MODELLING AND SIMULATION OF DEVICE TO DEVICE BASED PROTOCOL FOR ULTRA-RELIABLE LOW LATENCY COMMUNICATION

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ABSTRACT

This research project is about the simulation of Device to Device (D2D) communication using MATLAB coding. The focus of system design is for Ultra-Reliable Low Latency Communication (URLLC) system. It is important to understand the D2D communication concept through coding. By doing this way, it helps to save cost, easy to analyse which parameters affect the outputs. Also, it is very convenient to study the system using a simulation model. The design of the D2D concept in this research can be divided into three parts. The first part is the graphical display of the network. The second is coding to compute the latency and identify which nodes are sending and not sending the packet. The third part is about the plotting of the graphs for the packets sent and received. Generally, the idea is to look for latency (delay) and understand why there is latency happen in the network. The results show that more packet sends by the nodes will cause high latency. This is because of the contention of access to the network.

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$f(x)$	-	Function of x
g_n	-	Set of user belong to group n in the cell
K	-	Number of users
W_n	-	Transmit beamformer
BS	-	Base Station
D2D	-	Device-to-Device
E2E	-	End-to-End
IoT	-	Internet of Things
PS	-	Power Splitting
RF	-	Radio Frequency
SNR	-	Signal to noise ratio
TDMA	-	Time Division Multiple Access
URLLC	-	Ultra-Reliable and Low Latency Communication

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CHAPTER 1

INTRODUCTION

1.1 Overview of the research

The current wireless communication is very depending on the base station (BS) where the messages are routed to the users who are within the radio coverage formed by the BS. Too much depending on BS in broadcasting the messages will cause traffic congestion and overburden the communication network. In the later development of a wireless communication system, there are only a few researches proposed Device-to-Device (D2D) communication where the devices within the coverage of radio waves will communicate with the other devices. By doing this, full duplex communication can be achieved and it helps to reduce the burden of BS in handling the messages.

In D2D communications there are leaders who are the users successfully received the message from BS and successfully decoded the message. The leaders will relay the messages to the unsuccessful users who are unable to form a communication with the BS. Selection of leaders in the group of communication becoming important and it is the key success for the Ultra-Reliable and Low Latency Communication (URLLC) system. Therefore, it is important to explore the system in order to improve the D2D communications and makes it better in the network.

In URLLC, there are two phases of message transmission; in the first phase, the messages are sent to the users in a group, and in the second phase, the users who are termed as leaders will relay or switch the message to unsuccessful users who want to communicate with others. Basically, the first phase will use multicasting method, where multi groups of messages are combined into one and then multicast them to the respective group in the cell. On the other hand, the second phase will select the leaders, usually, multi-leaders are selected to route the messages. The leader selection becomes important and it is part of the protocol for D2D communications. The proposed leader selection is normally by using beamforming strategy which relies on the BS. Optimizing the sparse is used to ensure at least one leader is selected in the group of communication.

Thus, the main objective of this research is to model D2D communication. It is also assumed that the modelled communication system consists of three main nodes in D2D protocol. These three main nodes will communicate with each other and also communicate with other devices in the network. The term "UE" is defined as the user equipment that will be used in the system design and analysis of the results. The term "packet" represents part of the message. The word "backoff" is used to indicate the node is not sending or receiving the packets.

1.2 Problem statement

In practical, wireless communications for automation industry are hard to understand if there is no proper modelling and clear explanation in the theoretical perspective. Many engineers and researchers follow the practical guidelines to install the equipment and direct operate the system without any advice and knowing the problems. This leads to the system fails to work, consumes high power and unstable in operation.

Modelling of a wireless communication network can help to understand the whole scenarios and easy to find out the problematic parameters that cause the problems. Like in URLLC communication, the selection of a leader is an important process. If this process failed, the unsuccessful users could not receive messages and then the D2D communication cannot be formed. Under this situation, all the users will depend on the BS to send and receive messages, which add burden to the BS.

Apart from performing mathematical modelling and analysis, simulation is also important. The simulation can help to understand the overall propose ideas through the simulation results obtained. The simulation shows the graphs and data. The graphs are the output and it will change once the input parameters are changed. Thus, this will make people understand what parameters and which values will give a great effect on the outcomes. Another advantage of using simulation is that it is flexible and presentable. It helps to save cost on the practical implementation of the whole project. Without simulation, it is hard to prove the theories and hence have to spend money to perform practically test in order to validate the theories. Therefore, this project is proposed to model and simulate the D2D communication protocol that is beneficial to the URLLC.

