Efficient Resource Allocation and Sectorization for Fractional Frequency Reuse (FFR) in LTE D2D Systems

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Table of Contents

List of Tables

List of Figures

List of Acronyms

LTE	LONG TERM EVOLUTION
D2D	DEVICE TO DEVICE COMMUNICATION
FFR	FRACTIONAL FREQUENCY REUSE
NSN	Nokia Siemens Networks
ICI	Inter-cell interference
ITU	International Telecommunication Union
IMTA	International Mobile Telecommunications-Advanced
eNB	evolved NODE B
P2P	Peer-to-Peer
WSN	Wireless sensor network
SINR	Signal to interference plus noise ratio

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Abstract

The Fractional Frequency Reuse (FFR) is a resource allocation technique that can effectively mitigate inter-cell interference (ICI) in LTE based HetNets and it is a promising solution. Various FFR schemes have been suggested to address the challenge of interference in D2D systems. In this paper, we study the scopes of interference mitigation and capacity improvement. We propose a resource allocation scheme that gradually varies frequency resource share with distance from the eNodeB for both macrocellsand in order to attain better utilization of the resources. This is performed effectively using three layers in the cell. The proposal also employs high number sectors in a cell, low interference and good frequency reuse. Monte-Carlo simulations are performed, which show that the proposed scheme achieves significantly better throughput compared to the existing FFR schemes.

Chapter 1

Introduction

D2D communication in cellular networks is defined as direct communication between two mobile users without traversing the Base Station (BS) or core network.D2D communication is generally non-transparent to the cellular network and it can occur on the cellular frequencies (i.e., inband) or unlicensed spectrum (i.e., outband).

In a traditional cellular network, all communications must go through the BS even if both communicating parties are in range for D2D communication. This architecture suits the conventional low data rate mobile services such as voice call and text message in which users are not usually close enough for direct communication. However, mobile users in today's cellular networks use high data rate services (e.g., video sharing, gaming, proximity-aware social networking) in which they could potentially be in range for direct communications (i.e., D2D). Hence, D2D communications in such scenarios can highly increase the spectral efficiency of the network. Nevertheless, the advantages of D2D communications are not only limited to enhanced spectral efficiency. In addition to improving spectral efficiency, D2D communications can potentially improve throughput, energy efficiency, delay, and fairness.

A constant need to increase the network capacity for meeting the growing demands of the subscribers has led to the evolution of cellular communication networks from the first generation (1G) to the fifth generation (5G). There will be billions of connected devices in the near future. Such a large number of connections are expected to be heterogeneous in nature, demanding higher data rates, lesser delays, enhanced system capacity and superior throughput. The available spectrum resources are limited and need to be flexibly used by the mobile network operators (MNOs) to cope with the rising demands. An emerging facilitator of the upcoming high data rate demanding next generation networks (NGNs) is device-to-device (D2D) communication.

Efficient Resource Allocation and Sectorization for Fractional Frequency Reuse (FFR) in LTE D2D Systems:

1.1 Background and Motivation

Device-to-Device (D2D) communication is a new technology that offer many advantages for the LTEadvanced network such us wireless peer-to-peer services and higher spectral efficiency. It is also considered as one of promising techniques for the 5G wireless communications system and used in so many different fields such as network traffic offloading, public safety, social services and applications such as gaming and military applications.

Future cellular systems are changing rapidly because of the proliferation
Of smart phones, tablets and other media hungry devices. Specifically with the
Advancement of the smart gadgets, the demand for broadband application services has dramatically increased over the past few years. Recent Ericsson Mobility Report indicates that the exponential growth in the mobile data traffic will reach a nine-fold escalation by the year 2020 . Global mobile data traffic was 1.5 Exabyte's (EB) per month by the end of 2013, raises up to 2.5 EB per month at the end of 2014, which translates to 66.6 percent growth in the global mobile data traffic recorded in the year 2014. Moreover, updated Cisco industry report for this year forecasts that the mobile data traffic is expected to grow up to 24.3 EB per month by 2019.

To fulfill the future demands of the fifth generation (5G) wireless networks, wireless researchers have paid much attention on spectrum efficient solutions. Such data deluge is a natural outcome of the increasing number of mobile devices, Internet of Things, and smart city infrastructures, which inherently introduce machine type communications to the cellular networks. To meet these ambitious demands, ultra-dense HetNets have already been considered as a promising solution since densification of the network have the ability to boost network coverage and capacity, while reducingoperational and capital expenditures.

Next generation wireless communication systems aim to meet the high data rates, increased capacity, extended coverage, low complexity and low latency requirements defined by International Mobile Telecommunications-Advanced (IMTA) of the International Telecommunication Union (ITU). The formulation of the Long Term Evolution (LTE) into LTE-Advanced (LTE-A), make it possible to meet the IMTA requirements (peak data rates of 1Gbit/s for the downlink and 500Mbits/s for the uplink, and extended bandwidth support up to 100MHz) for the fourth generation (4G) mobile communication.

Hence, the interference cancellation or management schemes are imperative between cellular links and D2D links in order to avoid the decrease of total cell throughput.

To solve this problem, research on reducing interference between D2DRs and mUEs in cellular networks supporting D2D communication was conducted. When earlier studies are examined in, they suggested the technique of using D2D links' channels first if frequency bands were not already being utilized in the mBS, and observing the D2D links' channel status if all frequency bands are used and getting assigned the best channel from mBS.

Considering the increasing number of machine-type communications and context aware services/applications, another potential spectral efficient approach is D2D communication which provisions three main advantages over conventional HetNets:

1) **Proximity gain** provides high bit rates, low delay, and high energy efficiency as a result of short range between DUEs.

2) **Reuse gain** is obtained by sharing the radio resources exploited by higher level tiers.

3) **Hop gain**is achieved by eliminating the role of eNB by establishing a direct link between DUEs.

The motivation for D2D come directly from the user requirements and D2D communications will serve specific future needs. These needs include new types of short range services and data intensive short range applications. The emergence of context-aware and multimedia applications have constituted the motivation of using D2D technology.D2D communications will allow new types of services such multimedia downloading, video streaming, online gaming and peer-to-peer (P2P) file sharing.

In D2D communications the cellular network can handle phone calls and internet data traffic without additional networks load from the promotional material. However, there are many complexities of setting up and to deploy D2D communications in LTE advanced networks. These challenges and complexities include:

- D2D devices cause interference to the cellular users which affect the performance of the network devices.

- D2D communications define new QoS requirements that must be addressed.

Hence, LTE-advanced present two techniques of D2D communications that use Session

Initiation Protocol (SIP) and Internet Protocol (IP).These techniques have the benefit of providing the control over the D2D connectivity to the operator. The integration of D2D communications in LTE-A must take into account LTE-A interfaces and network elements.

D2D communication refers to technology that enable the communication between multiple D2D devices or users without having base station or intermediary devices on a network [4] .This makes D2D communication a key technology to solve some problems such as coverage and interference management .It increase also spectrum utilization and capacity and enhance network performance and throughput .Differing from the Bluetooth and Wi-Fi-direct, we categorize the D2D communication in cellular network based on the spectrum in which D2D communications occurs. Thus, D2D communication can occur on cellular system and in this case called Inband D2D or can occur in unlicensed spectrum and is called Outband D2D.

So the motivation of choosing **Inband communications** is usually the high control over licensed spectrum.

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1.2 CLASSIFICATION OF D2D COMMUNICATION

D2D communication in cellular network can be categorized into both

1) **Inband D2D**

2) **Outband D2D**

Based on the spectrum in which D2D communications occurs.

D2D communications is divided into two modes or categories called ' Inband underlay mode ' when the D2D communications use the cellular resources and spectrum and ' Inband overlay mode 'when cellular resources are allocated for the two D2D end devices that communicate directly.

High control over licensed spectrum is the key motivating factor for choosing the Inband D2D communication.

In other hand, the main motivation of using Outband D2D communications is the capacity to eliminate the interference between D2D links. Furthermore, Outband D2D communications is faced with a lot of challenges in the coordination between different bands.

