

Performance Analysis of D2D Communication over LTE-A Network with Mode Switching

Ali Esfandiar

Ph.D. student from Eastern Mediterranean University, Famagusta, North Cyprus, via Mersin 10. Turkey

Gürcü Öz

Associate Professor from Eastern Mediterranean University, Famagusta, North Cyprus, via Mersin 10. Turkey

Abstract

This paper is attentive in measuring Quality of Service (QoS) in D2D and RP communications over LTE-A network using Voice over IP (VoIP) application. In order to simulate various conditions and different location distribution in the network, different scenarios are simulated in OMNET++. The examined performance results illustrate that D2D communication performs very well in short distances and also, by increasing the distance between two mobiles, communication needs to change its path from the direct link which is also known as Side Link (SL) to the Relay Path (RP). In addition, our results demonstrate how employing Mode Switching (MS) in a suitable state can improve the QoS of communication in LTE-A and utilize the advantages of both D2D and RP communications.

Keywords

LTE-A, D2D, VoIP, Mode Switching

Introduction

With increasing the functionality of mobile devices in the concept of the connected world, smart cities, Internet of Things (IoT) and many innovative application services, cellular networks have been going through phenomenal fast evolution in recent years. Long Term Evolution (LTE)'s improved spectrum efficiency led to a better performance in terms of high data rates, low latency, more flexibility and seamless integration with other wireless networks. Furthermore, supporting both Time-Division Duplex (TDD) and Frequency-Division Duplex (FDD) and using adopted uprising technologies like Orthogonal Frequency Division Multiplexing (OFDM) and MIMO made LTE the core technology of cellular networks [1]. LTE design is based on Evolved Packet System (EPS) which consists of the Radio Access Network (RAN) known as Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) and an IP-based core network known as Evolved Packet Core (EPC). All applications included VoIP can be integrated over a flat architecture to prepare seamless connectivity between operators subscribers [2]. The next version of LTE was released in 2011 and known as LTE-Advanced (LTE-A). LTE-A inherited the advantage of LTE. By utilizing advanced wireless technologies namely Carrier Aggregation, Enhanced MIMO, Coordinative Multiple Point (CoMP) and Relay Node (RN) enhanced its properties in terms of coverage, bandwidth, peak rate,

delay time, throughput, user experience, etc. [3].

LTE-A protocol stack layers obsoleted in control and data plane, where

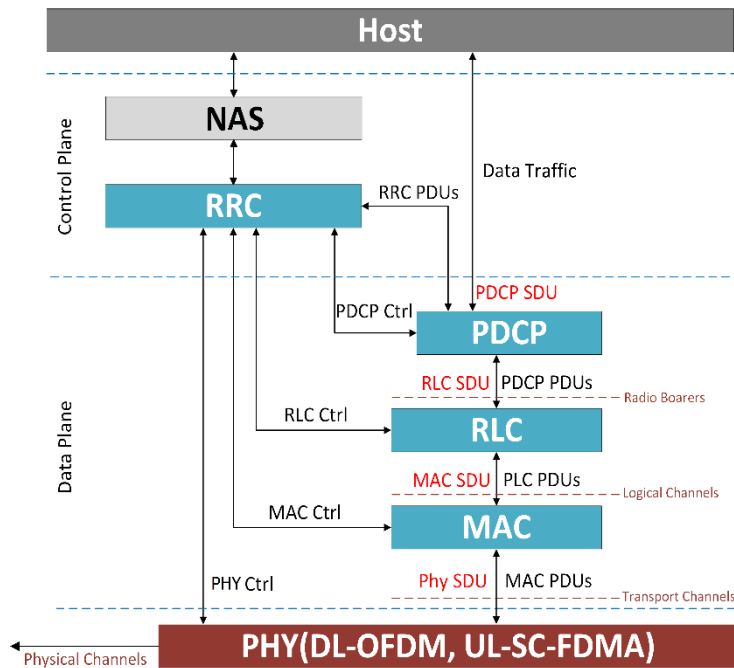


Figure 1: Life of an LTE packet in the protocol stack layers

All the User Equipments (UEs) and enhanced NodeBs (eNBs) in LTE-A networks must be equipped by LTE Network Interface Card (LTE NIC) module. All generated packets by application layer after being processed in transport layer by TCP or UDP and afterward in the network layer by Internet Protocol(IP), will enter into Network Interface (NIC) which includes the sublayers that are known as LTE-A protocol stack layers. 3rd Generation Partnership Project (3GPP) decided to separate transmission in LTE into two independent parts, which are known as control plane and data plane. In the data plane, data packets are produced by applications in UEs and are processed by protocols like UDP, TCP, and IP, while in the control plane the Radio Resource Control (RRC) layer generates the signaling messages which are used for coordination between UE and eNB. Figure 1 illustrates the

RRC controls all the data plane layers' parameters and also the layers in the data plane are responsible for managing data transmission.

