AN ADAPTIVE SOCIAL-AWARE DEVICE-TO-DEVICE COMMUNICATION MECHANISM FOR WIRELESS NETWORKS

FERAS ZEN ALDEN

DOCTOR OF PHILOSOPHY
UNIVERSITI UTARA MALAYSIA
2020

Awang Had Salleh
Graduate School
of Arts And Sciences

Universiti Utara Malaysia

PERAKUAN KERJA TESIS / DISERTASI
(Certification of thesis / dissertation)

Kami, yang bertandatangan, memperakukan bahawa
(We, the undersigned, certify that)

FERAS ZEN ALDEN

calon untuk Ijazah **PhD**
(candidate for the degree of)

telah mengemukakan tesis / disertasi yang bertajuk:
(has presented his/her thesis / dissertation of the following title):

"AN ADAPTIVE SOCIAL-AWARE DEVICE-TO-DEVICE COMMUNICATION MECHANISM FOR WIRELESS NETWORKS"

seperti yang tercatat di muka surat tajuk dan kulit tesis / disertasi.
(as it appears on the title page and front cover of the thesis / dissertation).

Bahawa tesis/disertasi tersebut boleh diterima dari segi bentuk serta kandungan dan meliputi bidang ilmu dengan memuaskan, sebagaimana yang ditunjukkan oleh calon dalam ujian lisan yang diadakan pada : ***13 Januari 2020.***
That the said thesis/dissertation is acceptable in form and content and displays a satisfactory knowledge of the field of study as demonstrated by the candidate through an oral examination held on:
January 13, 2020.

Pengerusi Viva: **Prof. Dr. Wan Rozaini Sheik Osman** Tandatangan
(Chairman for VIVA) *(Signature)*

Pemeriksa Luar: **Prof. Dr. Hj Mazani Hj Manaf** Tandatangan
(External Examiner) *(Signature)*

Pemeriksa Dalam: **Dr. Ahmad Suki Che Mohamed Arif** Tandatangan
(Internal Examiner) *(Signature)*

Nama Penyelia/Penyelia-penyelia: **Prof. Dr. Suhaidi Hassan** Tandatangan
(Name of Supervisor/Supervisors) *(Signature)*

Nama Penyelia/Penyelia-penyelia: **Dr. Adib Habbal** Tandatangan
(Name of Supervisor/Supervisors) *(Signature)*

Tarikh:
(Date) ***January 13, 2020***

Permission to Use

In presenting this thesis in fulfilment of the requirements for a postgraduate degree from Universiti Utara Malaysia, I agree that the Universiti Library may make it freely available for inspection. I further agree that permission for the copying of this thesis in any manner, in whole or in part, for scholarly purpose may be granted by my supervisor(s) or, in their absence, by the Dean of Awang Had Salleh Graduate School of Arts and Sciences. It is understood that any copying or publication or use of this thesis or parts thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to Universiti Utara Malaysia for any scholarly use which may be made of any material from my thesis.

Requests for permission to copy or to make other use of materials in this thesis, in whole or in part, should be addressed to:

Dean of Awang Had Salleh Graduate School of Arts and Sciences

UUM College of Arts and Sciences

Universiti Utara Malaysia

06010 UUM Sintok

Abstrak

Komunikasi Peranti-ke-Peranti (D2D) adalah elemen penting dalam rangkaian 5G yang membolehkan pengguna berkomunikasi baik secara langsung tanpa bantuan rangkaian atau dengan isyarat minimum melalui stesen pangkalan. Untuk komunikasi D2D yang berkesan, masalah berkaitan mod dan pemilihan padanan perlu ditangani. Dalam pemilihan mod, masalahnya adalah bagaimana menjamin pemilihan sentiasa memilih mod yang terbaik. Dalam pemilihan padanan, masalahnya adalah bagaimana memilih padanan yang optimum di antara padanan dari segi keadaan hubungan dan hubungan sosial antara padanan. Objektif utama penyelidikan ini adalah untuk mengenal pasti pemilihan mod antara peranti dan mewujudkan hubungan dengan sambungan padanan D2D terbaik tanpa kebocoran privasi. Teori Pembuatan Keputusan Pelbagai Atribut dan Pilihan Sosial diterapkan untuk mencapai objektif kajian. Skema pemilihan mod berdasarkan atribut Kekuatan Isyarat Diterima (RSS), kelewatan dan lebar jalur untuk memilih dan beralih antara mod yang tersedia dengan bijak berdasarkan peringkat tertinggi. Kemudian, skema pemilihan rangkai padan dicadangkan menggunakan atribut RSS, kelewatan, jalur lebar dan kuasa untuk mencari padanan yang optimum berasaskan hubungan sosial, dengan menilai tahap kepercayaan antara padanan serta mengecualikan padanan yang tidak dipercayai daripada pemangkatan yang akan meningkatkan kualiti optimum sambungan D2D. Skema yang dicadangkan disahkan dan diuji menggunakan perisian MATLAB. Dua senario utama, iaitu jaringan yang sesak dan kecepatan pengguna dipertimbangkan untuk menilai mekanisme yang dicadangkan dengan tiga pendekatan yang sedia ada di mana pemilihan berdasarkan atribut tunggal. Hasil yang diperoleh menunjukkan bahawa mekanisme yang dicadangkan melebihi pendekatan lain dari segi kelewatan, nisbah isyarat ke bunyi, nisbah penghantaran dan truput dengan prestasi yang lebih baik sehingga 70%. Mekanisme yang dicadangkan memberikan pertukaran yang lancar antara mod yang berbeza dan menggunakan pilihan rangkai padan automatik hanya dengan padanan yang dipercayai. Ia dapat diterapkan dalam berbagai jenis rangkaian yang melayani sejumlah besar pengguna dengan kelajuan pergerakan pengguna yang berbeza.

Kata kunci: Komunikasi Peranti-Ke-Peranti, Teknologi 5G, Rangkaian tanpa wayar heterogen, Teori Pembuatan Keputusan Multi-Atribut, Teori Pilihan Sosial.

Abstract

Device-to-Device (D2D) communication is an essential element in 5G networks, which enables users to communicate either directly without network assistance or with minimum signaling through a base station. For an effective D2D communication, related problems in mode and peer selection need to be addressed. In mode selection, the problem is how to guarantee selection always chooses the best available mode. In peer selection, the problem is how to select optimum peers among surrounding peers in terms of connection conditions and social relationships between peers. The main objectives of this research are to identify mode selection between devices and establishing a connection with the best D2D pair connection without privacy leakage. Multi-Attribute Decision Making and Social Choice theories are applied to achieve the objectives. Mode selection scheme is based on Received Signal Strength (RSS), delay and bandwidth attributes to choose and switch among the available modes intelligently based on the highest ranking. Then, the peering selection scheme is proposed using RSS, delay, bandwidth and power attribute to find an optimum peer with concerning social relationship, by evaluating trust level between peers and excluding the untrusted peers from ranking which will increase the optimum quality of D2D connection. The proposed schemes are validated and tested using MATLAB. Two main scenarios, namely crowded network and user speed were considered to evaluate the proposed mechanism with three existing approaches where the selection is based on a single attribute. The obtained results showed that the proposed mechanism outperforms other approaches in terms of delay, signal to noise ratio, delivery ratio and throughput with better performance up to 70%. The proposed mechanism provides a smooth switching between different modes and employs an automatic peering selection with trusted peers only. It can be applied in different types of network that serves the massive number of users with different movement speed of the user.

Keywords: Device-to-Device communication, 5G technology, Heterogeneous wireless network, Multi-Attribute Decision Making theory, Social Choice theory.

Acknowledgements

In the name of ALLAH, Most Gracious, Most Merciful:

"*Read; And your Lord is the Most Generous, Who taught by the pen, Taught man that which he knew not;*"

(The Holy Quran - Al-Alaq (96): 3-5)

Joining this program was an interesting station in my life. This long journey helps me to get a lot of experience and knowledge.

I would like to thank and send sincere gratitude to my supervisor Professor Dr. Suhaidi Hassan (The chair man of InterNetworks Research Laboratory (IRL), School of Computing, Universiti Utara Malaysia) for his support and guidance in the way of completing this research by providing the facilities to conduct seminars and different activities in IRL and in many different places around Malaysia. Also, I would to like to thank and express my deep feeling to my co-supervisor Assoiciate Professor Dr. Adib Habbal (Karabuk University, Tureky) for his assist and advice to keep this research move forward till reach to this stage. They gave me a space to develop myself and increase my ability and skills in research, they allowed me to join many seminars, conferences and workshops. Furthermore, I would like to thank my colleagues for their insightful comments and advantageous discussions.

I would like to thank my family, father Nader, mother Adeela, brother Fadi, sister Aila, my beloved wife Lina and daughter Yara for their support, understanding, dedication, devotion and encouraging. Without them, I would not go far in this long journey.

Abbreviation

ACK	-	Acknowledgment
AHP	-	Analytic hierarchy process
API	-	Application Programming Interface
BS	-	Base Station
BB	-	Beacon Broadcaster
CC	-	Carrier Component
CSI	-	Channel State Information
D2D	-	Device-to-Device
D2I	-	Device-to-Infrastracture
DS-I	-	Descriptive Study-I
DRM	-	Design Research Methodology
E2E	-	End-to-End
GRA	-	Grey Relational Analysis
GRC	-	Grey Relational Coefficient
HAW	-	Hierarchical Adaptive Weighting
JM	-	Joint Mode
KDMS	-	Kim Delay Mode Selection
LTE-A	-	Long Term Evolution-Advanced
MAC	-	Media Access Control
MAPS	-	Multi Attribute Peer Selection
MAMS	-	Multi Attribute Mode Selection
MADM	-	Multi Attribute Decision Making
MDP	-	Markov Decision-making Process
MEW	-	Multiplicative Exponent Weighting

MINLP	-	Mixed Integer Nonlinear Programming
MS	-	Mobile Station
NS3	-	Network Simulator 3
OAA	-	Outer Approximation Approach
PHY	-	Physical layer
PSMS	-	Peer Selection Mode Selection
PS-I	-	PrescriptiveStudy-I
PS-II	-	PrescriptiveStudy-II
PSNR	-	Peak Signal-to-Noise Ratio
PPP	-	Poisson Point Process
P2P	-	Peer-to-Peer
QoS	-	Quality of Services
RAT	-	Radio Access Technology
RRM	-	Radio Resource Management
RSS	-	Received Signal Strength
RC	-	Research Clarification
RTT	-	Round-Trip Time
SAW	-	Simple Additive Weighting
SINR	-	Signal to Interference Noise Ratio
TOPSIS	-	Technique Order Preference by Similarity to Ideal Solution
V2V	-	Vehicle-to-Vehicle Communication
VoIP	-	Voice over IP
UE	-	User Equipment
WLAN	-	Wireless Local Area Network
WP	-	Weighting Product

Table of Contents

List of Tables

List of Figures

CHAPTER ONE
INTRODUCTION

1.1 Overview

As wireless communication technology continues to evolve from one generation to another, connection systems' requirements are developed alongside to meet the expectations of users. Such expectations were brought by the entire evolution process that represents the ever-increasing demand for higher system throughput. Nowadays, as the demand for higher transmission rates continues unabatedly, a new generation of wireless technologies is being introduced into the communication society to meet the insistent demands of users. The key differences among the various generations of wireless communication systems (i.e., starting from the first generation 1G to the upcoming fifth-generation systems) are manifested in variations in data rates, data security, latency and the quality of services (QoS) [5]. These are often improved in successive generations for a more efficient system throughput and QoS performance. Currently, 4G networks (LTE or LTE-A) represent the best available operating networks that offer the best QoS in wireless networks [6, 7].

The latest versions of the above-mentioned wireless technologies can offer access to speed up to 1 Gb/s. However, this cannot be assumed sufficient to support the data throughput demands for future wireless networks especially with the predicted number of more than seven billion smart devices in use. These devices operate in a wireless network along with their accompanied bandwidth-hungry and delay-sensitive applications [8].

Therefore, the success of 5G ultimately depends on the smart integration of such novel concepts with existing radio access technologies as well as context-aware mapping of services and devices to evolve or novel technology components. With the advent of the new 5G network, which is considered as a revolution in modern wireless communications, the standards of infrastructures used in current communication networks need to be modified, enhanced or completely replaced with new features and techniques. Accordingly, the advanced 5G communication system can eventually meet the expected enhancements by [2]:

i) 1000 times bigger data size in the same area.

ii) 10 times to 100 times higher typical data rates for users.

iii) 10 times to 100 times higher number of connected devices.

iv) 5 times higher reduction of latency of End-to-End (E2E).

Figure 1.1. 5G Features [2]

Figure 1.1 shows that 5G will be folded into as follows:

Future applications require low latency where the needs for latency limit is roughly 1 ms especially for critical applications including remote surgery and virtual reality. Moreover, the expected data rate might reach 10 times the existing technology (amazingly fast) to accommodate the enormous demands of increase in the number of mobile users, applications demands and growth. For this reason, it is essential to include new technologies in wireless technology and apply current technologies in future networks. One of these technologies is Device-to-Device (D2D) communication system where the concept of a D2D communication system provides the connection for users during seamless mobility in the network [9]. The D2D communication is defined as the direct connection between two devices without traversing the BS or as indirect connection with transferring minimum data through the core network or BS [10], [11]. The cellular network encourages D2D communication application as it assists users to have higher data rate, decrease the delay and save power [12]. So, the D2D communication system enabler will be part of this revolution technology in future networks [13].

One of the critical challenges of the innovative current wireless network lies in keeping the mobile station (MS) connected anytime and anywhere at optimal level. To achieve the desired goal, seamless roaming between symmetric and asymmetric technologies becomes salient [14]. One of the best ways to increase the network capacity is by using D2D connection when the users are in the same area instead of transferring the data through the central infrastructure, which will satisfy the users and service providers [15], [16].

Due to the need to minimise the necessities and roles of Base Stations (BSs) in modern communications' systems, the Device-to-Device (D2D) technology plays a pivotal role in achieving the desired goals concerning the 5G network. D2D communication is one of the most advanced techniques that can be used to improve network's performance. D2D communication can increase coverage area by allowing users in the edge or near the coverage area to connect using D2D link [17],[18]. In a D2D communication system setting, devices within radio vicinity are allowed to take advantage of the D2D communication. Otherwise, the cellular network is used when a pair of communicating devices are not within the radio range of each other. The concept of the D2D communication system is illustrated in Figure 1.2 [19]. D2D communication system is a beneficial and efficient technique. Accordingly, the main advantages of implementing D2D cover the following areas:

i. It increases the overall system capacity by reducing the base station load by transferring data packets through D2D communication [20]. This feature can be reached by decreasing the interference from other sources like relay, device and base stations. Another issue is that the power consumption should be optimised by deploying power control approach. Finally, resource management and allocation are the main players in making robust system capacity by efficiently and optimally allocating the resources among devices, which are shown in Figure 1.2.

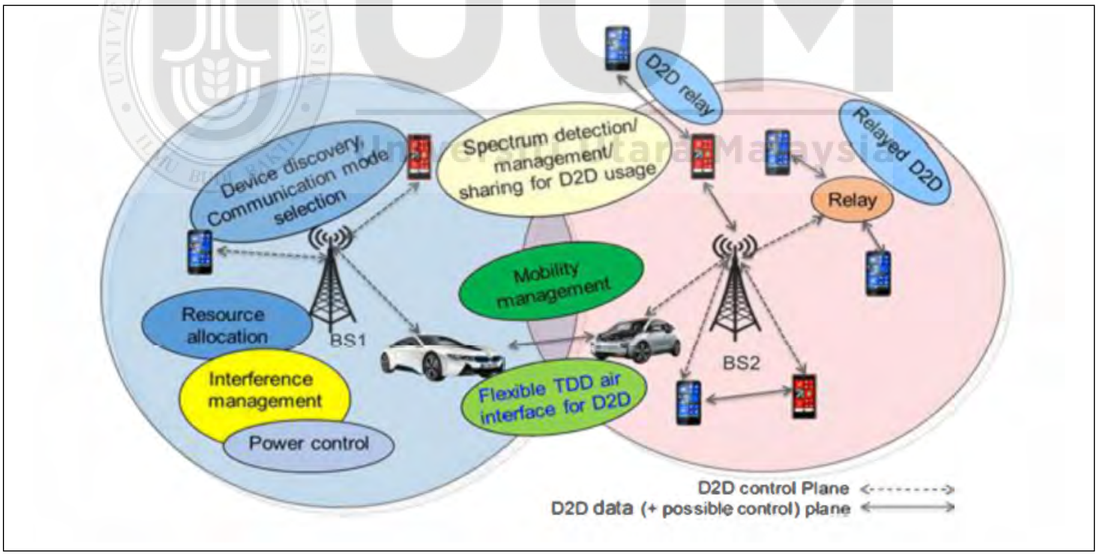

Figure 1.2. D2D Structure [3]

ii. It extends the coverage area of a network. For instance, when a device is out of the coverage area of the base station, it can use another device as a relay to have a connection with a particular base station. Technically speaking, the ad-hoc concept can play its role in providing connection to users in uncovered areas in the edge of the cells or blind areas in the network [21], which makes the extension of the coverage area realisable since it is non-centralised and can forward the data from one user to another in various routing ways and multi-hop until the data reach their destination. This can be adopted for D2D communication system in 5G networks, which increases the efficiency of the connection [12]. So, D2D communication improves the coverage by supporting a vast number of users with better performance level [22].

iii. It decreases power transmission and increases power efficiency. Recently, many techniques have been implemented to decrease the transmission power of 4G networks. New developments in energy-saving techniques have proved high capability to work with the 5G networks especially for D2D communication. One of these techniques involves classifying users into two groups known as primary and secondary users. By controlling the transmission power of the secondary user, the interference is decreased. As a result, the signal to interference-plus-noise ratio will be remarkably enhanced [23].

The D2D communication system provides a flat traffic load among cells. Serious problems arise when the cells' loads are imbalanced and vary with time. This is one of the important self-optimisation challenges in networks including the 5G network. The block or outage probabilities of heavily-loaded cells may be higher when the loads among cells are imbalanced. Moreover, a shortage of power/frequency resources may take place to sustain users' service demands in the congested cell(s) while the neighbouring cells may be experiencing underutilised resources. In such situations, load balancing can be applied to qualify or even avoid the occurrence of this type of problems [24, 25].

The predicted features of the next-generation network by enabling D2D communication system are expected to allow communications using different modes of connection among the available modes, which can be in the form of direct connections such as D2D communication link or Device-to-Infrastructure (D2I) communication through a network infrastructure like WLAN and LTE-A, which will in turn enable users to be supported by an efficient available connection all the time [26]. Therefore, the assessment and differentiation between the two technologies have to be accurately harmonised to qualify for the users' preferences. Otherwise, the mobile station will keep 'ping-ponging' between technologies as it searches for a better connection.

Due to the massive number of users and different types of application, the enabling of D2D communication needs to consider the relationship between users [27]. Thus, users need to check the relationship with their destination before establishing connection. The relationship between both peers should be built on trust to protect each other. So, applying the social-aware factors will enhance the privacy of users and establish a connection with trusted users and avoid the connection with untrusted users [15]. However, the success of applying D2D communication in the future depends on the trust situation because if trust is not considered, it will fail the D2D applications [22].

1.2 Research Motivation

The support for bandwidth-hungry and delay-sensitive is regarded as the most important service covered by D2D communication users. It also includes 3D immersive media, which were previously supported only by wired networks including the Gigabits Ethernet. However, they can be readily accessed by users now via mobile devices over wireless networks [2],[28]. Nonetheless, a critical review on existing wireless technologies has revealed that different wireless traffics corresponding to different delay-controlled QoS requirements can cohabit the same wireless network. For this reason, the D2D communication can support different types of users, applications and services with varying applications' demands and users' preferences [29].

In addition to the significance of D2D communication as a means of achieving spectral efficiency, increased system capacity and extended coverage area, D2D can also be used to reduce interference, end-to-end delay and power consumption in cellular networks. These features render D2D communication system into a formidable complementary technology for 5G wireless networks [30].

In conclusion, implementing the D2D communication is an important aspect of the 5G network that the future systems will hopefully overcome most of the limitations of the current technologies as long as they are fully controlled. On the other hand, the need to decrease the amount of data to be exchanged between BSs can be added as another advantage [10]. Hence, the challenge is not only in adopting D2D communication system, but also in providing a stable connection based on the conditions concerning social factors. Thus, trust between peers is imperative for an efficient D2D communication and to make it worth to be applied and merged with other technologies [31].

1.3 Problem Background

The modes include D2D communication representing direct mode and D2I communication where connection is established between the device and core networks including WLAN or cellular. For instance, the mode selection technique should be able to choose optimum connection mode to provide a stable connection without any failure in the connection and select the best communication mode during the communication period [32]. So, one of the relevant difficulties is how to keep providing a stable connection for users even when the connection is switching between different modes either through D2D or D2I mode. This makes it difficult to select the best mode and requires smart switching between modes. So, it will become challenging to establish a robust D2D connection.

Recently, the application of social factors in modern technologies has become universal due to the need of finding new ways to improve performance and satisfy the users. Peering selection process is based on selecting the peer to establish the D2D connection at a particular area, which is a challenging task due to the huge number of users [33]. The long period required in the selection process for the best device will cause high power consumption, which reflects on the battery drain speed. Furthermore, delay in obtaining the optimum D2D-pair is considered the main issue especially for delay-sensitive applications [34]. Some researches depend on the information from the social network for improving the D2D performance. Social information can define the common relationship between different users, which helps to improve peering selection through available users [35], [36]. Therefore, an appropriate social-aware peer selection scheme can be fused into the communication system to address these challenges [37]. The selection of peers is also challenging in terms of reliability since communicating with the wrong peers in the trusted relationship may affect data integrity and cause privacy leakage [35]. The performance of D2D communication can be improved if the peer is selected in an appropriate way based on the condition of communication and social-aware status. Consequently, in a case of inappropriate selection of peer, the connection may drop or become unstable [38]. The cooperation between users is essential to have an efficient D2D communication system; however, most users do not provide data to unknown users due to privacy issues. At this point, it is essential to define the relationship type to clarify the user status whether trusted (close friend, friend, a friend of friends), or not trusted (strangers/malicious) [20], [39].

Some studies have proposed several solutions to solve the problems such as in [40] that tried to solve the problem of mode selection for D2D by proposing a scheme that considers the load of traffic for bursty traffic model. The scheme enhanced average end-to-end delay, packet rate and dropping probability, which depend on queueing delay and waiting time. However, this solution is executed within a single cell and considers only delay attribute for making a decision of mode selection, whereby neglecting bandwidth and RSS. Also, the peering selection processes are not considered. Further, a joint mode selection was proposed in [41] to ascertain the required minimum rates of D2D links. The optimal mode operates in the relay or direct mode formulated as job assignment problem, which provides optimal solution in polynomial time. However, the solution depends only on power attribute and executed within a single cell with limited number of users.

Improving the performance of D2D communication requires connection with users for a long period, which means that the selection of peer and mode must be appropriate concerning the connection conditions and social status [38], [42]. In addition, further performance comparison indicated that the social dynamic peer selection scheme does not only maximise connection performance, but also guarantee high privacy protection. An advanced peering and mode selection techniques to establish a reliable D2D connection should be designed concerning users' demands and social-aware status in such a way that they can select the best peers and optimum mode of communication among available modes [28], [36].

1.4 Problem Statement

In the current and future networks, users could go through different modes of connection, which is challenging due to the random movement of mobile devices along with the availability of various communication modes for every device. The inaccurate prediction of the target mode reflects on the performance of the D2D communication system and affects its application in future networks negatively as most studies made the decision based on one or two attributes only (such as RSS and delay attributes). Therefore, enhancement in mode selection procedures is required to include more than one attribute in the mode selection decision to enhance the connection performance, which can be achieved by adopting Multi-Attribute Decision Making (MADM) theory.

When D2D connection is selected as a communication mode, the challenge is on how to select the best peer among the available peers due to the massive number of peers and hesitation on privacy limit. Also, most of peering selection studies considered only peer communication attributes (such as distance and delay attributes) in peering selection decision while ignoring relationship status that will affect the connection quality and user's privacy. Hence, MADM theory together with social-aware can improve peering selection procedures to enhance the connection performance.

Based on the discussion, the first challenge in enabling D2D communication system in wireless networks is in ensuring that the device can always select the correct mode and has an optimum switching between different modes to improve its performance. The second challenge lies in selecting the best trusted peer when a user chooses D2D mode to protect their privacy and in avoiding the connection with untrusted users. Accordingly, further studies on social-aware peer and mode selection techniques are needed to enhance the D2D communication performance.

1.5 Research Questions

To step forward with the wireless networks and D2D communication system, this study addresses the following questions:

i. How to select the optimum mode of connection among available modes to guarantee an efficient connection by considering multi attributes namely delay, RSS and bandwidth?

ii. How to select the best available trusted device to establish optimum D2D connection among the neighbouring devices by considering the social-aware relationship between pair devices and multi attributes namely delay, RSS, bandwidth and power?

iii. What is the impact of the proposed mechanism that is integrated between integrated between mode and peer selection schemes on the performance of delivery ratio, delay and throughput in heterogeneous networks in comparison with the existing studies?

1.6 Research Objectives

The objectives of this study on D2D communication are outlined as follow:

i. To design a mode selection scheme using Analytic Hierarchy Process (AHP) and Simple Additive Weighting (SAW) algorithm based on Multi-Attribute Decision Making (MADM) that selects the best mode of connection among available modes. The proposed scheme will select the best connection by estimating multi-attributes and considering users' preferences.

ii. To design a social-aware peer selection scheme adopting AHP and Hierarchical Adaptive Weighting (HAW) based on MADM theory and social choice theory, which selects the best available device for peering among the neighbouring devices for D2D device-pair concerning the users' preferences and relationship status between peers.

iii. To evaluate the performance of the proposed mechanism in terms of studied packet loss ratio, delay, Signal-Interference-to-Noise-Ratio (SINR) and throughput of the connection in the simulation environment.

1.7 Significance of the Study

This study is significant research as it proposed a new mechanism to provide the best connection among available modes in satisfying the users' demands. First, the proposed mechanism can select the mode of communication in the form of either cellular communication or direct device communication to establish a connection. Also, the mobile device will have the option to enhance its quality of experience by swiftly selecting the best available mode. Secondly, the proposed mechanism can facilitate the detection of a peering device with which to build a connection. Finally, the mechanism can be useful for future researchers and scientists to build and develop their techniques. The implications of this study include:

i. Improving the network's performance by efficient peering and mode selection procedures.

ii. The best connection of the D2D communication is always provided besides decreasing the effects of critical issues such as the inappropriate selection of the mode by proposing accurate mode's selection strategy.

iii. The best mode of communication when the D2D communication system enabled is achieved by finding a suitable mode during the communication time.

iv. Including of social-aware factors with the connection factors not only help in increasing privacy but also in improving the performance by excluding the untrusted peers from the evaluation part.

1.8 Scope of the Study

This study limits its scope to the D2D communication in 5G networks. It was aimed at enabling devices to connect with each other for data exchange, applications pairing and multimedia application with minimal or no intervention of the BS. However, this requires identifying the requirements for applying D2D communication in the future networks to make the D2D communication system efficient and improve its performance level without any failure. This study proposed a new strategy for enabling D2D communication in present and future networks to serve users in different and critical cases including indoor and outdoor environment, different density of users and different movement speed of users. The proposed mechanism was implemented based on the proposed models, which were the MADM theory and social choice theory.

1.9 Organisation of the Thesis

This study is organised into seven chapters. The chapters are outlined as follow:

Chapter One: This chapter provides an overview of the study. It highlights the key challenges in D2D communication system.

Chapter Two: This chapter presents and discusses important background information on the topic of this study. It critically reviews and evaluates previous studies regarding the topic of interest.

Chapter Three: This chapter explains the study design based on the Design Research Methodology (DRM) as the framework of this study. It also links all the study stages to propose and implement the D2D communication system.

Chapter Four: This chapter presents the validation of the proposed mode selection scheme and discusses its performance during the test time.

Chapter Five: This chapter demonstrates the validation of the proposed social-aware peering selection scheme and discusses the improvements in its performance.

Chapter Six: This chapter provides the evaluation of the proposed model and tests the model in different cases.

Chapter Seven: This chapter summarises study findings and explains the difficulties and limitations of this study.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

The general idea of this study has been presented and explained in Chapter One together with the main problems of D2D communication. This chapter generally reviews the background to the topic and the previous studies conducted on D2D communication specifically on the issues of mode selection and peering selection. It is divided into six sections. The first section introduces an overview of the D2D communication system. Next, the second section explains the various scenarios of D2D communications. After that, the latest developments related to the D2D communication system are explained in the third section of this chapter. The fourth section provides the procedures for peering and mode selection in the D2D communication system by providing more details and insights. The fifth section reviews the main theories of D2D communication. Lastly, the final section gives a summary of this chapter.

The last several years have witnessed an unforeseen evolution in mobile broadband traffic and users' desire for high speed data access. According to Cisco visual networking index, smartphone traffic will be higher than that of PC by 2022, where smartphone traffic will be 44% while the PC traffic will be 19% of IP traffic. Also, wireless and mobile devices will use 71% of IP traffic. Recent report published by Cisco declared that mobile data traffic will increase sevenfold between 2017 and 2022 reaching to 77.5 exabytes per month and 3% of all Internet video traffic will be due to video surveillance by 2022. The global mobile devices will expand from 8.6 billion in 2017 to 12.3 billion by 2022. Over 422 million of devices will be capable of achieving 5G. Globally, the average 5G Nexus will generate 21 GB of traffic per month by 2022 [43].

Such a massive desire of the users for mobile data has been the primary motivation behind seeking alternative cellular architectures. These can bring about paradigm shifts in the utilisation of limited available frequency resources in an efficient manner. Moreover, it is believed that introducing D2D communication into the heterogeneous multi-tier cellular networks will significantly promote the performance of recent 4G cellular technologies in terms of system capacity, coverage, peak rates, throughput, latency and user experience [44].

However, device and mode selection are now being effectively concerned on achieving better and more efficient D2D communication for future networks [45]. The D2D communication system can enhance the capacity of the network and network-level loading, ability to serve more users and improve the D2D peering discovery as well as mode selection procedures. These are the key factors to achieve future networks' goals if the D2D communication system is enabled.

Compared to other conventional communication techniques, D2D communication is a very efficient method for communication due to its short wavelength, high bandwidth and limited coverage. Also, a mobile device operating in D2D mode can simultaneously access multiple Radio Access Technologies (RAT) owing to its processing and computation power. It can be seen in most of today's smartphones that are capable of simultaneously accessing different types of RAT. Therefore, the ability of accessing multiple radios in a wireless device provides D2D communication flexibility to efficiently manage resource allocation, energy consumption, link establishment, applications and services. Furthermore, a set of D2D pairs can establish multi-hop routes or form a cluster, which may autonomously operate with zero minimal or total operators' control. Since the current 4G technologies may sooner or later become incapable of fulfilling the ever-growing demand for mobile traffic data, there is an urgent need for asymmetric mobility of mobile devices across different technologies (LTE/LTE-A & WLAN).

2.2 Application of the D2D Communication System

The concept of D2D communication can be applied in many applications and cases. It was found that D2D communication is a useful communication system for the industry, military activities, health care and safety purposes. The following examples illustrate some useful aspects of D2D communication:

i. Public Safety: These application scenarios can be classified as general and public safety use cases from subscribers' perspective. From the deployment's perspective, they can be categorised into 'within network coverage' and 'outside network coverage' [46].

ii. Vehicle-to-Vehicle Communication (V2V): One case of D2D communication can be used in V2V communication due to its reliability in some traffic safety use cases [47]. This system especially requires low latency to control the break between the vehicles as shown in Figure 2.1.

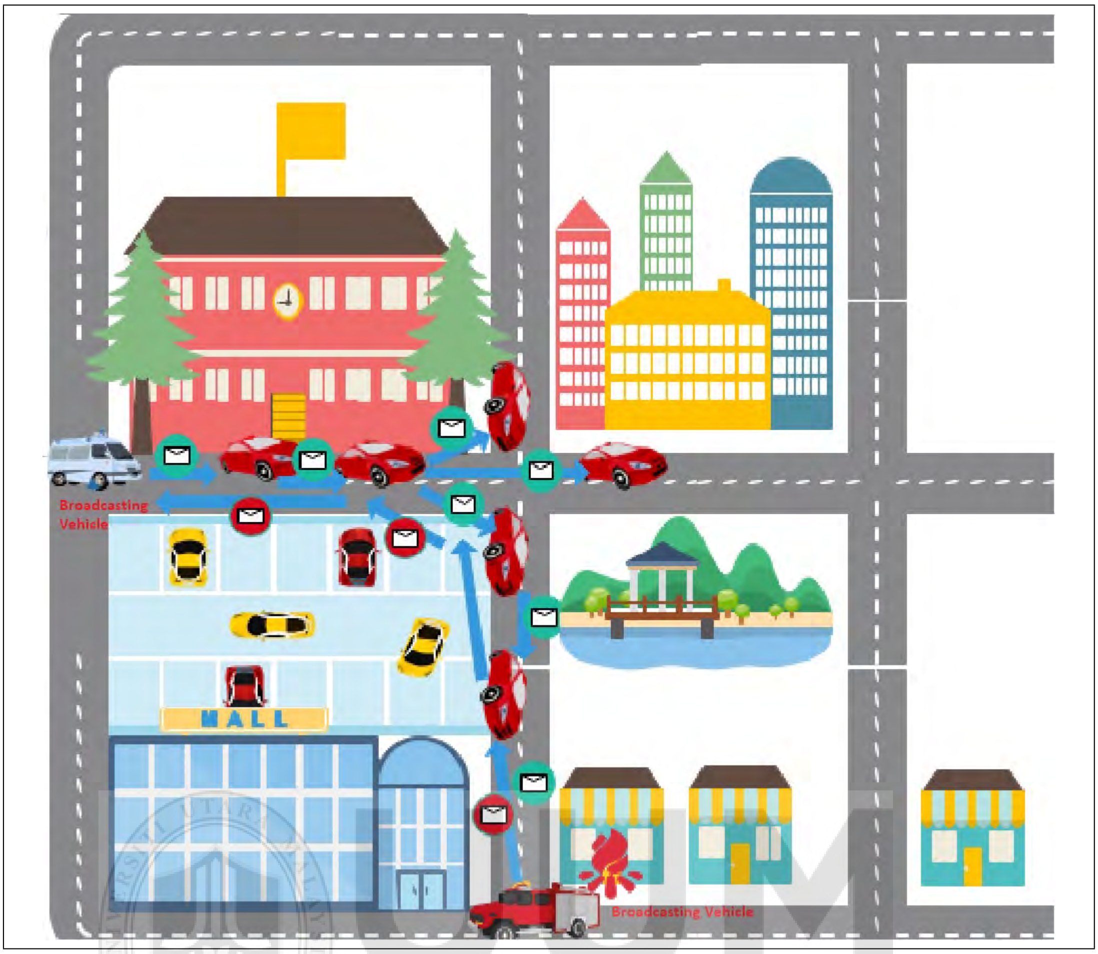

Figure 2.1. Vehicle-to-Vehicle Communication

iii. Sharing Network Information: The D2D communication system is useful in a group of multiple users. In a group, devices share information and parameters among themselves with minimal signalling from the networks such as handover and congested cells.

iv. Local Data Service: Providing local data service in the networks enables sharing all data types such as gaming, advertising and streaming over D2D communication. D2D technologies provide users with huge data rates with minimum dependence on cellular bandwidth. Moreover, the link condition between D2D peers is typically characterised by low latency, low power and higher security.

v. Data Security: In addition to other benefits, the D2D communication system is useful especially for a higher security system. Data is transferred between two peers without uploading it to the internet and stored in a specific device.

2.3 D2D Architecture

One of the major advantages of D2D communication is its ability to extend the cellular spectrum utilisation efficiency by exploiting spatial diversity gain. Such gain can be achieved using appropriate routing and interference management algorithm or by deploying an efficient network coding strategy, which guarantees Fair Resource Allocation and accurate mode selection for a reliable D2D communication. The crux of D2D components are explained in the following sub-sections:

2.3.1 Interference Management

Doppler et al. [48] and Xu et al. [49]provided more important insights into different aspects of D2D communication over-laid cellular networks. The focus of their study on the LTE-A cellular network over-laid D2D communications was on session and interference management. They studied the problems associated with mode selection in D2D communication based on LTE-A cellular networks. Accordingly, they proposed a scheme to estimate the achievable transmission rate in each mode (D2D mode or cellular mode) using channel measurements performed by users. After the rate estimation, each user was allowed to select his/her preferred mode of operation, which will guarantee its required transmission rate at each scheduling epoch. Simulation results demonstrated that the proposed approach, under the D2D communication mode, achieved up to 50% gain on system throughput over conventional cellular communication mode. An entirely different scheduling and mode selection strategies for D2D communication over-laid by OFDMA cellular networks were proposed [50]. The authors worked under the assumption that the system's time is typically divided into time

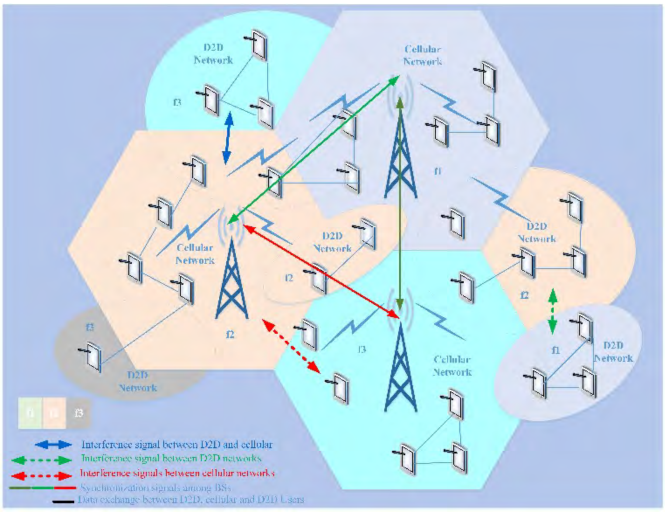

Figure 2.2. Interference Management

slots where every channel is divided into sub-channels. The essence of their approach was in maximising the mean sum-rate of the system throughput in terms of offered QoS by formulating a stochastic optimisation problem and solving this problem using the stochastic sub-gradient algorithm. A sub-channel opportunistic scheduling algorithm was developed from their solution, which obtained the CSI of D2D connection and cellular links as well as the offered QoS for each D2D user as input variables for making a scheduling decision. The numerical results were indicated to be significantly improved when this approach was applied. This gain arose when the average D2D pair was in closer proximity with each other as shown in Figure 2.2.

Zulhasnine et al. [51] suggested a concept of interference reduction for D2D connection to-cellular using BS to assign spectrum resources intelligently. The issue of spectrum assignment for D2D communications was addressed from the perspectives of both the UL and DL phases based on the Mixed Integer Nonlinear Programming (MINLP) scheme. Due to a very short scheduling time of the LTE-A network, which was not sufficient for solving MINLP, a different algorithm known as greedy heuristic strategy was proposed for D2D communication-to-cellular interference reduction using channel gain information. Particularly, the algorithm allocated the appropriate radio resource to D2D transmitter that was lower than the channel gain between the cellular UE and D2D transmitter during the DL phase.

The game theory is a well-known resource allocation strategy applied for D2D communication under-laid cellular networks [52], whereby schemes like sequential second price auction-based allocation and reverse iterative combination auction-based allocation are used to maximise the system sum rate over the DL resource sharing of both cellular modes and D2D communication system. Due to the constraints, complexity and target associated with spectrum assignment optimisation in D2D system-based communication, the most cost efficient assignment scheme could be either optimal/sub-optimal centralised or optimal/sub-optimal distributed. The communication and operation costs, whether in the simple scenario involving only a single D2D pair and a cellular UE or the complex scenario involving multiple pairs D2D users and cellular UEs, have not been widely researched and therefore need to be investigated. Moreover, one cannot be completely certain whether or not the optimum algorithm for the simple scenario can hold for overall cellular networks. Since the BS is capable of computing and scheduling according to the network state information gathered from UEs, the centralised-based algorithms are more likely to achieve a higher network-wide optimal, which requires a considerable amount of network information with a minimum period to compute the optimal solution. Thus, the centralised-based assignment algorithms should be thoroughly evaluated along with the rapidly changing network topology setting according to suggestions by 3GPP standards. In distributed-based schemes, D2D pairs are allowed to select the frequency bands autonomously. Compared to the centralised based, distributed-based strategies have so many advantages including flexibility, low complexity and high adaptability despite the difficulty to achieve overall network optimally.

