Islamic University of Technology (IUT)

# NUMERICAL METHOD FOR ESTIMATION OF FEASIBILITY OF DEVICE-TO-DEVICE COMMUNICATION IN LTE

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**November - 2015**

# Declaration

This is to certify that the project entitled "**NUMERICAL METHOD FOR ESTIMATION OF FEASIBILITY OF DEVICE-TO-DEVICE COMMUNICATION IN LTE"** is supervised by Md. Tawhid Kawser
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Dedicated To Our Parents

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# ABSTRACT

Device-to-device (D2D) communication is a promising new feature in LTE-Advanced networks. In conventional cellular networks, devices can only communicate with the base station via uplink or downlink paths. It fails to meet the ever-increasing demand of proximity-based social/commercial services and applications. The innovative architecture of D2D under laying LTE networks is therefore brought up to enable efficient discovery and communication between proximate devices. With D2D capability, devices in physical proximity could be able to discover each other using LTE radio technology and to communicate with each other via a direct data path. Apart from the general social/commercial use, the LTE D2D is further expected to address Public Safety communities.

This thesis is concerned with the numerical method for estimation of feasibility of device-to-device communication in LTE. Design requirements and choices in physical and MAC layer functions to support D2D discovery and communication under laying LTE networks are analyzed. In addition, a centralized scheduling strategy in base station is proposed to coordinate D2D data communication operating in LTE FDD downlink spectrum. The scheduling strategy combines multiple techniques, including mode selection, resource and power allocation, to jointly achieve an overall user performance improvement in a cell. Finally the performances of D2D data communication under laying LTE system are calibrated in a multi-link scenario via system-level simulation. D2D data communication is scheduled by base station with the proposed scheduling method and the hybrid D2D and cellular system is compared to pure cellular system, in which all traffics must go through base station.

The simulation results show that considerable performance gains are achieved by enabling direct D2D data paths to replace conventional uplink-plus-downlink data paths for local data traffic between proximate devices, and by allowing non-orthogonal re- source reuse between D2D and cellular downlink transmission. The initial tests demonstrate that the proposed scheduling method successfully mitigates interferences result- ing from the intra-cell resource reuse.

# List of Abbreviations

| | |
|---|---|
| AFH | Adaptive Frequency Hopping |
| AMC | Adaptive Modulation and Coding |
| AMP | Alternative MAC/PHY |
| AoA | Angle of Arrival |
| AoD | Angle of Departure |
| AP | Access Point |
| API | Application Programming Interface |
| ARQ | Automatic Repeat Request |
| AWGN | Additive White Gaussian Noise |
| BLE | Bluetooth Low Energy |
| BLER | Block Error Rate |
| BSS | Base Station Subsystem |
| CDF | Cumulative Distribution Function |
| CDM | Code Division Multiplexing |
| CFO | Carrier Frequency Offset |
| CoMP | Coordinated Multipoint |
| CP | Cyclic Prefix |
| CQI | Channel Quality Indication |
| C-RNTI | Cell Radio Network Temporary Identifier |
| CSI | Channel State Information |
| CSIT | Channel State Information at the Transmitter |
| CSMA/CA | Carrier Sense Multiple Access with Collision Avoidance |
| DL | Downlink |
| DM-RS | Demodulation RS |
| DPO | Distributed Power Optimization |
| DRX | Discontinous Reception |

| | |
|---|---|
| DTX | Discontinous Transmission |
| D2D | Device to Device |
| EESM | Exponential Effective Signal to Interference plus Noise Ratio Mapping |
| EPC | Evolved Packet Core |
| eNB | eNodeB |
| ESM | Effective SINR Mapping |
| E-UTRA | Evolved Universal Terrestrial Radio Access |
| E-UTRAN | Evolved Universal Terrestrial Radio Access Network |
| FEC | Forward Error Correction |
| FDD | Frequency Division Duplexing |
| FDMA | Frequency Division Multiple Access |
| GPS | Global Positioning System |
| GSM | Global System for Mobile Communications |
| HARQ | Hybrid Automatic Repeat Request |
| HeNB | Home Node B (over E-UTRAN) |
| IBSS | Independent Basic Service Set |
| ICI | Inter-Carrier Interference |
| ICIC | Inter-Cell Interference Coordination |
| InH | Indoor Hotspot |
| IoT | Internet of Things |
| ISI | Inter-Symbol Interference |
| ISM | Industrial Scientific and Medical |
| ITU | International Telecommunication Union |
| ITU-R | ITU Radiocommunication Sector |
| LTE | Long Term Evolution |
| LTE-A | Long Term Evolution Advanced |
| LoS | Line of Sight |
| L2 | Layer2 |
| L3 | Layer3 |

| | |
|---|---|
| MAC | Media Access Layer |
| MCI | Maximum Channel to Interference ratio |
| MCS | MAP Communication Server |
| MCN | Multihop Cellular Network |
| MIMO | Multiple-Input Multiple-Output |
| MIESM | Mutual Information Effective SINR Mapping |
| MNO | Mobile Network Operator |
| NFC | Near Field Communication |
| NLOS | Non Line of Sight |
| OFDM | Orthogonal Frequency Division Multiplexing |
| OFDMA | Orthogonal Frequency Division Multiple Access |
| PAPR | Peak to Average Power Ratio |
| PBCH | Physical Broadcast Channel |
| PCFICH | Physical Control Format Indicator Channel |
| PDCCH | Physical Downlink Control Channel |
| PF | Proportionally Fair |
| PFS | Proportional Fair Scheduling |
| PHICH | Physical Hybrid-ARQ Indicator Channel |
| PMI | Precoder Matrix Indication |
| ProSe | Proximity-Based Services |
| PRACH | Physical Random Access Channel |
| PSD | Power Spectral Density |
| PSS | Prixmary Synchronization Signal |
| PUSCH | Physical Uplink Shared Channel |
| PUCCH | Physical Uplink Control Channel |
| P25 | Project25 or APCO-25 |
| QoS | Quality of Service |
| RACH | Random Access Channel |
| RAN1 | Radio Access Network Working Group |

| | |
|---|---|
| RAR | Random Access Response |
| RA-RNTI | Random Access Radio Network Temporary Identifier |
| RB | Resource Block |
| RF | Radio Frequency |
| RI | Rank Indication |
| RIT | Radio Interface Technologies |
| RMa | Rural Macro |
| RRC | Radio Resource Control |
| RS | Reference Signals |
| Rx | Receiver |
| SAC | Set-based Admission Control |
| SAE | System Architecture Evolution |
| SA1 | Services Working Group |
| SA2 | Architecture Working Group |
| SC-FDMA | Single Carrier Frequency Division Multiple Access |
| SIG | Special Interest Group |
| SINR | Signal to Interference plus Noise Ratio |
| SISO | Single-INput Single-Output |
| SRIT | Sets of Radio Interface Technologies |
| SRS | Sounding Reference Signal |
| SSL | Secure Sockets Layer |
| SSS | Secondary Synchronization Signal |
| STA | Station |
| S-TMSI | SAE Temporary Mobile Subscriber Identity |
| TDD | Time Division Duplex |
| TDM | Time Division Multiplexing |
| TDMA | Time Division Multiple Access |
| TETRA | Trans European Trunk Radio System |
| TSG | Technical Specification Group |

| | |
|---|---|
| TTI | Transmission Time Interval |
| Tx | Transmitter |
| UE | User Equipment |
| UL | Uplink |
| UMa | Urban Macro |
| UMi | Urban Micro |
| UPnP | Universal Plug and Play |
| VoIP | Voice over IP |
| WAN | Wide Area Network |
| Wi-Fi | Wireless Fidelity |
| WBAN | Wireless Body Area Network |
| WIMAX | Worldwide Interoperability for Microwave Access |
| WLAN | Wireless Local Area Network |
| WPAN | Wireless Personal Area Network |
| ZC | Zadoff Chu |
| ZDO | ZigBee Device Object |
| 3G | 3r Generation |
| 3GPP | 3rd Generation Partnership Project |
| 4G | 4th Generation |

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## 1.6 Thesis Layout

This thesis comprises of five chapters.

**Chapter 1** represents the background of the present work, motivation, objectives and related work with this thesis.

**Chapter 2** discusses about fundamental principles of orthogonal frequency division multiplexing technique and characteristics of this modulated transmitted signal.

**Chapter 3** discusses on main drawback of OFDM that is Peak to Average Power Ratio problem and different techniques to reduce it.

**Chapter 4** focuses on coordinated scheduling of in-band D2D data communication

**Chapter 5** focuses on simulation Results

# CHAPTER 1 Introduction

The concept of Device-to-Device (D2D) transmissions underlaying LTE-Advanced network involves signals transmitted from one cellular user equipment (UE) being received at another cellular user equipment without passing through cellular infrastructural nodes (e.g. eNB, HeNB, etc.). This thesis is concerned with the numerical method for estimation of feasibility of device-to-device communication in LTE .Direct D2D technologies have already been developed in several wireless standards, aiming to meet the need for efficient local data transmission required by variant services in personal, public and industrial areas. Examples are Bluetooth, ZigBee in wireless personal area networks (WPANs), and Wi-Fi Direct in wireless local area networks (WLANs). The need of frequent communication between nearby devices becomes critical now with the capability of smart devices for content share, game play, social discovery, etc. whereas the conventional UL/DL transmission mode in cellular network fails to address this demand efficiently. Proximity-based social/commercial services and applications show great prospects. In order for operators to address this huge market and to offer their subscribers ubiquitous connections, operator-controlled direct D2D transmissions are studied in the context of next-generation wireless communication systems, such as LTE-Advanced and WiMAX. The D2D technologies aim to support the local discovery, identification and to enhance the network capacity and coverage.

Pushed by Qualcomm, D2D is proposed as a Rel.12 3GPP feature. D2D Study Item got approved in 3GPP SA1 (Services working group) in 2011, called ProSe (Proximity- based Services), and was complete in May 2013, at which time a corresponding Study Item began in RAN1 (Radio Access Network Working Group) to define the necessary support in the LTE radio interface. In the feasibilities study for ProSe [TR2, ], use cases and potential requirements are identified for discovery and communications between UEs that are in proximity, including network operator control, authentication, authorization, accounting and regulatory aspects. A part from general commercial/social use, it also addresses Public Safety communities that are jointly committed to LTE. The work in D2D physical and MAC layer specification is ongoing. Discussion includes evaluation requirements, D2D channel model, resource use, ProSe discovery and ProSe communication, etc.

This thesis surveys the development of both in-band (operating in operator's licensed band) and out-band (operating in unlicensed band) D2D technologies, together with opportunities and requirements of integrating D2D into LTE-Advanced networks, in order to understand the functions that LTE D2D should perform and the roles that network operators should play.

The design of LTE D2D physical and MAC layer is a wide topic. Our work outlines design requirements and choices in realizing two main features: D2D discovery and D2D data communication. Options and preferred solutions to incorporate in LTE the ability for devices to discover each other directly over the air and to communicate directly between them are identified.

Furthermore, a scheduling method in base station to coordinate D2D data trans- mission operating in the same licensed band is proposed. We target a very challenging topology in which local traffics are high enough to cause overload to the cellular net- work. The scheduling method aim to increase spectral efficiency gain (and thus offload the network) by allowing spatial reuse of the licensed spectrum between D2D and cellular UEs. The proposed scheduler does not have constraint on D2D range and number of D2D pairs in a cell. Therefore it can deal with different situations: both poor and goodD2D channel conditions, dense or sparse D2D deployment. Such generic D2D scheduling design is innovative, which permits to give an insight into system performances under simulation settings that approaching reality.

In Chapter 2, the background of D2D technologies is firstly surveyed. Existing out- band D2D technologies are presented. Focuses of literature studies on coexistence of D2D and cellular networks are also outlined, followed by the LTE D2D standardization process in 3GPP. Potential usages that might be promoted by cellular user proximity are listed. To support these usages, we analyze general functions that need to be provided by LTE D2D. Implementation challenges are also discussed.

Chapter 3 aims to identify physical and MAC layer design options and preferred solutions in order to enable devices in LTE to discover and communicate to each other directly over the air and to allow the LTE network to enable, manage, and control direct D2D discovery and communications under control of eNB. Related LTE physical and MAC specifications are firstly reviewed. Modifications and enhancements to LTE that allow incorporating D2D capability are then investigated, including D2D re- source use strategies, D2D synchronization, D2D discovery procedure and interference management for D2D data communication.

In Chapter 4, a centralized scheduling strategy in eNB to coordinate in-band D2D transmission under coverage is proposed. Firstly, literature studies on in-band D2D resource coordination are reviewed, followed by an in-depth discussion on important scheduling considerations. Different approaches and their interests are compared. Then studied scenario and scheduling objectives are described. Suggested scheduling strategies, combining multiple interference coordination techniques are detailed.

