1, 2, . . . , Y, denote a D2D pair. $D_{y,t}$ represents the transmitter of the D2D pair, while $D_{y,r}$ represents the receiver. There are totally Z resource blocks (RBs), denoted by R = {RB_1, RB_2, . . . , RB_Z}. Suppose that the BS and the transmitters of the D2D pairs transmit with power p_b and p_d, respectively. The transmit power of the BS allocated to each RB for cellular data transmission is equal. So, the transmit power on each RB is p_b/Z. The channel gains of the cellular communication link from the BS to the cellular UE A_x, the D2D communication link from $D_{y,t}$ to $D_{y,r}$, the interference link from the BS to $D_{y,r}$, the interference link from $D_{y,t}$ to A_x, and the interference link from $D_{y,t}$ to $D_{y',r}$ are represented by $g^z_{A_x}, g^z_{D_{y,t},D_{y,r}}, g^z_{b,D_{y,r}}, g^z_{D_{y,t},A_x}$ and $g^z_{D_{y,t},D_{y\prime,r}}$, respectively, where y $\neq y'$. The thermal noise is denoted by σ^2.

The instantaneous Signal-to-Interference-plus-Noise Ratio (SINR) at cellular UE A_x, when RB_z is allocated to it, can be given as

$$SINR^z_{A_x} = \frac{\frac{p_b}{Z} g^z_{A_x}}{\left[\sigma^2 + \left\{\left(\sum_{j\in Y,\, D_j \in C_z} p_d g^z_{D_{j,t},A_x}\right)\right\}\right]} \quad (1)$$

and the instantaneous SINR at the receiver of the D2D pair D_y, when RB_z is allocated to it for data transmission, can be given as

$$SINR^z_{D_y} = \frac{p_d g^z_{D_{y,t},D_{y,r}}}{[\sigma^2 + \{\sum_{i\in X,\, A_i \in C_z} \frac{p_b g^z_{b,D_{y,r}}}{Z}\} + (\sum_{j\in Y, j\neq y, D_j \in C_z} p_d g^z_{D_{j,t},D_{y,r}})]} \quad (2)$$

Where C_z represents the cluster of the traditional cellular communication links and the D2D communication links that share RB_z and D_n denotes the D2D pair.

Now the issue is to find out optimal resource block assignment solution for both the traditional cellular communication links and D2D communication links so that each links can properly perform their individual data transmission. Let $G_{(X+Y)\times Z} = \binom{L_{X\times Z}}{M_{Y\times Z}}$ can be an RB assignment solution, where $L_{X\times Z} = [\alpha_{x,z}]$ and $M_{Y\times Z} = [\beta_{y,z}]$ denotes the resource block assignment matrix for cellular and D2D communication links respectively.

The value of $\alpha_{x,z}$ and $\beta_{y,z}$ with x ∈ X, y ∈ Y , and z ∈ Z, can be defined as

$$\alpha_{x,z} = \begin{cases} 1, & \text{when RBz is allocated to } A_x\text{ ,} \\ 0, & \text{otherwise} \end{cases}$$

and

$$\beta_{y,z} = \begin{cases} 1, & \text{when RBz is allocated to } A_y\text{ ,} \\ 0, & \text{otherwise} \end{cases}$$

We can obtain the spectral efficiency denoted by SE_1 as

$$SE_{tot} = \sum_{z=1}^{Z} \left[\sum_{x=1}^{X} \log_2 \left(1 + SINR_{A_x}^{z}\right) \alpha_{x,z} + \sum_{y=1}^{Y} \log_2 \left(1 + SINR_{D_y}^{z}\right) \beta_{y,z} \right] \quad (3)$$

3.2 Traditional Underlay D2D Communication

Here we consider two cellular cells each with one base station in the center and a number of users as shown in Figure 3. The users are randomly distributed around the base station. Users are classified into two groups. One is of cellular users and another is of D2D users. Normally cellular users communicate with each other through the base station but in D2D communication two close by devices can communicate with each other. Two communicating devices form a D2D pair. The set of communications are defined as A = {U_1, U_2, …, U_B, U_{B+1}, …, U_{B+C}}, where U_i shows the i^{th} communication. B and C are the total number of cellular users and D2D pairs, respectively. Therefore, the first B elements are cellular users and the next C elements are D2D pairs. In other words, the set of cellular users is denoted by D = {U_1, U_2, …, U_B} and the set of D2D pairs is defined by E = {U_{B+1}, U_{B+2}, …, U_{B+C}}. R = {RB_1, RB_2, … , RB_K} indicates the set of the resource blocks. RB_i and K denotes the i^{th} resource block and total number of resource blocks, respectively.

