Comparative Study of VoIP Performance between Two D2D Enabled Mobile Nodes in an LTE-A Network

A Thesis Submitted in Partial Fulfillment
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Degree of Master of Engineering
In Software Engineering

by

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DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS

I hereby declare that this thesis contains literature survey and original research work by me, as a part of my Master of Engineering in Software Engineering studies.

All information in this document have been obtained and presented in accordance with academic rules and ethical conduct.

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Regards,

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Sudebi Mukherjee

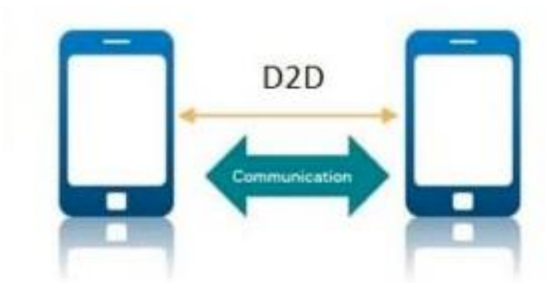
Abstract

With the evolution of communication networks, it has become very important to fulfill all the requirements of data transmission in an effective way with increased speed and performance. Device to Device communication is a technology that enables devices to connect and send data to each other without the intervention of a base station or an access point. Here a device can be a mobile device or any internet of thing like a smart phone or a smart watch etc.

Direct (or D2D) communications allow two UEs to communicate without passing through the eNodeB. However, the two UEs may still need to relay their communication through the eNB and follow the two-hop path traditional infrastructure mode as the UEs may not remain in hearing range of each other for the entire duration of communication. Hence the D2D communication should be able to switch from the direct mode to the infrastructure mode seamlessly, without this affecting the Quality of Service (QoS).

In this thesis work it is shown how mode switch may result in relevant packet losses and hence cause playout loss and playout delay. Along with it the same mobility pattern has been tested in IM mode where the two UEs communicate with each other only in IM mode and a comparison has been drawn between the two cases.

Contents



1 INTRODUCTION

1.1 Motivation of the Thesis

With the rapid growth in communication networks, there has always been a high demand to increase the capacity of data transmission. With the arrival and easy availability of smart phones, smart watches, other connecting devices and also the easy availability of data connection, future networks should not only be able to provide good quality of service and high efficiency but should also be able to work in dense networks with multiple communications.

Device to device communication commonly refers to the technologies that enable devices to communicate with each other directly without the involvement of a base station or an access point. The term device here refers to the user who uses a mobile or any other communicating device in human to human communications as well as machines in machine to machine communication (M2M) and it also refers to the vehicle in vehicle to vehicle communications(V2V).

The motivation for device to device communication comes directly from the user requirements and device to device communications will serve specific future needs. These needs include new types of short- and long-range services and data intensive short- and long-range applications. The emergence of multiple multimedia applications and context-aware applications has also motivated device to device communications. It will allow new types of services such as multimedia downloading, video streaming, online gaming and peer-to-peer (P2P) file sharing in the context of data sharing between mobile devices and other such communicating devices. As we are aware that in context sharing applications a user may be informed of a nearby restaurant, and the user can reserve a seat and get a coupon by making a call or sending a short message. Since most of the context-aware applications involve discovering and communicating with nearby devices, the D2D function can facilitate the discovery of neighbouring devices and reduce the communication cost between these devices. Secondly, M2M applications are fast growing recently. Since the cellular equipment's are getting smaller and cheaper, the wireless operators have great opportunities to connecting consumer electronic devices to their networks, e.g., washing machines and ovens.

As written above device to device communication can also be of vehicle to vehicle communication. Vehicle-to-vehicle communication (V2V communication) is the wireless transmission of data between motor vehicles. The key goal of V2V communication is to prevent accidents by sending important data like position and speed of other vehicles in transit near it. Depending upon how the technology is implemented, the vehicle's driver may simply receive a warning should there be a risk of an accident or the vehicle itself may take pre-emptive actions such as braking to slow down. Vehicle-to-vehicle communication can thus improve traffic management by allowing vehicles to also communicate with roadside infrastructure such as traffic lights and signs.

1.2 Focus of the Thesis

As mentioned earlier, the thesis focuses on mode switching D2D when the D2D communication switches from DM to IM and vice versa depending on various factors.

An analysis of the mode switching has been done on a mobility pattern using SimuLTE and the same mobility pattern has been tested in IM mode only keeping all the parameters same.

1.3 Organization of the Thesis

This thesis covers the following aspects of the challenges of D2D communication and the effects of mode switch in D2D.

1. **Chapter 2** discusses the traditional technologies that allows user equipment's to connect with each other and share data.
2. **Chapter 3** discusses the types of D2D communication based on licensed and unlicensed spectrum.
3. **Chapter 4** describes the LTE – A architecture and the different layers of LTE protocol stack.
4. **Chapter 5** gives an overview of device to device communication in LTE-A Network and introduces sidelink, uplink and downlink.

5. **Chapter 6** discusses about the mode switching D2D. Its effects and related works.
6. **Chapter 7** produces a comparative Study of VoIP Performance between two D2D Enabled Mobile Nodes in an LTE-A Network
7. **Chapter 8** Conclusion and remarks

2
Traditional Technologies

2.1 Bluetooth and Wi-Fi Direct

The above emerging services and applications are driving wireless operators to pursue the D2D function in their networks. IEEE 802.11 is a set of Media Access Control (MAC) and Physical Layer (PHY) specifications for implementing wireless area network (WLAN) computer communication. Wi-Fi or WIFI is a technology for wireless local area networking with devices based on the IEEE 802.11 standards.

Wi-Fi Direct, initially called Wi-Fi P2P, is a Wi-Fi standard enabling devices to easily connect with each other without requiring a wireless access point. Wi-Fi Direct allows two devices to establish a direct Wi-Fi connection without requiring a wireless router. Hence, Wi-Fi Direct is single radio hop communication, not multihop wireless communications, unlike wireless ad hoc networks and mobile ad hoc networks.

Wi-Fi becomes a way of communicating wirelessly, much like Bluetooth. It is useful for everything from internet browsing to file transfer and to communicate with one or more devices directly at typical Wi-Fi speeds.

The traditional D2D technologies such as Bluetooth and Wi-Fi-direct are inadequate. First, there are more than 5 billion cellular users globally, who can only realize D2D function by Wi-Fi or Bluetooth, which is not an integral part of the cellular networks and thus causes inconvenience customer usage experience. For example, both Bluetooth and Wi-Fi require manual pairing between two devices. The distance of Wi-Fi-direct is claimed to be 656 inches, which means that dozens of devices within the range may be on the list. This process will make the user quite cumbersome compared to making a phone call. Second, the traditional D2D technologies are unable to meet the requirements of some users or applications due to several technical limitations. Since most of the traditional D2D technologies work on the crowded 2.4GHz unlicensed band, the interference is uncontrollable. In addition, traditional D2D technologies cannot provide security and Quality-of-Service (QoS) guarantee as the cellular networks. Last but not the least, the wireless operators cannot make profits using traditional D2D technologies since they work independently without the involvement of the operators.

3 Classification of Device to Device Communication

D2D communication in cellular networks is defined as direct communication between two mobile users without traversing the Base station (BS) or core network. The cellular system that is adopting the D2D communications is the Long-Term Evolution i.e. LTE systems or more specifically the LTE-Advanced or LTE-A systems. Unlike Bluetooth and Wi-Fi-direct device to device communications in cellular networks are differentiated depending on the spectrum in which they occur. D2D communication is generally non-transparent to the cellular network and it can occur on the cellular spectrum or unlicensed spectrum [2]. If the communication occurs in the licensed spectrum then it is known as **Inband D2D** and if it occurs in the unlicensed spectrum then it is known as the **Outbound D2D.** Due to high control over licensed spectrum inband D2D is preferred over outband D2D. Though D2D communications can handle phone calls and network data traffic without additional load on the network but there are some complexities in the deployment of D2D in cellular networks. Firstly, it causes interference in the cellular network which thereby effects the performance of the network devices and secondly for device to device commutations in cellular networks new Quality of Service requirements must be taken care of. The integration of LTE-A networks and device to device communications must take into account LTE-A interfaces and network elements.

2.1 Spectrum Allocation

As discussed above, in terms of spectrum usage D2D communications can be divided into two types. Namely Inband D2D and outband D2D.