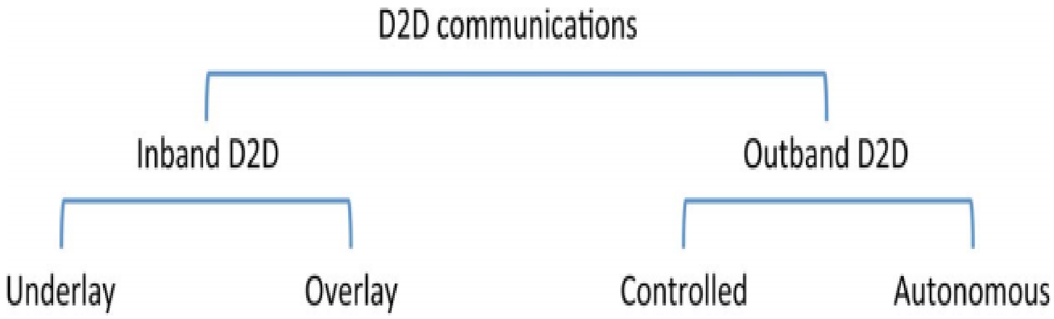

Fig 1.1 Classifications of D2D

Inband Communication

The motivation for choosing inband communication is the high control over licensed spectrum.Results show that QoS provisioning had lot of requirements by the consideration of the uncontrollability of interference in the unlicensed spectrum. In [3] the feasibility of D2D communications and its impacts in licensed spectrum are studied by simulation and analysis of different scenarios and authors show that by tolerating the increase of interference in licensed spectrum the D2D communication will be possible.
To improve the spectrum efficiency the D2D inband can reuse the time and frequency resources by d2D users (i.e. Underlay) or allocating time and frequency resources occupied by D2D users (i.e. overlay).
Under this, Inband communications can be divided into **underlay and overlay** categories.

Mainly In short

- Use the cellular spectrum for both D2D and cellular links.
- It has high control over cellular (licensed) spectrum.

- Interference in the unlicensed spectrum is uncontrollable which imposes constraints for QoS provisioning.

Undelay Inband D2D mode

In underlay inband mode, cellular and D2D communications share the same radio resources to date, most of the papers in literature are dedicated to D2D communications underlaying cellular network.

Overlay Inband D2D mode

In this mode, cellular and D2D are given dedicated cellular resources and those cellular resources are subtracted from cellular users in order to eliminate interference for the D2D communications on cellular transmissions.

Outband D2D communication

Nowadays, Outband D2D communication is attracting the attention of many researchers .In this category, D2D communication is performed in the unlicensed spectrum such as ISM 2.4G which made the interference between D2D and cellular communications impossible. On the other hand, 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.

The coordination between two different bands for achieving Outband D2D communication has a lot of challenges because in most cases the D2D communications occur in the above mentioned extra interface.Outband D2D communication can be classified into two categories or modes depend on the occurrence of the second interface .These modes are called controlled mode when the second interface in under cellular network or autonomous when D2D control is done by users and the occurrence of the second interface is not under cellular network.

Mainly In short

- D2D links exploit unlicensed spectrum.
- To eliminate the interference issue between D2D and cellular link.
- Requires an extra interface and usually adopts other wireless technologies (Wi-Fi Direct, Zig Bee).
- May suffer from the uncontrolled nature of unlicensed spectrum.

Needs cellular devices with two wireless interfaces.

D2D Outband communications: Controlled mode

In this category of D2D communications, all the literature propose to use the cellular network advanced management features to control D2D communication in order to improve the efficiency and reliability of D2D communications and to improve also the system performance in terms of throughput, power efficiency and multicast.

D2D Outband communications: Autonomous mode

Nowadays, there are very few works on this category. Autonomous D2D communication is motivated by reducing the overhead of cellular network. This category does not require any changes at the BS (eNB) and can be deployed easily.

1.3 Common FFR Schemes in D2D Systems:

The commonly known schemes for FFR, while considering deployment in D2D systems, are briefly described in this section.

Strict FFR

A cell is partitioned into two regions in this scheme: the center zone and the edge zone. For a cluster of N cells, the frequency band is divided into (N+1) sub-bands. The center zones of all cells are allocated a common sub-band. The rest of the sub-bands are allocated to the edge zone of the cells depending on the frequency reuse factor (FRF). Here, FRF is 1 and N for the center zone and the edge zone, respectively. A HeNB in the center zone uses the sub-band that is used by the eNB in the edge zone. Similarly, a Home eNB in the edge zone uses the sub-band that is used by the eNB in the center zone.The throughput maximizes when the center zone radius is set to 0.65 times the macrocell radius.

Soft FFR

A cell is partitioned into center zone and edge zone. For a cluster of N cells, the frequency band is divided into N sub-bands. The edge zones of the cells in a cluster are allocated different sub-bands and the center zone uses the sub-band selected for the neighboring cell's edge zone. Similar to strict FFR, a HeNB in the center zone uses the sub-band that is used by the eNB in the edge zone and a HeNB in the edge zone uses the sub-band that is used by the eNB in the center zone.

FFR-3

A cell is partitioned into center zone and edge zone along with three sectors. The frequency band is divided into four sub-bands, namely, A, B, C and D where sub-band A is made larger than others. Sub-band A is allocated to the center zone and the remaining three sub-bands are allocated to the edge zone of the three sectors. Here, FRF is 1 and 3 for the center zone and the edge zone, respectively. A HeNB in the center zone uses all the sub-bands except the sub-band that is used by the eNB in the center zone and a HeNB in the edge zone uses all the sub-bands except the one that is used by the eNB in that particular zone.The throughput maximizes when the center zone radius is set to 61 percent of the macrocell radius.

Optimal Static FFR (OSFFR)

Proposes OSFFR. Here, a cell is partitioned into center zone and edge zone along with six sectors. The frequency band is divided into seven sub-bands where one of the sub-bands is made larger than others and it is allocated to the center zone. The remaining six sub-bands are allocated to the edge zone of the six sectors. Here, FRF is 1 and 6 for the center zone and the edge zone, respectively. A HeNB in the center zone uses all sub-bands, except the one used in the center zone by the eNB as well as the sub-bands used by the eNB in the edge zone of the same sector and in the two edge zones adjacent to that sector. A HeNB in the edge zone uses all sub-bands, except the sub-band used by the eNB in the same edge zone.The throughput maximizes when the center zone radius is set to 54 percent of the macrocell radius.

3-Layer/3-Sector FFR

Proposes this scheme. Here, a cell is partitioned into three zones: inner or center zone, intermediate zone and outer zone along with three sectors. The frequency band is divided into four sub-bands. One sub-band is allocated to the center zone. The rest three sub-bands are allocated to the intermediate zones with FRF 3. Similarly, these three sub-bands are also allocated to the outer zones with FRF 3. However, the same two sub-bands are not allocated to the intermediate zone and outer zone of the same sector. A HeNB, whether it is in the center zone, intermediate zone or outer zone, uses all sub-bands except the one used by the eNB in its own zone.