In this model we are considering the dynamic nature of devices, so here we consider that some of the D2D devices are moving in nature. For this property, they can move from one cell to another adjacent cell. For this, there are some D2D devices which are static and some of them are dynamic also. We consider a fixed speed of the moving devices.

As in this model, we have two types of D2D devices, intra-cell and inter-cell D2D communication both will be there. When the devices are not moving from one cell to another then all interference will come from the same cell and intra-cell D2D communication will occur. But when moving D2D devices move from one cell to another then not only intra-cell but also inter-cell D2D communication will take place. Here intra-cell and inter-cell communication changing probability will be considered to decide that how many devices will be of dynamic nature and can move from one cell to another.

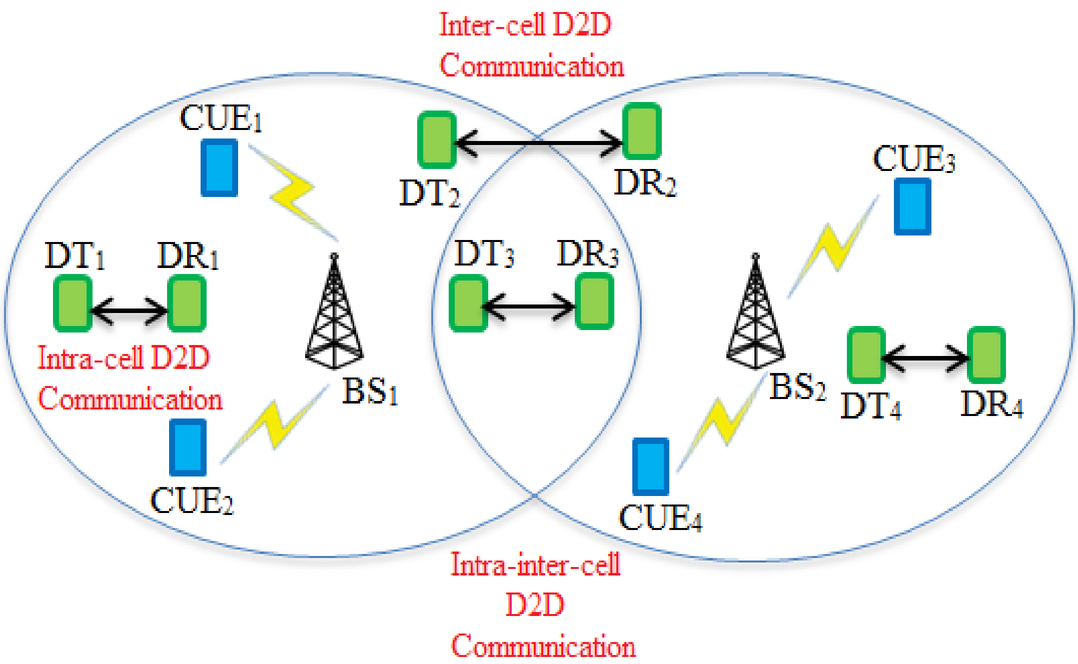

Figure 3.1: Underlay D2D communication with moving users.

In Figure 3 BS_1 and BS_2 are the base stations of two adjacent cells. CUE_1, CUE_2, CU_3 and CUE_4 are the cellular devices present inside the cells. Transmitter and receiver of first D2D pair is denoted by DT_1 and DR_1. Similarly (DT_2, DR_2), (DT_3, DR_3) and (DT_4, DR_4) denote the transmitters and receivers of second, third and fourth D2D pair. We also define different scenarios where intra-cell, inter-cell and intra-inter-cell D2D communication can take place. In this figure intra-cell D2D communication takes place between DT_1 and DR_1 and also for DT_4 and DR_4 as both the transmitter and receiver are within the same cell. We have seen inter-cell communication between DT_2 and DR_2 as two communicating devices are from different cells. Another kind of D2D communication, known as intra-inter-cell D2D communication occurs between DT_3 and DR_3.