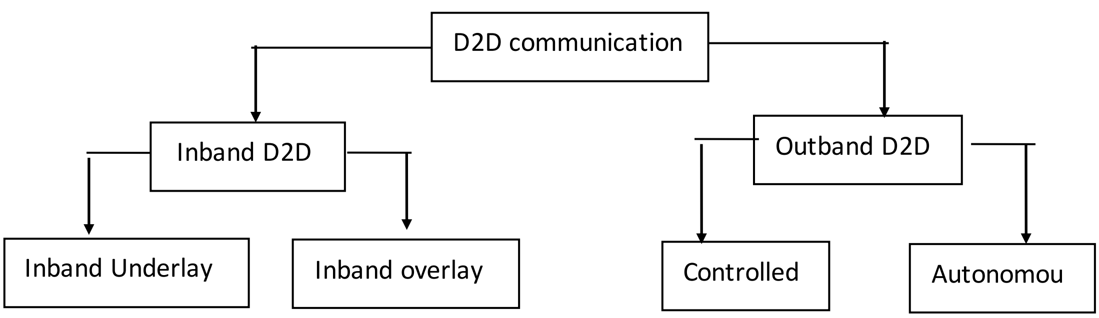


Figure 1: Types of Device to Device Communications

2.1.1 Inband D2D communications.

It can be further divided into two categories:

2.1.1.1 Inband underlay mode

In this mode cellular and D2D communications share the same radio resources [3]. D2D communications use the cellular resource and spectrum. spectrum efficiency, energy efficiency, and cellular coverage are improved and enhanced by the use of different techniques in underlay inband mode. The techniques include diversity techniques, interference reduction, resource allocation and also network coding [4],[5],[6],[7],[8],[9]. By allowing underlying direct D2D communications, LTE-advanced mobile network offers several advantages such as low end-to-end latency and high spectral efficiency.

The analysis in [10][11] presents and proposes new algorithms and interference management strategy to achieve capacity enhancement and to solve mode selection problem in cellular networks and D2D systems.

2.1.1.2 Inband overlay mode

In this mode cellular and D2D are given dedicated cellular resource and those cellular resource are subtracted from the cellular users. This is done to eliminate the interference caused in cellular transmissions due to D2D communications.

2.1.2 Outband D2D communications

Outband D2D communications are being researched now a days and are attracting many researchers. In this mode D2D communications are performed in the unlicensed spectrum hence interference between D2D and cellular communications are impossible. But since it uses unlicensed spectrum it may suffer the uncontrolled nature of unlicensed spectrum. For exploiting unlicensed spectrum another interface is needed that implements Wi-Fi, Zig Bee or Bluetooth. D2D communications generally occurs in the extra interface thus it faces many challenges. Depending on the occurrence of the second interface outbound D2D can be divided into two categories:

2.1.2.1 Controlled mode

In this mode the second interface is under the cellular network. The cellular network advanced management feature is used to control the D2D communications. This improves the efficiency and reliability of D2D communications. It also improves the system performance in terms of throughput, power efficiency and multicast.

2.1.2.2 Autonomous mode

In this mode the second interface in not under the cellular network and the D2D is controlled by users.

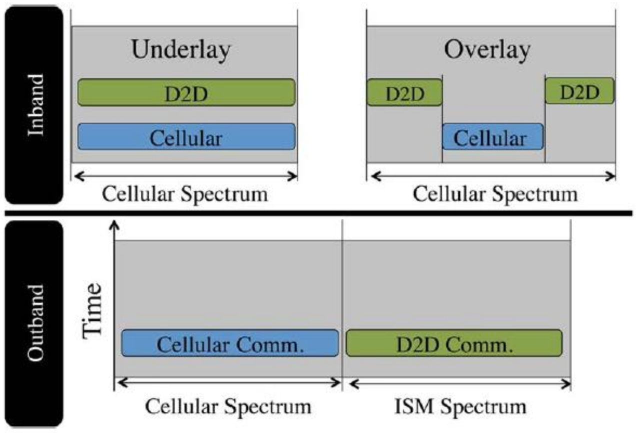


Figure 2: Schematic representation of underlay Inband, Overlay Inband and Outband D2D

The key motivating factor for choosing the Inband D2D communication is the high control over licensed spectrum whereas the main motivation of using Outband D2D communications is the capacity to eliminate the interference between D2D links. But Outband D2D communications faces a lot of challenges in the coordination between the different frequency bands.

4
LTE-A Architecture

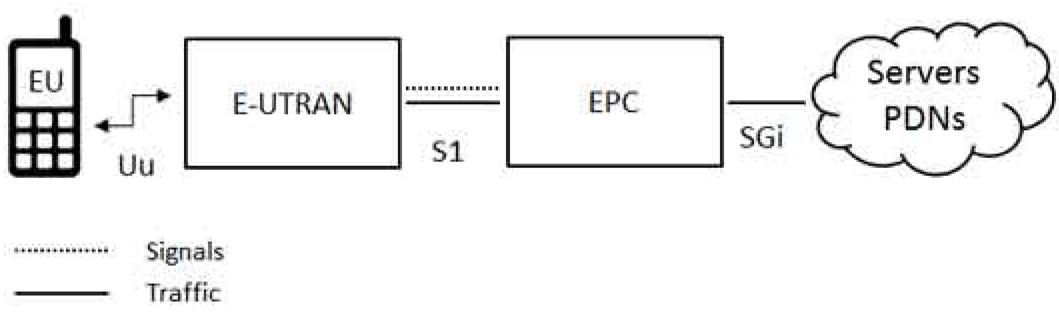
4.1 Components of LTE Network

To understand how D2D communication takes place or what is the underlying architecture of D2D communication, we first need to know about the LTE network and its Architecture.

LTE stands for **Long Term Evolution** and it was started as a project in 2004 by telecommunication body known as the Third Generation Partnership Project (3GPP). LTE evolved from an earlier 3GPP system known as the Universal Mobile Telecommunication System (UMTS), which in turn evolved from the Global System for Mobile Communications (GSM). First version of LTE was documented in Release 8 of the 3GPP specifications.

The LTE network comprises of three main components:

1. The User Equipment (UE)
2. The Evolved UMTS Terrestrial Radio Access Network (E-UTRAN)
3. The Evolved Packet Core (EPC)



The User Equipment (UE) is any device that is used directly by an end user to communicate. It can be a hand held telephone, a laptop computer equipped with mobile broadband adapter or any other device.

The E-UTRAN is the core component that handles the radio communication between the UE and the Evolved Packet Core (EPC).

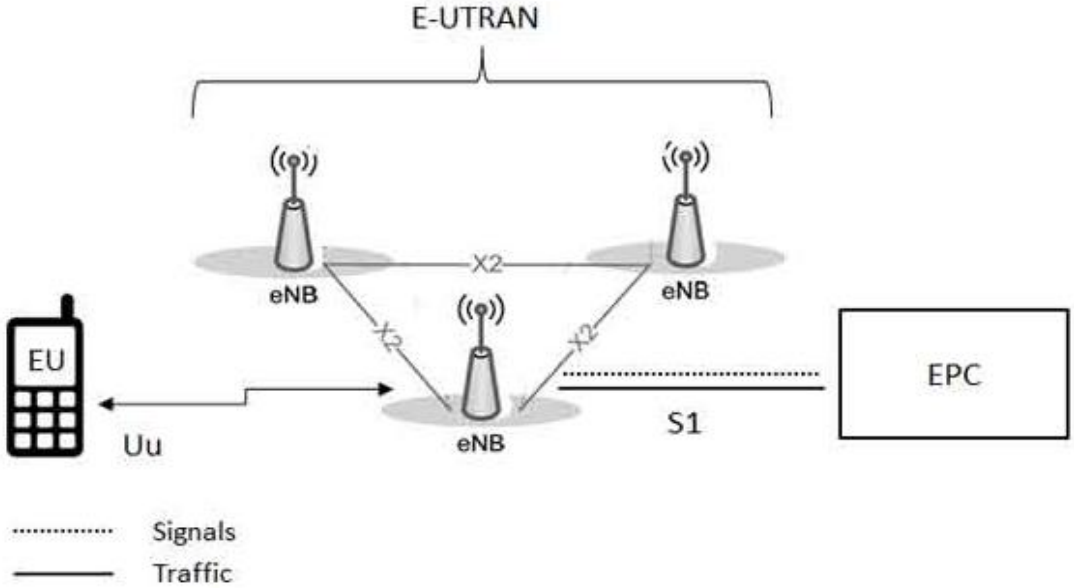


Figure 3: Architecture of E-UTRAN

The E-UTRAN has only a single component which is known as the eNodeB or eNB. The eNB is a base station that controls the UEs in one or more network cells. The base station that communicates with a UE is known as the serving eNB. A UE has a single serving eNB at a time which sends and receives radio transmissions to/form all the UEs and also the low-level operations of all UEs by sending messages.