IP packets, which are produced by the network layer in devices will enter the LTE NIC's sublayers (PDCP, RLC, and MAC) and then Physical layer. After passing the relevant processes (header compression, adding sequence number, segmentation/concatenation) in each sublayer, packets will be located into Transmission Blocks (TBs) and afterward, these TBs will be loaded in the Resource Blocks (RBs). RBs are the smallest unit of resources that can be devoted to a UE on the air interface [4]. All processes in each sublayer are under the control of RRC sublayer in the control plane. Also, RRC controls the connection between UEs and eNBs.

D2D Communication

3GPP has introduced Device-to-Device (D2D) communication in LTE release 12 under the name of Proximity Service (ProSe) in 2014 in order to respond to requirements of public safety positioning such as ambulances and police vehicles and also, the fast growth of data traffic especially on the commercial part, e.g. social networking and shop advertising. [5]

D2D communication technology is presently passing examination and enhancement steps in the LTE-A network, and it can be a big part of 5th Generation (5G) network systems in the approaching communication technologies. In the traditional cellular networks, packets were only transmitted between UEs and base stations, that are denoted as enhanced NodeB (eNB). This transmission is called RP. In RP communication, two UEs only are able to communicate via a two-hop path. On the other hand, D2D communication allows devices to share data packets directly to each other without sending data-packets via eNB that, this connection is called SL. Figure 2

from the RP to the SL and vice versa, to achieve efficient resource utilization without interrupting the communication or harming the QoS. The eNB is responsible for deciding about when and how MS must take place by monitoring the reported CQI by UEs. The final decision of the eNB is not certainly based on CQI. It may consist of one or different measured metrics, such as the represented data rate that can be efforted by channel, SINR, and also UE receiver properties [8].

Related Work

Most of the current researches in D2D communication area have often focused on resource allocation. Only a few papers have worked on cellular communication performance with performing MS. In [9], the D2D communication performance is compared with other heterogeneous networks such as WiFi direct, Zigbee, Bluetooth, and etc.

Also, it demonstrated that D2D technology covers more maximum transmission distance and supports significantly more data rate. The

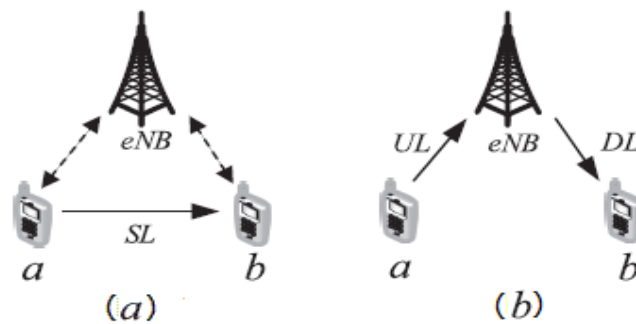


Figure 2: D2D connection through SL(a) and traditional two-hop

shows SL and normal two-hop path through UpLink (UL) and DownLink (DL) which is known as RP.

Mode Switching (MS)

The RRC in the eNB triggers the MS process which enables it to redirect communication

authors concluded that through a suitable MS and interference management, D2D communication can enhance the throughput of network and access rate remarkably without harming QoS by reducing signaling overhead for collecting channel quality state

reports. Work in [10] focused on the data plane in D2D communication and explained when the MS is performed, the receiver's address in the sender PDCP entity is changed. Therefore, all the data packets under the PDCP layer at the sender cannot be received by its first-hop receiver. Accordingly, the packets will be dropped and packet loss may occur as a result of MS. The authors proposed an auxiliary map to stay informed about the RLC PDUs and receive their acknowledgment in order to address this problem. The number of MS could be decreased by choosing the best time for MS which leads to a better performance with lower packet loss ratio. In [11] authors discussed how TCP packets behave during the MS procedure. The results showed TCP is significantly more sensitive to losses when MS is performed. This packet loss is interpreted as the congestion signaling during MS. This work targeted to improve the performance in D2D communication and RP communication by investigation of the MS process between two communication modes. And also, [12] proposed a framework to determine which communication should switch the mode between D2D and RP and when. They also presented how to allocate resources to D2D and RP UEs. Moreover, they stated that MS and packet scheduling should occur at completely independent time scales. Researchers also challenged the packet loss problem due to MS in [10] and illustrated how short periods and frequently MS processes increase packet loss. Their proposed framework managed the coexistence of D2D and RP flows in the UL subframes. Authors in [13] discussed MS and resource allocation problems for D2D unicast communication and proposed a method that involves the estimation of MS metrics. Also, [14] studied the optimal MS in multi eNBs systems. However, both of these works are by no means covered the QoS of communication with MS and the effects of MS on the

performance of D2D communication. While this paper investigates most of the QoS metrics including CQI, throughput, bit error rate, packet loss ratio, MOS and end-to-end delay time of both communication modes and the effects of MS on the communication quality.