2.3.2 Routing Algorithms

Routing algorithms for D2D communications have attracted a lot of attention in [53], [54],[55] and [56]. Kaufman et al. [53] supported the view that D2D communications should reuse or share the same up-link channels of the over-laid cellular communications. However, the chances are high that such a channel sharing or reuse of up-link resources by D2D users may generate undue interference to cellular up-link transmissions. To prevent this, the authors suggested that before the D2D users reuse or transmit in the cellular up-link channel, they should first estimate the path-loss between the D2D transmitter and the BS by monitoring the received power of the downlink control signals. Accordingly, the D2D transceivers can maintain a low transmission power below the predefined threshold to avoid interference to cellular users. For instance, the D2D users may be prohibited from transmitting data if its required transmission power is more than the minimal interference threshold.

Dynamic source routing algorithm was proposed by Rasmussen et al. [57] for routing in D2D multi-hop networks. Simulation results showed a significant improvement in D2D links with respect to stronger path-loss component minimisation. This was due to the fact that path-loss improves with the decrease in interference caused by D2D transmission to the BS. In [58], a graph-based resource allocation scheme was proposed by Zhang et al. for D2D under-laid cellular networks in which an optimal resource allocation was mathematically modelled as a nonlinear problem with NP-Hard (non-deterministic polynomial-time hard). In addition, the authors proposed a sub-optimal, graph-based approach to handle interference and increase network capacity. Based on this graph approach, each cellular or D2D link was represented by a vertex where each edge connecting two vertices represented a potential interference path between the two links.

2.3.3 Channel State Information (CSI)

Zakrzewska et al. [14] have studied a single-cell scenario in which a cellular user and D2D users pair reused the same frequency channel based on the assumption that the BS strictly monitors the CSI of all the links; it controls the transmit power and resources utilisation of all the D2D links. The essence of the proposed scheme was in achieving a sum-rate maximisation with limited transmit power. This can be accomplished under three different link sharing modes namely the orthogonal sharing mode, non-orthogonal sharing mode and cellular sharing mode. The simulation results of the single-cell [14] and multi-cell scenarios under the proposed algorithm showed that D2D transmission caused only a minimal interference to the cellular transmission. This scheme can be considered an interference-aware resource allocation, which demonstrated the ability to increase system sum-rate up to 45%. A similar scenario has been studied [56] whereby the BS only has limited knowledge of the average CSI of both D2D connection and cellular links. However, in [14], the BS possessed an explicit knowledge of the instantaneous CSI of all links.

2.3.4 Radio Resource Management (RRM) and Optimization

Efficient management of radio resource of cellular systems provides a platform to optimally allocate bandwidth to the D2D users in a systematic manner to boost system capacity. Depending on the type of air interfaces of the devices, D2D pairs can communicate either in the licensed or unlicensed spectrum resources [59]. Basically, the frequency resources are assigned to D2D users based on the rule of spectrum assignment of a specific network. However, major challenges are to be encountered in spectrum management and assignments in D2D communications. These challenges include the dynamic nature of D2D networks that deals with the distributions and mobility of D2D users, the limited time for computing and scheduling of resources as well as the channel state information of the network that is required for optimal scheduling. In an attempt to address these challenges, optimal and sub-optimal solutions were put forward based on distributed or centralised techniques to optimise spectrum allocation for D2D communication, maximise system capacity, optimise energy efficiency, improve the system total sum rate or that of a particular group of users, minimise interference and outage probability as well as to obtain specific fairness. When exploiting the licensed cellular band for the D2D communication, D2D users can access the licensed cellular resources using the cellular up-link spectrum to achieve this goal. However, the UL cellular frequency bands are always underutilised. The benefits of allocating UL resource for D2D link are obvious from the perspectives of system complexity, interference control and design cost. Therefore, consideration should be made to determine resource allocation as the first priority requirement for D2D users, whereby the allocation scheme aims to fulfil QoS requirements of the D2D communication [60],[61].

2.4 D2D Communication System Framework

The explanation in this part includes three main sections explaining the D2D communications phases. In the first section, the overview of mode selection phases is made, which contains subsections discussing mode selection types, relationship between D2D performance and mode selection as well as reviews of relevant studies in mode selection. Then, the second main section includes the overview of peering discovery phase. Then, the third main section addresses peering selection phase while its subsections discuss the relation between D2D performance and peering selection as well as explain the previous studies on peering selection in the D2D communication system.

2.4.1 Mode Selection Phase

Mode selection is one of the main processes to enable D2D communication system; basically, the selection is either direct connection, which is D2D mode or traditional connection via infrastructure known as cellular or WLAN, which can be named as D2I mode [16], [3], [62]. In the case of D2D communication, devices should be aware of each other's mobility, able to detect/monitor the moving direction of each device and detect whether both of them are in the same cell under the same serving BS or different cells since a huge number of devices are connected to the network [45].

Recently, D2D communication performance has been related to the efficiency of the entire procedures. So, robust mode selection process will reflect positively on the D2D communication system (and at the same time on the performance of the future network) [63]. The importance of effective mode selection to assist the D2D communication system stems from selecting the unsuitable mode. The benefit of mode selection is that it reduces the power usage in a device [64]. Also, the dynamic mode selection can increase the capacity of the cell and improve the performance of the network overall [48].

2.4.1.1 Mode Types

The mode types are D2D mode, cellular/core network mode and reuse mode. The D2D communication mode happens when the connection between pairs takes place to directly exchange data without using network infrastructure resources [40]. The cellular mode happens when the connection exchange the data through the base station (centre of the network/cell). The reuse mode happens when the connection is going to exchange the data in two sides via D2D link with minimum network bandwidth although some researches conducted their studies on mode selection based on main modes, which are direct mode (D2D communication mode) and network mode (such as cellular mode).

When two devices communicate with each other, they encounter several critical challenges during the communication process. Mode selection is the first challenge, which determines whether the connection should be entirely independent of BS involvement or if the connection will be controlled by a single BS or by multiple BSs. Meanwhile, the second challenge determines the D2D resource allocation mode [65]. To date, licensed spectrum resources' access in D2D communication has three resource allocation modes [66]:

1. Underlay Mode: whereby the D2D users' pair and the cellular user coexist in the same spectrum band with massive potential so that the best spectrum reuse efficiency can be achieved. Among the critical challenges in this type of resources' sharing mode are in solving the problem of D2D-to-cellular and cellular-to-D2D interference and controlling it effectively.
2. Overlay Mode: whereby a portion of frequency resources are dedicated only for D2D communication, whereas the remaining portions are assigned for cellular communication. This mode does not create any undue interference problems between D2D communication and cellular networks.
3. Cellular Mode: direct link D2D communications are not enabled in this mode type. Instead, D2D users are allowed to communicate through the base station (core network) as an intermediate relay slightly similar to the traditional cellular system.

The three different resource allocation modes highlighted above are set to serve the users when the D2D communication is available. These modes involve a single cellular UE and a pair of D2D users under practical constraints of sum rate such as minimum and maximum spectral access restriction, maximum and limitation transmit power, average channel state information (CSI) and guaranteed Signal to Interference Noise Ratio (SINR) in the cellular domain [56, 67].

Min et al. [68] proposed a scheme to optimise the D2D communications' reliability while receiving mode selection. They defined three receive modes for D2D under-laid cellular networks. The receive modes are:

i. The desired signal that is initially received and decoded by the D2D communication system before filtering other background signals as noise.

ii. The D2D connection initially conceals other background signals before decoding the desired signal.

iii. The BS re-transmits the interference reference from cellular communication to the D2D receiver.

The last mode was proposed to improve the reliability of D2D communication and the outage probability among all three receive modes. The results were investigated to compute the outage probability. The outage probability for each D2D user can be separately calculated for every receive mode using the closed-from analyses. At every point in time, the best mode (the mode with the lowest outage probability) was dynamically selected by users. The mobile device's energy consumption was noticeably reduced when the outage probability calculations were performed by the BS, which subsequently gave the results to each user. However, this approach tended to increase the computational load at the BS. The proposed receive method, according to the numerical results, improved the outage probability, which also increased the reliability of D2D communications.

2.4.1.2 Overview on Mode Selection Studies

Chien et al. [69] suggested a joint resource allocation and mode selection scheme for a more generic setting involving multiple cellular UEs and D2D pairs. It was aimed at establishing optimal operation mode as well as transmitting power and radio access to achieve maximum sum rate. Wen et al. [70] improved the total rate of all D2D communication and cellular UEs using a joint scheme, which comprised centralised power control, mode selection and resource allocation based on the estimation of resource block efficiency by applying collision avoidance strategy and dividing them into small clusters. However, the results were inefficient in terms of user distribution and link selection since it adopted simple distribution resource management for D2D users.

G Yu et al. [62] considered a joint scheme of power allocation and mode selection for maximising system energy consumption efficiency. This was carried out by exhaustively searching for all available mode combinations of all D2D users and cellular devices where the improvement enhanced the throughput level in the cell and maintained the SINR for cellular and D2D links. They investigated the joint mode selection, channel assignment and power control problem in D2D communication underlaying cellular networks. They also optimised the overall system throughput. The developed low-complexity algorithms were proposed according to different network loads.

Meanwhile, K Akkarajitsakul et al. [9] studied mode selection process by adopting coalition game theory to provide the cooperation between users by assuming that the channel state information for all involved links was known by a coordinator in BS, which reduced the transmission cost and D2D pairs in the same coalition with no interference. However, it reflected on the network overall with high interference ratio as it made the selection based on the power attribute only where the D2D links in the same coalition may interfere with links in different coalitions.

Y Huang et al. [71] proposed a mode selection scheme that selects the mode based on specific condition to choose one of the available modes (cellular mode, D2D reuse mode, D2D direct mode) if the distance is bigger than D2D, thus limiting the scheme select cellular mode. If the distance is within the acceptable range, the resource block is checked whether or not it is enough. If it is enough, the scheme would then select D2D direct mode; if not, the interference level will be checked. If it is still acceptable, the scheme would choose D2D reuse mode; if not, the scheme will select cellular mode. The multi-level condition has been seen to increase the accuracy of mode selection decision with a high rate of using direct mode. As the proposed approach considered only SINR and distance attributes, the main drawback of this research was that energy efficiency factor and imperfect CSI were not considered in this study.

J Li et al. [72] proposed a greedy algorithm and a heuristic scheme to solve the interference problems based on a genetic algorithm that improved the Peak Signal-to-Noise Ratio (PSNR) and increased the capacity of system. So, the overall system throughput improved when it applied on the mixed network. In this approach the decision considered SINR and power attributes. So, The main drawback of this approach was that the proportional throughput among users were badly dropped where most of the bandwidth were allocated to specific users.

Furthermore, J Kim et al. [40] used bursty traffic model to design an adaptive mode selection scheme to improve the overall packet rates for device-to-device (D2D) communication systems by considering the bursty traffic model. The main concern of this scheme was on reducing the delay, delivery ratio and improving the data rate by allowing the users to select any available mode specially when it is connected to the network the delay value will be close to zero as it took the decision based on delay attributes only. This approach did not study the throughput as it main heart of D2D applications; by default, this approach will be facing big issue in throughput factor for application varieties supported by D2D communication.

Y Liu [73] adopted a graph-based approach to enhance the performance of the network in a centralised manner as well as guarantee a fair and balanced utilisation of network resources when users seek to increase the throughput that will increase the power consumption. However, the proposed solution will increase the interference level in the network that may affect the quality of the connection.

TD, Hoang et al. [41] aimed to maximise the sum rate of the network by guaranteeing the required minimum rates for cellular and D2D links where it considered the power attributes to select the suitable mode. The proposed work was aimed at selecting between different modes based on connection conditions that can improve the decision in mode selection by considering more attributes in the selection process.

Also, H ElSawy et al. [74] proposed a mode selection scheme based on the bias factor and power control cut-off threshold by linking this factor with quality to compare between different modes. The results showed that underlay D2D communication was capable of improving the system performance in terms of spatial frequency reuse, link spectrum efficiency and spatial spectrum efficiency. Significant performance gained in the total network performance can be expected from underlay D2D communication with the deployment of interference management methods. The scheme showed better performance compared to the traditional mode selection based on distance and reduced power usage.

In particular, the bias factor controls the interference protection for cellular users and the intensity of enabled D2D communication where it considered the power and distance attributes to take the decision. The results showed that there exists an optimal D2D bias factor that depends on the network objective. The power control cut-off threshold controlled the trade-off between the SINR outage and truncation outage. An appropriate value of the cut-off threshold that balanced between the two outage probabilities can be obtained using the developed framework, which is needed to include interference management techniques to improve the performance of D2D-enabled cellular network.

From the overview of previous studies in Table 2.1, most of the studies considered their tests on single-cell [62], [74], [76], [41], [40], [72] , [62], [9], [71] which may not give the correct analysis for the scenario due the difference in communication conditions between single-cell and multi-cell scenario. To overcome this with more reliable tests and implementations, the scenario must consider multi-cells set up and obtain the results for having a better view of the proposed solution. Also, the way of deciding was depended on limited parameters as input without considering other parameters, which will not give a high margin of reliability. In [75], only distance has been considered as the main factor in making the decision, which was not efficient as the SINR might not be good enough to establish the connection although the pairs are within the acceptable range to establish the connection based on distance. So, more factors need to be considered to have a better result. Since the authors in [74] and [71] considered one more factor besides distance for making the decision in mode selection, better result was obtained where [74] considered power level in the input while [71] considered SINR. Recently, the performance and accuracy of result using two parameters seemed insufficient as can be seen in [71] where it has ignored power efficiency, which means that the proposed model may not be applied or improve the performance of mode se-

Table 2.1
Comparison Between Mode Selection Previous Studies

Ref	Method/Algorithm	Advantages	Disadvantages	Attribute
[75]	distance-dependent algorithm	Easy and fast to process the selection	Not always right decision	Distance
[62]	low-complexity algorithms	Maximize throughput	Not consider the other parameters Single Cell	SINR Power
[9]	coalitional game theory	guarantee lower transmission cost	Limited devices The Base station control the links Single Cell	Power
[71]	mode selection method	Increase the data rate for users	Not consider the power efficiency Single Cell	SINR Distance
[72]	greedy algorithm and a heuristic algorithm	Increase the capacity of system users Improve PSNR (peak)	Single Cell	SINR Power
[40]	bursty traffic model	Increase data rate Decrease packet drop	Single Cell Not consider other factors	delay
[73]	graph-based approach	throughput is increasing	High transmit power	SINR
[41]	Hungarian method for mode selection	Improve data rate	Single Cell	Power
[76]	outer approximation approach (OAA)	Fairness in divide the bandwidth	Single Cell	Power
[74]	flexible mode selection scheme	More stable SINR Lower average transmit power	Single Cell	Power distance

lection. However, most related studies considered only one or two parameters and applied them in single-cell scenarios, thus suggesting that enhancements and development are still needed to obtain better mode selection procedure, which will reflect the D2D communication performance. So, the need to depend on several parameters in taking decision by considering the period of taking decision can improve mode selection and can be applied to different types of application.

2.4.2 Peer Discovery Phase

Peer discovery phase relays the information to devices to set up communication. Peer discovery is mandatory for two potential devices so that a connection can be established for D2D communication on the direct link. However, the interested peering parties have to listen only to detect the discovery signal. The discovery signal can be designed as a sequence and messages, which include at least the target identity. In this case, both the proximity and identity discovery will occur at the device side. In some cases, multiple requests of the discovery signal are required due to the high demands for resources and high multiplexing factor. The discovery signal is a mere sequence, which is also called a beacon. It is in the form of a preamble channel that includes identifying information following the principles as considered below [77]:

i. Peak-to-average-power-ratio of discovery signal should be as low as possible.

ii. Low correlation among discovery signals interference can be strong due to the short distance between D2D pairs.

In dense D2D user cluster, there is a lower correlation requirement for discovery beacons as D2D users increase considerably. However, the possibility of interference with typical cellular traffic is high. The main approaches of peering discovery are shown in the following subsections:

2.4.2.1 Direct Discovery Approach

The main types of peer discovery approach include direct discovery, beacon-based discovery and network-assisted discovery. However, for D2D communications, most of the recent conducted studies have focused on only one particular type, which is the direct discovery approach. Based on this approach, devices can establish direct communication links between peers without assistance from any network. The discovery in this scenario is accomplished by some randomised procedures in one of the communicating peers known as the Beacon Broadcaster (BB), which plays the role of sending the beacon. The BB accomplishes this task by periodically broadcasting identity (beacon) to other devices in a network to announce its presence. Devices that received the beacon will decide whether or not to establish D2D communication with the BB device. This approach can be expanded and requires no involvement of any BSs [10]. However, the operators cannot stop illegal users from announcing forbidden information or listening to legitimate D2D peers using the operators' licensed band. The direct discovery approach has been effectively researched in other systems including WLAN and Bluetooth, but its functionality was not originally enabled in traditional LTE cellular network.

A-priori case of network assisted D2D peer discovery explains a situation in which the network is able to intervene in the discovery by recognising D2D users, coordinating time and frequency allocations for sending/scanning/receiving of beacons. In a-priori case, the network discovers the D2D candidates prior to establishing a communication session between two D2D User Equipment (UE). In a-priori scheme, the device can either broadcast the beacon resources directly across all D2D nodes within its coverage area, or it can fully participate in the discovery process and connection of potential

D2D pairs. In any case, the D2D communication transmitter and receiver first register their presence with the serving BS. This, in turn, authorises the D2D transmitter to generate the beacon. Comparing the D2D communication system with other existing technologies clarified the importance of developing the D2D communication as shown in Table 2.2 [78]:

Table 2.2
A Comparison between D2D Communication and Other Existing Techniques

Technology	D2D Communication	WLAN Direct	ZigBee	Bluetooth 4.0
Standardization	3GPP LTE-Advanced	802.11	802.15.4	802.15.3a
Frequency	Licensed band for LTE-Advanced	2.4 GHz, 5 GHz	868/915 MHz, 2.4 GHz	3.1–10.6 GHz
Maximum distance	10–1000 m	200 m	10–100 m 10	10 m
Maximum data rate	1 Gb/s	250 Mb/s	250 kb/s	480 Mb/s
Device discovery	BS coordination	ID broadcast and embed soft access point	ID broadcast or coordinator assistant	Manual pairing
Application	Public safety, content sharing, local advertising, cellular relay	Content sharing, group gaming, device connection	Home entertainment and control, environmental monitoring	Wireless USB, HD video, precision location and tracking systems, auto radar

2.4.2.2 Network Assisted Discovery

Based on this approach, the device discovery is fully network assisted. The device transmits beacon information to the BS to inform it about its intention to communicate with another device. The BS establishes a transmission link between the devices after acquiring identity and channel state information between the two potential peers. This approach is known as centralised or semi-centralised. The network can mediate in the discovery process by recognising D2D candidates, coordinating time and frequency allocations for sending/scanning/receiving of the beacon signals and by providing identity information.

The beacon-based discovery approach is one of the commonly used schemes in many systems including the WLAN access point broadcasts Service Set Identifier, which enables wireless devices to discover the access point. Basically, the request-based discovery is generally a well-known approach, which is being used by many devices around the world. A UE that can be discovered is allowed to broadcast a request message to allow other devices to discover it. The discovering UE thereafter returns feedback acknowledgement to the UE that is being discovered to complete the entire discovering process. The 3GPP standard has investigated both approaches; they are open for consideration for further LTE-based D2D discovery. When a UE wants to be discovered, it broadcasts discovery signals to other UEs in an open discovery mode where no permission is required. It does so without expecting any acknowledgements from the discovering UE. In such case, beacon-only can be applied. Beacon can be a sequence providing information such as received power level for synchronisation and/or proximity estimation. It can also become a long message carried along the channel like UE ID and/or some information related to the application layer. Otherwise, the discoverable UE should obtain an acknowledgement from discovering UE to ensure accurate transmission. In other words, the received discovery feedback can be used to optimise the power consumption efficiency. This is referred to as Non-Network-assistance detection, which sometimes requires reconfiguration although it can hardly change since detection is mostly applied on the case without any network coverage. In this situation, the ID of the discoverable UE and other necessary application layer information are required in the beacon [12].

2.4.3 Peer Selection Phase

Before two devices can establish a D2D communication, the peers must go through peer discovery and selection process. A pair of devices is considered as D2D candidates if they are able to detect each other. The general steps for D2D communication are the steps that begin from the discovery phase until both devices start their communication.

2.4.3.1 Prior Steps of Peer Selection

The steps of linking between peer discovery and peer selection can be explained as follow [12]:

i. In the discovery phase, each device searches for a potential peer within its radio proximity for D2D communication. It evaluates the identity of the discovered peer to determine its credibility for D2D communication. This phase involves a number of messages, which are exchanged between devices and BS in which information about their respective link qualities are communicated. Then, the communication procedure is established whereby the new D2D pairs can initiate actual communication.

ii. The communication phase involves channel estimation, mode selection, resource allocation, power control, actual information transmission and reception. When the mode selection chooses to communicate using a D2D link, the peer has to select its suitable peer to establish the link using a procedure called peering selection [35], [79], [36].

2.4.3.2 Selection Based on Social-Aware Status

An efficient peering selection is important due to the massive increase of users and connected devices to the network. Social information can be considered in selection decision, which can play a role in protecting privacy if the selection considers the trust relationship between users. Also, the selection process might be enhanced by adopting social factors [27], [39]. To make the adoption of the social-aware factors applicable, the selection must be fast and able to design it in a way that can improve the selection and minimise processing time [80]. So, the enhancement on performance and privacy drive can be used in multi-attribute decision modelling to find the best peer and establish the D2D connection, while the communication and social attributes can be used to rank the peers and select the best one [39].

2.4.3.2.1 Applying trust factor on peering selection procedures

In [81] the social-trust-aided D2D communication was proposed by considering the social trust to improve the D2D communication and the clustering coefficient in graph theory was employed to check the social-link possibility. Using social trust among users with secure transmission may obtain the ideal bound of potential performance. Nevertheless, these approaches were based only on social relationship to apply the D2D communication system. Social relationships cannot guarantee that the D2D connection can meet the stability and performance level required to establish the connection. The continuous mobility of the device reflects negatively on the performance of the D2D connection if the connection conditions are not considered. the social-trust-aided D2D communication was proposed by considering the social trust to improve the D2D communication and the clustering coefficient in graph theory was employed to check the social-link possibility. Using social trust among users with secure transmission may obtain the ideal bound of potential performance. Nevertheless, these approaches were based only on social relationship to apply the D2D communication system. Social relationships cannot guarantee that the D2D connection can meet the stability and performance level required to establish the connection. The continuous mobility of the device reflects negatively on the performance of the D2D connection if the connection conditions are not considered.

Also, in [82], the connection was established based on trusted relationships between peers by evaluating the users based on social actions for peers. They built the evaluation process to check the peers based on these scales, which are close to real value. This way, the connection between peers guaranteed the trusted relationship between peers before establishing the connection, but it regretted the connection conditions that may cause losing the connection or degradation of the services.

In an article published by [83], the authors proposed dynamic social trust management method considering the trust relationship between peers for serving the massive number of connected device to the network, increasing throughput and improving the network capacity. The main drawback of this method is that the connectivity among users is very limited where the social-aware approach is selected for the particle users to be communicated with each other. For that, the connectivity will be limited to a specific group and these clusters are only communicated with each other through a base station. For instance, the link will fail and some users will be totally blacked out, so the PDR will increase dramatically.

2.4.3.3 Overview about Related Studies

In peering selection phase, the consideration is on how to choose the best available peer from the group of available devices/relays. As previously mentioned, the process of establishing D2D connection is done through two phases starting from discovering the devices around the user/device until communication phase where the selection process comes to establish the D2D connection [84]. The selection process needs to determine the user's conditions (such as direction and speed) and type of data required to receive or transfer in choosing the destination correctly [85]. Because of the mobility of users/devices in the network, the auto-update of the information about the users need to be updated every time unit. So, the Round-Trip Time (RTT) needs to exchange between devices to give information about the location as well as user status and the devices may share this information with the BS and save it as long as it is needed [38].

So, it is essential to enhance power efficiency and improve the QoS in D2D communication to develop a dynamic peer selection method with novel social-aware spectrum power trading based on user preferences [36]. However, the solution for dynamic peer selection based on social-aware factors might be based on social and proximity factors [86]. Hence, the involvement of social-aware factors in wireless network was adopted in many types of research. In peering selection, the ability to establish a connection with a peer who ties socially with the sender is much higher [87].

The main concerns in peering selection are the random movement of peers and how to start a trusted connection [10]. So, peering selection considers the social relationship with the destination to establish a trusted connection [35]. The impact of social-aware factors is important in communication system since the behaviour of end-user will affect the performance of the D2D link positively or negatively in terms of privacy protection and exchanging data [27].

2.5 Decision Making Theory in D2D Communication System

In D2D communication networks, mobile devices are allowed to communicate in one of two communication modes at a time like the D2D mode. Here, the two communicating parties exchange data purely on the direct link with no intervention needed on cellular infrastructure such as the BSs or either in cellular mode. Here, the pair of communicating devices communicate using cellular services for peer-to-peer transmission or while transmitting over the direct link between the peers. The theories behind the various ways of transmissions display a spectrum of mathematical tools for modelling and analysing the individual or collective behaviours of D2D users. Therefore, new methods in this area are required to solve the problems related to connection drops, which are yet to be adequately addressed, as well as bandwidth limitation and high latency [52].

Due to the complexity of application and massive number of connected devices, the need to select the best mode and peers in a D2D communication system is essential to guarantee a high-performance level that complies with 5G networks goals. So, the process of selection needs to be built on the strong base by considering all possible parameters to make the right decision with adequate time. From these points, the importance of depending on Multi-Attribute Decision Making (MADM) may assist the future network and applies or develops new algorithms based in these theories to consider all possible factors in the network and always select the best solution. Also, with this massive number of connected devices, the need to consider the social-aware factors cannot be neglected. In the communication system, the social-aware factors can affect the whole network if the connection chooses peers with bad behaviours. So, from these points, it is pertinent for theories and algorithms to determine the social behaviours and define the types of relationship between different parties. Social Choice Theory is one of these theories that explains the types of relationship between them. The theory investigates the collection of preferences and understands them for every person to rank or group them according to different parameters. Social networking for D2D communication finds and exploits the interaction patterns between the users, both people and objects from a social network, to enhance the efficiency of D2D networks based on proximity information.

2.5.1 Multi Attribute Decision Making (MADM)

Due to multi criteria variables needed to be factored for network selection decision making, Multiple Attributes Decision Making (MADM) theory was proposed to offer the best solution in terms of selecting the most suitable network that satisfies mobile users' preferences. Numerous MADM approaches include Simple Additive Weighting (SAW), Hierarchical Adaptive Weighting (HAW), Analytic hierarchy process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Multiplicative Exponent Weighting (MEW), Grey Relational Analysis (GRA) and Weighting Product (WP), which have been used by researchers to solve most network selection-related problems [88]. Some of these algorithms are used to rank the best networks that meet the expected quality of service requirements. Other algorithms such as the analytic network process and the AHP are used to assign weights to various attributes. Meanwhile, ranking algorithms are used along with weighting algorithms to select the best network. However, no algorithm is available to prove the best one among others in terms of ranking [89].

2.5.1.1 Analytic hierarchy process (AHP)

The Analytic Hierarchy Process (AHP) is among the algorithms under the MADM theory. It contains two main parts; first is calculating the weights of the studied attributes while the second evaluates the alternative based on values of attributes and their weights. The uniqueness of this algorithm is on how it calculates weights and finds the most accurate value, which was created by Thomas Saaty [1]; it starts by building the pairwise comparison matrix of the relationship class. The matrix is filled by numerical values based on the importance of each row component to its opposite column component. Numerical contents are maintained in a relative importance distribution following the importance scale [89]. The intensity of importance is given an odd number from 1 to 9 against its level of importance where 2, 4, 6 and 8 are intermediate values. However, that is uncertain. If other values are to be assumed, this should follow the same constraints of AHP pairwise comparison matrix and yield the same results [1].

2.5.1.2 Simple Additive Weighting (SAW)

SAW is also known as weighted linear combination or scoring methods, which is the simplest and most commonly used multi-attribute decision technique. This method is based on the weighted average. An evaluation score is calculated for each alternative by multiplying the weighted value given to the alternative of that attribute with the weights of relative importance directly assigned by the decision-maker followed by summing of products for all criteria. The advantage of this method is that it is a proportional linear transformation of the raw data, which means that the relative order of magnitude of the standardised scores remains equal [90].

The proposed mechanisms adopted SAW approaches owing to its simplicity of applying it in different network topologies and scenarios, which reduces the time of finding the best mode and peer.

In SAW, the overall score of a candidate is decided by the weighted sum of all parameters' values. The basic logic of SAW in this context is to obtain a weighted sum of the normalised form of each parameter of the overall candidate networks. Normalisation is therefore required to have a comparable scale among all parameters. Then, the selection depends on the formulation of the problem that has the highest/lowest score to choose the highest score (in network, the selection of highest score means that it is the best target network). The status of each candidate is gained by evaluating its parameters with the affected weight of each one as shown in the following equation:

$$A_{SAW} = \underset{i}{Max} \sum_{j}^{m} (X_{ij}.W_j) \tag{2.1}$$

Where A: the expected candidate

X: the affected parameter

W: parameter's weight

2.5.1.3 Hierarchical Adaptive Weighting (HAW)

Hierarchical Adaptive Weighting (HAW) is known as a simple hierarchical combination of scoring method [91]. HAW depends on the ranking of alternatives from higher to a lower value. So, the highest value in the top should be selected and conduct the needed action. HAW is excluded from the selection due to the irregularity of its curve behaviour. HAW is a two-step approach similar to SAW. The difference between these two algorithms is normalisation way to rank the alternative. HAW algorithm is easy to apply and understand, but the weights of the attributes are arbitrarily assigned.

$$A_{HAW} = \underset{i}{Max} \sum_{j}^{m} (X_{ij}.W_j^T) \tag{2.2}$$

Where W^T the transpose of vector W

2.5.1.4 Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

In the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), the selected candidate is the closest to the ideal solution. It is based on the concept that the selected candidate network is the closest to the ideal possible solution and the farthest from the worst possible solution. Ideal solution can be obtained by giving the best possible values to each parameter. The ideal solution is obtained using the best values for each metric as shown in the following equation:

$$A_{TOPSIS} = \underset{i}{Max} \sum_{j}^{m} (C_i^j). \tag{2.3}$$

Where C represents the distention candidate

2.5.1.5 The Multiplicative Exponent Weighting (MEW)

The Multiplicative Exponent Weighting (MEW) is another MADM scoring method that uses multiplication for connecting network parameters ratings. Its decision problem can be expressed as a matrix form where each row i corresponds to the candidate while each column j corresponds to the parameter. The equation, which expresses this algorithm, is shown below:

$$A_{MEW} = \underset{i}{Max} \frac{\prod_j^N (X_{ij}^{W_j})}{\prod N_j (X_{ij}^{**})^{W_j}} \tag{2.4}$$

2.5.1.6 Weighting Product (WP)

WP approach is similar to SAW but the scaled property values of each interface are powered by *wj* while the overall score is a product of the values made across the attributes. The selected interface is:

$$A_{WP} = \underset{i}{Max} \prod_{j}^{m} (X_{ij}^{W_j}) \tag{2.5}$$

The ranking of GRA is performed by building Grey relationships with a positive ideal network. A normalisation process to deal with benefit and cost metrics is required and the Grey Relational Coefficient (GRC) of each network is calculated. The GRC is the score used to describe the similarity between each candidate network and ideal network. The selected network is the one with the highest similarity to the ideal network [92],[93].

2.5.1.7 Comparison between MADM Algorithms

To achieve an efficient application of multi-attribute algorithms, comparison has to be made between the main MADM approaches of SAW, HAW, TOPSIS, MEW and GRA to differentiate the type of services. The common advantages of all the methods include the ability to make a decision based on multi-attribute and to integrate with other methods or approaches. On the other hand, the common disadvantages of all the methods are normalisation and inaccurate data, which are hard to control. Table 2.3 illustrates the main advantages and disadvantages of MADM methods.

Table 2.3
Comparison Between Main MADM Approaches

Approach	Advantage	Disadvantage
SAW	Simple and able to implement in different platforms Have good performance for different application Give good result Flexible Able to integrate with the others algorithms and technique	Low value criteria can be affect the result of high value criteria Normalization
HAW	Simple and able to implement in different platforms Flexible	Normalization If the attribute number is high the result may be wrong
AHP	Weighting calculation accurate Simple way to find the weight	The normalization not always accurate and complex
TOPSIS	-the concept is simple and comprehensive -good performance for voice connections	sensitive to criteria value Normalization
MEW	-the least sensitive method -good performance with data connections	penalizes alternatives with poor attribute values more heavily
GRA	-can handle many parameters, giving a precise solution -good performance for data connections	complicated -length of the process increases with the number of levels and pair-wise decisions

Most studies examined their evaluation on applying MADM algorithms in different areas including the wireless network. The main benefit is that these algorithms can take the decision based one multi attributes. From this point, after the comparison as shown in Table 2.3 between main algorithms bases on MADM theory, the D2D communication system may have an improvement in performance when the decision is made based on more than one or two attributes. So, it is clear that the advantages of SAW and HAW approaches are promising as they strengthen and improve the values of applying them from their stability in taking the decision and the limited number of the related attributes. Also, to solve the instability in calculating the weights, the proposed model adopted AHP to calculate the weighting value for different attributes to avoid the weaknesses of both algorithms (SAW & HAW). AHP can help calculating the attribute's weight accurately, which gives the suitable weight for every parameter based on priority and types of application. By integrating these algorithms, the proposed mechanism can avoid the weakness, instability of adopting only one of them and increase the efficiency of the decision taken based on this integration.

2.5.1.8 MADM Algorithms in Wireless Networks

In wireless networks, MADM algorithms have been adopted in various researches to enhance the selection and decision in their proposed model [94]. The MADM algorithms can be applied in different ways; it is possible to integrate it with different theories or approaches such as game theory and fuzzy logic [95], to have hybrid algorithm based on more than one MADM algorithm [96], and can be used with the human interaction including social factors [97].

The MADM approaches are used to enhance the decision in the network by considering more than one attribute select the network, user, channel or application [98]. Many advanced technologies start applying MADM algorithms to evaluate the selection of the network and enhance the QoS where MADM considering the impact of each attribute based on cost, link conditions and user preferences [94], [97].

2.5.2 Social Choice Theory

Due to the massive number of connected devices to the networks, the improvement of performance is needed in any possible way based on communication aspect or any possible choice to enhance privacy and performance of the connection. So, the social factors should be considered to achieve the expected performance of future networks concerning the privacy of the users. One of the theories on social is social choice theory, which is designed to study the collective decision process and procedure based on a group of models and inputs of the individuals to affect the outputs. The core of this theory is in analysing the individual's preferences collection and ranking/grouping the individuals based on their choice. One of the social factors is trust, which is important to protect and enhance the privacy of individuals [99], [100], [101].

The basic model is as follows: Consider a set $N = 1,2,\ldots,n$ of individuals ($n \geq 2$). Let $X = x,y,z,\ldots$ be a set of social alternatives such as relationships, age and gender,

Each individual $i \in N$ has a preference ordering Ri over these alternatives: a complete and transitive binary relation on X to evaluate the preferences of each individual in N.

For example, $N = 1,2,3$ and $X = x,y$

Individual 1 is prefer x to y

Individual 2 is prefer y to x

Individual 3 is prefer x to y

The majority of these groups are individuals that prefer x to y. In this case, the individuals ranked their choice based on more than one social metrics, and the final decision will be based on most selected on from the individuals. Also, if the goal of the social metrics is to group the individuals, it could depend on one or more social metrics to group them based on the most common metric.

For example, $N = 1,2,3,4,5,6,7$ and $X = x$ (Assume x represents the trust relationship between individuals). The relation between individuals could be different from one another depending on the relationship for every individual with the others that could be trusted or not trusted. The relationship for individual 1 with the trusted group $T = 2,4,7$ while untrusted group $UT = 3,5,6$. Individual 1 can be in a trusted group. However, the relationship for individual 2 with the others could be different from individual 1, which can be trusted group $T = 2,3,4,5$ while untrusted group $UT = 6,7$. However, the group could be more than two that is related to the metric type and way of grouping them (the trusted group could be divided into two sub-groups to a family group and close friends group).

In D2D communication, the social-aware metrics such as relationships and age should be considered and test based on different scenarios. The social-aware metrics can be different in different places/situation and related to the type of application, user gender or any other aspects. The social-aware needs to be defined accurately to make sure that it will enhance the performance of the connection and increase/protect the privacy [35].

One of the most important metrics is trust because the relationship between different users should be trusted to exchange the data safely without any leak in data or threat the privacy of users. The trust factor can be used to assist the D2D system in selecting the device, whereas the social-trust level is related to the social relationships between devices [102].

The D2D communication could enhance its performance by adopting this theory and integrate it with MADM theory. It can give more reliability for D2D connection with a high level of trust. The trust factor can minimise the processing time by filtering the untrusted users and evaluate only trusted users. So, the relationship between users could continue to play the main role in selecting and establishing trusted D2D connection.

2.6 Summary

This chapter has provided a detailed and in-depth background of the D2D communication system and networks. D2D communication models have been critically reviewed and analysed with respect to content and significance. These models constituted the basis of theoretical framework of this study. In addition, this chapter has emphasised that peering and mode selection schemes are necessarily required. In mode selection studies, the review showed how the studies selected the mode based on one or two attributes in a particular area where the performance level is still needed to be enhanced to enable D2D communication effectively. While in peer selection studies, most of previous studies made the selection based on connection conditions (based one or two attributes) or based on social-aware relationship stats between pair devices. So, the enhancement on the mode and peer selection schemes can effectively find the best D2D connection on wireless networks. In Chapter 3, the research design or methodology is presented and discussed to achieve the objectives of this study. An evaluation of the proposed scheme is also demonstrated and explained in the following chapter.

CHAPTER THREE
RESEARCH METHODOLOGY

3.1 Introduction

This chapter presents the methodology of this study. DRM was adopted to design the research methodology of this study, which was divided into eight sections. The second section discusses the research design of this study. The third section explains the first stage of the Design Research Methodology (DRM), which is known as Research Clarification (RC). It discusses the aims of the RC stage, the methods that support this stage and main variables. The fourth section explains the second stage called Descriptive Study-I (DS-I). This section presents and discusses the steps of providing an accurate and deep understanding of the current situation. It also designs the reference model and proposes the conceptual model of this study. The fifth section addresses the peering discovery scheme, which was adopted in designing the proposed model of the study. This scheme was named Prescriptive Study-II (PS-II). The sixth section discusses the mode selection scheme. The seventh section presents performance evaluation methods and metrics. Finally, the eighth section summarises the chapter.

3.2 Research Design

This study was aimed at designing a mechanism that serves the D2D communication by addressing challenges in enabling the D2D communication in future networks and discusses the evaluation of the proposed schemes. Research design or methodology is generally defined as the systematic, theoretical analysis of the procedures applied to a field of study. Methodology involves the procedures of describing, explaining and predicting phenomena to solve a particular problem in a research [103].

Methodology is fundamentally required in research to achieve the objectives of a study through logical and scientific procedures. The methodology of this study was drew upon DRM, which helped to organise and link the different stages of this study. This study also attempts to design a peering selection and mode selection schemes to enable D2D communication in future networks. A mode selection scheme always serves to communicate using the best available mode. Finally, the validation and verification of the proposed mechanism were carried out by MATLAB.

3.3 Research Approach

The main goal of this study is to design peering and mode selection schemes for the D2D communication system. These schemes choose the best peer device to establish the D2D connection in the initial stage of discovery scheme. Moreover, the proposed schemes consider the status of connection and stability of devices and, therefore, they select the best available modes of communication namely D2D, cellular network and WLAN networks [104]. Hence, it is crucial to understand the required criteria and difficulties of peering discovery and mode selection to design the proposed scheme. The DRM methodology was used to define the stages of this study.

The framework of the study was based on DRM to obtain the results, achieve the objectives and answer the questions of this study. DRM is a guideline to plan the framework. It helps shaping the ideas and showing the results. Systematic design for the planning and execution of research helps in mapping a variety of inputs in the analysis and amalgamation towards the right communication to attain the research output and suitably employ various research methods [105].