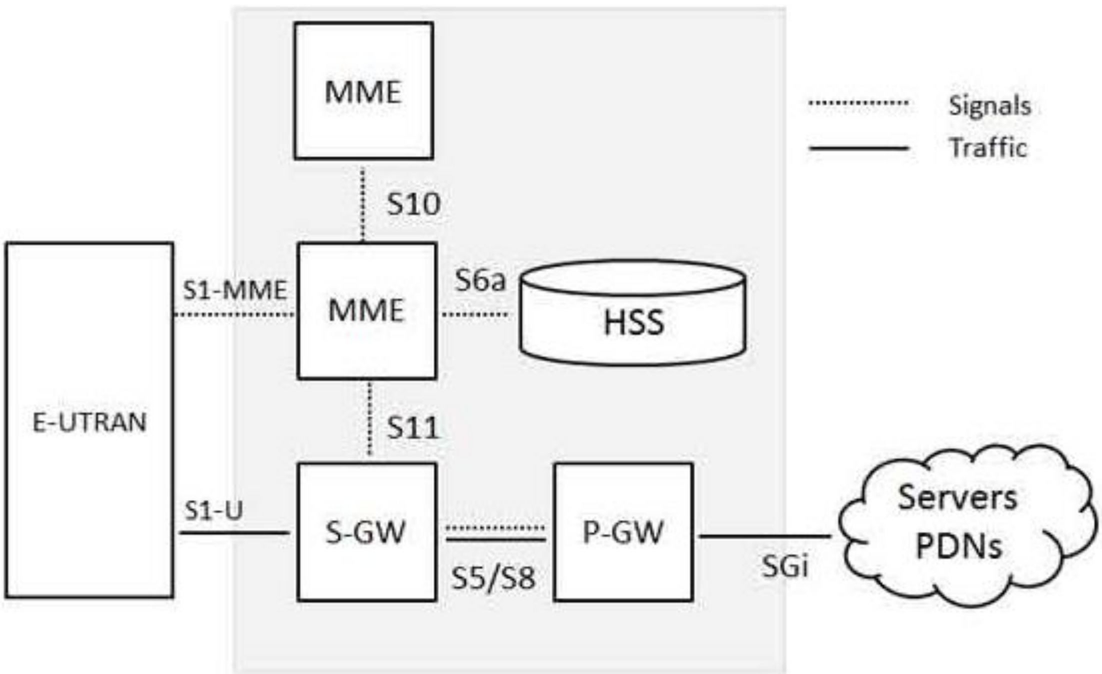


Figure 4: Architecture of EPC

4.1.1 Components of EPC:

1. **Home Subscriber Server (HSS):** It is a central database that contains all information about network operator's subscribers.

2. **Packet Data Network (PDN) Gateway (P-GW) :** The P-GW communicates with outside world and is identified by an access point name (APN)

3. **Serving Gateway (S-GW):** The S-GW serves the purpose of a router between the base station and the P-GW.

4. **Mobility Management Entity (MME):** It controls the UEs high level operation by signalling messages and HSS.

5. **Policy Control and Charging Rule Function:** PCRF resides inside the P-GW and is responsible for policy control decision making and flow based charging functionalities.

6. **S5/S8:** These are the interfaces between S-GW and P-GW. The interface is known as S5 when the S-GW and P-GW in the same network and is known as S8 when the two systems reside in different networks.

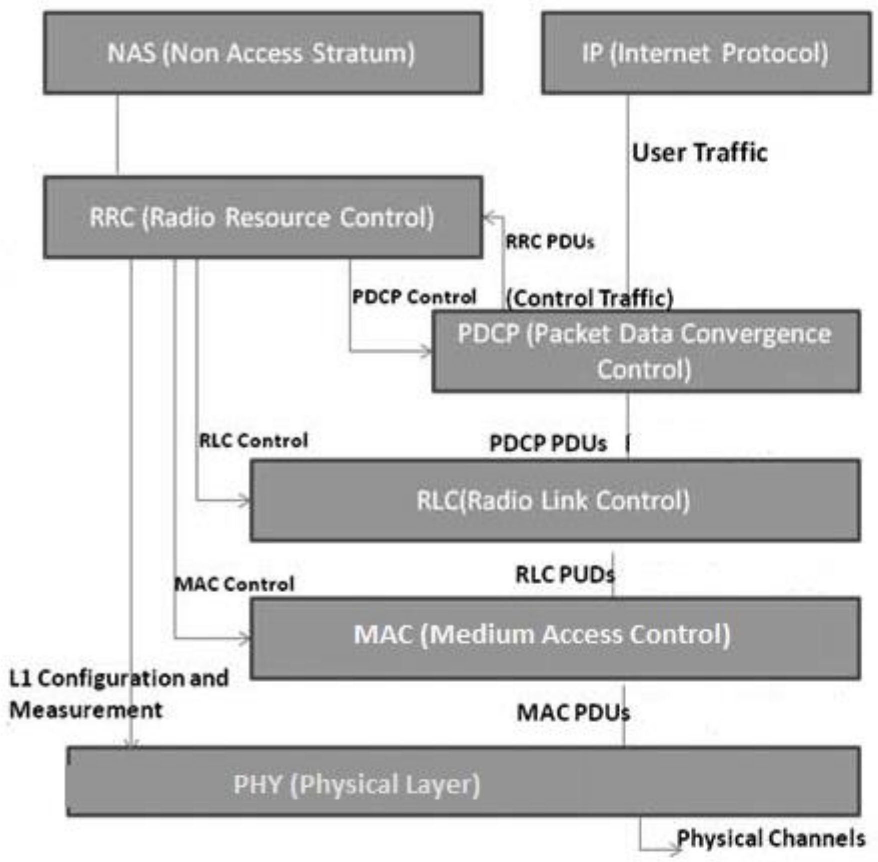


Figure 5: LTE-A Protocol Stack

4.1.2 Layers of LTE Protocol Stack

1. **Physical Layer**

   The physical layer carries all information from the MAC transport layer and is responsible for error detection on transport layer, Hybrid ARQ, physical channel modulation/demodulation and link adaptation, frequency and time synchronization etc.

2. **Medium Access Control**

   MAC layer is responsible for mapping between logical channels and transport channels, Multiplexing of MAC SDUs from one or different logical channels to form transport blocks (TB) which are then delivered to the physical layer on transport channels, de multiplexing of MAC SDUs from one or different logical channels from transport blocks (TB) delivered from the physical layer on transport channels, Scheduling information reporting, Error correction through HARQ etc

3. Radio Link Control

There are 3 possible modes of operation of the RLC layer. Namely Transparent Mode (TM), Unacknowledged Mode (UM), and Acknowledged Mode (AM). The RLC Layer is responsible for transfer of upper layer PDUs to the lower layer by converting them to RLC SDUs, error correction through ARQ, concatenation, segmentation and reassembly of RLC SDUs. It is also responsible for re-segmentation of RLC data PDUs, reordering of RLC data PDUs, duplicate detection etc

4. Packet Data Convergence Protocol

PDCP Layer is responsible for Header compression and decompression of IP data, maintenance of PDCP Sequence Numbers (SNs), In-sequence delivery of upper layer PDUs at re-establishment of lower layers, Duplicate elimination of lower layer SDUs at re-establishment of lower layers for radio bearers mapped on RLC AM, Ciphering and deciphering of user plane data and control plane data, Integrity protection and integrity verification of control plane data, Timer based discard, duplicate discarding etc

5. Radio Resource control

The RRC sublayer is responsible for broadcast of System Information related to the non-access stratum (NAS), broadcast of System Information related to the access stratum (AS), Paging, establishment, maintenance and release of an RRC connection between the UE and E-UTRAN and Security functions.

4.1.3 User Data Flow through the LTE protocol layers

When an IP packet arrives at the Packet Data Convergence Protocol (PDCP) layer, they are ciphered and numbered to form PDCP Packet Data Units (PDUs). These are then sent down to the Radio Link Control (RLC) layer in the form of RLC Service Data Units (SDUs), which are kept in the RLC buffer. As already discussed above, according to the standard of D2D communications, there are three modes of operation in the RLC layer. RLC layer does segmentation and reassembly of these SDUS to make the RLC PDUs. The RLC layer performs duplicate detection and reordering on reception of the RLC PDUs. The RLC layer then adds a header based on RLC mode of operation. The UM is considered as the standard for D2D communication. RLC submits these RLC PDUs (MAC SDUs) to the MAC layer. The MAC requests to the RLC an RLC PDU of a given size. It then collects some RLC SDU from the RLC buffer, performs fragmentation and concatenates them to form necessary RLC PDUs which are then transferred to the MAC layer. The MAC layer on reception of the RLC PDUs adds header and does padding to create the MAC PDU which is also known as the transmission Block (TB). MAC layer submits MAC PDU to physical layer for transmitting it onto physical channels.

