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Performance Evaluation of Relaying and Discovery Methods for Device-to-Device Communication

تقويم أداء طرق الترحيل والأستكشاف لاتصالات جهاز إلى جهاز

A Dissertation Submitted in Partial Fulfillment for the Requirements for the M.SC Degree in Electronics Engineering

(Communication Engineering)

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AM very thankful to my supervisor Dr. Salaheldin Edam *who helped and encouraged me during the process of preparing the thesis. The endless hours that we have spent in discussion have made this thesis into a much greater work than I could ever have accomplished alone.*

I dedicate this piece of work to my parents who have always given me an endless support, to my friend's for being cooperative and informative, teachers and everyone who helped me in completing this thesis.

To each of the above, I extend our deepest appreciation.

Abstract

The need for communication and other types of services is very high in daily bases and especially on disaster situation. The Device-to-device (D2D) communication as an underlay to cellular networks has gained increasing popularity as one of the main technology solutions for the enhancement of 5G network. the user equipment's (UEs) in close proximity to each other, may communicate directly instead of through the eNodeB this helps to achieve better performance than that offered via eNodeB by offloading the eNodeB resources. this thesis focus mainly on D2D in a decentralized emergency scenario where the eNodeB is totally damaged, the main target was to find a suitable solution for discovery and selecting D2D pairs in disaster scenario using different algorithms simulated on Matlab program. As a result, the average number of D2D pairs that can be selected were compared with respect to the number of active devices and the probability of outage. After that, the effectiveness of using the D2D as a relay and its performance were evaluated in two modes, Amplify-and-Forward (AF) and Decode-and-Forward (DF) relaying. In the AF mode, the performance of the system with and without relay has been compared. Secondly the relay operated as DF, the performance of different error control mechanisms that can be used for relay networks, has been analyzed in terms of delay and transmission efficiency.

In the 1st phase, Device peer discovery the results showed that the outage probability can be decreased to about 33% when using the data rate algorithm compared to SINR and distance algorithm. While in the 2nd phase the results indicated that the overall system performance can be increased in terms of capacity, spectral efficiency and decreased latency when using the D2D as a relay.

المستخلص

إن الحاجة إلى التواصل و الأنواع الأخرى من خدمات الإتصال أصبحت ضرورية في الحياة اليومية و خاصة في حالات الكوارث والطوارىء. اكتسبت الاتصالات من جهاز إلى جهاز باعتبارها الأساس الذي تقوم عليه الشبكات الخلوية شعبية متزايدة كأحد الحلول التكنولوجية الرئيسية لتعزيز شبكة الجيل الخامس.قد تتواصل أجهزة المستخدم القريبة من بعضها البعض بشكل مباشر بدلاً من خلال محطة الارسال والاستقبال الاساسية مما يساعد على تحقيق أداء أفضل من الأداء المقدم عبر المحطة الاساسية عن طريق تقليل استهلاك موارد نظام الإتصال .تركز هذه الأطروحة بشكل أساسي على تقييم أداء طرق الترحيل والأستكشاف لاتصالات الجهاز إلى جهاز .وكان الهدف الرئيسي هو إيجاد حل مناسب لاكتشاف واختيار أزواج الجهاز الى جهاز في سيناريو الكوارث باستخدام خوارزميات مختلفة تمت محاكاتها على برنامج الماتلاب.نتيجة لذلك ، تمت مقارنة متوسط عدد ألازواج التي يمكن اختيارها من حيث عدد الأجهزة النشطة واحتمال الانقطاع. بعد ذلك ، تم تقييم فعالية استخدام الجهاز إلى جهاز كملاحق وأدائه في وضعين ، وهما التضخيم والى الامام -وفك الشفرة والى الامام في وضع التضخيم ، تمت مقارنة أداء النظام مع وبدون مرحل. ثانياً ، تم تحليل التتابع الذي يتم تشغيله كـ فك الشفرة ، وهو أداء مختلف آليات التحكم في الأخطاء التي يمكن استخدامها لشبكات الترحيل ، من حيث التأخير وكفاءة الإرسال.

في المرحلة الأولى ، أظهرت نتائج اكتشاف نظير الجهاز أن احتمال الانقطاع يمكن أن ينخفض إلى حوالي 33٪ عند استخدام خوارزمية معدل البيانات مقارنة مع نسبة الإشارة إلى الضوضاء وخوارزمية المسافة. بينما تشير النتائج في المرحلة الثانية إلى أنه يمكن زيادة الأداء الكلي للنظام من حيث السعة والكفاءة الطيفية والكمون المنخفض عند استخدام الجهاز إلى الجهاز كترحيل.

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List of Abbreviations

Abbreviation	Acronyms
AWGN	Additive White Gaussian Noise
ARQ	Automated Repeat Request
ACK	Acknowledgement
BS	Base Station
BLER	Block Error Rates
CQI	Channel Quality Indicator
CP	Cyclic Prefix
D2D	Device to Device
DMRS	Demodulation Reference Signals
DeNB	Donor eNB
ETSI	European Telecommunication Standard Institute
eNB	Enhanced Node B
FHS	Frequency Hopping Sequences
HARQ	Hybrid Automated Repeat Request
ITU-T	International Telecommunication union Telecommunication
IR	Incremental Redundancy
LA	Link adaptation
MSE	Mean Square Error
MMSE	Minimum Mean Square Error
MI	Mutual Information

MS	Mobile Station
MCS	Modulation and Coding Scheme
ProSE	Proximity Services
PARA	Peak to Average Power Ratio
PUSCH	Physical Uplink Shared Channel
Qos	Quality of Service
RS	Reference Signals
RN	Relay Node
SINR	Signal to Interference and Noise Ratio
SC-FDMA	Single Carrier Frequency Division Multiple Access
SDL	Sphere Decoder Like
TETRA	Terrestrial Trunked Radio
UE	User Equipment

List of Symbols

Chapter One

Introduction

Chapter One
Introduction

1.1 Preface

Information and communication technologies deliver a vital services and systems for our day-to-day lives as well as in crisis and disaster situations like earthquakes, floods and tsunamis, they are taking place from time to time in many places around the world. The need for communication and other types of services is very high after such events. The communication infrastructure is often damaged to large extents, making services unavailable or at least heavily congested. Therefore, a number of activities, research efforts and standardization activities have been started quite recently in the area of disaster-resilient communication. For example, standardization activities such as ITU-T Focus Group on Disaster Relief System and ETSI TETRA have already occurred and currently are being developed further. Meanwhile 3GPP also started work on critical communication to launch Proximity Services (ProSE) and Group calls [1].

On the other hand, the increasing number of users, huge amount of data and the need for high data rate push us towards to the evolution of cellular communication networks from the first generation (1G) to the fifth generation (5G). The 1G introduced the first cell phone, 2G presented the first text messages cell phone and 3G was the beginning of real browsing online and support real-time application services to the mobile phone users with high-speed data. They continued to develop the generation until reaching the 5G nowadays[2].

The 5G will be capable to handle thousands of times of traffic more than today's network and will be ten times faster than LTE. We expect to have more than 50 billion connected devices to utilize the cellular network services by the end of 2020. The goals of 5G technology are 1,000x increase in capability, support for 100+ billion connections, up to 10 Gbit/s speeds and below 1ms latency which is not fulfilled in LTE-A. Also, centralized base station (eNB) that control everything in mobile network as in LTE-A become more problem than a solution, as mobile users increase and traffic overhead on base station results in increasing of the mobile outage, low spectral efficiency, and low data rate[3].

One of the main technology solutions for enhancement of 5G network that started in the LTE and will be the main topic of this thesis is Device-to-device (D2D) communications. D2D communication often refers to the technology that allows user equipment (UE) to communicate with each other with or without the involvement of network infrastructures such as an access point or base stations. D2D is promising as it is used to make ultra-low latency communication possible[2].

The D2D Communication system can be explained by visualizing a two level 5G cellular network and named them as macro cell level and device level. The macro cell level comprises of the BS to device communications as in an orthodox cellular system. The device level comprises of D2D communications. If a device links the cellular network through a base station, then it will be operating in the macro cell level and if a device links directly to another device or apprehends its transmission through the support of other devices, then it will be on the device level. In these types of systems, the BS will persist to attend the devices as usual. But in the congested areas and at the cell edges, an ad hoc mesh network is created and devices will be permitted to communicate with each other[1].

In the insight of device level communications, the base station either have full or partial control over the resource allocation amid source, destination, and relaying devices, or not have any control.

1.2 Problem statement

In disaster situation the infrastructure of mobile networks may be paralyzed or partially collapsed, which make the procedure of the rescue very difficult. An Alternative method with minimum interference and best guaranteed quality of service (QOS) should be used for the communication between the survivor and the rescue team.