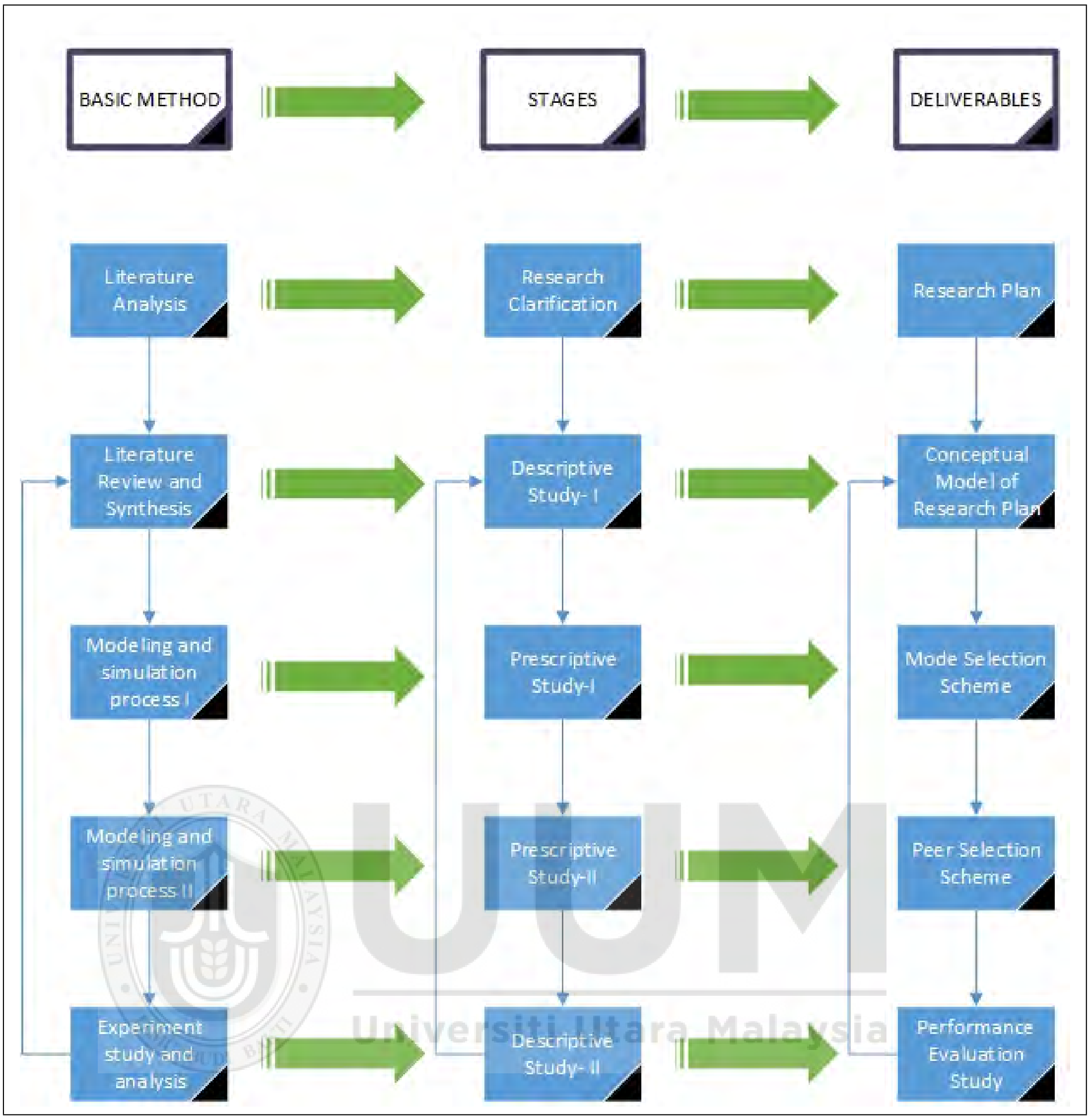

Figure 3.1. Research Organization Based on DRM Methodology

The DRM methodology consists of many stages as shown in Figure 3.1. The first stage is Research Clarification (RC). This stage defines the main points to establish a study, including the motivation behind the study and the scope of the study. The second stage is the Descriptive Study-I (DS-I) stage. It discusses relevant studies' schemes and links them with the proposed scheme of this study. The third stage is Prescriptive Study-I (PS-I), which explains and validates the proposed scheme for mode selection. The fourth stage is the Prescriptive Study-II (PS-II) stage, which explains and validates the proposed scheme for peer selection. The fifth stage is Descriptive Study-II (DS-II), which verifies and evaluates the proposed scheme in many cases and scenarios. The process in Figure 3.1 shows three phases horizontally arranged representing methods, stages and deliverables. The dark arrows illustrate the input and output of each stage. Meanwhile, light arrows illustrate the flow of direction across each stage [106].

3.4 Research Clarification (RC)

Research clarification (RC) involves understanding in the research area in detailed. It focuses on research organisation and relation between different steps. In addition, there are five points that should be clarified to achieve RC as follow:

i. Research Motivation: It clarifies the points where studying D2D communication system is useful and important.

ii. Problem Statement: It explains the main problem in D2D communication.

iii. Research Questions: They are necessary and logical questions as to why research in D2D communication is worth doing and what benefits can this study generate for society and humanity.

iv. Research Objectives: These define the main ideas studied in this study.

v. Research Scope: It determines the study's contribution based on the research problem.

Figure 3.2. Research Clarification Steps

Figure 3.2 shows the flowchart of this study. The chart shows the motivation behind the study, benefits, advantages, as well as the points concerning the development of D2D communication. The flowchart illustrates the problems identified and discussed including the gaps in the current methods of peering discovery and mode selection. The questions and objectives of this study were also identified. The last step is the scope of the study, which limited the points to be investigated in this study.

3.5 Descriptive Study-I (DS-I)

DS-I explains the main steps of a research and provides a critical review within the same research area to come up with the latest challenges and problems in the studied

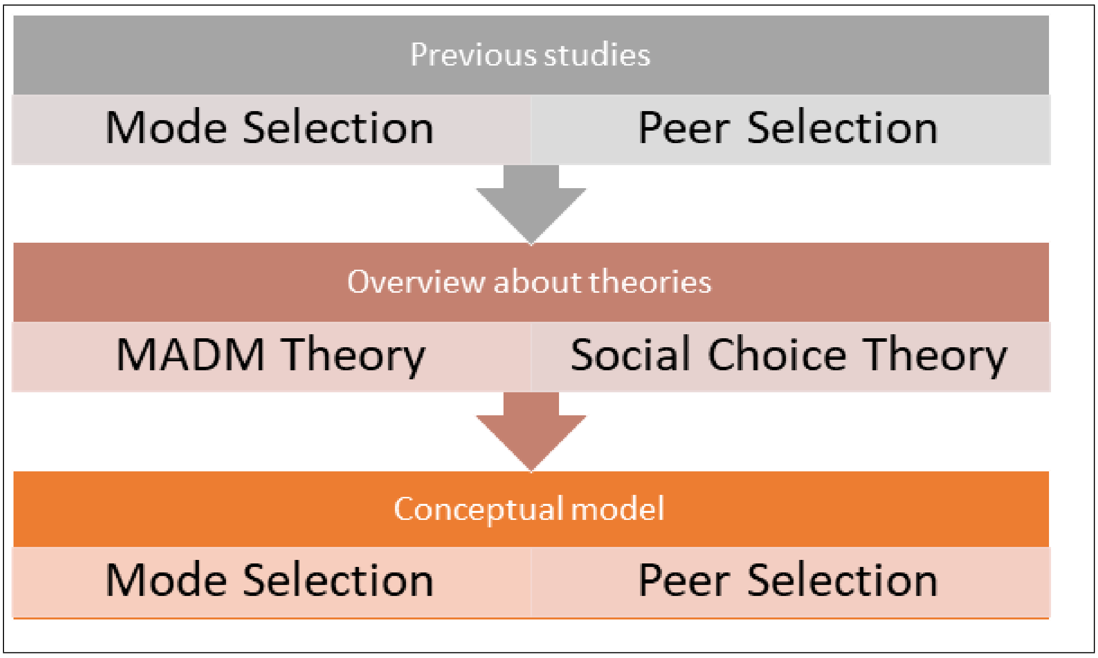

Figure 3.3. Main Steps of DS-I

area. Then, it shows the theories behind the research to find a solution or enhance the current situation. After that, it proposes a conceptual model with its components. The main steps of DS-I are as shown in Figure 3.3:

i. A critical review of previous studies: In this part, the review provides an overview of most related studies to the proposed mode and peering selection schemes besides showing their strangeness and limitations.

ii. An overview of related theories: This part includes the explanation of the adopted theories, which are MADAM and social choice theory, with showing the importance of the integration between these theories.

iii. A conceptual model of the proposed mechanism for D2D connection. It consists of mode selection with initiation and decision-making schemes for choosing the best available mode. Then, it shows the process of selecting the target peer device and decision-making schemes to select the best available peer to establish the connection.

The DS-I conceptual model contains various steps with many repetitions as shown in Figure 3.4. Each step provides an accurate and deep understanding to propose a good conceptual model with an efficient performance.

Figure 3.4 shows the sequence of processes that include switching between different modes through mode selection scheme and selecting peers through peering selection scheme. Both schemes are based on MADM as the decision is based on multi-attribute, which can increase the efficiency of decision and stability of connection. In addition, the peering selection scheme adopts social-aware factors to filter available peers based on social relationship between peers. The process from the beginning of communication includes the mode selection process either D2D mode or D2I mode and selection of the best peer when the D2D mode is selected.

To guarantee a high level of D2D communication performance, the process of both schemes should work smoothly and continuously together.

The initial process starts by defining the type of data required to exchange or transfer, which will affect the weights of different attributes. Then, the next step is to compare the attributes together based on Saaty table comparison and build the comparison matrix [1]. Then, by adopting the AHP algorithm, the weight values are calculated and prepared for the proposed schemes in the next stages. Then, the mode selection schemes start by putting the initial values of weights and basic values of user conditions (Speed, direction and communication time). Then, the scheme evaluates the available modes based on SAW algorithm to select the best available mode (D2D/ D2I mode).

During the communication time, the searching of modes and peers continues once the D2D mode is selected the next process checks the active peers, which are able to communicate using the D2D communication mode. The input of the peering selection scheme is based on the main initial stage (weights values and user conditions). Then, it goes through two main processes; one is the social filtration based on social relationship status while the other is based on HAW algorithm to evaluate the peers after filtration based on MADM theory. After that, the peering selection scheme selects the best peer to establish D2D connection.

Finally, the schemes provide effective mode selection to switch between the modes and continue the connection whatever the communication mode is. Also, the social awareness helps to enhance the selection of peers, which will protect the privacy of users. These steps are conducted during the communication time to guarantee the selection of the best mode of communication among available modes as well as the selection of the best peer to communicate through the D2D communication system.

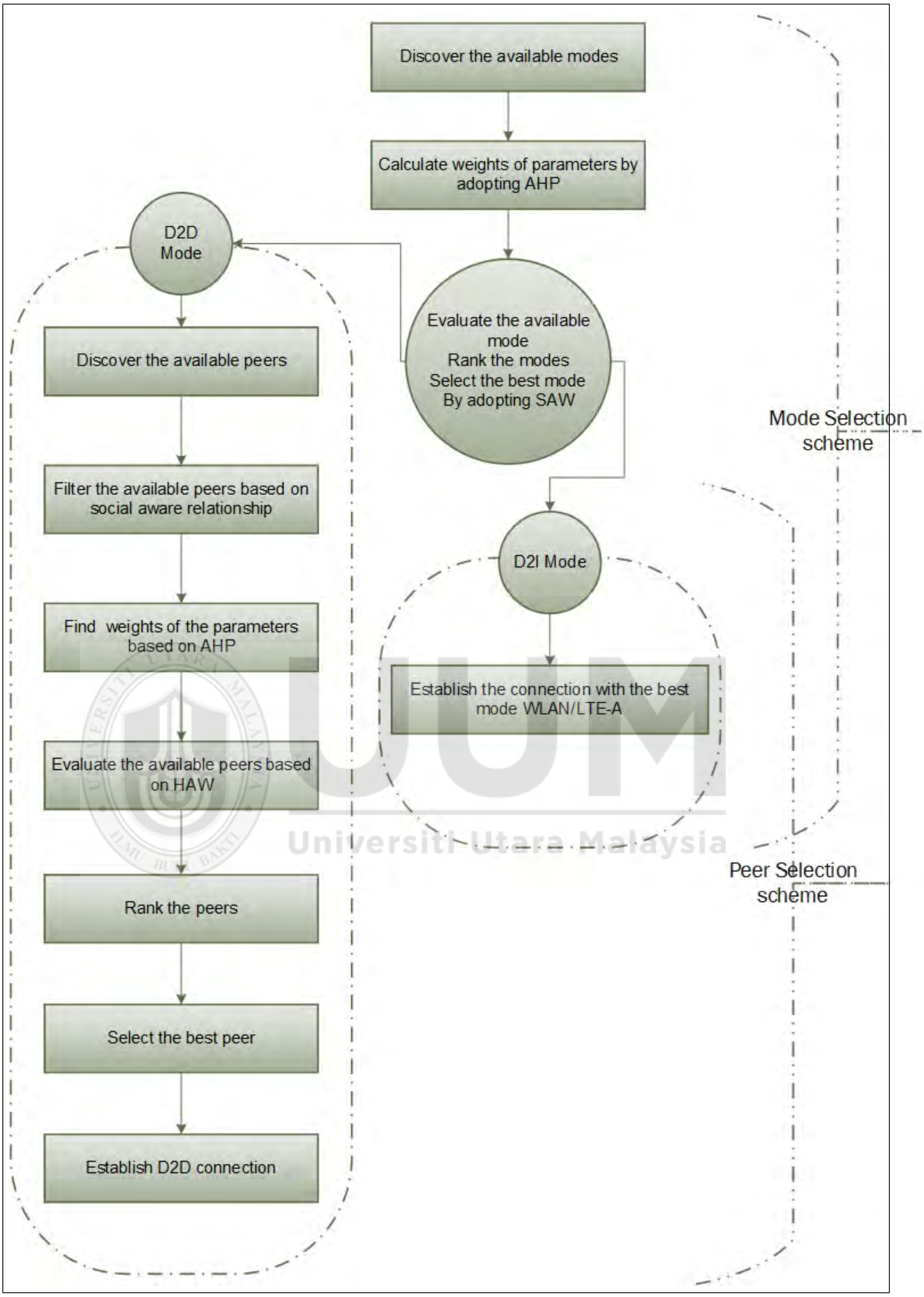

Figure 3.4. Conceptual Model of The Proposed Mechanism

3.6 Prescriptive Study

The prescriptive study is the core of DRM. This section starts by introducing the weighting calculation algorithm for the proposed schemes. The weighting algorithm is based on AHP algorithm to find the suitable weight for each attribute. Then, the prescriptive study includes the steps of designing the mode and peer selection schemes in the following sub-sections. To reach to the accurate weights for different attributes, the algorithm must go through many steps as follow:

- Define the selected attributes for each scheme: In this step, the algorithm aims to choose the main attributes related to the decision of the selection process for both schemes later. In mode selection scheme, the selected attributes are RSS, bandwidth and delay, whereas in peer selection scheme, the selected attributes are RSS, power, bandwidth and delay. The RSS attribute is selected as it is an important parameter to testify the connection strengths and confirm to the device whether or not the signal from the destination is strong enough. Meanwhile, the bandwidth attribute is selected because it plays important role in the stability of connection when the device has enough bandwidth to transfer the data. The delay attribute is also selected as it affects the connection status and the ability to establish the connection or drop it. The power attribute is selected on peer selection scheme only since it may cause loss of connection and to avoid establishing the connection with low power devices or with inefficient power devices. In addition, in the mode selection scheme, the power level is stabled; thus, it is not the main attribute in taking decision in the selection.

- Comparison between different attributes: To establish the comparison, it is very important to identify the data type to know the importance level of each attribute compared to others. Then, it compares the preferences between different attributes depending on the scale from 1 to 9 as proposed by [1]. Based on AHP algorithm, the calculation of weighting for different attributes is done through many steps, which start by defining the type of data. Therefore, the first step in the schedule is to compare between the attributes based on the following values shown in the Table 3.2:

Table 3.1
AHP Scale [1]

Scale Value	Verbal Scale
1	Equal Importance
3	Moderate Importance
5	Strong Importance
7	Very Strong Importance
9	Extreme Importance
2,4,6,8	Intermediate Values

Based on Table 3.2, the proposed schemes are able to find a suitable weight for each metric, the used metrics in the schemes are RSS, bandwidth, delay and power.

- Build the comparison matrix: The dimension of the matrix is different for each scheme. In the mode selection scheme, it is 3 by 3 while in peering selection scheme, it is 4 by 4. The results will be different according to scenarios and schemes. For this reason, the scheme improves the mode selection performance by specifying the importance of the selected parameters, which enhances the accuracy of selection. Therefore, the scheme has to follow many steps to find suitable weights for each parameter.

$$X = \begin{bmatrix} x_{11} & x_{12} & x_{13} & x_{14} \\ x_{21} & x_{22} & x_{23} & x_{24} \\ x_{31} & x_{32} & x_{33} & x_{34} \\ x_{41} & x_{42} & x_{43} & x_{44} \end{bmatrix} \tag{3.1}$$

Where the value of x_{ij} is based on the comparison between pair parameters while the elements in the matrix X are distributed by considering that $x_{ij} = 1/x_{ji}$ and $x_{ii} = 1$.

- The normalisation matrix: Then, the initial matrix is built based on the comparison. Next, creating the normalisation matrix should follow the following equation:

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \tag{3.2}$$

Where n is a number of the selected metrics, x_{ij} is a comparison value between different metrics.

$$R = \begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} \\ r_{21} & r_{22} & r_{23} & r_{24} \\ r_{31} & r_{32} & r_{33} & r_{34} \\ r_{41} & r_{42} & r_{43} & r_{44} \end{bmatrix} \tag{3.3}$$

Then, the weighting calculation is done based on the following equation:

$$W_j = \frac{\sum_{j=1}^{n} r_{ij}}{n} \tag{3.4}$$

Where W_j is the weight of the selected metric (RSS or delay or bandwidth or power), n is the number of selected metrics, r_{ij} is a normalisation value.

- Find the weighting values of each attribute: From the previous equation, the final results express the weighting value of different attributes as follow:

$$W = \begin{bmatrix} W_1 \\ W_2 \\ W_3 \\ W_4 \end{bmatrix}$$

The adopted AHP algorithm is used to calculate the weights of the selected criteria to find the accurate weight of each criterion. The expected outcomes of weighting calculation scheme can be obtained from Algorithm 3.1 as follow:

Algorithm 3.1 Weight Calculation

```
Select data type
Define the selected attribute to be weighted
Insert comparison between pair attributes
Generate the comparison matrix
Normalise the comparison matrix
Calculate the equation (3.4)
The comparison matrix return vector matrix
W={W1, W2, W3, W4}
```


It is worth mentioning that the sum of the weights is 100%. The parameters are compared with each other by checking the importance between parameters as shown in Table 3.1 assuming that the data type is conversational video. Then, this comparison is put in the matrix based on the assumption of exchanging multimedia. Then, the matrix includes the results of the comparison between the attribute with each other based on Table 3.1 to find the value of importance based on the scale from 1 to 9 [1].

For more clarification, this section shows the numerical example to illustrate the main steps of weight calculation based on AHP algorithm. So, it is very important to know the attributes number, which is three in mode selection scheme and four in peer selection scheme. Also, the data type is multimedia, which can affect the comparison results.

First, in mode selection scheme, the selected attributes are delay, RSS and bandwidth. So, to build the comparison matrix in mode selection scheme, comparison has to be made on each attribute with the other attributes. The matrix dimension is 3 by 3; the first row compares the importance of the delay attribute with delay, RSS and bandwidth where it can be as follow {1, 7, 5}. So, the value when compared the attribute with itself is equal to 1. As can be seen in the first element, the importance of delay compared to RSS is much equal to 7 while the importance of delay compared to bandwidth is equal to 5. The second row of the matrix is based on the comparison of importance between RSS attribute with delay, RSS and bandwidth as follows {1/7, 1, 1/5}. So, the value when the importance of RSS is compared with delay is equal to 1/7, the importance when comparing the attribute with itself is equal to 1 as shown in the second element, whereas the importance of RSS compared to bandwidth is equal to 1/5. The third row of the matrix is based on the comparison of importance between bandwidth attribute with delay, RSS and bandwidth, which can be as follows {1/5, 5, 1}. So, the value when the importance of bandwidth is compared to delay is equal to 1/5, the importance of bandwidth compared to RSS is equal to 5 while the importance when comparing the attribute with itself is equal to 1 as can be observed in the third element. The comparison matrix is as follows:

$$Y = \begin{bmatrix} 1/1 & 7/1 & 5/1 \\ 1/7 & 1/1 & 1/5 \\ 1/5 & 5/1 & 1/1 \end{bmatrix} \tag{3.5}$$

Then, the normalisation step is based on the Equation 3.2, the value of the normalisation elements can be shown as follow:

- The first row is:

$x_{11} = \frac{1}{1+\frac{1}{7}+\frac{1}{5}} = \frac{35}{47}$, $x_{12} = \frac{7}{7+1+5} = \frac{7}{13}$, $x_{13} = \frac{5}{5+\frac{1}{5}+1} = \frac{25}{31}$

- The second row is:

$x_{21} = \frac{\frac{1}{7}}{1+\frac{1}{7}+\frac{1}{5}} = \frac{5}{47}$, $x_{22} = \frac{1}{7+1+5} = \frac{1}{13}$, $x_{23} = \frac{\frac{1}{5}}{5+\frac{1}{5}+1} = \frac{1}{31}$

- The third row is:

$x_{31} = \frac{\frac{1}{5}}{1+\frac{1}{7}+\frac{1}{5}} = \frac{7}{47}$, $x_{32} = \frac{5}{7+1+5} = \frac{5}{13}$, $x_{33} = \frac{1}{5+\frac{1}{5}+1} = \frac{5}{31}$

So, the normalisation matrix can be shown as follow:

$$Y = \begin{bmatrix} 35/47 & 7/13 & 25/31 \\ 5/47 & 1/13 & 1/31 \\ 7/47 & 5/13 & 5/31 \end{bmatrix} \tag{3.6}$$

Then, the process calculates the weights based on the Equation 3.4. The steps of this part are as follow:

$W_1 = W_D = (\frac{35}{47} + \frac{7}{13} + \frac{25}{31})/3 = 0.69653$

$W_2 = W_{RSS} = (\frac{5}{47} + \frac{1}{13} + \frac{1}{31})/3 = 0.07185$

$W_3 = W_B = (\frac{7}{47} + \frac{5}{13} + \frac{5}{31})/3 = 0.23161$

So, the weighting vector can be shown as follow:

$$W = \begin{bmatrix} 0.69653 \\ 0.07185 \\ 0.23161 \end{bmatrix} \tag{3.7}$$

At the same way, these steps can be applied on the peer selection scheme on the four different attributes (delay, RSS, bandwidth, power) to find the weights of each attribute.

3.6.1 Prescriptive Study-I (PS-I)

The PS-I step is included in the design of the proposed mode selection scheme. The proposed network mode selection process describes the main steps in PS-I according to the conceptual model and system model validation process. The mode selection process begins with the conceptual framework by calculating the weighting values of different attributes based on AHP algorithm as mentioned previously. Later, a mode selection by adopting SAW algorithm from MADM theory is applied to design the analytical model with the required attributes. Then, the whole system is made based on the conceptual and analytical models. The expected outcomes of PS-I are as follow:

i. The proposed scheme for mode selection is designed and implemented.

ii. The proposed scheme is validated. Since mobility and networks are changing, this step of the conceptual model explains the required procedures in mode selection operation with respect to the network structure of the heterogeneous mode selection, which may need to switch between different modes.

iii. The first objective is achieved.

3.6.1.1 Validation of Mode Selection Scheme

To guarantee high performance of the D2D communication, the effective scheme of mode selection is required to switch between different modes. Based on the communication's requirements for stability and connection efficiency, the optimum target mode of communication has to be selected to guarantee optimum connection for all available modes including D2D communication, cellular, or WLAN network. The mode selection scheme aims to choose the optimum mode, which satisfies the D2D communication's demands; the following steps are to be followed:

Algorithm 3.2 Mode Selection Scheme

```
Call weighting algorithm
Generate the weights of selected attributes
input w_RSS, w_d, w_B, RSS_th, d_th, b_th
Let N be the number of mobile devices
Let n be the index of mobile devices
Let R be the number of the technologies
Let r be the index of technologies
Let R1 be the index of maximum reduce
Let r1 be the index of distance with the target technologies
for each (n ∈ N, r ∈ R) & r1 ⩽ R1the do;
Check the available modes
if RSS_k^r ⩾RSS_th & D_k^r ⩽d_th & B_k^r⩾ b_th
Calculate (3.13)
Rank the modes
Update the list of modes
else, remove it from suggestion list
end if
end for
```


The proposed scheme adopted the AHP algorithm and developed it to do the calculations of the weights for selected parameters in the MAMS-D2D scheme. In the MAMS-D2D scheme, the attributes were distributed in the matrix as shown in Equation 3.6. Based on the adopted AHP algorithm and the previous equation, the proposed algorithm found the suitable weights for selected parameters and after normalisation, the weights were shown in the matrix as follow:

$$W = \begin{bmatrix} W_1 \\ W_2 \\ W_3 \end{bmatrix} \tag{3.8}$$

Where W_1 is equal to the weight of delay , W_2 is equal to the weight of RSS and W_3 is equal to the weight of bandwidth.

Then, the scheme moved to find the values of the selected attributes and arrange them in the matrix based on SAW algorithm after some steps as follow:

Step1: In linear scale transformation, the value of the criterion was divided by the maximum value of the criterion for all alternatives; therefore, the delay, RSS and bandwidth were calculated as follow:

$$r_{ij} = max\,(x_{ij}/x_j) \tag{3.9}$$

$$r_{ij} = min\,(x_j/x_{ij}) \tag{3.10}$$

Equation 3.9 was used when there was benefit attribute which means the value of this attribute will be better as long as it is bigger such as bandwidth attribute, whereas Equation 3.10 was used in the presence of cost attribute which means as long as the value of the attribute smaller it will be better for the connection such as delay attribute. This resulted in the new matrix R.

$$R = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} \tag{3.11}$$

Where every line represents one mode (from one BS or one peer) and column one represents delay after normalisation based on Equation 3.10, column two represent RSS after normalisation based on Equation 3.9 and column three represent bandwidth after normalisation based on Equation 3.9.

Step 2: In this process, a set of weights W_1, W_2 and W_3 , from the weighting vector was calculated based on AHP algorithm as mentioned previously. the weighting vector will multiply with R matrix. This process resulted in a new Matrix V as shown below:

$$V = \begin{bmatrix} v_{11} & v_{12} & v_{13} \\ v_{21} & v_{22} & v_{23} \\ v_{31} & v_{32} & v_{33} \end{bmatrix} = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & w_3 r_{13} \\ w_1 r_{21} & w_2 r_{22} & w_3 r_{23} \\ w_1 r_{31} & w_2 r_{32} & w_3 r_{33} \end{bmatrix} \tag{3.12}$$

Step 3: In this process, the summation of the new values resulted from the previous step was calculated as:

$$A_i^* = \sum_{j=1}^{3} v_{ij} \tag{3.13}$$

Step 4: From the Equation 3.13, The alternatives were ranked according to descending value. The set of alternatives A_i can now be ranked according to the descending order of the alternatives where the highest value indicates the best performance. The final matrix V consisted of three columns (RSS, delay, bandwidth) and multi-row depending on the number of available modes. The value of every cell in the matrix was equal to the value of the normalised alternative * the weight (Normalised value of *delay* $*W_1$). After the multiplication of values, the scheme found the total value of every line by aggregating all the values that line together (Row 1= $v_{11} + v_{12} + v_{13}$). Later, the scheme ranked the modes and selected the best one with the highest value.

3.6.2 Prescriptive Study-II (PS-II)

PS-II includes the design of the proposed scheme for peer selection, which is built on the Hierarchical Adaptive Weighting (HAW) algorithm social choice theory by filtering the user based on relationship. The main steps in PS-II are based on the conceptual model and system model validation. The selection process begins with the conceptual framework to select a suitable device. It starts by defining the relationship and identifying whether or not it is trusted. If it is trusted, the scheme applies the MADM approach, specifically the HAW algorithm, to design the analytical model based on the required attributes. Then, the whole system is made based on the conceptual and analytical models. The expected outcomes of PS-II include the following:

i. The proposed scheme for peering discovery is designed and implemented.

ii. The proposed scheme is validated. In order to start the D2D connection, the MADM is utilised to guarantee that the connection occurs with optimum peer among the available devices through the selection phase.

iii. The second objective is achieved.

3.6.2.1 Validation of Social-Aware Peering Selection Scheme

First of all, the mobile device checks the available mobile devices that meet the requirements for D2D communication. Then, it will be added as an option for the D2D pair device if it does. Otherwise, it will be ignored from the suggestions' list. Next, the list of the available devices are ordered and the best one will be chosen to establish D2D connection. For this scheme, the main criteria to be focused on are RSS, bandwidth, delay and power efficiency as shown below:

Algorithm 3.3 Peer Selection Scheme

```
Call weighting algorithm
Generate the weights of selected attributes
input w_d, w_q, w_RSS, w_B , RSS_th, b_th, d_th, q_th,
Let N be the number of mobile devices
Let n be the index of mobile devices
Let D_max be the maximum distance allowed
Let d_i be the index of distance with current destination
for each n ∈ N & d_i ≤ D_max do;
if RSS_n^k ⩾ RSS_th & D_n^k ⩽ d_th & B_n^k ⩾ b_th & q_n^k ⩾ q_th
Check the Relationship SRI Value
If SRI>1
      SIV=2
      Calculate (3.20)
elseif SRI=0
      SIV=1
      Calculate (3.20)
else, remove it from suggestion list
end if
Rank the trusted users
Update the user list
else, remove it from suggestion list
end if
end for
```


The peering selection scheme consists of three parts. First, the scheme finds the suitable weights of the selected attributes based on AHP algorithm as mentioned previously. Second, by applying the social choice theory, the scheme checks the relationship type between users based on trust level to avoid establishing the connection with untrusted users. Third, by adopting HAW algorithm, the scheme evaluates the trusted available peers based on the connection condition with respecting the attributes values and weighting value of each attribute. These processes in peering selection scheme aim to establish the D2D connection with the best trusted user.

The weighting algorithm can find a suitable weight for each metric and the results will vary for different scenarios. The peering selection scheme adopts the AHP algorithm. It is developed to calculate the weights for selected parameters in peering selection scheme assuming that the required data will be multimedia. The weighting vector is shown in the matrix as follows:

$$W = \begin{bmatrix} W_1 \\ W_2 \\ W_3 \\ W_4 \end{bmatrix} \tag{3.14}$$

Where W_1 is equal to the weight of RSS, W_2 is equal to the weight of delay, W_3 is equal to the weight of bandwidth and W_4 is equal to the weight of power.

Then, the process of the peering selection scheme moves to the next step; the filtration of the available users based on relationship and trust factor that can filter the users based on relationship, give the trusted users higher value and avoid communicating with untrusted users as defined below:

$$If\, SRI = \begin{cases} > 1 & Then\, SIV = 2 \\ = 0 & Then\, SIV = 1 \\ < 0 & Then\, SIV = 0 \end{cases} \tag{3.15}$$

Whereby SRI is a Social Relationship Index and SIV is Social Index Value. The social-aware peering selection scheme checks the relationship between both peers and if it is lower than zero, it is considered as untrusted relationship, which then delete the peers from the list. If it is equal to zero, it will be considered as a normal trusted relationship; nevertheless, if it is higher than 1, it will be considered as high trusted relationship and give the SIV that is equal to two to these peers.

Then, the process of the social-aware peering selection scheme moves to the next step; based on HAW algorithm, the ratio of r_{ij} is the sub-score of the alternative i with regard to the j criterion defined as follows:

$$r_{ij} = v_{ij} / \sum_{i=1}^{n} v_{ij} \tag{3.16}$$

$$r_{ij} = \frac{1}{v_{ij}} / \sum_{i=1}^{n} \frac{1}{v_{ij}} \tag{3.17}$$

Whereby $i = 1, 2, 3, 4, ..., n$ is the number of available users, $j = 1, 2, 3, 4$ is number of selected attributes, v_{ij} is the real value of one attribute (delay or RSS or bandwidth or power).

The first Equation 3.16 is used when there is a benefit criterion such as RSS, bandwidth and power, whereas the second Equation 3.17 is used when there is a cost criterion such as delay. This will result in a new matrix

$$R = \begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} \\ r_{21} & r_{22} & r_{23} & r_{24} \\ r_{31} & r_{32} & r_{33} & r_{34} \\ r_{41} & r_{42} & r_{43} & r_{44} \end{bmatrix} \tag{3.18}$$

Then, the scheme goes through the preparation of ranking the available peers based on the selected criterion and scenario. The calculated weight in the first step will be used to calculate the vector for hierarchical mission effectiveness H as given by:

$$H = R * W^T \tag{3.19}$$

Whereby W^T is the transpose of vector W

$$SAPS_{D2D} = SIV * H \tag{3.20}$$

Finally, the proposed scheme ranks the alternatives according to their descending values. The set of the alternatives can now be ranked according to the descending order, whereby the highest value represents the best performance and most trusted peer.

3.7 Descriptive Study-II (DS-II)

The DS-II involves the evaluation of the designed schemes as well as expected performance outcomes. This is an important stage of this study. It plans to quantify the contribution of this study by accurately meeting the design's specifications. Conventional modelling and experimental measurements were the methods used to evaluate the performance.

3.7.1 Experiment Environment

According to Kurkowski in [107], a simulation is an often-used tool in the analysis of a research output. Many scholarly papers that have been recently published used two main tools namely Network Simulator 3 and MATLAB. In rare cases, however, a number of papers used the NS3's results and put them into MATLAB to carry out the final evaluation in terms of throughput, delay, packet loss ratio, fairness and spectral efficiency.

3.7.1.1 Network Simulator 3 (NS-3)

The NS-3 simulator is a discrete event simulator basically used for research and education purposes. It is an open-source; meaning that it is not bound to any company. It is driven by the research community to develop new models. The suggestions from the NS-3 mailing lists are considerations for improving the network simulator. NS-3 is run on a Linux operating system. However, it is also flexible to set up a virtual box on other operating systems. NS-3 is written in C++ and interfaced by python application programming interface (API).

3.7.1.2 MATLAB

MATLAB version R2017a was used as an experimental tool in this study. MATLAB is a high-level language and interactive environment for technical computing developed by MathWorks. It is the fourth-generation programming language created to allow math and computation, algorithm development, modelling, prototyping, visualisation and data analysis. Moreover, MATLAB has been used in many applications including control design, image processing, signal processing and communication, as well as database connectivity and reporting.

In this study, the proposed schemes were tested using MATLAB due to its ability to build the network based on standards. In addition, it allows to apply many cases and scenarios by understanding the main concept of the network and knowing the required information for developing and setting up the model. Therefore, the comparison approaches [108] and [41] were implemented based on the provided mathematical model in respected researches.

3.7.1.3 Environments and Steps

Basically, MATLAB determines the location of all users and to which cell they are belonged. This involves many steps from defining the networks components until obtaining the results of the performance evaluation. It starts by setting up the networks including cellular network and WLAN as well as enabling D2D communication network. Then, preparation for the mode is done by considering all cases to test, validate and evaluate the proposed schemes and mechanisms.

In the Figure 3.5, The implementation starts by defining the type of data (such as conversational video) needed by the user where it is the key points to determine the minimum requirements (threshold values) of establishing the connection. The calculation of the weights is done based on AHP algorithm. Then, the communication period and speed of movement are inserted for the user. After that, the user starts moving and the mode selection scheme, based on SAW algorithm, identifies the best mode and selects it. The mode selection could be D2D mode or D2I mode. If it is D2I, the user establishes the connection using WLAN or cellular network based on the best available one. If the mode selection scheme chooses D2D mode, the social-aware peering selection, based on HAW algorithm, will evaluate the available peers on the movement area and select the best one based on connection condition and trusted relationship status. However, these steps will be repeated until the end of period. Finally, once the time of connection completes the experiments results are plotted for the studied parameters such as throughput and delay.

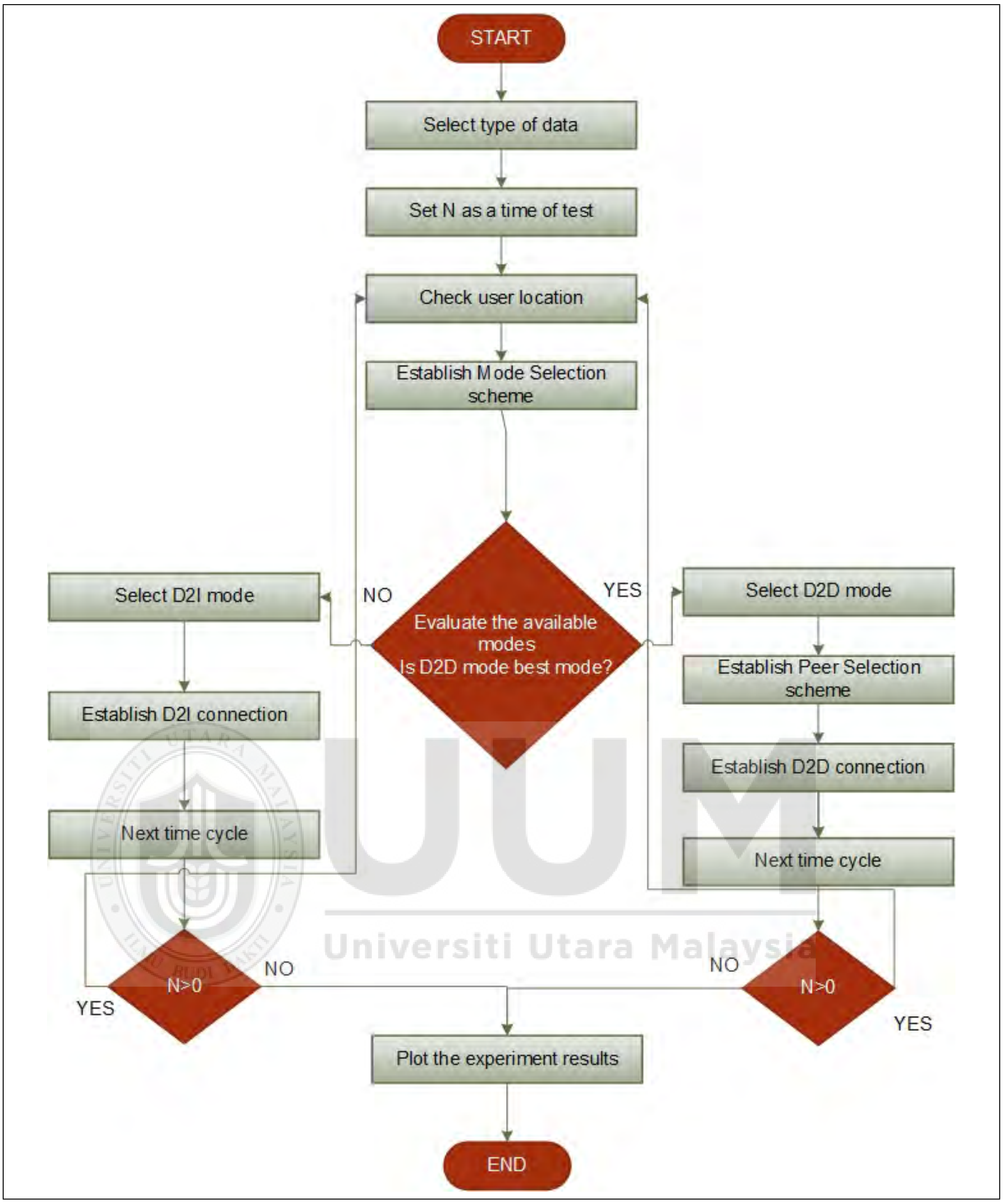

Figure 3.5. Experiment Steps

3.7.2 System Model and Designed Scheme

The network topology used in this experiment, it includes many cellular networks' BS by allowing the users to switch their communication mode between the cellular mode network link and D2D link mode, which is known as a mode selection process. The mode selection procedures allow switching between different modes; the efficiency of selection can be affected in different types of networks' topologies including outdoor or indoor environment [109],[110].