Simulation Setup

This work is an investigation of the effect of various distances and locations of UEs on the performance of communication over RP and SL connections. The weak performance of the D2D communication in long distances triggers MS procedure. We focused on D2D and RP communication performances to understand the best mode for data transmission and the suitable time for performing the MS process during communication. In order to perform these analyses, various scenarios are simulated. In all the scenarios two UEs are performing sending and receiving which are in the cell coverage area of the same eNB. These UEs are able to communicate through normal RP or SL. The mobility state of the two UEs is static. The simulations are performed for each specific distance between two UEs and the eNB. The distance between the UEs is increased by changing the location of UEs after collecting the results of the simulated set. The distance is increased by a 10 m interval.

Since the simulations are performed to compare the performance metrics between D2D and RP communications, the maximum distance for MS results is selected based on the maximum distance that D2D communication can effort. Table 1 presents settings for the simulation parameters. This study investigates how different distances and locations of UEs affect communication performance using some important metrics. By studying the performance of RP and D2D modes, the best moment for MS implementation will be recognized according

to the channel quality of each mode. The examination method is quantitative, using one-to-one communication between two UEs in a single cell of the LTE-A. OMNET++ 5.1 has been employed as the simulator using INET-3.6.4 and SimuLTE libraries [15].

Table 1- General Parameters of Simulation

LTE-A Network Parameter	Assigned Value
Carrier Frequency	2 GHz
Channel Bandwidth	5 MHz (25 RBs)
Path Loss Model	ITU-R, Urban Macro [16]
eNB Tx Power	46 dBm
UE Tx Power	24 dBm
Cable Loss	2 dB
Fading Model	JAKES
eNB Antenna Gain	18 dB
UE Antenna Gain	0 dB
UE Noise Figure	7 dB
eNB Noise Figure	5 dB
Thermal Noise	-104.5 dBm
Mobility Model	Stationary (OMNET++ Model)
Simulation Time	50 seconds(s)

The UEs are placed in different locations in order to obtain various performances of the network. Therefore, different scenarios are used and their various results are collected and presented.

We attempted to show how VoIP traffic reacts during the simulation by examining the following metrics:

- **End-to-End Delay:** The amount of time that a packet spends in its journey from the sender endpoint to the receiver endpoint.
- **Throughput:** It is calculated at the end of transmission by dividing the total received bytes/bits by simulation time.
- **Bit Error Rate:** Because of movement and variety of the number of UEs in the cell, the signal power in the air

interface is changing during the transmission time and it can make some error in the transmitted bits on their path to the receiver. The bit error rate is detected by a Hybrid Automatic Repeat reQuest (HARQ) scheme in the MAC sublayer [17].

- **Channel Quality Indicator (CQI):** CQI is a 4-bit integer number and is based on sensed SINR at the UE. CQI carries a discrete value from 0 to 15.
- **Mean Opinion Service (MOS):** MOS is a ranking of the QoS for VoIP and Video streams. Basically, MOS is obtained from experts assessment and observation that is affected by packet loss ratio and packet size.
- **Packet Loss Ratio:** It is calculated by comparing the percent of the sent packets at the sender and lost packets.

Results and Discussions

As the performance metrics CQI, end-to-end delay, throughput, MOS, packet loss ratio and bit error rate are employed to support the analysis of the QoS performance of the simulated scenarios. The initial network configuration which is used to simulate different scenarios is given in Figure 3. Initial locations and movement directions of UEs are also illustrated in the figure. We attempted to accomplish various conditions for both RP and SL locating two UEs in different distances from the eNB and from each other. As a result of each movement, the distances of UEs from the eNB is half of the D2D distance. For example, when the D2D distance is 20 m, it means horizontally the

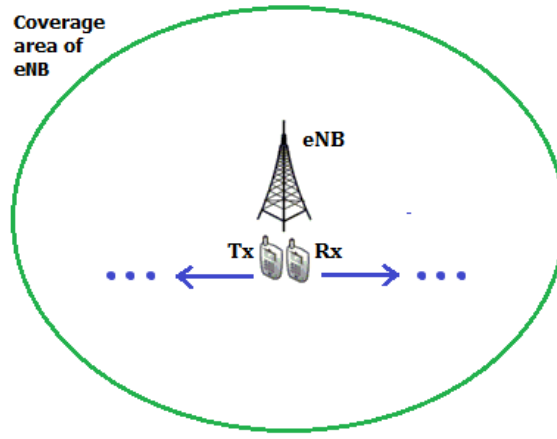


Figure 3: Initial state of network configuration

distances of UEs from the eNB is 10 m. When UEs move further away from the eNB, the received power changes which lead to a change of SINR. Accordingly, CQI changes [18, Table 7.2.3-1 and 7.2.3-2].