1.3 Research objectives

The objectives of the research are as follows;

(i) To model the D2D communications using MATLAB code.

(ii) To evaluate the relationship between packet arrival rate and queue size and sample rate.

1.4 Research scopes

In order to implement the project and meet the objectives requirements, the following limitations were employed:

(i) MATLAB command prompt is used in developing the D2D communication system.

(ii) MATLAB graphs are plotted to show the UE packet.

(iii) Three nodes representing the UE are modelled and simulated.

1.5 Report organisation

This project report consists of five chapters. These five chapters are introduction, literature reviews, methodology, results and discussions, and conclusion and recommendations.

Chapter 1 explains the overall idea and concept of the research. This chapter also shows the problem statements and objectives. The scopes of the research are explained in this chapter. Chapter 2 presents the literature reviews. This chapter discusses an overview of URLLC system, D2D communication, and reviews of the current related research. Chapter 3 presents the methods used to implement the research. This chapter also explains the software used in the research. Chapter 4 presents the results and discussion. This chapter explains the simulation results obtained from the simulation works. Chapter 5 summarizes the research works. In addition, suggestions for future work to improve the simulation results are stated in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Nowadays, D2D communications are popular in wireless sensor networks. The applications can be seen in industries, securities and even in education. For automation industries, D2D communications are usually referred to as the wireless sensor network. These sensors control the machines, apparatus and monitor the building environments like checking the temperature, humidity as well as enhance the security system in the building. The URLLC scheme is a very new scheme where the system allows the communication devices to communicate with each other and in order to reduce the burden the main controller. The main controller here refers to the BS. In this scheme, readers play an important role to understand the URLLC and how it works to transfer the data within the cell or coverage. This section reviews the principle of URLLC. It is important to know each component in the URLLC before proposing the D2D protocol to solve the issue of too much depending on BS. This section also reviews the published related works to support the research.

2.2 Overview of URLLC system

The term URLLC refers to the 5G communication system and usually applied to the automotive industries. In the URLLC, the latency is 1 ms latency and error rate about 10-9 [1]. The general concept of URLLC applied to the automotive can be seen in Figure 2.1 [2].

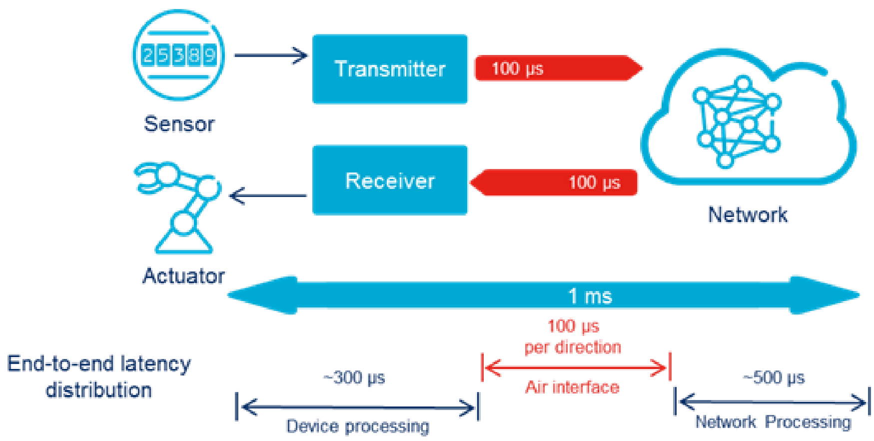

Figure 2.1: The URLLC system linked to an Internet network or mobile network [2]

From the system as shown in Figure 2.1, the sensor attached to the system detects the signals from the natural environment. The signals are then sent to the network via the controller and Internet access point (gateway). In order to get a response from the sensor, the system will process the received signals from the internet network and then will feedback to the actuator. The actuator interprets the information signals and then responses accordingly. Normally, the total time used is about 1 ms.

Note that, the key point here is the signals entering the network. This network is not a normal network but it is the 5G mobile network. In the 5G network, there will be an IoT function and other high-speed data processing functions. In URLLC, the BS is the access point to the entire network. BS is responsible for sending the message and receiving the message from the sensor nodes to the network and from the network to the sensor nodes, respectively [3].

