Improving Network Performance by Enabling Device-to-Device Communication over Heterogeneous Networks

Feras Zen Alden, Suhaidi Hassan, and Adib Habbal
InterNetworks Research Laboratory, School of Computing,
Universiti Utara Malaysia, 06010 UUM, Sintok, Kedah, Malaysia.
feraszen2004@hotmail.com

***Abstract*—An overview of Device-to-Device (D2D) communication systems and the various roles of D2D in next-generation networks are presented in this paper. D2D communication will be the preferred choice of operators in the future, for its ability to improve the performance of the network without investing excessive resources in the base station (BS). Various configurations of D2D communication can be applied in the network to enhance the quality of service (QoS) in order to meet user requirements. The model presented in this paper can be used to test the connection quality of the mobile stations in various scenarios when they are communicating directly without the intervention of BS. Results have been collected for mobile stations with and without D2D communication and improvement has been observed when mobile stations are using D2D communication, compared to normal operation without any D2D communication available. The results showed that D2D communication could be used not only to meet the demands of users but also in order to expand the coverage area of the base station where either received signal strength is low or blind spots exist in the region.**

***Index Terms*—Device-to-Device (D2D); Future Network; 5G; Peer Discovery.**

I. Introduction

As the 5G network, considered as a revolution in modern wireless communication, will be unveiled in due course, the infrastructure standards used in current communication networks need to be modified, enhanced or completely replaced with new features and techniques to enable the 5G communication system to meet the expected requirements [1].

Given the need to minimize the requirements and roles of Base Stations (BS) in modern communications systems, Device-to-Device (D2D) technology will play a salient role in achieving these goals in 5G networks [2]. D2D communication is a direct connection between two devices without traversing the BS or core network [3]. It is one of the most advanced techniques that can be used to improve network performance and at the same time increase the coverage area but prior to the discovery process it needs to scan the surrounding mobile stations [4].

In D2D settings, devices within radio vicinity are allowed to take advantage of D2D communication. Otherwise, the cellular network is used when a pair of communicating devices are not within communication range of each other. Figure 1 shows the concept of the D2D communication system as METIS suggests in [5]. We can see that D2D communication can play an important role in situations concerning public safety, crowded cells and support for future networks. The load on the cellular network and users' distance from the BS play important roles in selecting the communication mode (i.e. D2D or cellular). Obviously, D2D communication is a significant technique which can:

- Extend the coverage area of a network, because the connection is mainly between two nodes (Mobile Stations) and that it does not fully rely on the base station, the coverage area can be extended according to the mobile stations' distribution. Technically speaking, the Ad-hoc concept is partially adopted in 5G networks that makes the extension of the coverage area realizable.
- Increase power efficiency. Recently, many techniques have been used to decrease the transmission power for 4G networks. New developments in energy-saving techniques have proved highly capable of working with 5G networks, especially for D2D communication. One of these techniques involves dividing users into two groups, namely, primary and secondary users. By controlling the transmission power of the secondary user, interference sharply decreases and the signal to interference-plus-noise ratio increases significantly [6].
- Balance the traffic load among cells. A serious problem arises when cells' loads are not balanced and vary with time. This is one of the major self-optimization concerns in networks like 5G. The outage probabilities of heavily loaded cells may be higher when the loads among cells are not balanced and there is a shortage of power/frequency resources to sustain the service demand of users in the overcrowded cell(s); at the same time, the neighbouring cells may be experiencing underutilization of resources. In this situation, load balancing may be applied to qualify or even avoid the occurrence of this type of problem [7], [8].

The current 4G technologies will shortly become incapable of meeting the growing demand for mobile traffic data, so there is a need for asymmetric mobility of mobile devices across different technologies [9][10].