Chapter 5 evaluates the scheduler proposed in Chapter 4 through system-level simulation in a multi-link network model. A general description of evaluation methodology is firstly given. System simulation approaches, as well as channel models are presented. Choices of deployment scenario, network layout, parameters and assumptions are then detailed. Performance metrics, mainly the per user average throughput and the system spectral efficiency are simulated in different settings. Finally, the chapter is concluded by a discussion.

Chapter 6 concludes the thesis and future research directions are proposed.

# CHAPTER 2 Introduction to D2D technologies

## 2.1 Overview

The main purpose of this chapter is to survey the background of D2D technologies, The prospect of integrating D2D in cellular network, and possible requirements. As is well-known, out-band (operating in unlicensed band) D2D technologies have been developed decades ago. Nowadays there exist several different protocols and standards, such as Bluetooth, ZigBee, NFC, Wi-Fi Direct, etc. In section 2.2, existing out-band D2D technologies will be presented and compared. The coexistence of D2D and cellular transmission has been brought up long time ago in some pioneer literature studies.

Basically two forms of architecture are mentioned: multi-hop D2D relay and one-hop direct D2D between endpoints. The focus of literature studies are presented in section 2.3. Integrating D2D in LTE-Advanced network is a recent research topic that attracts many industrial interests and is being rapidly developed in the 3GPP LTE standardization. In section 2.4, firstly interests and challenges of providing D2D capabilities in LTE network are analyzed. Then the launch of LTE D2D as study items in 3GPP LTE standardization is introduced. Use cases and scenario that support D2D usages at service level are drafted in 3GPP and several examples are illustrated in this section.

## 2.2 Existing out-band D2D technologies

Face to the great prospect of applications with wireless D2D transmission in personal, public and industrial areas, many competitive out-band D2D technologies have already been developed. A brief comparison of several popular D2D standards are listed in the table below.



| Standard | Bluetooth | ZigBee | NFC | Wi-Fi Direct |
|---|---|---|---|---|
| Range (nominal) | 10m(~100m for Class 3 radio) | ~100m indoor LoS, ~ 1.6km outdoor LoS, extended range due to mesh network | <0.2m | ~200m |
| Discovery energy consumption | Low in v4.0 Low Energy, High otherwise | Low | Low | Fair with power management |
| Set-up time | <0.006s with BLE, <6s otherwise | <0.02s | <0.1s | <15s |
| Reliability | Good in v4.0 due to dedicated advertising channels | Good due to Mesh topology | Good due to point-to-point topology | Sometimes poor due to asynchronous channel scan |
| Security | vulnerable - discovery is unencrypted and no trusted authentication of device identification | vulnerable (similar as Bluetooth) | secure due to its extreme short range point-to-point topology, encryption supported | vulnerable (similar as Bluetooth) |
| Maximum Rate | 24 Mbps (v3.0 +HS) | 250Kbps | 106/212/424 Kbps | 250Mbps |
| Strength | wide range of service support due to co-existence of Bluetooth Classic/High Speed/Low Energy protocols | Low energy low cost, mesh networking capability, suitable for sensor network and infrared replacement | Extremely simple setup, security, suitable for contactless payment | High speed content sharing, game playing, etc. Pervasive use of Wi-Fi radio |

# Bluetooth

Bluetooth is probably the most well-known technology which is created by Ericsson in 1994 and was originally developed as RS-232 data cable replacement for short-range communications, such as phones, headsets, keyboards and mice. It was standardized as IEEE 802.15.1, for wireless personal area network (WPAN) with fixed, portable and moving devices within or entering personal operating space. Bluetooth technology now goes way beyond that. High-speed data transfer (up to 24 Mbit/s) is enabled by the use of a Generic Alternate MAC/PHY (AMP) in Bluetooth Core Specification Version

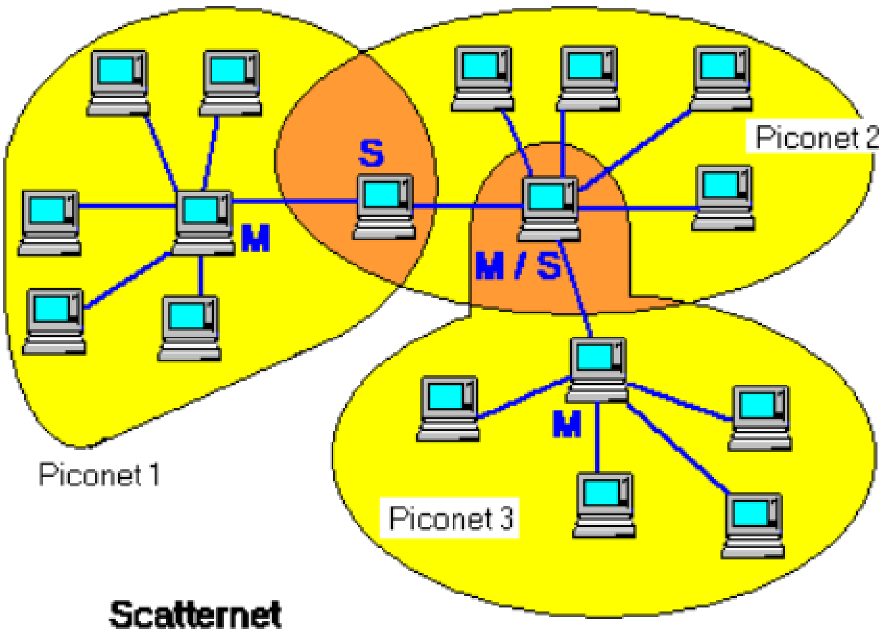


**Figure 2.1** — Bluetooth piconet and scatternet structure

Bluetooth Core Specification provides both link layer and application layer definitions, which includes device and service discovery as a fundamental part of the protocol. A Bluetooth device can search for other Bluetooth devices either by scanning the local area for Bluetooth enabled devices or by querying a list of bonded (paired) devices. If a device is discoverable, it will respond to the discovery request by sharing some information, such as the device name, class, and its unique MAC address. Using this information, the device performing discovery can then choose to initiate a connection to the discovered device.

Bluetooth technology operates in the unlicensed ISM band at 2.4 to 2.485 GHz, using a spread spectrum, frequency hopping, full-duplex signal. The applied adaptive frequency hopping (AFH) improves resistance to interference by avoiding using crowded frequencies in the hopping sequence. The range of Bluetooth technology is application specific and may vary according to class of radio used in an implementation (up to 100m).

## ZigBee

ZigBee is best suited for periodic or intermittent data or a single signal transmission from a sensor or input device, intended for embedded applications requiring low data rate, long battery life and secure networking. Typical applications include: smart lighting, remote control, safety and security, electric meters, medical data collection, embedded sensing, etc. It is the leading standard for products in the area of home/building automation, smart energy, health care, etc.

ZigBee is based on IEEE 802.15.4 standard, and complete the standard by adding Four main components: network layer, application layer, ZigBee device objects (ZDOs) and manufacturer-defined application objects. Its network layer natively supports both star and tree topology, and generic mesh networks. Radios in a mesh network can talk to many other radios (devices) in the network, not just one. The result is that each data packet communicated across a wireless mesh network can have multiple possible paths to its destination. This flexibility provides high reliability and more extensive range. One of the prominent feature of ZigBee is its low-power and its low latency. ZigBee nodes can sleep most of the time, and can go from sleep to active mode in 30ms or less. For this reason, ZigBee is favored in monitor and control sensor systems, especially with battery-operated devices. But the low rate of ZigBee makes it less suitable for social use D2D communication between mobile phones. Bluetooth and wi-Fi direct, for example, can adapt to a much large range of mobile applications.

## NFC

NFC is a set of standards for smartphones and similar devices to establish wireless communication with each other by bringing them into close proximity, usually no more than 10 cm. NFC uses magnetic induction between two loop antennas located within each other’s near field, effectively forming an air-core transformer. Typical NFC applications include contactless payment, digital name card exchange, information exchange, access control, fast pairing and connection establishment for other D2D technologies such as Wi-Fi Direct. NFC alone does not ensure secure communications. Higher-layer cryptographic protocols such as SSL can be used to establish a secure channel. However, due to its extreme short range and point to point mode operation, NFC is naturally more secure than other existing D2D technologies. According to ABI research [ABI, b], NFC handsets shipped in 2012 is 102 million, and are anticipated to increase by 481% from 2012 to 2015. Although NFC becomes a popular standard for smartphone D2D connection, due to its extreme short range, similar as ZigBee, it is not suitable for most of the D2D mobile applications.

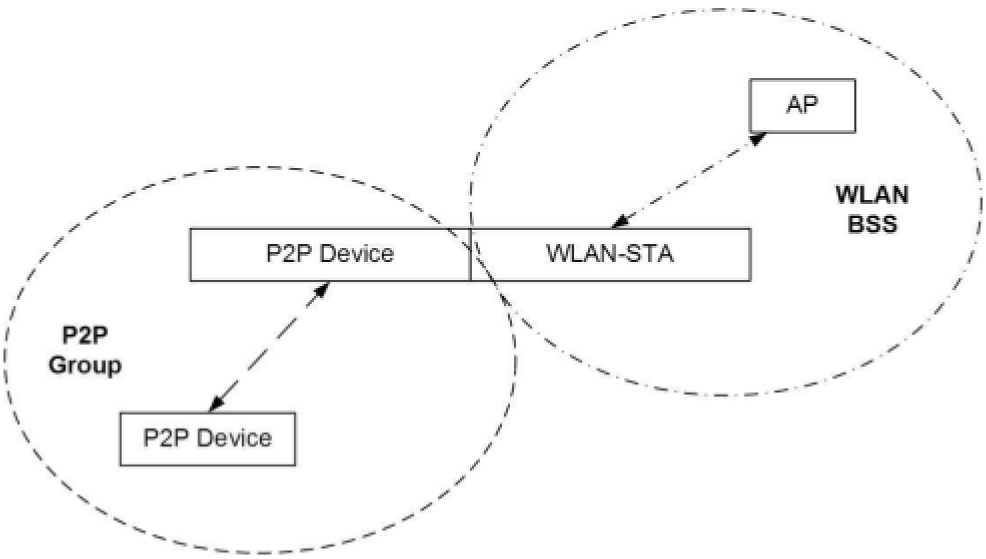


**Figure 2.2** — Wi-Fi Direct network structure

## Wi-Fi Direct

Wi-Fi (IEEE 802.11) standard is the dominant way in WLAN communication, Notably for Internet access. Although ad-hoc mode of operation is already enabled in Wi-Fi standard, known as independent basic service set (IBSS), the poor interoperability and standardization of setting up IBSS network, as well as the lack of security and efficient energy use impede commercialization of direct device to device connectivity functions. With the increasing demand of easy content sharing, display, synchronization between proximate devices, the Wi-Fi Alliance released Wi-Fi CERTIFIED Wi-Fi Direct specifications which define a new way for Wi-Fi devices to connect to each other directly at typical Wi-Fi rates (up to 250Mbps) and range (up to 200 meters). Wi-Fi Direct is initially called Wi-Fi Peer-Peer(P2P). As P2P, instead of D2D, is the term used in Wi-Fi Direct specification, we conform to this terminology in the following part of introduction to Wi-Fi Direct technology

## 2.3 The coexistence of D2D and cellular transmission

### In literature studies

The coexistence of D2D and cellular transmission has been mentioned in literature studies for about ten years. D2D in cellular network can exist in two different forms (Figure 2.3). In one form, the pair of D2D users are endpoints (source and sink) of a communication session. In another form, at least one D2D user of the pair act as a relay to form a multi-hop connection between the base station and the endpoint user. Many have proposed to leverage D2D link to increase the system capacity or cellular network coverage, or to balance traffic load between different base stations.

#### Multi-hop D2D relay

Authors in [Luo et al., 2003], [Bhatia et al., 2006], [Zhao and Todd, 2006], [Papadogiannis et al., 2009], [Law et al., 2010], [Li et al., 2008], [Raghothaman et al., 2011] have proposed multi-hop D2D relay for cellular transmission for the purpose of cellular capacity enhancement.