1.3 Proposed solution

To overcome the disaster connectivity issues this thesis proposed the use of D2D communication with best discovery method in case of totally or partially damaged network infrastructure.

1.4 Objectives

The aim of this project is to evaluate and compare the different discovery methods for D2D communication in case of disaster scenario and to investigate the effectiveness of using the D2D as a relay station, In addition to the following objectives:

- To decrease the outage probability.
- To enhance data rate and throughput.
- To decrease the latency.

1.5 Methodology

The methodology can be described through the following stages. At first, an overview of the previous projects also Information will be gathered through literature review. Secondly an extensive study and selection of network architecture and number of MS will be made in the work-package. Thirdly, the system model and the operational algorithms will be represented. Finally, the analyses will be made based from the results of Matlab simulation

1.6 Thesis Outlines

The thesis composed of five chapters and organized as follows:

- Chapter 1 will be the introduction about the project in general.

- Chapter 2 gives an overview on D2D communications and challenges. A short summary on topics that is related to D2D communications is described in details in terms of architecture, access technology, and applications.

- In chapter 3, the network architecture and the cellular layout for different scenario are presented with the complete mathematical equations used in simulations.

- In chapter 4, presents the results and analysis of the graphs based on Matlab simulation.at the end of the chapter performance evaluation of the different scenarios will be discussed in details.

- In chapter 5, the main results of this projects are summarized. And some possible future studies are suggested to extend this research.

Chapter Two

Literature Review

Chapter Two
Literature Review

This chapter gives an overview of the D2D technology and a detailed description of the device to device peer discovery technology that are the basis for this thesis. In addition to the related work.

2.1 An Overview of D2D Communications

The term D2D communications refers to direct short-range communications between terminals of a mobile network, without the intermediate transmission to a base station (BS). Two UEs are D2D candidates if they find each other during the peer discovery process. However, these D2D candidates can only exchange information over the direct link if the criterion for mode selection is satisfied. Mode selection is a process of deciding whether the D2D candidates should communicate in D2D mode or should just stick to cellular mode. This is important because in some cases, the direct link (also referred to as D2D link) may have worse quality than the cellular links, making it unnecessary to operate in D2D mode [4].

In general, the procedure of D2D communication take place in two stages which are the discovery phase and communication phase. In the discovery phase, the UEs try to discover potential peer in proximity for D2D communication and determines the identification of the founded peer. Moreover, this phase includes a number of messages that have to be exchanged between UEs and between UEs and BS, providing information about their respective link qualities. Once this information is available at the BS, it may serve as the basic input to the mode selection in the communication phase. After completing the discovery phase the new D2D candidates can have actual communication. The communication phase includes channel estimation, mode selection, resource allocation, power control, and the actual transmission of the information.in this thesis the peer discovery will be the primary concern[4].

2.2 Peer Discovery

In both the wireless ad hoc and the cellular cases, the discovery is initiated by one party transmitting a well-known synchronization or reference signal sequence which is referred to as the beacon. Such a beacon is exemplified by the primary and secondary synchronization sequences in LTE or known frequency hopping sequences (FHS) and specific FHS packets in Bluetooth [5].

The general discovery procedure for D2D communication is described as follows: at first, a UE sends a discovery signal to detect potential UEs in proximity; then the identity of UEs can be exchanged between the new pair which are determined to be D2D candidates; at last, the message about the link quality is exchanged between UEs and between UEs and BS under the control of the BS.

In general, there are two types of peer discovery approaches for D2D communications: -

2.2.1 Direct Discovery

Where the device communicates with each other directly without the help of the network. The discovery can be made possible through some randomized process and one of the peers assuming the responsibility of sending the beacon. The UE broadcasts identity periodically so that other UEs may be aware of its existence and decides whether it shall start a D2D communication with it. This approach is distributed and does not need the involvement of the BS. However, the operator cannot forbid illegal users to announce or listen information to/from the D2D peers using the operators' licensed band [6].

As shown in figure 2.1 it shows the direct discovery scenarios. Where UE 1 and UE 2 act as source and destination respectively, while UE 4 will work as a relay between UE 3 and UE 5. If UEs transmit beacons to advertise their presence, peer discovery might be completed by themselves. This type of discovery is the best solution for public safety networks. In this scenario the UE selects which resources to use for transmission and selected at random to minimize the collision risk [7].

Side link is a kind of communication links between device and device without going through gNB. It means that it requires new physical layer scheme. But to reduce the design alterations of existing implementation, the new physical layer is designed not to vary too much. We will use very similar waveform in D2D communications based on SC-FDMA in both directions [6].

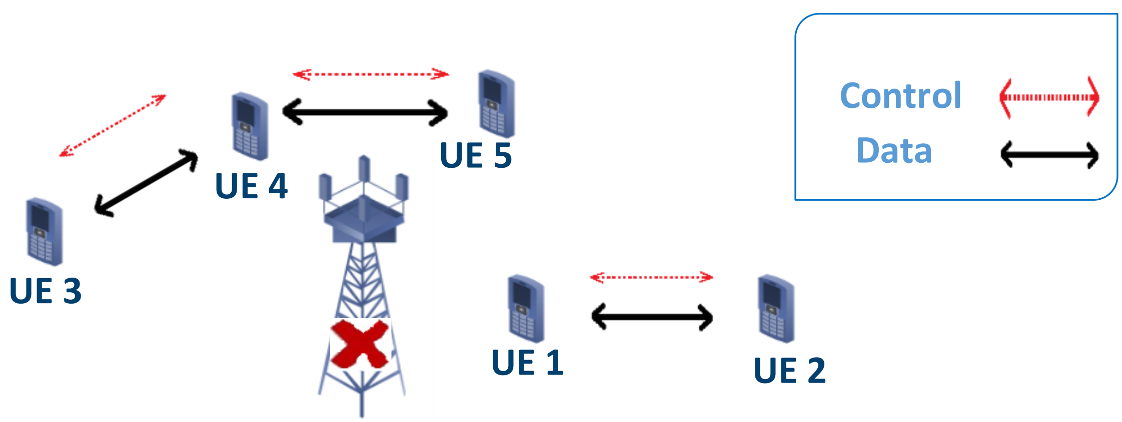


Figure 2.1 Direct Discovery Scenario's.

2.2.2 Network Assisted Discovery

In this type of discovery, the devices identify and detect each other with an assist of network. The UE informs the BS about its aim to communicate with another UE and sends the beacon signal. Then the BS orders some message exchanges between the devices, in order to acquire identity and information about the link between them. This approach is centralized or semi centralized, and the network can facilitate the discovery process by recognizing D2D candidates, coordinating the time and frequency allocations for sending/ scanning beacon signals, providing identity information, etc.

In this type of discovery, the eNB can dynamically assign resources to the UE for D2D transmission to guarantee no collision between any side link transmission and any uplink transmission, or between side link transmissions.

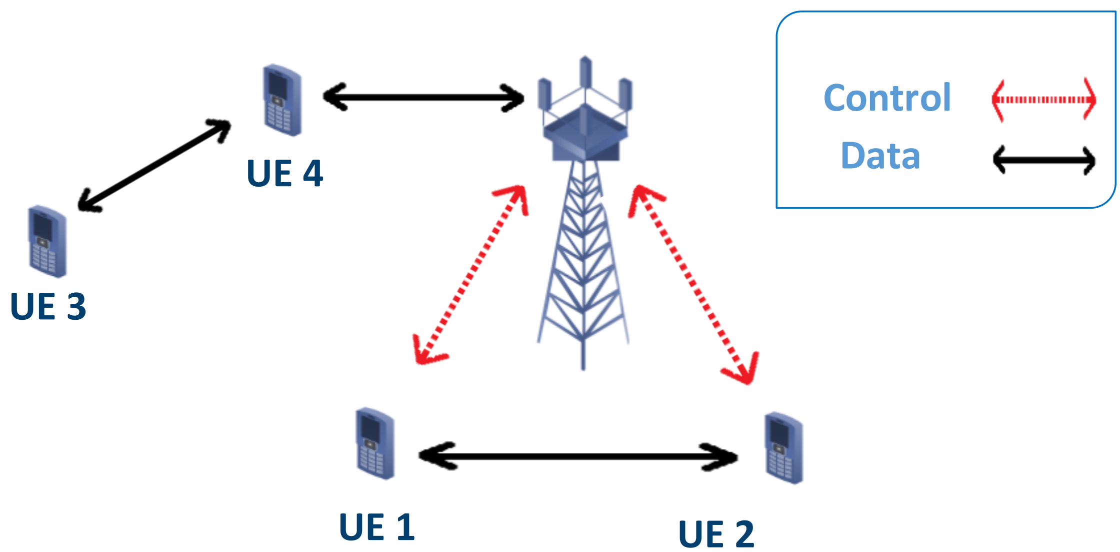


Figure 2.2 Network Assisted Discovery Scenario's.