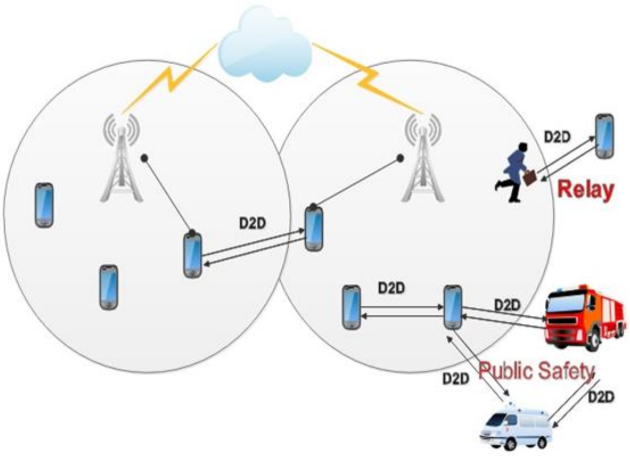

Figure 1: D2D Architecture

II. MOTIVATION

The goal of this study is to show the differences in performance when D2D communication is available, by implementing a new mechanism for peer discovery, showing improvement in the performance metrics. The most important features in enabling D2D communication are to support bandwidth-hungry and delay-sensitive multimedia applications, which were previously supported only by wired networks but now can be done by mobile devices over the wireless networks [11]. However, critical investigation of the existing wireless technologies has revealed that different wireless traffics corresponding to different delay-controlled QoS requirements can cohabit in the same wireless network. For this reason, D2D communication will support different types of users, applications and services with varying application demands and users preferences [12].

In addition to the significance of D2D communication as a means of achieving spectral efficiency, increased system capacity, and extended area coverage, D2D can be used to reduce interference, end-to-end delay, and power consumption in cellular networks. These features render D2D a formidable complementary technology for 5G wireless networks [13]. D2D communication always provides the best connection along with decreased effects on critical issues, such as inaccurate prediction of the target BS and inappropriate selection of target technology, by proposing the right network selection strategy. So, a Simple Additive Weighting (SAW) mechanism is proposed to find an optimum peer-based multi-attribute decision making (MADM) approach which will increase the optimum quality of service connection for the D2D-pair [14].

III. D2D PEER DISCOVERY PROCEDURE

Before two devices establish a D2D communication, the peers must go through a mode-selection and peer-discovery process. Mode selection can provide a more generic setting that involves multiple cellular operators and multiple D2D links, aiming to establish the optimal operation mode, transmit power and radio access to achieve maximum sum rate [15]. Also, the joint scheme of power allocation and mode selection can optimize the system energy consumption efficiency by exhaustively searching for all available mode combinations of all D2D and cellular devices [16]. Peer discovery is mandatory for two potential devices which want to set up a connection for D2D communication on a direct link. Two devices are considered as a D2D candidate pair if they can discover each other during the peer discovery process. Anyway, before D2D candidates are able to exchange data over the direct link, both have to agree on a standard criterion for mode selection. The general discovery steps for D2D communication are defined in two phases: discovery and communication [6].

Discovery phase: in this phase, each device searches for a potential peer within its radio proximity for D2D communication and evaluates the identity of the discovered peer to determine its credibility for D2D communication. This phase also involves a number of message exchanges between devices and between devices and BS, in which information about their respective link qualities is communicated. Once this information is available on the BS, it may serve as the primary input to facilitate the mode selection in the communication phase.

Communication phase: after completing the discovery phase, the new D2D pairs can initiate an actual connection. The communication phase involves channel estimation, mode selection, resource allocation, power control, and then the actual information transmission and reception. During the mode-selection process, the two communicating parties decide on the communication mode. This is important because, sometimes, the quality of the direct links may be in a worse state than the cellular links, making it unacceptable to operate in D2D mode. In addition, when the D2D pairs choose to communicate over the direct link (D2D mode), the mode selection parameters can be further extended if the D2D link is allowed to share spectrum resources with the cellular links. Mode selection can be performed either semi-statically before the D2D connection is established or dynamically per time slot along with resource allocation and power control.