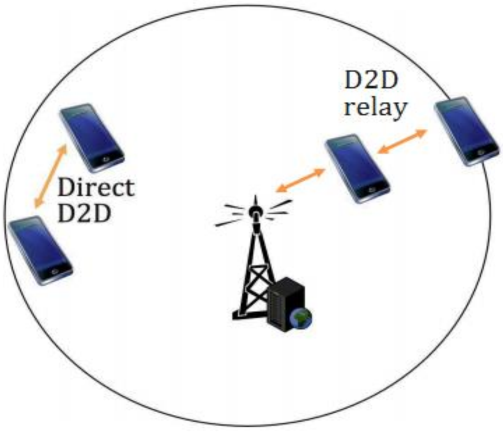


**Figure 2.3** — Two forms of D2D: Direct D2D and D2D relay

## 2.4 LTE D2D

In 2.4.1 potential usages that might base on cellular user proximity are firstly listed. Principle functions that need to be provided by LTE D2D in order to support these proximity-based usages are analyzed. Implementation challenges to both operators and device manufacturers are discussed. Then in 2.4.2 The progress of LTE D2D in 3GPP standardization is presented. The design guideline provided by 3GPP covering different D2D use cases and scenarios is summarized.

### 2.4.1 Interests and challenges of D2D-enabled LTE network

With the popularity of smart devices, and the potential huge market of proximity-based services and applications, there is an urgent need to integrate D2D mode transmissions in the next-generation cellular network to enable efficient discovery and communication between proximate users, and to eventually provide ubiquitous connections and a rich range of services to mobile users.

The potential usages that might base on mobile user proximity can be categorized as follows:

• Commercial/social use: local discovery and interaction with connected devices,

• Interactive local guidance: interactive guidance for customers, tourists, commuters, and users of commercial and public services, using smart beacons, sensors and content servers embedded within objects in the environment. For example, advertisements from nearby stores/restaurants, presentation of art pieces in museums, flight/subway information, vacancy in parking lots, etc. From service receivers' perspective, a user might preset personalized interests in order to be alerted by services from nearby area, such as notification of a sale, ticketing, restaurant recommendations, traffic jam warning, events organization etc.

• Connection to M2M/V2V: D2D-enabled devices can serve as a controller of Machine-to-Machine (M2M) and Vehicle-to-Vehicle (V2V) networks. They can further provide cellular network connection to M2M/V2V, serving as gateways between M2M/V2V and cellular networks.

• Social discovery: discovery of nearby persons linked by social network (e.g. Facebook, LinkedIn), with mutual interests (e.g. professional, personal), or attending a same event (e.g. party, concert, match), etc.

• Entertainments: usually involves a large variety of personal devices, such as mobile smart devices, game consoles, cameras, TVs, screens, storage memories. Typically for content sharing, local gaming, and local multicasting.

b. Enhanced networking: D2D technology can be used to enhance the connectivity of devices to an infrastructure network - typically for access to the Internet or operator services. Usages can be divided into two sub-categories:

1) Traffic offload: from cellular infrastructure network to D2D link when the two endpoint devices are in proximity. The D2D communication can be either in operator's licensed band or in WiFi band if both devices are

equipped with WLAN antenna. The traffic can be data or voice/video call. The D2D offloading might alleviate network congestion, enforce the link quality and reduce the power use between two proximate devices.

2) Coverage extension: A device obtains access to an infrastructure network (Inter- net or cellular network) through the assistance of one or more devices that act as relays or access gateways This can provide network coverage to devices that

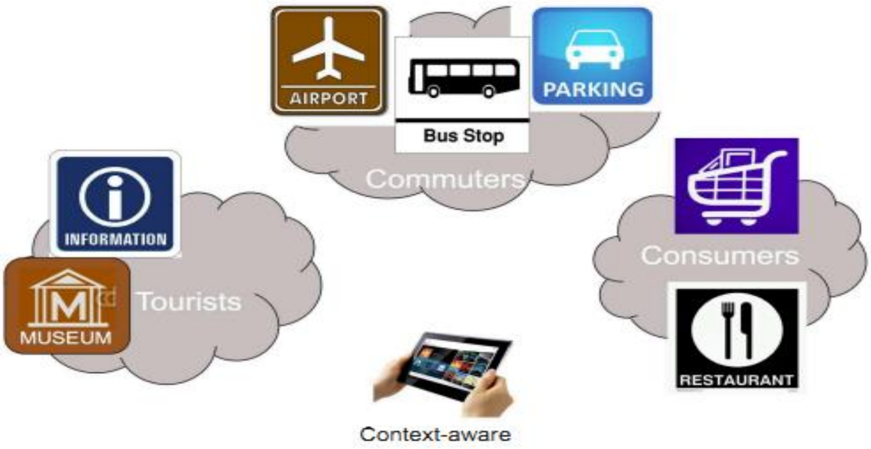


**Figure 2.4** — D2D usage example: Interactive local guidance


**Figure 2.5** — D2D usage example: Connection to M2M/V2V

Figure 2.6 — D2D usage example: Social discovery

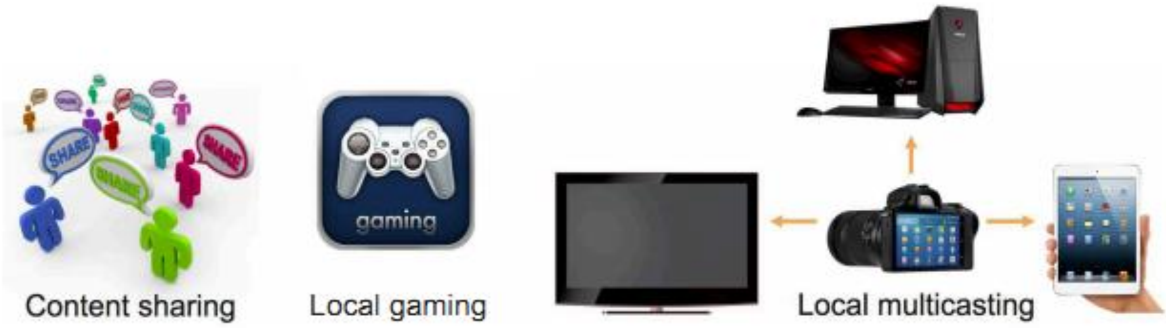


Figure 2.7 — D2D usage example: Entertainments

We identify three principle functions that allow LTE D2D to address the above- mentioned potential services.

**1) D2D discovery:**

D2D discovery is a process that allows devices in physical proximity to discover each other using LTE radio technology. In the general case, this discovery is performed within LTE network coverage and under the control of the operator (e.g. with radio resources assigned by the operator, and authorized by the operator). But it is also desired that discovery can be performed with partial (in which one UE of the D2D pair is under the network coverage and another one is not) or no network coverage.

LTE D2D might support much larger discovery range comparing to other wireless D2D technologies such as Bluetooth and Wi-Fi Direct. The use of licensed spectrum may allow for more reliable discovery than other D2D technologies operating in unlicensed ISM band. The SIM card can be used for authentication and holding discovery permissions, especially the 3rd parties/merchants permissions to discover users. The D2D discovery developed for LTE network could even potentially replace the Wi-Fi Direct for establishing a WLAN Wi-Fi connection between two proximate Wi-Fi capable UEs. The operator could manage the proximity information (e.g. distance information, the network location area code, radio coverage status user discovery capabilities, and preference, etc.), offering to its users/partners the opportunity to use/build advanced proximity-based services.

**2) D2D data communication:**

D2D data communication allows data path happening directly between proximate D2D UEs instead of passing through eNBs. The operator could offload its network from proximity-based service traffic by switching data traffic from an infrastructure path to a direct D2D path with service continuity. In contrasts to the pending issues with the current existing D2D technologies on the data/traffic protection, secured D2D communications can be enabled by operator's management, which will boost the usages. The operator's control also enables a QoS framework which provides differential treatment based on D2D services, data traffic flows, and subscribers, etc. In case that network coverage is not available, similar to the direct D2D discover function, the direct D2D communication is expected to function autonomously with pre-configure parameters.

**3) D2D relay:**

D2D relay allows multi-hop paths to be formed between an infrastructure network (Internet or cellular network) and an endpoint UE. D2D relay can be used to enhance data throughput of cell-edge users, but can be also used to share connection to an endpoint UE lack of direct access to the infrastructure networks. D2D relay can extend network coverage for both indoor and outdoor UEs, with low cost, which complements the current coverage extension solutions in LTE using heterogeneous network (HetNet) such as Pico cell and Femto cell.

The integration of the D2D capabilities in LTE network poses challenges to both operators and device manufacturers. The operator is face to:

• Technical complexity of service management (e.g. user preference, privacy issues, frequency of discovery inquiries, QoS monitoring of D2D link, charging policy, etc.)

• Sensitive privacy issues in tracking user location and activities, collecting user preference and habitude, or selling user information to other actors imply privacy stakes.

• Interoperation of different operators (e.g. share spectrum, user location information, user preference) to enable users subscribing to different operators to discover and communicate to each other.

On device manufacturers' side, development of D2D compatible devices with the

New discovery and direct communication capability also involves higher cost and complexity. Design of sensing ability, gateway function, efficient battery consumption, advanced security, etc. can be very complicated.

### 2.4.2 D2D in 3GPP LTE standardization

Initially integrating D2D in LTE-Advanced network was strongly pushed by Qualcomm, who developed previously a proprietary technology called FlashLinq into its radios that allows cellular devices to automatically and continuously discover thousands of other FlashLinq enabled devices within 1 kilometer and communicate, peer-to-peer, at broadband speeds without the need for intermediary infrastructure. Unlike Wi-Fi Direct's peer-to-peer technology, Qualcomm's FlashLinq can share connectivity to a cellular network. In FlashLinq discovery, public/private expressions qualifying basic information about the device or user are mapped to tiny 128-bit packages of data to be broadcasted. Flash Linq is a synchronous TDD OFDMA technology operating on dedicated licensed spectrum and is featured by its high discovery range (up to a kilo- meter), discovery capacity (thousands of nearby devices) and distributed interference management.

## 2.5 Conclusion

In this chapter, the background of D2D technologies is introduced. Four popular out- band wireless D2D technologies: Bluetooth, ZigBee, NFC, Wi-Fi Direct have been presented. Their usage cases, market prospects, network structure, PHY/MAC characteristics (rate, power, range, etc.) are compared. The topic of integrating D2D into cellular network has appeared in literature study decades ago but has not received enough attention. The hybrid D2D and cellular network architecture in literature study can be roughly divided into two categories: Multi-hop D2D relay and direct D2D between endpoints. D2D relay is mainly proposed to increase the cellular network capacity or coverage, or to balance traffic load between different base stations. Although in some works, direct D2D communication between endpoint UEs does have been proposed to replace inefficient UL/DL mode transmission between proximate UEs, as the usages were quite limited before the emergence of 4G network and smartphone, the literature studies were not abundant.

As the need of proximity-based services increases rapidly with the popularity of smart mobile devices, integrating D2D into the LTE-Advanced network appears as a promising solution and attracts great interests. The potential usages are analyzed and are categorized into social/commercial use and networking enhancement. To address these potential usages, three principle functions: direct D2D discovery, direct D2D communication and D2D relay, are identified. Challenges to operators and device manufacturers are also anticipated.

With the increasing interests shown by industrial actors in integrating D2D into LTE network, study items of LTE D2D are taking off in different 3GPP technical specification groups, from service level to physical and MAC layer. Apart from social/commercial use, 3GPP decided that LTE D2D should also address public safety communities. The progress of LTE D2D in 3GPP standardization is presented. The LTE D2D system design guideline is completed in 2013 by 3GPP, which analyses conditions, service flows and potential requirements that are necessary for supporting variant proximity-based usages. Principle use cases and scenarios covered by this guideline for general commercial/social use and network offloading are summarized.

# CHAPTER 3 Physical and MAC layer Characteristics of LTE

## 3.1 Overview

In the previous chapter, three principle functions: D2D discovery, D2D data communication and D2D relay, which allow LTE D2D to address potential usages, have been identified. In this chapter, the focus is on the D2D discovery function and D2D data communication function only. We aims to identify physical and MAC layer design options and preferred solutions in order to realize these two D2D functions in LTE PHY/MAC framework. However, proposing a complete PHY/MAC layer design solution is far beyond the capability of this individual thesis work. This chapter highlights design aspects related to resource use, synchronization, random channel access and interference management, which are cruxes to D2D discovery function and to D2D data communication function.

A generic design of D2D discovery and transmission procedures across all the scenarios is preferred. Three coverage scenarios can be distinguished:

- In coverage: Both D2D transmitter and receiver are under the network coverage.
- Out of coverage: Both D2D transmitter and receiver are out of network coverage.
- Partial coverage: Either D2D transmitter or receiver is out of network coverage.