As shown in figure 2.2 It assigns resources depending on the feedback info sent by the UE which is known as the CQI. The 4-bit CQI value indicates an estimate of the MCS that the UE can receive dependably. It is based on the measured received signal quality on the downlink. The BS controls how often and when the UE feeds back

2.3 D2D Design Aspects

They are many design features that need to be considered before deploying D2D architecture and the most important ones are discussed in the below sections.

2.3.1 D2D Modulation Format

Currently, LTE uses SC-FDMA in the UL and OFDMA in the DL as the choice of waveform format. The D2D communications will be based on SC-FDMA in both directions for two reason first because SC-FDMA is much more efficient than OFDMA in terms of low peak to average power ratio (PARA) and Cubic Metrics secondly implementing SC-FDMA receiver is more difficult since the single carrier transmission requires relatively complex equalization at the receiver [7].

2.1.3.2 D2D Frame Structure

We assume that all communication is done in FDD band. The Cellular communication takes place in FDD DL that may causes inefficient spectrum usage of UL especially in symmetric radio resource partition systems, such as symmetric FDD because the traffic load of DL is currently much heavier than that of UL. While the D2D takes place in UL band in FDD and UL sub frame in TDD as shown in Figure 2.3

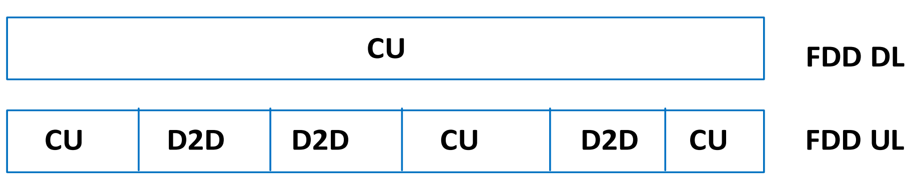


Figure 2.3 Cellular and D2D frame structure

From this perspective, camping D2D on UL resource is more reasonable especially in FDD. More importantly, the total interference level in UL spectrum is significantly less than that in DL spectrum, which may have substantial impact on transmission performance. Time slots in UL frames are assigned for D2D signaling and for data. The signaling occurs between the BS and the D2D and therefore it is seen as cellular communication. All CU are able to transmit and receive independently of other D2D links. Most communication sessions are bidirectional. The mutual independence makes the D2D communication flexible; larger data transfer can occur simultaneously with short bidirectional exchange of data, without one having to wait for the other and less coordination is required from eNB (i.e., less signaling by BS).

2.3.3 D2D Burst Timing

The timing of the transmissions is one of the most important features in D2D network it is necessary to synchronize the sender and receiver and to be able to manage the interference efficiently. LTE-A uses frame transmission with long symbol duration (LTE-A symbol length is 67 ls) and cyclic signal extension (LTE-A has 5 and 17 ls defined), which facilities the time synchronization requirements of the frames. Given that D2D links are practical mainly for devices with relatively low mobility speeds, normal cyclic extension of LTE-A should be more than enough for D2D links. In principle, it would be sufficient with shorter extensions, but keeping the LTE-symbol compatibility seems beneficial from an implementation perspective. In addition, a potential multi-hop solution for D2D communication could benefit from this large time tolerance. The burst timing might originate from the eNB timing when one of the D2D terminating devices communicates to the eNB.

2.3.4 D2D Signaling

Signaling is used to manage the resource allocation for all communication devices. The BS should inform D2D devices which frequency band and time slot they are going to use. Preliminary signaling for D2D communication is performed on the time slots which are allocated for cellular communications; there is no specific signaling time slot for D2D communication. When a D2D session is initiated, devices may need to signal each other to coordinate and negotiate the send and receive times. Predefined preambles can be used for the start and the end messages. The dynamics of the session play a major role for signaling overhead (i.e., additional signaling is required if links are short-lived due to mobility or resource availability [28].

2.3.5 D2D Synchronization

In an LTE network-assisted D2D scenario, the two UEs of the D2D pair are synchronized with the eNB, implying that slot and frame timing as well as frequency synchronization is acquired. Also, other fundamental system parameters (Such as cyclic prefix (CP) length and duplexing mode) are known by the UEs. Therefore, the D2D candidates can be assumed to be synchronized to each other prior to D2D bearer establishment. To maintain time (i.e., OFDM symbol) and frequency synchronization in D2D mode (between two subsequent eNB mode selection decision instances), the D2D pair could use reference signals (RS) similar to the LTE demodulation reference signals (DMRS). For example, for the physical uplink shared channel (PUSCH), LTE uses DMRS in every slot and a similar solution can be used for the D2D bearer as well. However, we can assume that the UEs keep synchronizing with their serving eNB and therefore, in practice there will probably be no need for a specific D2D synchronization mechanism [27].

2.3.6 D2D Mobility

The mobility range of D2D is limited, due to the limited transmission power. The acceptable ranges of D2D links in environments where D2D coexists with cellular network need to be further evaluated. D2D radio should be designed for relatively stationary devices due to its short range. However, some limited mobility support should be offered. The conventional mobility situation is to handover IP connections from cellular networks to D2D networks and vice versa if possible [10].

2.3.7 D2D Link Adaptation

Link adaptation (LA) targets to make the most of the system efficiency and this can be achieved by providing self-adaptation of the functional points to the dynamics of the signal-to-interference-plus-noise-ratios and block error rates (BLER). The main building block of LA is the selection of modulation and coding scheme, but also automated repeat request (ARQ) retransmission can be seen as a part of the LA. LA uses channel measurements to select the instantaneous modulation and code rate, but also information about the amount of data in the transmission buffer can be used to identify when there is no need to maximize the data rate. Hybrid ARQ (HARQ) can increase the efficiency compared to traditional [11].

ARQ by combining multiple transmissions. The BLER in D2D mode could vary largely depending on whether a D2D link operates on dedicated resources or reuses cellular resources. The BLER operation point might be higher when compared to cellular links, and higher variation between different frames can be expected due to the less, controlled interference environment. For the mapping of SINR to BLER points, the EESM (Exponential Effective SINR

Mapping) system metric is used. LA and HARQ can be handled directly by D2D devices in the case of D2D communication.

2.3.8 D2D Power Control

D2D communication can work in both fixed power scheme and fixed SINR target scheme. In the fixed Tx power case, all users in D2D mode use the same Tx power.

This scheme is simple, but it does not work well due to the possible large dynamic range of the D2D SINR. The dynamic range of D2D SINR is dependent on the overall interference situation. With random resource allocation/scheduling for all UEs, there can be significant interference from cellular mode UEs to D2D mode UEs. In this case, the dynamic range of D2D SINR is rather large, but with dedicated resources the dynamic range is lower. In the fixed SINR target case, the selection of the SINR target will affect the total Tx power and the final SINR directly. High SINR target requires more Tx power for D2D users, and the final SINR for those D2D users can be improved. However, there could be a risk of increasing the overall interference level to the users of the cellular mode. Other schemes are an (LTE-A) open loop1 fraction power control scheme and a closed loop2 power control scheme. In both schemes, the maximum allowed power is set to Pmax = 24 dBm. Power control plays an important role in RRM function when D2D and cellular links use overlapping resources.

2.4 The Relaying concept

One of the application of the D2D is relaying. With relaying functionality broadband cellular network coverage can be enhanced without a wired backhaul [8]. The radio link between the eNB and the UE has two hops. The link between the eNB (also called Donor eNB (DeNB)) and the Relay Node (RN) is called backhaul link. The link between the RN and the UE is called access link.

Standardization activities are under way at 3GPP on LTE Advanced with the aim of achieving high-speed, high-capacity communication beyond LTE. In LTE Advanced an important issue in addition to achieving high-speed, high-capacity communication is greater throughput for cell edge user, and one means now being studied to accomplish this is relay technology for relaying radio transmission between a base station and mobile station. Relays are expected to extend coverage in an efficient manner in varies types of locations such as places where fixed-line backhaul links are difficult to deploy.

2.4.1 Relays Classifications

Depending on their nature and complexity the Relay Node has two roles. It works like eNB with the UE, and as a UE with the eNB as. There are two types of relays [8]. The first type is amplify-and-forward relays or repeaters which amplify and forward the received analog signal forward. This means that the repeater amplifies also noise and interference as shown below in Figure 2.3. The second type is decode-and-forward delay. These relays decode and re-encode the received signal before forwarding it to the receiver as shown below.