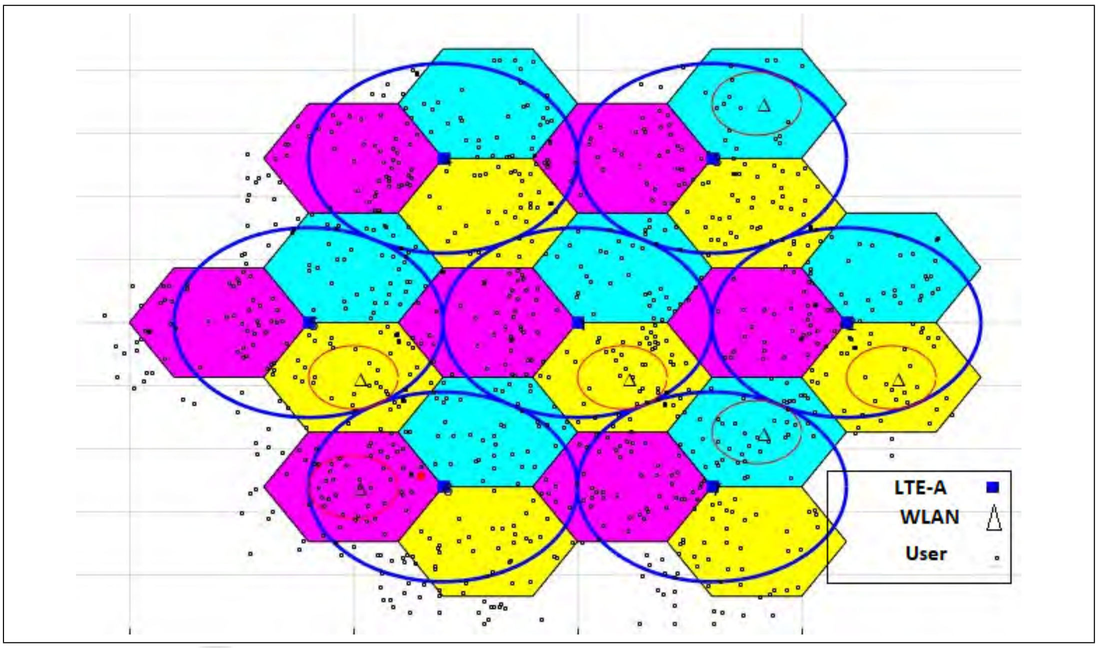

Figure 3.6. Network Topology

The proposed mechanism is examined in this study including D2D mode and D2I mode (LTE-A or WLAN) as shown in Figure 3.6. The mode selection scheme can provide a connection for users in different types of environment; indoors or outdoors. On the other hand, licensed bands such as LTE-A can also provide communication inside the coverage in current and future networks. The cooperation and harmony between different bands are the main key in achieving future networks' goals in a high data rate per user and with low cost. To always obtain the best connection and enable connection for the out-of-cell coverage devices, many issues need to be addressed. These can be divided into two groups. The first group concerns on how to select the device's mode. The second one is on the choice of the best peer device among available devices which is done in the peering selection scheme. However, the network topology in the Figure 3.6 is applied in this study for different stage of verification, validation and evaluation with respecting of the setting of each case.

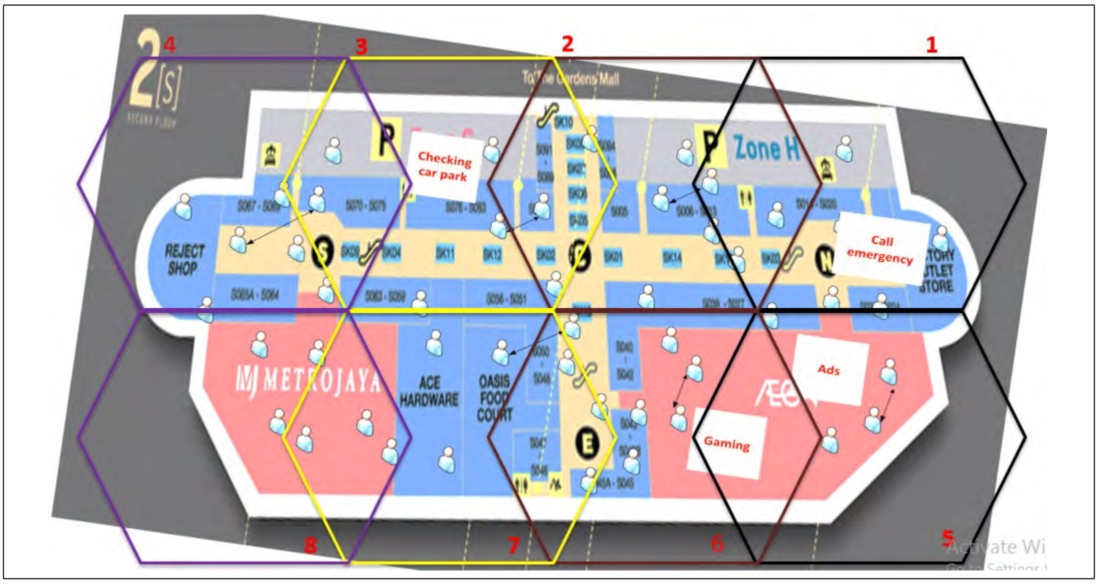

Figure 3.7. Indoor environment architecture

3.7.2.1 Mode Selection

The main goal of this study is to design a mode selection scheme for choosing the best mode among different modes of communication in the network. This scheme was applied to validate its performance in mode selection when the D2D communication system is enabled. This topology can be applied in many scenarios and case studies such as shopping centres, festivals and smart cities. The specification used for the set of traffic models to choose the environment type of the implementation whether it is indoor or outdoor which is based on the value of path loss exponent. The path loss exponent plays a role in selecting the environment type whether indoor or outdoor, which affects the path loss (related to SINR) and power transmission values [111],[112], [113].

The indoor environment can exist in many cases such as shopping centres, offices, internal buildings or any airports halls. The indoor environment includes open cubicle areas and walled areas where the walls are different and the materials of walls are the combination of different type of materials, which may change the channel condition in the area [114]. For validation in this case, indoor environment like shopping mall,

Figure 3.8. Outdoor environment architecture

which normally has multi floors for offices and stores with basement floors underground and many upper ground parking lots, can be used. Figure 3.7 shows example of the floor plan.

The outdoor environment considered for this study were university campus as an outdoor scenario (open areas and outside the buildings' areas), open sports areas, public parks and an outdoor shopping area. The outdoor areas may have different types of materials, which can affect channel conditions such as trees, cars, buildings in the area and weather conditions [110]. For the validation of this case, an open area around a shopping centre can be considered as example since there are different activities that take place in this area such as parking, sports activities, as well as in open restaurants and cafes. Figure 3.8 shows example of the plan of the open area.

Attribute Selection

The system model can serve many scenarios and test the performance based on these scenarios. In this study, the validation tested the mode selection scheme for indoor and outdoor environment. The selected attributes were different from one scenario to another along with the weights of the selected attributes. The diverse types of application require different amounts of data and different channel condition. This study began by setting the network properties and users' status (static or moving). Also, the experimental time was specified and the weighting of attributes for RSS, delay and bandwidth were respected in implementing the mode selection scheme.

The main input attributes considered in mode selection were generally classified into network-related and user-related attribute as described below. The network-related attributes represent those related to the core network's resources, which help in providing services according to users' demands. These include:

i. Received Signal Strength (RSS): The received power of the MS, which differs from mode to mode. The strength of RSS is lower when the user is away from the sender station and it determines the availability of the signal for MS.

ii. Delay (D): This attribute is a measure of average delay variable. It is scaled in milliseconds.

iii. Bandwidth: This attribute is a measure of average bandwidth variable within the access mode.

3.7.2.2 Peering Selection

The distribution of users in the wireless network is denser in some areas compare to other areas on the map. However, random distribution of users in the network is based on Poisson Point Process (PPP), which reflects ultra-dense users' distribution in the network as shown in Figure 3.9 [115]. In practice, the users are distributed randomly in the network. Therefore, the homogeneous PPP is required for users' distribution in the network for different case studies.

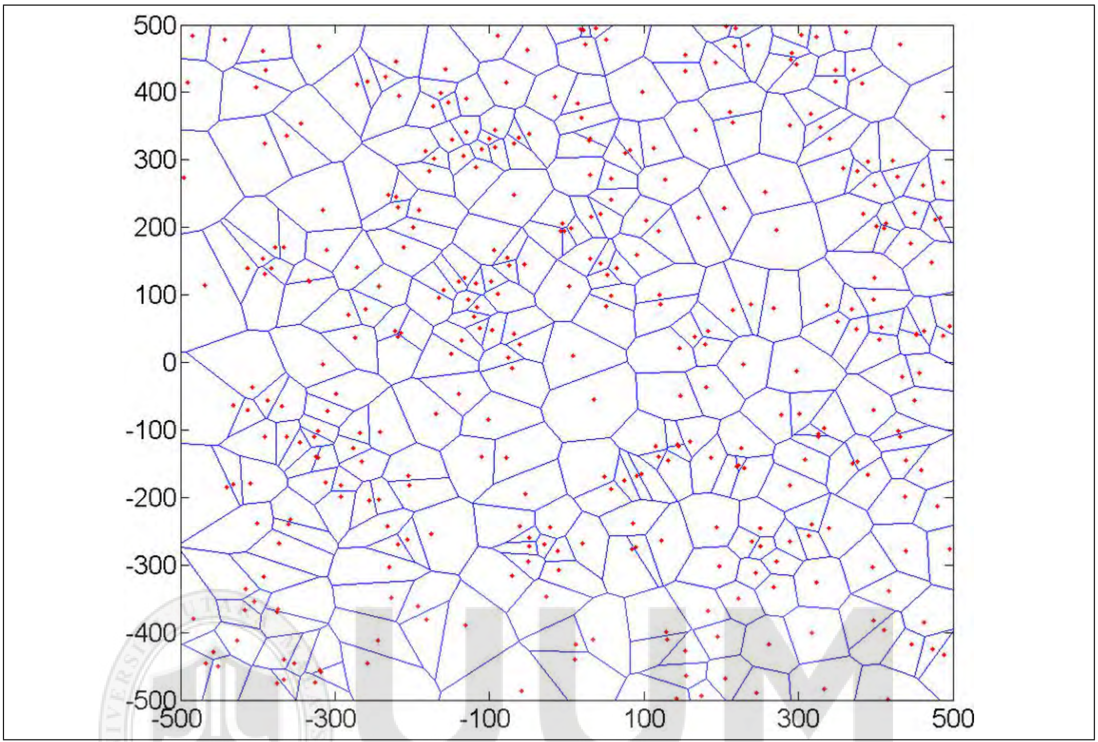

Figure 3.9. User Distribution [4]

Social-Aware Factors

As the number of connected devices increases, more studies have been conducted to add social-aware elements in the networks. So, in the proposed scheme of peering selection, the social-aware factors help to guarantee the decision of D2D link based on trust factor by improving the selection level to establish connection through avoiding communication with the untrusted or less trusted users. In the implementation process, the peering selection scheme assumes that the users in the surrounding area are divided into trust level groups that are equally distributed.

Attributes Selection

The selected criteria vary from one scenario to another, which affect the weights of the selected criteria. Therefore, different types of application require different amounts of data to be exchanged/transfer, which needs different connection conditions. In this study, the network properties and the user's status (moving speed) were set. In addition, the time was specified and the weights of attributes for RSS, delay, bandwidth, and power efficiency were calculated by adopting AHP algorithm. The weighting value of each parameter was based on the data type.

3.7.3 Implementation Metrics

Table 3.2 and Table 3.3 present the main scenario parameters utilised by the proposed model to show the robustness of the proposed schemes compared to other related schemes with similar parameters. The proposed schemes and mechanism were tested in many cases, which included all the application's demands in Table 3.2 and are illustrated in Table 3.3. Based on this specification, four different traffic models have been defined according to real time and non-real time (Table 3.2). Three of them are real time traffic models namely Voice over IP (VoIP) and video. The non-real time traffic model is FTP applications' packet, which introduced this study where the values in the table express the minimum data requirements (threshold values) for different applications.

Table 3.2 explains the application's demands for different application types, which included conversational voice, live streaming, real time application and FTP. It determines the bandwidth requirements, delay budget and the loss rate. The parameters are shown in Table 3.2 as follow:

Table 3.2
Minimum Requirement of Applications

Application	Bandwidth Requirement [kpbs]	Delay Budget [ms]	Loss Rate
Conversational voice	64	100	10^{-2}
Conversational video (live streaming)	242	150	10^{-3}
Real time application	Arrival_rate (x)	50	10^{-3}
ftp	2000 to 5000	≧300	10^{-6}

Table 3.3
Experiment Settings

Parameters	**Values**
Cellular Network & General Setting	
Cell Radius	500 m
Bandwidth	20 MHz
Transmission mode	Closed Loop Spatial Multiplexing (CLSM)
Number of Cell	7
Number of RBs/CC	100
Environment Type	Indoor/Outdoor
eNodeB Height	20 m
UE Height	1.5 m
eNodeB Tx power	46 dBm
UE Tx power	23 dBm
WLAN Network Setting	
Cell Radius	100 m
Number of Access Point	6
Users/Device Setting	
Number of active users	500 to 25000
User speed	Up to 40 km/h

Table 3.2 shows the main parameters used to build a network in this study. First, It shows the main parameters of the network topology for the cellular network which is served by Long-Term Evolution-Advanced (LTE-A) Radio Access Technology (RAT). In this part, it shows the main parameters such as cell radius of every cell, the bandwidth, cell numbers, transmitters power and the height of transmitter. Then, It shows

the Wireless Local Area Network (WLAN) parameters including the cell radius and number of access points. Finally, it shows the number of active devices/ peers in the network and the range of the user speed. The network topology can be shown in the Figure 3.6 which can be applied in many scenarios and locations such as shopping centres, festivals and the smart cities.

3.7.3.1 Evaluation Parameters

System throughput is defined as an aggregate of the transmitted packets with respect to time from all D2I connections or D2D connections. The aggregate system throughput is defined as:

$$thr = \frac{1}{T}\sum_{i=1}^{N}\sum_{t=1}^{T} N_{RB_i} \times RB_{size}(t) \tag{3.21}$$

Whereby T is the total time for implementation, RB is the resource block assigned for a practical user , whereas i is the size of resource block at time t.

The Delay factor is calculated based on the proposed equation:

$$Delay = Transmission_t + Propagation_t + Scheduling_t + Buffer_t \tag{3.22}$$

Where;

$Transmition_t = Packetlength/Datarate$

$Propagation = D * 10^3/C$

D is the distance between the user and the destination whether it is BS or device, C is the speed of the scheduling time that depends on the type of mode chosen and the buffering value is linked to the network status and links' conditions.

$$SINR = 10 * log_{10}(P_r/(10^{-6})) \tag{3.23}$$

Where;

$P_r = 10^{-2} * 10^{(P_T/10)*D^{(-n)}}$

The *SINR* is the signal-to-interference-plus-noise ratio (SINR), *Pr* is the power received and *PT* is the transmitted power required to analyse the probability of a successful transmission.

The proposed scheme served the network in different scenarios for validation and evaluation purposes. The validation for mode selection of the scenario included indoor and outdoor environment, while the validation for peering selection scheme included the high and low density of users in the network. The evaluation included a general case, different number of users in the network and the time when the users are moving in the network at a different speed. In the implementation stage, the calculation was made all the time to ensure that the best peer and mode were selected for establishing the connection. Choosing the weight of the selected metrics plays a key role in identifying the case study and scenario correctly, which will reflect on the improvement of the performance value.

3.7.4 Confidence Level of Experiment Results

Performance evaluation and validation aims to achieve the expected performance level for the criteria previously explained. The ultra-dense users' distribution and random movement were set in the experiment to create different scenarios such as crowded area (different density of users in the network) and different environment (indoor/outdoor). So, the randomness of the scenarios will cause random values for different metrics. For instance, the exact values cannot be achieved, but it is possible to get estimated result from a number of different runs of experimental results. To conclude, the result is expressed on estimation and give a level of confidence on the outcome of the proposed schemes. For this reason, every case study and scenario were tested for 10-15 times with different and random values. The results of this setup gave 95% confidence as average.

3.8 Verification of enabling D2D communication system

In the this case, the system performance was verified by enabling the D2D communication system and comparing the performance in one case where the D2D communication was enabled and in another case where the D2D communication was disabled. The verification of the D2D model involved a comparison of the system performance when the D2D communication system was enabled with the performance when the D2D communication system was disabled.

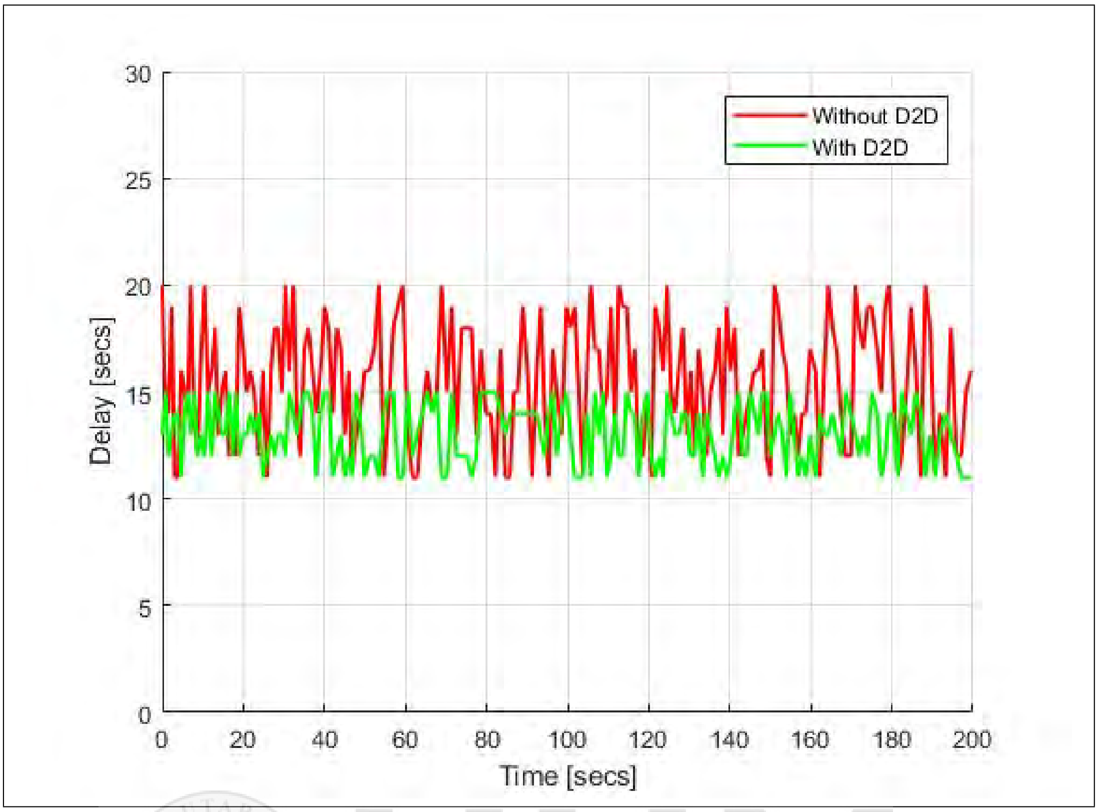

Figure 3.10. Delay Verification during the Time of Study

The obtained results revealed a high level of delay in the network performance without enabling the D2D approach during the time of the study as shown in Figure 3.10. The connection showed that the system without enabling D2D communication always demonstrated a higher delay than that of enabling D2D communication system. This happened because all packets were transmitted through one network, which provided the highest RSS in the packet ques. The network was highly congested (the buffer was full with the packet). Therefore, the buffering delay and scheduling delay were much higher than those from enabling D2D communication system. Accordingly, the D2D communication system was found to improve the delay factor level.

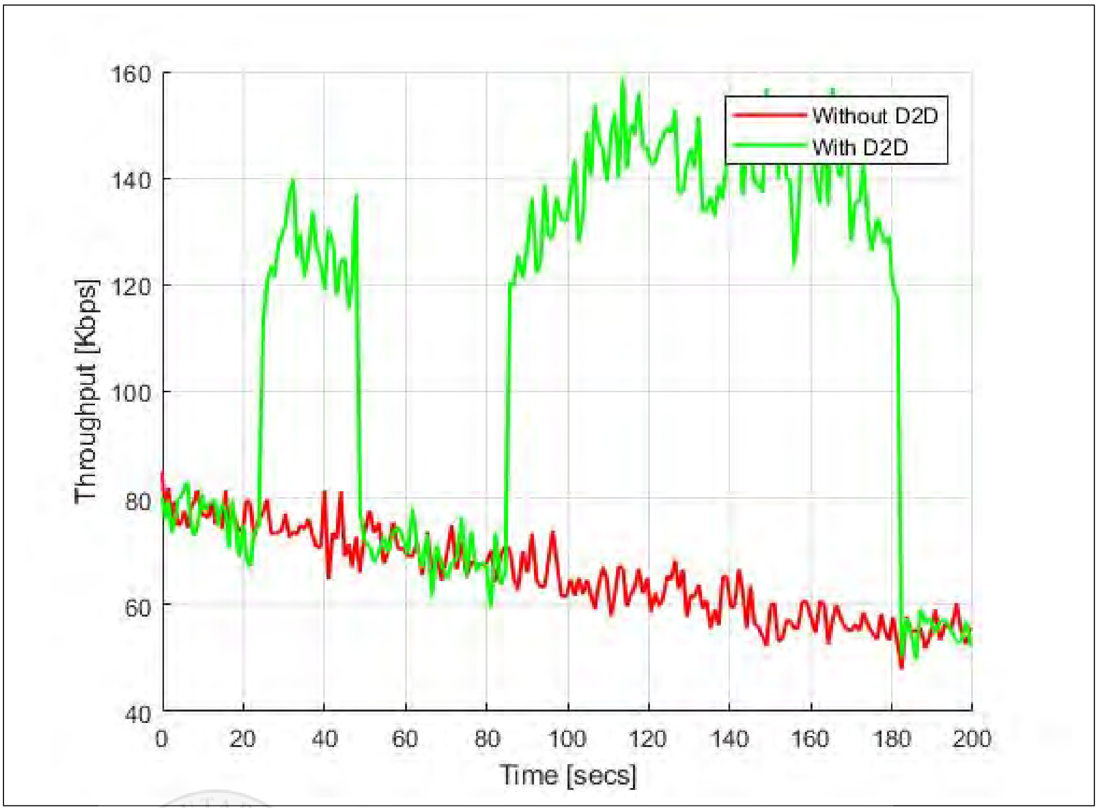

Figure 3.11. Throughput Verification during the Time of Study

The obtained results can be classified into five phases based on Figure 3.11. These phases are as follow:

Phase 1: From 0 to 22 seconds, both approaches showed similar performance in terms of throughput as the cases had selected the LTE-A network while the mobile station started moving with unavailable devices in the area.

Phase 2: From 22 to 50 seconds, the mobile station moved in a particular area where the number of devices had increased. During this phase, the D2D connection showed better performance than the other case by 30% as the D2D communication system was enabled.

Phase 3: Both approaches exhibited similar performance in terms of throughput from

50 to 82 seconds as the cases had selected the LTE-A network while the mobile station started moving with no available devices in the area.

Phase 4: From 82 to 184 seconds, the mobile station moved in a particular area where the number of devices had increased. In this phase, D2D communication exhibited better performance than the other case by 50% as the D2D communication system was enabled.

Phase 5: Both approaches demonstrated similar performance in terms of throughput from 184 to 200 seconds as the cases had selected the LTE-A network while the mobile station started moving with unavailable devices in the area and the mobile station is become further from the BS.

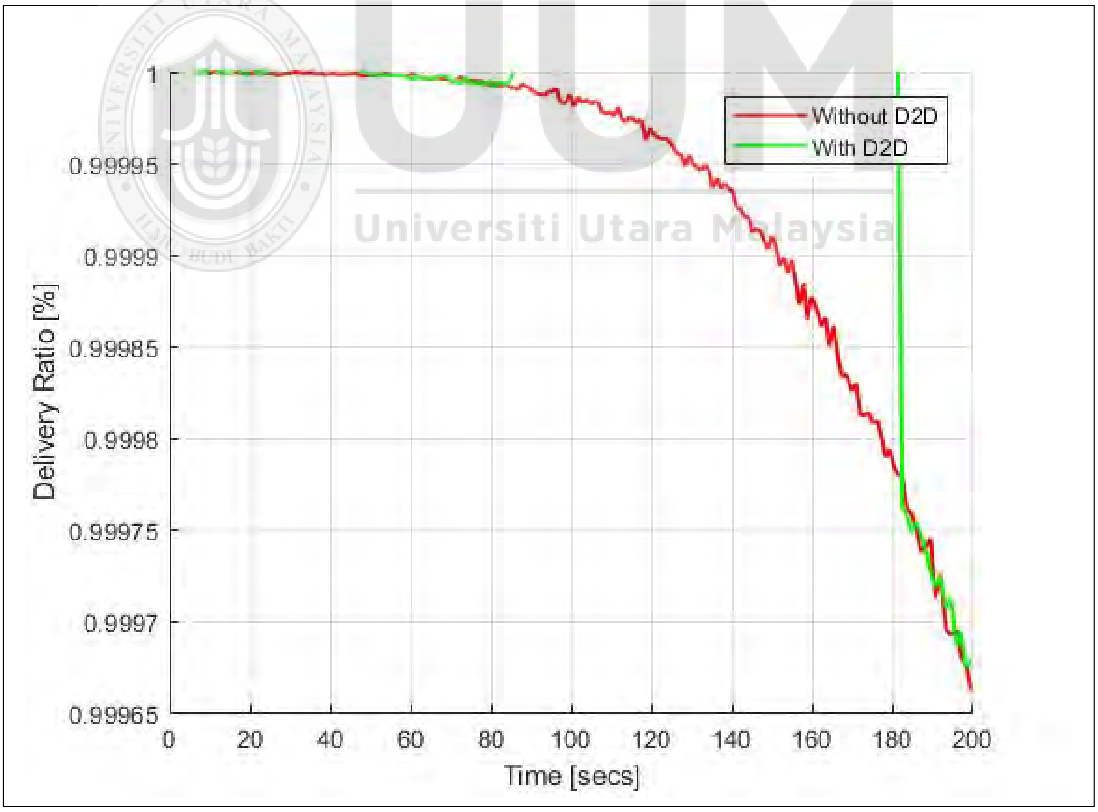

Figure 3.12. Delivery Ratio Verification during the Time of Study

Based on Figure 3.12, the delivery ratio reached 100% until 182 seconds compared to the system without enabling D2D communication system. The delivery ratio also started decreasing in 90 seconds while when the mobile station chose to connect to LTE-A network with far distance from BS which make the delivery ratio level reach to 99.6%. The system performance showed better values when the D2D connection was enabled. However, the periods when the connection was changed did not decrease below the value of 99.6%.

3.9 Summary

This chapter has presented and discussed in detailed the research design so that the research objectives can be achieved and the research questions can be answered. This study developed the D2D communication system by proposing an advanced mechanism. The proposed schemes were based on the MADM theory to improve the discovery process and select the best mode of connection by considering the mobility status of the user. Five main activities have been highlighted in this chapter in accordance with DRM. The first activity was the RC stage, which discussed the methods to support the initial stage of this study. RC aims to identify and refine the problem of this study, study questions and objectives, which are academically and practically worthwhile and realistic. DS-I was the second activity, which discussed the necessary steps for an accurate and deep understanding of the present situation. It designed the reference model and proposed the conceptual model of this study. The third and fourth activities have highlighted the methods adopted in designing the proposed peering and mode selection schemes known as PS-I and PS-II, respectively. The last activity was the DS-II, which evaluated the designed schemes of enabling D2D communication.

CHAPTER FOUR
MODE SELECTION SCHEME

4.1 Introduction

This chapter presents the designing of the proposed mode selection scheme for the D2D communication system by enabling wise switching between different communication modes in heterogeneous networks. It demonstrates the system model, design and description of the new scheme for mode selection, which is called Multi-Attribute Mode-Selection (MAMS-D2D) scheme, to improve the D2D communication system's performance in heterogeneous networks.

During mode selection process, the two communicating parties decide their mode of communication. The mode selection is important since the quality of direct links may sometimes be in a worse state than the cellular links' state that make the D2D communication system efficient and acceptable to operate in the network. The proposed scheme focused on mode selection between different types of modes among networks concerning the connection condition and selection of the best available mode. Also, the validation of MAMS-D2D scheme was discussed.

To validate the MAMS-D2D scheme, the comparison of performance is needed. The validation of MAMS-D2D scheme was compared with the RSS approach, which is a basic method for selecting the destination in wireless communication system [116]. It is used to compare different schemes since it is easy to set it up and most of the current networks use it to establish the connection based on RSS strength [117]. The RSS approach depends on RSS signal; once the device receives a signal, that means the opposite part (mode or peer) is able to establish the connection. This can help in selecting the way of communication based on only RSS value. It is built on the RSS signal received from the nearby users or BS, which will decide whether or not it is a suitable communication based on this signal [117], [118]. The MAMS-D2D scheme helps in managing the connection through different modes, which have different performance values. Such enhancements are important to increase the connection's quality level for users and network providers. The MAMS-D2D scheme improves the performance values for different scenario and topology. The setup of topology including LTE-A, WLAN and D2D communication is enabled. The extreme user's requirements and increment of the user's number make the current infrastructure to be limited. This motivates this current study to develop new methods of connection and give flexibility to users and networks to use their preferred choices of connection mode. User distribution in the network will not be balanced and the density of users will be different from one area to another. Accordingly, this follows the PPP distribution scheme.

4.2 Description and Design of MAMS-D2D Scheme

The proposed MAMS-D2D scheme showed the results of implementing the SAW scheme. The implementation metrics can be applied in many case studies in the network where operators' and users' demands need to be met. This situation can show the connection status while the user is moving among the cells randomly. Figure 4.1 illustrates how the multi-attribute parameters are considered by the scheme and become an input for evaluating the available modes.

The mode selection scheme is put through many steps to assure the best mode selection and provide a stable mode of connection during communication time. First, it defines the input metrics, which are the weighting parameters including (w_B,w_{RSS} and w_D) and the threshold values of the selected attributes (RSS_{th}, d_{th}, and b_{th}) based on standard values. The weighting values are calculated as previously shown based on AHP algorithm. Next, the evaluation of the available mode starts by checking if

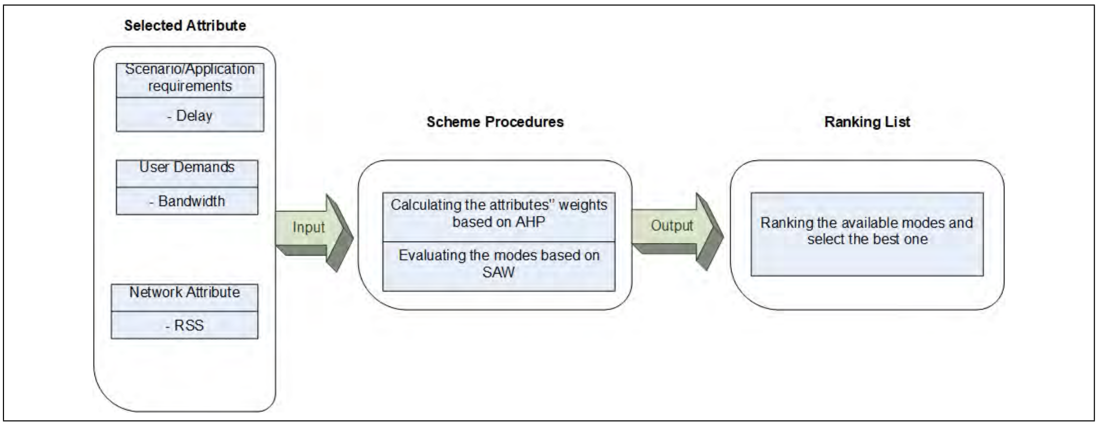

Figure 4.1. Mode Selection Scheme Description

every attribute meets the requirement through comparison with threshold value as previously in the mode selection algorithm. Then, it builds a matrix with the available modes with many rows equal to the number of available modes and the column equal to attribute numbers. Based on SAW algorithm, the scheme selects the best mode. In linear scale transformation, the value of the criterion is divided by its maximum value in all alternatives, therefore;

$$SRSS_{ij} = RSS_{ij}/RSS_j^* \tag{4.1}$$

$$SB_{ij} = B_{ij}/B_j^* \tag{4.2}$$

$$SD_{ij} = min\,(D_j/D_{ij}) \tag{4.3}$$

When there is a benefit attribute, the equation like *RSS* and *Bandwidth* is used, but when there is a cost or its minimum, *Delay* is used. From these equations, the new matrix R can be obtained as follows:

$$R = \begin{bmatrix} SRSS_{11} & SB_{12} & SD_{1n} \\ SRSS_{21} & SB_{22} & SD_{2n} \\ SRSS_{31} & SB_{32} & SD_{33} \end{bmatrix} \quad (4.4)$$

Then, this process results in a new Matrix V where $V$is as shown below:

$$V = \begin{bmatrix} v_{11} & v_{12} & v_{13} \\ v_{21} & v_{22} & v_{23} \\ v_{31} & v_{32} & v_{33} \end{bmatrix} = \begin{bmatrix} w_{RSS}SRSS_{11} & w_B SB_{12} & w_D SD_{13} \\ w_{RSS}SRSS_{21} & w_B SB_{22} & w_D SD_{23} \\ w_{RSS}SRSS_{31} & w_B SB_{32} & w_D SD_{33} \end{bmatrix} \quad (4.5)$$

Then, the schem evaluate each available mode based on the connection value with respect to the weighting values of the different attributes as shown in the following equation:

$$MoSe_{D2D_k^r} = w_B \left(\frac{B_k^r}{max B} \right) + w_D \left(\frac{1/D_k^r}{min\,(1/D)} \right) + w_{RSS} \left(\frac{RSS_k^r}{max RSS} \right) \quad (4.6)$$

Finally, the scheme selects the mode that can provide maximum value of Equation (4.6). The Equation 4.6 checks every available mode to rank them and selects the best one based on return value from the Equation 4.6.

The MAMS-D2D scheme procedure is shown in Figure 4.2. There are several steps that have to be taken in MAMS-D2D scheme to make sure that it chooses the best available mode. The mode selection scheme procedure starts the evaluation process to identify the available technology. Then, the scheme goes through defining the speed, direction of movement and the time of movement are defined in the input of the experiment. Then, the scheme defines the importance of different attributes until the end of connection time. The main attributes are considered to give weighted importance of each attribute. It is very important to know the scenario condition as the importance of the attribute value is different in different scenario. So, the adopted AHP algorithm calculates the weights of the selected attributes which are delay, RSS and bandwidth.

Next, the scheme evaluates the available modes based on the connection condition and the scheme ranks the available modes. Finally, the scheme sends a request to start communication through the best mode. In the case of connecting through LTE-A/WLAN, the direct connection is established through LTE-A/WLAN. In other cases, it chooses to communicate using D2D link, which starts by communicating with the best peer in the surrounding area. The processes in this part are repeated during the time of communication. When the processes completed, the communication stops.

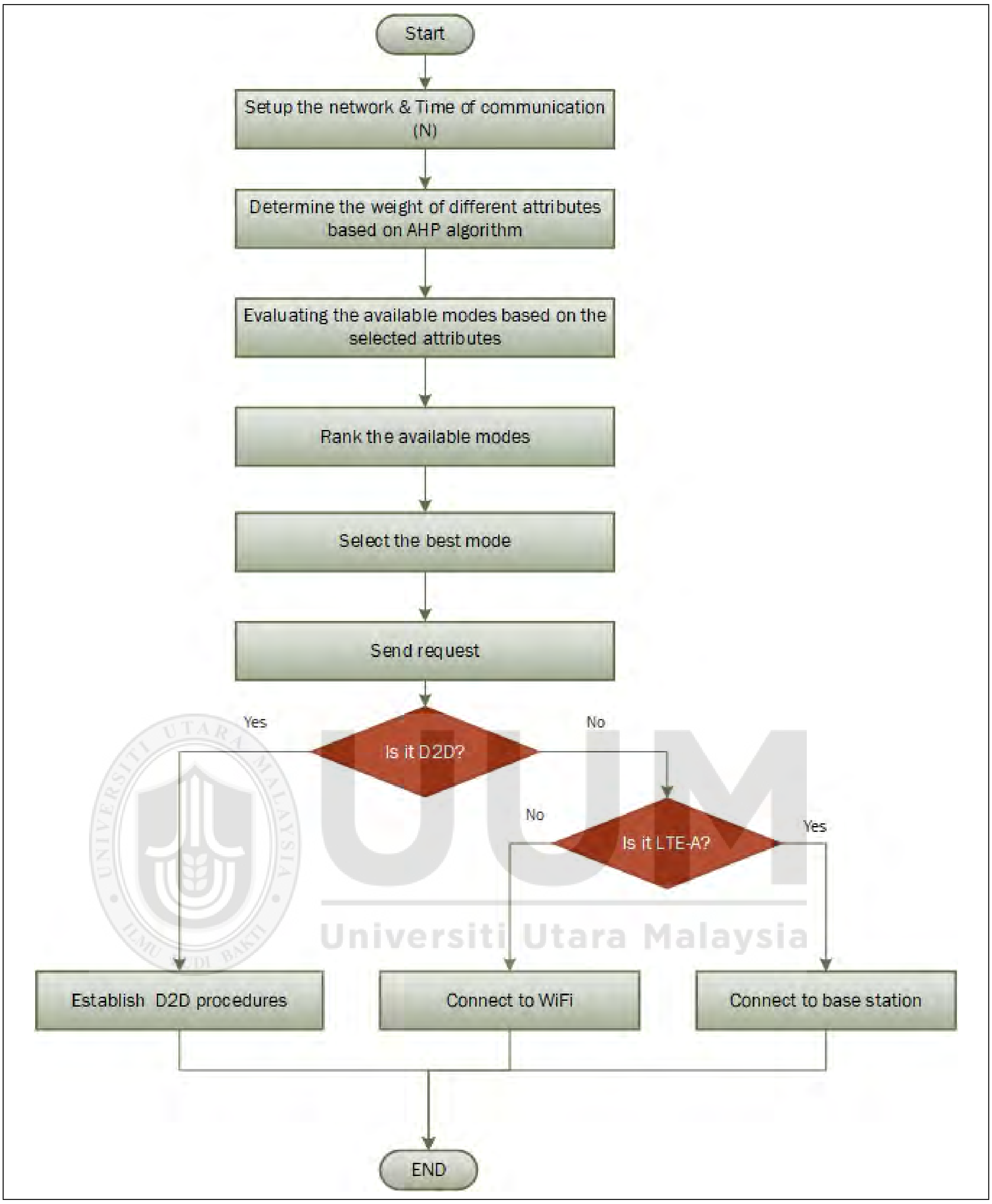

Figure 4.2. Mode Selection Scheme Steps

The calculations in this study were carried out by mathematical process to determine the best mode of connection between the mobile user and the destination, whether it is BS or D2D link. First, the mathematical process calculates the value of the main parameters of the network and users. These were considered in the mathematical calculation after setting up the network topology. The main parameters were delay, SINR and throughput. Second, the scheme evaluates all values of the connection for each mode in the surrounding area to establish the connection after choosing the best mode of connection based on the user's preferences.

4.3 Theoretical Analysis

The MAMS-D2D scheme aims to increase the efficiency and reality of communication link, which can be achieved by enabling D2D communication. The efficiency of mode selection by enabling the D2D communication system can further improve network's effectiveness [40].

All the modes in the network share the same infrastructure network and the D2D communication can serve the users to control the data usage from the BS [71]. Mode selection aims to maximise the data transmission capacity from BS to all users [119]. The users and their needs play a key role in the selection of mode as the required data are reached from outside the network and no other users need them. This is also similar when the data are required from many users in the same network or one user wants to share his data with others [120]. It is preferable that the source of data is near the D2D mode and vice versa. Moreover, when the load of the data usage is high, the D2D communication can help by reducing it and improve the performance of the BS to serve the community in the best way possible [121].