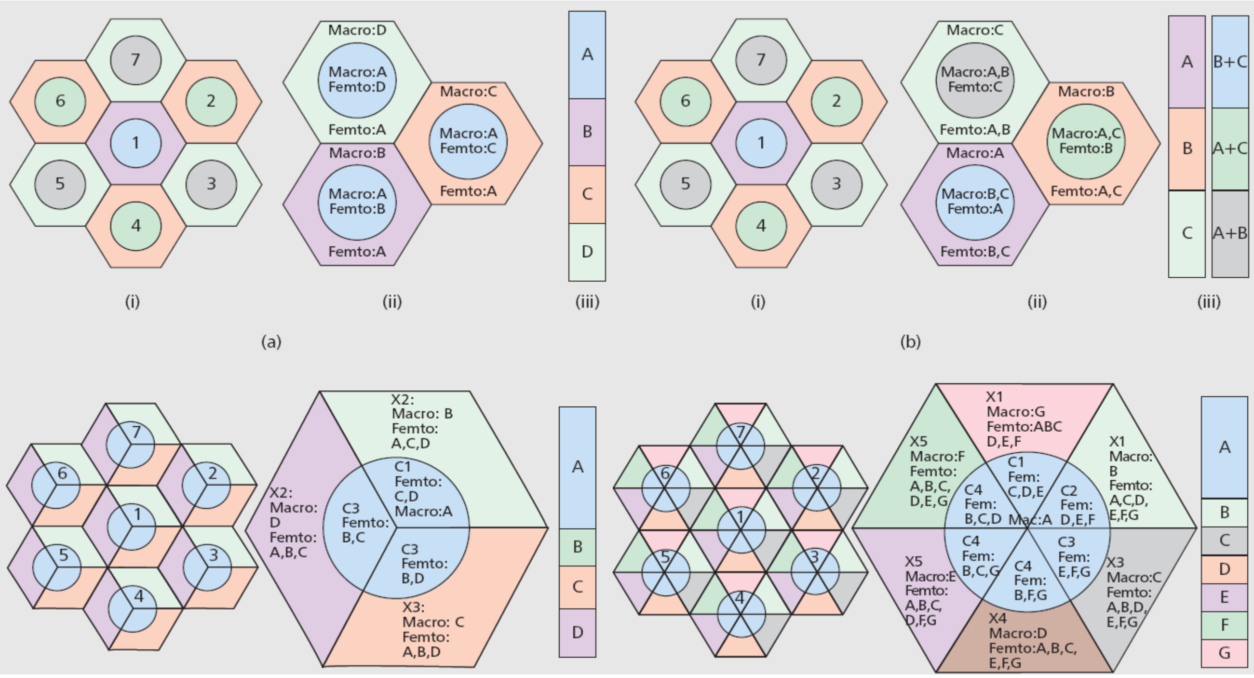

Fig1.2: Strict FFR, Soft FFR, FFR-3, Optimal Static FFR (OSFFR)

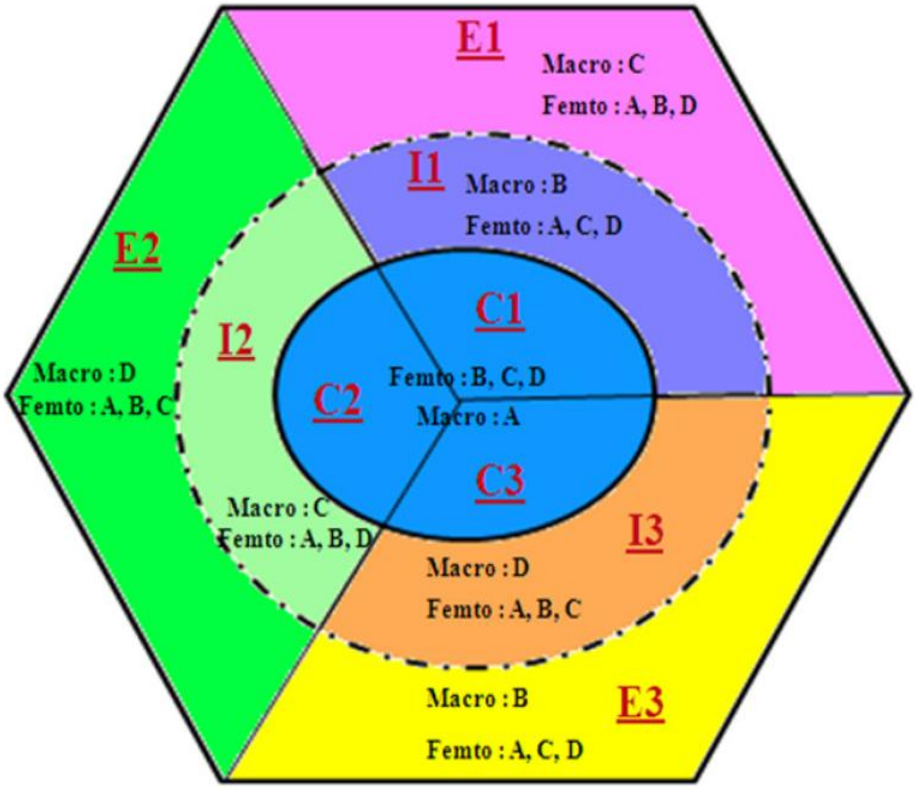

Fig 1.3: 3-layer/3-sector FFR

Chapter 2

Overview of Efficient Resource Allocation and Sectorization for Fractional Frequency Reuse (FFR) in LTE D2D Systems

2.1 Introduction

The Evolution of Cellular Technology :

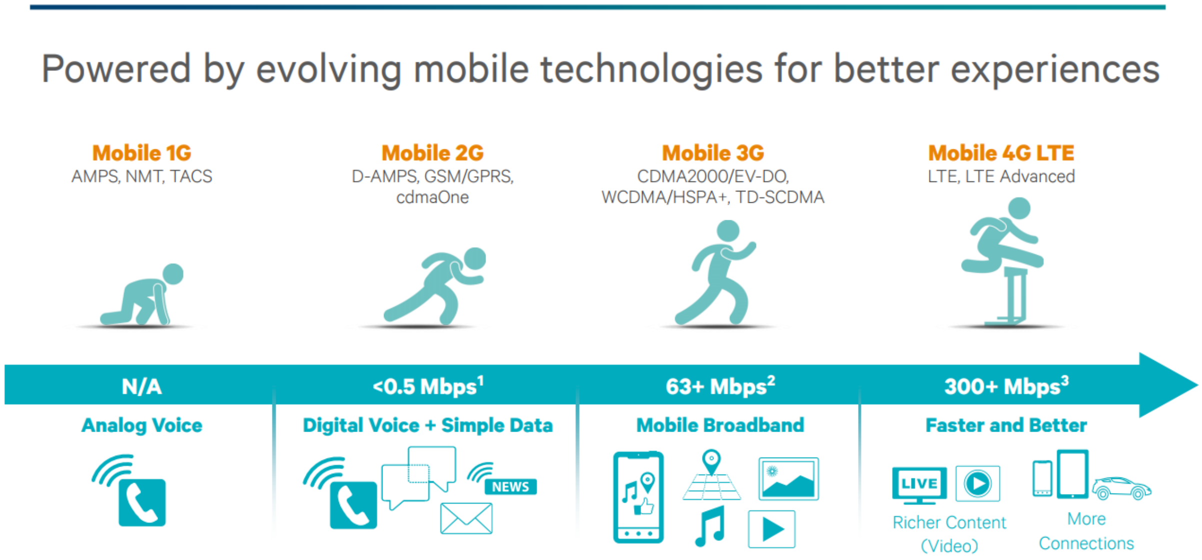

Fig: 2.1 Evolution of Cellular Technologies

1G: First Generation Cellular Phones

In the 1970s, the First Generation, or 1G, mobile networks were introduced. These systems were referred to as cellular, which was later shortened to "cell", due to the method by which the signals were handed off between towers. Cell phone signals were based on analog system transmissions, and 1G devices were comparatively less heavy and expensive than prior devices. Some of the most popular standards deployed for 1G systems were Advanced Mobile Phone System (AMPS), Total Access Communication Systems (TACS) and Nordic Mobile Telephone (NMT). The global mobile phone market grew from 30 to 50 percent annually with the appearance of the 1G network, and the number of subscribers worldwide reached approximately 20 million by 1990.The main technological development that distinguished the First Generation mobile phones from the previous generation was the use of multiple cell sites, and the ability to transfer calls from one site to the next as the user travelled between cells during a conversation. The first commercially automated cellular network (the 1G generations) was launched in Japan by NTT in 1979.

In 1984, Bell Labs developed modern commercial cellular technology, which employed multiple, centrally controlled base stations (cell sites), each providing service to a small area (a cell). The cell sites would be set up such that cells partially overlapped. In a cellular system, a signal between a base station (cell site) and a terminal (phone) only need be strong enough to reach between the two, so the same channel can be used simultaneously for separate conversations in different cells.

2G: GSM and GPRS Networks

In the early 1990s, 2G phones deploying GSM technology were introduced. Global System for Mobile communications, or GSM uses digital modulation to improve voice quality but the network offers limited data service. As demand drove uptake of cell phones, 2G carriers continued to improve transmission quality and coverage. The 2G carriers also began to offer additional services, such as paging, faxes, text messages and voicemail. The limited data services under 2G included WAP, HSCSD and MLS.