Using network configuration in Figure 3, different simulation scenarios are created by changing distance between the UEs from 0 to 120 for D2D mode and 0 to 300 for RP mode and results are presented in the form of graphs in Figures 4-7 for the mentioned metrics.

the figure, it is observed that while the distance increases the CQI decreases for both mode. The CQI of RP stabilizes up to 130 m and then descends lightly. On the other hand, the D2D CQI has a speed descend after 10 m and it lies down on value 2 after 80 m that is not a good feasibility level of D2D communication. The observations illustrate the RP is performing better at long distances.

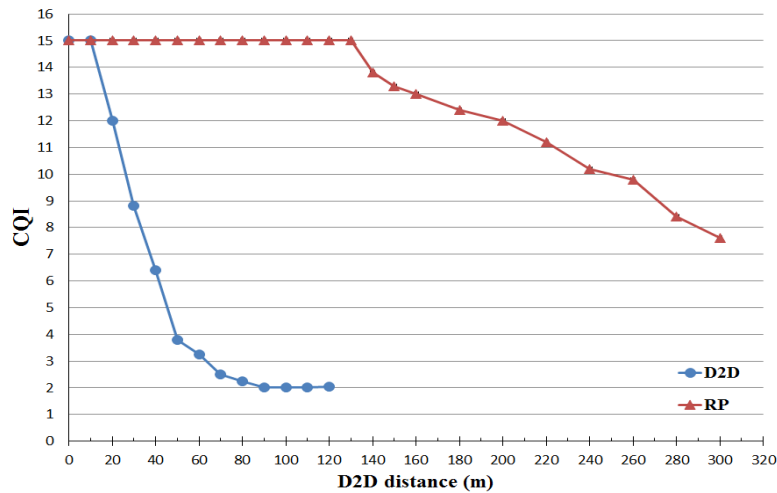


Figure 4: CQI

Figure 4 shows CQI results by changing the distance between UEs and accordingly changing the distance from the eNB. From

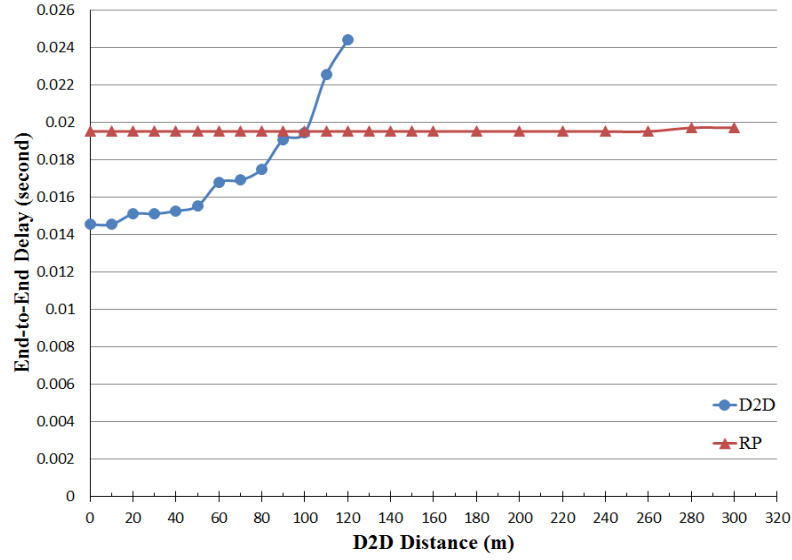


Figure 5: End-to-End delay in D2D and RP communication modes

The behavior of D2D CQI results in Figure 4 is similar to the results in [19].

Figure 5 shows end-to-end delay results for D2D and RP communications. As shown in the figure, at low distances end-to-end delay related to RP is remarkably higher than D2D, which confirms lower delay advantages of the D2D communication (up to 100 m). Since in D2D communication, packets are sent directly to the destination, they need less time to arrive. On the other hand, in RP mode,

packets are sent to the eNB and after assembling packets in the eNB's NIC layers as described in [10], need to be sent to the receiver node, which causes longer distance and longer time for the packets to be received by the receiver. It is clear that the end-to-end delay in D2D communication is significantly lower than RP for short distances (the distances less than 100 m) as depicted in Figure 5.