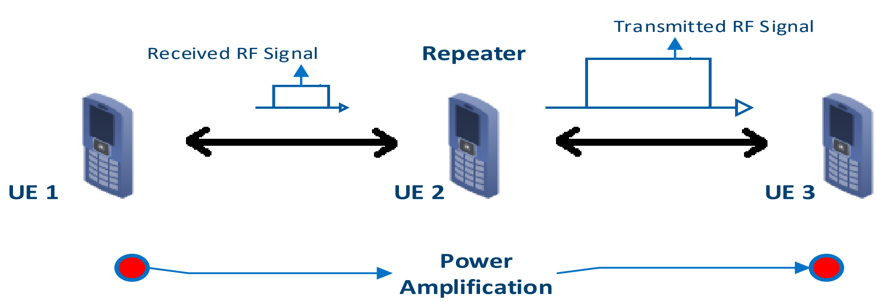


Figure 2.4 Amplify and Forward Relay

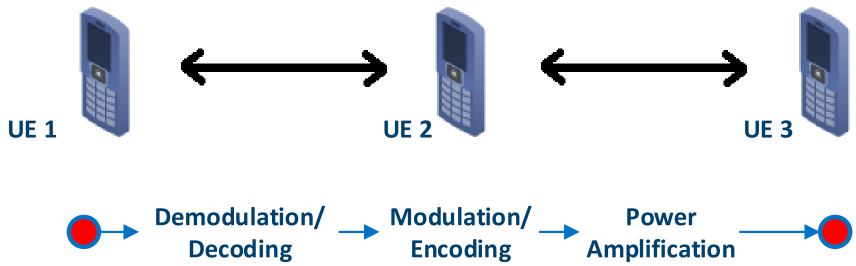


Figure 2.5 Decode and Forward Relay

2.4.2 ARQ Mechanisms

Recently, wireless multi-hop relaying communication has been researched as a key technique for improving cell coverage and capacity but due to various fading and interference, data transmissions are highly prone to be corrupted. The error can be further propagated and even amplified, as data packets are forwarded across multiple hops. In addition, data packets can be dropped at the intermediate RSs due to buffer overflow. Meanwhile, it has been shown in [9] that throughput would experience dismal degradation as the number of hops increases, even in an error-free multi-hop environment. Therefore, in order to meet the performance and reliability requirement of next generation mobile systems, an efficient error control mechanism for multi-hop transmission is indispensable. Two simple yet highly effective error control techniques are designed for single hop system ARQ and the more recent HARQ.

ARQ is a classic error detection and recovery mechanism widely used in contemporary communications system. If data packet is lost or corrupted, transmitter can do a retransmission if it receives a negative acknowledgement (ACK) from the intended receiver or its local ARQ transmission timer expires.

HARQ is an advanced cross-layer technique that has been recently adopted by many wireless systems to leverage coding gain and improve the reliability.

There are two main flavors of HARQ, namely chase combining (CC) and incremental redundancy (IR). HARQ can be used either independently, or in conjunction with ARQ to provide robust data transmission. However, traditional ARQ mechanisms are optimized for single-hop systems. If traditional ARQ mechanisms are used in a multi-hop environment without modification, problems arise, such as redundant data retransmission and long end-to-end latency. Moreover, in a multi-hop environment, more complex and intelligent ARQ mechanisms are required to manage data transmission across multiple links.

To solve these problems, new ARQ mechanisms more suited for a multi-hop environment are suggested as follows: end-to-end ARQ, hop by- hop ARQ, and Relay Station- ARQ, according to the way in which they recover from errors. Each type of ARQ mechanism has its own benefits and drawbacks, which we will describe it, bellow:

2.4.2.1 The End-to-End ARQ

Figure 2.5 shows the behavior of an end-to-end ARQ mechanism. With the end-to-end ARQ mechanism, the RN just relays the data and feedback between the source node and the destination node and takes no additional action. This ARQ mechanism uses a single error recovery protocol that covers a complete multi-hop route. So, the same protocol state is used for all hops and any link failure is managed by the source and the destination nodes without the aid of the RN. The end-to-end ARQ mechanism is very simple and deals with handover easily, because the source node knows the status of transmitted ARQ blocks. However, it has many drawbacks, such low transmission efficiency and long transmission delay, because the source node retransmits the data that the RN has already received successfully but that the destination node has failed to receive. In addition, the delay in the RN's receiving the retransmitted data from the source node is very long, because it is always triggered by a retransmission timeout or a feedback message sent by the destination node.

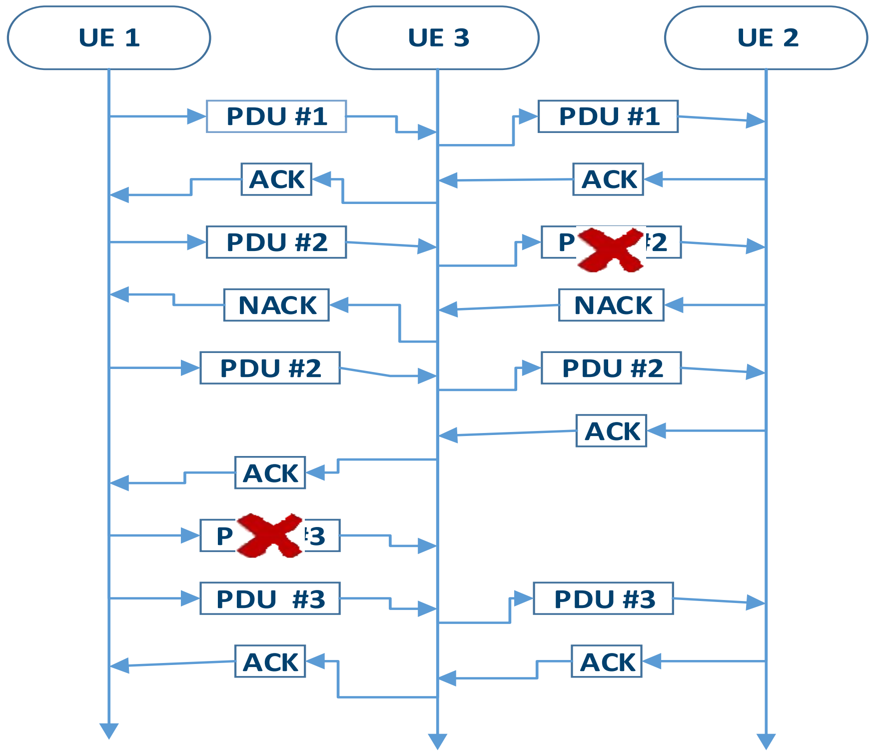


Figure 2.6 Behavior of the end-to-end ARQ mechanism.

2.4.2.2 Hop-By-Hop ARQ

Figure 2.6 shows the behavior of a hop-by-hop ARQ mechanism. With this mechanism, the RN not only relays the data but also generate its own feedback. This ARQ mechanism uses an error recovery protocol that operates independently in each link. It has high transmission efficiency and short transmission delay, because any transmission failure can be recovered in each hop. However, the complexity of the RN increases and the data may be queued or lacked in the RN, because the data transmission of one link does not consider the data transmission of another link. In addition, when the MS performs a handover, it must report additional information about its block status to the BS, because the ARQ block status in the BS and the MS are managed separately.

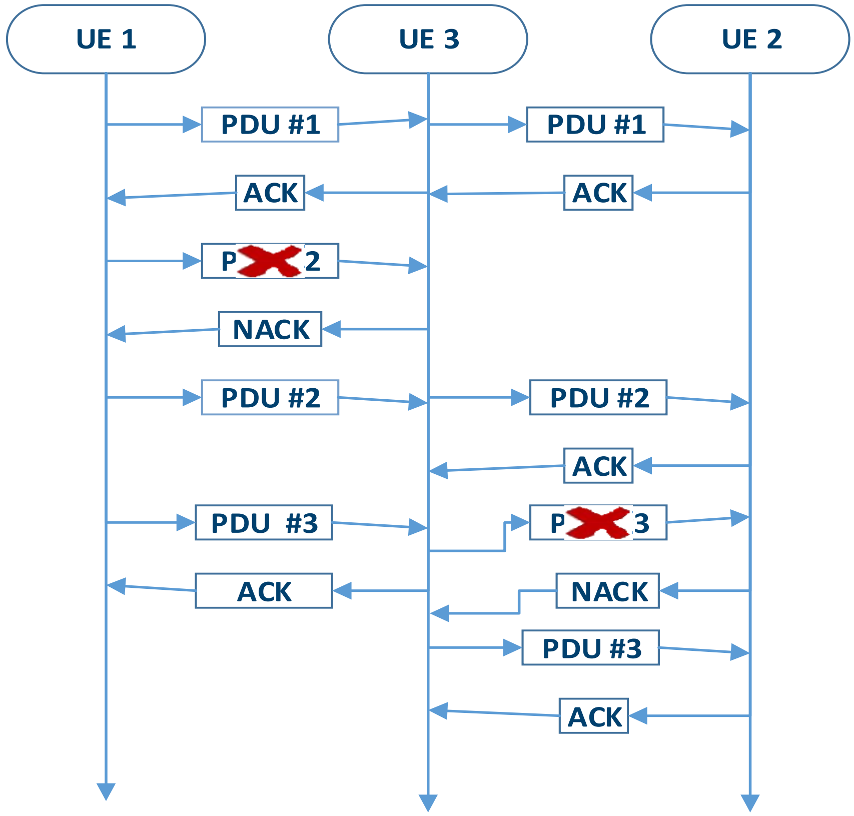


Figure 2.7 Behavior of the hop-by-hop ARQ mechanism.