The proposed mechanism of peer discovery is very important in finding the best partner to establish the connection between pairs of devices. The main attributes are considered as Receive Signal Strength (RSS), delay, cost and battery drain. The wireless communication system RSS and delay attributes are the most important values that need to be checked before starting the connection. Also, power consumption needs to be studied during peer finding, as it may affect the lifetime of the connection. Finally, the cost attribute can play a role in choosing the peer as it helps to increase the optimal level of QoS and satisfy the user. Many telecommunication researchers have studied how to minimize the cost of using the technologies for accessing the Internet or mobile applications [17].

The connection between devices using D2D communication goes through many steps. When the device selects communication using the D2D mode, our new mechanism for peer discovery will assist it in finding the best peer in the surrounding area. As shown in Figure 2, the device starts the peer-discovery process to identify the active users in the surrounding area which are capable of communication. At this time, the user builds a list of the available devices and orders them according to the preferences and connection weightages for the main attributes. Then, the user sends a request to start the D2D connection with the highest-rated device on the list. If the request is denied or the connection fails, the request will send to the next device on the list and keep sending requests until it establishes a D2D connection. This procedure of peer discovery continues to run while the user is still connected, using D2D communication. So, if the connection fails or a better peer in the surrounding area is found, the connection will be handed over to that peer.

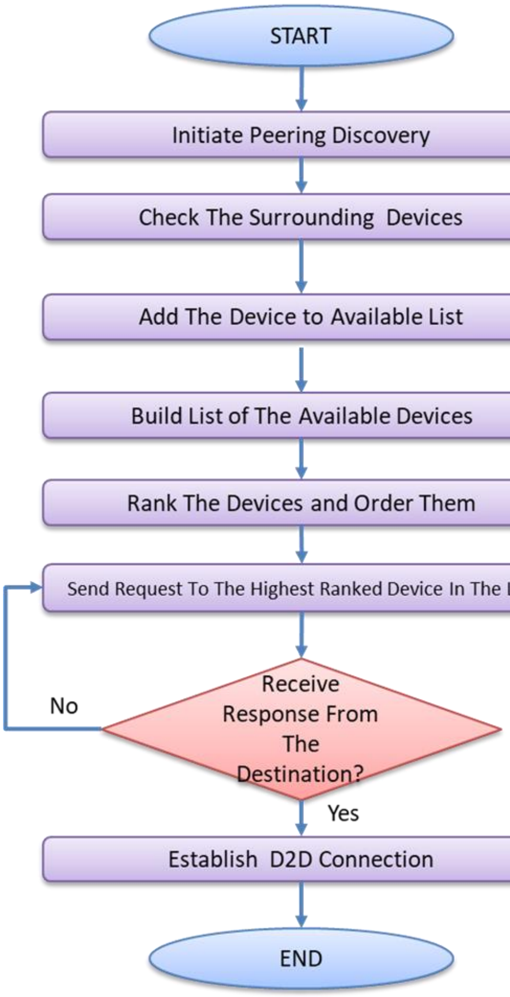

Figure 2: D2d Peer-Discovery Procedures and Steps

IV. EXPERIMENTAL RESULT AND DISCUSSION

Implementing the proposed mechanism for peer discovery is an important aspect of D2D communication in 5G networks, so that future systems may overcome most of the limitations of current technologies since they will be wholly controlled. On the other hand, the need to decrease the amount of data to be exchanged between BSs is also an advantage2. So, comparing the performance when enabling the D2D communication system with that without enabling D2D can give us a good idea about the importance of enabling D2D communication over a future network. Our proposed model shows the main result of implementing the SAW algorithm and our simulation setup is shown in Table 1. The performance metrics of this simulation can be applied to future network needs and meet operators' and users' demands. This situation can show the connection status while the user is moving among the cells randomly. Table 1 shows the main parameters which are used to build our network. However, the network topology serves users using multi Radio Access Technology (RAT) like Long-Term Evolution-Advanced (LTE-A) and Wireless Local Area Network (WLAN), as shown in Figure 3. This topology could be applied in many scenarios and case studies such as shopping centres, festivals and the smart city.