The advantages of the MAMS-D2D scheme can be provided for both service providers and users. The scheme enhances channel quality, coverage and capacity in different types of environment. Coverage can be enhanced by improving the use of D2D communication, which can be carried out by improving the SINR level. Meanwhile, channel quality can be enhanced by improving the delay margin on the connection for different types of environment. Capacity is increased by increasing the bandwidth value for users and reducing the attempts to connect through the network base station. In this study, the following assumptions were made to design the system model for implementing the MAMS-D2D scheme:

i. Three RATs were considered in this scheme namely D2D communication, LTE-A and WLAN in the designing and implementation of the proposed scheme in this study.

ii. Many cases of different types of environment (indoor and outdoor) and the network setup were considered for validation and decision making of the RAT selection as the requirements differ based on different cases.

iii. This study exclusively focused on mode selection for the outdoor and indoor environment.

4.4 Validation of Mode Selection Scheme

In this section, the implementation of a mode selection scheme goes through two cases:

- First case: Comparing the system performance in the outdoor environment case between MAMS-D2D scheme and RSS approach. The RSS approach was considered only on the highest received signal, whereby all devices may be connected to the same network, which can provide the highest received signal. Comparison showed the strengths of enabling the D2D communication system and how the proposed scheme can improve the overall performance of the network.

- Second case: Comparing the proposed scheme with RSS approach in the indoor environment. This comparison showed improvements in network performance.

4.4.1 First Case: Outdoor Environment

The implementation of this case showed the performance validation for mode selection scheme in the outdoor environment. This experiment underwent a lot of tests and examination to ensure the reliability of the validation and results' values.

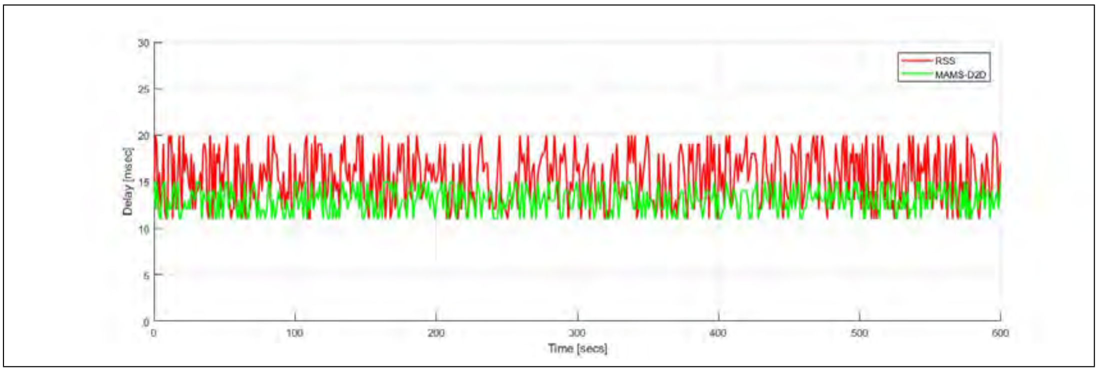

Figure 4.3. Delay during Outdoor Phase

The connection ranged from 0 to 600 seconds. The RSS approach always showed a higher delay than that of MAMS-D2D scheme. This happened because the RSS approach may have selected the mode with higher RSS, but not better bandwidth. So, the selection, when based on only RSS, may not be the best choice as shown in Figure 4.3.

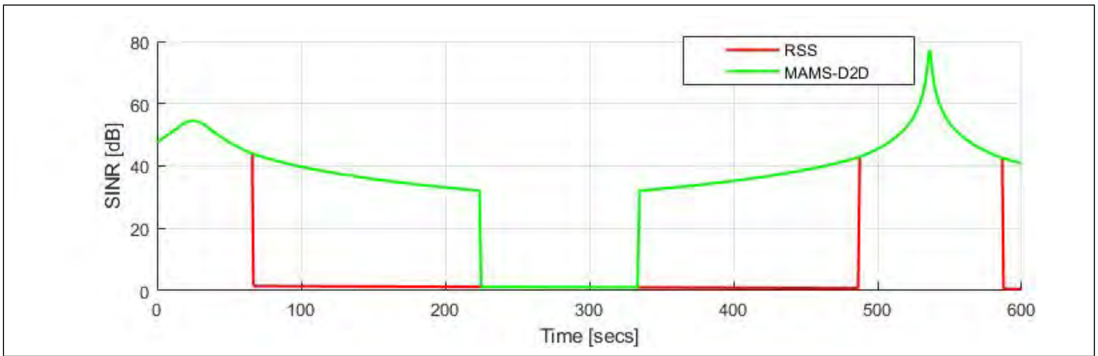

Figure 4.4. SINR during Outdoor Phase

Based on Figure 4.4, the performance validation regarding SINR metric was clear. As shown in Figure 4.6 for the time ranging from 0 to 70 seconds, the SINR for both MAMS-D2D scheme and RSS approach showed similar levels of performance and were connected using D2D connection. From 70 to 220 seconds, the RSS value dropped to near 0 where it is connected to the LTE-A network facing high level of interference So, the available bandwidth is almost 0 and the signal level is weak. However, it was still connected, while the MAMS-D2D scheme kept connecting using D2D link with a better value in SINR compared to the RSS approach. From 220 to 330 seconds, both approaches showed similar performance. From 330 to 480 seconds, MAMS-D2D scheme was seen more robust against interference affected by the connection using the D2D communication system. Accordingly, the performance in this period showed better performance in MAMS-D2D scheme approach, which was roughly 45% compared to RSS approach. This showed that the MAMS-D2D scheme had selected the mode with the lowest interference level. From 480 to 580 seconds, the connection used D2D communication system where both approaches showed similar performance. From 580 to 600 seconds, the value of RSS approach dropped, while MAMS-D2D scheme kept showing a better value than RSS. The results in this period showed better performance in MAMS-D2D scheme approach, which was roughly 40% compared to the RSS approach. This clearly suggests that the MAMS-D2D scheme can provide better performance than the RSS approach.

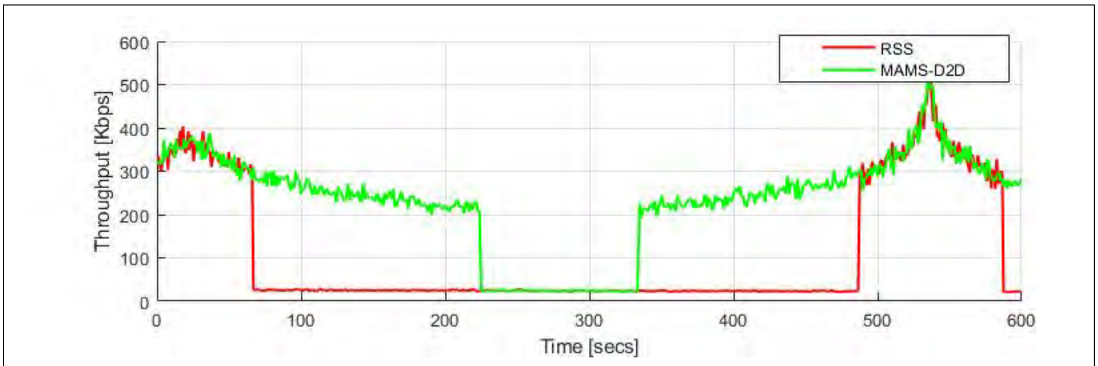

Figure 4.5. Throughput Validation for Outdoor Phase

Figure 4.5 shows the performance validation regarding the throughput value during the communication time. Based on Figure 4.6 from 0 to 70 seconds, the throughput for both MAMS-D2D scheme and RSS approach showed similar levels of performance and both were connected using D2D connection. From 70 to 220 seconds, the RSS value dropped to near 10 Kbps but was still connected, while the MAMS-D2D scheme kept connecting using D2D link with a better value of throughput, which was roughly between 200 Kbps and 300 Kbps compared to the RSS approach. From 220 to 330 seconds, both approaches showed similar performance,where the proposed scheme chooses to connect to LTE-A network as show the best performance among available modes. From 330 to 480 seconds, MAMS-D2D scheme was observed more robust against interference and link conditions affected by connecting using the D2D communication system. Accordingly, the performance in this period showed a better performance value in terms of throughput in MAMS-D2D scheme, which was roughly 45% compared to the RSS approach. This proved that the MAMS-D2D scheme had selected the mode with higher throughput when possible. From 480 to 580 seconds, the connection used the D2D communication system where both approaches showed similar performance. From 580 to 600 seconds, the value of throughput in the RSS approach dropped again, while MAMS-D2D scheme kept showing a better value than RSS. The results in this period showed better performance in the MAMS-D2D scheme, which was roughly 40% compared to the RSS approach. The results clearly shows that the MAMS-D2D scheme can provide better performance than the RSS approach. It worth to mention that the SINR Figure 4.4 and throughput Figure 4.5 show almost the same performance the reason is that and from mathematical background Shanon capacity is based on SINR as the SINR going up the offered bandwidth will be higher then the throughput will be higher.

4.4.2 Second Case: Indoor Environment

The implementation of this case showed the performance validation for the mode selection scheme in the indoor environment. This test underwent a lot of tests to ensure the reliability of the validation and the results' values. The mobile station kept moving in the network where the number of devices was seen increased. The MAMS-D2D scheme demonstrated better performance than the RSS approach by 10%. This was because MAMS-D2D scheme chose to connect using D2D connection, whereas the RSS approach kept connecting to LTE for more time.

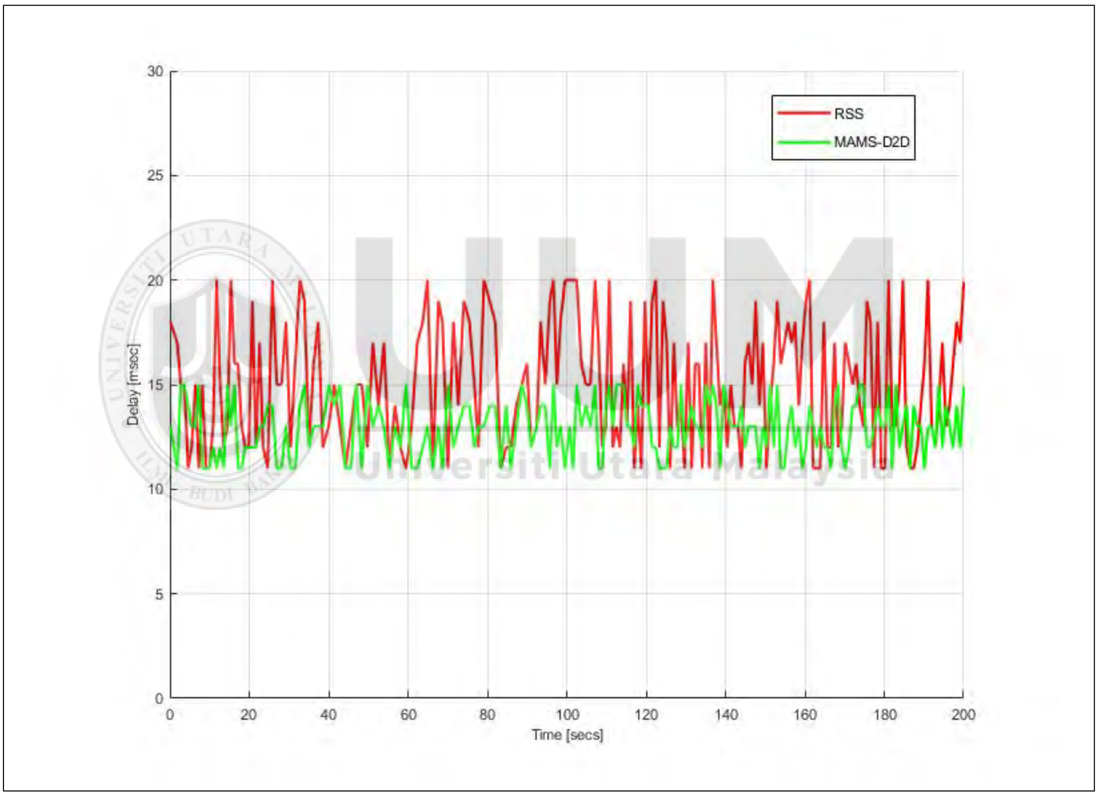

Figure 4.6. Delay during Indoor Phase

Figure 4.6 shows the connection ranging from 0 to 200 seconds, whereby the RSS approach showed a higher or similar delay level as MAMS-D2D scheme. In the overall, the communication time of the MAMS-D2D scheme showed better performance level, which proved that MAMS-D2D scheme has lower delay value compared to that of the

RSS approach.

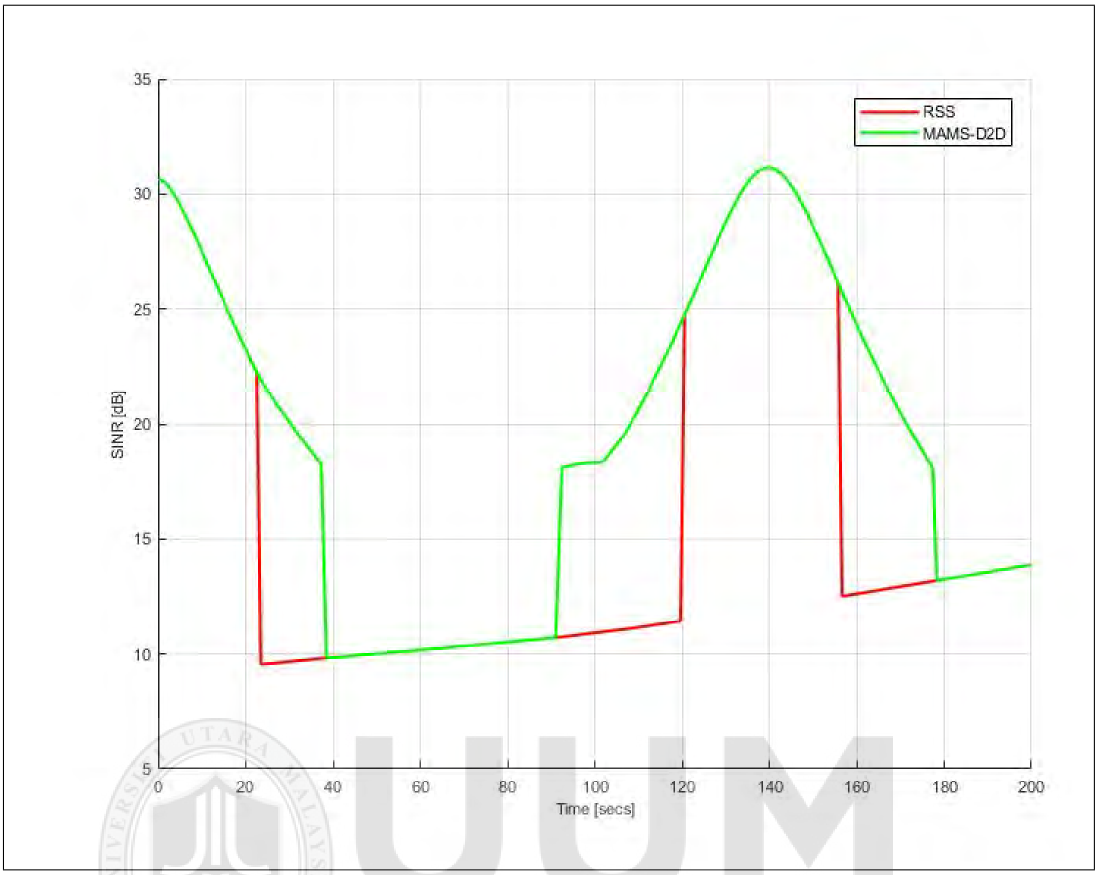

Figure 4.7. SINR during Indoor Phase

Figure 4.7 shows the performance validation regarding the SINR metric. From 0 to 25 seconds, the SINR for RSS and MAMS-D2D scheme showed similar performance. From 25 to 40 seconds, MAMS-D2D scheme was presented more robust against interference affected by keeping the connection using the D2D communication system, while the RSS dropped the value for this period. Accordingly, the performance in this period showed better performance in the MAMS-D2D scheme by roughly 20% compared to the RSS approach. This proved that the MAMS-D2D scheme had considered selecting the mode with the lowest interference level. From 40 to 90 seconds, the SINR dropped as the mobile station connected back to LTE-A network. However, it remained within the accepted level and showed similar performance value with the RSS approach for this period. From 90 to 120 seconds, the MAMS-D2D scheme was shown more robust against interference affected by keeping the connection using the D2D communication system, while the RSS dropped the value for this period. Therefore, the performance in this period showed better performance in the MAMS-D2D scheme, which was roughly 25% compared to the RSS approach. This proved that the MAMS-D2D scheme had considered selecting the mode with the lowest interference level. From 120 to 160 seconds, the SINR for both RSS and MAMS-D2D scheme showed similar performance and chose to connect using D2D link, which gave a high value of the SINR. From 160 to 180 seconds, the MAMS-D2D scheme showed more robustness against interference affected by keeping the connection using the D2D communication system, while the RSS drooped the value for this period. Accordingly, the performance in this period showed better performance in the MAMS-D2D scheme by roughly 30% compared to the RSS approach. This proved that the MAMS-D2D scheme had considered selecting the mode with the lowest interference level. Finally, from 180 to 200 seconds, the SINR dropped since the mobile station was connected back to LTE-A network. However, it remained within the accepted level and showed similar performance value with the RSS approach for this period.

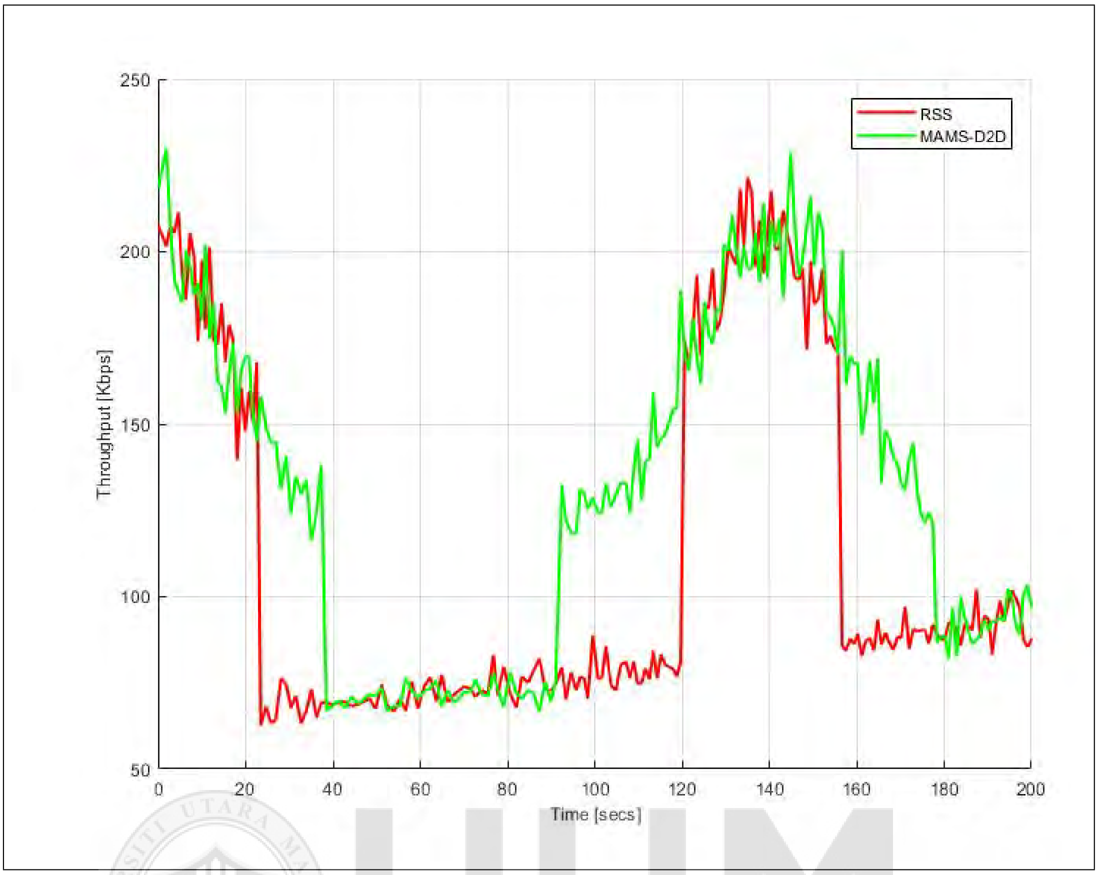

Figure 4.8. Throughput during Indoor Phase

Figure 4.8 shows the performance validation concerning throughput validation. From 0 to 25 seconds, the throughput for both RSS and MAMS-D2D scheme showed similar performance and chose to connect using the D2D link, which gave a high value of the throughput. From 25 to 40 seconds, the MAMS-D2D scheme was seen more robust against interference affected by keeping the connection using the D2D communication system, while the RSS dropped the value for this period. Therefore, the performance in this period showed better performance in MAMS-D2D scheme by roughly 20% compared to the RSS approach. From 40 to 90 seconds, the throughput dropped as the mobile station was connected back to LTE-A network. However, it remained within the accepted level and showed similar performance value with the RSS approach for this period. From 90 to 120 seconds, the MAMS-D2D scheme was shown more robust against interference affected by keeping the connection using the D2D communication system, while the RSS dropped the value for this period. Accordingly, the performance in this period showed better performance in the MAMS-D2D scheme approach by roughly 25% compared to the RSS approach. This proved that the MAMS-D2D scheme had considered selecting the mode with the highest throughput level. From 120 to 160 seconds, the throughput for both RSS and MAMS-D2D scheme showed similar performance and chose to connect using the D2D link, which gave a high value of the throughput. From 160 to 180 seconds, the MAMS-D2D scheme showed more robustness against interference affected by keeping the connection using the D2D communication system, while the RSS dropped the value for this period. Therefore, the performance in this period showed better performance in MAMS-D2D scheme by roughly 30% compared to the RSS approach. This proved that the MAMS-D2D scheme had considered selecting the best available mode with the highest throughput level. Finally, from 180 to 200 seconds, the throughput dropped as the mobile station was connected back to LTE-A network. However, it remained within the accepted level and showed similar performance value with the RSS approach for this period.

4.5 Summary

This chapter has presented the design and steps of the MAMS-D2D scheme. This scheme has helped improving the performance of the D2D communication system. It has also proved the importance of implementing the D2D technology in future networks. The performance results of the MAMS-D2D scheme showed better performance for the network compared to RSS approache. It supported the D2D scheme and showed noticeable improvements when mode selection was depended on multi-attribute metrics. This scheme was aimed at serving users in indoor and outdoor environment, which secures a stable connection with the best available modes in a particular area.

Moreover, it has demonstrated how the mode selection scheme with enabling D2D helps in improving the performance level in different types of environment. This factor plays a key role in satisfying the community's needs and serving users in different cases with a high-performance level due to the multi-attributes of the D2D scheme. This scheme has been seen capable of deciding to always choose the best mode.

CHAPTER FIVE
SOCIAL-AWARE PEERING SELECTION SCHEME

5.1 Introduction

This chapter introduces a new social-aware peering selection scheme. This scheme is called 'Social-Aware Multi Attributes D2D Peering Selection (SMAPS-D2D) scheme' for enabling an efficient D2D communication system in heterogeneous networks. The SMAPS-D2D scheme focuses on peering selection based on social-aware factors among the available peers in the network with respect to the connection's condition and choice of establishing D2D connection with the best available peer in the surrounding area.

Due to the movement of user, the selection of destination will be temporary or for short time of connection. So, the selection should concern about the changes in the communication conditions and possibility of privacy leakage. The social relationship may enhance the time of finding the peer for establishing the D2D connection that raises the gain of D2D communication [36].

The different number of users and a diversity of users' interests need to have effective peer selection with a high level of accuracy, which means the selection decision should consider multi-attribute and social status. Thus, establishing the connection based on only RSS strength will not be applicable for the real scenarios where many researchers depended on RSS strength to test their eligibility in establishing the connection [87].

The PPP distribution is used in wireless networks to distribute BSs, node, users and infrastructure components based on the entire plane [122]. The PPP distortion starts by defining the total number of nodes or required density or both (typically start the distribution from a point (0,0) in network topology and the set up of the nodes depends on the area size and the nodes number) . Then, the process moves to define the base point and minimum distance allowed to detect the destination nodes [122], [123]. The reason for depending on PPP distribution is because the performance level will be different in different density and way of node distribution. So, the PPP distribution reflects the real way of nodes distribution in a real network topology [124].

Hierarchical Adaptive Weighting (HAW) can play a significant role in peering selection for D2D communication. HAW can add many enhancements to the decision making for the D2D peer connection since it enables the multi-attribute to be considered while ensuring that the pair of devices connect along with users' preferences. It is worth mentioning that this approach is considered as a new area of research in D2D communication. The proposed mechanisms adopted HAW approaches due to the simplicity of its application in different network topologies and scenarios, which reduces the time of finding the best peer.

5.2 Description and Design of the SMAPS-D2D Scheme

The SMAPS-D2D scheme procedures are shown in Figure 5.1. The SMAPS-D2D scheme follows many steps to ensure that it always chooses the best available peer in the surrounding area. The scheme contains three main stages as follow:

- **The initial process**

This part of the scheme starts by defining different criteria to find the weight of selected parameters. In peering discovery procedures, the main attributes are considered to give them weight, include power, delay, RSS and bandwidth. First, it is imperative to identify the type of data since the importance of the criteria value will be different for a different type of data (the type of data could be text, voice, video or all together). Also, the definition of the user conditions is done in this stage, which includes movement speed, direction and time of movement of the user. Then, the scheme calculates the weights by adopting AHP algorithm and the output of this step is the percentage of the attribute's weight.

- **The filtering process**

This process is done to ensure a communication with a trusted user. In this process, the scanning of available users checks the type of relationship between user and destination, which could be trusted user or untrusted user. If it finds any untrusted user, it will remove it from the available users. Also, the trusted user will be divided into two levels based on the relationship type.

- **The decision process**

This part starts by checking the users until establishing the D2D connection. The SMAPS-D2D scheme ranks the available users with considering the weighting value based on type of data/application. The scheme process goes through an evaluation process to evaluate peers. It evaluates whether the peers in the allowed distance and available to communicate or not and whether or not they meet the connection requirements based on threshold value. The SMAPS-D2D scheme ranks the available peers based on the value of different attributes (RSS, delay, bandwidth and power) with respecting to the difference in the weighting value of those attributes. The request of establishing the connection is sent to the first user in the list (best available user). If the destination user rejects the request, the sender will keep sending a request to the following user in the list till one accept the request. This process continues until the communication is done with the best available peer. Once the user accepts the request, the D2D connection will establish. The main steps of the SMAPS-D2D scheme continue during the whole time of the peering discovery and the mode selection process or they stop when the communication time finishes.

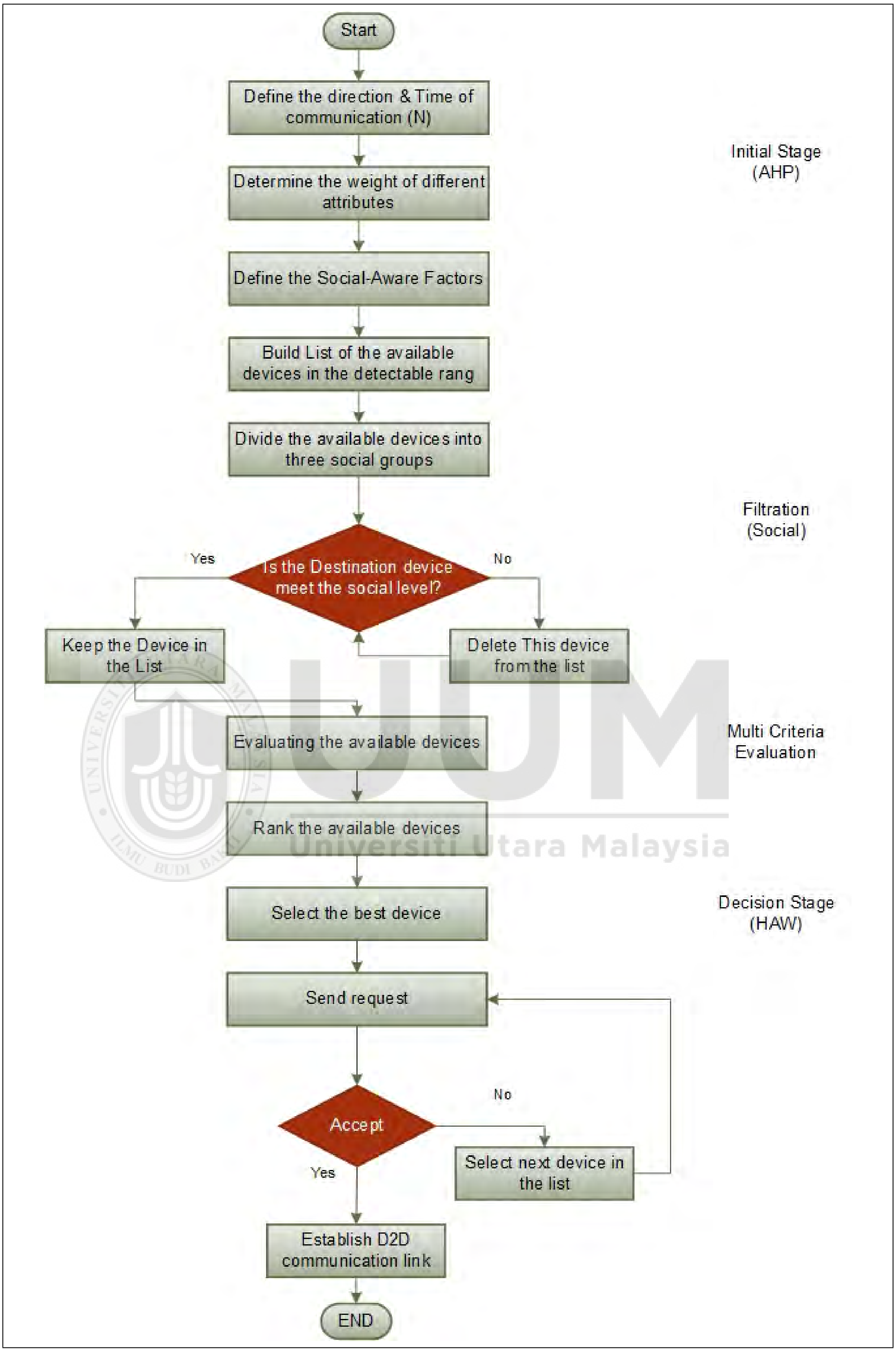

Figure 5.1. Peering Selection Scheme Steps

5.2.1 Implementation Process

The implementation of the proposed peer discovery scheme is designed for efficient D2D communication in wireless networks. The scheme consists of many steps as shown in Figure 5.1 starting from initial stage and weighting calculation till establish D2D connection. So, the scheme implementation goes as follow:

1) determine the important parameters and calculate their weights by adopting AHP algorithm.

2) run the social-aware filtration to delete untrusted users.

3) make validation of the surrounding peers based on RSS, delay, bandwidth and power with respecting to the weighting values of each parameter and social relationship level between peers to rank them with adopted HAW algorithm.

4) establish D2D communication.

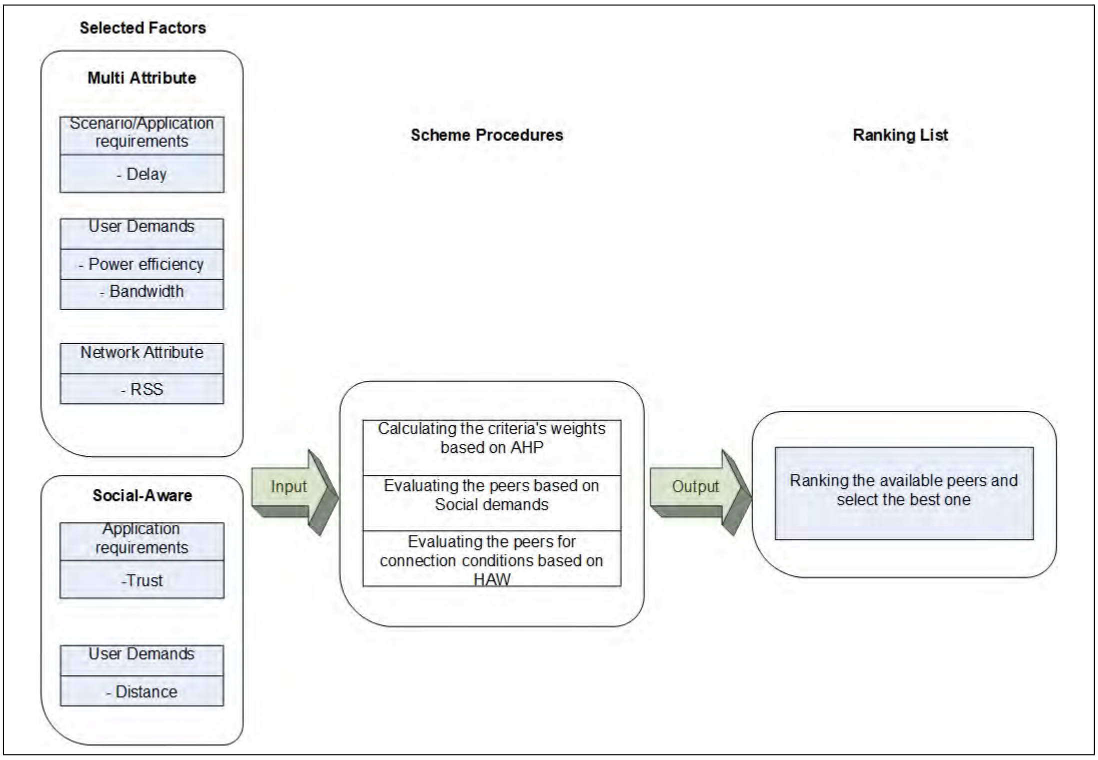

Figure 5.2. Peering Selection

Figure 5.2 shows the peering selection in the scheme that clarifies the main input of the SMAPS-D2D scheme as well as the scenario's requirements, users' demands and network-related attributes. The social peering selection scheme consists of many steps. The scheme starts by defining the threshold value for the selected attributes namely RSS_{th}, b_{th}, d_{th}, q_{th} as well as the weights of the attributes (w_d,w_q,w_{RSS},w_B), which is done based on AHP algorithm. Therefore, the SMAPS-D2D scheme starts from the point of defining the parameters' weights by adopting AHP algorithm. The SMAPS-D2D scheme's procedures take these inputs and use them in terms of finding the best available peer, which represents the output of the scheme. The SMAPS-D2D scheme adopts HAW algorithm and social-aware theory in the implementation process to improve the selection of destination peer.

Basically, the core of the scheme is divided into two parts; one part checks the relationship with the other peers to filter the untrusted peers and the second for evaluates the peers in terms of connection conditions. Then, it filters the users based on the social relationship using social-aware evaluation. Then, the scheme checks the relationship status that shows the trusted or untrusted peers. The scheme then filters untrusted peers and removes them from the list. For trusted peers, they will be under two groups of highly trusted (such as family) and normal trusted (such as a friend). The scheme will give priority to trusted peers by doubling the value of connection, which means the peers prefer to contact in D2D communication with highly trusted peers when it is possible. After that, the filtering result and weighting values are put to the next step to rank the available users using HAW algorithm. Then, the scheme checks the connection condition to evaluate the peers based on HAW algorithm for all available peers to build a matrix as follows:

$$HRSS_{ij} = RSS_{ij} / \sum_{i=1}^{n} RSS_{ij} \tag{5.1}$$

$$HB_{ij} = B_{ij} / \sum_{i=1}^{n} B_{ij} \tag{5.2}$$

$$HD_{ij} = \frac{1}{D_{ij}} / \sum_{i=1}^{n} \frac{1}{D_{ij}} \tag{5.3}$$

$$Hq_{ij} = \frac{1}{q_{ij}} / \sum_{i=1}^{n} \frac{1}{q_{ij}} \tag{5.4}$$

Where$HRSS_{ij}$ is the normalisation value of RSS_{ij}, HB_{ij} is the normalisation value of bandwidth B_{ij}, HD_{ij} is the normalisation value of delay D_{ij} and Hq_{ij} is the normalisation value of power q_{ij}.

When there is benefit attribute in the equation, *RSS* and *Bandwidth* are used, but when there is cost or its minimum, *Delay* and *power efficiency* are utilised. From these equations with the assuming that there are three peers, we can have the new matrix *R* as follows:

$$R = \begin{bmatrix} HRSS_{11} & HB_{12} & HD_{13} & Hq_{14} \\ HRSS_{21} & HB_{22} & HD_{23} & Hq_{24} \\ HRSS_{31} & HB_{32} & HD_{33} & Hq_{34} \end{bmatrix} \tag{5.5}$$

Then, the process of applying of the weighting values of the different attributes will result in a new Matrix V . The V matrix is as shown below:

$$V = \begin{bmatrix} v_{11} & v_{12} & v_{13} & v_{14} \\ v_{21} & v_{22} & v_{23} & v_{24} \\ v_{31} & v_{32} & v_{33} & v_{24} \end{bmatrix} = \begin{bmatrix} w_{RSS}^T HRSS_{11} & w_B^T HB_{12} & w_D^T HD_{13} & w_q^T Hq_{14} \\ w_{RSS}^T HRSS_{21} & w_B^T HB_{22} & w_D^T HD_{23} & w_q^T Hq_{24} \\ w_{RSS}^T HRSS_{31} & w_B^T HB_{32} & w_D^T HD_{33} & w_q^T Hq_{34} \end{bmatrix} \tag{5.6}$$

Later, the user will select the best peers in the user area (in the current time) where the ranking value of the available users is as follow:

$$PeDi_{D2D} = SIV * \left(w_{RSS}^T HRSS_{ij} + w_B^T HB_{ij} + w_D^T HD_{ij} + w_q^T Hq_{ij} \right) \tag{5.7}$$

Where SIV is the social index value. For highly trusted user SIV is 2, for normal trusted user SIV is 1 and for untrusted user SIV is 0.

Finally, the scheme evaluates the peers based on last equation and ranks them to select the highest rank for establishing the D2D connection with the best trusted peer. The process of sending a request to establish a D2D connection starts until one of the available devices accepts the request and establishes the D2D connection..

5.3 Theoretical Analysis

The D2D communication system aims to serve devices in the network by providing connection as long as other peers in the surrounding area are available to exchange data. The scheme provided the best connection among the available peers. The testing results of the SMAPS-D2D scheme showed improvements in performance factors. The proposed scheme adopted MADM theory and Social Choice theory. The SMAPS-D2D scheme applied these theories and tested performance in many critical cases. The traditional classification of matching problems was based on the weights of the metrics of the communication link. In validating the peering selection scheme, the proposed scheme focused on four metrics namely RSS, Delay, Power and Bandwidth. Also, the social-aware filtering were represented by testing the relationship between users based on relationship factor.

5.3.1 Social-Aware Filtering

Social-Aware filtration plays an essential role in increasing the efficiency of peer selection. In the future networks, the system can define the relationship between different users and, based on this relationship, can divide the users into two groups as trusted peers group and untrusted peers group. This process helps to filter the users and avoid the communication with an untrusted user, which may harm the user or loss-sensitive data.

To enable social-aware factors, the scheme defines the main factors considered to choose the peer based on trust factor. One of the main factors that could assist in establishing the D2D connection is a trust relationship between peers. Trust factor is very important for users to exchange the data with one peer or more. Starting the connection with an untrusted user may cause losing of data or contact with a harmful user that might use or spy the personal data. In this scheme, the trust factor is considered using multi-level of trust, which is split into two main categories; trusted peers and untrusted peers. Then, the trusted users are divided into two sub-groups based on the type of relationship between both users. The relationship level could be high trusted user or normal (low) trusted user.

5.3.2 Initial Peering Selection

The peering selection scheme sets the rules of finding the best peer and selects it to establish a D2D connection depending on the user's demands and application/data type. Any active device in the acceptable rang can be available. In this case, the scheme identifies potential peering devices is the network's area.

Following the higher layer corresponding to identification, there are minimum resources utilised at the physical layer for D2D discovery. It is possible to support multiple D2D user pairs for discovery within some given time slots.

5.3.3 The Peering Selection Decision

Peer selection can be time and energy-consuming if network assistance is not available. The device is involved in making the decision of selecting the destination to improve data transmission capacity and resource utilisation. D2D communications may be implemented by reusing the same frequency channels involving decision and scheduling methods for spectrum sharing to use these sources more efficiently. If a device requires to establish a D2D communication, the network and the origin peer has to find the possible peers that can be employed as a destination peer by a peer selection procedure [35].