First we are developing the equations for normal users (not dynamic in nature) using Shannon formula. Then we modify the formula for our model by using intra and inter-cell communication changing probability.

Here M = $\{m_{i,r}\}$, is resource assignment matrix where $m_{i,r} = 1$ means i^{th} user utilizes r^{th} resource block and $a_{i,r} = 0$ shows that the r^{th} resource block is not used by i^{th} user. In our system, every nodes represent a communication, either a cellular or a D2D communication. We know that sharing a resource block between two cellular users is not allowed. Since the base station is their receiver, if two cellular users share a resource block the receiver cannot differentiate the signals. For this, there is no interference between cellular users.

We denote maximum spectral efficiency of i^{th} communication at r^{th} resource block, either cellular user or D2D pair, by $SE_{i,r}$ and defined based on Shannon formula as

$$SE_{i,r} = \log_2\left(1 + \ SINR_{i,r}\right) \tag{4}$$

where $SINR_{i,r}$ is the signal to interference plus noise ratio which can be expressed as

$$SINR_{i,r} = \frac{m_{i,r}\, p_{i,r}\, g_{i,i,r}}{\sigma^2 + I_i^r} \tag{5}$$

In (5) $p_{i,r}$ is the transmission power of the i^{th} node at r^{th} resource block and $g_{i,j,r}$ is the channel gain between transmitter of the i^{th} node and receiver of the j^{th} node at r^{th} resource block. σ^2 denotes the noise power. T_i^r is the total interference from other nodes to i^{th} node which can be written as

$$T_i^r = \sum_{j=1, j\neq i}^{B+C} m_{j,r}\, T_{j,i,r} = \sum_{j=1, j\neq i}^{B+C} m_{j,r}\, p_{j,r} g_{j,i,r} \tag{6}$$

By substituting (6) in (5), we obtain

$$SINR_{i,r} = \frac{m_{i,r}\, p_{i,r}\, g_{i,i,r}}{\sigma^2 + \sum_{j=1, j\neq i}^{B+C} m_{j,r} p_{j,r} g_{j,i,r}} \tag{7}$$

The goal is to maximize the spectral efficiency of the network, which can be written as

$$S_t = \sum_{i=1}^{B+C} \sum_{r=1}^{K} SE_{i,r} = \sum_{i=1}^{B+C} \sum_{r=1}^{K} log_2(1 + \text{SINRi, r}) \quad (8)$$

Putting the value of $SINR_{i,r}$ in (8) we get the spectral efficiency of the network as

$$SE_{net} = \sum_{i=1}^{B+C} \sum_{r=1}^{Q} log_2 \left(1 + \frac{m_{i,r}\, p_{i,r}\, g_{i,i,r}}{\sigma^2 + \sum_{j=1, j\neq i}^{B+C} m_{j,r} p_{j,r} g_{j,i,r}}\right) \quad (9)$$

In (6) we consider only the interference within a single cell (intra-cell interference).

3.3 Intra-cell and Inter-Cell Communication Changing Probability

We can derive this probability by using fluid flow mobility model. Using the fluid flow mobility model, the cell boundary crossing rate for users can be calculated as

$$\eta_0 = \frac{2v}{\pi r}$$

Here, v is the speed of the mobile station and r is the radius of the concerned cell.

We denote the unencumbered call duration by a random variable τ, which is assumed to follow an exponential distribution with parameter μ. Denote the mean of τ as $\bar{\tau}$. We know that

$$\mu = \frac{1}{\bar{\tau}}$$

Here τ_1 denotes the delay that mobile station enters into the cell and τ_2 denotes the delay that mobile station moves out the cell. $\bar{\tau}$ is the mean of τ_1 and τ_2.

The intra and inter-cell communication changing probability of the mobile units can be calculated as

$$\rho = \frac{\eta_0}{\eta_0 + \mu} \quad (10)$$

3.4 Probabilistic Analysis of dynamic D2D Devices

Here in this paper we are considering dynamic user scenario where some of the D2D users are moving from one cell to another. For this kind of nature SINR and spectral efficiency of the network will also be affected as it made impact on interference. We make a probability equation based on the intra and inter-cell communication changing probability for this purpose.