It is required that in-band D2D operates under the control of network when the network coverage is available so that the impact of in-band D2D transmission to the current LTE network is manageable. That is to say, the network is able to identify, authenticate and authorize D2D UEs participating in D2D discovery, and is able to determine resources and power of direct D2D transmissions. Meanwhile, a design that allows UEs to perform D2D functions whether they are under network coverage or out- of-coverage is desired. However, as in-coverage is the main situation for both general and public safety specific scenarios [TR2, ], a design considering network control is the essential start. Additional self-organization features enabling D2D functions without coverage could be built on that main D2D system afterwards. This allows simplifying implementation and specification. It is worth noting that D2D should work in inter- operator scenario where D2D transmitter and receiver locate in different operators network. The inter-operator scenario, together with the out of network scenario, implies that D2D transmitter and receiver might be originally not synchronized to each other and the initialization of D2D link should be able to act in an asynchronous fashion.

Another important requirement is that the D2D design should reuse as much as possible the current LTE physical and MAC features in order to minimize core and RF specification impacts from the integration of D2D into LTE radio access. It is crucial to understand existent LTE physical and MAC framework in order to integrate D2D functions. Therefore in this Chapter, key LTE physical and MAC layer characteristics and procedures for both uplink and downlink transmissions are firstly reviewed. Design options and preferred solutions, for random channel access in D2D discovery, and for interference management of D2D data communication, are identified.

### 3.2 LTE Physical and MAC layer Specifications

In this section, LTE physical and MAC layer specifications, relevant to our consideration of D2D discovery and communication design, are reviewed.

Channel access methods are fundamentals in wireless communication system, and are tightly related to resource allocation method and interference management techniques. In section 3.2.1, Orthogonal Frequency-Division Multiple Access (OFDMA) downlink channel access method and Single-Carrier Frequency Division Multiple Access (SC-

FDMA) uplink channel access method used in LTE network are presented. It is required that in-band D2D link use compatible channel access method so that the intra-spectrum interference is manageable.

In order for two entities to communicate efficiently, it is essential that the transmitter and the receiver have the same notion of time. Furthermore, OFDM-based channel access is highly sensitive to carrier frequency errors. Therefore both timing and frequency synchronization should be achieved at the initial stage of communication. An LTE UE can only be scheduled for transmission with an eNB if its transmission timing is synchronized to the eNB. In LTE, UEs synchronize its downlink timing and frequency to eNB via cell search procedure, and its uplink timing to eNB via uplink Random Access. The transmitter of synchronization signals include its identity in the synchronization signals in order to be identified by the receiver. The detailed LTE downlink and uplink synchronization procedures are presented in section 3.2.2, for a better understanding of D2D synchronization issues and D2D discovery procedure design.

Once a UE get synchronized to eNB and authenticated by the network, its downlink or uplink transmission is scheduled by the eNB. Resource assignment is based on channel estimation and is conveyed to UEs via control signaling.

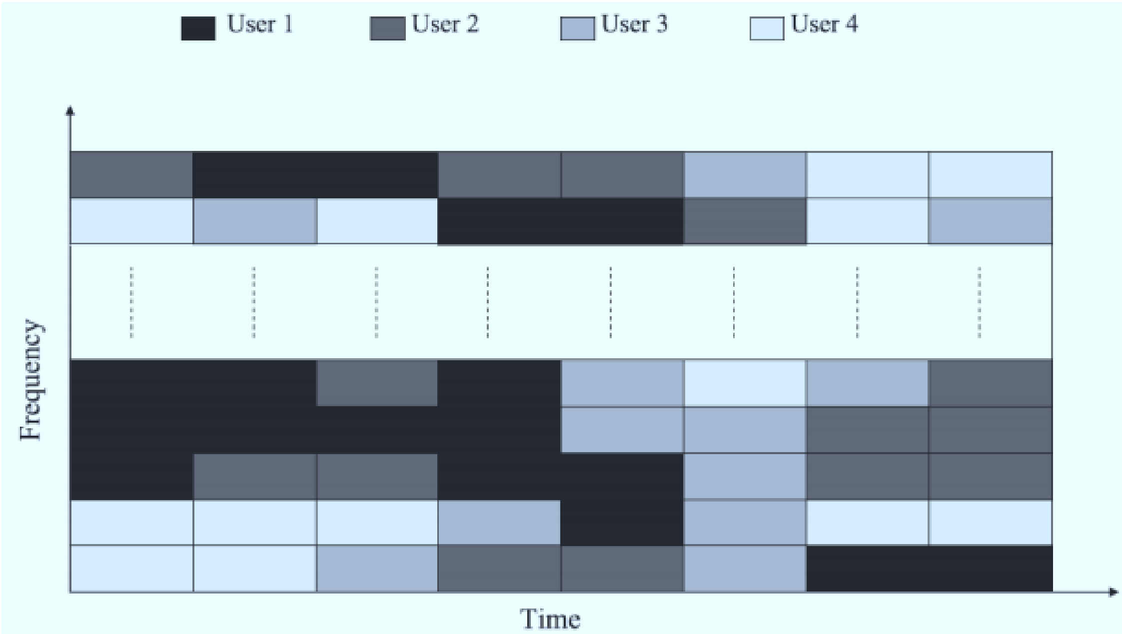


**Figure 3.1** — Resource Allocation Principle in LTE

### 3.2.1 Channel Access Method

A channel access method allows terminals connected to the same transmission medium to share the same communication channel. A channel access method is based on a physical layer multiplexing method, and concerns MAC layer protocols dealing with issues such as addressing, assigning multiplex channels to different users, and avoiding collisions. It is critical to achieving good system performance. The LTE downlink adopts OFDMA as multiple access method. It is an extension of OFDM modulation scheme to the implementation of a multiuser communication system. In OFDMA, subsets of subcarriers are distributed to different users at the same time so that multiple users can be scheduled to receive data simultaneously. In LTE, OFDMA is combined with time partition so that the basic unit of resources allocated to one user is a subset of subcarriers for a specific time duration. This basic unit in LTE consists of 12 continuous subcarriers for a duration of 1 ms (one slot) is termed a Resource Block (RB), which is the smallest unit of resource that can be allocated to one user.

It enables a scheduler to assign resources dynamically and flexibly, based on time variant frequency-selective channel of each user, and thus makes it possible to achieve high spectral efficiency and QoS of each individual. The primary advantage of OFDM over single-carrier schemes is its robustness against multipath distortions. Channel equalization at the receiver can be highly simplified due to the flat channel condition over a narrow band (a subset of subcarriers) created by OFDM mechanism.

However, one of the major drawbacks of multicarrier transmission is the high peak- to-average power ratio (PAPR) of the transmit signal. Time domain signal of OFDM symbol varies strongly due to the fact that it is actually the superposition of sinusoidal waves, each corresponds to a frequency domain data symbol independently modulated by a different subcarrier (such that the amplitude of each sinusoidal wave depends on the corresponding constellation point presenting the frequency domain data symbol). The high PAPR causes inefficient power consumption and challenges amplifier design.

Therefore in LTE uplink, where UE power efficiency is demanding and costly amplifier is unaffordable, SC-FDMA featuring low PAPR is adopted as multiple access method. The SC-FDMA signal looks like single-carrier, but is actually generated in a multicarrier process very similar to OFDMA. However, unlike OFDM, in SC-FDMA the signal modulated onto a given subcarrier is not a single data symbol but a linear combination of all the data symbols transmitted at the same time instant. Therefore in each symbol period, all the transmitted subcarriers of an SC-FDMA signal carry a component of each modulated data symbol. In time domain the superposition of sinusoids has its single-carrier property, which results in a much lower PAPR.

### 3.2.2 Frequency and timing synchronization

The design of an OFDMA system poses stringent requirement on frequency and timing synchronization. OFDMA is highly sensitive to Carrier Frequency Offset (CFO) and time-varying channels. Carrier Frequency Offset refers to the difference between radio frequencies in the transmitter and the receiver. Frequency errors typically arise from a local oscillator frequency drifts between the transmitter and the receiver. It might also result from phase noise in the receiver, or relative movement between the transmitter and the receiver (Doppler spread).

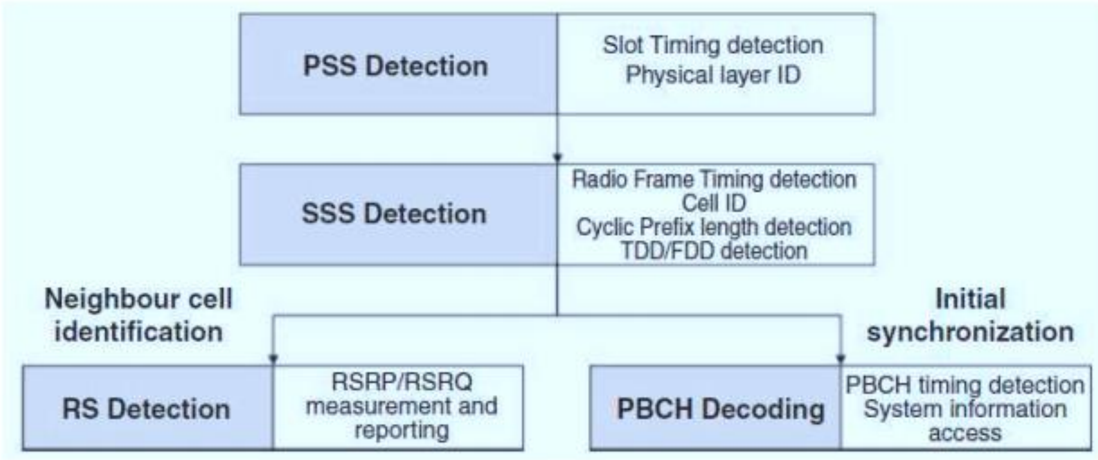


**Figure 3.3** — Cell Search Procedure

In LTE, the frequency and timing synchronization is accomplished by cell search procedure and uplink random access. The cell search procedure allows UE acquiring symbol and frame timing, and compensate carrier frequency errors resulted from mismatch of the local oscillators between the transmitter and the receiver as well as the Doppler shift caused by any UE motion. The cell search synchronization procedure leverages two specially designed downlink broadcast signals: the Primary Synchronization Signal (PSS) and the Secondary Synchronization Signal (SSS). These two signals not only enable the frequency and timing synchronization, but also indicate the physical layer cell identity, the cyclic prefix length and cell duplex mode (Frequency Division Duplex (FDD) or Time Division Duplex (TDD)). Depending on whether it concerns the initial synchronization or the neighbor cell identification, after the detection of these two signals, the user either decodes the Physical Broadcast Channel (PBCH) to acquire crucial system information, or detects Reference Signals (RS) transmitted from neighbor cells for cell reselection or handover.

The detection of the PSS has to be non-coherent, as the UE does not have a priori knowledge of the channel at the beginning of cell search synchronization. The construction of the PSS is from Zadoff-Chu (ZC) sequences, which is in particular suitable for non-coherent detection due to its flat frequency-domain autocorrelation property and its low frequency offset sensitivity. The fixed position of the PSS in a radio frame enables a UE to acquire the slot boundary timing independently of the Cyclic Prefix (CP) length. The Contention-based random access procedure consists of four-steps:

**Step 1**

The UE randomly chooses a random access preamble signature. Similar to the PSS used in downlink synchronization, the preamble signature is also based on ZC sequences.

**Step 2**

The eNB sent the Random Access Response (RAR) and addressed with a Random Access Radio Network Temporary Identifier (RA-RNTI), identifying the time frequency slot in which the preamble was detected. UEs collided by selecting the same signature in the same preamble time-frequency resource would each receive the RAR. If the UE does not receive a RAR within a time window pre-configured by the eNB, it goes to Step 1 and selects another preamble signature. The RAR conveys the identity of the detected preamble, a timing alignment for uplink transmission, an initial uplink resource grant for transmission of the Step 3 message, and a temporary Cell Radio Network Temporary Identifier (C-RNTI).

**Step 3**

The UE send the Layer2/Layer3 (L2/L3) message on the assigned Physical Up- link Shared Channel (PUSCH). It carries the C-RNTI if the UE already has on (RRC_CONNECTED UEs) or an initial UE identity (the SAE Temporary Mobile Subscriber Identity (S-TMSI) or a random number). Colliding UEs are not aware of their collision, and will also collide in the same uplink time-frequency resources when transmitting their L2/L3 message.