5.4 Validation of Social-Aware Peering Discovery Scheme

In this section, the implementation shows how it can enhance the performance by applying the MADM theory (RSS, delay, bandwidth and power) and social-aware factor based on trust level and goes through two cases of the SMAPS-D2D scheme:

- First case: Comparing the system's performance with the RSS approach using low density of available users. This comparison shows the strengths of SMAPS-D2D scheme even when the number of trusted users are low in the network.

- Second case: Comparing SMAPS-D2D scheme with RSS approach when the high density of users is available and showing improvements in the connection performance with applying the social-aware factor based on trust level.

5.4.1 First Case: Low Density of Available Users

The proposed model showed improvements in performance when the number of available users was low. This indicated that users were randomly distributed in the network and located in the network using the PPP distribution technique. In this case, the users' density was low, which means that the available users for D2D connection were low as well as shown in Figure 5.3(a).

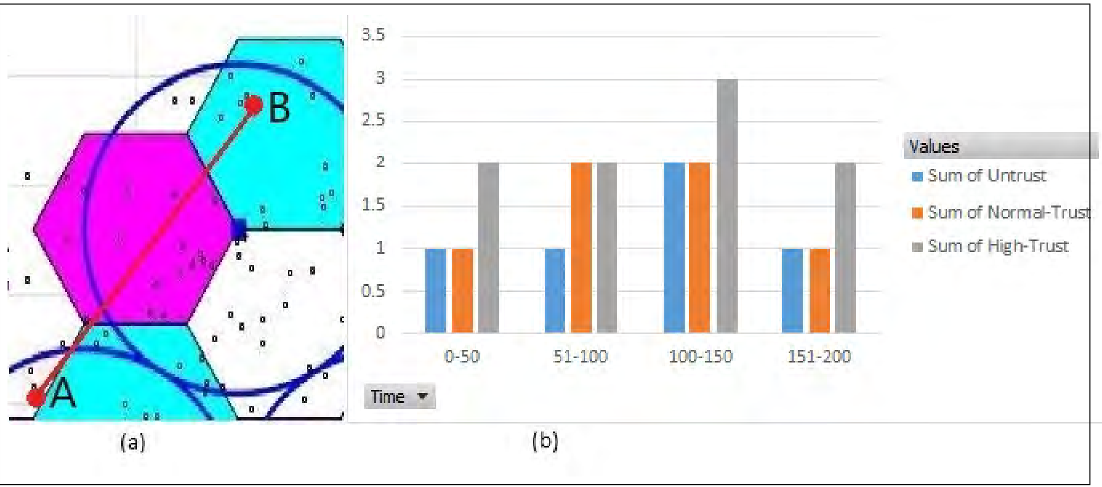

Figure 5.3. Sum of users based on trust level

Figure 5.3(a) shows the movement of the user from point A to point B during the studied communication time. It is clear that the user's density is different from one location to another in the networks and it reflects on the conditions of connection and the number of trusted or untrusted users in the detectable range. As the number of users in the network decreases, it means that the number of trusted users will also reduce as the scheme divides the users into three groups equally. So, from the Figure 5.3(a), the number of users for each group is distributed during the communication time as shown in the Figure 5.3(b). In the Figure 5.3(b), the number of users is shown based on trust level during the communication time. In the first period, from 0 to 50 seconds, the user can detect 4 users (2 highly trusted users, 1 normal trusted user, 1 untrusted user). In the second period, from 51 to 100 seconds, the number of detected users increased where it can detect 5 users (2 highly trusted users, 2 normal trusted user, 1 untrusted user). In the third period, from 101 to 150 seconds, the number of detected users increased where it can detect 7 users (3 highly trusted users, 2 normal trusted user, 2 untrusted user). In the fourth period, from 151 to 200 seconds, the number of detected users decreased where it can detect 4 users (2 highly trusted users, 1 normal trusted user, 1 untrusted user).

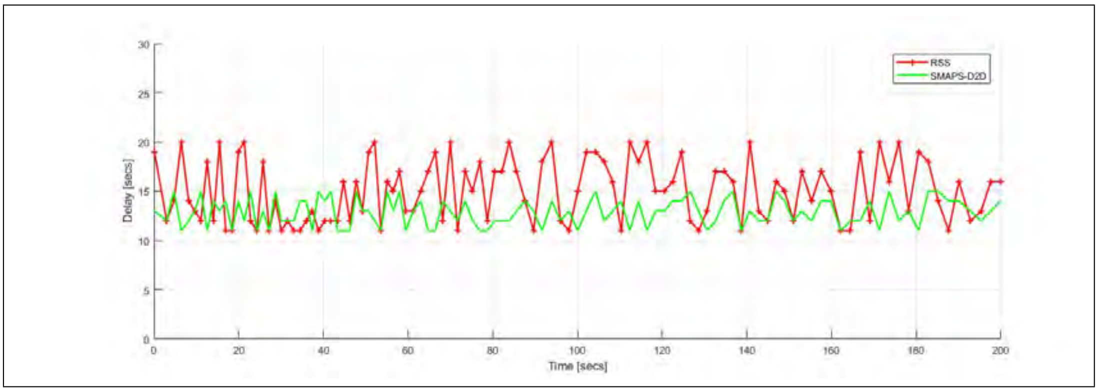

Figure 5.4. Delay Validation during Time of Study

The connection time was ranged from 0 to 200 seconds. The average of the delay in RSS approach showed higher delay level than that of SMAPS-D2D scheme. In some points, the delay of RSS approach showed lower value but during 200 seconds, the delay in SMAPS-D2D scheme was seen better than the RSS approach for more the 160 seconds as shown in Figure 5.4.

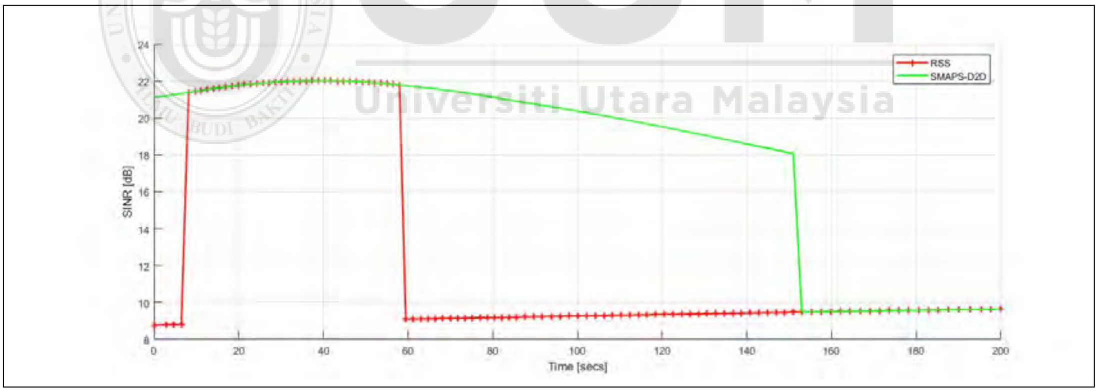

Figure 5.5. SINR Validation during Time of Study

According to Figure 5.5, the resulted time was ranged from 0 to 10 seconds where the SINR showed better performance in SMAPS-D2D scheme than RSS approach. Then, from 10 to 60 seconds, the SINR for RSS approach and SMAPS-D2D scheme showed similar performance. Then, from 60 to 150 seconds, the SMAPS-D2D scheme was shown more robust against the connection changes. The results in this period showed better performance in the SMAPS-D2D scheme by roughly 30% compared to the RSS approach. This proved that the SMAPS-D2D scheme had selected the best device with ability to take the correct decision during the movement. Then, the SMAPS-D2D scheme and RSS approach provided similar SINR level from 150 to 200 seconds. On the average, the SMAPS-D2D scheme provided better performance than RSS approach during the communication time for 100 seconds and the rest of the time presented similar performance level.

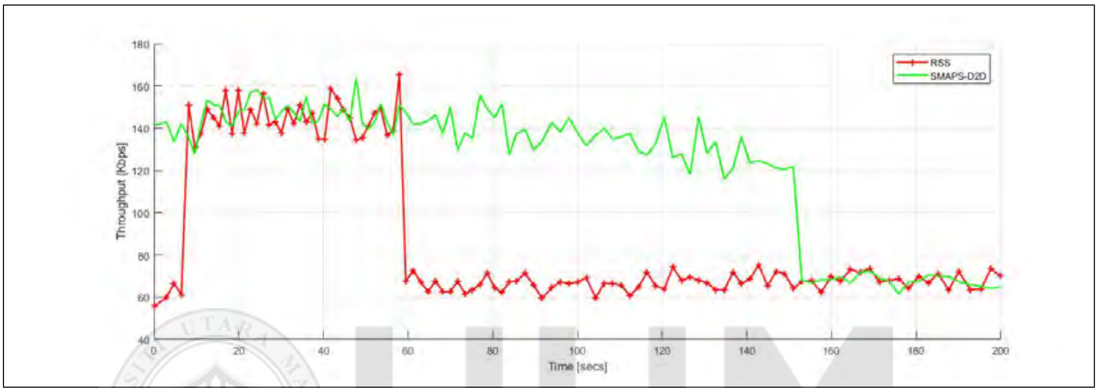

Figure 5.6. Throughput Validation during Time of Study

Based on Figure 5.6, the results can be divided into four phases, as follow:

Phase 1: From 0 to 10 seconds, the SMAPS-D2D scheme showed better performance than the RSS approach. The performance level in SMAPS-D2D scheme was better by 55%.

Phase 2: From 10 to 60 seconds, the performance of SMAPS-D2D scheme and RSS approach was almost similar.

Phase 3: From 60 to 150 seconds, the performance of RSS approach dropped while the SMAPS-D2D scheme continues in the high level of throughput. The performance level in SMAPS-D2D scheme was better by 50%.

Phase 4: From 150 to 200 seconds, SMAPS-D2D scheme dropped with throughput value as no enough trusted peers in this period. The throughput value of SMAPS-D2D scheme was almost similar to that of RSS approach and remained on this level until the end of communication.

Overall, the performance showed better performance compared to the RSS approach where the applying of trusted factor on the peering selection scheme kept on giving acceptable performance level. The performance as shown from the previous results of SINR, throughput and delay, the trusted factor is considered. The power of trusted factor is shown by eliminating the untrusted devices to be connected. If the connection happens with untrusted devices, the connectivity will avoid them and if no trusted devices in the detectable area, the device will connect to the network as in this case from 160 till 200 seconds, there is no trusted device available. In the contract, the results showed a very stable connection, constant delay performance and good throughput level.

5.4.2 Second Case: High Density of Available Users

The proposed model showed better performance while the user density in the network is high. This indicated that users are randomly distributed in the network and located in the network using the PPP distribution technique. In this case, the user's density is high and located in the network for the studied area as shown in the Figure 5.7(a).

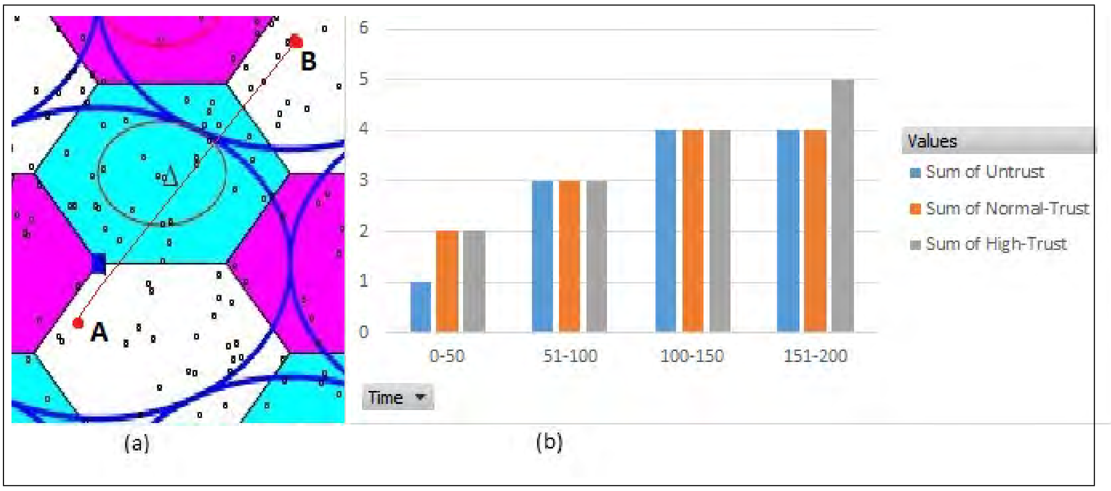

Figure 5.7. Sum of users based on trust level

The Figure 5.7(a) shows the movement of the user from point A to point B during the studied communication time. The user's density is higher compared to the previous case and it is also different from one location to another in the network. As the number of the users in the network increases, it means that the number of trusted users will maintain at a good level as the scheme divides the users into three groups equally. In the Figure 5.7(b), the number of users is based on trust level during the communication time. In the first period, from 0 to 50 seconds, the user can detect 5 users (2 highly trusted users, 2 normal trusted users, 1 untrusted user). In the second period, from 51 to 100 seconds, the number of detected users increased where it can detect 9 users (3 highly trusted users, 3 normal trusted users, 3 untrusted users). In the third period, from 101 to 150 seconds, the number of detected users increased where it can detect 12 users (4 highly trusted users, 4 normal trusted users, 4 untrusted users). In the fourth period, from 151 to 200 seconds, the number of detected users increased where it can detect 16 users (5 highly trusted users, 4 normal trusted users, 4 untrusted users).

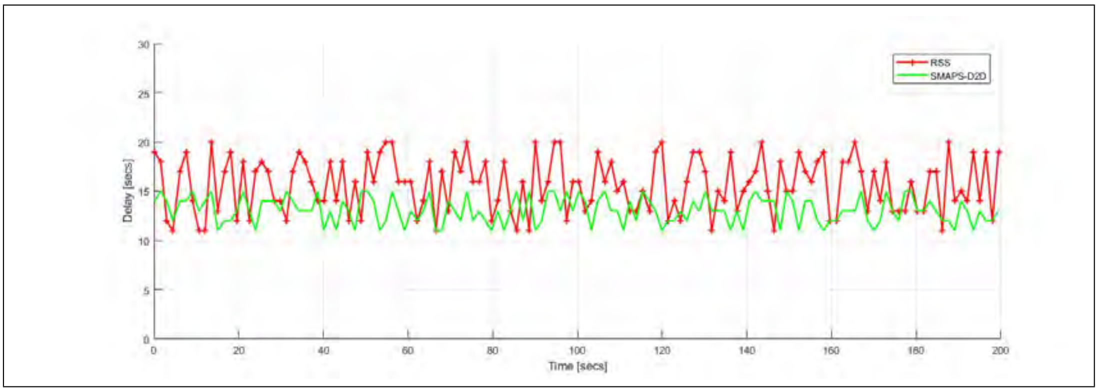

Figure 5.8. Delay Validation during Time of Study

Figure 5.8 shows the validation result, which ranged from 0 to 200 seconds. The average of the delay in RSS approach showed a higher delay level than SMAPS-D2D scheme. By comparing the result, the SMAPS-D2D scheme showed better performance than RSS approach by 17%.

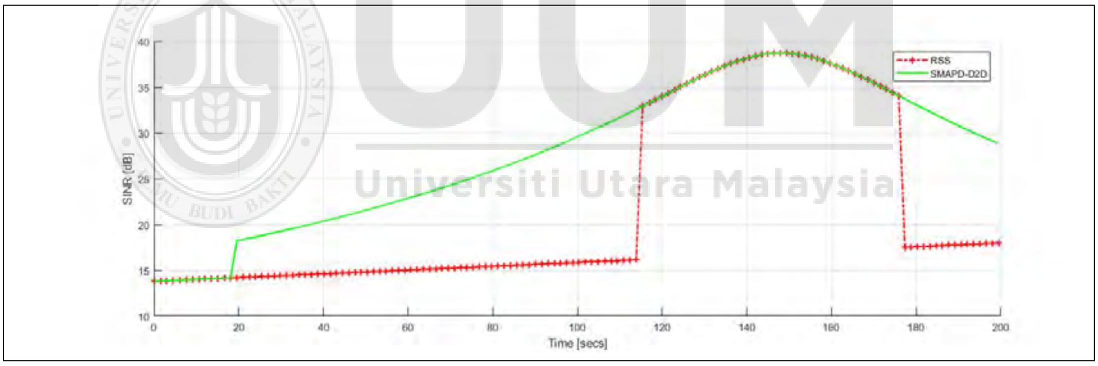

Figure 5.9. SINR Validation during Time of Study

Figure 5.9 shows the performance validation regarding the SINR metric. It can be seen that the result from 0 to 18 seconds for both RSS and SMAPS-D2D scheme showed similar performance. Then, from 18 to 116 seconds, the SMAPS-D2D scheme showed more robustness and better performance compared to RSS approach by roughly 30% than the RSS approach during this period, proving that the SMAPS-D2D scheme had selected the best device. From 116 to 178 seconds, the SINR level of RSS approach jumped to a high value with similar performance level as SMAPS-D2D scheme. From

178 to 200 seconds, the SINR level dropped to lower value in RSS approach while the SMAPS-D2D scheme protected the high level of SINR and during this period, the SINR level in SMAPS-D2D scheme was better than RSS approach by 45%. Thus, the overall performance of SINR was demonstrated better in SMAPS-D2D scheme than RSS approach by 22%.

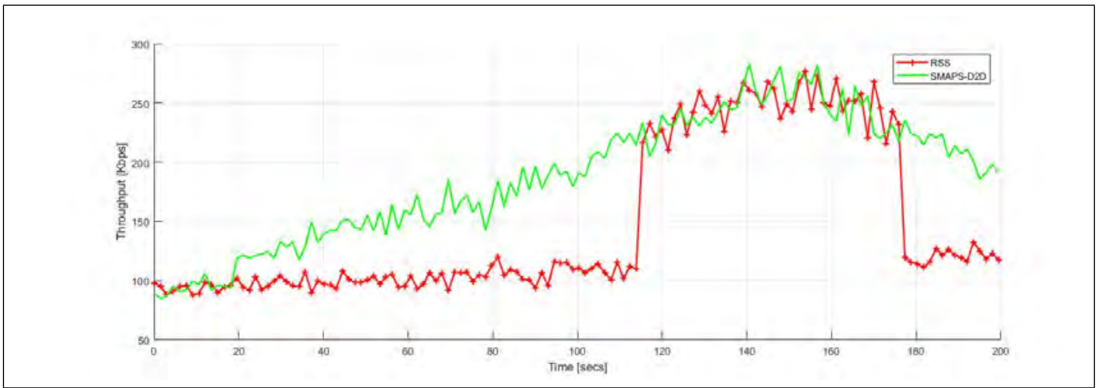

Figure 5.10. Throughput Validation during Time of Study

The results can be divided into four phases as shown in Figure 5.10:

Phase 1: From 0 to 18 seconds, both approaches showed similar performance in terms of throughput value.

Phase 2: From 18 to 116 seconds, the mobile station kept moving in a particular area, where the number of devices was increased. The SMAPS-D2D scheme showed better performance than the RSS approach by 30%. This was because SMAPS-D2D scheme chose to connect using a D2D connection, whereas the RSS approach kept connecting to network infrastructure for a longer period.

Phase 3: From 116 to 178 seconds, the throughput level in RSS approach appeared to be similar to SMAPS-D2D scheme where both approaches showed similar performance in terms of throughput during this period.

Phase 4: From 178 to 200 seconds, the mobile station kept moving in the network where the number of devices was increased. The SMAPS-D2D scheme kept showing better performance than the RSS approach by 45% when its throughput value decreases. This was because the SMAPS-D2D scheme chose to connect using D2D connection, whereas the RSS approach kept connecting to the core of the network for a longer period.

In this case, the overall performance was better compared to the RSS approach. The comparison on performance was done based on the previous results of SINR for throughput and delay where the trusted factor is considered. As shown in the results, the trusted devices are available during the communication time. So, the connection with untrusted users is avoided.

5.5 Summary

This chapter has discussed the advantages of using the proposed scheme SMAPS-D2D scheme, which helped to improve the effectiveness of the D2D communication technology and proved the importance of D2D communication system as a new technology to the future networks. The results of the proposed scheme for peering selection showed better network performance. Better results have been obtained when the network supported the D2D connection based on social-aware factors. It has also showed how users could keep their connection alive in even when their density is low and shows how it considers the trust factor in the peering selection. In addition, the results have showed better performance when the devices seek to communicate in the same area.

This model mainly aims to design a SMAPS-D2D scheme for D2D communication so that future systems can overcome most limitations of the current technologies since they are entirely controlled by BS. This model has the advantage of decreasing the amount of data to be exchanged between BSs. The proposed scheme SMAPS-D2D illustrated the main results of implementing the HAW scheme for the selection based on connection conditions and enabling the trust function to validate the selection based on social-aware factors. The performance metrics of this model can be applied to future networks, which will satisfy the operators' needs and meet the users' demands. This scheme can provide D2D connection while the user is roaming among cells. The setup shows the main parameters used to build the network structure.

CHAPTER SIX
PERFORMANCE ANALYSIS OF THE PROPOSED MECHANISM

6.1 Introduction

Based on the results and discussion in Chapter 4 and Chapter 5, the proposed SMAPS-D2D and MAMS-D2D schemes have been discussed. In this chapter, the evaluation of the proposed mechanism in different cases and scenarios is discussed and explained in detailed. The proposed mechanism focused on peer and mode selection during the mobility of the device among the networks concerning the connection condition to select the best available connection.

The proposed MAMS-D2D and SMAPS-D2D schemes served the network for different scenarios. In the implementation of SMAPS-D2D scheme, the calculation procedure was carried out all the time to guarantee the selection of the best peer with respect to social-aware factors. Further, the implementation of MAMS-D2D scheme served with the mode selection between different modes in the networks, it concerned with the connection condition and selected the best available mode. Thus, the weight of the selected metrics played a key role in evaluating different case studies and scenarios.

6.2 The Framework of the Proposed Mechanism's Implementation

The implementation of the proposed mechanism is presented and discussed in this section. As shown in the Figure 6.1, the implementation process contains of two main stages; the first is the initial stage and the second one is the stage of integration between Multi Attribute Mode Selection scheme (MAMS-D2D) and Social-aware Multi Attribute Peering Selection (SMAPS-D2D) scheme. To balance the mechanism in the implementation, it should consider all the components on the mechanism and link them together effectively. In the initial stage, the mechanism sets the main inputs including the selected attributes of both schemes, user movement speed, direction and time of connection. Then, the mechanism moves to the preparation of weights calculation of the selected attributes based on AHP algorithm. In the integration stage, the mechanism synchronises between MAMS-D2D and SMAPS-D2D schemes. The MAMS-D2D scheme defines the available modes in the surrounding area. Then, it evaluates the modes based on selected attributes (Delay, RSS, Bandwidth) with respect to their weights, which are calculated based on AHP algorithm. The modes are then ranked to select the best mode of connection (whether it is D2I or D2D mode). Once the mechanism selects the D2D mode, it needs to adjust the weights to make them suitable with the selected attributes (Delay, RSS, Bandwidth, Power) in the SMAPS-D2D scheme. Then, it defines the available peers in the detectable range. After that, it divides the available peers into three groups (highly trusted peers, normal trusted peers, untrusted peers). Untrusted peers are removed from the list of available peers. Then, it evaluates the trusted available peers based on the selected attributes with respect to them weights. After that, it ranks the peers to select the best trusted peer.

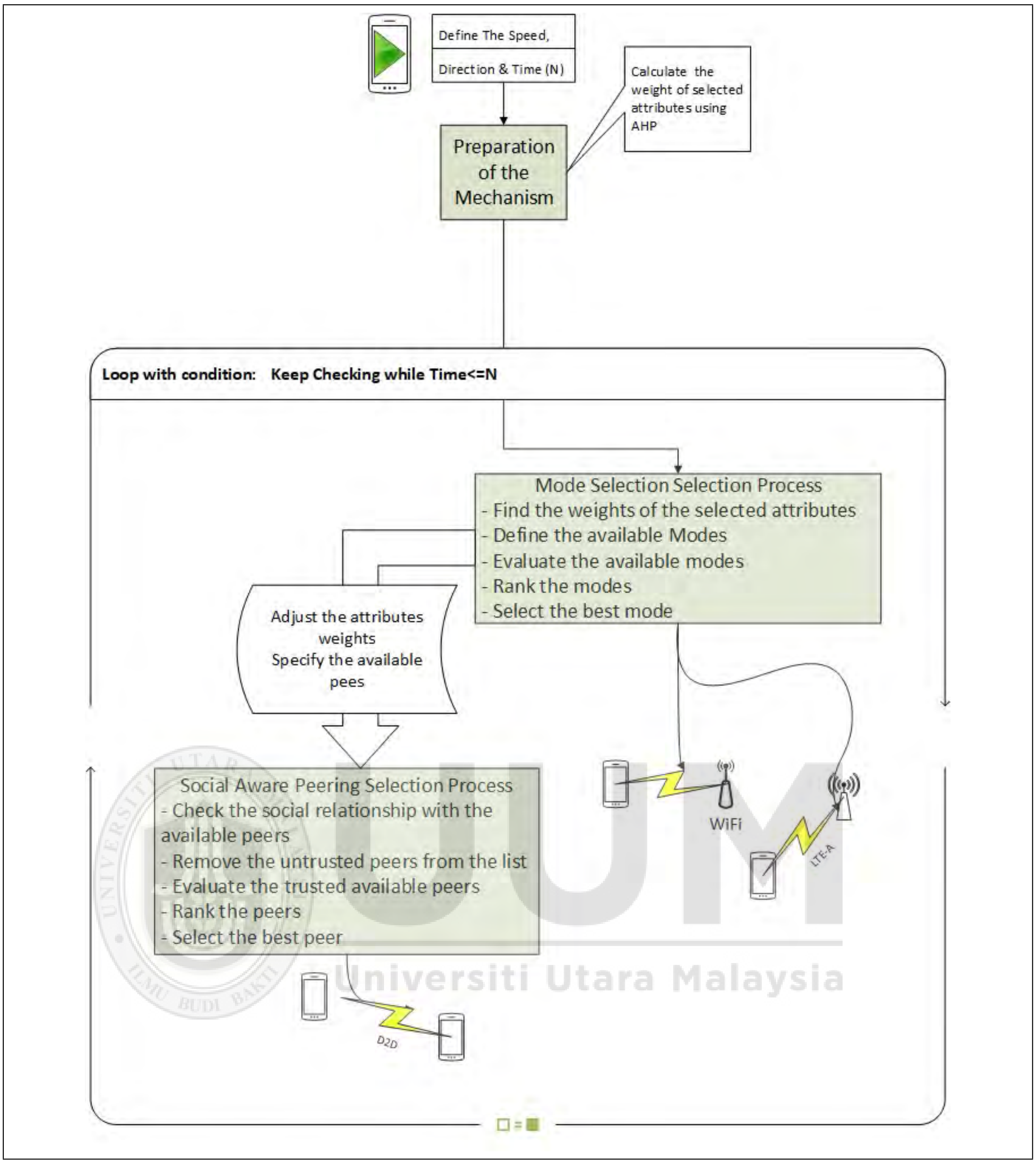

Figure 6.1. Framework of the Proposed Mechanism Implementation

As previously mentioned, steps of both stages continued during one unit of time and the integration stage kept on repeating during the time of communication. They stopped once the time reached the N (the total time of communication).

6.3 Performance Analysis of SPSMS-D2D Mechanism

The proposed Social-aware Peering Selection and Mode Selection for D2D mechanism (SPSMS-D2D) Mechanism performance was examined for evaluation with WLAN available. In this case, a comparison of the system performance between the proposed SPSMS-D2D Mechanism and other approaches in the network was conducted namely Joint-Mode (JM) approach and Kim Delay Mode Selection (KDMS) approach as these approaches were validated in the networks with enabling D2D communication system and every approach focused on different attributes on the selection decision. JM approach focuses on power allocation and using it when the D2D connection work in different modes [41]. While, KDMS approach is based on delay value to make the decision [40]. This case also involved comparing the results of the SPSMS-D2D mechanism and those of other approaches when the connection went through WLAN, LTE-A and D2D communication.

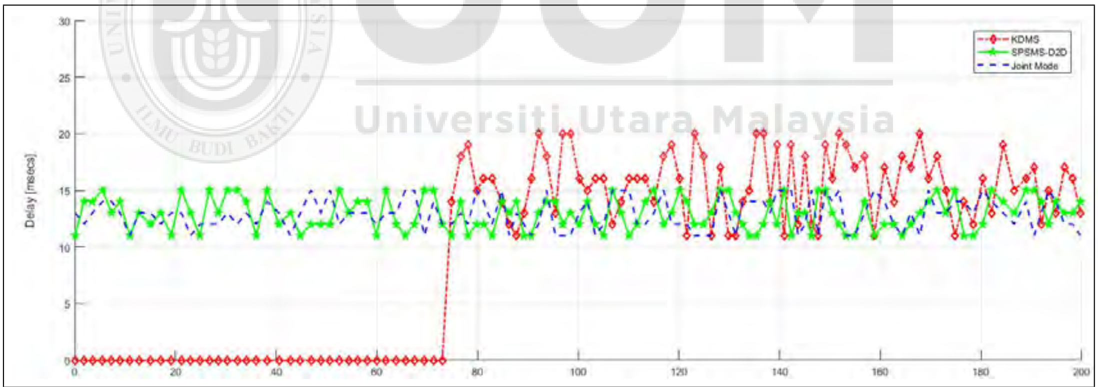

Figure 6.2. Delay Analysis

The connection was ranging from 0 to 200 seconds. As can be seen in Figure 6.2, from 0 to 75 seconds, the KDMS approach showed lower delay than JM approach and SPSMS-D2D mechanism as it connected to the WLAN network the delay value was close to zero. From 75 to 200 seconds, the delay level in KDMS approach increased to a level higher than JM approach and SPSMS-D2D mechanism as average in this period.

Meanwhile, the network was seen highly congested. The buffering delay and scheduling delay were therefore much higher than the SPSMS-D2D mechanism. However, SPSMS-D2D mechanism distributed the load over all networks for each data transmission, which evaluated the delay performance among the available networks as shown in Figure 6.2. So, In KDMS approach, the delay level as average was better than the SPSMS-D2D mechanism when it connected to WLAN network and higher value when it connected to LTE-A network as the selection is based on delay attribute only regardless other attributes.

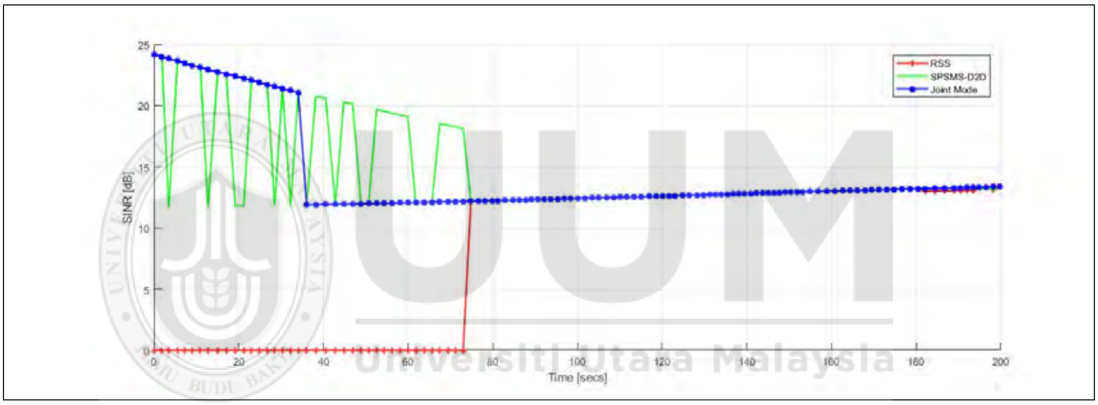

Figure 6.3. SINR Analysis

The SINR performance value is shown in Figure 6.3. From 0 to 38 seconds, the SINR for KDMS approach was close to zero while it was in higher level for JM approach and SPSMS-D2D. It was clear that the SPSMS-D2D mechanism at some points chose to connect to infrastructure, which means that the peers in that points were untrusted. From 38 to 75 seconds, the KDMS approach level was remained low. The SINR value for JM approach dropped down while the average value of SINR in SPSMS-D2D mechanism was higher than both approaches. Furthermore, the SPSMS-D2D mechanism demonstrated a good performance level. Accordingly, the performance in this period showed a better value in SPSMS-D2D at 30% compared to JM approach and more than 90% compared to KDMS approach. From 75 to 200 seconds, the SINR level for all approaches was shown at the same level during this period. Throughout the period of this study, the SPSMS-D2D mechanism showed better performance by 10% than that of JM approach and by 30% compared to KDMS approach. However, in KDMS the SINR value when it connected to WLAN network close to zero which mean the interference is almost infinity. So, by calculate Signal/Interference it was almost zero which means there is a detected signals which failed to perform well in the device which will affect the offered bandwidth value. While the JM approach showed better performance than KDMS approach as the selection in this approach based on distance and SINR values. However, the performance level during the studied time for SPSMS-D2D mechanism showed better level than KDMS and JM approaches.

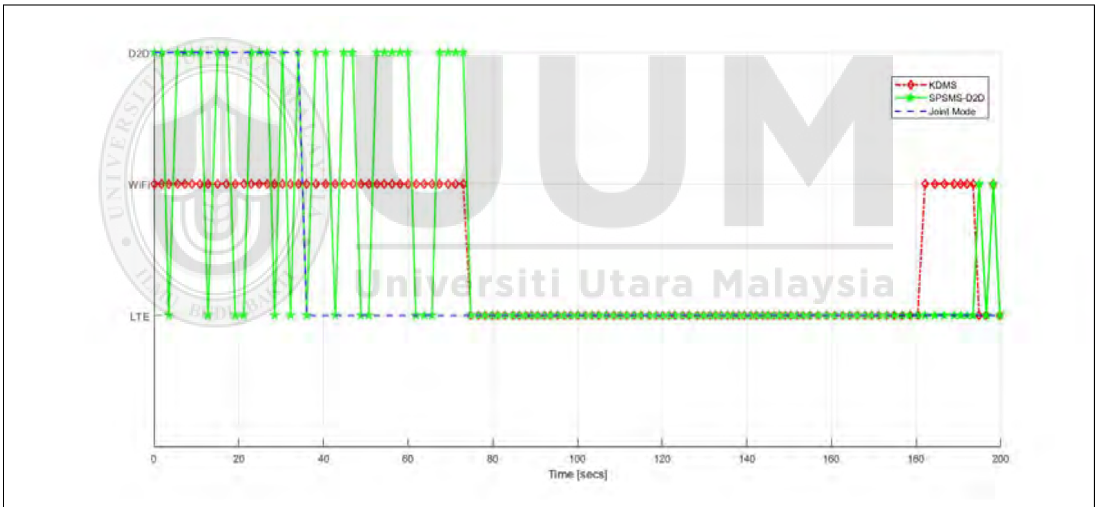

Figure 6.4. RAT Selection Analysis

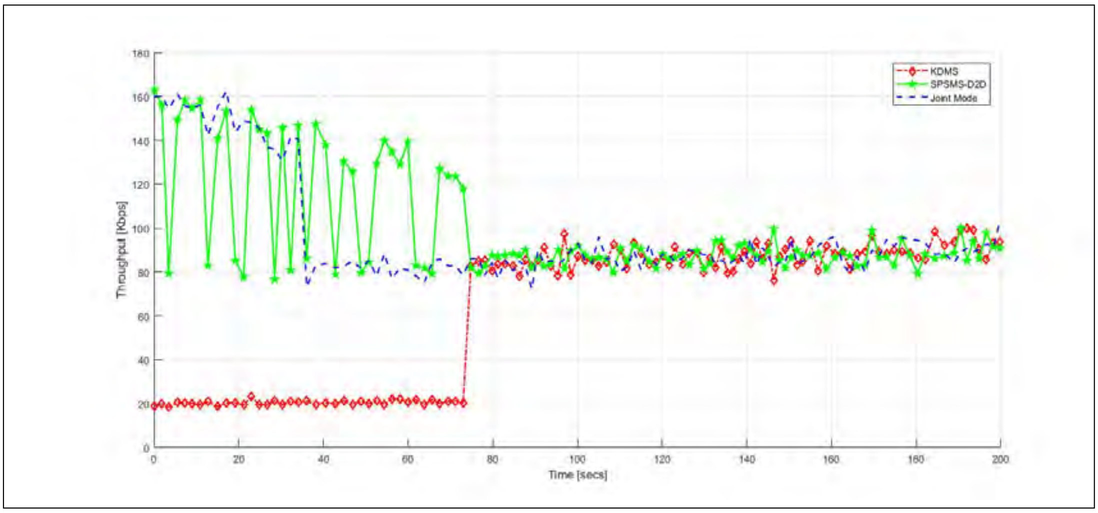

Figure 6.5. Throughput Analysis

The results based on Figure 6.4 and Figure 6.5 can be divided into three phases as follow:

Phase 1: From 0 to 38 seconds, the KDMS approach showed a low level of performance for throughput while the JM approach showed a higher one, but the throughput in SPSMS-D2D mechanism as average was less than JM approach in this period due to the social-aware factor, which means that the SPSMS-D2D protected the privacy of the users when the destination peers were untrusted.

Phase 2: From 38 to 75 seconds, the user kept moving in a particular area. The throughput level in JM approach dropped down while that in KDMS approach remained at the lowest level, whereas the throughput in SPSMS-D2D mechanism showed better performance than the other two approaches. Therefore, in KDMS approach this value in this period is not enough to serve the user as it was about 20 Kb/S which is enough for only signaling message like discovery message.

Phase 3: From 75 to 200 seconds, the throughput performance in SPSMS mechanism dropped to the same level in JM approach while the KDMS approach jumped to the same level. So, all approaches showed similar performance in terms of throughput as they had selected the LTE-A network as shown in Figure 6.5.

According to Figure 6.4, the enabling D2D communication system in the network allowed using the D2D communication link, which was reflected in the performance value for different metrics. In this case, the KDMS is failed to connect using D2D mode during this communication time as it made the selection based on delay attribute only.

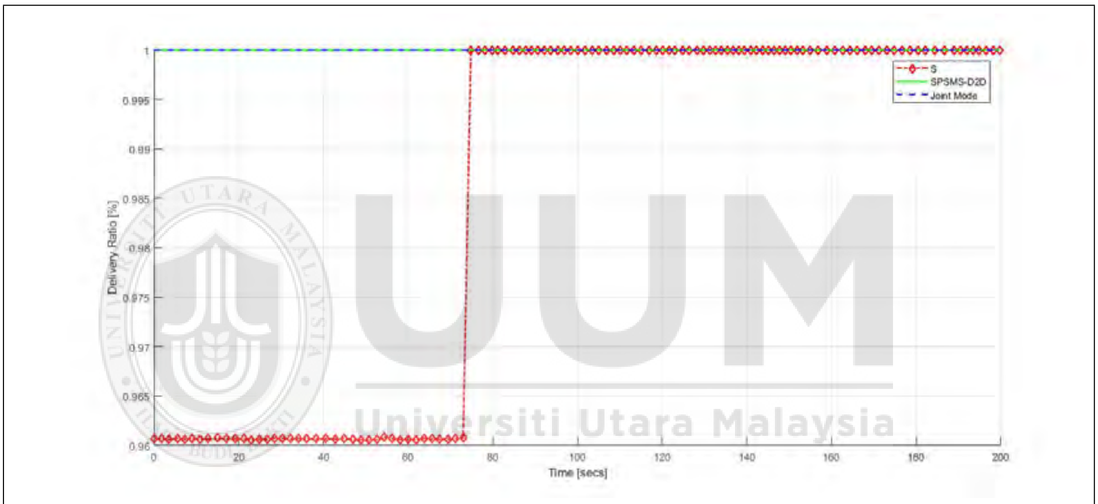

Figure 6.6. Delivery Ratio Analysis

As shown in the Figure 6.6, the delivery ratio was found to be the same for SPSMS-D2D mechanism and JM approach with 100% delivery ratio all the time, which was first at 96% in the period from 0 to 75 seconds and increased to 100% from 75 to 200 seconds.

6.4 Performance Evaluation of SPSMS-D2D Mechanism

This section discusses the testing of the proposed model. The evaluation involved different cases and showed the average of the performance level of the obtained results as well as the improvements achieved. First, the evaluation began by testing the change in the user's movement speed, which may affect the connection condition. Second, the number of users in the network was tested, which affects the availability of the devices for the D2D connection.