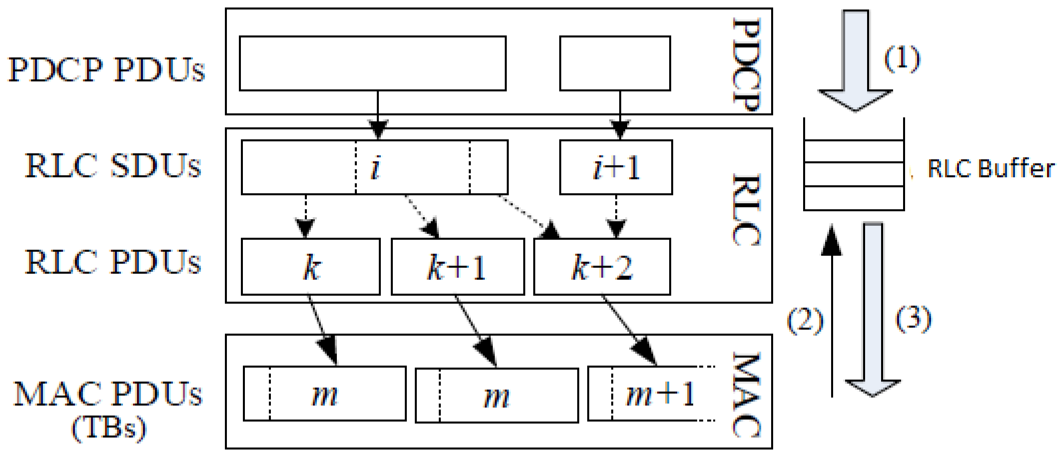


Figure 6: User Data flow through LTE protocol layers

5
Device to Device communication in LTE-Advanced

5.1 D2D in LTE-A Network

3GPP Release 12 of the LTE-Advanced standard specifies a general concept of proximity-based services (ProSe) that allows physically close devices to discover themselves and communicate via direct links [13]. ProSe is meant for Public safety communication as well as for commercial applications but it emphasises more on public safety communications. ProSe direct communication is a communication between two or more UEs in proximity that are ProSe-enabled and ProSe direct discovery is a procedure where a ProSe-enabled UE discovers another ProSe-enabled UEs in its vicinity by using only the capabilities of the two UEs.

The D2D communication in LTE-A network is also known as LTEDirect as it supports direct communication between UEs in the licensed spectrum.

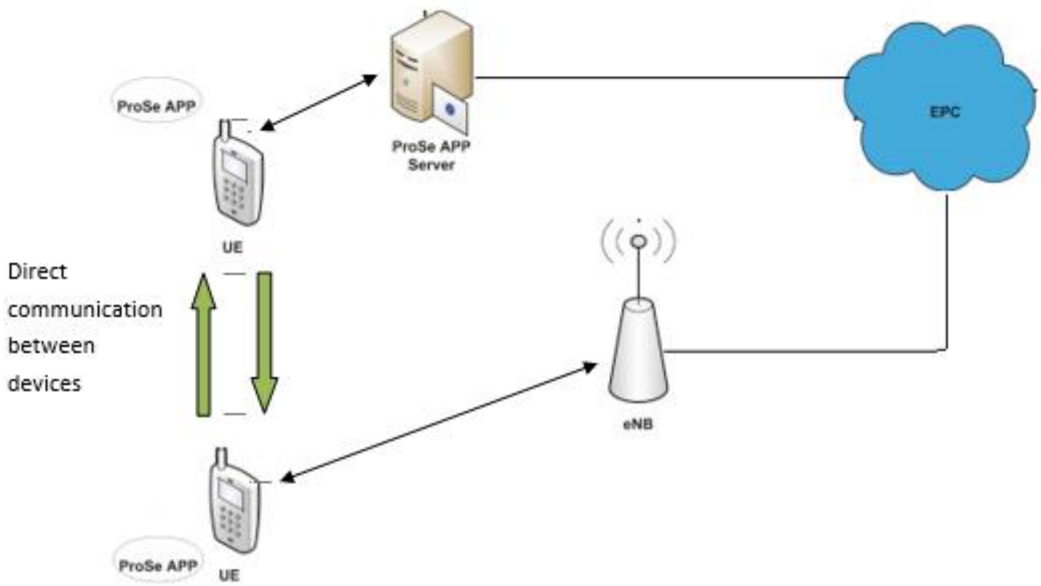


Figure 7: D2D communication architecture under LTE network

The Base station or eNodeB or eNB is connected to the EPC and can communicate directly with the user equipment (UE) using cellular communication i.e. **Uplink** and **Downlink**. The direct link between the UEs is known as **Sidelink** and the UEs operate via Time Division duplex or Frequency Division duplex. Several synchronization signals are defined in 3GPP which are used by the UEs to synchronize with the eNB and other UEs. An UE can have various ProSe applications installed in it which can exchange data with ProSe app in remotely located ProSe server. When an UE wants to communicate with another it first undergoes through ProSe discovery and then it can communicate directly. Since the D2D communication in LTE Network is an underlay D2D communication hence the cellular and D2D links share the same spectrum and resources. In underlay mode the UEs are under the supervision of eNB and eNB is responsible for resource allocation.

Figure 8: Illustration of Sidelink, Uplink and Downlink in LTE-A network

Though D2D a promising technique for offloading local traffic from cellular base stations by allowing local devices, in physical proximity, to communicate directly with each other and also by relaying, D2D is also a promising approach to enhancing long-distance service coverage, but there are many challenges to realizing the full benefits of D2D.

5.2 Major D2D challenges

- Minimizing the interference between legacy cellular and D2D users operating in underlay mode is still an active research issue.
- Resource sharing and allocation are amongst the most important issues in cellular D2D networks.
- Radio resources such as spectrum and transmit power is another resource type that must be efficiently managed

6
Mode Switching D2D

Network-controlled direct communications or D2D communications are currently being investigated and is being standardized in the framework of LTE-Advanced and there is a huge possibility of the D2D communications to become a part of the upcoming 5G systems. Enabling devices to communicate directly, without using the traditional two-hop infrastructure path having the eNodeB as a relay, is expected to reduce latency, enable frequency reuse on a spatial basis, and possibly reduce energy consumption at the eNB itself. Typical uses of D2D communication are high data rate services where the endpoints are in range for direct communications, like file sharing, gaming and social networking [2].

In one-to-one communications, the two endpoints (user equipment's, say Mobile) – may not remain in hearing range of each other for the entire duration of the communication. Even if they do, the infrastructure path may still allow higher data rates, or the eNB may simply decide not to use the direct path at some point to optimize frequency reuse on a cell-wise scale. For this reason, it is necessary to allow the two communicating devices to switch from the direct path, or sidelink to the infrastructure path and back, without disrupting the communication or the Quality of service (QoS).

6.1 Effect of mode switch in D2D communication

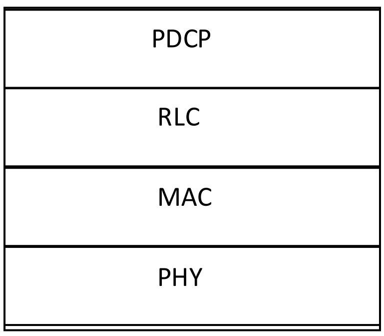


Figure 9: LTE – A Architecture Protocol Stack.

IP packets traverse the Packet Data Convergence Protocol (PDCP), where they are ciphered and numbered to form PDCP Packet Data Units (PDUs). These are then sent down to the Radio Link Control (RLC) in the form of RLC Service Data Units

(SDUs), which are kept in the RLC buffer. RLC layer does segmentation of these SDUS to make the RLC PDUs. RLC adds header based on RLC mode of operation. And submits these RLC PDUs (MAC SDUs) to the MAC layer. MAC layer submits MAC PDU to physical layer for transmitting it onto physical channels.

In the downlink (DL), the eNB allocates resource Blocks (RBs) to transmissions directed to the User Equipment's (UEs) associated to it on each TTI. In the uplink (UL), the eNB issues transmission grants for each UE, specifying which RBs they can use, using what transmission format.

We consider a cell, served by an eNB, and two D2D-capable UEs in the coverage area of the cell. We assume that the UEs are close enough for direct communication to take place. These UEs represent the endpoints of a D2D communication.

These UEs can communicate either directly, i.e., in D2D mode (DM), or using the eNB as a relay, i.e., in Infrastructure mode (IM).