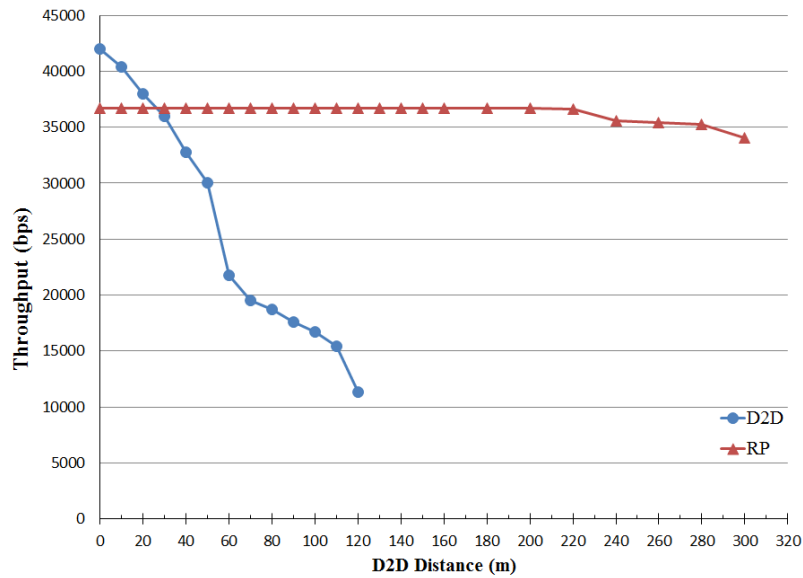


Figure 6: Throughput in D2D and RP communication modes throughput

Figure 6 shows the throughput results for both D2D and RP communications. As shown in the figure, D2D throughput starts with higher performance when compared with the RP throughput at low distances. Although it descends with a fast slope, it is still higher than RP throughput up to 30 m. Afterward, it continues descending almost with the same gradient up to 50 m. But from 50 m to 60 m it loses approximately 30% of its performance. On the other hand, RP throughput is less than D2D throughput until 30 m and then remains the same up to 220 m.

behavior is similar to the throughput results in [20, Figure 5].

Figure 7 shows the MOS performance of D2D and RP communications. As shown in the figure, MOS of D2D remains at the highest level and declines with a deep slope after 50 m. On the other hand, the MOS of RP performs well without any change for long distances (up to 300 m). D2D communication delivers high quality similar to RP up to 50 m.

The packet loss ratio of D2D and RP communications is illustrated in Figure 8. As

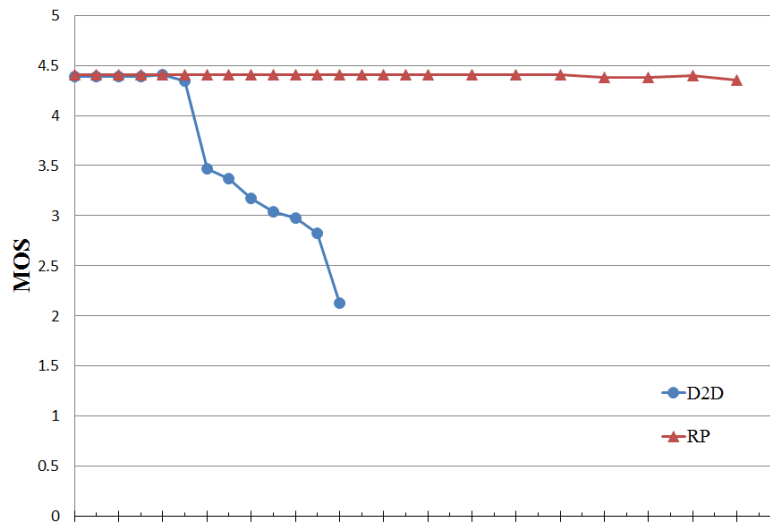


Figure 7: MOS performance in D2D and RP communication modes

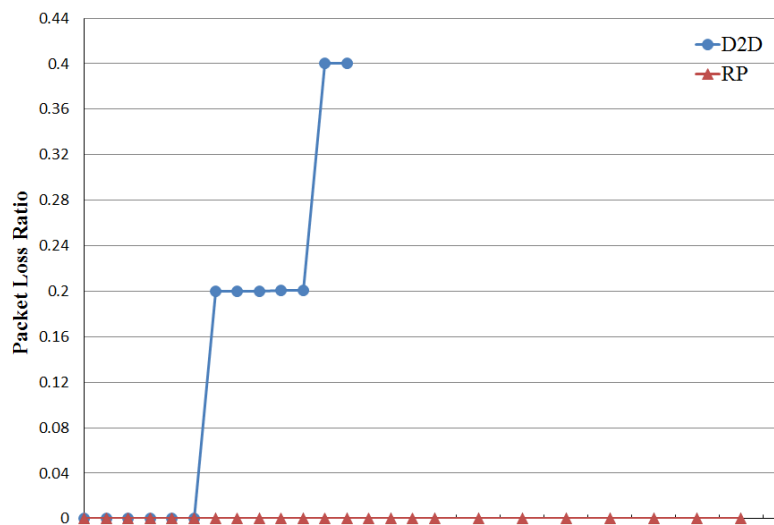


Figure 8: Packet Loss Ratio in D2D and RP communication modes

The obtained throughput results in Figure 6

illustrated in the figure, the packet loss ratio

stabilizes around zero up to 50 m for D2D, which is the same as the RP packet loss ratio. Then it jumps to 0.2 loss ratio at 60 m which is a high ratio for packet loss, even for loss

configuration given in Figure 3 and the parameter setting provided in Table 1.