2.4.2.3 Relay Station ARQ

As a RS-ARQ approach, a relay ARQ mechanism is suggested in [10]-[11]. Figure 2.7 shows the behavior of the relay ARQ mechanism. This ARQ mechanism uses a single error recovery protocol that covers the complete multi-hop route, just as does the end-to-end ARQ mechanism.

However, in this case, the RN relays the data and feedback between the source and destination nodes and generates its own feedback and transmits it to the source node, as does the hop-by hop ARQ mechanism. If the RN receives the data from the source successfully but fails to send the data to the destination node, the destination node sends an ARQ feedback message to communicate the NACK to the RN. The RN then relays it to the source node, together with an RN feedback message (RS ACK) that tells the source node that the RN has received the packet successfully. The source node is thus informed by the RS ACK and the NACK that the RN has received the data successfully but has failed to send the data to the destination node.

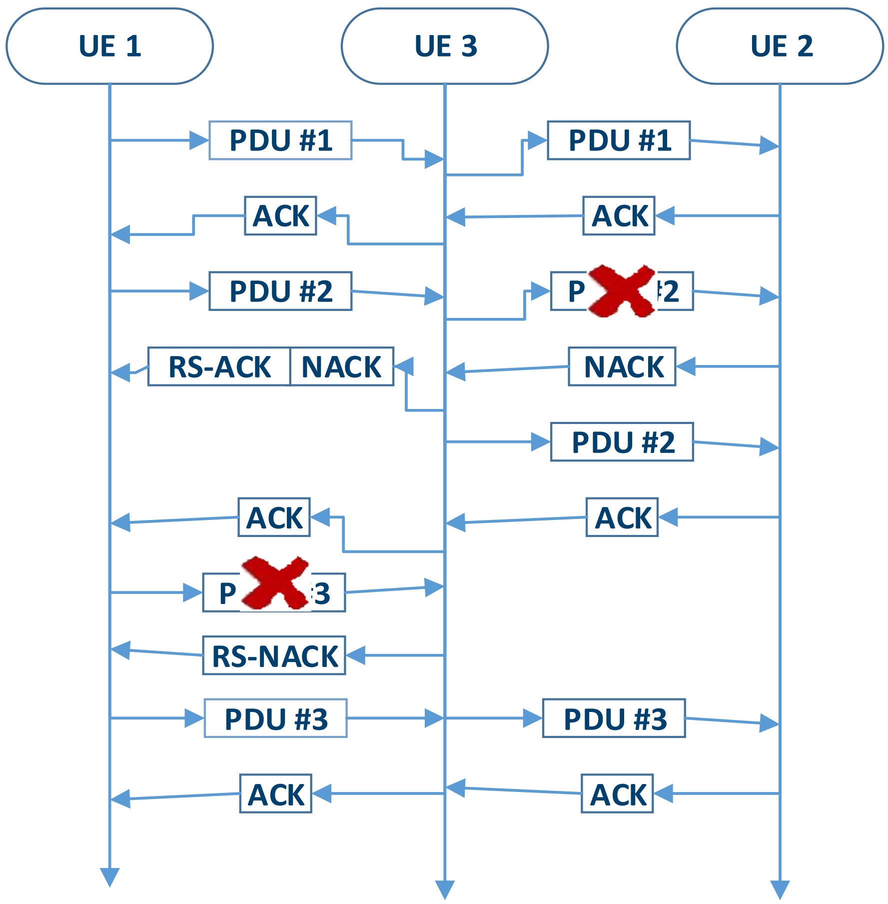


Figure 2.8 Behavior of the relay ARQ mechanism.

Hence, the source node does not retransmit the data. It waits until the RN sends the data to the destination node successfully. If the RN fails to receive the data from the source node, it sends an RN feedback message that contains the RS NACK, which indicates to the source node that the RN has failed to receive the packet. Upon receiving the RS NACK, the source node recognizes that the RN fails to receive the data and retransmits it. This relay ARQ mechanism has high transmission efficiency and short transmission delay, roughly equivalent to those of the hop-by-hop ARQ mechanism. In addition, the relay ARQ mechanism deals with MS handover easily, just as does the end-to-end ARQ mechanism, because the source node knows the status of transmitted ARQ blocks. However, the complexity of the RN increases.

2.5 Related Works

The authors of [12], Jedidi and Besbes proposed a new approach for D2D discovery applicable for the public safety scenario. The scheme was based on spreading approach using orthogonal codes. The transmitted signal of a victim is spreaded to an orthogonal code from Hadamard matrix so when received with the amount of other signals, it can be isolated. The detection depends on the correlation process between the received signals and the expecting spreaded SOS. A successful detection relies on a threshold value.

In [13] the authors proposed a low-power peer discovery scheme for D2D services that uses the spatial correlation of wireless channels. The proposed scheme, exploited the tradeoff between the power consumption and the accuracy/scope of peer discovery by adjusting the length of the beacon reception period. In particular, beacon transmission is allocated based on values of channel components such that nearby users transmit beacon at similar time instants due to the spatial correlation of channels. Accordingly, users seeking D2D peers in close proximity to them can reduce the length of their beacon reception period and accordingly reduce their power consumption.

Hayat and Ngah in [14] proposed Device discovery for D2D communication in in-band cellular networks using sphere decoder like (SDL) algorithm. The group of devices forms a lattice structure, and it is positioned in the coverage area. The hypersphere is constructed based on the power knowledge of a discoverer device which helps for accurate and fast device discovery in a lattice structure. Besides, sphere decoder like (SDL) algorithm is applied for quick and precise discovery in the lattice structure.

On the other hand, the multiple input multiple output (MIMO) relay channel has attracted a lot of interest where the source, relay, and destination have multiple antennas. Use of MIMO technique in a wireless relay network has gained special attentions in recent years due to its ability to provide significant improvements in data rate and reliability compared with single-antenna systems. Antenna selection strategies for amplify and forward relaying were proposed in (Peters and Heath 2008)[15], capacity performance analysis for MIMO relay channels with single antenna relay was investigated in (Chen et al. 2009)[16], fixed relays with multiple antennas in a two hop wireless network was analyzed in (Adinoyi and Yanikomeroglu 2007)[17] and the outage performance of several transmit antenna selection strategies in the amplify and forward MIMO relay channel has been analyzed by (Cao et al. 2009)[18].

Chapter Three

System Model

Chapter Three

System Model

3.1 Introduction

In this project the focus will be only on uncentralized scenario for selection of D2D pairs the process of peer discovery should be efficient, so that D2D links are discovered and established quickly. the D2D communication may be a comparatively new technology in cellular networks. Therefore, widely acceptable solutions for peer discovery are still missing.

From the perspective of the network, device discovery can be controlled by the base station either tightly or lightly. Peer discovery in cellular networks is divided into with or without UEs transmit "discovery beacons" [19], [20]. Beacons are 128-bit service layer identifier used in D2D discovery, they are expressions which can represent identity, services, interest or location. A device can be broadcasting through the air an expression like we are a coffee shop, a device with application filters out relevant expressions from all it detects through air interface so we can get expressions for emergency or other interesting things. So, we can send our positions to other mobile and we can calculate SINR based on any algorithm.

If UEs transmit beacons to advertise their presence, peer discovery might be completed by themselves. Several existing wireless technologies, depend on peer discovery with beacons e.g., Bluetooth and Wi-Fi Direct [21]. This D2D discovery without the gNodeB support is the best solution for public safety networks. In this scenario transmission mode2 (UE-selected) is used where the UE selects which resources to use for transmission. The resources are selected at random to minimize the collision risk [7].