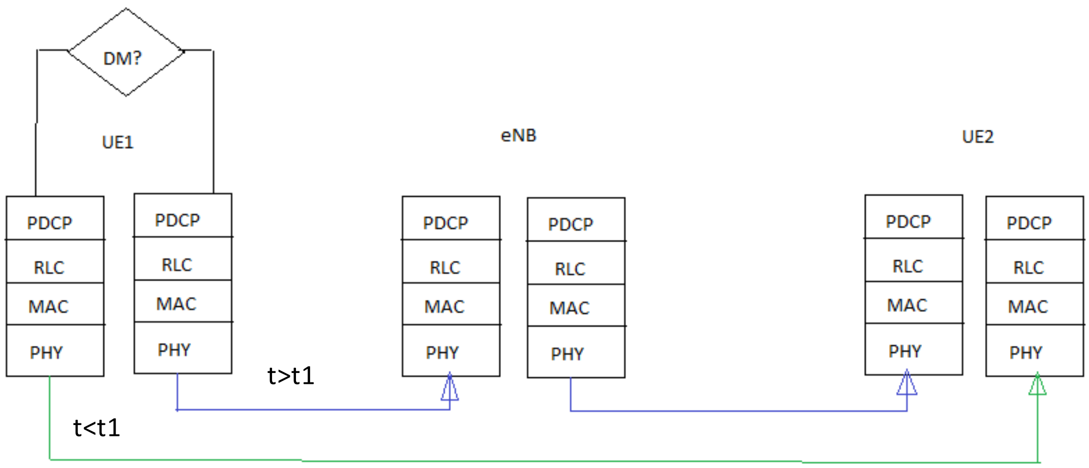


Figure 10: Effect of mode switch on D2D

In Figure 2 UE1 and UE2 are the transmitter and receiver respectively. Due to user equipments mobility and to changes in the environment, an eNB should be able to select dynamically whether a D2D communication occurs in Direct Mode or Infrastucture Mode.

We assume that UE1 is communicating with UE2 in DM. Hence UE1 and UE2 have a PDCP peering session established, with its sequence numbers and ciphering. When the communication is switched to IM, two different PDCP peerings must be used. One UE1 and the eNB i.e the UL and the other between the eNB and UE2 i.e the DL. Since the PDCP sessions are independent, hence the sequence numbers and sets of keys for ciphering/deciphering are different. Since different PDCP entities come with different RLCs, the RLC PDU sequence numbers of the SL path of DM mode cannot be assumed to be valid on the UL/DL path of the IM path either

In Figure2 the green line demonstarte the DM and the blue line the IM mode. With reference to the above diagram, say, at a time t1 UE1's RLC wants to send down a PDU with sequence number say X. However is the mode is switched to Im at t1, then a new peering will be established i.e. UE1 will peer with eNBs PDCP/RLC entioties which will expect a different next RLC sequence number. Thus, all data in the RLC buffer of the old DM connection cannot be sent on the new peering and hence needs to be discarded. Also, the fragments of the RLC SDU that has already been sent to the receiver i.e. UE2 will also be discarded. The same problem occurs also when switching from IM to DM. These losses may be significant and can effect the QoS.

6.2 Related Work

Mode selection algorithms for one-to-one D2D communications has been a research topic. Dynamic mode selection has also been suggested in [14]. Solutions [15] and [16] assumes that the PDCP buffers PDUs, and, at a mode switch, the sender, receiver and eNB should exchange signalling information to agree on which PDCP PDU number should be transmitted next on the new path. The data plane may be halted while the above signalling occurs hence it is likely to generate huge playout delays. [17] proposes tunneling at the PDCP level when the D2D connection traverses the IM path. PDCP-level tunneling requires that the destination perform deciphering twice but mode switching losses has been left open. Solution [18] proposes two solutions to tackle the problem of mode switching losses. The first one, called local solution, uses additional data structures at the sender side only to retransmit possibly unreceived data and the second solution, RLC tunneling, relies on the eNB to act as a relay at the RLC layer for a flow whose PDCP entities are located only on the terminals. Though there has been numerus studies in mode switch but this work differs from others in the fact that it has compared the performance of two D2D enabled devices in mode switch and IM mode.

7
Comparing D2D mode switching and Infrastructure mode communication using SimuLTE

SimuLTE is a simulation tool enabling complex system level performance-evaluation of LTE and LTE Advanced networks.

The simulation is carried out twice. Initially the simulation runs in Mode Switch mode and then again, the simulation is run in Infrastructure mode keeping the voip mobility pattern and all other parameters same.

In SimuLTE, in Single-Pair Mode Switching, two UEs have a peering established and the swing back and forth in a straight line to cause periodical mode switch from D2D or Direct mode to infrastructure mode and vice versa. The eNB select the mode depending on the best CQI of the modes.

Initially, the UEs are close to each other, i.e. 20 meters away. As the simulation begins the UEs move away from each other till the distance between the two UEs is 200 meters and then again, they move closer. The uEs swing back and forth at to change the quality of the D2D link whereas the quality of the Ul remains the same.

7.1 Illustration of the simulation Model

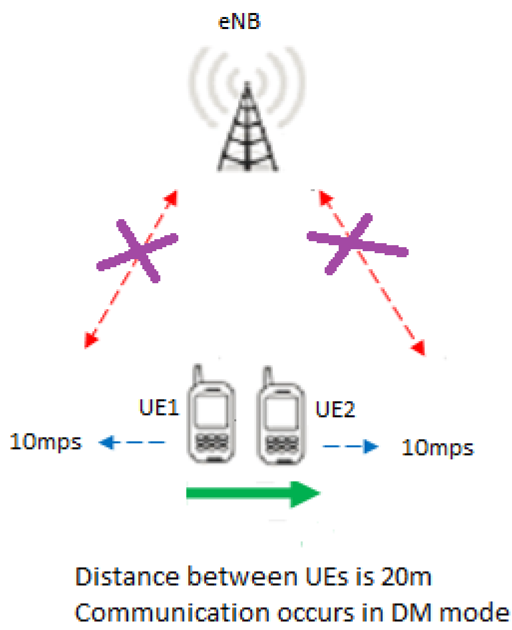


Figure 11: **Stage 1:** The UEs are close to each other, i.e 20m and the eNB detects better CQI in DM mode so communication occurs in DM mode.

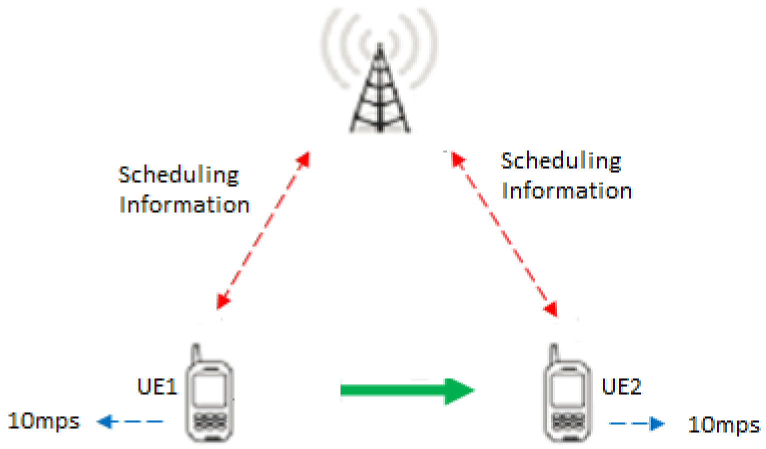


Figure 12: **Stage 2:** The UEs have moved far from each other thereby decreasing the CQI in DM link. The eNB detects drop in CQI and shares information to have a mode switch from DM to IM

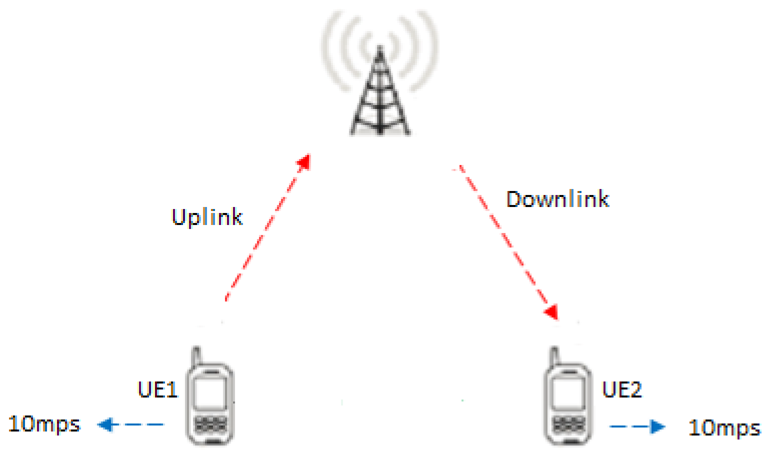


Figure 13: **Stage 3**: The eNB schedules the communication in IM mode and hence the data is transferred through eNB via uplink and downlink.