The unique features of URLLC are the scale, risk, and tail [2]. The scale is defined as the resources allocation in the network. The resources are referring to the antennas, sensors, and nodes that appear in the network. The scale can be big or small. Often the sparse will exists as all these resources are grouped differently. The risk is about the dynamic of communication devices that could cause the communication loss problems. The loss in communication could be because of highly dynamic and entering the point where the radio coverage is less or in the borderline of next coverage. The tail, on the other hand, refers to the random traffic demand. Usually, a statistical model is used to analyze the effectiveness of the tail in wireless communication. Both the latency and intra- or inter-cell interferences will provide information about the tail [4].

In addition, there are two terms commonly used in URLLC system. The first is 'latency' and the second is 'reliability'. Latency includes End-to-End (E2E) latency, user plan latency, and control plan latency. The E2E latency describes the air communication that including delay, processing of the message and retransmit of message [5]. The user plan latency determines the time for successful deliver the message from one layer to another layer in the network layer. The control latency, on the other hand, defines the transmit time required to successfully deliver the message from one point to another point [6]. Whereas the reliability defines the probability of message successfully sent to the receiver over a period of time. This reliability usually works well when the data or message is sending and receiving in a busy network. The allocated time to successfully sent the message is 1 ms [7].

2.3 Overview of D2D communications

The concept of D2D communications is a device to device communication under the coverage of radio frequency. The scenario of D2D can be seen in Figure 2.2 [8]. From Figure 2.2, D2D communications can be divided into two types. The first type is the communication between a BS to only one or two devices as shown in Figure 2.2 (a). In this type, the two devices are communicating with each other. The second type is the communication between a BS to multiple devices and normally will form a D2D or multiple D2D communications as shown in Figure 2.2 (b). The second type of D2D communication has a complex network and fewer burdens the BS [9].

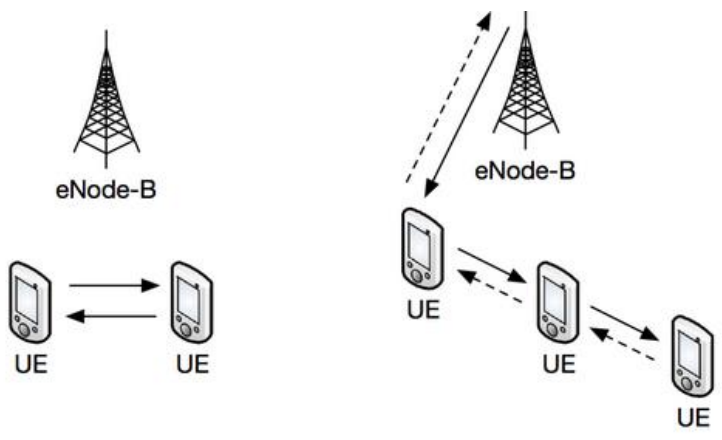

Figure 2.2: The concept of D2D communication, (a) device to device, and (b) device to multiple devices [10]

The data communication in the nodes is the important parameters in the D2D communications system. When the device is hidden due to an obstacle, the communication will breakdown and the device will look for another device to continue the communication. This may cause message temporary unable to be sent to the destination. The message will then be sent out again when the devices are available in the network [11]. In general, the best modulation technique used in D2D communication is the time division multiple access (TDMA) [12]. This is because the TDMA has the time slot for data and buffers some of the times to avoid collision and error correct [12]. Note that, the D2D communication discusses here refers to the sensor network. Each sensor network is assumed comprises of a controller where a transmitter and receiver are found [13].