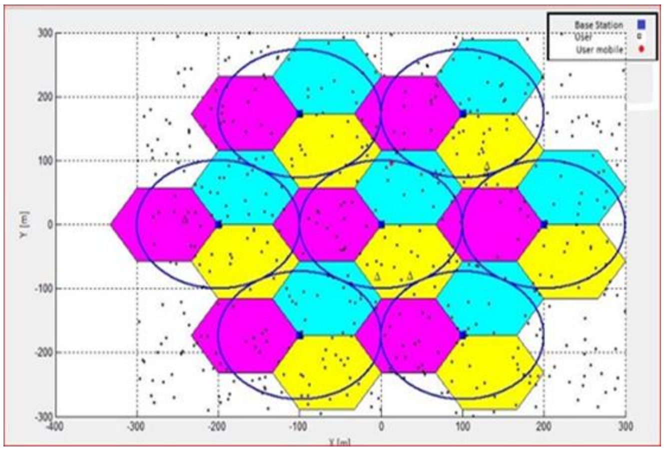

Figure 3: Network Topology

Basically, the proposed model is implemented using MATLAB simulation, we define the user situation by movement speed, movement period, direction and demands.

Table 1
Simulation Setting

Item	Value
Number of Cells	7
Users	1000
User type	Smartphone
User mobility	Static/walking
Traffic volume	7 Tbyte/h
Communication Technology	LTE-A, WLAN

In addition, the status of coverage and required data rate per user and per cell can be changed according to the network situation, such as BS failure or crowded cells and used to study and test many scenarios and respect specific scenario requirements and conditions.

Also, the user outside the coverage area is allowed to connect with surrounding devices, which in turn extends the coverage area especially to areas where the network's coverage is not reachable. The proposed model can test many situations by changing the input of some parameters. As shown in Figure 4, when we start the simulation we can define the user speed, which will reflect the user mobility status, whether static or walking or vehicle. Also, the simulation time and the weighting attributes for RSS, delay, cost, and power efficiency could be defined at the same time.

The performance of the connection is tested while the user is moving among cells randomly (with D2D connection and without D2D). As shown in Figure 5, during the studied time the average delay with enabled D2D reduced the length of delay compared with that when D2D was not enabled. We can see that from 0 to 20 sec the D2D connection approach shows ultra-delay value since the optimum user is chosen to be connected to a destination device. Then, from 20 to 25 sec the device's peer connection delay starts to grow up to 35 msec, so the user prefers to connect to a different device to enhance the connection quality. It worth mentioning that the 5-second period is delay tolerance, during which the device can change its peer; this time gap is set to prevent a ping-pong effect caused by changing the peer connected to a destination.

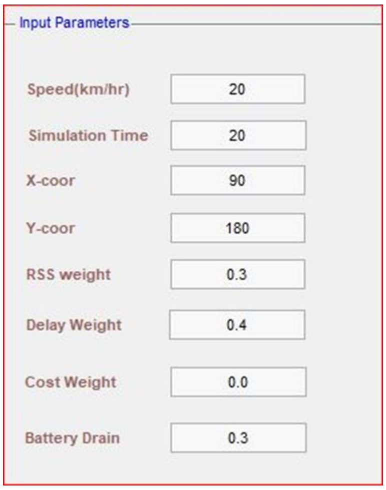

Figure 4: Input Parameters in Simulation

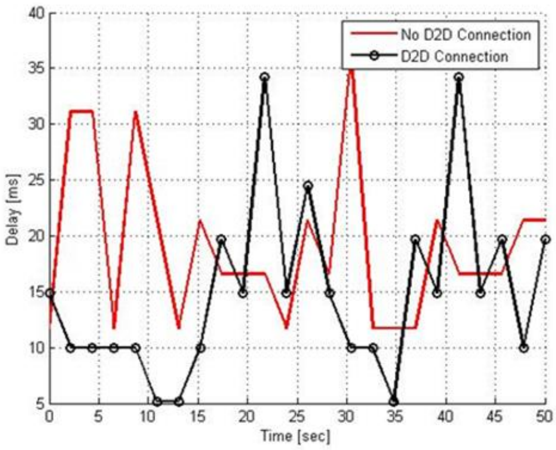

Figure 5: Delay during the simulation time

Also, as shown in Figure 6, we find that the performance in terms of SINR is improved because the new mechanism for peer discovery of D2D connection can decrease the interference value, which affects the SINR value.