Since the simulation is run under same voip mobility pattern keeping all the parameters same, the CQI for IM mode is always 15.

7.2 Simulation Parameters

Position of UEs and eNB

Initial X eNB = 300

Initial Y eNB = 300

Initial X UE1 = 290

Initial Y UE1 = 400

Initial X UE2 = 310

Initial Y UE2 = 400

Constraint Area Min X UE1 = 200

Constraint Area Max X UE1 = 290

Constraint Area Min X UE2 = 310

Constraint Area Max X UE2 = 400

Mobility Type = Linear Mobility

Mobility Speed = 10mps

Carrier Frequency = 2100e+6Hz

7.3 Simulation Comparison and Result Analysis

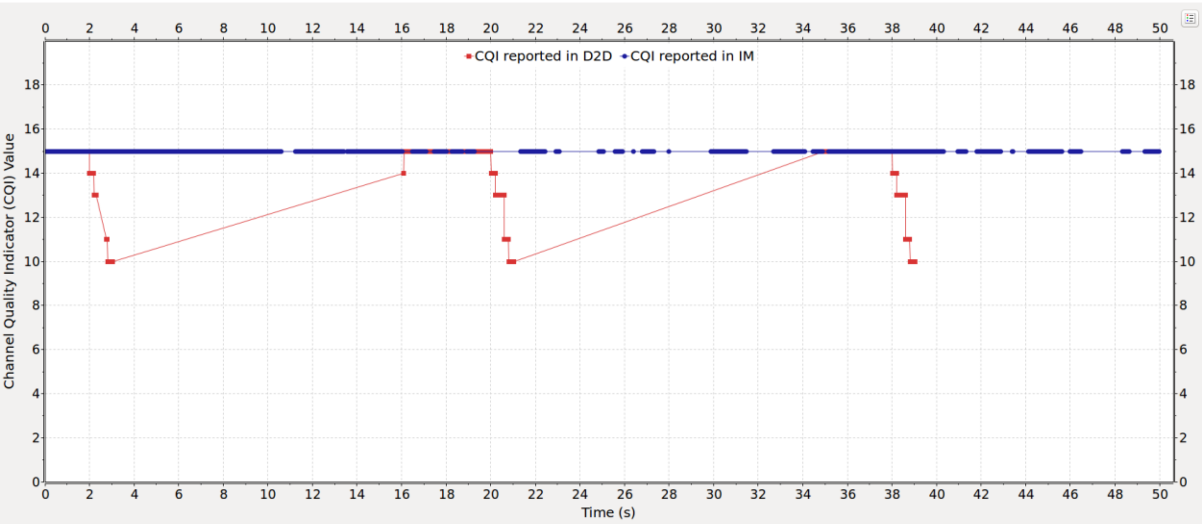


Figure 14 : The CQI for D2D link in Mode Switch Mode and UL/DL in IM mode

In the above chart,the red line depicts the CQI of the D2D mode and the blue line depicts the CQI of the UL and DL. From the chart, we can infer that that as the UEs move away from each other the CQI of the D2D link drops from 15 to 10, whereas the CQI for UL remains 15. Hence, at time when CQI for the D2D links become 10, the eNB selects the Infrastureture mode. Hence there is a swith from DM to IM. Again when the UEs start moving towards each other and the distance between the two decreases the CQI of the D2D link increases to 14 and the eNB selects the D2D mode and hence again there is a mode switch from DM to IM. Simmilarly we see that the CQI for D2D link again falls to 10 at t=21 and there is a switch from DM to IM and a switch from IM to DM at t = 35.

So we see there is a mode switch from DM to IM at t = 3, t = 21 and t=39 and from IM to DM at t = 16, t=35.

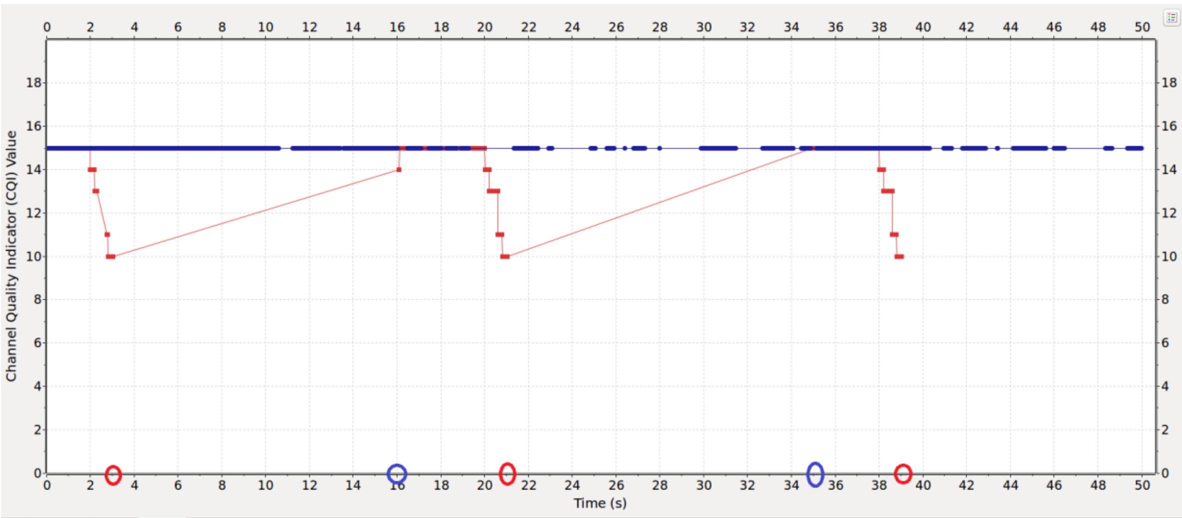


Figure 15 : Identifying mode switches when communication occus in Mode switch. The time slots encircled in red indicates a mode switch from DM to IM and the time slots encircled in blue indicates mode switch from IM to DM.

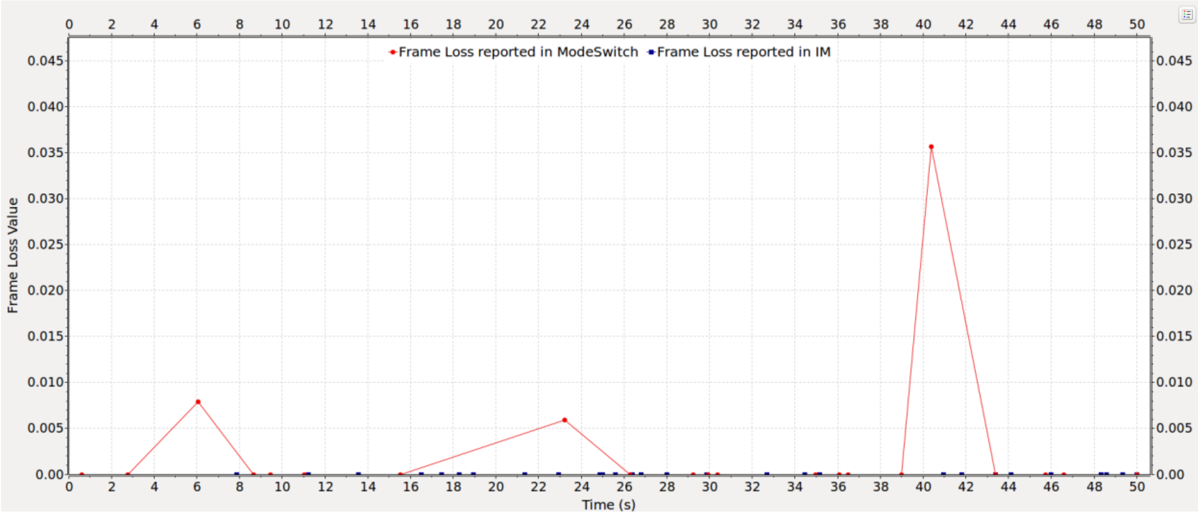


Figure 16: VoIP Frame Loss

In the above chart, the red line depicts the Frame loss in Mode switch mode and the blue dots refer to the frame loss in IM mode. We see that the frame loss percentage is higher under mode switch. The frame loss in this case is due to mode switch. Whereas if we look into the frame loss pattern when the simulation is run only in IM mode we see that the frame loss is almost negligible as the CQI is same throughout the communication. The average UL CQI at the eNB is steady due to its maintaining nearly constant distance from both the UEs.