The power consumption for each node and the entire communication system are also being an issue in the research. The suggested power management or effectively improve the power in for D2D communication is by using energy harvesting [14]. The energy harvesting will convert the radio frequency into DC energy so that the sensor nodes are getting power up [15]. In order to achieve ultra-reliable communication in D2D communication, two phases of transmission protocol were proposed in [16]. In the first phase of the D2D transmission protocol, the received signal for the k_{th} user in the group n is given by [16]:

$$\begin{aligned} y_{k,n}{}^{(I)} &= h_{k,n}^{T} x^{(I)} + z_{k,n}^{(I)} \\ &= h_{k,n}^{T} \omega_n^{(I)} s_n + h_{k,n}^{T} \sum_{j \neq n} \omega_j^{(I)} s_j + z_{k,n}^{(I)} \end{aligned} \tag{2.1}$$

where,

$h_{k,n}^{T}$: the downlink channel from BS to the k_{th} user in the group n,

$x^{(I)}$: the transmit signal of the BS,

$z_{k,n}^{(I)}$: the superposition of the AWGN and the inter-cell interference,

$\omega_n^{(I)}$: the transmit beamformer for the combined user message of group n,

s_n : the combined symbol intended for all the users in group n, and

$\sum_{j \neq n} \omega_j^{(I)} s_j$: summation of the transmit beamformer for the combined user message of group j and the combined symbol intended for all the users in a group j.

All the parameters shown above are best to describe as phase I of the transmission in the URLLC system. In phase II, the received signal for the unsuccessful user is expressed as [15]:

$$y_{k,n}{}^{(II)} = 0 \tag{2.2}$$

and the corresponding Signal to Noise Ratio (SNR) is given by [16],

$$y_{k,n}^{(II)} = \frac{\left|\sum_{j \neq n} h_{k,n,i,n} f_{i,n}^{(I)} \sqrt{P}\right|}{\sum_{j \neq n} \left|\sum_{i=1}^{k_j} h_{k,n,i,} f_{i,j}^{(I)} \sqrt{P}\right|^2} \tag{2.3}$$

where,

$h_{k,n,i,n}$: the downlink channel from BS to the k_{th} user in the group n,

$f_{i,n}^{(I)}$: the beam former for the first phase,

$\sqrt{P}$: the transmit power, and

$f_{i,j}^{(I)}$: the beam former for the second phase.

In order to achieve the URLLC, the beam former must capable of improving the number of users that successfully received the signal. The beam former design should target the right users and accurately determine the highest number of users that receive the message from the BS. This can be defined as [15]:

$$\max\mathrm{imize} \sum_{\mathrm{n=1}}^{\mathrm{N}} |\, \Phi_{\mathrm{n}}^{(\mathrm{I})} \,| + \sum_{\mathrm{n=1}}^{\mathrm{N}} |\, \Phi_{\mathrm{n}}^{(\mathrm{II})} \,| \tag{2.4}$$

Maximize in this equation is the maximum number of user that successfully received the message from the BS.

2.4 Key components in D2D communication

In the D2D communication system the following parameters are important:

(i) the power consumption of the devices,

(ii) the routine of a message from one device to another device,

(iii) beware of the broadcasting message,

(iv) radio coverage and hidden terminals, and

(v) the latency.

2.4.1 The power consumption of the devices

One of the challenges in the D2D communication system is power consumption. The energy consumption will increase if the number of devices keeps on communicating with each other in the network. The device is the user terminal. Thus, the device will become heavy if more and more messages are routed from one device to another device. Also, the power must be enough to support the communication. Figure 2.3 illustrates the power consumption graphs for different devices used in D2D communications.

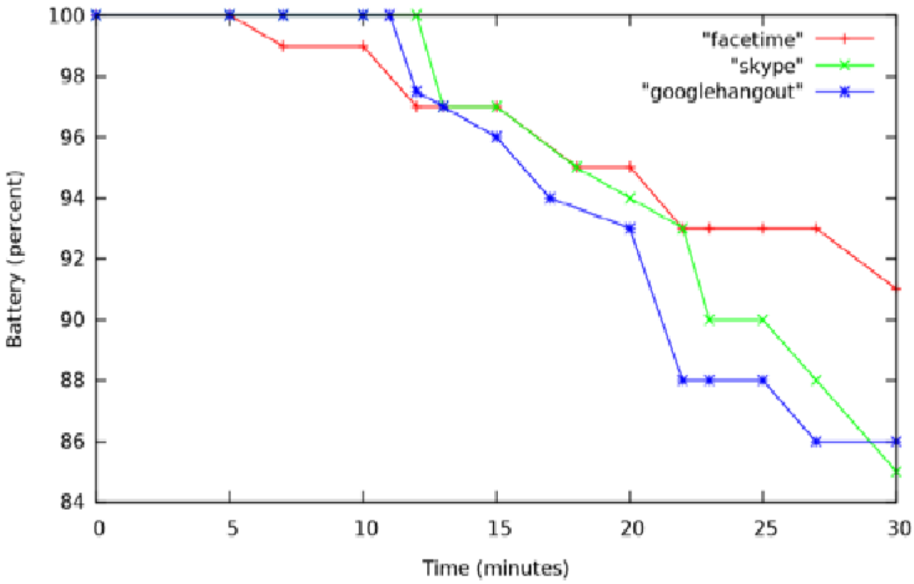

Figure 2.3: Power consumption graphs [17]