Finally, as shown in Figure 7, the RSS level in our result moving at the acceptable level gives an optimum value over all the studied period. So, the proposed mechanism gives us a stable connection and provides a connection to users in the all expected situations. The peer mechanism helps by improving the connection performance and achieving better value when it is enabled for D2D communication systems.

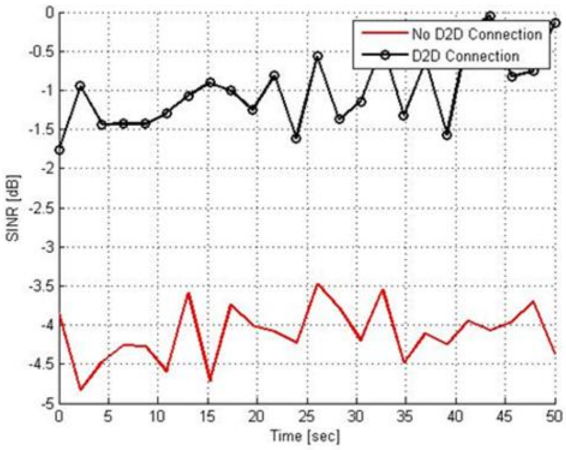

Figure 6: Signal Interference to Noise Ratio during the simulation time

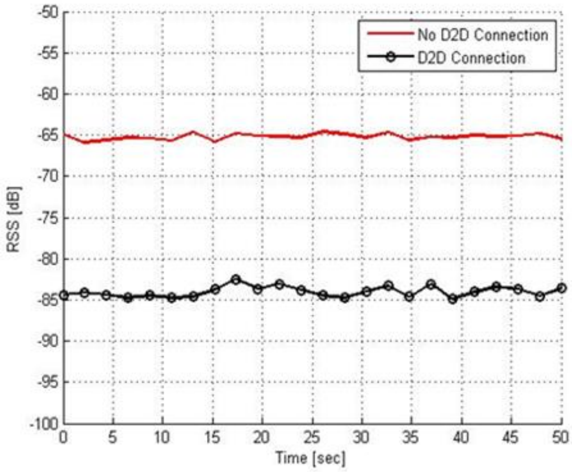

Figure 7: Receive Signal Strength during the simulation time

As we can see, the improvement in the average delay value brings us closer to the expected value for 5G. The simulation results show that the D2D communication system is a promising technology which can improve network performance and provide the optimum connection to users in many critical scenarios.

V. CONCLUSION

The increase in the number of devices connected to networks and the new application and technology raises many challenges for the researchers in providing a service to users and high-quality connection. For these reasons, new standards and techniques will be needed for current and future networks. This model supports coexistence of the existing multi-RAT interfaces and can be extended to support future RAT networks such as 5G networks by adding more metrics and system features. We have proposed this new model to show the importance of enabling D2D communication systems in the network and how D2D becomes a unique solution that allows users within it to stay connected even when the network BS is down. D2D will be part of future networks and will support the network infrastructure, helping users to use more applications and assisting society in public safety, traffic jam control, vehicle-to-vehicle communication, and so on.

Compared to other conventional communication techniques, D2D communication is a very efficient method of communication because of features such as short wavelength, high bandwidth and limited coverage. Also, a mobile device operating in D2D mode can simultaneously access a multiple RAT subject to its processing and computation power, as can be seen in most current smartphones which are capable of simultaneously accessing different types of RAT. Therefore, the ability of multiple radio access in wireless device offers D2D communication the flexibility to efficiently manage resource allocation, energy consumption, link establishment, applications and services.

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