The overall procedure of D2D (Sidelink) communication and corresponding Physical/MAC feature will pass through three main steps which are the synchronization, discovery and at last the communication. In order to demodulate the data, transmitter (Tx) and receiver (Rx) have to be synchronized in time and frequency and to know who will be responsible of synchronization, usually the synchronization is handled by either the BS or UE in this case it will be the responsibility of the UE and its process will be as shown in Figure 3.1

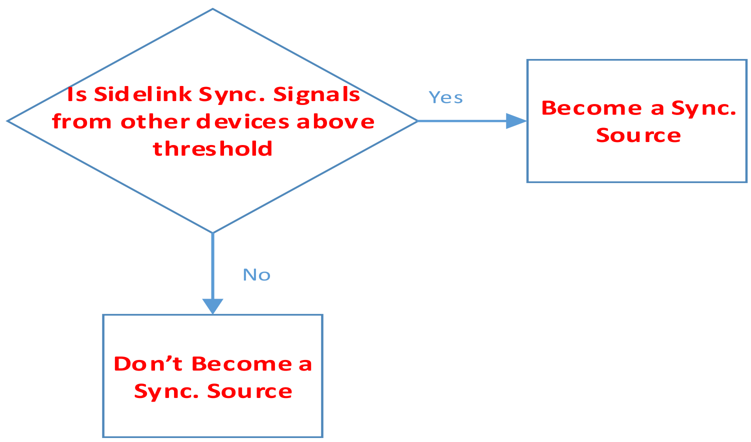


Figure 3.1 D2D Synchronization.

The Methods of Discovery in uncentralized case strategy will be as follows:

a) Beacons will be sent for device discovery broadcasted using side link channel PSDCH using preconfigured discovery resource pools [22]

b) Filtration of this beacons by receiver (Rx) and acknowledge response with all main information: temporary ID, location, SINR will be sent.

c) Resource pools configurations for D2D transmission and reception will be sent on PSCCH and PSSCH up to eight resource pools [23]

d) Decision of selection of D2D pair’s candidate will be the responsible of the transmitter (TX) according to the algorithm that we will use for discovery.

3.2 Algorithms for D2D pair Selection

Three algorithm were chosen and discussed in briefly in the following section

3.2.1 Minimum distance of discovery between D2D devices algorithm

This method may be used by rescue teams for searching for survivors in places around them. In this Algorithm the selecting criteria will be based on the shortest distances between devices with regards to the values of minimum SINR threshold value for the system to work. It works as shown below in figure 3.3

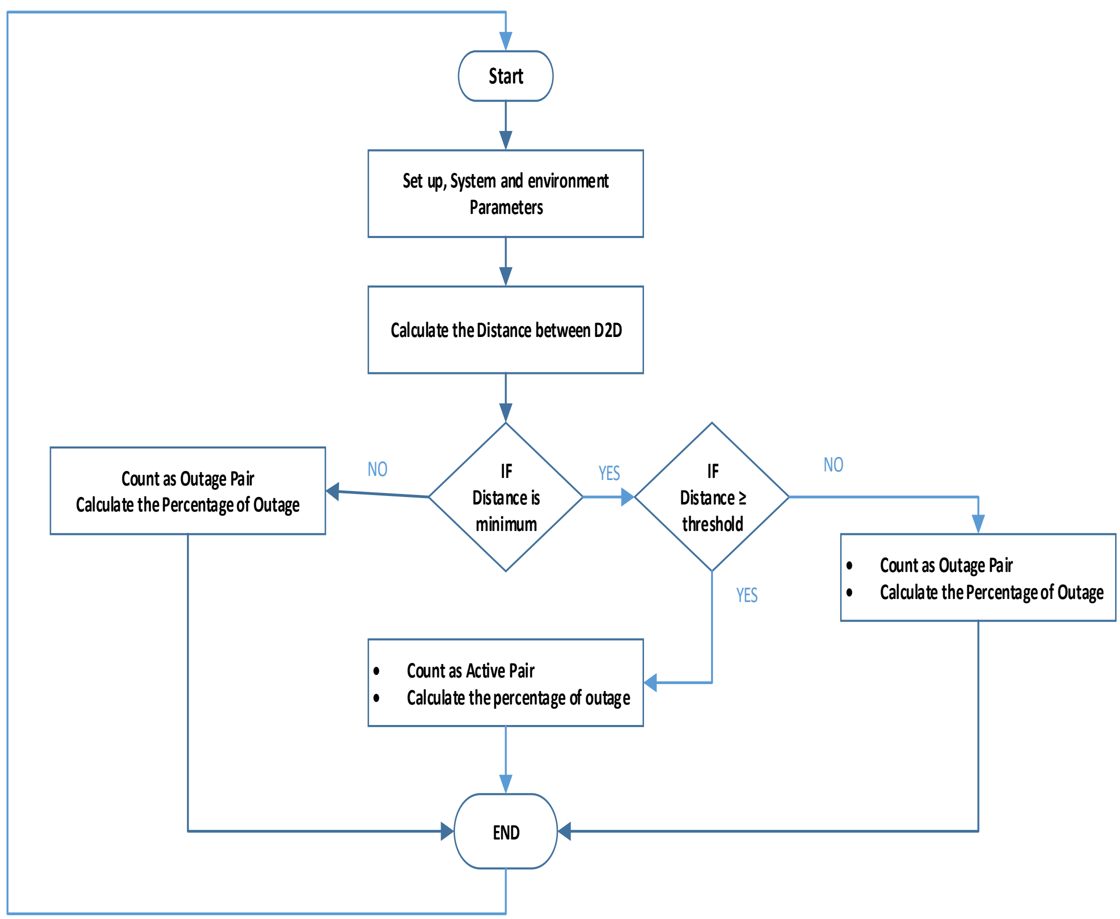


Figure 3.2 D2D Discovery using Minimum Distance Algorithm.

3.2.2 Maximum SINR with no limit on distance of discovery algorithm

In this algorithm selection will be based on SINR values. we choose D2D pair if they meet the minimum threshold of SINR and we select the best pair with maximum SINR values in the two directions, this algorithm may be the best one theoretically as we didn’t consider the threshold of the distance of discovery, It works as shown below in figure 3.3

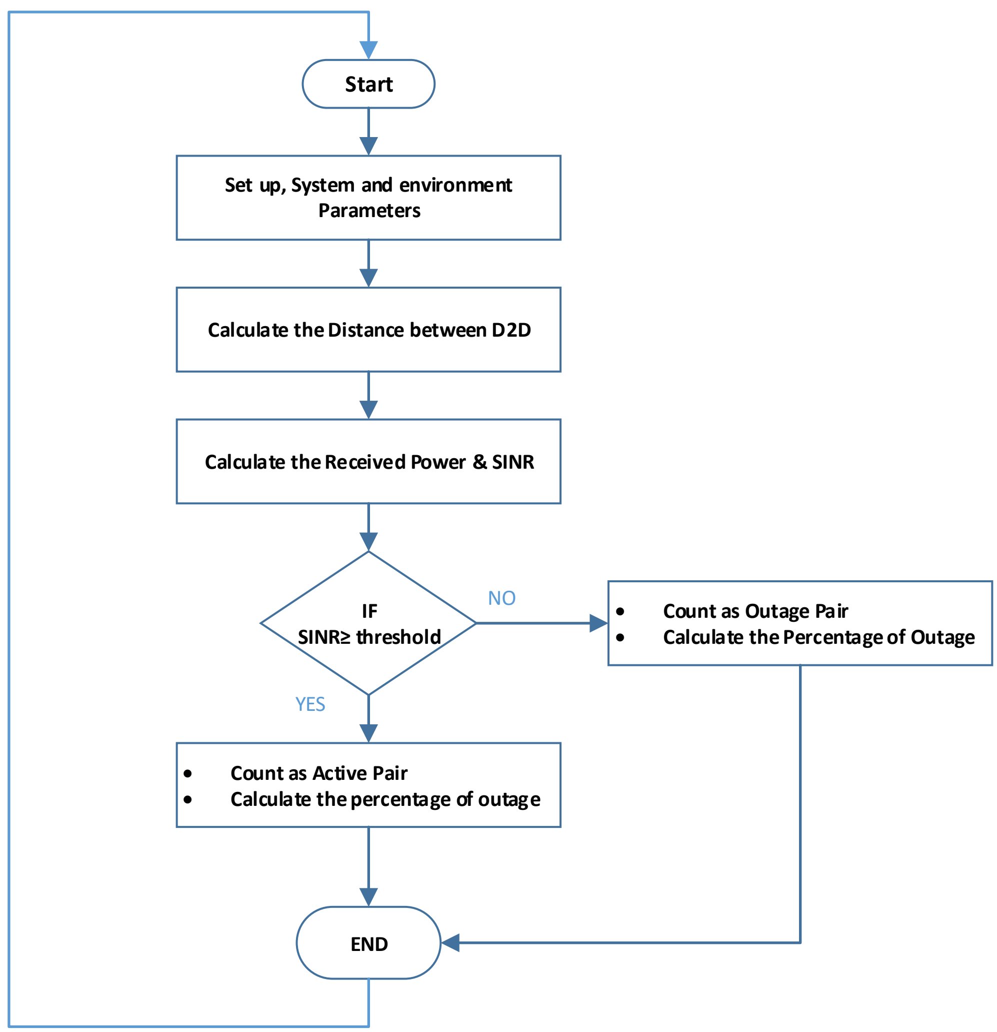


Figure 3.3 D2D Discovery using Maximum SINR Algorithm.