Proposed Scenario with MS

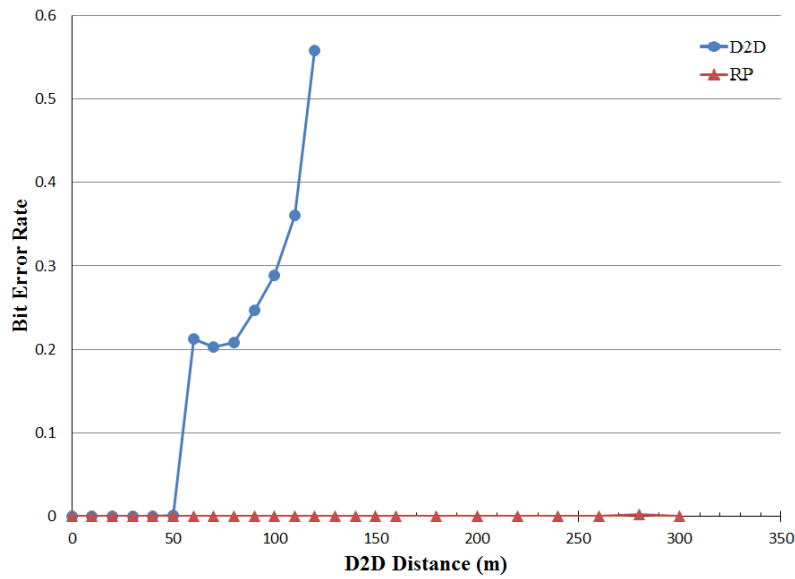


Figure 9: Bit Error Rate in D2D and RP communication modes

tolerant services like VoIP [21]. This jump takes place after 50 m. The behavior of the packet loss ratio is the same as the behavior of throughput as shown in Figure 6 and MOS behavior as shown in Figure 7. The packet loss ratio of D2D remains constant at 0.2 from 60 m to 100 m then suddenly jumps up to 0.4 at 120 m. However, the packet loss ratio of RP remains at zero level up to the furthest simulated distances (up to 300 m).

Figure 9 shows the bit error rate of both D2D and RP communications. As is shown in the figure, after 50 m the bit error rate in D2D dramatically increases to 0.2 which advocates the trends in the other investigated metrics in this scenario. Differently, the bit error rate in the RP remains zero until the distance between two UEs arrives 220 m, and then extremely slightly increases.

Base on the simulation results we choose 50 m as the distance threshold between two UEs, in terms of the best distance for performing MS. This threshold is selected based on the simulation results with network

This scenario is designed in a way that both D2D and RP communication modes are performed, respectively. In this scenario, in the first 50 m, data packets are sent through SL and afterward, packets are sent over RP (i.e. from 60 m up to 160 m). The simulation results of this scenario are illustrated in Figures 10-12 while the red line (the vertical line) presents the point of the MS in the simulation.

Figure 10 illustrates CQI for D2D and RP with mode switching. As shown in the figure, the CQI of D2D mode behaves similarly to the corresponding CQI results in Figure 4. However, after performing MS it suddenly moves up from 4 to the high level of RP CQI in 60 m which still remains in level 15. The

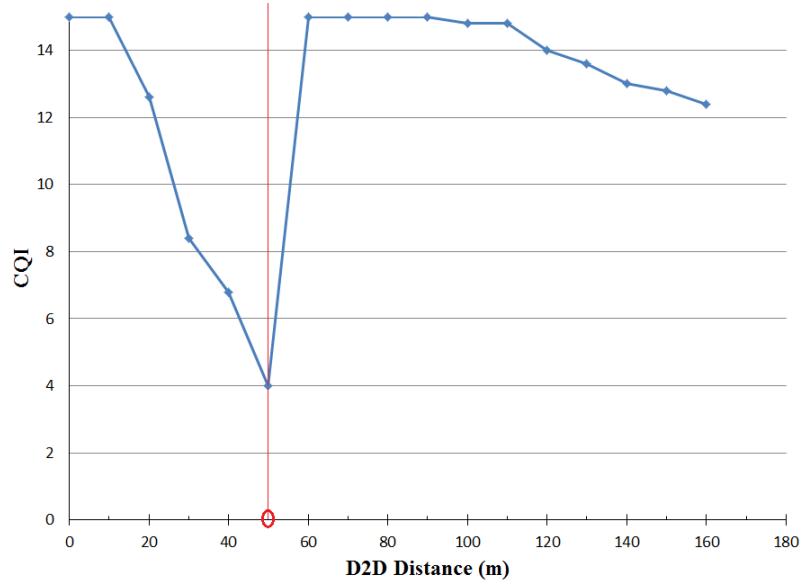


Figure 10: CQI with the MS

improvement of CQI results after MS implementation (after 50 m) is significant. Figure 10 illustrates CQI for D2D and RP with mode switching. As shown in the figure, the CQI of D2D mode behaves similarly to the corresponding CQI results in Figure 4. However, after performing MS it suddenly moves up from 4 to the high level of RP CQI in 60 m which still remains in level 15. The

improvement of CQI results after MS implementation (after 50 m) is significant. Figure 11 illustrates end-to-end delay for D2D and RP with mode switching. Based on the results in the figure, the end-to-end delay is stabled by MS after 50 m. Figure 12 shows that initially, the throughput is at a high level which is close to 49000 bps. By increasing the distance, it demonstrates an