An intermediary phase, 2.5G was introduced in the late 1990s. It uses the GPRS standard, which delivers packet-switched data capabilities to existing GSM networks. It allows users to send graphics-rich data as packets. The importance for packet-switching increased with the rise of the Internet and the Internet Protocol, or IP. The EDGE network is an example of 2.5G mobile technology.In the 1990s, the 'second generation' (2G) mobile phone systems emerged, primarily using theGSM standard. These 2G phone systems differed from the previous generation in their use of digital transmission instead of analog transmission, and also by the introduction of advanced and fast phone-to-network signaling. The rise in mobile phone usage as a result of 2G was explosive and this era also saw the advent of prepaid mobile phones.

The second generation introduced a new variant to communication, as SMS text messaging became possible, initially on GSM networks and eventually on all digital networks. Soon SMS became the communication method of preference for the youth. Today in many advanced markets the general public prefers sending text messages to placing voice calls.

Some benefits of 2G were Digital signals require consume less battery power, so it helps mobile batteries to last long. Digital coding improves the voice clarity and reduces noise in the line. Digital signals are considered environment friendly. Digital encryption has provided secrecy and safety to the data and voice calls. The use of 2G technology requires strong digital signals to help mobile phones work properly.

2.5G Mobile Systems

The move into the 2.5G world will begin with General Packet Radio Service (GPRS). GPRS is a radio technology for GSM networks that adds packet-switching protocols, shorter setup time for ISP connections, and the possibility to charge by the amount of data sent, rather than connection time. Packet switching is a technique whereby the information (voice or data) to be sent is broken up into packets, of at most a few Kbytes each, which are then routed by the network between different destinations based on addressing data within each packet. Use of network resources is optimized as the resources are needed only during the handling of each packet.

The next generation of data heading towards third generation and personal multimedia environments builds on GPRS and is known as Enhanced Data rate for GSM Evolution (EDGE). EDGE will also be a significant contributor in 2.5G. It will allow GSM operators to use existing GSM radio bands to offer wireless multimedia IP-based services and applications at theoretical maximum speeds of 384 kbps with a bit-rate of 48 kbps per timeslot and up to 69.2 kbps per timeslot in good radio conditions. EDGE will let operators function without a 3G license and compete with 3G networks offering similar data services. Implementing EDGE will be relatively painless and will require relatively small changes to network hardware and software as it uses the same TDMA (Time Division Multiple Access) frame structure, logic channel and 200 kHz carrier bandwidth as today's

GSM networks. As EDGE progresses to coexistence with 3G WCDMA, data rates of up to ATM-like speeds of 2 Mbps could be available.

GPRS will support flexible data transmission rates as well as continuous connection to the network. GPRS is the most significant step towards 3G.

3G : High speed IP data networks

As the use of 2G phones became more widespread and people began to use mobile phones in their daily lives, it became clear that demand for data services (such as access to the internet) was growing. Furthermore, if the experience from fixed broadband services was anything to go by, there would also be a demand for ever greater data speeds. The 2G technology was nowhere near up to the job, so the industry began to work on the next generation of technology known as 3G. The main technological difference that distinguishes 3G technology from 2G technology is the use of packet switching rather than circuit switching for data transmission.

The high connection speeds of 3G technology enabled a transformation in the industry: for the first time, media streaming of radio and even televisioncontent to 3G handsets became possible.

In the mid 2000s an evolution of 3G technology begun to be implemented, namely High-Speed Downlink Packet Access (HSDPA). It is an enhanced 3Gmobile telephony communications protocol in the High-Speed Packet Access (HSPA) family, also coined 3.5G, 3G+ or turbo 3G, which allows networks based on Universal Mobile Telecommunications System (UMTS) to have higher data transfer speeds and capacity. Current HSDPA deployments support down-link speeds of 1.8, 3.6, 7.2 and 14.0 Mbit/s. Further speed increases are available with HSPA+, which provides speeds of up to 42 Mbit/s downlink and 84 Mbit/s with Release 9 of the 3GPP standards.

High-Speed 4G Mobile Networks

The current generation of mobile telephony, 4G has been developed with the aim of providing transmission rates up to 20 Mbps while simultaneously accommodating Quality of Service (QoS) features. QoS will allow you and your telephone carrier to prioritize traffic according to the type of application using your bandwidth and adjust between your different telephone needs at a moment's notice.

Only now are we beginning to see the potential of 4G applications. They are expected to include high-performance streaming of multimedia content. The deployment of 4G networks will also improve video conferencing functionality. It is also anticipated that 4G networks will deliver wider bandwidth to vehicles and devices moving at high speeds within the network area.Consequently, the industry began looking to data-optimized 4th-generation technologies, with the promise of speed improvements up to 10-fold over existing 3G technologies. It is basically the extension in the 3G technology with more bandwidth and services offers in the 3G. The expectation for the 4G technology is basically the high quality audio/video streaming over end to end Internet Protocol.The first two commercially available technologies billed as 4G were the WiMAX standard and the LTE standard, first offered in Scandinavia by TeliaSonera.

One of the main ways in which 4G differed technologically from 3G was in its elimination of circuit switching, instead employing an all-IP network. Thus, 4G ushered in a treatment of voice calls just like any other type of streaming audio media, utilizing packet switching overinternet, LAN or WAN networks via VoIP.

4G LTE data transfer speed can reach peak download 100 Mbit/s, peak upload 50 Mbit/s, WiMAX offers peak data rates of 128 Mbit/s downlink and 56 Mbit/s uplink.

2.2 Existing Models:

Device-to-Device Communication in Cellular Networks with Fractional Frequency Reuse -Huiling Zhu and Jiangzhou Wang

In this paper, a two-layer cellular model with 19 cells, as shown in Fig. 1, is used for analysis. In the two-layer cellular model, each cell is divided into two areas: central area and edge area. The same frequency is reused among the areas with the same pattern of shadow shown in the figure. In this network, the frequency within the central area of one cell is reused in every cell, while the frequency within the edge area of one cell is reused every three cells. The frequency reuse factor in the central area is one, whereas the frequency reuse factor in the edge area is 1/3. In the ith (i=1,…,19) cell, there is one base station (BS), i BS , located in the center of the cell. In each cell, one frequency can only be shared by one D2D pair and one CUE. According to [14], when the D2D pair is very close to a CUE, the frequency should not be shared between them. Therefore, in order to avoid strong interference, only one D2D pair located in the edge area can share the frequency with one CUE located in the central area. In Fig. 1, the first cell, i.e. 1 = i , is assumed as the reference cell, and 1 BSis the reference BS. In Fig. 1, a reference CUE shown by the black point in the central area of the first cell shares frequency with a D2D pair in the edge area, i.e. the linked two circle points. This paper investigates the performance for the D2D pair sharing the downlink resources of the cellular network for its transmission with the reference CUE in the central area of the first cell. Under this situation, all other eighteen BSs outside the first cell and the transmit DUE of the D2D pair will cause co-channel interference to the reference CUE in its downlink transmission. Also, all the nineteen BSs in the system will cause co-channel interference to the receive DUE of the D2D pair in their transmission

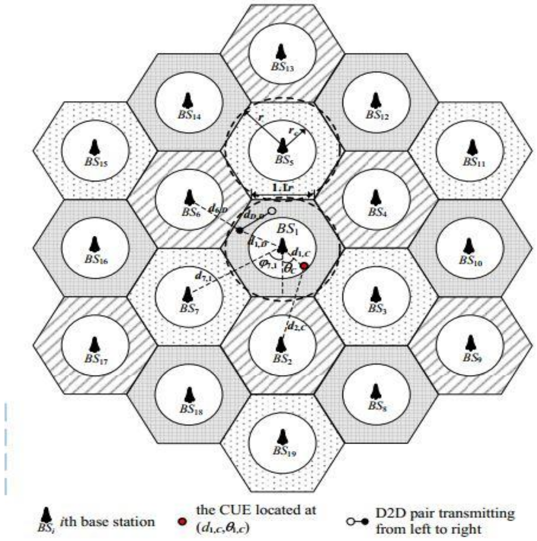

Figure 1 A two-layer cellular network with FFR

Considering FFR in cellular systems is an efficient method to improve the performance of the OFDMA cellular network, and D2D communication as an underlay to the cellular network can effectively improve the spectral and energy efficiency, in this paper, the performance of D2D communication is investigated as an underlay to the FFR based OFDMA system, in terms of spectral efficiency. The effects of the radius ratio of the central area to the whole cell is extensively studied. The following conclusions can be drawn.