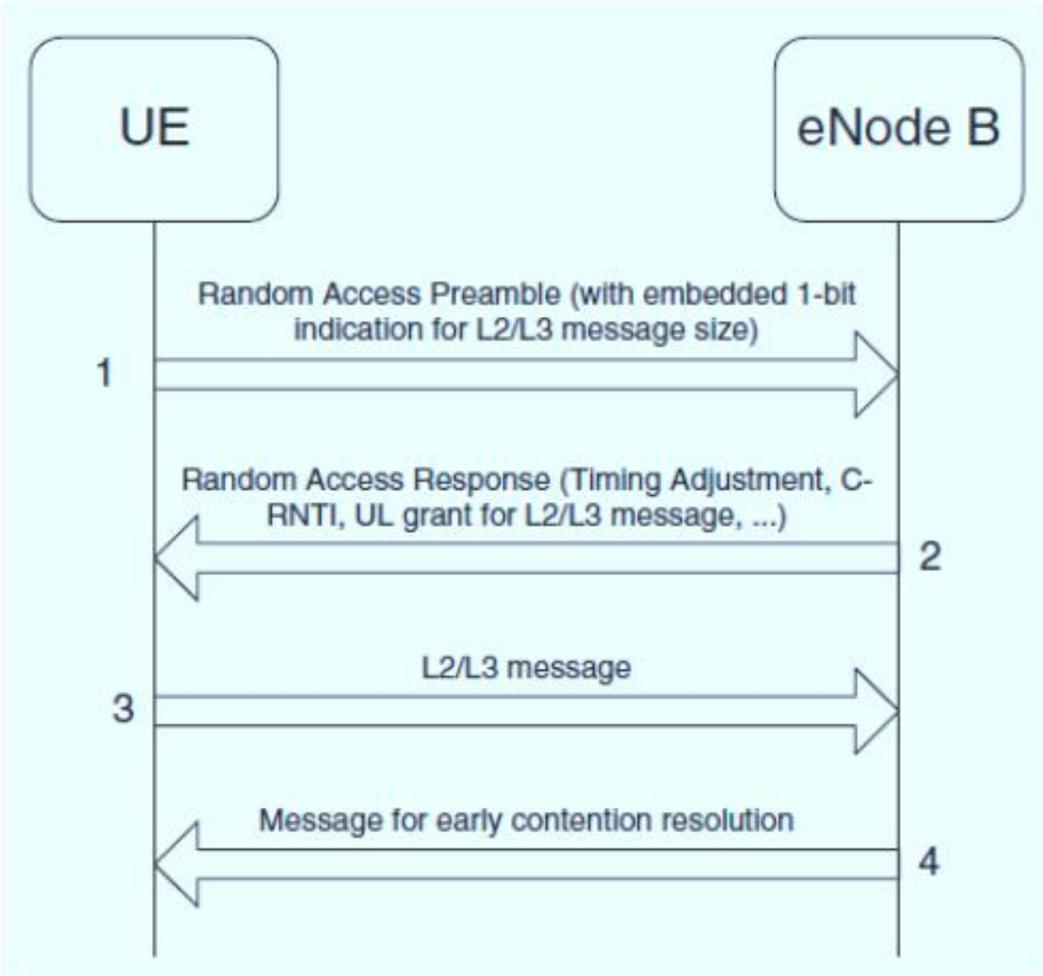


**Figure 3.4** — Contention-based RACH procedure

**Step 4**

The contention resolution message uses HARQ. It is addressed to the UE identity (C-RNTI or an initial UE identity) whose L2/L3 message in Step 3 has been successfully decoded and is followed by the HARQ feedback transmitted by the UE which detects its own identity in the contention resolution message. Other UEs understand there was a collision, transmit no HARQ feedback, and can quickly exit the current random access procedure and start another one.

### 3.2.3 Transmission procedure basics

In order to communicate with an eNB, the UE must firstly identify the broadcast transmission from an eNB and synchronize to it. This is achieved by means of special synchronization signals embedded in the OFDM structure described before. In RRC_CONNECTED, the E-UTRAN allocates radio resources to the UE to facilitate the transfer of data via shared data channels. The dynamic frequency and time resource allocation is indicated by a control channel, which should be monitored by the UE. In downlink transmission, the UE estimates the channel condition based on the reference signals inserted in the OFDM structure in order to perform coherent demodulation. Similarly, in uplink transmission, coherent demodulation is also facilitated by reference signal based channel estimation. The uplink Demodulation RSs (DM-RSs) of a given UE occupies the same bandwidth as its PUSCH/PUCCH transmission and are time-multiplexed with the data symbols.

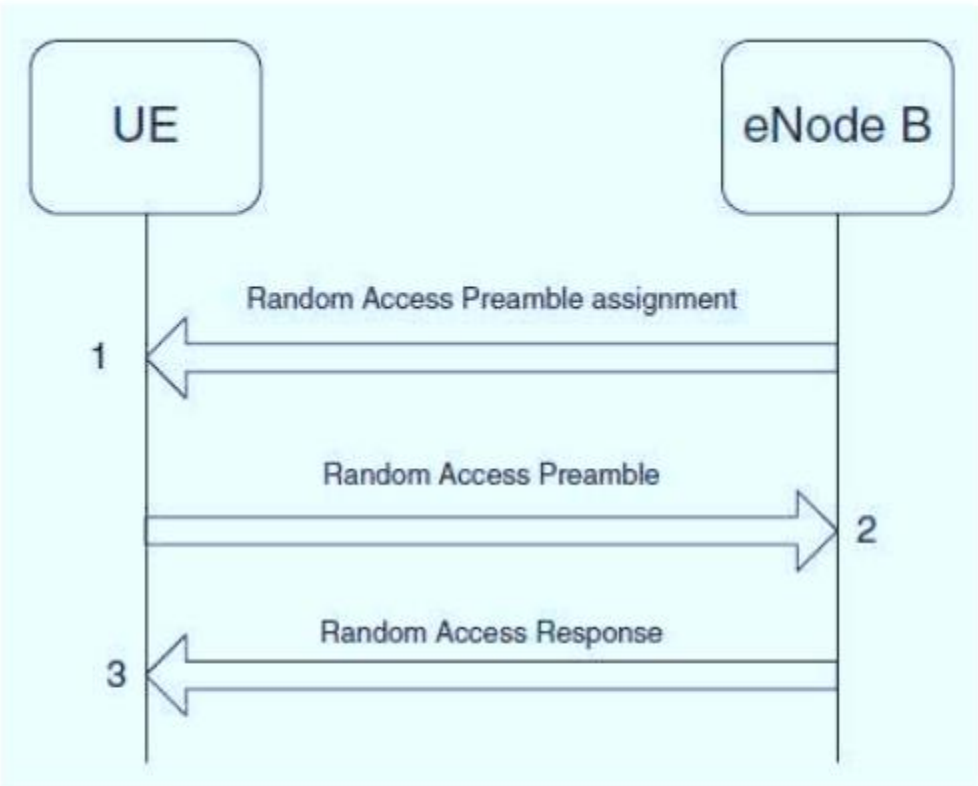


**Figure 3.5** — Contention-free RACH procedure

The radio channel condition is a key factor to the UE performance. The quality of the signal depends on the channel quality, the level of interference from other transmitters, and the noise level. In order to optimize system capacity and coverage, the transmitter should try to match the modulation, coding scheme to the variations in received signal quality for each user. This technique is called link adaptation or adaptive modulation and coding (AMC). Furthermore, the radio channel condition contributes to higher spectral efficiency as the multi-user scheduling in time and frequency can take advantage of the user channel frequency selectivity.

Information about the channel conditions at the eNB is obtained in different manner in LTE downlink and uplink. In downlink, it is usually the UE which measures the instantaneous channel status and report to the network the recommended transmission configuration on the downlink shared channel. In uplink, the eNB may directly make its own estimate of the channel status by using Sounding Reference Signals (SRSs) or other signals transmitted by the UEs.The channel status report in downlink is the recommended value based on UE estimation. The eNB's final decision is not necessarily the same. It might consist of one or several pieces of information: Channel-quality indication (CQI), representing the data rate that can be supported by the channel, taking into consideration the SINR and the characteristics of the UE's receiver. A CQI points to a modulation scheme and coding rate combination predefined in CQI table. Rank indication (RI), providing the preferred number of spatial-multiplexing transmission layers in MIMO system. Precoder matrix indication (PMI), providing the preferred beamforming pattern in each spatial-multiplexing transmission layer in MIMO system.

### 3.2.4 Interference coordination

Resources allocated to different users in a macro cell are usually orthogonal to avoid intra-cell interference. Main interference might come from transmitters in neighboring cells on the same resources known as Inter-Cell Interference (ICI) and might impact the throughput performance, especially that of cell-edge users. In LTE Rel.10 heterogeneous network deployments is supported, where small cells (pico cells or femto cells) overlay within the coverage area of macro cellular network. Heterogeneous deployments sharing the same spectrum enables higher spectral reuse but present more challenge to interference coordination.

## 3.3 LTE D2D PHY and MAC layer design choices

After reviewing LTE physical and MAC layer specifications, in this section we will propose D2D design choices, taking into consideration the compatibility and impacts to the current LTE physical and MAC framework. We start with resource use and synchronization issues, which are fundamental and determinative to transmission efficiency and are common to both D2D discovery and D2D data communication functions. Then design aspects of D2D discovery and D2D data communications are analyzed separately.

### 3.3.1 General consideration of D2D resource use

In principle, D2D may use a combination of UL and DL spectrum for FDD and UL and DL sub frames for TDD. Modification on RF design of current UE devices is necessary. The problem is quite different for TDD UE and FDD UE. In TDD, the traditional half-duplex UE antenna put constraints on D2D transmission. As conventional TDD UEs are not able to transmit and receive at the same time, when UEs are transmitting in D2D mode, it cannot receive downlink signals from eNB at the same time. Therefore, UEs transmitting in D2D mode might miss important information transmitted from eNB. Similarly, in TDD uplink scenario, D2D receiver cannot transmit signals to eNB in the meantime. An advanced full duplex antenna might allow a D2D UE to transmit and to receive simultaneously on the same carrier, but can have the problem of leakage, antenna size, and high cost, etc. Therefore full duplex antenna is not a practical solution for the moment. An alternative solution can be time resource partition for cellular and D2D transmission, which effectively avoid this simultaneous transmission and reception problem, but at the expense of spectral efficiency gain. In case that spectral efficiency is a concern, it is possible to trade off scheduling complexity for spectral efficiency, for example, use semi-static time resource partition or even dynamic scheduler for resource allocation.

In FDD systems, UEs do not conventionally transmit signals on the downlink spec- trum or receive on uplink spectrum. Therefore, in-band D2D requires implementations on UE RF to enable transmitting and/or receiving on an additional spectrum. In addi- tion, the same isolation problem as what we mentioned in TDD case might also occur.

RF interference can be severe when a UE receives on the DL band from eNB and transmits on the DL band to another UE at the same time, and vice versa for the UL band. Implementation of full duplex D2D is technically difficult as the requirement of RF isolation between Tx and Rx chains may be quite severe. Alternatively, D2D resource could be scheduled to avoid concurrent transmission and receiving on the same band. For in-band D2D transmission, it is possible to allocate dedicated resources, or to allow overlapping resource use between D2D transmission and cellular transmissions. In dedicated resource use, a certain part of licensed spectrum is reserved uniquely to D2D transmission, and therefore interference between D2D and cellular transmissions is avoided. But this method makes worse use of spectrum than overlapping resource use, as it does not adapt to D2D load in a cell.

In overlapping resource use, interference avoidance is quite challenging. It is possible to avoid intra-cell interference by, for example, centrally assigning orthogonal resources to D2D and cellular UEs in the same cell. However, avoidance of inter-cell interference between D2D and cellular transmission in neighbor cells requires cooperation of neigh- boring eNBs to jointly perform inter-cell interference coordination, which can be highly complicated. The performance gain of the overlapping resource use scheme therefore largely depends on the applied interference management techniques. Note that resource allocation and many other interference management techniques are effective only when transmissions are synchronized. The D2D synchronization issues will be analyzed in the following section.

### 3.3.2 Synchronization

Synchronization is fundamental and determinative to transmission efficiency. Synchronized communication allows efficient spectral reuse with interference coordination. In synchronous mode, energy consumption of transmission is much lower.

As introduced before, transmission of data and control channels in current LTE system is basically time-synchronized. Multi-carrier modulation, such as OFDMA or SC-FDMA, requires not only time synchronization but also tight frequency synchronization. Typically only synchronization errors of up to a few percent of the subcarrier spacing are tolerable in OFDM systems. Therefore if D2D uses multi-carrier modulation as in LTE DL and UL, tight time and frequency synchronization are required in order that interference can be coordinated.

LTE synchronization is achieved through unsynchronized procedures and channels. DL synchronization is conducted by eNBs broadcasting PSS/SSS every 5ms. "Always on" DL synchronization is indispensable so that UEs will not miss important system information and UEs receive DL data in an efficient way. On the contrary, UL synchronization is conducted in an "on demand" fashion. A UE that is inactive for a certain period of time is allowed to lose uplink synchronization to save UE battery and radio resources. It resumes UL synchronization procedure through random access channel PRACH when it has signals to transmit.