6.4.1 Different Speed of User

In this evaluation stage, a comparison was made between the results of the proposed mechanism and other approaches' results when the user moved at different speed rates. The obtained results revealed that the user's speed range in the proposed model was between 5 to 40 km/h. The evaluation of the proposed model underwent many experimental to test the model's strengths and weaknesses.

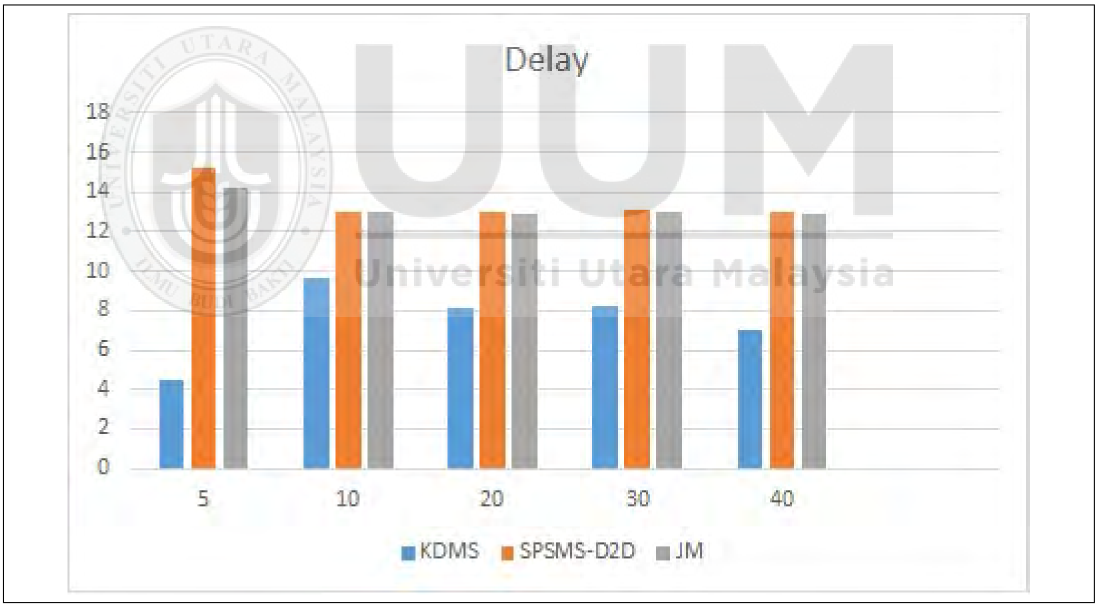

Figure 6.7. Delay Evaluation for Different Speed

The delay evaluation was tested to show the stability of the proposed mechanism in when the user moved among the network in different speed. The evaluation also aimed to prove that the proposed approach can accommodate different speed rates and maintain the acceptable delay value compared to other approaches.

Figure 6.7 shows that at the speed of 5 km/h, the KDMS approach showed better delay level than SPSMS-D2D mechanism and JM approach by about 60% because the decision in KDMS based on delay factor only. Also, it was noticed at the speed rates of 10, 20, 30, and 40 km/h the KDMS approach kept the delay level better than SPSMS-D2D mechanism and JM approach between 20% to 50%. Therefore, the proposed mechanism achieved acceptable level of delay but was not the best one as showed in the results. So, the evaluation should include the other evaluation metrics to have better view about the proposed mechanism.

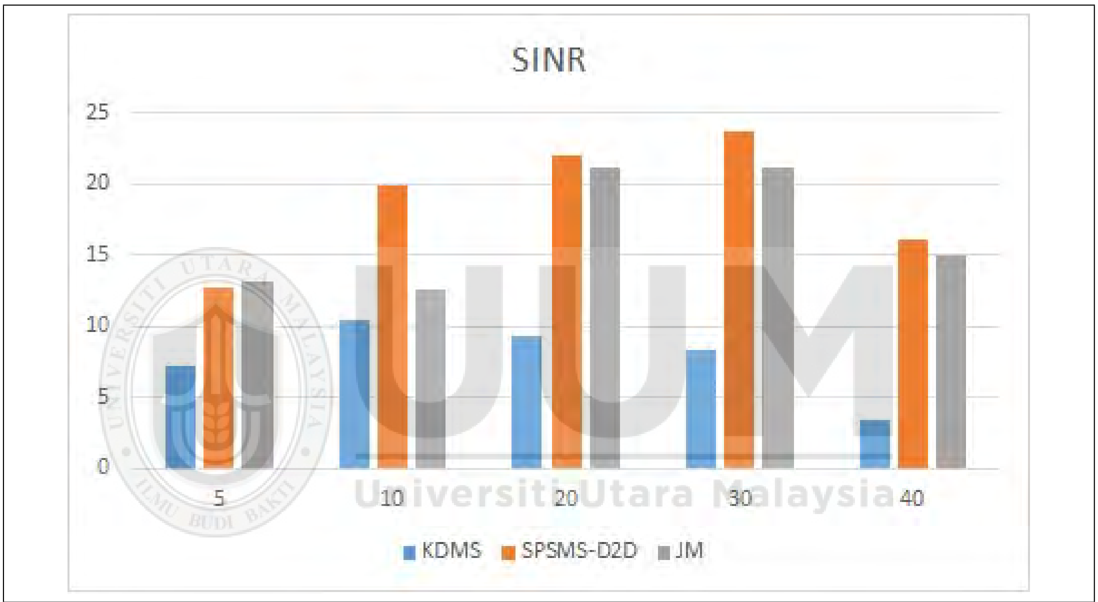

Figure 6.8. SINR Evaluation for Different Speed

The SINR evaluation was carried out at different speed rates using a different level of user movement speed to show how the proposed mechanism can deliver the highest SINR level. The test underwent different speed rates to test reality from 5km/h to 40 km/h. Therefore, the proposed mechanism was used in testing, whereby the time margin and the connection condition changed during the movement of the user.

As proof of the concept, as shown in Figure 6.8, the SPSMS-D2D mechanism demonstrated as average better performance than that of other approaches. At the speed rate of 5 km/h, the SPSMS-D2D mechanism showed better performance level of SINR than the KDMS approach at about 35% and almost similar to JM approach. This enhancement was achieved because the proposed mechanism took the decision of selection based on multi attributes with considering the social relationship between peers. When the user movement speed increased to 10, 20, 30 and 40 km/h, the SPSMS-D2D mechanism showed stable values of SINR, and better performance compare to KDMS approach and JM approach. The performance of SPSMS-D2D mechanism better than the KDMS approach from 30% to 60%. While the SPSMS-D2D mechanism performance compares to JM approach showed a lower value by about 2% in the speed of 5Km/h, but in other rates, it showed better performance than JM approach from 5% to 45%. Therefore, the SINR level in SPSMS-D2D mechanism showed better performance level with considering the privacy of the peers, which may make the performance close to JM approach but in all cases stayed better than the KDMS approach.

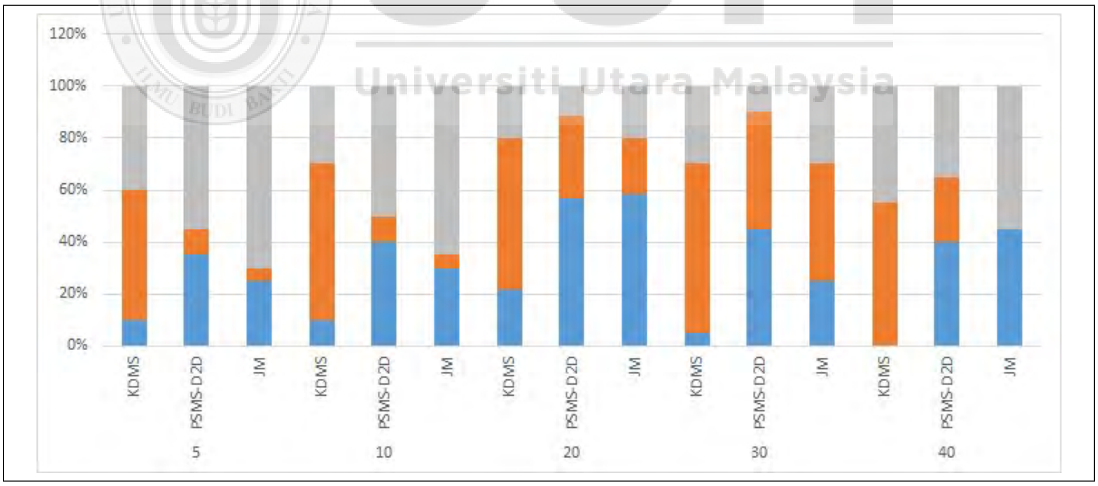

Figure 6.9. Mode Selected for Different Speed

In the Figure 6.9, it showed the percentage of every selected mode which is affect on the overall performance. The SPSMS-D2D mechanism showed balanced selection between different modes and it selected D2D mode and switched between modes even when the speed increase from 5Km/h to 40Km/h while in the KDMS approach, it preferred to connect using WLAN network and JM approach preferred to connect using LTE-A network.

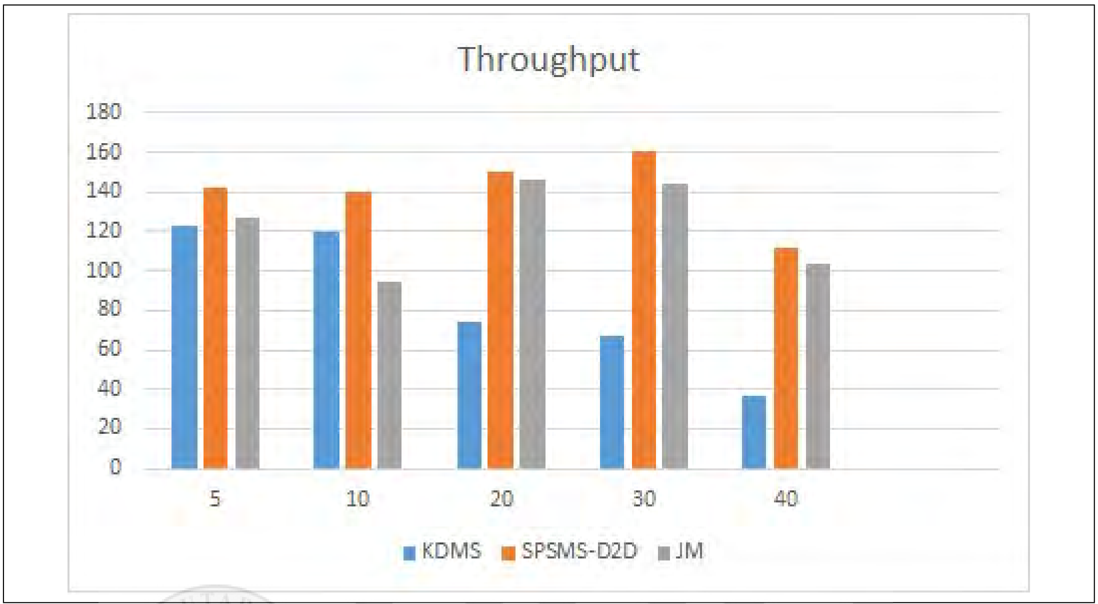

Figure 6.10. Throughput Evaluation for Different Speed

The throughput evaluation was used to evaluate the received data rate at the user's side during moving time. The throughput level related to the link condition and the value changed according to the user movement among the network. The throughput evaluation was carried out at different movement speed of the user when going through the network to show how the proposed SPSMS-D2D mechanism can deliver the highest throughput level to match the reality.

As an evident proof of the concept, as shown in Figure 6.10 the SPSMS-D2D approach showed better performance than other approaches' performance. At the speed rate of 5 km/h, the SPSMS-D2D mechanism exhibited a better performance at about 8% and 10% than JM approach and KDMS approach, respectively. At the speed 40 km/h and for the enhancement at high-speed rates, the proposed model achieved better performance at about 5% compared to JM approach and at about 60% compared to KDMS approach. So, the SPSMS-D2D mechanism showed stable throughput level when the user movement speed increased from 5 km/h to 40 km/h with better performance level compare to other approaches.

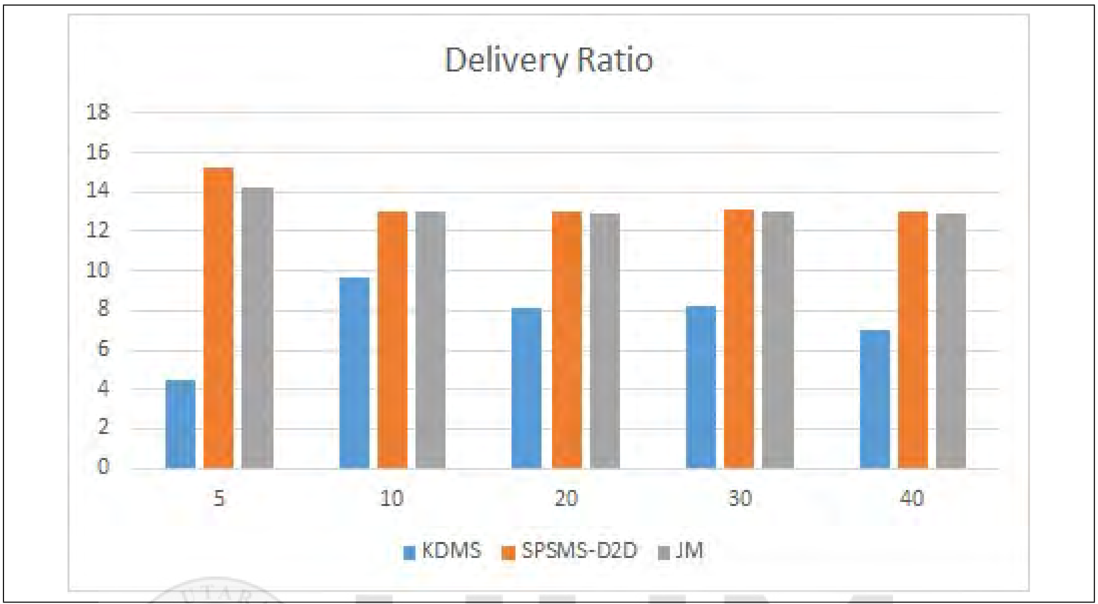

Figure 6.11. Delivery Ratio Evaluation for Different Speed

Figure 6.11 illustrates the delivery ratio, which may decreased in KDMS approach and JM approach when the speed increased from 5 to 40 km/h while the proposed SPSMS-D2D mechanism achieved better performance than the performance of other approaches with not less than 99.5% of delivery ratio in all evaluation cases for different speed rate.

6.4.2 Different Number of Users in the Network

A comparison was made between the results of the proposed mechanism and other approaches when the user moved in different user number density. The user number in this evaluation case was ranged between 500 users to 2500 users in the network topology.

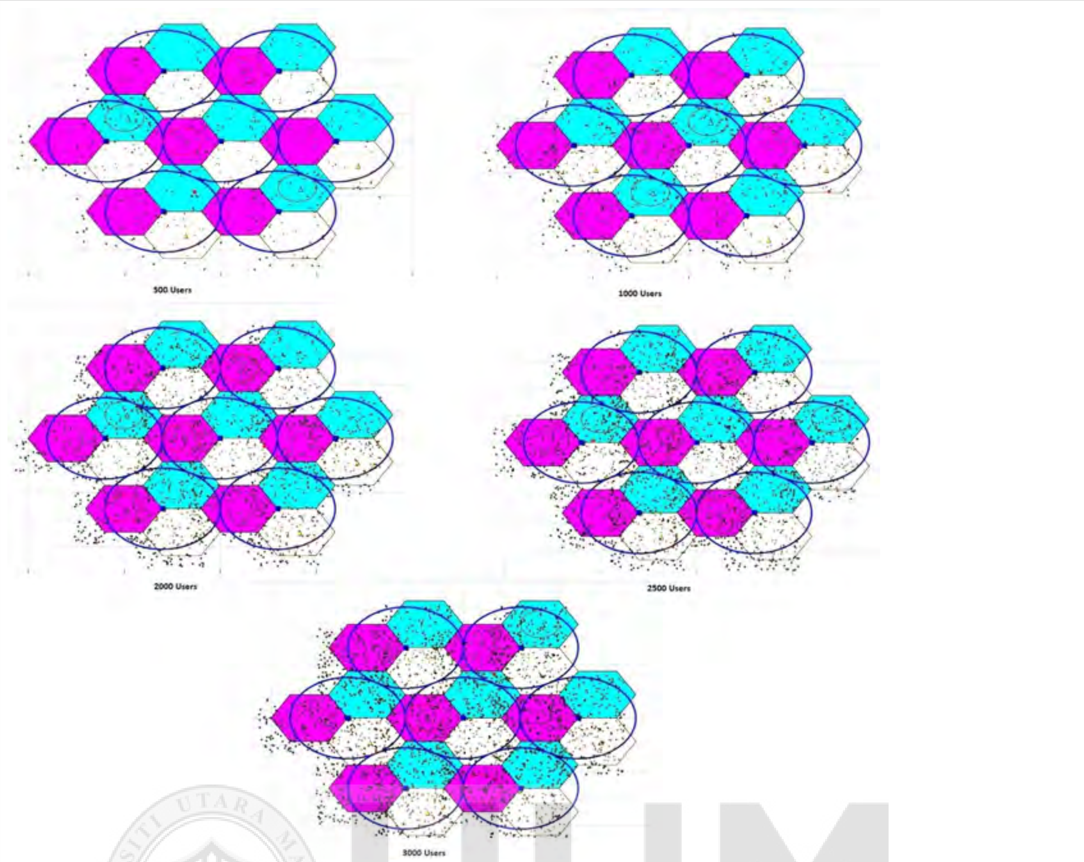

Figure 6.12. Density Based on Number of Users

Figure 6.23 shows the user density. This evaluation stage tested the performance metrics of the proposed mechanism against other approaches.

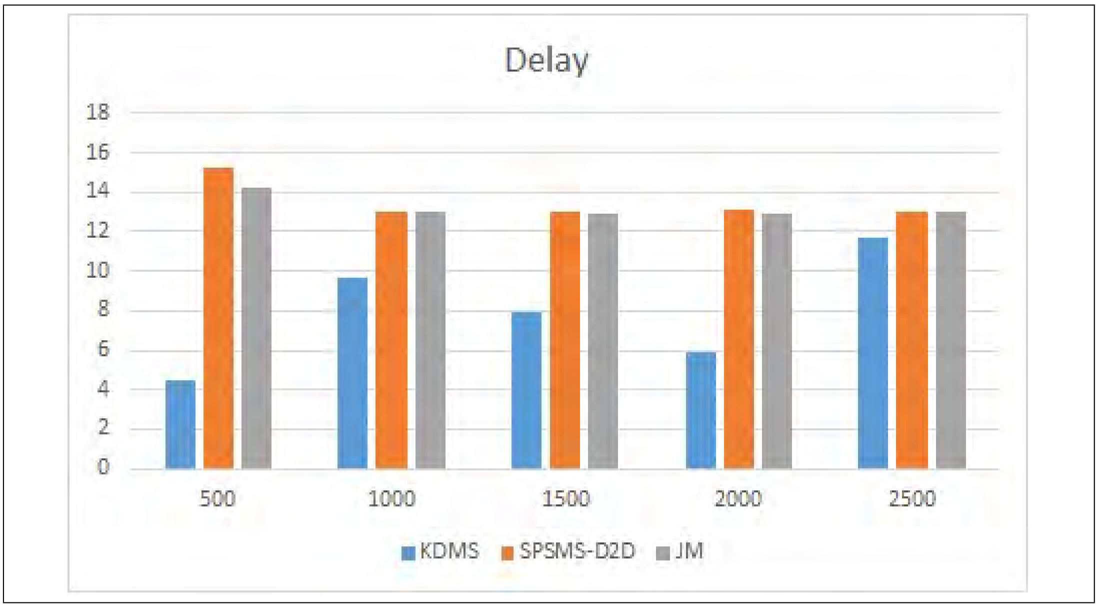

Figure 6.13. Delay Evaluation for Different Number of Users

In the Figure 6.13, the evaluation aimed to prove that the proposed approach can accommodate different numbers of users and maintain the delay value compared to other approaches. When the number of users reached 500, the SPSMS-D2D mechanism achieved enhancement by about 4% compared to the JM approach but the KDMS is lower by about 60% than the SPSMS-D2D mechanism. A similar performance was noticed when the number of users reached 1000, 1500, 2000 and 2500 users in the network. It is worth to mention that when the number of users reached 2500, the SPSMS-D2D mechanism accomplished the good performance level and the value of delay is close to other approaches. The results indicated that the proposed mechanism can successfully implement the D2D communication system.

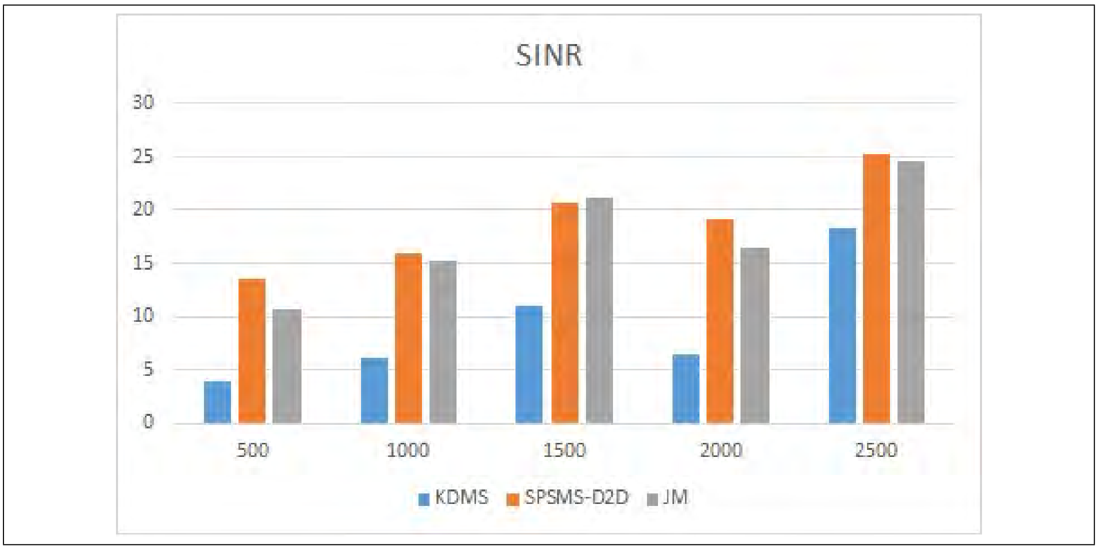

Figure 6.14. SINR Evaluation for Different Number of Users

The SINR evaluation was carried out for a different number of users in different approaches to show how the proposed SPSMS-D2D mechanism can deliver the highest SINR level. In this evaluation, the test went through different number of users in the network with constant speed to test reality. To prove the concept, in Figure 6.14 the SPSMS-D2D approach showed better performance than other approaches. When the number of users reached 500, the SPSMS-D2D mechanism achieved better performance at about 75% and 20% than the KDMS approach and JM approach , respectively. This enhancement was achieved because the proposed model gave a higher priority to select the peer and mode based on MADM with concerning the social relationship to filter the users and avoid to select to establish D2D connection with the untrusted peer. When the number of users reached 2500, an enhancement was achieved at high density of users which may affect the connection conditions. Accordingly, the proposed mechanism showed better performance for different users number in the network, it was better than KDMS approach between 20% to 75% while it as better than JM approach from about 5% to 25%.

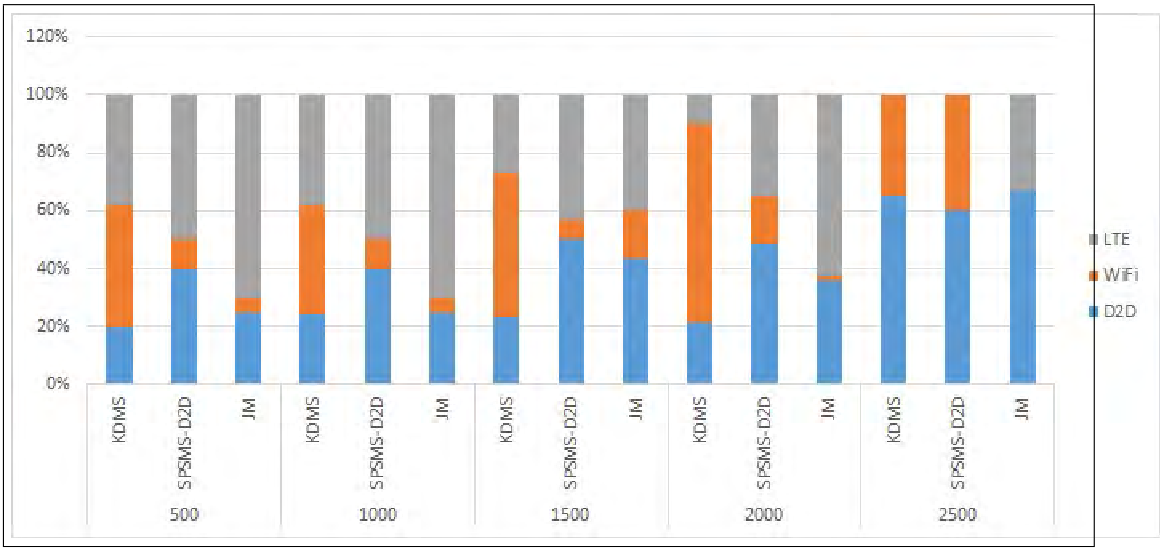

Figure 6.15. Mode Evaluation for Different Number of Users

Figure 6.15 shows the selected modes to establish the connection for the different tests when D2D communication system enabled in the network. It showed that the possibility of selected the D2D connection increased when the number of users increased in the network which is reflected in the performance value for different metrics.

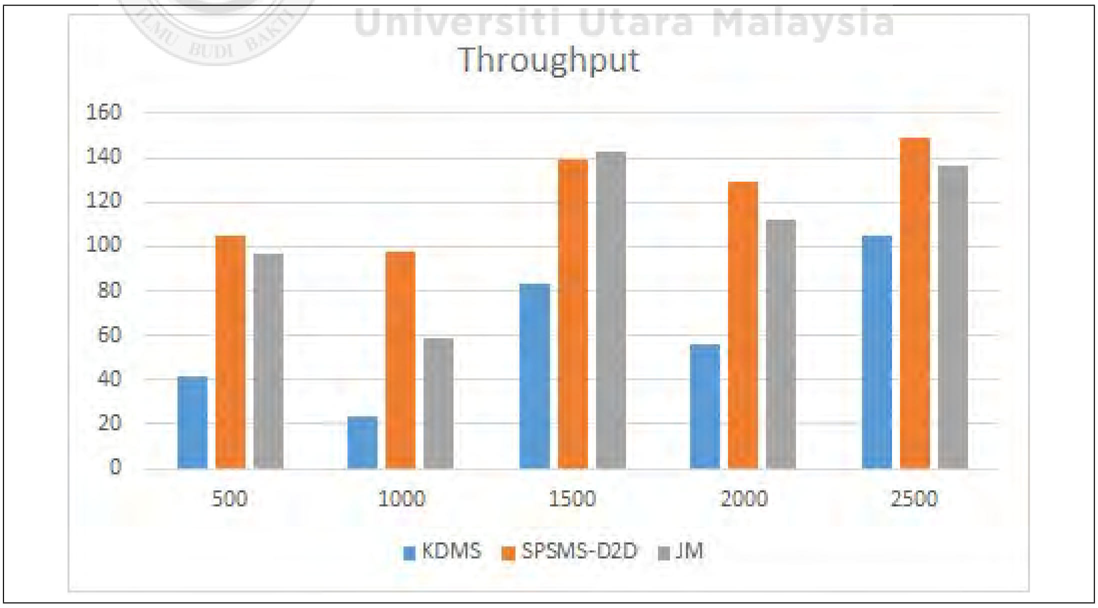

Figure 6.16. Throughput Evaluation for Different Number of Users

The test went through different numbers of users to test reality and stability. To match the reality, the proposed SPSMS-D2D mechanism was tested in these different cases. To prove the concept, as shown in Figure 6.16 the SPSMS-D2D mechanism demonstrated better performance than other approaches' performance. When the number of users reached 500, the SPSMS-D2D mechanism showed better performance at about 5% and 60% than the JM approach and the KDMS approach, respectively. When the number of users reached 2500, an enhancement in high density of users was achieved. Therefore, the proposed model showed better performance at about 15% compared to the JM approach and at about 25% compared to the KDMS approach.

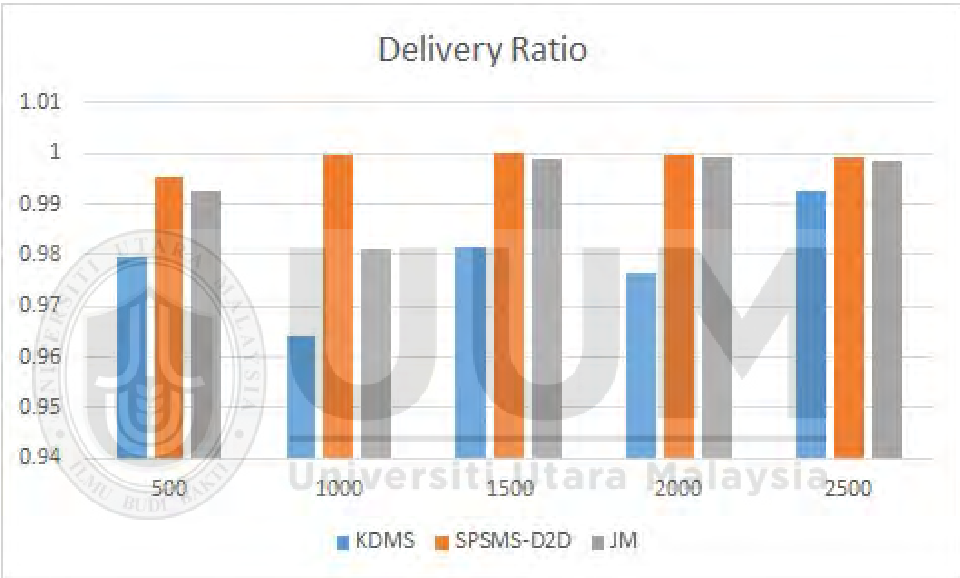

Figure 6.17. Delivery Ratio Evaluation for Different Number of Users

As shown in Figure 6.17, the delivery ratio was always better in the proposed mechanism compared to the delivery ration in other approaches. This occurred when the number of users changed from 500 to 2500 users. In all evaluation cases, the proposed mechanism achieved better results than the performance of other approaches with not less than 99.5% to 100% of delivery ratio.

6.5 Summary

This chapter has presented and discussed in detail the results of the proposed mechanisms' experiment in various scenarios. The obtained results emphasised the importance of the D2D communication system for future networks in any expected scenario. A comparison has been made between the results of the proposed mechanism with JM approach and KDMS approach. The obtained results showed improvements in the average performance level during the experiment time when the user moved through unstable areas. The findings also demonstrated improvements when the connection went through three different modes. The evaluation underwent two stages; first, the evaluation of performance carried out when the user moved at different speed rates while the second was a performance evaluation made when there was a change in the number of users in the network. In both stages, the results in the proposed mechanism showed better performance compared to JM and KDMS approaches.

CHAPTER SEVEN
CONCLUSION

7.1 Summary of the Study

This study aims to expand the D2D communication system and implement D2D mechanism for a heterogeneous network besides validating and evaluating the proposed mechanism in this study. This chapter is divided into four sections. An overview of the study for the importance of implementing the D2D communication system in the future networks is given in the first section where the findings of this study are presented and explained. The contributions of this study are forwarded in the second section. The third section discusses the limitations of this study. Useful recommendations for further studies are advanced in the fourth section of this chapter.

This study was aimed at designing the mechanism to serve the D2D communication system. It has discussed the issues and challenges related to D2D communication. An evaluation of the proposed mechanism has been carried out in this study. The proposed peering selection scheme was designed to enable D2D communication in heterogeneous networks. In addition, a mode selection scheme, which enables always-best connection, has been proposed in this study. The methodology, which was adopted to achieve the study objectives, was drawn upon DRM. In order to achieve the objectives of the study, a technical methodology, which has been discussed in Chapter 3, was essentially followed. Then, the implementation processes of the proposed mechanism have been carried out by MATLAB.

The advantages of the D2D communication system have motivated this study to propose a novel mechanism to tackle the problems and limitations in this area. Although a mode selection scheme has been described in the scholarly literature, there is a need for further improvement in mode selection scheme that can deal with different environments with the presence of thousands of users in the same area where all of them need to be connected; many users may also need to communicate with each other in the same area. As explained in Chapter 1, the current mechanisms are simple and depend on one or multi metric to test the performance. However, they perform poorly when the number of users highly increases. In addition, the available mechanisms cannot perform well when there is a need to use D2D connection in heterogeneous networks with high density and frequent movement with different speeds. Therefore, the proposed mechanism might be fundamentally helpful in certain critical cases, considering multi parameters in choosing the destination device. This helps to improve the network performance and provide reliable and stable connection for users in these cases

Previous related studies in this area have been reviewed in Chapter 2 along with the comparison between them. According to the literature, the D2D communication system has several unique features, which necessitate the implementation of the proposed approach. In addition, well-known mechanisms have been critically reviewed to provide a deeper understanding on the performance issues in mechanisms for enabling the D2D communication system. This inspired the D2D model to implement SMAPS-D2D and MAMS-D2D schemes to enhance the network's performance. Therefore, an evaluation of the connection's features has been reviewed and studied. To achieve the objectives of this study, DRM was adopted as a methodology framework or guideline. The implementation process was proposed using MATLAB experimental tools. Multi attributes have been considered, which are related to the system's model and different case studies.

Basically, the device checks available modes on the surrounding area. So, the MAMS-

D2D scheme will rely on multi-criteria to make decision namely RSS, Delay and Bandwidth. The main role of MAMS-D2D scheme is to calculate the accurate weight directed to make the decision of connecting with the best peer. MAMS-D2D scheme solved the challenges in always finding the best available mode and avoided connection drops when switching between different modes. Also, the AHP algorithm was adopted to efficiently calculate the weight for related parameters. Then, the SAW was proposed to choose the optimum D2D connectivity. With respect to the result of MAMS-D2D scheme validation, improvement has been seen in the performance metrics namely delivery ratio, throughput, SINR, switching between different RATs and delay by 10% in some points, which reached to 25% on indoor environment and 45% on outdoor environment. The validation of the MAMS-D2D scheme showed that optimum solution can be reached using the multi-criteria in effective and creative ways to make the decision.

The device starts to check available devices on the surrounding area that can provide a stable connectivity as well as guaranteed application demands and user preferences. For doing so, the multi-attribute decision making of this SMAPS-D2D scheme will rely on multi-attributes to make decision namely RSS, Delay, Bandwidth and Power consumption. The main role of SMAPS-D2D scheme is to calculate the accurate weight directed to make the decision of connecting with the best peer. The SMAPS-D2D scheme solved the challenges in always finding best available peer and providing stable connection. So, the AHP algorithm was adopted to efficiently calculate the weight for related criteria. Then, the HAW was proposed to choose the optimum D2D connectivity. With respect to the result of SMAPS-D2D scheme validation, improvement in the performance metrics was observed on delivery ration, throughput, SINR and delay by 10% in some points and reached to 45% on another points. This validation of the SMAPS-D2D scheme showed optimum solution that can be achieved using the multi-attributes in effective and creative ways to make the decision. This study concluded that mobile stations should always have reliable connections with available technologies to satisfy the demands required by users.

7.2 Contributions of the Study

The main contribution of this study is in the design of D2D mechanisms for the wireless networks to reduce connection's performance delay and improve SINR, throughput and the packet delivery ratio. The new mechanism can work together to provide a high level of QoS and improve connection's efficiency between paired devices. Other contributions of this study include the following:

i. The proposed MAMS-D2D scheme can provide a smooth choosing between different modes, which controls the mode selection based on Simple Additive Weighting (SAW) algorithm. The MAMS-D2D scheme can find the best mode of connection by considering the environment status, application demands and user preferences.

ii. The proposed SMAPS-D2D scheme can employ an automatic peering selection during connection time, which controls the peering identification and selection based on social-aware relationship between peers depending on trust level and connection conditions by adopting Hierarchical Adaptive Weighting (HAW) algorithm. The SMAPS-D2D scheme can find the destination of peer by considering the application demands, relationship between peers and user preferences. The proposed scheme will then select the best trusted peer to establish the connection based on estimated multi-attributes namely the Received Signal Strength (RSS), delay, power and the offered bandwidth.

iii. The proposed SPSMS-D2D mechanism is able to support coexistence in the existing multi mode of connection when D2D mode is enabled in different wireless networks and can be extended to support the future networks by considering further criteria and networks' features.

iv. The proposed SPSMS-D2D mechanism was designed and implemented in many cases as well as the integration of AHP, HAW and SAW considering the social relationship between peers are implemented in MATLAB, which simulates a real communication environment.

7.3 Limitations of the Study

This study involved choosing the best method that can support and serve the D2D communication system in the current and future networks. The proposed model's setup was based on critical cases, whereas the assumption in the experiment setup was set to focus on random movement of one device where multi-devices should be considered. Hence, this study has limitations in relation to the number of device movement at the same time where the proposed mechanism evaluates the movement of one user among the network. So, increasing the number of users and evaluating their performance when they are moving among the network at the same time will show the strengths and weaknesses of the mechanism.

However, it was very difficult to cover all the aspect of experimentation with different tools such as test-bed measurement in this study. The evaluation was carried out using only experiment since implementing the proposed mechanism in a real platform is difficult in terms of available financial resources to provide real measurements and characterisation of the real channel between D2D connection and other available modes.

Simple mode selection procedures have obtained unsatisfactory results. Therefore, a new mode selection procedure has been proposed. The new procedure considered the quality of D2D link and different interference situations when cellular uplink or downlink resources were shared. The proposed mechanism also considered the performance of the cellular link for D2D terminals. The results of this study revealed that the proposed mode selection procedure can ensure a reliable D2D communication with the expectation of limited interference. However, interference was not fully considered in this study.

7.4 Future Aspects

The proposed mechanism in this study has improved the mode and peering selection mechanism for an efficient enabling of D2D communication system in wireless networks, which achieved improvements in the network performance. A number of useful directions and recommendations for further studies, including rectifying the limitations outlined above, are as follow:

a) Extending the scenario: The setup of implementation of this study can be extended to cover public safety cases. Nevertheless, this study can be applied in many other cases such as base station failure, V2V and real-time applications.

b) Conducting the test while many devices are moving at the same time: In some cases, many devices are capable of moving among the network topology. Therefore, it is very important to test the network performance when many sides are mobile.

c) Evaluating other case studies: Applying routing approaches, multi-hop connection as well as one-to-many communication can be used to improve this study. d) Experiment limitation: Further studies can be applied in practical test-bed and real-time measurement.

e) Evaluating D2D mechanism in a real environment: The proposed mechanism has been implemented extensively and evaluated using real environment imitation. Nonetheless, extending the evaluation to a real environment may reveal new challenging issues.

REFERENCES

[1] T. L. Saaty, "Decision-making with the AHP:Why is the principal eigenvector necessary," *European journal of operational research*, vol. 145, no. 1, pp. 85–91, 2003.

[2] A. Osseiran, F. Boccardi, V. Braun, K. Kusume, P. Marsch, M. Maternia, O. Queseth, M. Schellmann, H. Schotten, H. Taoka, *et al.*, "Scenarios for 5g mobile and wireless communications: the vision of the metis project," *Communications Magazine, IEEE*, vol. 52, no. 5, pp. 26–35, 2014.

[3] Z. Li, M. Moisio, M. A. Uusitalo, P. Lundén, C. Wijting, F. S. Moya, A. Yaver, and V. Venkatasubramanian, "Overview on initial metis d2d concept," in *5G for Ubiquitous Connectivity (5GU), 2014 1st International Conference on*, pp. 203–208, IEEE, 2014.

[4] M. Mirahsan, R. Schoenen, S. S. Szyszkowicz, and H. Yanikomeroglu, "Measuring the spatial heterogeneity of outdoor users in wireless cellular networks based on open urban maps," in *Communications (ICC), 2015 IEEE International Conference on*, pp. 2834–2838, IEEE, 2015.

[5] Z. Ding, Y. Liu, J. Choi, Q. Sun, M. Elkashlan, I. Chih-Lin, and H. V. Poor, "Application of non-orthogonal multiple access in lte and 5g networks," *IEEE Communications Magazine*, vol. 55, no. 2, pp. 185–191, 2017.