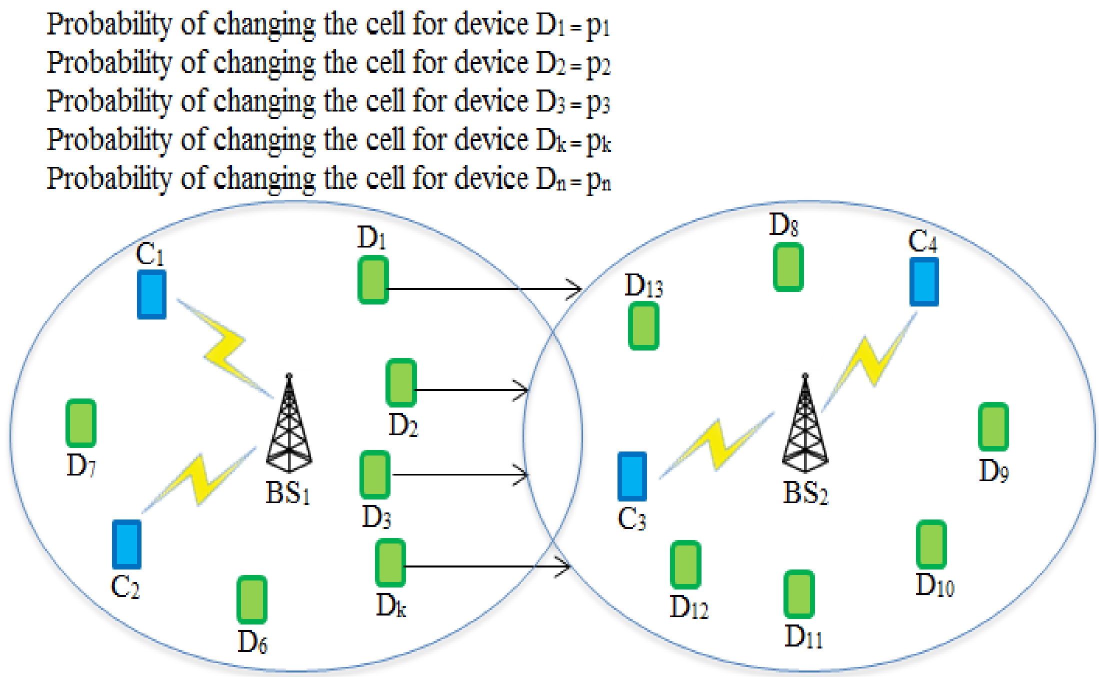

Figure 3.2: Snapshot of the movement of D2D devices.

Here in Figure 3.2 BS_1 and BS_2 are the base stations of two adjacent cells. C_1 and C_2 are the cellular devices of the first cell which are assumed to be static in nature. Similarly the second cell also has C_3 and C_4. D_1, D_2, D_3 and D_k are the moving D2D devices inside the first cell. It is previously told that not all the D2D devices are of dynamic nature, so there are some static D2D devices also inside the cell like D_6 and D_7. Similarly D_8, D_9, …, D_{13} are the D2D devices present in another cell. For the device D_1, we assume that the probability of changing the cell is p_1. Similarly for D_2 and D_3 probability is p_2 and p_3. We also assume that all the D2D devices inside the cell have the same probability of changing their position from one cell to another as speeds of the moving devices are same. So, here in our consideration, $p_1 = p_2 = p_3$ and so on.

Now we are trying to formulate the probability equation for this scenario. Suppose, there are k number of moving devices. For an individual device, the probability of moving from one cell to another is $p_1 = \rho$. We can get the value of ρ from (11). So, the probability of devices having remained within the cell after all movement is completed is

$$P_y = (1-p_1)\,(1-p_2)\,(1-p_3)\,\ldots\,(1-p_k)$$

$$= \sum_{i=1}^{k}(1 - p_i) \quad (11)$$

Probability of users moving from one cell to adjacent cell

$$P = (1-p_y)$$

$$= 1- \sum_{i=1}^{k}(1 - p_i)$$

So, when we are calculating interference from other users in the equation (7) then we will consider only the users which will be present within the cell after moving. So take this probability into consideration we can modify (7) as

$$\text{SINR}_{i,r} = \frac{m_{i,r}\, p_{i,r}\, g_{i,i,r}}{\sigma^2 + (\sum_{j=1, j\neq i}^{B+C} m_{j,r} p_{j,r} g_{j,i,r}(1-p))} \quad (12)$$