3.2.3 Maximum Data Rate with no limit on distance of discovery algorithm

In this algorithm selection will be based on the modulation index and Data rate values. It works as shown below in figure 3.4.

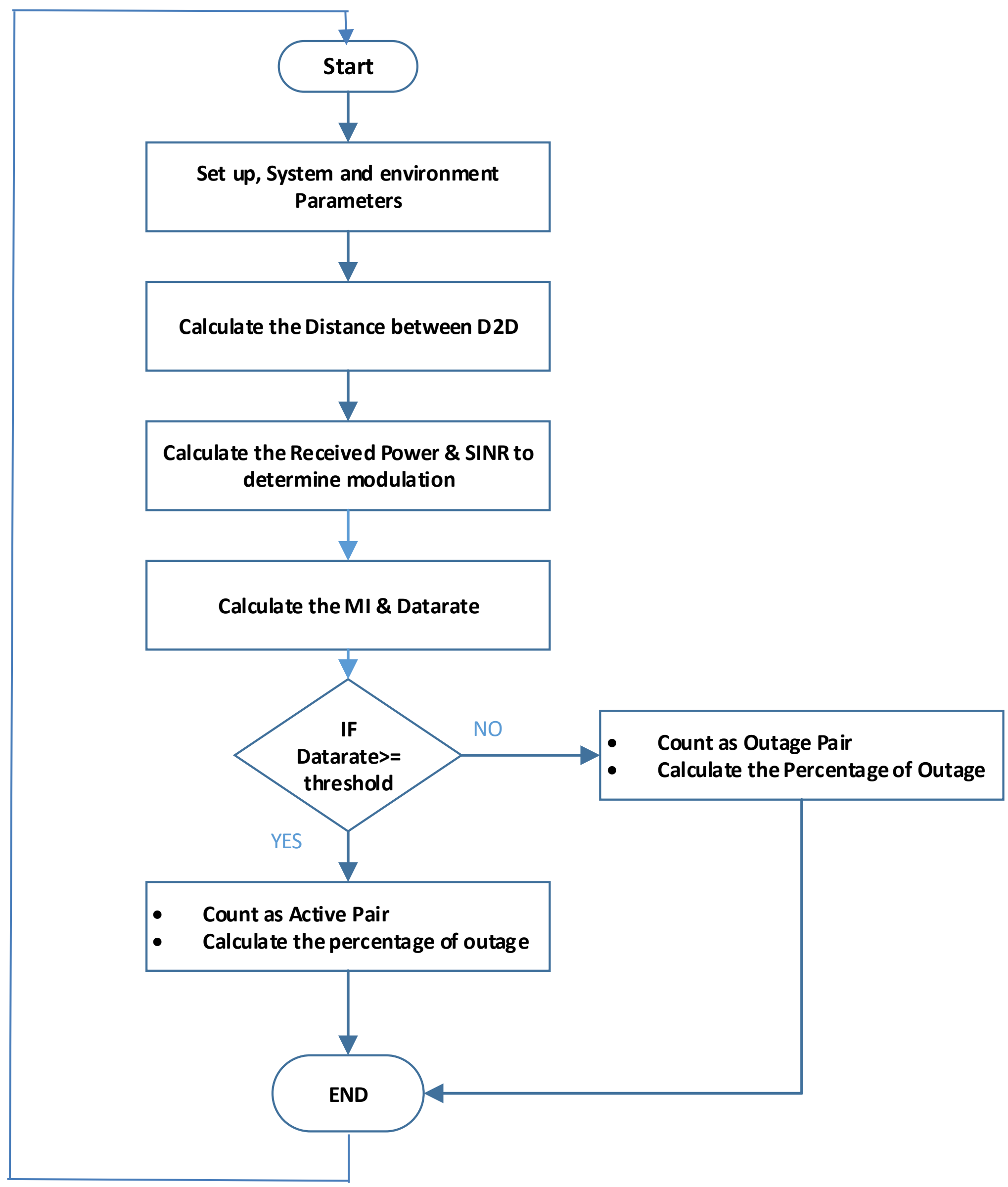


Figure 3.4 D2D Discovery using Maximum Data Rate Algorithm.

3.3 Amplify and forward Analysis

In this scenario, the D2D will simply works as a repeater. The UE3 in the middle receives the signal from UE1, amplifies this signal, and forwards it to the far UE2. Although AF relays are simple and have short delays, they are beneficial in most noise-limited system deployments as they amplify both interference and noise along with the desired signal.

3.3.1 Simplified Path Loss Model

The complexity of signal propagation makes it difficult to obtain a single model that characterizes path loss accurately across a range of different environments. Accurate path loss models can be obtained from complex analytical models or empirical measurements when tight system specifications must be met or the best locations for base stations or access point layouts must be determined. However, for general tradeoff analysis of various system designs it is sometimes best to use a simple model that captures the essence of signal propagation without resorting to complicated path loss models, which are only approximations to the real channel anyway. Thus, the following simplified model for path loss as a function of distance is commonly used for system design:

$$P_r = P_t K [\frac{d_0}{d}]^{\gamma} \quad \textbf{(3.1)}$$

The dB attenuation is thus

$$P_r \, dBm = P_t \, dBm + K \, dB - 10 \, \gamma \log_{10}[\frac{d_0}{d}] \quad \textbf{(3.2)}$$

In this approximation, *K* is a unit less constant which depends on the antenna characteristics and the average channel attenuation, d_0 is a reference distance for the antenna far-field, and γ is the path loss exponent. The values for K, d_0, and γ can be obtained to approximate either an analytical or empirical model. In particular, the free space path loss model, two-ray model, Hata model, and the COST extension to the Hata model are all of the same form as (3.1). Due to scattering phenomena in the antenna near-field, the model (3.1) is generally only valid at transmission distances $d > d_0$, where d_0 is typically assumed to be 1-10 m indoors and 10-100 m outdoors. When the simplified model is used to approximate empirical measurements, the value of K <1 is sometimes set to the free space path gain at distance d_0 assuming omnidirectional antennas:

$$K\,dB = 20\log_{10}\frac{\lambda}{4\pi d_0} \quad \textbf{(3.3)}$$

And this assumption is supported by empirical data for free-space path loss at a transmission distance of 100 m. Alternatively, K can be determined by measurement at d_0 or optimized (alone or together with γ) to minimize the mean square error (MSE) between the model and the empirical measurements. The value of γ depends on the propagation environment: for propagation that approximately follows a free-space or two-ray model γ is set to 2 or 4, respectively. The value of γ for more complex environments can be obtained via a minimum mean square error (MMSE) fit to empirical measurements; alternatively, γ can be obtained from an empirically-based model that takes into account frequency and antenna height. A table summarizing γ values for different indoor and outdoor environments and antenna heights at 900 MHz and 1.9 GHz is given below [24].

Path loss exponents at higher frequencies tend to be higher while path loss exponents at higher antenna heights tend to be lower. Note that the wide range of empirical path loss exponents for indoor propagation may be due to attenuation caused by floors, objects, and partitions [25].

Table 3.1 Typical path loss exponent

Environment	γ range
Urban macro cells	3.7-6.5
Urban microcells	2.7-3.5
Office Building (same floor)	1.6-3.5
Office Building (multiple floor)	2-6
Store	1.8-2.2
Factory	1.6-3.3
Home	3

3.3.2 Signal-to- Noise Power Ratio

SNR is commonly used in wireless communication as a way to measure the quality of wireless connections. Typically, the energy of a signal fades with distance, which is referred to as a path loss in wireless networks. Conversely, in wired networks the existence of a wired path between the sender or transmitter and the receiver determines the correct reception of data. In a wireless network one has to take other factors into account (e.g. the background noise, interfering strength of other simultaneous transmission).