To support D2D services in LTE, new channels, signals, and procedures need to be developed and it is fundamental to consider which D2D channel/procedure shall operate in a synchronous way, and which ones can operate in an asynchronous way.

D2D discovery is required to work in cellular networks where the cells are not time- synchronized (e.g. interoperator discovery), and in scenarios where there are only partial or no network coverage. It is necessary that discovery is able to operate in an asynchronous fashion. Other unsynchronized operation might include control signaling procedures for setting up connections or triggering a session between connected entities.

It is preferred, however, that D2D discovery and control signaling procedures mentioned above can perform in a synchronized fashion whenever they are allowed, so that performance advantages of synchronous transmission can be fully exploited. The method to achieve "always on" synchronization for D2D UEs will be explained afterwards.

### 3.3.3 D2D discovery

To fulfill the requirements for the purpose of D2D discovery over the air, two functions are essential:

1. Proximity detection: UEs can be aware of the existence of other nearby UEs supporting D2D.

2. Identity detection: UE can detect the identification of nearby UEs supporting D2D. The procedure of D2D discovery generally starts with proximity detection, followed by identity detection. To realize proximity detection, an obvious solution is to apply a scan/search mechanism using beacon sequences, as used in other D2D technologies, e.g. Bluetooth and Wi-Fi Direct. A UE, which is willing to be detected by nearby UEs, can broadcast beacon sequences. As the detection of beacon sequences can be the first contact of two D2D UEs, and as D2D transmitter and receiver might be originally unsynchronized (e.g. in different operatorsâ network, or in out-of-network scenario), UEs must be able to decode asynchronous beacon sequence. It is preferred that synchronization can be achieved through beacon sequence at the initial stage of D2D discovery so that subsequent messages can benefit from synchronized transmission. A structure similar to RACH preamble in LTE UL synchronization can be applied to beacon sequence design if SC-FDMA is used for D2D, or PSS/SSS like synchronization signals can be applied if OFDMA is used for D2D.After the transmission of beacon sequence for proximity detection, there are two ways to convey UE identity associated with the beacon sequence: either by transmitting a subsequent message containing its identity or via network signaling. In the latter method, UEs report their detected beacon sequences to the network, and the network may inform UE the corresponding identity by higher level signaling. However, this method incurs additional overhead and power consumption. Moreover, if either of the discovering and discovered UEs is out of network coverage, special signaling mechanism needs to be designed for identity detection. For example, either the out-of-coverage UE tries to get access to network through UE relay, either an alternative UE-UE identity exchange mode is designed for out-of-coverage case. On the contrary, the first method offers

a network coverage independent discovery solution and it simplifies signaling design. Both proximity detection and identity detection are based on discovery signal, therefore inquiring of the identity and service related information from the network could be avoided. It will be interesting to investigate if the structure of transmitting a beacon sequence plus a subsequent message can offer a universal solution for all use cases and discovery types.

The resource use of D2D discovery signal is a key design factor and can be decom- posed into several design choices:

1. Whether D2D uses dedicated resources or overlapping resources with cellular transmissions.
2. Whether D2D operates in DL or UL resources.
3. In case of dedicated resource use, how to multiplex D2D discovery signals with cellular transmission.
4. How do multiple D2D links multiplex

As mentioned in section 3.3.1, if D2D uses dedicated resource, interference from D2D transmission to cellular transmission could be avoided, whereas if D2D uses overlap- ping resources with cellular transmission, interference management can be challenging. Asynchronous discovery signals transmitted from D2D UEs out-of coverage or from D2D UEs belonging to other operators networks might beyond the control of an eNB.

### 3.3.4 D2D data Communication

Contrary to D2D discovery signal, which contains only a few bits, D2D data traffic often involves data streaming, local gaming, etc., and thus can be much heavier. In addition, the total traffic varies a lot in time. Therefore dedicated resource use is inefficient for D2D data communication. Overlapping resource use with cellular transmission is highly desired in order to make better use of the scarce licensed spectrum.

The key problem in overlapping resource use is interference management. Most

Importantly, interference from D2D to cellular transmission should be strictly controlled by the network in order to protect cellular transmission when D2D UEs are in coverage or in partial coverage. Management of inter-D2D interference is also necessary for efficient D2D data Communications. In LTE, intra-cell interference is managed by an eNB by orthogonalzing the resources allocated to UEs whereas inter-cell interference is naturally alleviated by associating UEs to the strongest eNB.



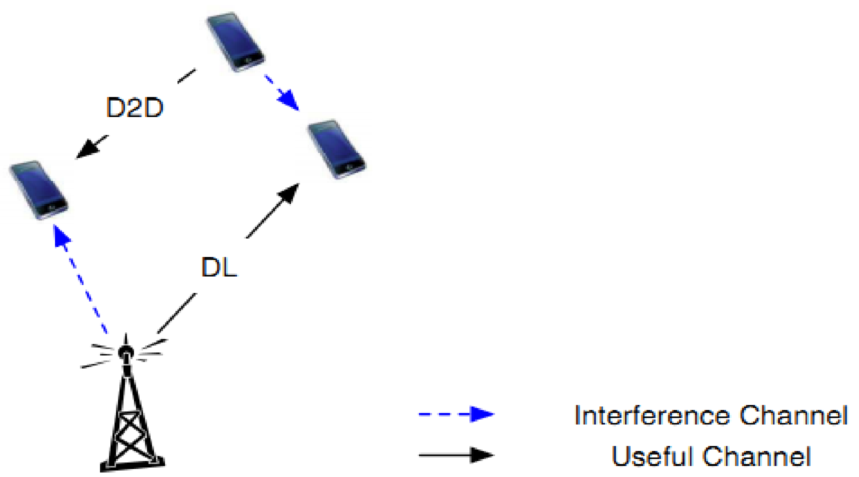


**Figure 3.8** — Near-far problem in hybrid network with overlapping resource use

To coordinate the hybrid communication and to achieve efficient resource reuse, we identified four techniques that can be used.

1. Resource allocation: Resource can be orthogonal between D2D and cellular transmissions, and/or among D2D transmissions in order to alleviate intra-cell interference. However, the spectrum might be underutilized, which leads to suboptimal system performance. Intra-cell resource reuse based on location information or SINR estimation might lead to an optimal use of resources.

2. Power control: Power control is another key elements to manage interference and to solve the near-far problem. Power control is also applicable to cases where network control is not available.

3. HARQ: HARQ is a retransmission mechanism, which can enhance D2D performance in a spatial reuse scheme by simple repetition of D2D transmission in multiple sub frames. Useful signal energy is accumulated at the D2D receiver and D2D transmission range is extended. HARQ is especially beneficial to D2D trans- missions out of network coverage, where interference can be severe, and required transmission range of public safety applications can be long (at the order of kilo- meters).

4. Mode selection: mode selection allows a soft switch between D2D mode and conventional UL/DL mode communications in order to achieve efficient resource use, which should be decided by eNB.

Usually eNBs are the main entities to perform coordination, and the central co- ordination in eNBs requires signaling support, for example, reports of channel measurement, assignments of resources and power, etc. We can distinguish three levels of centralization.

## 3.4 Conclusion

In this chapter, physical and MAC layer design requirements, options and preferred solutions for a good function of D2D discovery and D2D data communication in LTE networks are discussed.

# CHAPTER 4 Coordinated Scheduling of in-band D2D data communication

## 4.1 Introduction:

The purpose of this chapter is to propose a method for resource allocation in uplink for D2D users in a complex cell. As mentioned in the previous chapter, the key problem in D2D data communications interference management. Two kinds of interference are introduced by in-band D2D: inter-D2D interference, and interference between D2D and cellular transmission. Particularly, the interference from D2D to cellular transmission should be strictly controlled to minimize the impact of D2D transmission on existing LTE cellular transmissions.

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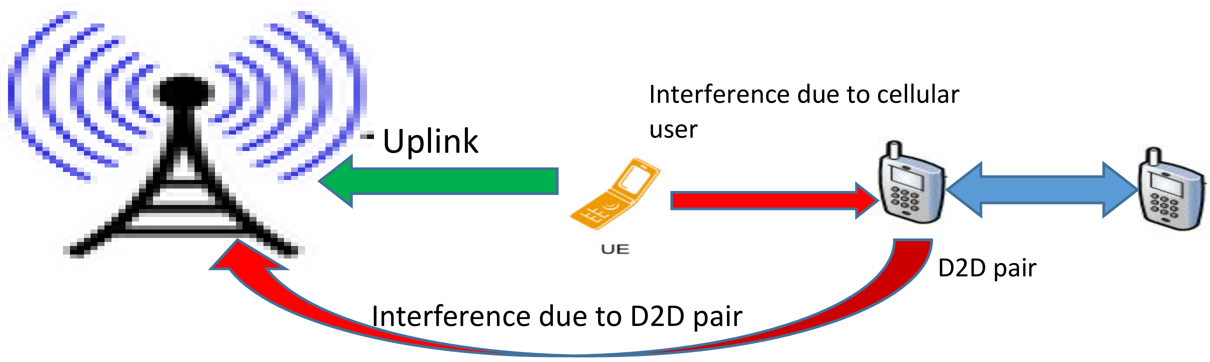



**Figure 4.1** : interference in a cell if eNB ,cellular user and D2D pair are In the same line

In section 4.2, literature studies on in-bandD2D resource coordinationis firstly reviewed, followed by an in-depth discussion on important scheduling considerations. Section 4.3 describes assumed scenario in our study and objectives. A complete method is proposed in section 4.4.Section 4.5 concludes the contribution of this chapter.

### 4.2 Scheduling issues in coordinated in-band D2D scheduling :

In this section, literature studies on in-band D2D resource coordination is reviewed. Their focuses and deficiencies are analyzed. Important scheduling considerations are discussed.

#### 4.2.1 Literature studies on in-band D2D resource coordination:

Although efficient spectrum sharing between D2D and cellular UEs is quite a new topic, paradigms of spectrum sharing in cognitive radio networks have been widely studied. In a network supporting cognitive radio, unlicensed users (secondary users)sense the spectrum of wireless service providers (WSPs) and opportunistically use the spectrum that is normally assigned to licensed users (primary users) but not being used at a particular time and geographic location. The admission of a secondary user to the spectral resources is often called admission control. Both centralized and distributed admission control methods have been investigated in literature studies. Many have used a SINR-based criterion and have assumed the constraints that the interference caused by secondary users on the primary network has to be kept below a maximum allowable limit, [Xing et al., 2007], [Islam et al., 2007], [Le and Hossain, 2008],[Kim et al., 2008], [Tadrous et al., 2010], [Tadrous et al., 2011]for example.Inspired by the admission control works (notable [Tadrous et al., 2011]) in cognitive radio networks, the authors of [Liu et al., 2012]propose a coordinated set-based admission control (SAC) algorithm for D2D links. The optimization criterion of centralized admission control algorithm SAC is to maximize the number of admitted D2D links, with QoS and power constraints. The capacity of the admitted set is further maximized by distributed power optimization (DPO). Due to the fact that capacity optimization is not directly treated in a centralized scheduler. A simplified admission control mechanism is taken by articles[Doppler etal., 2009],[Janis et al., 2009], [Yu et al., 2009]by assuming that a cellular resource block is admitted by only one D2D link in the cell. D2D resource and power are under full control of eNB in order to avoid intra-cell interference. Yet in another article [Xu et al., 2010], resources of each D2D link are decided in a distributedway,using contention basedCSMA/CAprotocolinD2DMAClayer.Acertain level of coordination is achieved as eNB provides additional position information to D2D users in order that D2D links avoid reusing the same spectrum as UL UEs which locate closely to D2D receivers, in which way interference from UL UE to D2D receivers is avoided.

Some studies concentrate on D2D transmission in UL channels [Liu et al., 2012],[Xu et al., 2010], [Yu et al., 2009]. In [Liu et al., 2012], interference is controlled through a centralized set-based admission control algorithm. Under the transmit power limit and QoS constraints, a set of D2D UEs that can sharing the same resources with UL UE is calculated iteratively by the algorithm. eNB should gather channel conditions, QoS level and other related information from D2Ds. However in a practical system, this exchange of information is too much to be realistic. In [Xu et al., 2010], the author assumes that LTE fractional power control can be used in D2D so that interference from D2D to eNB can be avoided efficiently. On the contrary, interference from UL UE to D2D is addressed. Each D2D pair autonomously determines the resource allocation and interference is avoided by using position information's tracked and broadcasted by eNB. In [Yu et al., 2009], interference is mitigated through power optimization in reuse mode and mode switching if reuse mode becomes inefficient.