1. Irrespective of the signal to noise ratio, the optimal radius radio of the central area to the whole cell is around 0.5.

2. The spectral efficiency increases with increasing the ratio of the power for the D2D transmission to the power for the cellular transmission

FFR-based Resource Allocation Scheme for Device-to-Device Communication-Syed Tariq Shah, JaheonGu, and Min Young Chung,Syed Faraz Hasan

Device-to-Device communication allows two cellular devices to communicate with each other without a base station.By relieving the base station from relaying data to and from different devices, D2D communication aims at increasing the system capacity. Long Term Evolution (LTE) is a recent technology that is rapidly attracting considerable attention. LTE-Advanced (LTE-A) to further enhance the communication experience. LTE-A is being explored from many difference perspectives, for example, MIMO, carrier aggregation and device-to-device (D2D) communication etc. There are two types of UEs in a network that supports D2D communication [1]. The first is the D2D UEs (DUEs) that do not communicate through eNB. The second is the cellular UEs (CUEs) that send their data through eNB using the conventional method. If CUEs

And DUEs operate on the same frequency, they can cause significant interference to each other. Therefore, intelligent resource allocation is extremely important for the effective use of D2D communication. Fractional Frequency Reuse (FFR) [2] allows the reuse of a frequency band by breaking it into smaller ones. Here in our proposed scheme …. An eNB controlled resource allocation scheme for D2D communication underlaying an LTE-A Time Division Duplex (TDD) network will use soft frequency reuse. It also uses SC-FDMA for evaluating D2D communication. On the other hand, the DUEs can reuse the uplink resources of CUEs. The main advantage of reusing the uplink resources is that eNB can effectively coordinate interference between CUEs and DUEs in comparison with the case where downlink resources are reused. Each cell within the proposed architecture is divided into four different sectors SC, S1, S2, and S3 as shown in Figure 1. The frequency band allocated to a cell is also divided into four partitions FC, F1, F2, and F3. According to the proposed scheme, a DUE can use any partition (FC, F1, F2, F3) except for the one allocated to its sector. The resource allocation starts with eNB gathering the information on channel gains of all UEs.

2.3System Model and Problem Formulation :

We consider a hexagonal multi-cell LTE femtocell based network with FFR deployment. We consider sectorization of the cells. We assume that the sectors in a cell are sequentially numbered clockwise around the cell and represented as *s* and there are *S* number of sectors in each cell. In addition, there can be different regions based on the distance from the macro eNB in each sector. This kind of regions in each sector will be termed as layers in this paper. We assume that the layers in a sector are represented as *l* where $l = 1$represents the center layer. *l* sequentially increases outwards and there are *L* number of layers in each sector. We assume that the sub-carriers are represented as *k* and there are *K* number of sub-carriers in the whole available bandwidth. The downlink SINR for macro-user *m* on sub-carrier *k* can be expressed by

$$SINR_m^k = \frac{P_M^k \; G_{m,M}^k}{N_0 \Delta f + \; \sum_{M' \neq M} P_{M'}^k \; G_{m,\; M'}^k + \sum_D P_D^k \; G_{m,D}^k} \qquad (1)$$

Where $G_{m,M}^k$ and $G_{m,M'}^k$ represent the channel gain, on sub-carrier *k*, between macro-user *m* and serving macrocell$M$ and between user *m* and neighbor macrocellsM', respectively. P_M^k and $P_{M'}^k$ are the transmit power on sub-carrier *k*, of serving cell M and whole neighbor cell set M', respectively. P_D^k is the transmit power of neighbor D2D on sub-carrier k. $G_{m,D}^k$ represents the channel gain between user *m* and neighbor D2D on sub-carrier *k*.N_0 is the white noise power spectral density, and Δf refers to the sub-carrier spacing. Δf is set to 15 kHz in LTE.

Similarly, the downlink SINR for femto-user *f* on sub-carrier *k* can be expressed by

$$SINR_d^k = \frac{P_D^k G_{d,D}^k}{N_0 \Delta f + \sum_M P_M^k G_{d,M}^k + \sum_{D' \neq D} P_{D'}^k G_{d,D'}^k} \qquad (2)$$

where $G_{d,D}^k$ and $G_{d,D'}^k$ represent the channel gain, on sub-carrier *k*, between D2D-user *d* and serving D2D cell*D* and between user *d* and neighbor femtocells *D'*, respectively. P_D^k and $P_{D'}^k$ are the transmit power on sub-carrier *k*, of serving cell *D* and whole neighbor cell set *D'*, respectively. P_M^k is the transmit power of neighbor macrocells*M* on sub-carrier k. $G_{d,M}^k$ represents the channel gain between user *d* and neighbor macrocells on sub-carrier *k*.

A macro- or D2D-user is represented as *u* where $u \in \{m,d\}$.The channel gain is dominantly affected by Rayleigh fading *H*, log-normal shadowing X_α, and path losses PL_u. So, the channel gain of a user *u* on sub-carrier *k* can be shown as follows:

$$G_{u,M\,or\,D}^k = 10^{(-PL_u + X_\alpha)/10} . \left| H_u^k \right|^2 \qquad (3)$$

Path loss is calculated according to two formulas, shown in Table 2 [10]. The practical capacity of a user *u* on sub-carrier *k* can be given by

$$C_u^k = \Delta f . \log_2 (1 + \alpha SINR_u^k) \qquad (4)$$

whereα a is a constant for target Bit Error Rate (BER), and defined by $\alpha = -1.5/\ln(5BER)$ [16]. Here, we set BER to 10^{-6}.

We assume that there are $N_m^{S,l}$ and N_d^S number of macro- and D2D-users in layer l of sector s, respectively. The overall cell throughput for macro-users can be expressed as follows:

$$R_M = \sum_{s=1}^{S}\sum_{l=1}^{L}\sum_{m=1}^{N_m^{s,l}}\sum_{k=1}^{K}\beta_m^k C_m^k \tag{5}$$

where β_m^k represents the sub-carrier assignment to macro-users. When the sub-carrier k is assigned to macro user m, $\beta_m^k = 1$ and otherwise, $\beta_m^k = 0$. Thus,

$$\beta_m^k \in \{0,1\}, \forall m. \tag{6}$$

Similarly, the overall cell throughput for D2D-users can be expressed as follows:

$$R_D = \sum_{s=1}^{S}\sum_{l=1}^{L}\sum_{d=1}^{N_d^{s,l}}\sum_{k=1}^{K}\beta_d^k C_m^k \tag{7}$$

Where β_d^k represents the sub-carrier assignment to D2D-users. When the sub-carrier k is assigned to D2D-user d, $\beta_d^k = 1$, and otherwise, $\beta_d^k = 0$. Thus,

$$\beta_d^k \in \{0,1\}, \forall f. \tag{8}$$

The total transmit power of a macro eNB P_{eNB} cannot exceed its maximum transmit power capability $P_{eNB}^{\max}$. So,

$$P_{eNB} = \sum_{s=1}^{S}\sum_{l=1}^{L}\sum_{m=1}^{N_m^{s,l}}\sum_{k=1}^{K}\beta_m^k P_M^k \le P_{eNB}^{\max} \tag{9}$$

Similarly, the total transmit power of a HeNB P_{HeNB} cannot exceed its maximum transmit power capability $P_{HeNB}^{\max}$. Assuming that a Home eNodeB serves a total of N_d^F number of D2D-users,

$$P_{HeNB} = \sum_{d=1}^{N_d^D}\sum_{k=1}^{K}\beta_d^k P_D^k \le P_{HeNB}^{\max} \tag{10}$$

The total cell throughput is $R_T = R_M + R_F$. So, the optimization problem can be formulated as follows while satisfying (9) and (10):

$$\begin{aligned}\max_{S,L,\beta_m^k,\beta_d^k} R_T = \max_{S,L,\beta_m^k,\beta_d^k} & \sum_{s=1}^{S}\sum_{l=1}^{L}\sum_{m=1}^{N_m^{s,l}}\sum_{k=1}^{K}\beta_m^k C_m^k \\ & + \sum_{s=1}^{S}\sum_{l=1}^{L}\sum_{d=1}^{N_d^{s,l}}\sum_{k=1}^{K}\beta_d^k C_m^k\end{aligned} \tag{11}$$

The optimization problem is NP-complete for which the solution is not evident. FFR schemes described in Section 2 are essentially few existing or already proposed sub-optimal solutions. In this paper, we propose a sub-optimal solution that achieves higher overall throughput identifying the solution closer to the optimum.