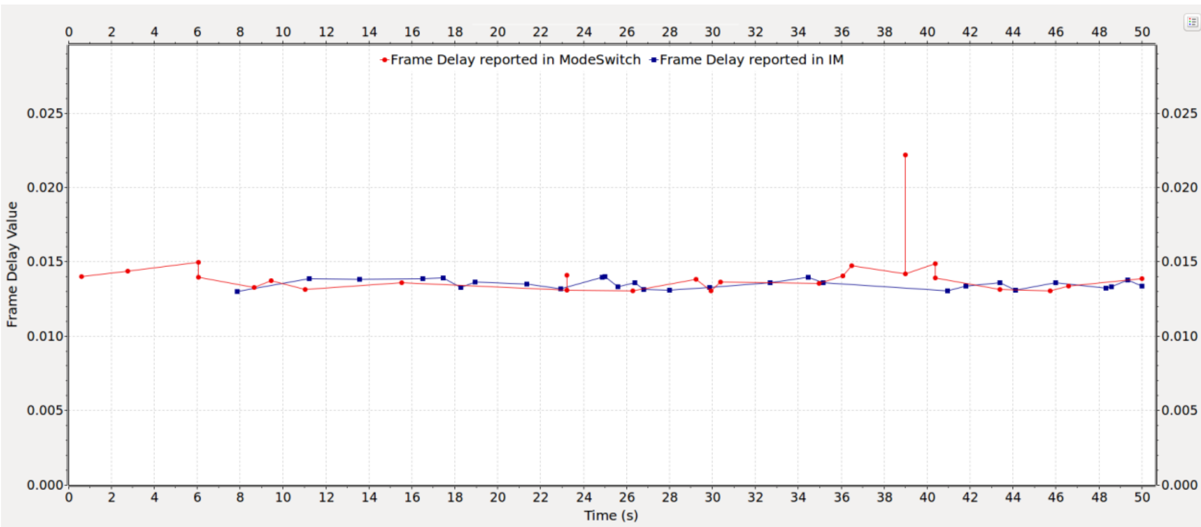


Figure 17: Voip Frame Delay

In the above chart, the red line depicts the Frame delay in Mode switch mode and the blue line refers to the frame delay in IM mode.

From the above diagram we can infer that there is frame delay in both mode switch and IM mode but in mode switch scenario the frame delay increases every time there is a mode switch from DM to IM. The chart shows that at t=21 and t=39, the delay percentage has increased.

Compared to mode swicth, in IM mode the Frame delay has less variations when the CQI is steady.

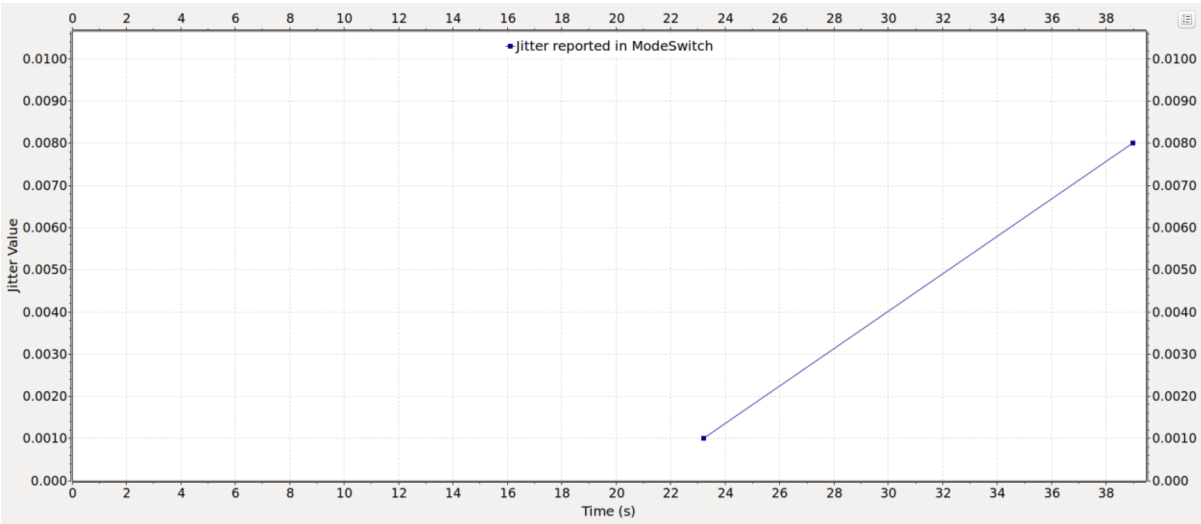


Figure 18: Voip Jitter

The above diagram, depicts that the network transmission experience higher jitter and hence increased delay in receiving packets in IM mode of mode switch whereas In DM transmissions there is almost no jitter. The chart also depicts that under simmilar circumstances, there is no Jitter if the communication occurs only in IM mode.

Since Playout delay compensates for network delay, delay jitter, we would see how its effects the playout delay.

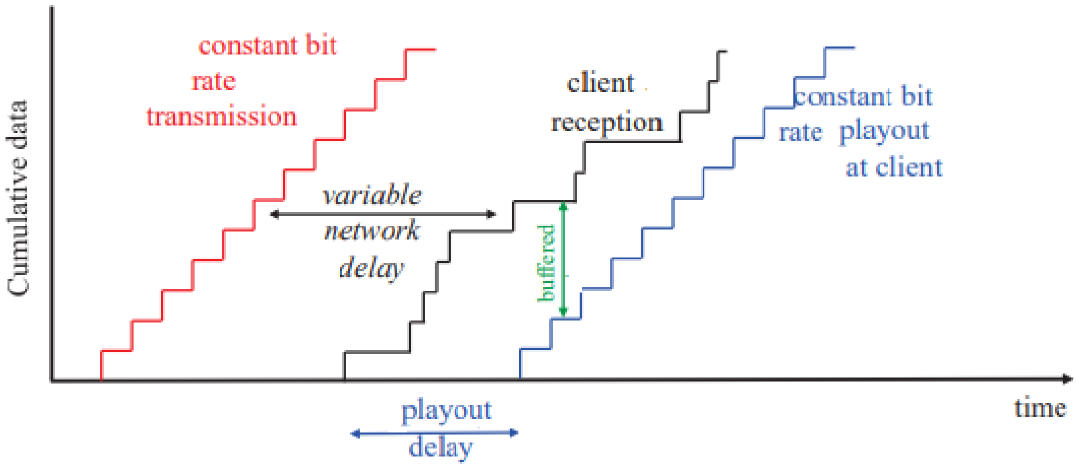


Figure 19: Playout Delay

The playout delay (or, more accurately, end-to-end application-to-application delay) is defined to be the difference between the playout time at the receiver and the generation time at the sender. If the playout delay in jitter buffer is increased then less packet are lost due to late arrival, but more delay is added to the voice call. A reduction in the playout delay turns out in less delay but more packet loss.The playout delay of the voice packets needs to be continuously adapted in order to maintain an acceptable compromise between late packet loss and tolerable additional delay over the entire duration of the voice call.