In [Doppler et al., 2009], [Janis et al., 2009], [Chen et al., 2012], D2D reusing both DL and UL channels are both studied. In [Doppler et al., 2009], interference fromD2D to cellular UEs are controlled through power limitation and mode switching. In[Janis et al., 2009], interference from D2D to eNB in UL channel and from DL UE toD2D in DL channel is limited by power control. User diversity in macro cell is exploited to further mitigate interference.

Some articles addressing centralized D2D scheduling also propose that eNBs, as central coordinators, could choose the most efficient transmission mode for each potentialD2D pair. That is to say, after detecting data flows between a pair of UE transmitter and receiver in proximity, the eNB decide whether this pair of UEs is scheduled inD2D mode using D2D resource allocation strategy, or in conventional UL plus

DL mode using UL and DL resources respectively. Some articles propose that D2D mode selection is performed before D2D link establishment. In [J. E. Korneluk and Rodrigues, ],[L. Sun and Jia, ], a D2D distance dependent criterion is suggested to switch betweenD2D mode and UL/DL mode. Authors of [Xu and Wang, 2012] distinguish twos scenarios: D2D UEs and cellular UEs share the same RBs and use different RBs. For the first scenario, a minimum interference sustained by eNB is considered to make the decision on transmission mode. Whereas a system throughput based mode selection criterion is proposed for the second scenario.[Doppler et al., 2009], [Yu et al., 2009], [Doppler et al., 2010]proposethatD2Dmode selection is performed during resource allocation phase: Three modes are compared:

• Non orthogonal resource sharing mode: RBs are shared between a D2D link and a cellular link.

• Orthogonal resource division mode: D2D links use resources that are unoccupied by cellular UEs.

• Cellular mode: D2D traffic is relayed via eNB as in conventional UL/DL mode. Scenario of containsonlyoneD2Dlinkandonecellular link. For each RB, the eNB selects one out of the three modes to maximize the sum rate. In [Doppler et al., 2009], the total spectrum is split into several sub bands.

Both cellular UE and D2D UE are assigned to a single sub band at a time. eNB assigns the mode for a UE peer offering the highest throughput taking into account the amount of resources each mode will get.

### 4.3 Assumed scenario in our study and objectives :

We have calculated the SINR and Throughput and corresponding probability of D2D communication in a 3 sector cell .We have calculated for one sector in a cell but considering different position of cellular user in the cell .D2D communication usually occur in cell edge area .So we varied or D2D position in the edge area and cellular user position in all over the cell.

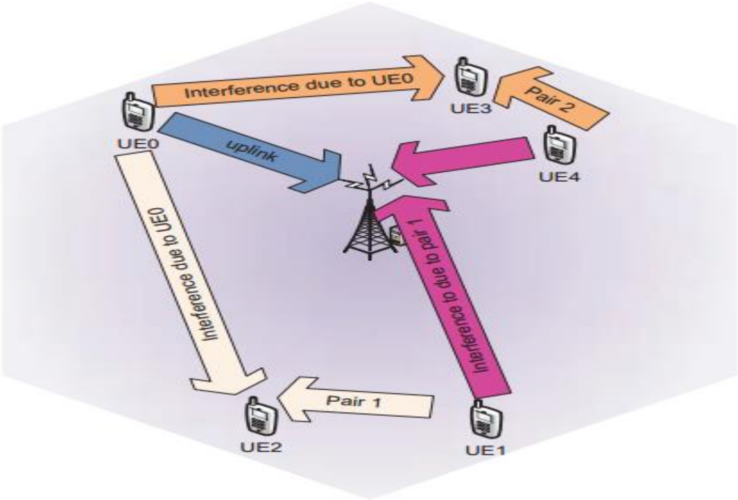
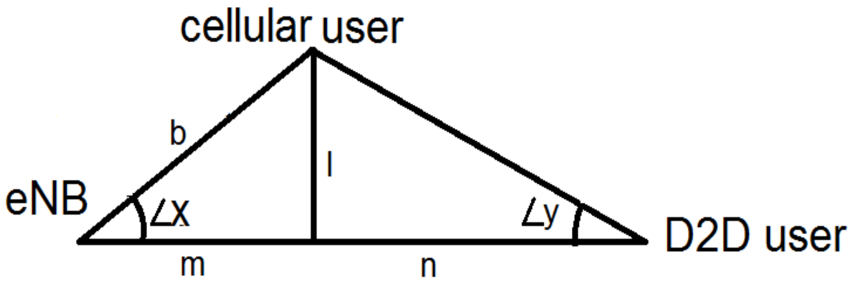



**Figure4.2**: interference in a cell where cellular users and D2D pair are in random position

### 4.3.1. Calculation method :

We assumed in a sector of a cell cellular user and d2d pair are positioned like below :




Here we can calculate the distances using these equations:

b= m/ cos(x);

l=b*sin(x);

y=inv.tan(l/n);

a= n/(cosy);

Here, m+n =190 meter (for the simulation we used cell radius 190 m )

Now we can see that if we change the position of cellular user keeping D2D user position fixed then we can get all the distances and angular position of cellular user by changing randomly any value of angle ‘x’ and distance ‘b’ . by changing these value we can get various cellular user to D2D user distances and calculate SINR in between them .

For calculation purpose we can use these equations:

- **Total path loss** :

$PL_{dB,B,u}(.)= 40(1-4*(10\text{^}-3)h_b)*\log_{10}(d/1000)-18\log_{10}(h_b)-21\log_{10}(f_c)+80$

Here fc is the carrier frequency in MHz

$h_b$ is the base station antenna height (in meter)

- **Linear gain between the eNodeB and a user u is:**

$G_{Bu}=10\text{^}-(PL_{dB,B,u})/10$

- **For D2D communication, the gain between two UEs u and v is :**

$G_{uv} =K_{uv}(d_{uv})\text{^}-\alpha$

Here,

Constant path loss exponent α,

Normalised constant $K_{uv}$;

$d_{uv}$=distance between transmitter u and receiver v.

- **SINR of the D2d receiver d during uplink phase is:**

$\gamma_d^{UL}=(P_d*G_{dd})/(N_O+I+P_C * G_{Cd})$

- **SINR of eNodeB is :**

$\gamma_{eNB}^{C}=(P_C*G_{CB})/(N_O+I+P_d * G_{dB})$

- **Power :**

$P=P_o+\alpha*PL+10\log10M+\triangle_{TF} + f_{TPC}$;

P=Physical uplink shared channel power;
Here,
Po =Basic parameter for open-loop set points in power control ;
α=parameter used to reduce the effect of PL(varies between 0 to 1);
PL=Path Loss;
M=The number of resource blocks allocated on the sub frame ;
$\triangle_{TF}$ = Depends on Modulation and Coding Scheme (MCS)
$f_{TPC}$ =Closed loop fine power adjustment

**SIMULATION ASSUMPTION S:**

| **3 Sector cells (uniform distribution of cellular user)** | |
|---|---|
| Cell Radius | 200m |
| Constant path loss exponent(a) | 3 |
| Carrier frequency(fc) | 2000 MHz |
| Base station antenna height(hb) | 25m |
| Constant for target bit error rate(α) | -1.5/ln(5*10^-6) |
| Receiver's thermal noise density(N0) | 3.98107*10^-9 |
| Intercell interference(I) | 10^-8 |
| Normalised constant $K_{uv}$ | 1 |

### 4.4 Conclusion:

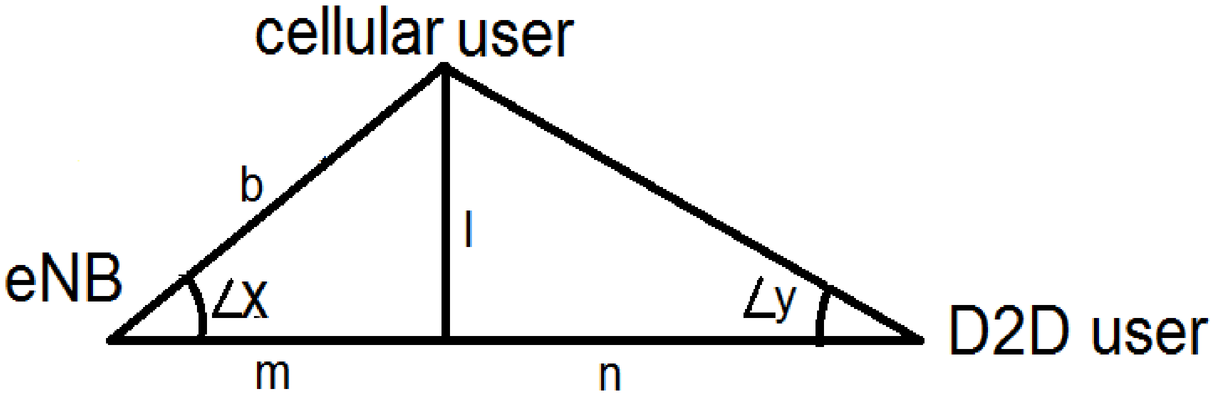
In this chapter we discussed about our proposed calculation method. One thing need to mention that our calculation had been done for uplink case .In the next chapter we will show our simulation result.

# CHAPTER 5 Simulation Results

In this chapter we will discuss about our simulation which have been done by matlab using equations described in chapter 4 .Our first simulation was to finding if our work was going in a right direction or not. After that we calculated the area in a cell sector for a particular SINR range. We have plotted pdf for those simulation . We also simulated for finding the area if we want to have a SINR more than a particular value. From that simulation we calculated cdf .Simulation results were quite satisfactory.

**5.1 .verification of our proposal:**

In this section we will show our result which have shown us that our progression was in a logical way. We have said in chapter 4 that we calculated everything in a complex cell by considering this figure:




For a fixed angle x if we change our cellular user position then we have found that SINR has declined if the cellular user distance has been increased. We know that SINR is the ratio between signal and noise. So it’s obvious that if user is closer to eNB so the signal strength will be higher so SINR will be higher. And inversely, signal strength will be lower if the distance is higher.

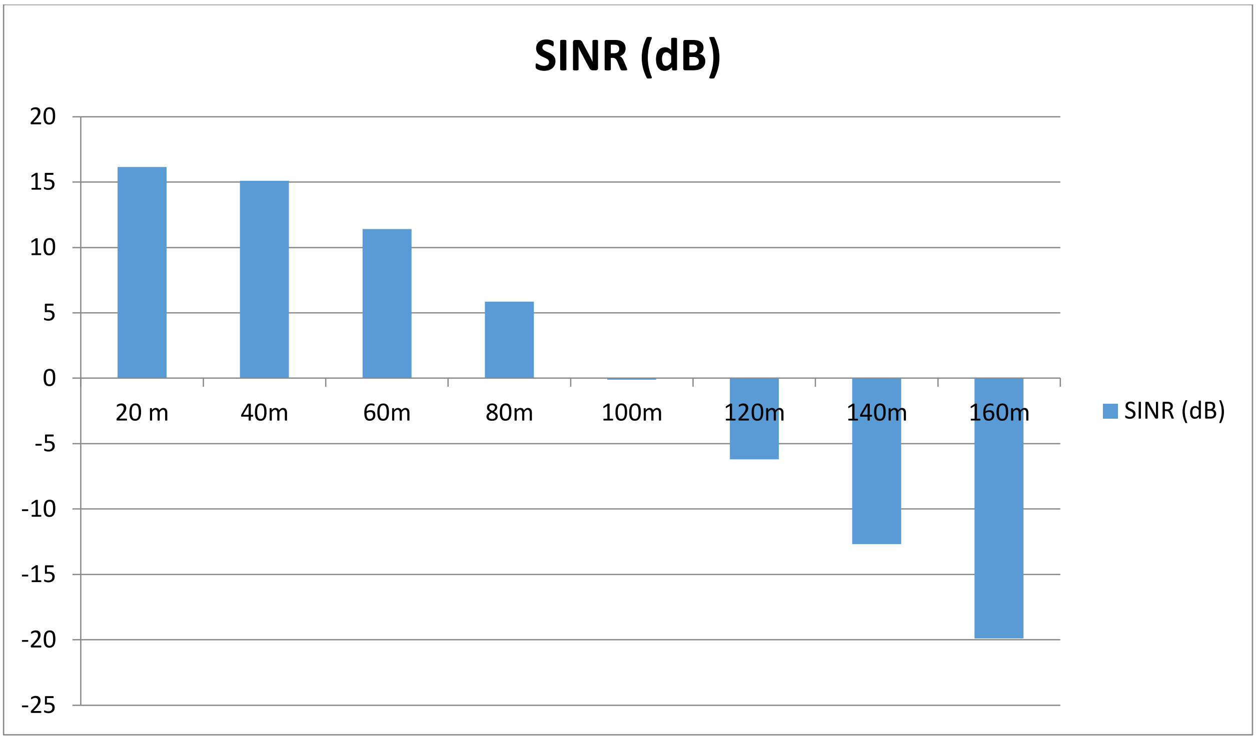



**Figure5.2**: plotting of SINR vs distance

**5.2 Area calculation:**

After we have been assured by our simulation that we were going in the right direction. We then changed out cellular user position by various angle and distance and find out the area for particular SINR range where the cellular user can be in the cell. For calculating the area we have used polar plot. We changes the angle x and for every x we took the maximum distances.

| **Angle 0.25 deg.** | **Angle 0.5 deg.** | **Angle 0.75 deg.** |
|---|---|---|
| 20.0002 m | 30.0003 m | 40.0004 m |
| 20.0008 m | 30.0011 m | 40.0015 m |
| 20.0017 m | 30.0026 m | 40.0034 m |

| | | |
|---|---|---|
| 20.0030 m | 30.0046 m | 40.0061 m |
| 20.0048 m | 30.0071 m | 40.0095 m |
| 20.0069 m | 30.0103 m | 40.0137 m |
| 20.0093 m<br>20.0122 m<br>20.0154 m | 30.0140 m<br>30.0183 m<br>30.0231 m | 40.0187 m<br>40.0244 m<br>40.0309 m |

Table: for maximum distances for fixed angles.