Then the total spectral efficiency of the network will be

$$\sum_{i=1}^{B+C} \sum_{r=1}^{Q} log_2 \left(1 + \frac{m_{i,r}\, p_{i,r}\, g_{i,i,r}}{\sigma^2 + (\sum_{j=1, j\neq i}^{B+C} m_{j,r} p_{j,r} g_{j,i,r}(1-p))}\right) \quad (13)$$

We can also apply this probability in first scheme also for both cellular and D2D users. Applying the probability (1) can be written as

$$SINR_{A_x}^{z} = \frac{\frac{p_b}{Z}\, g_{A_x}^{z}}{\left[\sigma^2 + \{\left(\sum_{j\in Y,\, D_j \in C_z} p_d g_{D_{j,t}, A_x}^{z}\right)(1-\rho)\}\right]} \quad (14)$$

Similarly (2) also be modified as follows

$$SINR_{D_y}^{z} = \frac{p_d g_{D_{y,t}, D_{y,r}}^{z}}{[\sigma^2 + (\sum_{i\in X,\, A_i \in C_z} \frac{p_b g_{b, D_{y,r}}^{z}}{Z}) + \{(\sum_{j\in Y, j\neq y, D_j \in C_z} p_d g_{D_{j,t}, D_{y,r}}^{z})\,(1-p)\}]} \quad (15)$$

So, for the scheme discussed in section II A spectral efficiency of the network SE'_{tot} will be

$$SE'_{tot} = \sum_{z=1}^{Z} [\, \sum_{x=1}^{X} \log_2 (1 + SINR'^{z}_{A_x})\, \alpha_{x,z}$$

$$+ \sum_{y=1}^{Y} \log_2 (1 + SINR'^{z}_{D_y})\; \beta_{y,z} \quad (16)$$

Chapter 4

Numerical Analysis

In this section, the performance of the proposed algorithm under different scenarios is evaluated. We assume that there is a base station in the center of each cell and the users are randomly distributed around the base station. Maximum distance between D2D pairs is 10 m. Carrier frequency, resource blocks bandwidth and maximum power of users are set to 1.8 GHz, 180 kHz and 23 dBm respectively. The parameters used for simulation results are given in Table 1. The channel gain consists of large scale pathloss and small scale fading. Concepts of different pathloss models and small scale fading is discussed in [21-22]. Large scale pathloss, denoted by L based on winner model is defined [23] as

$$L = 22.7 \log_{10} d + 27 + 20 \log_{10} f_c \tag{17}$$

Where f_c is the carrier frequency and d is the distance between D2D pairs.

Here we assume small scale fading as Rayleigh fading and modeled by jakes model. A Rayleigh fading channel is subjected to a given Doppler spectrum can be generated by synthesizing the complex sinusoids. Jakes model is modeled as

$$h_1(t) = 2\sum_{n=1}^{N_0}(\cos\emptyset_n \cos w_n t) + \sqrt{2}\cos\emptyset_N \cos w_d t$$

and

$$h_2(t) = 2\sum_{n=1}^{N_0}(\sin\emptyset_n \cos w_n t) + \sqrt{2}\sin\emptyset_N \cos w_d t$$

where $h_1(t)$, $h_2(t)$, $\emptyset_n$ and $\emptyset_N$ are the real and imaginary components of channel at t^{th} time instance, initial phases of the n^{th} doppler shifted sinusoid and maximum doppler frequency (f_m) shifted sinusoid, respectively and $w_d = 2\pi f_m$ with $w_n = w_d \cos\emptyset_n$ [24].

Noise power is calculated from noise power density and channel bandwidth. Channel bandwidth is considered here as 10 MHz and temperature is also considered as normal temperature.