The results present in Figure 2.3 are the research results obtained from the experimental testing in D2D communication. Notice that, as the time increases and if the device continues to support the D2D communication, then the power will be mitigated more than 25 minutes. The power drops from 100% to 84% and will continue to drop in subsequence of time. As a matter of fact, it is suggested to have a power consumption management system to manage the D2D communication. One of the suggested methods is by using "sleep" and "awake" modes to control power consumption. The "sleep" mode means when the device is not used in communication, it will turn into "sleep" mode. In the sleep mode, it does not means the device is turned OFF or not in use. The sleep mode means the device still in operation but in a rest mode or in a standby mode.

When the device is called by instruction, then the sleep mode will be switched to "awake" mode. In this mode, the device will be turned in operation automatically. In addition, the power consumption will be high. To have effective control of power consumption, the device must be put into sleep mode when not in use and put into an awake mode when in use.

2.4.2 Routine of message

In the transceiver base station, communication with user terminals or devices occurs when the messages are routed from devices to the transceiver base station or from transceiver base station to the devices. This is a traditional communication and currently employed in all the 3G and 4G wireless network. The routing of the message becomes important in wireless communication.

For D2D communication, the routing of the message is from one device to another device. Hence, this will encounter the following problems:

(i) the contention of the channel to get access into the device network,

(ii) the ON and OFF operation of the device, and

(iii) the data rate and phone features.

The contention of the channel to get access to the device network will increase if the number of messages is increased in the network. The routed message sometimes gets stuck in one of the devices. This because of the device could be turned OFF and the network has to find another device to route the message, thus this is time-consuming and introduces the latency operation in the network.

When the device is turning OFF suddenly or turning ON suddenly, this will also affect the routine of the message and increase the delay. The network principle is always looking for the shortest path to route the message and direct it to the receiver in a short period of time. Therefore, if there is a terminal suddenly turns ON and that terminal is the fast route to reach the destination, then the network must perform switching to switch the message to that terminal. The switching process must be done is fast without losing the message. Any message loss should ask for resending.

Another quite common issue happens is the data rate varies from one device to another device. Different brands of mobile terminals will have different features including the data rate operation. Therefore, when designing a D2D communication, a certain range of data rate should be set in the network operating system so that the data sent and received can be synchronized. The routine of a message from one device to another device should also follow some protocols like MAC system to avoid message collision or message drops. Due to the limitation of the channels, the MAC should control the message route in the following steps:

(i) device intends to send a message should listen to the idle of the channel.

(ii) if the channel is idle, the message is allowed to the route. Under this condition, the channel is occupied and the system should block other devices to send and receive the message.

(ii) wait until the message is reaching the destination and the transmitter is receiving the acknowledgement message, then repeat step (i).

MAC is one of the important protocols to control message flows into the network. This MAC will become more important as the number of the device is increasing. Thus, this will give the challenge to the MAC to handle a high volume of the message in the network.

2.4.3 Broadcasting of message

In performing the D2D communication, one should take into consideration the broadcasting of the message. By definition, the D2D communication is a point to point, whereas the broadcasting of message is from point to multipoint. When the broadcasted message is available, the network should stop the D2D communication and switch to broadcast mode. In broadcast mode, the transceiver base station broadcasts the message to all the devices under its radio coverage. In general, a broadcasting message consists of two types of message:

(i) announcement from the network operator, and

(ii) the advertisement message.

When broadcasting is happening, all the devices will receive the same message. They only can receive when they are in the network radio coverage.

2.4.4 Radio coverage and hidden terminal

By definition, the radio coverage can be determined by Free Space Path Loss (FSPL) equation given by

$$\text{FSPL} = \left(\frac{4\pi d}{\lambda}\right)^2 \tag{2.5}$$

where, λ = wavelength measured in meter, and

d = distance between transceiver base station to the terminal or devices.