[6] P. Sharma, "Evolution of mobile wireless communication networks-1g to 5g as well as future prospective of next generation communication network," *International Journal of Computer Science and Mobile Computing*, vol. 2, no. 8, pp. 47–53, 2013.

[7] J. G. Andrews, S. Buzzi, W. Choi, S. V. Hanly, A. Lozano, A. C. Soong, and J. C. Zhang, "What will 5g be?," *Selected Areas in Communications, IEEE Journal on*, vol. 32, no. 6, pp. 1065–1082, 2014.

[8] C.-X. Wang, F. Haider, X. Gao, X.-H. You, Y. Yang, D. Yuan, H. Aggoune, H. Haas, S. Fletcher, and E. Hepsaydir, "Cellular architecture and key technologies for 5g wireless communication networks," *Communications Magazine, IEEE*, vol. 52, no. 2, pp. 122–130, 2014.

[9] K. Akkarajitsakul, P. Phunchongharn, E. Hossain, and V. K. Bhargava, "Mode selection for energy-efficient d2d communications in lte-advanced networks: A coalitional game approach," in *2012 IEEE international conference on communication systems (ICCS)*, pp. 488–492, IEEE, 2012.

[10] A. Asadi, Q. Wang, and V. Mancuso, "A survey on device-to-device communication in cellular networks," *Communications Surveys & Tutorials, IEEE*, vol. 16, no. 4, pp. 1801–1819, 2014.

[11] Z. Zhou, G. Ma, M. Dong, K. Ota, C. Xu, and Y. Jia, "Iterative energy-efficient stable matching approach for context-aware resource allocation in d2d communications," *IEEE Access*, vol. 4, pp. 6181–6196, 2016.

[12] G. Fodor, E. Dahlman, G. Mildh, S. Parkvall, N. Reider, G. Miklós, and Z. Turányi, "Design aspects of network assisted device-to-device communications," *Communications Magazine, IEEE*, vol. 50, no. 3, pp. 170–177, 2012.

[13] A. Aijaz, M. Dohler, A. H. Aghvami, V. Friderikos, and M. Frodigh, "Realizing the tactile internet: Haptic communications over next generation 5g cellular networks," *IEEE Wireless Communications*, vol. 24, no. 2, pp. 82–89, 2017.

[14] A. Zakrzewska, S. Ruepp, and M. S. Berger, "Towards converged 5g mobile networks-challenges and current trends," in *ITU Kaleidoscope Academic Conference: Living in a converged world-Impossible without standards?, Proceedings of the 2014*, pp. 39–45, IEEE, 2014.

[15] M. Nitti, V. Popescu, and M. Fadda, "Using an iot platform for trustworthy d2d communications in a real indoor environment," *IEEE Transactions on Network and Service Management*, vol. 16, no. 1, pp. 234–245, 2018.

[16] S. Hakola, T. Chen, J. Lehtomaki, and T. Koskela, "Device-to-device (d2d) communication in cellular network-performance analysis of optimum and practical communication mode selection," in *2010 IEEE wireless communication and networking conference*, pp. 1–6, IEEE, 2010.

[17] B. Bangerter, S. Talwar, R. Arefi, and K. Stewart, "Networks and devices for the 5g era," *Communications Magazine, IEEE*, vol. 52, no. 2, pp. 90–96, 2014.

[18] A. Samuylov, A. Ometov, V. Begishev, R. Kovalchukov, D. Moltchanov, Y. Gaidamaka, K. Samouylov, S. Andreev, and Y. Koucheryavy, "Analytical performance estimation of network-assisted d2d communications in urban scenarios with rectangular cells," *Transactions on Emerging Telecommunications Technologies*, vol. 28, no. 2, 2017.

[19] H. Tullberg, Z. Li, A. Hoglund, P. Fertl, D. Gozalvez-Serrano, K. Pawlak, P. Popovski, G. Mange, and O. Bulakci, "Towards the metis 5g concept: First view on horizontal topics concepts," in *Networks and Communications (EuCNC), 2014 European Conference on*, pp. 1–5, IEEE, 2014.

[20] W. Zhi, K. Zhu, Y. Zhang, and L. Zhang, "Hierarchically social-aware incentivized caching for d2d communications," in *2016 IEEE 22nd International Conference on Parallel and Distributed Systems (ICPADS)*, pp. 316–323, IEEE, 2016.

[21] M. N. Tehrani, M. Uysal, and H. Yanikomeroglu, "Device-to-device communication in 5g cellular networks: challenges, solutions, and future directions," *Communications Magazine, IEEE*, vol. 52, no. 5, pp. 86–92, 2014.

[22] L. Militano, A. Orsino, G. Araniti, M. Nitti, L. Atzori, and A. Iera, "Trusted d2d-based data uploading in in-band narrowband-iot with social awareness," in *2016 IEEE 27th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, pp. 1–6, IEEE, 2016.

[23] E. Larsson, O. Edfors, F. Tufvesson, and T. Marzetta, "Massive mimo for next generation wireless systems," *Communications Magazine, IEEE*, vol. 52, no. 2, pp. 186–195, 2014.

[24] G. Araniti, C. Campolo, M. Condoluci, A. Iera, and A. Molinaro, "Lte for vehicular networking: a survey," *IEEE communications magazine*, vol. 51, no. 5, pp. 148–157, 2013.

[25] Y. Kawamoto, J. Liu, H. Nishiyama, and N. Kato, "An efficient traffic detouring method by using device-to-device communication technologies in heterogeneous network," in *Wireless Communications and Networking Conference (WCNC), 2014 IEEE*, pp. 2162–2167, IEEE, 2014.

[26] A. Asadi and V. Mancuso, "Network-assisted outband d2d-clustering in 5g cellular networks: theory and practice," *IEEE Transactions on Mobile Computing*, vol. 16, no. 8, pp. 2246–2259, 2017.

[27] Y. Li, T. Wu, P. Hui, D. Jin, and S. Chen, "Social-aware d2d communications: Qualitative insights and quantitative analysis," *IEEE Communications Magazine*, vol. 52, no. 6, pp. 150–158, 2014.

[28] M. Agiwal, A. Roy, and N. Saxena, "Next generation 5g wireless networks: A comprehensive survey," *IEEE Communications Surveys & Tutorials*, vol. 18, no. 3, pp. 1617–1655, 2016.

[29] E. Hossain, M. Rasti, H. Tabassum, and A. Abdelnasser, "Evolution toward 5g multi-tier cellular wireless networks: An interference management perspective," *Wireless Communications, IEEE*, vol. 21, no. 3, pp. 118–127, 2014.

[30] Y. Sambo, M. Z. Shakir, K. Qaraqe, E. Serpedin, M. A. Imran, *et al.*, "Expanding cellular coverage via cell-edge deployment in heterogeneous networks: spectral efficiency and backhaul power consumption perspectives," *Communications Magazine, IEEE*, vol. 52, no. 6, pp. 140–149, 2014.

[31] L. Militano, A. Orsino, G. Araniti, and A. Iera, "Nb-iot for d2d-enhanced content uploading with social trustworthiness in 5g systems," *Future Internet*, vol. 9, no. 3, p. 31, 2017.

[32] M. Peng, S. Yan, K. Zhang, and C. Wang, "Fog-computing-based radio access networks: issues and challenges," *IEEE Network*, vol. 30, no. 4, pp. 46–53, 2016.

[33] P. Gandotra, R. K. Jha, and S. Jain, "A survey on device-to-device (d2d) communication: Architecture and security issues," *Journal of Network and Computer Applications*, vol. 78, pp. 9–29, 2017.

[34] S. Huang, B. Liang, and J. Li, "Distributed interference and delay aware design for d2d communication in large wireless networks with adaptive interference estimation," *IEEE Transactions on Wireless Communications*, vol. 16, no. 6, pp. 3924–3939, 2017.

[35] M. Nitti, G. A. Stelea, V. Popescu, and M. Fadda, "When social networks meet d2d communications: A survey," *Sensors*, vol. 19, no. 2, p. 396, 2019.

[36] Y. Gao, Y. Xiao, M. Wu, M. Xiao, and J. Shao, "Dynamic social-aware peer selection for cooperative relay management with d2d communications," *IEEE Transactions on Communications*, vol. 67, no. 5, pp. 3124–3139, 2019.

[37] E. Hossain and M. Hasan, "5g cellular: key enabling technologies and research challenges," *IEEE Instrumentation & Measurement Magazine*, vol. 18, no. 3, pp. 11–21, 2015.

[38] C. Zhang, A. Y. Wang, and X. Hei, "Relay discovery and selection for large-scale p2p streaming," *PloS one*, vol. 12, no. 4, p. e0175360, 2017.

[39] A. Nadeem and H.-S. Cho, "Social-aware peer selection for device-to-device communications in dense small-cell networks," *Electronics*, vol. 8, no. 6, p. 670, 2019.

[40] J. Kim, S. Kim, J. Bang, and D. Hong, "Adaptive mode selection in d2d communications considering the bursty traffic model," *IEEE Communications Letters*, vol. 20, no. 4, pp. 712–715, 2016.

[41] T. D. Hoang, L. B. Le, and T. Le-Ngoc, "Joint mode selection and resource allocation for relay-based d2d communications," *IEEE Communications Letters*, vol. 21, no. 2, pp. 398–401, 2017.

[42] M. Zulhasnine, C. Huang, and A. Srinivasan, "Towards an effective integration of cellular users to the structured peer-to-peer network," *Peer-to-Peer Networking and Applications*, vol. 5, no. 2, pp. 178–192, 2012.

[43] V. Cisco, "Cisco visual networking index: Forecast and trends, 2017–2022," *White Paper*, vol. 1, 2018.

[44] J. Liu, Y. Kawamoto, H. Nishiyama, N. Kato, and N. Kadowaki, "Device-to-device communications achieve efficient load balancing in lte-advanced networks," *IEEE Wireless Communications*, vol. 21, no. 2, pp. 57–65, 2014.

[45] K. Doppler, C. B. Ribeiro, and J. Kneckt, "Advances in d2d communications: Energy efficient service and device discovery radio," in *Wireless Communication, Vehicular Technology, Information Theory and Aerospace & Electronic Systems Technology (Wireless VITAE), 2011 2nd International Conference on*, pp. 1–6, IEEE, 2011.

[46] A. Kumbhar, F. Koohifar, I. Güvenç, and B. Mueller, "A survey on legacy and emerging technologies for public safety communications," *IEEE Communications Surveys & Tutorials*, vol. 19, no. 1, pp. 97–124, 2017.

[47] W. Sun, E. G. Ström, F. Brännström, K. C. Sou, and Y. Sui, "Radio resource management for d2d-based v2v communication," *IEEE Transactions on Vehicular Technology*, vol. 65, no. 8, pp. 6636–6650, 2016.

[48] K. Doppler, M. Rinne, C. Wijting, C. B. Ribeiro, and K. Hugl, "Device-to-device communication as an underlay to lte-advanced networks," *Communications Magazine, IEEE*, vol. 47, no. 12, pp. 42–49, 2009.

[49] C. Xu, L. Song, Z. Han, D. Li, and B. Jiao, "Resource allocation using a reverse iterative combinatorial auction for device-to-device underlay cellular networks," in *Global Communications Conference (GLOBECOM), 2012 IEEE*, pp. 4542–4547, IEEE, 2012.

[50] C.-H. Yu, O. Tirkkonen, K. Doppler, and C. Ribeiro, "Power optimization of device-to-device communication underlaying cellular communication," in *Communications, 2009. ICC'09. IEEE International Conference on*, pp. 1–5, IEEE, 2009.

[51] M. Zulhasnine, C. Huang, and A. Srinivasan, "Efficient resource allocation for device-to-device communication underlaying lte network," in *Wireless and Mobile Computing, Networking and Communications (WiMob), 2010 IEEE 6th International Conference on*, pp. 368–375, IEEE, 2010.

[52] L. Song, D. Niyato, Z. Han, and E. Hossain, "Game-theoretic resource allocation methods for device-to-device communication," *IEEE Wireless Communications*, vol. 21, no. 3, pp. 136–144, 2014.

[53] B. Kaufman and B. Aazhang, "Cellular networks with an overlaid device to device network," in *Signals, Systems and Computers, 2008 42nd Asilomar Conference on*, pp. 1537–1541, IEEE, 2008.

[54] T. Peng, Q. Lu, H. Wang, S. Xu, and W. Wang, "Interference avoidance mechanisms in the hybrid cellular and device-to-device systems," in *Personal, Indoor and Mobile Radio Communications, 2009 IEEE 20th International Symposium on*, pp. 617–621, IEEE, 2009.

[55] H. Min, J. Lee, S. Park, and D. Hong, "Capacity enhancement using an interference limited area for device-to-device uplink underlaying cellular networks," *Wireless Communications, IEEE Transactions on*, vol. 10, no. 12, pp. 3995–4000, 2011.

[56] C.-H. Yu, K. Doppler, C. Ribeiro, and O. Tirkkonen, "Performance impact of fading interference to device-to-device communication underlaying cellular networks," in *Personal, Indoor and Mobile Radio Communications, 2009 IEEE 20th International Symposium on*, pp. 858–862, IEEE, 2009.

[57] L. K. Rasmussen, T. J. Lim, and A.-L. Johansson, "A matrix-algebraic approach to successive interference cancellation in cdma," *Communications, IEEE Transactions on*, vol. 48, no. 1, pp. 145–151, 2000.

[58] R. Zhang, X. Cheng, L. Yang, and B. Jiao, "Interference-aware graph based resource sharing for device-to-device communications underlaying cellular networks," in *Wireless Communications and Networking Conference (WCNC), 2013 IEEE*, pp. 140–145, IEEE, 2013.

[59] S. Ryu, S.-K. Park, N.-H. Park, and S. Chung, "Development of device-to-device (d2d) communication based new mobile proximity multimedia service business models," in *Multimedia and Expo Workshops (ICMEW), 2013 IEEE International Conference on*, pp. 1–6, IEEE, 2013.

[60] X. Zhu, S. Wen, G. Cao, X. Zhang, and D. Yang, "Qos-based resource allocation scheme for device-to-device (d2d) radio underlaying cellular networks," in *Telecommunications (ICT), 2012 19th International Conference on*, pp. 1–6, IEEE, 2012.

[61] Q. Duong, Y. Shin, and O.-S. Shin, "Resource allocation scheme for device-to-device communications underlaying cellular networks," in *Computing, Management and Telecommunications (ComManTel), 2013 International Conference on*, pp. 66–69, IEEE, 2013.

[62] G. Yu, L. Xu, D. Feng, R. Yin, G. Y. Li, and Y. Jiang, "Joint mode selection and resource allocation for device-to-device communications," *IEEE transactions on communications*, vol. 62, no. 11, pp. 3814–3824, 2014.

[63] M. Jung, K. Hwang, and S. Choi, "Joint mode selection and power allocation scheme for power-efficient device-to-device (d2d) communication," in *2012 IEEE 75th vehicular technology conference (VTC Spring)*, pp. 1–5, IEEE, 2012.

[64] H. H. Hussein and S. M. A. El-Kader, "Enhancing signal to noise interference ratio for device to device technology in 5g applying mode selection technique," in *2017 Intl Conf on Advanced Control Circuits Systems (ACCS) Systems & 2017 Intl Conf on New Paradigms in Electronics & Information Technology (PEIT)*, pp. 187–192, IEEE, 2017.

[65] B. Peng, C. Hu, T. Peng, Y. Yang, and W. Wang, "A resource allocation scheme for d2d multicast with qos protection in ofdma-based systems," in *Personal Indoor and Mobile Radio Communications (PIMRC), 2013 IEEE 24th International Symposium on*, pp. 12383–2387, IEEE, 2013.

[66] C.-H. Yu, K. Doppler, C. B. Ribeiro, and O. Tirkkonen, "Resource sharing optimization for device-to-device communication underlaying cellular networks," *Wireless Communications, IEEE Transactions on*, vol. 10, no. 8, pp. 2752–2763, 2011.

[67] K. Doppler, C.-H. Yu, C. B. Ribeiro, and P. Jänis, "Mode selection for device-to-device communication underlaying an lte-advanced network," in *Wireless Communications and Networking Conference (WCNC), 2010 IEEE*, pp. 1–6, IEEE, 2010.

[68] H. Min, W. Seo, J. Lee, S. Park, and D. Hong, "Reliability improvement using receive mode selection in the device-to-device uplink period underlaying cellular networks," *IEEE Transactions on Wireless Communications*, vol. 10, no. 2, pp. 413–418, 2011.

[69] C.-P. Chien, Y.-C. Chen, and H.-Y. Hsieh, "Exploiting spatial reuse gain through joint mode selection and resource allocation for underlay device-to-device

communications," in *Wireless Personal Multimedia Communications (WPMC), 2012 15th International Symposium on*, pp. 80–84, IEEE, 2012.

[70] S. Wen, X. Zhu, Z. Lin, X. Zhang, and D. Yang, "Optimization of interference coordination schemes in device-to-device (d2d) communication," in *Communications and Networking in China (CHINACOM), 2012 7th International ICST Conference on*, pp. 542–547, IEEE, 2012.

[71] Y. Huang, A. A. Nasir, S. Durrani, and X. Zhou, "Mode selection, resource allocation, and power control for d2d-enabled two-tier cellular network," *IEEE Transactions on Communications*, vol. 64, no. 8, pp. 3534–3547, 2016.

[72] J. Li, R. Feng, W. Sun, L. Chen, X. Xu, and Q. Li, "Joint mode selection and resource allocation for scalable video multicast in hybrid cellular and d2d network," *IEEE Access*, vol. 6, pp. 64350–64358, 2018.

[73] Y. Liu, "Optimal mode selection in d2d-enabled multibase station systems," *IEEE Communications Letters*, vol. 20, no. 3, pp. 470–473, 2016.

[74] H. ElSawy, E. Hossain, and M.-S. Alouini, "Analytical modeling of mode selection and power control for underlay d2d communication in cellular networks," *IEEE Transactions on Communications*, vol. 62, no. 11, pp. 4147–4161, 2014.

[75] S. Xiang, T. Peng, Z. Liu, and W. Wang, "A distance-dependent mode selection algorithm in heterogeneous d2d and imt-advanced network," in *2012 IEEE Globecom Workshops*, pp. 416–420, IEEE, 2012.

[76] M. Azam, M. Ahmad, M. Naeem, M. Iqbal, A. S. Khwaja, A. Anpalagan, and S. Qaisar, "Joint admission control, mode selection, and power allocation in d2d communication systems," *IEEE Transactions on Vehicular Technology*, vol. 65, no. 9, pp. 7322–7333, 2015.

[77] Y. Peng, Q. Gao, S. Sun, and Z. Yan-Xiu, "Discovery of device-device proximity: Physical layer design for d2d discovery," in *Communications in China-Workshops (CIC/ICCC), 2013 IEEE/CIC International Conference on*, pp. 176–181, IEEE, 2013.

[78] D. Feng, L. Lu, Y. Yuan-Wu, G. Li, S. Li, and G. Feng, "Device-to-device communications in cellular networks," *IEEE Communications Magazine*, vol. 52, no. 4, pp. 49–55, 2014.

[79] V. Pilloni, P. Navaratnam, S. Vural, L. Atzori, and R. Tafazolli, "Cooperative task assignment for distributed deployment of applications in wsns," in *2013 IEEE International Conference on Communications (ICC)*, pp. 2229–2234, IEEE, 2013.

[80] C. Zhao, S. Yang, X. Yang, and J. A. McCann, "Rapid, user-transparent, and trustworthy device pairing for d2d-enabled mobile crowdsourcing," *IEEE Transactions on Mobile Computing*, vol. 16, no. 7, pp. 2008–2022, 2016.

[81] X. Chen, Y. Zhao, Y. Li, X. Chen, N. Ge, and S. Chen, "Social trust aided d2d communications: Performance bound and implementation mechanism," *IEEE Journal on Selected Areas in Communications*, vol. 36, no. 7, pp. 1593–1608, 2018.

[82] L. Weifeng, Z. Mingqi, X. Jia, C. Siguang, Y. Lijun, and X. Jian, "Cooperative caching game based on social trust for d2d communication networks," *International Journal of Communication Systems*, vol. 33, no. 9, p. e4380, 2020.

[83] N. Saxena, F. H. Kumbhar, and A. Roy, "Exploiting social relationships for trustworthy d2d relay in 5g cellular networks," *IEEE Communications Magazine*, vol. 58, no. 2, pp. 48–53, 2020.

[84] T. T. Gunes, H. Afifi, *et al.*, "Hybrid model for lte network-assisted d2d communications," in *International Conference on Ad-Hoc Networks and Wireless*, pp. 100–113, Springer, 2014.

[85] N. Namvar, N. Bahadori, and F. Afghah, "Context-aware d2d peer selection for load distribution in lte networks," in *2015 49th Asilomar Conference on Signals, Systems and Computers*, pp. 464–468, IEEE, 2015.

[86] Z. Zhang, T. Zeng, X. Yu, and S. Sun, "Social-aware d2d pairing for cooperative video transmission using matching theory," *Mobile Networks and Applications*, vol. 23, no. 3, pp. 639–649, 2018.

[87] W. Xu, S. Li, Y. Xu, and X. Lin, "Underlaid-d2d-assisted cooperative multicast based on social networks," *Peer-to-Peer Networking and Applications*, vol. 9, no. 5, pp. 923–935, 2016.

[88] K. P. Yoon and C.-L. Hwang, *Multiple attribute decision making: an introduction*, vol. 104. Sage publications, 1995.

[89] R. Trestian, O. Ormond, and G.-M. Muntean, "Performance evaluation of madm-based methods for network selection in a multimedia wireless environment," *Wireless Networks*, vol. 21, no. 5, pp. 1745–1763, 2015.

[90] A. Afshari, M. Mojahed, and R. M. Yusuff, "Simple additive weighting approach to personnel selection problem," *International Journal of Innovation, Management and Technology*, vol. 1, no. 5, p. 511, 2010.

[91] A.-S. Nedher, S. Hassan, and N. Katuk, "On multi attribute decision making methods: Prioritizing information security controls," *Journal of Applied Sciences*, vol. 14, no. 16, pp. 1865–1870, 2014.

[92] E. Stevens-Navarro and V. W. Wong, "Comparison between vertical handoff decision algorithms for heterogeneous wireless networks," in *Vehicular technology conference, 2006. VTC 2006-Spring. IEEE 63rd*, vol. 2, pp. 947–951, IEEE, 2006.

[93] R. Trestian, O. Ormond, and G.-M. Muntean, "Game theory-based network selection: Solutions and challenges," *IEEE Communications surveys & tutorials*, vol. 14, no. 4, pp. 1212–1231, 2012.

[94] J. Contreras-Castillo, S. Zeadally, and J. A. Guerrero Ibáñez, "A seven-layered model architecture for internet of vehicles," *Journal of Information and Telecommunication*, vol. 1, no. 1, pp. 4–22, 2017.

[95] M. Subramani and V. B. Kumaravelu, "A three-stage fuzzy-logic-based handover necessity estimation and target network selection scheme for next generation heterogeneous networks," *Journal of Circuits, Systems and Computers*, p. 2050092, 2019.

[96] M. Sadik, N. Akkari, and G. Aldabbagh, "Sdn-based handover scheme for multi-tier lte/femto and d2d networks," *Computer Networks*, vol. 142, pp. 142–153, 2018.

[97] Y. Zhao and W. Song, "Social-aware energy-efficient data dissemination with d2d communications," in *2016 IEEE 83rd Vehicular Technology Conference (VTC Spring)*, pp. 1–5, IEEE, 2016.

[98] G. Caso, L. De Nardis, and M.-G. Di Benedetto, "Toward context-aware dynamic spectrum management for 5g," *IEEE Wireless Communications*, vol. 24, no. 5, pp. 38–43, 2017.

[99] A. Sen, "Social choice theory: A re-examination," *Econometrica: journal of the Econometric Society*, pp. 53–89, 1977.

[100] W. Gaertner, *Domain conditions in social choice theory*. Cambridge University Press, 2001.

[101] U. Endriss *et al.*, "Logic and social choice theory," *Logic and philosophy today*, vol. 2, pp. 333–377, 2011.

[102] F. Chiti, R. Fantacci, and L. Pierucci, "Social-aware relay selection for cooperative multicast device-to-device communications," *Future Internet*, vol. 9, no. 4, p. 92, 2017.

[103] C. R. Kothari, *Research methodology: Methods and techniques*. New Age International, 2004.

[104] K. W. Choi and Z. Han, "Device-to-device discovery for proximity-based service in lte-advanced system," *IEEE Journal on Selected Areas in Communications*, vol. 33, no. 1, pp. 55–66, 2015.

[105] A. Habbal, *TCP Sintok: Transmission control protocol with delay-based loss detection and contention avoidance mechanisms for mobile ad hoc networks*. PhD thesis, Universiti Utara Malaysia, 2014.

[106] L. T. Blessing and A. Chakrabarti, *DRM: A Design Reseach Methodology*. Springer, 2009.

[107] S. Kurkowski, T. Camp, and M. Colagrosso, "Manet simulation studies: the incredibles," *ACM SIGMOBILE Mobile Computing and Communications Review*, vol. 9, no. 4, pp. 50–61, 2005.

[108] J. Kim, S. Kim, J. Bang, and D. Hong, "Adaptive mode selection in d2d communications considering the bursty traffic model," *IEEE Communications Letters*, vol. 20, no. 4, pp. 712–715, 2016.

[109] S. Wu, H. Wang, and C.-H. Youn, "Visible light communications for 5g wireless networking systems: from fixed to mobile communications," *Ieee Network*, vol. 28, no. 6, pp. 41–45, 2014.

[110] S. Rangan, T. S. Rappaport, and E. Erkip, "Millimeter-wave cellular wireless networks: Potentials and challenges," *Proceedings of the IEEE*, vol. 102, no. 3, pp. 366–385, 2014.

[111] T. S. Rappaport, S. Sun, R. Mayzus, H. Zhao, Y. Azar, K. Wang, G. N. Wong, J. K. Schulz, M. Samimi, and F. Gutierrez, "Millimeter wave mobile communications for 5g cellular: It will work!," *IEEE access*, vol. 1, pp. 335–349, 2013.

[112] K. Haneda, L. Tian, H. Asplund, J. Li, Y. Wang, D. Steer, C. Li, T. Balercia, S. Lee, Y. Kim, *et al.*, "Indoor 5g 3gpp-like channel models for office and shopping mall environments," in *Communications Workshops (ICC), 2016 IEEE International Conference on*, pp. 694–699, IEEE, 2016.

[113] J. Miranda, R. Abrishambaf, T. Gomes, P. Gonçalves, J. Cabral, A. Tavares, and J. Monteiro, "Path loss exponent analysis in wireless sensor networks: Experimental evaluation," in *2013 11th IEEE International Conference on Industrial Informatics (INDIN)*, pp. 54–58, IEEE, 2013.

[114] Z. Yang, C. Wu, Z. Zhou, X. Zhang, X. Wang, and Y. Liu, "Mobility increases localizability: A survey on wireless indoor localization using inertial sensors," *ACM Computing Surveys (Csur)*, vol. 47, no. 3, p. 54, 2015.

[115] M. Kamel, W. Hamouda, and A. Youssef, "Ultra-dense networks: A survey," *IEEE Communications Surveys & Tutorials*, vol. 18, no. 4, pp. 2522–2545, 2016.

[116] Y.-S. Lu, C.-F. Lai, C.-C. Hu, Y.-M. Huang, and X.-H. Ge, "Path loss exponent estimation for indoor wireless sensor positioning.," *KSII Transactions on Internet & Information Systems*, vol. 4, no. 3, 2010.

[117] Y. Liu, "Received signal strength based wireless source localization with inexact anchor position," *arXiv preprint arXiv:1908.03202*, 2019.

[118] A. Omri, M. O. Hasna, and M. Z. Shakir, "Mode selection schemes for d2d enabled aerial networks," *arXiv preprint arXiv:1711.02220*, 2017.

[119] K. Zhu and E. Hossain, "Joint mode selection and spectrum partitioning for device-to-device communication: A dynamic stackelberg game," *IEEE Transactions on Wireless Communications*, vol. 14, no. 3, pp. 1406–1420, 2015.

[120] J. Kim, G. Caire, and A. F. Molisch, "Quality-aware streaming and scheduling for device-to-device video delivery," *IEEE/ACM Transactions on Networking*, vol. 24, no. 4, pp. 2319–2331, 2016.

[121] Y. Cao, T. Jiang, and C. Wang, "Cooperative device-to-device communications in cellular networks," *IEEE wireless communications*, vol. 22, no. 3, pp. 124–129, 2015.

[122] I. Flint, H.-B. Kong, N. Privault, P. Wang, and D. Niyato, "Analysis of heterogeneous wireless networks using poisson hard-core hole process," *IEEE Transactions on Wireless Communications*, vol. 16, no. 11, pp. 7152–7167, 2017.

[123] S. Srinivasa and M. Haenggi, "Distance distributions in finite uniformly random networks: Theory and applications," *IEEE Transactions on Vehicular Technology*, vol. 59, no. 2, pp. 940–949, 2010.

[124] R. W. Heath, M. Kountouris, and T. Bai, "Modeling heterogeneous network interference using poisson point processes," *IEEE Transactions on Signal Processing*, vol. 61, no. 16, pp. 4114–4126, 2013.

[125] P. Cheng, L. Deng, H. Yu, Y. Xu, and H. Wang, "Resource allocation for cognitive networks with d2d communication: An evolutionary approach," in *Wireless Communications and Networking Conference (WCNC), 2012 IEEE*, pp. 2671–2676, IEEE, 2012.

[126] Y.-Q. Cheng, V. Wu, R. Collins, A. R. Hanson, and E. M. Riseman, "Maximum-weight bipartite matching technique and its application in image feature matching," in *Visual Communications and Image Processing'96*, pp. 453–462, International Society for Optics and Photonics, 1996.

[127] K. Doppler, M. P. Rinne, P. Jänis, C. Ribeiro, and K. Hugl, "Device-to-device communications; functional prospects for lte-advanced networks," in *Communications Workshops, 2009. ICC Workshops 2009. IEEE International Conference on*, pp. 1–6, IEEE, 2009.

[128] P. Jänis, V. Koivunen, C. Ribeiro, J. Korhonen, K. Doppler, and K. Hugl, "Interference-aware resource allocation for device-to-device radio underlaying cellular networks," in *Vehicular Technology Conference, 2009. VTC Spring 2009. IEEE 69th*, pp. 1–5, IEEE, 2009.

[129] S. B. Johnson, S. Nath, and T. Velmurugan, "An optimized algorithm for vertical handoff in heterogeneous wireless networks," in *Information & Communication Technologies (ICT), 2013 IEEE Conference on*, pp. 1206–1210, IEEE, 2013.

[130] R. Knopp and P. A. Humblet, "Information capacity and power control in single-cell multiuser communications," in *Communications, 1995. ICC'95 Seattle,'Gateway to Globalization', 1995 IEEE International Conference on*, vol. 1, pp. 331–335, IEEE, 1995.

[131] A. Sendonaris, E. Erkip, and B. Aazhang, "User cooperation diversity. part ii. implementation aspects and performance analysis," *Communications, IEEE Transactions on*, vol. 51, no. 11, pp. 1939–1948, 2003.

[132] A. Sendonaris, E. Erkip, and B. Aazhang, "User cooperation diversity. part i. system description," *Communications, IEEE Transactions on*, vol. 51, no. 11, pp. 1927–1938, 2003.

[133] R. Tamijetchelvy and G. Sivaradje, "An optimized fast vertical handover strategy for heterogeneous wireless access networks based on ieee 802.21 media independent handover standard," in *Advanced Computing (ICoAC), 2012 Fourth International Conference on*, pp. 1–7, IEEE, 2012.

[134] H. Te Sun and K. Kobayashi, "A new achievable rate region for the interference channel," *IEEE transactions on information theory*, vol. 27, no. 1, pp. 49–60, 1981.

[135] K. Vanganuru, S. Ferrante, and G. Sternberg, "System capacity and coverage of a cellular network with d2d mobile relays," in *MILITARY COMMUNICATIONS CONFERENCE, 2012-MILCOM 2012*, pp. 1–6, IEEE, 2012.

[136] C. Xu, L. Song, Z. Han, Q. Zhao, X. Wang, and B. Jiao, "Interference-aware resource allocation for device-to-device communications as an underlay using sequential second price auction," in *Communications (ICC), 2012 IEEE International Conference on*, pp. 445–449, IEEE, 2012.

[137] X. Yan, Y. A. Şekercioğlu, and S. Narayanan, "A survey of vertical handover decision algorithms in fourth generation heterogeneous wireless networks," *Computer Networks*, vol. 54, no. 11, pp. 1848–1863, 2010.

[138] Y. Cao, T. Jiang, and C. Wang, "Cooperative device-to-device communications in cellular networks," *IEEE wireless communications*, vol. 22, no. 3, pp. 124–129, 2015.

[139] X. Lin, J. Andrews, A. Ghosh, and R. Ratasuk, "An overview of 3gpp device-to-device proximity services," *IEEE Communications Magazine*, vol. 52, no. 4, pp. 40–48, 2014.

[140] B. Kaufman, J. Lilleberg, and B. Aazhang, "Spectrum sharing scheme between cellular users and ad-hoc device-to-device users," *IEEE Transactions on Wireless Communications*, vol. 12, no. 3, pp. 1038–1049, 2013.

[141] M. J. Yang, S. Y. Lim, H. J. Park, and N. H. Park, "Solving the data overload: Device-to-device bearer control architecture for cellular data offloading," *IEEE Vehicular Technology Magazine*, vol. 8, no. 1, pp. 31–39, 2013.

[142] B. Wang, L. Chen, X. Chen, X. Zhang, and D. Yang, "Resource allocation optimization for device-to-device communication underlaying cellular networks," in *Vehicular Technology Conference (VTC Spring), 2011 IEEE 73rd*, pp. 1–6, IEEE, 2011.

[143] P. Phunchongharn, E. Hossain, and D. I. Kim, "Resource allocation for device-to-device communications underlaying lte-advanced networks," *IEEE Wireless Communications*, vol. 20, no. 4, pp. 91–100, 2013.

[144] C.-H. Yu and O. Tirkkonen, "Device-to-device underlay cellular network based on rate splitting," in *Wireless Communications and Networking Conference (WCNC), 2012 IEEE*, pp. 262–266, IEEE, 2012.

[145] L. B. Le, "Fair resource allocation for device-to-device communications in wireless cellular networks," in *Global Communications Conference (GLOBECOM), 2012 IEEE*, pp. 5451–5456, IEEE, 2012.

[146] O. Omotere, L. Qian, and X. Du, "Performance bound of ad hoc device-to-device communications using cognitive radio," in *Globecom Workshops (GC Wkshps), 2013 IEEE*, pp. 654–659, IEEE, 2013.

[147] D. Tsolkas, E. Liotou, N. Passas, and L. Merakos, "A graph-coloring secondary resource allocation for d2d communications in lte networks," in *Computer Aided Modeling and Design of Communication Links and Networks (CAMAD), 2012 IEEE 17th International Workshop on*, pp. 56–60, IEEE, 2012.

[148] L. Song, D. Niyato, Z. Han, and E. Hossain, "Game-theoretic resource allocation methods for device-to-device communication," *IEEE Wireless Communications*, vol. 21, no. 3, pp. 136–144, 2014.

[149] L. Lei, Z. Zhong, C. Lin, and X. Shen, "Operator controlled device-to-device communications in lte-advanced networks," *IEEE Wireless Communications*, vol. 19, no. 3, 2012.

[150] L. B. Le, "Fair resource allocation for device-to-device communications in wireless cellular networks," in *Global Communications Conference (GLOBECOM), 2012 IEEE*, pp. 5451–5456, IEEE, 2012.

[151] R. Rathiya, A. Anitha, and J. Jayakumari, "Efficient qos oriented vertical handoff scheme in the integration of wimax/wlan networks," in *Information & Communication Technologies (ICT), 2013 IEEE Conference on*, pp. 378–381, IEEE, 2013.

[152] D. He, C. Chi, S. Chan, C. Chen, J. Bu, and M. Yin, "A simple and robust vertical handoff algorithm for heterogeneous wireless mobile networks," *Wireless Personal Communications*, vol. 59, no. 2, pp. 361–373, 2011.

[153] K. Ahmavaara, H. Haverinen, and R. Pichna, "Interworking architecture between 3gpp and wlan systems," *IEEE Communications Magazine*, vol. 41, no. 11, pp. 74–81, 2003.

[154] Y. Choi, H. Kim, S.-w. Han, and Y. Han, "Joint resource allocation for parallel multi-radio access in heterogeneous wireless networks," *IEEE Transactions on Wireless Communications*, vol. 9, no. 11, pp. 3324–3329, 2010.

[155] A. Haider, I. Gondal, and J. Kamruzzaman, "Dynamic dwell timer for hybrid vertical handover in 4g coupled networks," in *Vehicular Technology Conference (VTC Spring), 2011 IEEE 73rd*, pp. 1–5, IEEE, 2011.

[156] I. F. Akyildiz, W.-Y. Lee, M. C. Vuran, and S. Mohanty, "Next generation/dynamic spectrum access/cognitive radio wireless networks: A survey," *Computer networks*, vol. 50, no. 13, pp. 2127–2159, 2006.

[157] B.-J. Chang and J.-F. Chen, "Cross-layer-based adaptive vertical handoff with predictive rss in heterogeneous wireless networks," *IEEE Transactions on vehicular technology*, vol. 57, no. 6, pp. 3679–3692, 2008.

[158] L. Xia, J. Ling-ge, H. Chen, and L. Hong-Wei, "An intelligent vertical handoff algorithm in heterogeneous wireless networks," in *Neural Networks and Signal Processing, 2008 International Conference on*, pp. 550–555, IEEE, 2008.

[159] H. Zhang, L. Song, Y. Li, and G. Y. Li, "Hypergraph theory: Applications in 5g heterogeneous ultra-dense networks," *IEEE Communications Magazine*, vol. 55, no. 12, pp. 70–76, 2017.

[160] S. Ryu, S.-K. Park, N.-H. Park, and S. Chung, "Development of device-to-device (d2d) communication based new mobile proximity multimedia service business models," in *Multimedia and Expo Workshops (ICMEW), 2013 IEEE International Conference on*, pp. 1–6, IEEE, 2013.

[161] X. Zhu, S. Wen, G. Cao, X. Zhang, and D. Yang, "Qos-based resource allocation scheme for device-to-device (d2d) radio underlaying cellular networks," in *Telecommunications (ICT), 2012 19th International Conference on*, pp. 1–6, IEEE, 2012.

[162] Q. Duong, Y. Shin, and O.-S. Shin, "Resource allocation scheme for device-to-device communications underlaying cellular networks," in *Computing, Management and Telecommunications (ComManTel), 2013 International Conference on*, pp. 66–69, IEEE, 2013.

[163] R. Jain, D.-M. Chiu, and W. R. Hawe, *A quantitative measure of fairness and discrimination for resource allocation in shared computer system*, vol. 38. Eastern Research Laboratory, Digital Equipment Corporation Hudson, MA, 1984.

[164] V. Cisco, "Cisco visual networking index: Forecast and methodology 2016–2021.(2017)," 2017.

[165] O. Bello and S. Zeadally, "Intelligent device-to-device communication in the internet of things," *IEEE Systems Journal*, vol. 10, no. 3, pp. 1172–1182, 2016.

[166] M. N. Hindia, M. M. Fadoul, T. Abdul Rahman, and I. S. Amiri, "A stochastic geometry approach to full-duplex mimo relay network," *Wireless Communications and Mobile Computing*, vol. 2018, 2018.

[167] C. Zhang, A. Y. Wang, and X. Hei, "Relay discovery and selection for large-scale p2p streaming," *PloS one*, vol. 12, no. 4, p. e0175360, 2017.

[168] A. Omran, A. BenMimoune, and M. Kadoch, "Mobility management for d4d in hetnet," in *2017 IEEE 30th Canadian Conference on Electrical and Computer Engineering (CCECE)*, pp. 1–5, IEEE, 2017.

[169] A. S. Tan and E. Zeydan, "The impact of d2d connections on network-assisted mobile data offloading," in *2018 International Symposium on Networks, Computers and Communications (ISNCC)*, pp. 1–6, IEEE, 2018.

[170] M. Lahby and A. Sekkaki, "Optimal vertical handover based on topsis algorithm and utility function in heterogeneous wireless networks," in *2017 International Symposium on Networks, Computers and Communications (ISNCC)*, pp. 1–6, IEEE, 2017.