Table 1: Simulation Parameters

Parameter name	**Value**
Cell radius (r)	1000 m
Carrier frequency (f_c)	1.8 GHz

Channel bandwidth	10 MHz
Number of resource blocks (Q)	8
Maximum distance of D2D pairs (d)	10 m
Maximum power of D2D transmitters (p_d)	23 dBm
Maximum power of cellular devices	23 dBm
Noise power density	-174 dBm
Speed of the devices (v)	3 m/s (min), 30 m/s (max)
τ_1, τ_2	2 s
π	22/7
BS's transmit power (p_b)	46 dBm
Path loss model	Winner model in [23]
Small scale fading	Rayleigh fading in [24]

In this section, we calculate spectral efficiency with respect to number of communications for both traditional underlay D2D communication and optimal resource sharing scheme. We calculate it for both static devices and moving devices. We consider three cases of moving devices here. First we consider that 25% of total D2D devices are moving out of the cell. Then we apply it in our method considering the fact of 25% moving devices. Next we calculate for 50% and 75% moving devices also in the same way. In this paper Q =Z= 8, B and C are variable. The speeds of the devices are considered as 36 km/hr.

4.1 Comparison of SE for Only D2D Devices

In this case we are considering only the D2D devices. There is no consideration of cellular devices. As, in our method, some of the D2D devices are dynamic in nature, we take the consideration of intra-cell and inter-cell communication changing probability to calculate the spectral efficiency of the network. We have seen that spectral efficiency is increasing with the increase of moving D2D devices.

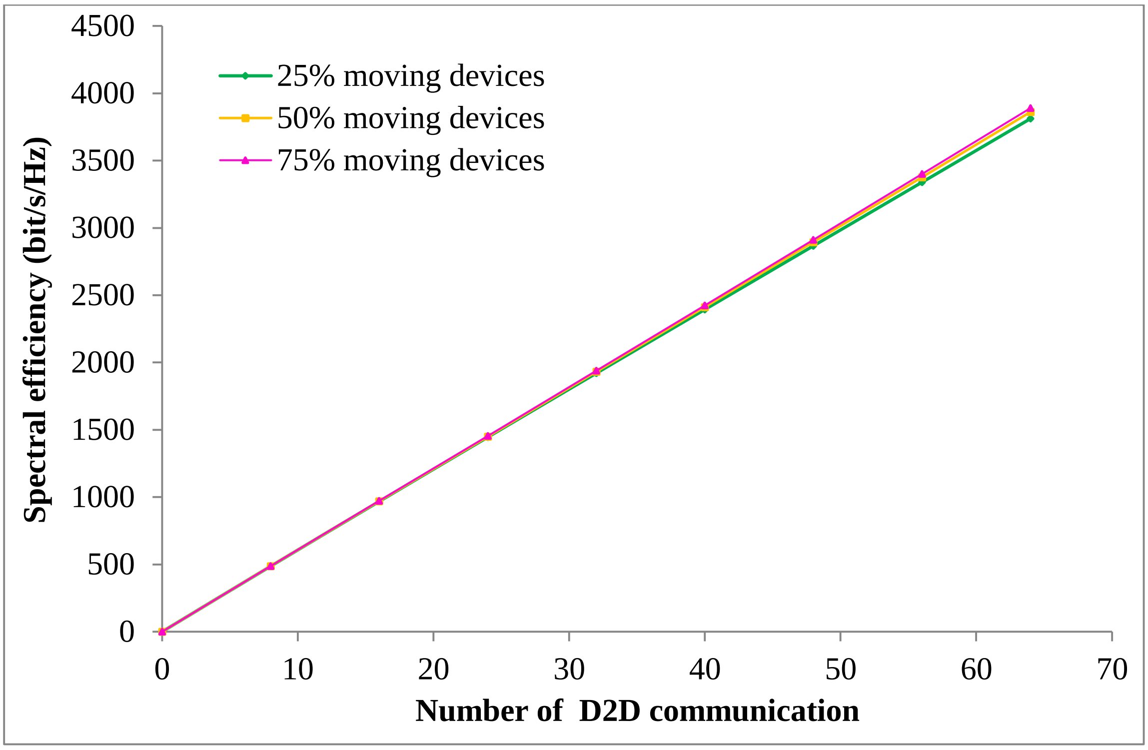

Figure 4.1: Comparison of spectral efficiency for only D2D devices.