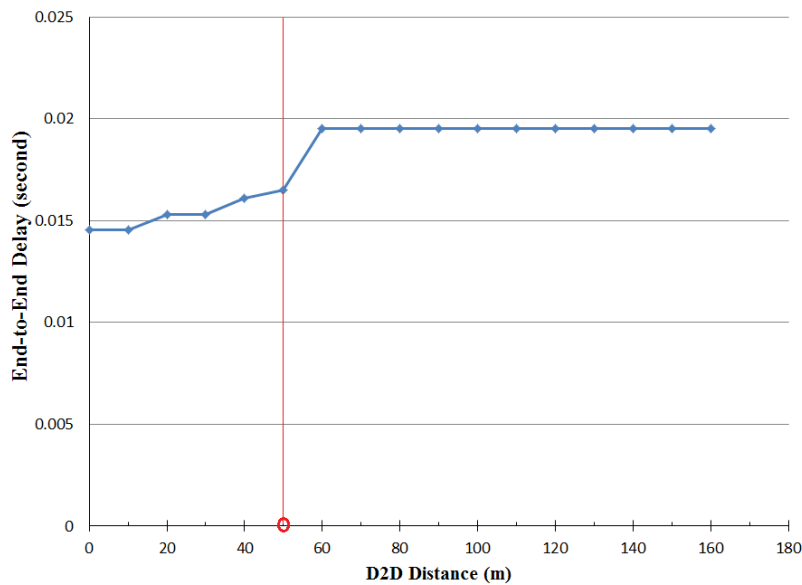


Figure 11: End-to-End Delay with the MS

almost dip falling in D2D communication

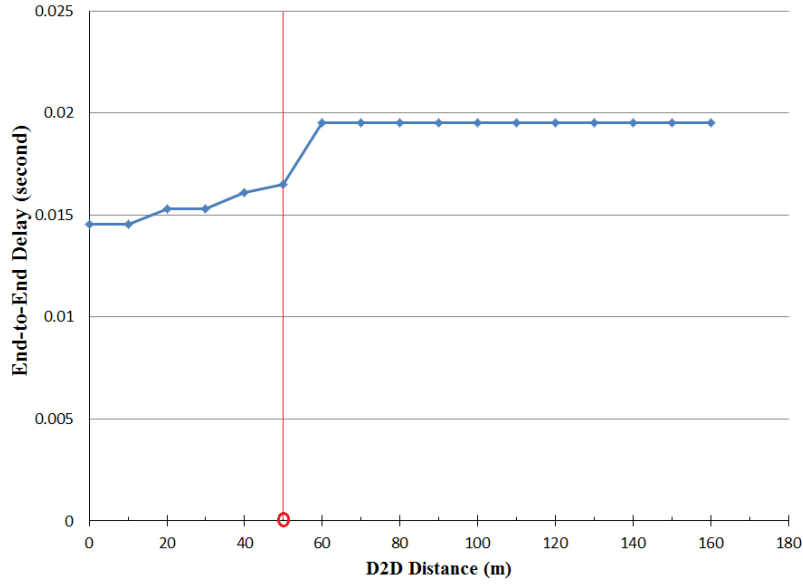


Figure 12: Throughput with the MS

which loses roughly 27% of its value, after MS it increases to 45000 bps level.

We utilized the MS after 50 m distance, which is after the significant performance loss, to show how the MS implementation can recover and reclaim the quality of the communication. Based on the detailed simulation results, the accurate threshold could be 47 m for MS.

Conclusions

In this paper, we have conducted some scenarios to examine the performance of D2D communication (SL) and the traditional two-hops path communication through eNB (RP) in LTE-A network by utilizing VoIP packets as the application data. In order to improve the quality of communication and profit the advantages of both type communications, the MS process is employed to enable users to send data traffic through the RP or SL to the receiver. We conducted some scenarios in OMNET++ to simulate various conditions of UEs' distribution and accordingly channel quality in both D2D and RP communications. Therefore, each mode is simulated several times with different distances.

From simulation results, it is observed that when two mobile devices are close to each other but far away from the eNB, D2D mode is the best choice for communication. The D2D communication performance in the edge of cell coverage area is satisfactory while path loss of long distance from the eNB harms RP communication quality. On the other hand, D2D communication in long distances between the UEs shows a low-quality performance, while RP communication delivers a good QoS.