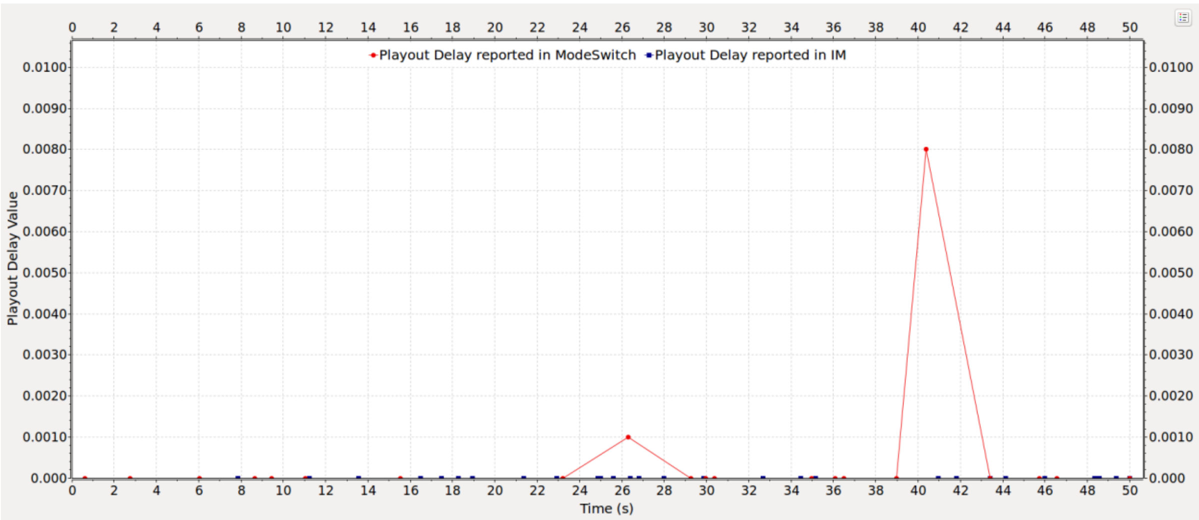


Figure 20: VoIP Playout Delay

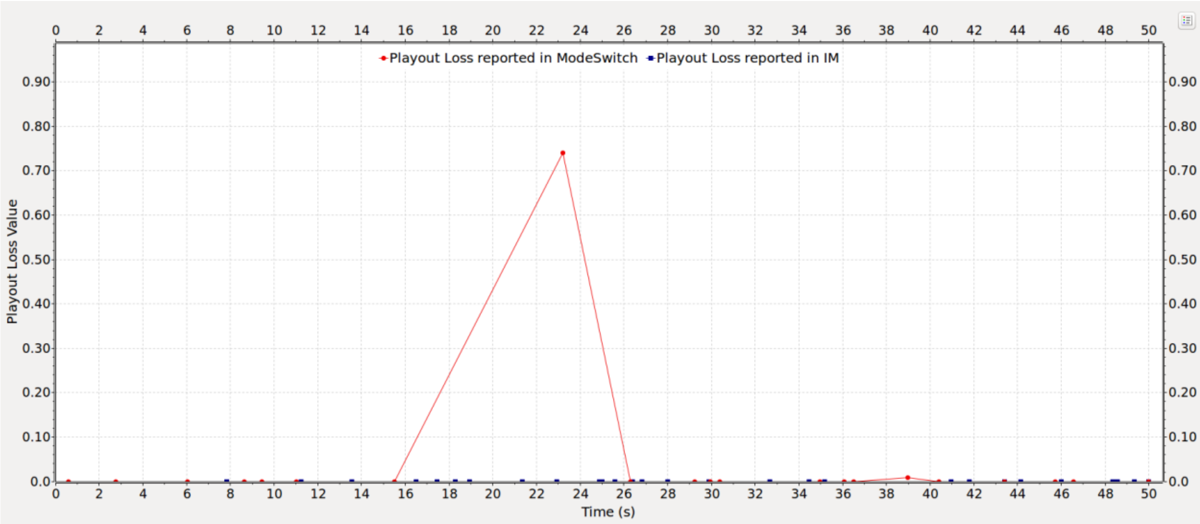
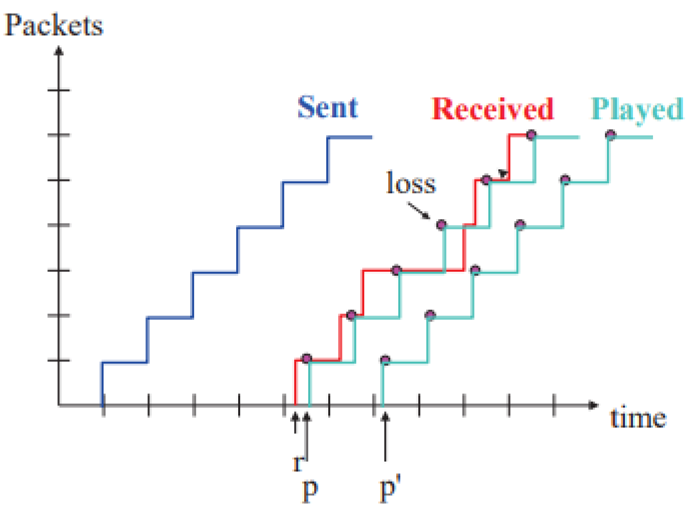


Figure 21: VoIP Playout Loss

In the above two charts the red line depicts the voip playout delay and voip playout loss in mode switch and the blue dots indicate the playout loss and playout delay, when the simulation is run only in IM mode.

If we consider figure 19 and Figure 20 we would see that in mode switch, when the tranmission is in IM mode there is more chances of playout loss and hence there are chances of increased playout delay to occur. From the above figures we see that there is more playout loss if the playout delay is less. This has been been explained below.



If playout begins at p, 4th packet will arrive too late and if playout begins at p', all packets can be played on time. So in figure 10 the packet that arrived at t = 23 was lost as the playout delay was less i.e 100ms compared to the playout delay at t = 41 which is 800 ms.

The above charts depict that in mode switch when the communication mode is in DM, there is no playout loss and hence there is negligible playout delay. Comparing it to the case when the communication occurs entirely in IM mode, we see that there is negligible playout loss and hence negligible playout delay.

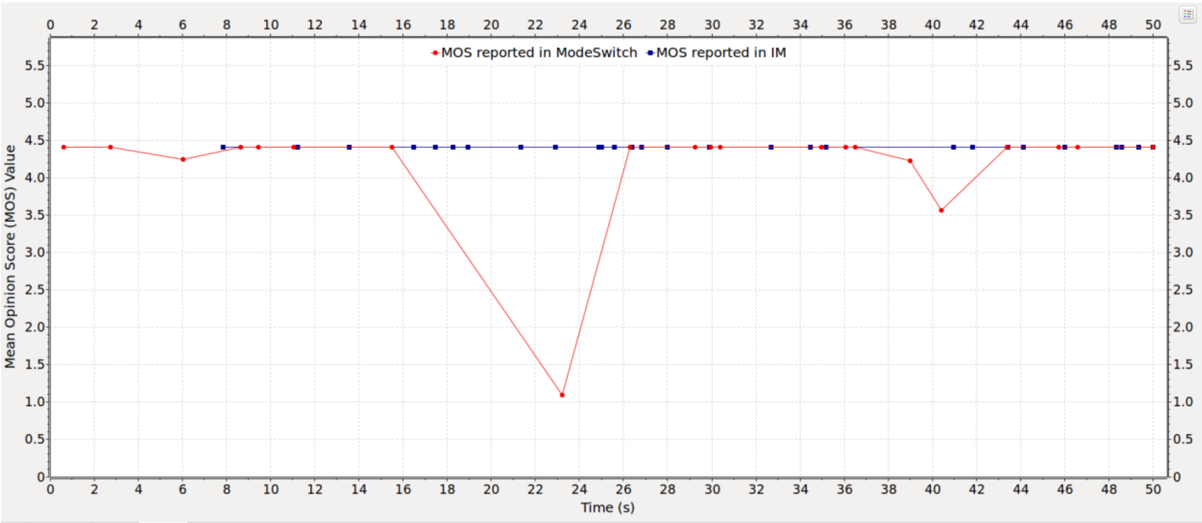


Figure 22: VoIP MOS

MOS or Mean Opinion Score gives VoIP testing a number value as an indication of the perceived quality of received voice after being transmitted and compressed using codecs. This measurement is the result of underlying network attributes that act upon data flow and is useful in predicting call quality.

MOS measures subjective call quality for a call. MOS scores range from 1 for unacceptable to 5 for excellent.

VOIP calls often are in the 3.5 to 4.2 range.

In the above figure, we see that the MOS in mode switch is mostly between the voip call range except at points t=23 and t-41 when the IM mode is active and there are frame losses at these points. So when the communication undergoes mode switch the call quality drops everytime there is a mode switch from DM to IM.

But if we compare to the case when the communication occurs entirely in IM mode we see that due to negligible frame losses and playout loss and playout delay, the MOS is almost same throughout the duration of the communication with a good quality of voip.

So, if we compare the mean values of MOS of the two simulation scenarios we find that under mode switch D2D the mean of MOS is 4.19525 whereas when the communication occurs only in IM under the similar conditions the mean of MOS is 4.40928. Hence we can conclude that, under the simmilar circumstances when a D2D communication undergoes a mode switch the voip quality meets the standard requirement for a voip call but, when the same communication occurs only in IM mode, provided the CQI is steady and good, the MOS is better than the previous case and hence the call quality is better.

As the two voip call under two different modes varies by a minimum of score, we can definetly consider mode switch in D2D communication when the distance between the UEs increases and they are no more in the hearing range of each other.

8 Conclusion and Remarks

MOS (Mean Opinion Score) is the most well-known measure of voice quality. It is a subjective method of quality assessment. Upto 1% is usually undetectable, more than 3% is the maximum permitted within industry standards.

So, when we compare the simulation results of the same mobility pattern under two different scenarios, we find that in both the case the MOS is greater than 4 for the maximum duration of the simulation. But in mode switch there are sudden drops in the MOS value and it goes below acceptable range during the when mode switch occurs from DM to IM, but the mean MOS still is greater than 4.

Our paper work leads us to two paths. Firstly we can communicate only in IM mode as we see that it gives a better MOS and secondly we can take into consideration the mode switch which would help in reducing network load.

So we can conclude from our simulation results that the voip quality actually degrades a little due to mode switch but still the effects of it is acceptable considering the fact that the percentage of degradation in QoS is very minimal and considering the fact that communications occuring in DM mode will reduce the network load, mode switch is highly acceptable considering the fact that the communication can be continued without highly decreasing the Quality of Experience.

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