In Figure 5 we are considering only the D2D devices. So, the interferences coming from cellular devices to D2D devices is not present here. We take the spectral efficiency of the network for 25%, 50% and 75% moving D2D devices of all D2D devices.

4.2 Comparison of SE for Only Cellular Devices

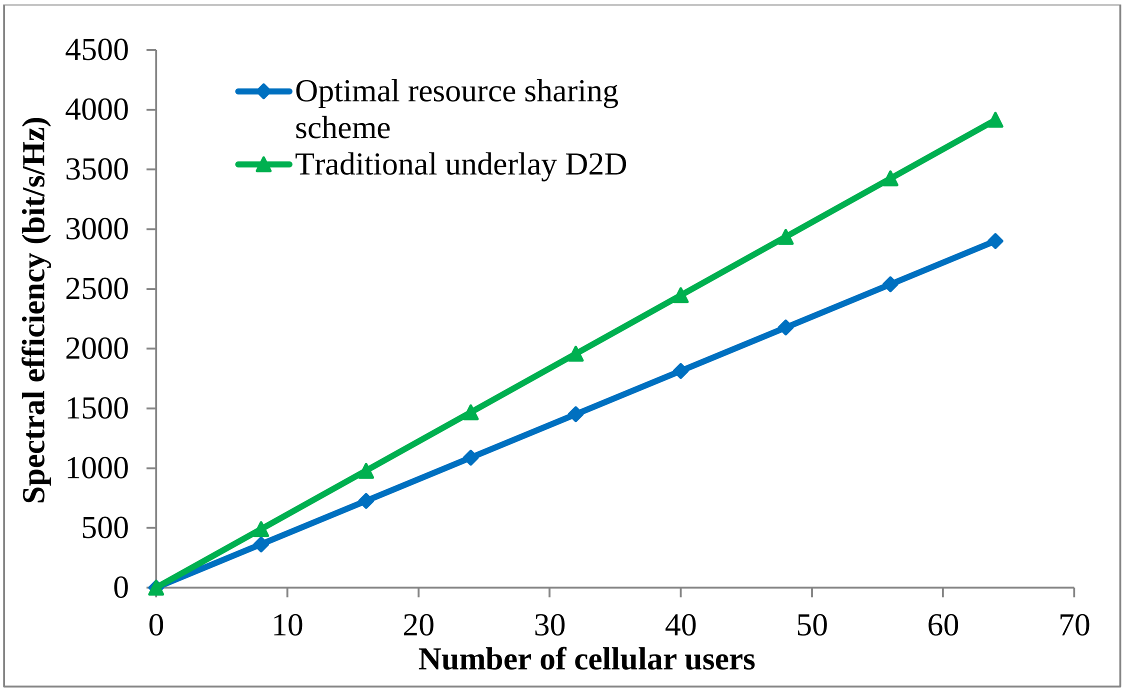

Figure 4.2: Spectral efficiency comparison for only cellular devices.

We compare spectral efficiency of previously discussed two schemes discussed in section 3.1 and 3.2 for only cellular devices in Figure 4.2. We have seen that underlay D2D discussed in section 3.2 performs better than optimal resource sharing scheme discussed in section 3.1 in terms of spectral efficiency.