In addition to this, in short distances (up to 30 m) between two mobile devices, D2D communication performance in end-to-end delay and throughput is remarkably superior to RP. Also, it is illustrated that after 30 m distance D2D throughput is lower than RP throughput while the calculated end-to-end delay of the D2D mode is significantly shorter than end-to-end delay time in RP mode. The results of the designed scenarios demonstrate that D2D communication faces an unpleasant packet loss ratio and bit error rate when D2D distance is more than 48m. Therefore, RP mode is the best alternative for communication before facing the performance decline in D2D communication. Our last scenario demonstrates how a suitable

MS can recover a harmed communication and how by adjusting MS at an appropriate distance can utilize the advantages of both communication modes.

References

- [1] Astély, D., Dahlman, E., Furuskär, A., Jading, Y., Lindström, M., & Parkvall, S. (2009). LTE: the evolution of mobile broadband. *IEEE Communications magazine*, 47(4): 44-51
- [2] Atayero, A. A., Luka, M. K., Orya, M. K., & Iruemi, J. O. (2011). 3GPP long term evolution: Architecture, protocols and interfaces. *International Journal of Information and Communication Technology Research*, 1(7): 306-310.
- [3] Liu, J., Kato, N., Ma, J., & Kadowaki, N. (2015). Device-to-device communication in LTE-advanced networks: A survey. *IEEE Communications Surveys & Tutorials*, 17(4): 1923-1940.
- [4] Dahlman, E., Parkvall, S., & Skold, J. (2013). 4G: LTE/LTE-advanced for mobile broadband. Academic press.
- [5] 3GPP TS, (2014). Study on LTE device to device proximity services: radio aspects (Release 12), 3GPP TS 36.843, vol. 12.0.1.
- [6] Nardini, G., Viridis, A., & Stea, G. (2016). Simulating device-to-device communications in OMNeT++ with SimuLTE: scenarios and configurations. *arXiv preprint arXiv:1609.05173*.
- [7] Yu, C. H., Tirkkonen, O., Doppler, K., & Ribeiro, C. (2009, April). On the performance of device-to-device underlay communication with simple power control. In *Vehicular Technology Conference, 2009. VTC Spring 2009*. IEEE 69th: 1-5.
- [8] Feng, J. (2013). Device-to-device communications in lte-advanced network (Doctoral dissertation, Télécom Bretagne, Université de Bretagne-Sud).
- [9] Feng, D., Lu, L., Yuan-Wu, Y., Li, G., Li, S., & Feng, G. (2014). Device-to-device communications in cellular networks. *IEEE Communications Magazine*, 52(4): 49-55.
- [10] Nardini, G., Stea, G., & Viridis, A. (2018). A scalable data-plane architecture for one-to-one device-to-device communications in LTE-Advanced. *Computer Networks*, 131: 77-95.
- [11] Nardini, G., Stea, G., and Viridis, A., (2016). Performance evaluation of TCP based traffic over direct communications in LTE-Advanced, in *Vehicular Technology Conference (VTC Spring)*, 2016 IEEE 83rd: 1-5.
- [12] Nardini, G., Stea, G., Viridis, A., Sabella, D., & Caretti, M. (2017). Resource allocation for network-controlled device-to-device communications in LTE-Advanced. *Wireless Networks*, 23(3): 787-804.
- [13] Gupta, R., & Kalyanasundaram, S. (2016, September). Transmission mode selection and resource allocation for D2D unicast communications. In *Vehicular Technology Conference (VTC-Fall)*, 2016 IEEE 84th: 1-6.
- [14] Liu, Y. (2016). Optimal mode selection in D2D-enabled multi-base station systems. *IEEE Communications Letters*, 20(3): 470-473.
- [15] Nardini, G., Viridis, A., & Stea, G. (2016). Simulating device-to-device communications in OMNeT++ with SimuLTE: scenarios and configurations. *arXiv preprint arXiv:1609.05173*.
- [16] Access, E. U. T. R. (2010). Further advancements for E-UTRA physical layer aspects (Rel. 9), 3rd Generation Partnership Project (3GPP). Sophia-Antipolis, France, 13.
- [17] Larmo, A., Lindström, M., Meyer, M., Pelletier, G., Torsner, J., & Wiemann, H. (2009). The LTE link-layer design. *IEEE Communications magazine*, 47(4): 52-59.
- [18] Access, E. U. T. R. (2008). and Evolved Universal Terrestrial Radio Access Network (E-UTRAN). Overall description, 126.
- [19] Viridis, A., Nardini, G., & Stea, G. (2016, July). Modeling unicast device-to-device communications with SimuLTE. In *Link-and System Level Simulations (IWSLS)*, International Workshop on IEEE: 1-6.
- [20] Wei, L., Hu, R.Q., Li, Q.C. and Wu, G. (2014, June). Energy-efficiency of multi-hop device-to-device communications underlaying cellular networks. In *2014 IEEE International Conference on Communications (ICC)* IEEE: 5486-5491.
- [21]

Shafiei, M. M., & Jameel, A. J. Performance Analysis of Voice Over LTE Using OMNeT++.