From table we can see the maximum values are 20.0154 m, 30.0231 m, 40.0309 m For x =0.25 , 0.5 and 0.75 degree. We then calculated the are using geometric equation.

Area = (x/2) * pi * (max radious ) $^{2}$

### 5.3 Simulation result for finding PDF:

Simulation result for finding PDF is given below.

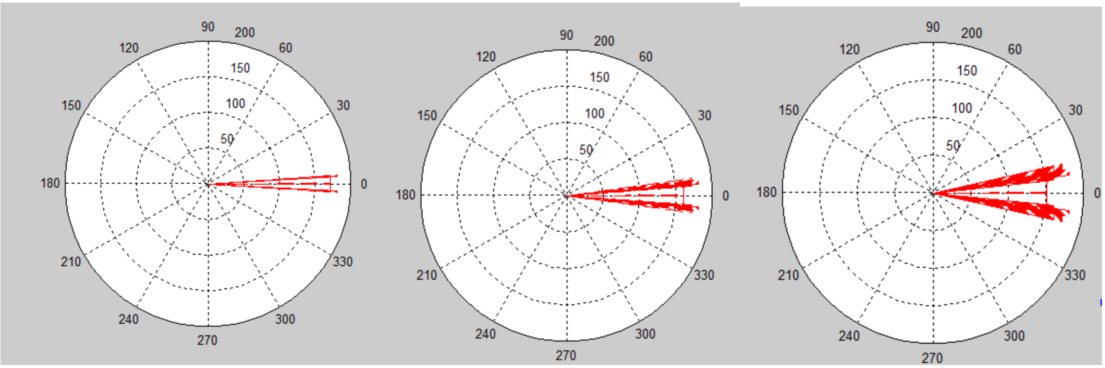



**Figure5.3**: SINR -30 to -25 ; SINR -25 to -20 ; SINR -20 to -15

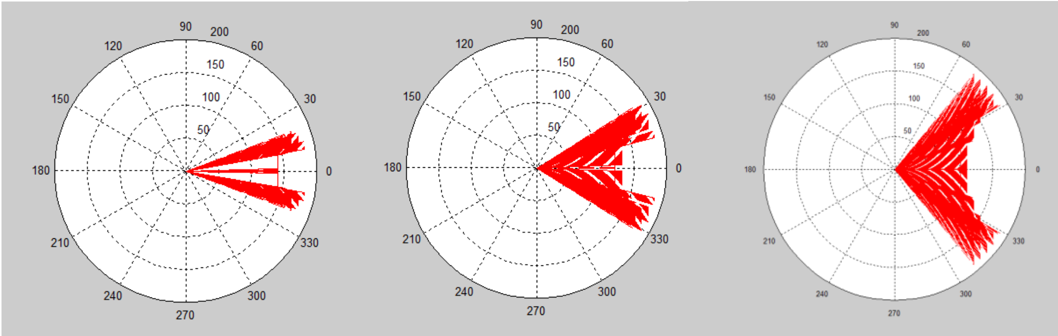



**Figure5.4**: SINR -15 to -10 ; SINR -10 to -5 ; SINR -5 to 0

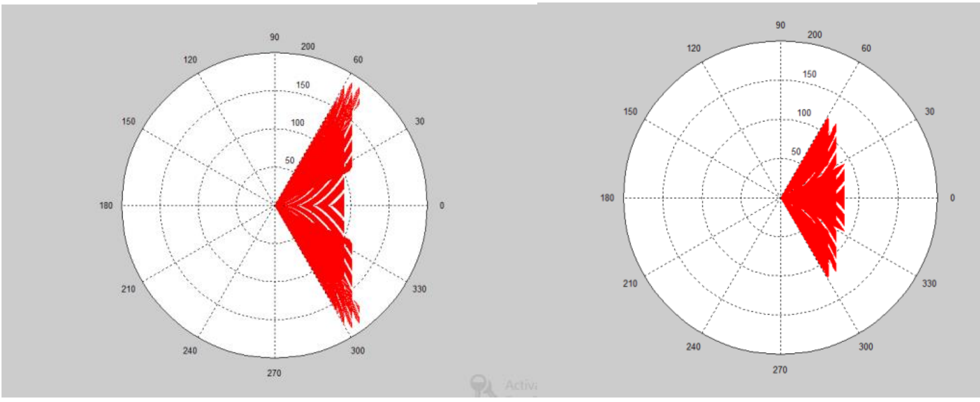



**Figure5.5**: SINR 0 to 5dB ; SINR 5 to 10dB

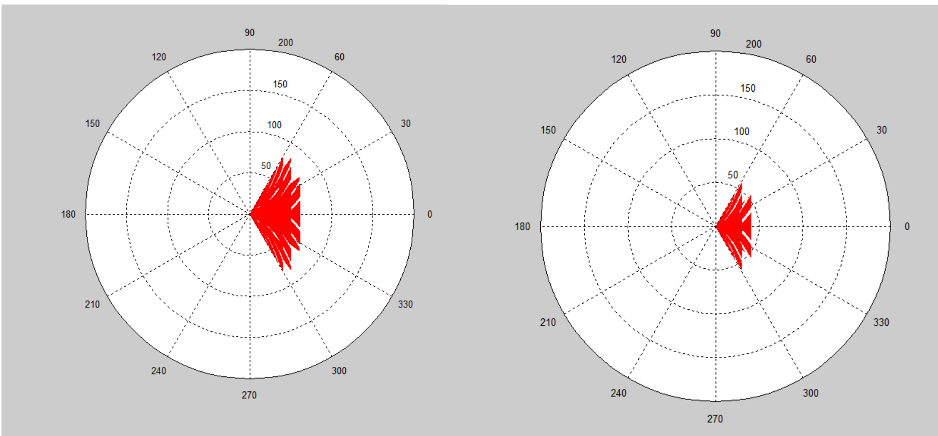



**Figure5.6**: SINR 10 to 15dB ; SINR 15 to 20dB

PDF  plot is given below:

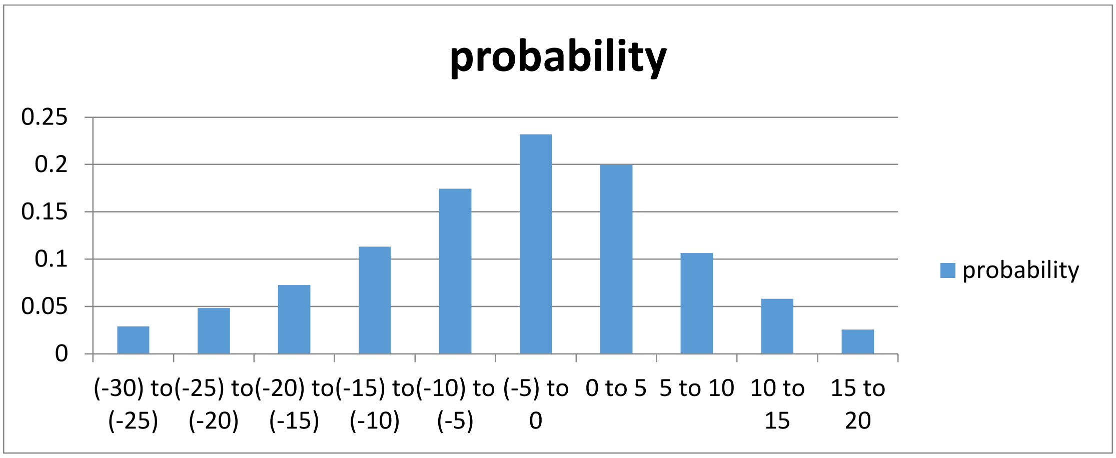



**Figure 5.7**: PDF plot

## 5.4 Simulation results for finding CDF:

Simulation results for CDF calculation are given below:

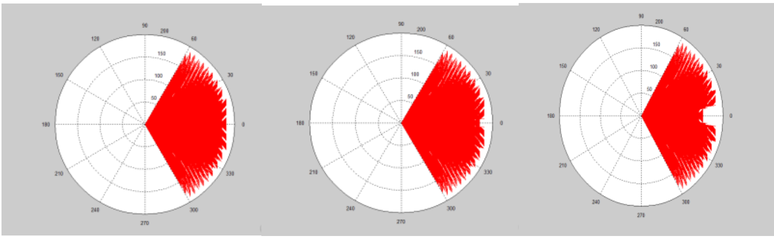


**Figure5.8:** SINR >-40dB; SINR> -30dB; SINR>-20dB

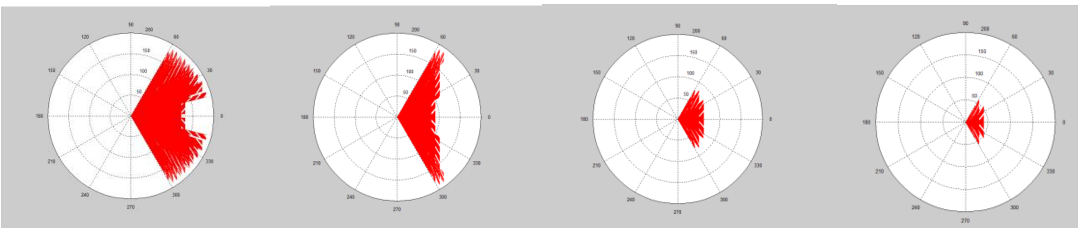


**Figure 5.9:**SINR >-10dB; SINR> 0dB; SINR>10dB; SINR>15dB

**CDF:**

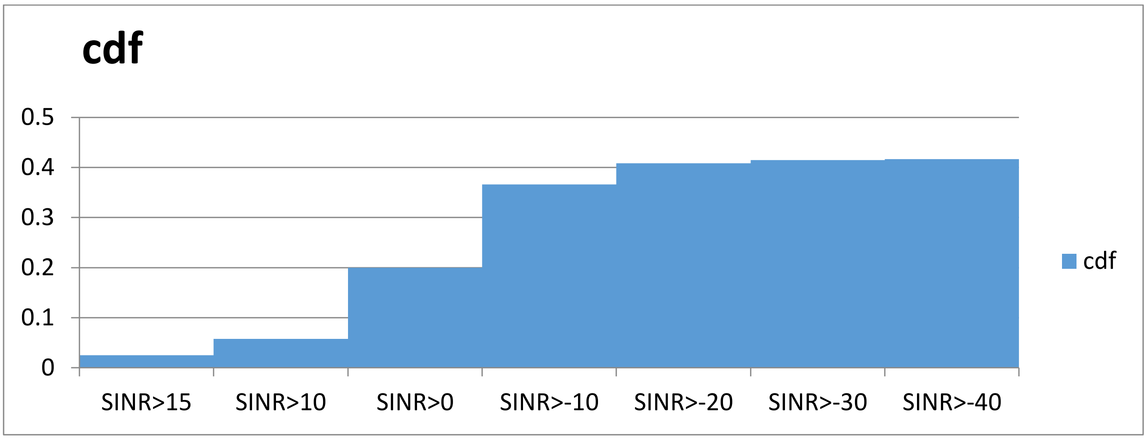



**Figure 5.10:** CDF of Probability for various SINR range

## 5.5 Conclusion:

In this chapter all the simulation results have been shown, the red area defines where the cellular user can be located if he wants to get particular SINR.

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