4.3 Comparison of Spectral Efficiency for Dynamic D2D Devices:

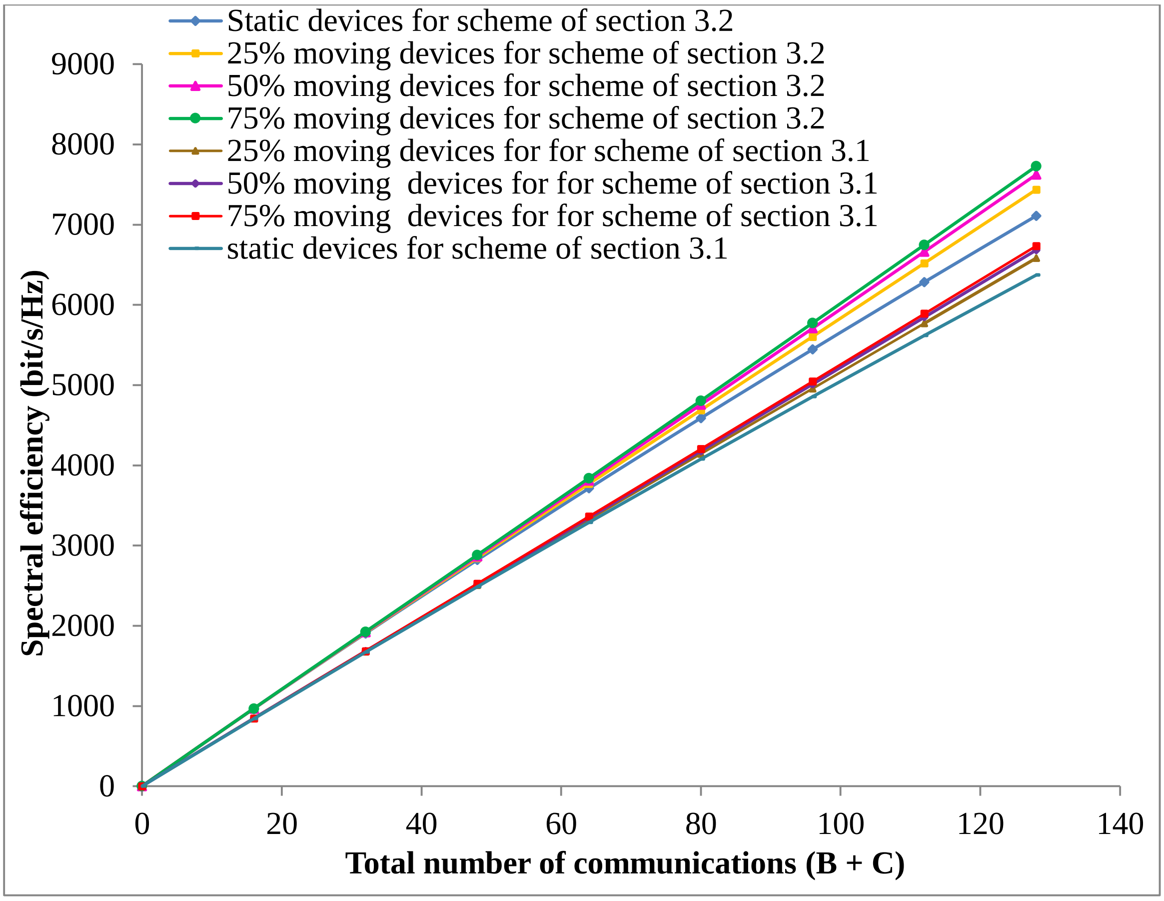

Figure 4.3: Comparison in terms of spectral efficiency with different schemes.

In Figure 4.3 comparison in terms of spectral efficiency for different schemes is done. We calculate SE for both static and dynamic devices here. First we calculate the SE of traditional underlay D2D communication discussed in section 3.2 and optimal resource sharing scheme discussed in section 3.1. First, in both the cases we assume that there are no moving devices inside the system. Then we calculate SE for 25%, 50% and 75% moving devices of total D2D devices for both the scheme described before in section 3.2 and section 3.1.

We have noticed that SE is increased with the increment of moving devices for respective schemes. We set 8 as the number of resource blocks while doing these calculations of spectral efficiency. If we can increase the number of resource blocks inside a system then SE will also increase as more resource blocks results in less interference between the devices.

Chapter 5

Conclusion

In this paper, we propose an effective method for resource allocation to improve the spectral efficiency of the network for underlay D2D communication. First we have discussed traditional underlay D2D communication and optimal resource sharing scheme for static users and equations are also formulated for this case. Then we consider our proposed algorithm for dynamic devices and modify the equations accordingly for our purpose. In this method we can efficiently serve large number of devices with a limited number of resource blocks. We consider both the intra-cell interference and inter-cell interference together to calculate the overall interference. Also, a minimum SINR is considered for cellular communications to guarantee the quality of service (QoC). We use the Gauss-Markov mobility model while calculating the intra and inter-cell communication changing probability.

Future Work

Here we assume that all the cells are identical in shape and there are same numbers of nodes in each cell. We also assume that speeds of all the devices within a cell are same. Taking the account of devices with different velocities in the same cell in resource allocation algorithm is left for future work. Validation of the results using popular simulation tools is also an important aspect for future.

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