Considerations for a Sub-optimal Solution

We describe below some considerations that aim to reach a sub-optimal solution for use in practice. We assume that the assignment of sub-carrier *k* in layer *l* of sector *s* for macro- and femto-users are represented by $\beta^{k}_{m,s,l}$ and $\beta^{k}_{d,s,l}$, respectively. $\beta^{k}_{m,s,l}$ or $\beta^{k}_{d,s,l}$ are set to 1, if the sub-carrier *k* is assigned and set to 0, otherwise.

i. To limit CCI, a sub-carrier can be allocated to only one macro-user in each sector. So,

$$\sum_{l=1}^{L}\sum_{m=1}^{N_m^{s,l}} \beta^{k}_{m} \in \{0,1\}, \forall k.$$

ii. To limit cross-tier interference, we assume that the same sub-carriers are not allocated to macro- and femto-users in the same layer in a sector. Thus,

$\beta^{k}_{m,s,l} \neq \beta^{k}_{d,s,l}$ if $\beta^{k}_{m,s,l} = 1, \forall k.$

iii. The central layer can be allocated sub-carriers using FFR=1. Identifying these sub-carriers as k_C and the center layer as $l = C$,

$\beta^{k}_{m,s,l=C} = 1$, and $\beta^{k}_{m,s,l\neq C} = 0$, $k = k_C$.

Since 1 is the lowest frequency reuse factor, k_C may include a good number of sub-carriers from the available bandwidth.

iv. When $k \neq k_C$, to limit CCI, we assume that the same sub-carriers are not allocated to macro-users in adjacent sectors in a cell. Since sector $s+1$ and s-1are adjacent to sector *s*,

$\beta^{k}_{m,s,l} \neq \beta^{k}_{m,s+1,l}$, if $\beta^{k}_{m,s,l} = 1$, $k \neq k_C$

and

$\beta^k_{m,s,l} \neq \beta^k_{m,s-1,l}$, if $\beta^k_{m,s,l} = 1, \quad k \neq k_C$.

v. Since the two outer layers of adjacent cells lie next to each other, to limit CCI, we assume that the same sub-carriers are not allocated to macro-users in these outer layers. In a hexagonal multi-cell network, the sector of the adjacent cell, which is aligned with sector *s*, can be equivalently found as $\lfloor s + S/2 \rfloor$. Identifying the outer layers as $l = O$,

$\beta^k_{m,s,l=0} \neq \beta^k_{m,\left|s+\frac{s}{2}\right|,l=0}$, if $\beta^k_{m,s,l=0} = 1,\ k \neq k_C$

vi. When $\beta^k_{d,s,l} = 1$, as *l* decreases, the associated P^k_M can be decreased due to smaller path loss and the sub-carrier allocation causes less interference to neighboring cells. Similarly, as *l* decreases, the associated $G^k_{m,M'}$ decreases due to larger path loss from the neighbor macrocells and the sub-carrier allocation suffers from less interference.

vii. When $\beta^k_{m,s,l} = 1$, the associated $SINR^k_m$ improves as *l* decreases and so, the macro service can use the sub-carrier more efficiently. On the other hand, when $\beta^k_{d,s,l} = 1$, the associated $SINR^k_d$ improves as *l* increases because of reduced cross-tier interference and so, the D2D operation can use the sub-carrier more efficiently.

viii. $\beta^k_{d,s,l} = 1$ may be used repeatedly for different D2D together leading to increased D2D throughput. However, in this case, the HeNBs need to be installed at predesigned places to limit the co-tier interference and the cross-tier interference as well.

ix. A macro- or D2D-user can only be allocated one or more whole resource blocks (RBs). Each RB consists of 12 sub-carriers and so, it is 180 kHz wide. Let us assume that the *n* numbered RB contains sub-carriers {*n1, n2, n3, ..,nx, ..., n12*}. Thus,

if $\beta^k_{m,s,l} = 1$ where $k \in nx,$, then $\beta^{nx}_{m,s,l} = 1, \forall nx.$;

if $\beta^k_{d,s,l} = 1$ where $k \in nx,$ then $\beta^{nx}_{f,s,l} = 1, \forall nx.$.

x. It is possible to vary the resource share more gradually with distance from the eNB using higher value of *L*. *L* = 3 is physically realizable with tight radio planning and [12] proposes three layers in each sector. However, $L > 3$ is formidable and so, it may not be considered.

xi. Higher sectorization uses narrower antenna beamwidth at the eNB and thus, causes less inter-cell interference. So, a high value of S can reduce the inter-cell cross-tier interference. $S = 6$ is physically realizable with tight radio planning and [11] considers six sectors in each cell for FFR. However, $S > 6$ is formidable and so, it may not be considered.

2.4Proposed Scheme

In this section, we present a greedy heuristic algorithm, based on the considerations in Section 4, for frequency resource allocation with an attempt for a sub-optimal solution with better throughput. For simplicity, we assume uniform distribution of the users. To attain efficient use of sub-carriers, we propose higher resource share for macro use in areas closer to the eNB and also, higher resource share for D2D use in areas further away from the eNB. In order to materialize such variation in frequency allocation more gradually, we use high value for L and so, we set $L = 3$. [12] already proposes three layers with three sectors in each cell. Besides, to reduce the inter-cell cross-tier interference, our proposal uses six sectors. It is shown that a 6-sector cell, in general, can attain significantly higher cell throughput compared to a 3-sector cell [17]. The use of $S = 6$ along with $L = 3$ requires high number of antennas and a lot of cabling [18]. Also, it will engender high number of interferers and overlapping regions and so, a very delicate radio planning will be required [17]. However, these difficulties may be accepted due to the improvement in throughput shown in Section 6 to meet the high data rate demand.

Identifying the intermediate layers as $l = I$, we set $l \in \{O, I, C\}$. There are a total of 18 sub-areas, namely, O1, O2, O3, O4, O5 and O6 in the outer region; I1, I2, I3, I4, I5 and I6 in the intermediate region; C1, C2, C3, C4, C5 and C6 in the center region, as shown in Figure 1. We assume that the outer, intermediate and center regions are identified as $O_i^m, I_i^m \, and \, C_i^m$, respectively, for macro services in sector i. Similarly, the outer, intermediate and center regions are identified as $O_i^f, I_i^f \, and \, C_i^f$, respectively, for D2D services in sector i. We propose a resource allocation scheme based on the considerations in Section 4 with an attempt to minimize all kinds of interferences. To exemplify the resource allocation scheme, the available bandwidth is divided into 7 sub-bands (SBs),denoted as, A, B, C, D, E, F and G. Each sub-band consists of a number of complete resource blocks (RBs). The sub-bands A to F are sequentially numbered twice from 1 through 6 and also, from 7 through 12 (i.e., both SB_2 and SB_8 represent sub-band B). The sub-band G is denoted as SB_C. Algorithm 1 shows an example of allocation of sub-bands in different sub-areas for macro and femto services. Figure 1 illustrates this allocation.

Algorithm 1: Sub-band Allocation Algorithm

```
Let $SB_C$ be the sub-band allocated to the central layer for macro services using
  FFR=1
Make sub-band $SB_C$ larger compared to all other sub-bands
for i = 1 to 6 do
    $O_i^m \leftarrow SB_i$
    $I_i^m \leftarrow SB_{i+2} + SB_{i+4}$
    $C_i^m \leftarrow SB_C + SB_{i+2} + SB_{i+4}$
    $O_i^d \leftarrow SB_C + SB_{i+1} + SB_{i+2} + SB_{i+4} + SB_{i+5}$
    $I_i^f \leftarrow SB_C + SB_{i+1} + SB_{i+3} + SB_{i+5}$
    $C_i^f \leftarrow SB_{i+1} + SB_{i+3} + SB_{i+5}$
end for
```

Table 1 demonstrates the relative frequency resource share for macro use as well as D2D use in different layers. It is assumed that each of the sub-bands from A to F contains 6 RBs and the sub-band G contains 14 RBs. The radius of center and intermediate layers are chosen 0.4 and 0.7 times the macrocell radius, respectively. For macro services, when the same sub-band is used in adjacent layers, the sub-band is assumed to be uniformly used over the whole area and the frequency resource used per unit area is computed to determine the resource share in each layer. The cell is considered circular in this computation. For D2D services, the relative amount of sub-band allocation in different layers is used to compute the relative resource share. As Table 1 shows, there is an achievement of ample gradual decrease and increase in resource share with distance from the eNB for macro use and femto use, respectively, leading to an efficient utilization of the resources.