As can be seen from equation (2.4), the FSPL will increase if d is increased. When the FSPL increases, the power loss will increase and hence, the device receives the signal in very weak condition. The FSPL can be used to determine the radius of radio coverage by making the assumption that the coverage is in 360°. Within the coverage, all the devices will receive strong radio signals and vice versa. Some devices are out from the coverage area or in the borderline. In this case, these devices are considered hidden. The characteristic of hidden terminal or devices are:

(i) they are active but not receiving any signals for communication,
(ii) they are out of coverage,
(iii) they are very far from the base transceiver station, and
(iv) they cannot become a leader in D2D communication.

When devices wanted to form the D2D communication, it is advised that the network can automatically register the entire known device in the network. For the next communication, all these devices will be activated fast as their information are already in the database of the network. If all the devices are in and out, then this will create a delay for D2D registration.

2.4.5 The latency

This factor is the most important and often used to analyse the message reaching the destination. The latency is about the delay in the entire communication system. The latency can be increased or decreased depending on the communication setup and features of the network. The latency could happen in D2D communication if:

(i) the devices are in and out from the network coverage,
(ii) the devices are increased in the network,

(iii) flooding of the message in the network,

(iv) no MAC protocol,

(v) the low data rate, and

(vi) high buffering in the network.

By definition, the latency is

$$\text{Latency} = \text{propagation delay} + \text{serialization delay} \tag{2.6}$$

where both the propagation delay and serialization delay are defined as follows;

$$\text{Propagation delay} = \text{distance} / \text{speed} \tag{2.7}$$

$$\text{Serialization delay} = \text{packet size}/\text{transmission data rate} \tag{2.8}$$

By substituting equations (2.6) and (2.7) into equation (2.5), yield:

$$\text{Latency} = \text{distance}/\text{speed} + \text{packet size}/\text{data rate} \tag{2.9}$$

Basically, the unit of the latency is in second. Practical communication latency is in millisecond, microsecond or even nanosecond or picosecond.

In practical, the network always has different latency. This is because the different time response of each terminal or device and they might be located in the different distance from the transceiver base station. Fundamentally, the nearest terminal or device should have short latency compare those in very far.

2.5 Review of the previous related works

The D2D protocol for URLLC communications had been proposed and studied since 10 years ago. There was a moderately number of researches proposed and presented the simulation results for the outcomes of the research. This section reviews some of the works related to this research. Table 2.1 shows the summary of the previous related research works in D2D communications protocol and URLLC system. In [16], the 2D2 protocol linked to a 5G communication network is proposed. This D2D uses a machine to machine to send and receive data. The information or the data are related to the sensor data. The data is routed from one machine to another machine and then terminated in the BS.

In the scheme proposed in [17], the D2D protocol is more emphasis on reliability and latency. More mathematical models can be found to describe the user plan latency, E2E latency and the tail of the URLLC. The most important thing about the URLLC is less relies on the BS. The devices can send information to each other. In order to compromise on the URLLC principle, two phases of communications are required [18]. In the first phase, the BS sends a message to the users and the users will compete among each other to receive the message from the BS. In the second phase, the successful users will decode the message and will then be selected as a leader. Next, the leader will then send the message to unsuccessful users those who need to send and receive the message to the BS [18].

The communication is then formed among all the users in the same coverage of the radio waves [18]. The communication continues as long as there is a leader in a particular group of the cell. For low-latency communication, it is important to enabling fast demodulation and decoding of the received data packet, which requires that the receiver can actually start the processing as early as possible. To enable this, reference (or pilot) signals should be transmitted before the actual data transmission and time-domain interleaving of data should be avoided. With such early decoding, it should be possible for a receiver to demodulate and decode the transmission just a few microseconds after the transmission ended. Moreover, the data and the control signals should be multiplexed in a manner that it allows fast control signaling which reduces the queuing delays [19].

2.6 Summary

The chapter discussed the theory and review of the research works related to URLLC system and D2D communications. Generally, the ways all the papers explained the URLLC and D2D are the same. Some are proposing their own technique to improve the system and some used mathematics to describe the system design [20]-[22]. In this work, a simulation study by using MATLAB is proposed to study the relationship between the packet arrival rate and queue size, and sample rate.

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