The sub-band sizes may vary and we propose a careful selection of sub-band sizes considering potential data rate requirements. Our proposal limits itself to a fixed resource allocation based on the available radio network planning (RNP) related information. It obviates the need for adaptive control. However, an extension of the proposal can be adaptive allocation considering the channel quality of the users at different frequencies as well as their current data rate demands. In this case, the resource share is adjusted with time among eNodeBs, sectors and layers. The channel-dependent scheduling (CDS) will be more efficient with the adaptive allocation. The eNodeBs may use a distributive control of adaptive resource allocation with an attempt for local optimization. For this purpose, new fields can be added to the Load Information message, which currently exists in the specification for exchange of information between neighboring eNodeBs over the X2 interface. These fields may contain information like the

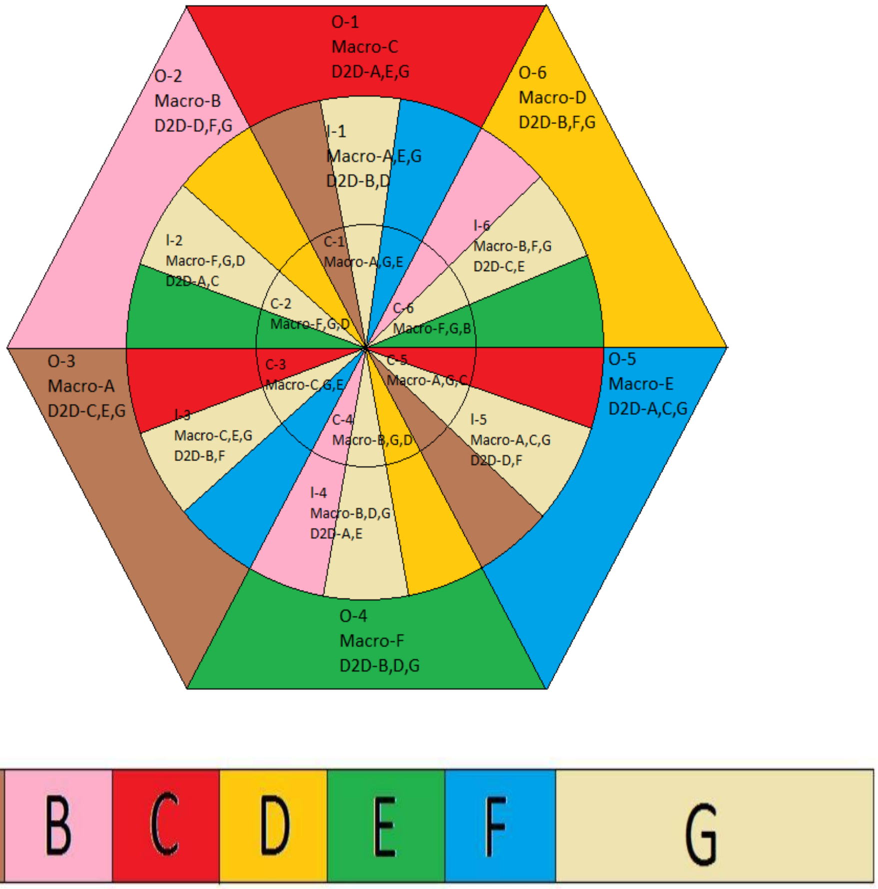

FIG 2.2 : FFR DEPLOYMENT IN PROPOSED SCHEME

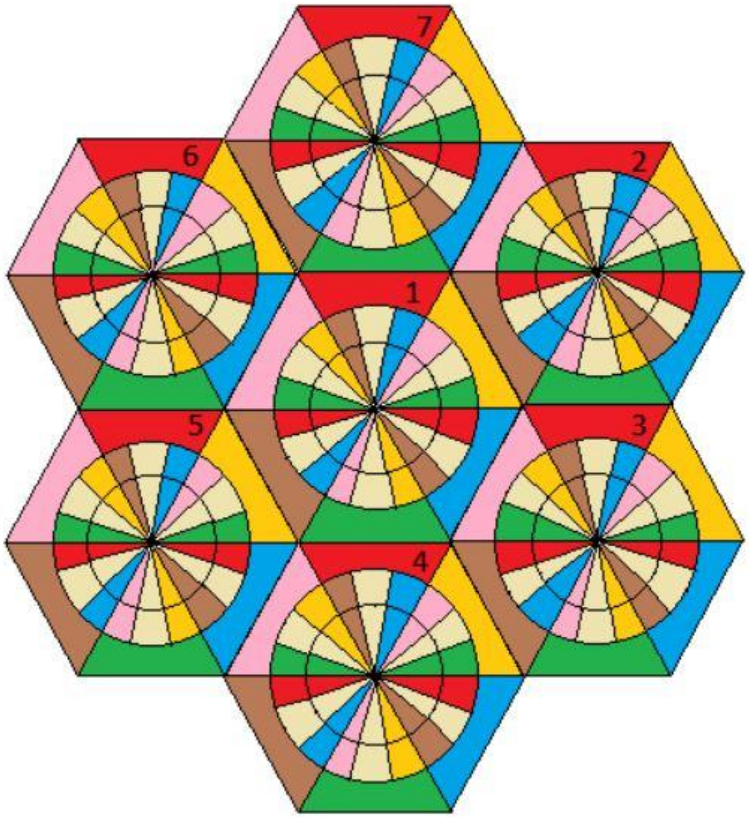

FIG2.3 : FFR DEPLOYMENT IN PROPOSED SCHEME.

2.5Algorithm : Sub-band Allocation Algorithm

```
Let $SB_C$ be the sub-band allocated to the central layer for macro services using FFR=1
Make sub-band $SB_C$ larger compared to all other sub-bands
for i = 1 to 6 do
    $O_i^m \leftarrow SB_i$
    $I_i^m \leftarrow SB_{i+2} + SB_{i+4} + SB_C$
    $C_i^m \leftarrow SB_C + SB_{i+2} + SB_{i+4}$
    $O_i^d \leftarrow SB_C + SB_{i+2} + SB_{i+4}$
    $I_i^d \leftarrow SB_{i+1} + SB_{i+5}$
end for
```

2.6 Mathematical Calculation :

Simulation Assumptions

Parameter	Macrocell	D2D
Cell Radius	280m	50m
eNB Transmit Power	15W,19W,22W	0.06mW
Sub-Band Size (A-F)	1.08 MHz(6 RBs)	
Sub-band Size(G)	2.52 MHz(14 RBs)	
Canter layer radius	0.4 of macrocell radius	
Intermediate layer radius	0.7 of macrocell radius	
Channel Model: Path Loss (Outdoor)	28+35log10(d) dB	60.05+4.32*10log(d)dB

Table 2.1 Simulation Assumptions

For macro (inner)

$$SINR_m^k = \frac{P_M^k \; G_{m,M}^k}{N_0 \Delta f \; + \; \sum_{M' \neq M} P_{M'}^k \; G_{m,\; M'}^k \; + \; \sum_D P_D^k \; G_{m,D}^k}$$

Now for the upper term,

PL = 28+ 35 log (280*0.2)
= 89.18 dB

$$G_{u,\,M}^k \; = 10^{(-PL_u + X_\alpha)/10} . |H_u^k|^2$$

We consider $X_\alpha = 0$ and $H_u^k = 1$

G = 10^(-89.18/10)
= 1.2* 10^-9

As in the inner cell there are three macro cells so the upper term
= 15*1.2*10^-9 +15*1.2*10^-9+15*1.2*10^-9*2.5
= 8.1*10^-8

The main signal gets interference from 3 ways so the power lost due to those interference are calculated below:

Now due to the interference

PL = 28+ 35 log (280*10.24)
= 149.01 dB
G = 1.256*10^-15

PL = 28+ 35 log (280*10)
= 148.65 dB
G = 1.364*10^-15

PL = 28+ 35 log (280*0.2)
= 89.18 dB
G = 1.2*10^-9*2

So now the denominator becomes
= 19*1.256*10^-15 + 22*1.364*10^-15*2 + 19*1.2*10^-9*2
= 4.56*10^-8

So,

$$SINR_m^k = 355381.62$$

And from that throughput we get as

$$C_u^k = \Delta f . log_2(1 + \alpha SINR_u^k)$$

C = 4.68*10^6* $\log_2$(1+0.123*355381.62)
= 72.15 MbPS

For macro (intermidiate)

$$SINR_m^k = \frac{P_M^k \; G_{m,M}^k}{N_0 \Delta f \; + \; \sum_{M' \neq M} P_{M'}^k \; G_{m,\; M'}^k \; + \; \sum_D P_D^k \; G_{m,D}^k}$$

Now for the upper term,

PL = 28+ 35 log (280*0.55)
= 104.56 dB

$$G_{u,\,M}^k \;= 10^{(-PL_u + X_\alpha)/10} . |H_u^k|^2$$

We consider $X_\alpha = 0$ and $H_u^k = 1$

G = 10^(-89.18/10)
= 3.5*10^-11

As in the inner cell there are three macro cells so the upper term
= 19*3.5*10^-11 +19*3.5*10^-11+19*3.5*10^-11*2.5
= 2.9925*10^-9

The main signal gets interference from 3 ways so the power lost due to those interference are calculated below:

Now due to the interference

PL = 28+ 35 log (280*10.42)
= 149.275 dB
G = 1.18*10^-15

PL = 28+ 35 log (280*9.89)
= 114.06 dB
G = 1.42*10^-15

Due to D2D,

PL = 28+ 35 log (280*0.55)
= 104.56 dB
G = 3.5*10^-11

So now the denominator becomes

= 19*(1.42+1.872)*10^-15+ 3*3.5*10^-11*0.06*10^-3

= 6.8848*10^-14

So,

$$SINR_m^k = 416.8$$

And from that throughput we get as

$$C_u^k = \Delta f . log_2(1 + \alpha SINR_u^k)$$

C = 4.68*10^6* $\log_2$(1+0.123*416.8)

= 26.71 MbPS

For macro (Outer)

$$SINR_m^k = \frac{P_M^k \ G_{m,M}^k}{N_0\Delta f \ + \ \sum_{M' \neq M} P_{M'}^k \ G_{m,\ M'}^k \ + \ \sum_D P_D^k \ G_{m,D}^k}$$

Now for the upper term,

PL = 28+ 35 log (280*3.73)

= 133.66 dB

$$G_{u,\,M}^k = 10^{(-PL_u + X_\alpha)/10} . |H_u^k|^2$$

We consider $X_\alpha = 0$ and $H_u^k = 1$

G = 10^(-133.66/10)

= 4.3*10^-14

As in the inner cell there are three macro cells so the upper term

= 22*4.3*10^-14

The main signal gets interference from 3 ways so the power lost due to those interference are calculated below:

Now due to the interference

PL = 28+ 35 log (280*9.16)+4.5 ; A_{dB} = 4.5
= 152.53 dB
G = 6.58*10^-16

Due to D2D,
PL = 28+ 35 log (280*9.16)+2.25 ; A_{dB} = 2.25
= 149.57 dB
G = 1.10*10^-15

So now the denominator becomes
= 19*6.58*10^-16*2 + 0.06*10^-3*1.10*10^-15*2
= 2.5*10^-14
So,

$$3SINR_m^k = 37.8$$

And from that throughput we get as

$$C_u^k = \Delta f . log_2(1 + \alpha SINR_u^k)$$

C = 1.08*10^6* $\log_2$(1+0.123*37.83)
= 2.71 MbPS

For D2D (inner):

In the inner layer there can't be any D2D service. The more it deviates from the centre the D2D will be needed. In the inner layer the macro throughput is maximum. So there is no need for D2D communication there.
For D2D (Intermidiate)

$$SINR_d^k = \frac{P_D^k\ G_{d,D}^k}{N_0 \Delta f\ +\ \sum_M P_M^k\ G_{d,\ M}^k +\ \sum_{D' \neq D} P_{D'}^k\ G_{d,D'}^k}$$

Now for the upper term,

PL = 60.05+ 4.32*10 log (50*3.73)
= 122.23 dB

$$G_{u,M}^k = 10^{(-PL_u + X_\alpha)/10} . |H_u^k|^2$$

We consider $X_\alpha = 0$ and $H_u^k = 1$

G = 10^(-122.23/10)
= 5.98*10^-13

As in the inner cell there are three macro cells so the upper term
= 0.06*10^-3*5.98*10^-13*2
= 7.176*10^-17

The main signal gets interference from 3 ways so the power lost due to those interference are calculated below:

Now due to the interference from Macro

PL = 60.05+4.32*10log(50*9.89)+15.02 ; A_{dB} = 15.02
= 191.46 dB

G = 7.14*10^-20

Due to D2D,

No interference due to D2D

So now the denominator becomes
= 19*7.14*10^-20*2
= 2.7132*10^-18

So,

$$SINR_m^k = 26.54$$

And from that throughput we get as

$$C_u^k = \Delta f . log_2(1 + \alpha SINR_u^k)$$

C = 2.16*10^6* $\log_2$(1+0.123*26.54)
= 4.5 MbPS

For D2D (Outer)

$$SINR_d^k = \frac{P_D^k \; G_{d,D}^k}{N_0 \Delta f \; + \; \sum_M P_M^k \; G_{d,\,M}^k + \; \sum_{D' \neq D} P_{D'}^k \;\; G_{d,D'}^k}$$

Now for the upper term,

PL = 60.05+ 4.32*10 log (50*6.71)
= 169.16 dB

$$G_{u,\,M}^k \;= 10^{(-PL_u + X_\alpha)/10} . |H_u^k|^2$$

We consider $X_\alpha = 0$ and $H_u^k = 1$

G = 10^(-169.16/10)
= 1.21*10^-17

As in the inner cell there are three macro cells so the upper term
= 0.06*10^-3*1.21*10^-17*2
= 4.185*10^-20

The main signal gets interference from 3 ways so the power lost due to those interference are calculated below:

Now due to the interference from Macro

No interference due to Macro

Due to D2D,

PL = 60.05+4.32*10log(50*9.16)+2.25 ; $A_{dB} = 2.25$
= 177.25 dB
G = 1.88^-18

So now the denominator becomes
= 22*1.88^-18*2
= 7.26*10^-22

So,

$$SINR_m^k = 57.64$$

And from that throughput we get as

$$C_u^k = \Delta f . log_2(1 + \alpha SINR_u^k)$$

C = 4.68*10^6* $\log_2$(1+0.123*57.64)
= 14.05 MbPS

2.7Results :

	Inner Layer	Intermediate Layer	Outer Layer
PL(dB)	89.18	104.56	133.66
PLm(dB)	297.66	153.42	151.81
PLd(dB)	89.18	30.73	149.56
Δf(Mhz)	4.68	4.68	1.08
α	0.123(const)	0.123(const)	0.123(conts)

SINR	355281.62	416.8	37.83
T(Mbps)	72.15	26.71	2.7

Table 2.2: Result for (Macro cell)

	Intermediate Layer	Outer Layer
PL(dB)	122.23	158.09
PLm(dB)	9.89	---
PLd(dB)	----	169.18
Δf(Mhz)	2.16	4.68
α	0.123(const)	0.123(const)
SINR	26.54	57.64
T(Mbps)	4.5	14.05

Table 2.3:Result for D2D cell

Conclusion

In the inner layer the power of macro is less and it increases gradually when we move to the outer layer.D2D is absent in the inner layer ,in the outer layer D2D is most powerful . Intermediate layer has small D2D power.In the model we proposed it is proposed for only single user.In future we wish to take this model further to include more users.

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