In an AWGN channel the modulated signal s(t) = {u(t)ej2πfct} has noise n(t) in the network, added to it prior to reception. The noise n(t) is a white Gaussian random process with mean zero and power spectral density N0/2. The received signal is thus r(t) = s(t) + n(t).We define the received signal-to- noise power ratio (SNR) as the ratio of the received signal power P_r to the power of the noise within the bandwidth of the transmitted signal $s(t)$. The received power P_r is determined by the transmitted power and the path loss, shadowing, and multipath fading as shown above in equation (3.2). The noise power is determined by the bandwidth of the transmitted signal and the spectral properties of $n(t)$. Specifically, if the bandwidth of the complex envelope $u(t)$ of $s(t)$ is B then the bandwidth of the transmitted signal $s(t)$ is $2B$. Since the noise $n(t)$ has uniform power spectral density $N0/2$, the total noise power within the bandwidth $2B$ is $N = N0/2 \times 2B = N0B$. So the received SNR is given by

$$\text{SNR} = \frac{P_r}{N_0 B} \qquad \textbf{(3.4)}$$

The SNR is often expressed in terms of the signal energy per bit E_b or per symbol E_s as

$$\text{SNR} = \frac{P_r}{N_0 B} = \frac{E_s}{N_0 B T_s} = \frac{E_b}{N_0 B T_b} \qquad \textbf{(3.5)}$$

Where T_s is the symbol time and T_b is the bit time (for binary modulation $T_s = T_b$ and $E_s = E_b$). For data pulses with $T_s = 1/B$, e.g. raised cosine pulses with $\beta = 1$, we have $\text{SNR} = E_s / N_0$ for multilevel signaling and $\text{SNR} = E_b / N_0$ for binary signaling. For general pulses, $T_s = k/B$ for some constant k, in which case $k \cdot \text{SNR} = E_s/N_0$. The quantities $\gamma s = E_s / N_0$ and $\gamma b = E_b / N_0$ are sometimes called the SNR per symbol and the SNR per bit, respectively. For performance specification, we are interested in the bit error probability P_b as a function of γb. However, for M-array signaling (e.g. MPAM and MPSK), the bit error probability depends on both the symbol error probability and the mapping of bits to symbols. Thus, we typically compute the symbol error probability Ps as a function of γs based on the signal space concepts and then obtain Pb as a function of γb using an exact or approximate conversion. The approximate conversion typically assumes that the symbol energy is divided equally among all bits, and that Gray encoding is used so that at reasonable SNR, one symbol error corresponds to exactly one-bit error. These assumptions for M-array signaling lead to the approximations

$$\gamma_b \approx \frac{\gamma_s}{\log_2 M} \quad \textbf{(3.6)}$$

$$P_b \approx \frac{P_s}{\log_2 M} \quad \textbf{(3.7)}$$

Table 3.2 Theoretical minimum SNR at base band demodulator input

SNR Requirements Versus Coding Rate and Modulation Scheme		
Modulation	Code Rate	SNR[dB]
QPSK	1/8	-5.1
	1/5	-2.9
	1/4	-1.7
	1/3	-1.0
	1/2	2.0
	2/3	4.3
	3/4	5.5
	4/5	6.2
16 QAM	1/2	7.9
	2/3	11.3
	3/4	12.2
	4/5	12.8
64QAM	2/3	15.3
	3/4	17.5
	4/5	18.6

According to the calculated SNR the modulation type can be chosen as shown above in Table 3.2

3.3.3 Capacity

The channel capacity is the tightest upper bound on the rate of information that can be reliably transmitted over a communications channel in bits per second (bps), developed by Claude E. Shannon ,and it is given by the following formula[26].

$$\mathbf{C} = \mathbf{B} \times \boldsymbol{log_2}(\mathbf{1} + \mathbf{SNR}) \quad \textbf{(3.8)}$$

3.3.4 Data Rates

It can be defined as the speed with which data can be transmitted over the channel is called data rate, it often measured in *megabits per second*. These are usually abbreviated as *Mbps*. We can derive the data rate by multiplying mutual information with the bandwidth of the sub channel. The net bit rate of the PHY layer is less than this value because of channel coding.

$$\text{Data rate} = \text{MI} \times \text{BW} \quad \textbf{(3.9)}$$

For determining the required link level results, we build upon the mutual information (MI) method [27]. This works by applying a formula from SNR to MI, and then from MI to BER (bit error ratio) and PER (packet error ratio) to get the packet error probability. For the first step the performance data of modulation schemes typically comes from link level simulations. MI has the meaning of the number of effective bits that can be transported at a certain SNR level. It is always below the Shannon bound

$$\text{MIShannon (SNR)} = \log_2(1 + 10^{SNR/10dB}) \quad \textbf{(3.10)}$$

In reality, each modulation grade comes with its own MI level, depending on SNR. For the SNR → MI we have developed an analytic expression by fitting the link level result data with a suitable function. In low SNR regions, MI is limited by the Shannon bound. In high SNR regions it is saturated and limited by the number of bits the modulation scheme supports (m). The region in between is influenced by both effects and handled by this new formula:

$$\mathrm{MI}\ (\mathrm{SNR}, \mathrm{m}) = \frac{1}{([s.MI\mathrm{shannon}(SNR)]^{-w}+m^{-w})^{1/w}} \quad \textbf{(3.11)}$$

Using the following abbreviations

$$\mathrm{s} = \mathrm{s}\ (\mathrm{m}) = 0.95 - 0.08. (\mathrm{m\ mod\ 2}) \quad \textbf{(3.12)}$$

$$\mathrm{w} = \mathrm{w}\ (\mathrm{m}) = 2\mathrm{m} + 1 \quad \textbf{(3.13)}$$

Where m is the modulation index, i.e. the number of bits per symbol (1=QPSK...8=QAM256). The scale factor s (m) reveals the remarkable fact that square-shaped modulation constellations (m=2, 4, 6, 8) perform slightly better than the other I/Q asymmetric constellations. The MI value has the unit of [Mbit/s/Hz].

3.3.5 Spectral and Energy Efficiency

Spectrum Efficiency (SE) or bandwidth efficiency refers to the information rate that can be transmitted over a given bandwidth in a specific communication system. It is a measure of how efficiently a limited frequency spectrum is utilized by the physical layer protocol, and sometimes by the media access control (the channel access protocol). The link spectral efficiency of a digital communication system is measured in *bit/s/Hz*, or, less frequently but unambiguously, in *(bit/s)/Hz*.

At the end, the total capacity for all multi-hop communications will define the energy efficiency (EE) and spectral efficiency (SE) performance of multi-hop D2D communications. The overall instantaneous transmission vector for energy efficiency (EE) comprised by the EE elements from every link is defined by [28].

$$\text{EE} = \frac{\text{Capacity}}{\text{H}\times\text{P}_t} \tag{3.14}$$

Where H represents the number of hops on every link and P_t is the maximum transmission power of the UE. The same way, we can define SE vector as:

$$\text{SE} = \frac{\text{Capacity}}{\text{BW}} \tag{3.15}$$

3.3.6 Bit Error Rate

Is the percentage of bits that have errors relative to the total number of bits received in a transmission, usually expressed as ten to a negative power. It is an indication of how often a packet or other data unit has to be retransmitted because of an error. Too high a BER may indicate that a slower data rate would actually improve overall transmission time for a given amount of transmitted data since the BER might be reduced, lowering the number of packets that had to be resent. With digital systems, it is the output quality of the information that is the primary concern. Since the information is digital and usually has a binary representation, this quality is measured in terms of the average bit error rate (BER). A bit error occurs whenever the transmitted bit and the corresponding received bit do not agree.

Under the assumption that the symbol error rate is the same as bit error rate, we may formulate the performance comparison of the different modulation–demodulation strategies shown in Table 3.3. We have split the table between baseband and band pass counterparts where they exist. Although *M*-arry PAM does have a band pass equivalent, it is rarely used; QAM is typically used instead.

Table 3.3 represent a Comparison of BER Performance for Various Modulation–Demodulation Strategies. Detection is Coherent Unless Otherwise Indicated. (The β Parameter is the Number of Bits per Symbol in the in-Phase or Quadrature Dimension.)

Table 3.3 Comparison of BER Performance

Modulation–Demodulation		**Bit Error Rate**
Baseband	**Band pass**	
On–off PAM	ASK	$Q(\sqrt{\frac{Eb}{N0}})$
Bipolar PAM	BPSK	$Q(\sqrt{\frac{2Eb}{N0}})$
M-ary PAM	-	$2\frac{M-1}{M}Q(\sqrt{\frac{6\beta}{M^2-1}}\sqrt{\frac{Eb}{N0}})$
	QPSK	$Q(\sqrt{\frac{2Eb}{N0}})$
	M-arry QAM	$2\frac{\sqrt{M}-1}{\sqrt{M}}Q(\sqrt{\frac{6\beta}{M-1}}\sqrt{\frac{Eb}{N0}})$
	Binary FSK	$Q(\sqrt{\frac{Eb}{N0}})$
	Differential BPSK	$\frac{1}{2}\exp(-\frac{Eb}{N0})$

Using the mathematical equations discussed in the above section the performance of the system for the amplify and forward scenario is evaluated as shown below in figure 3.5.

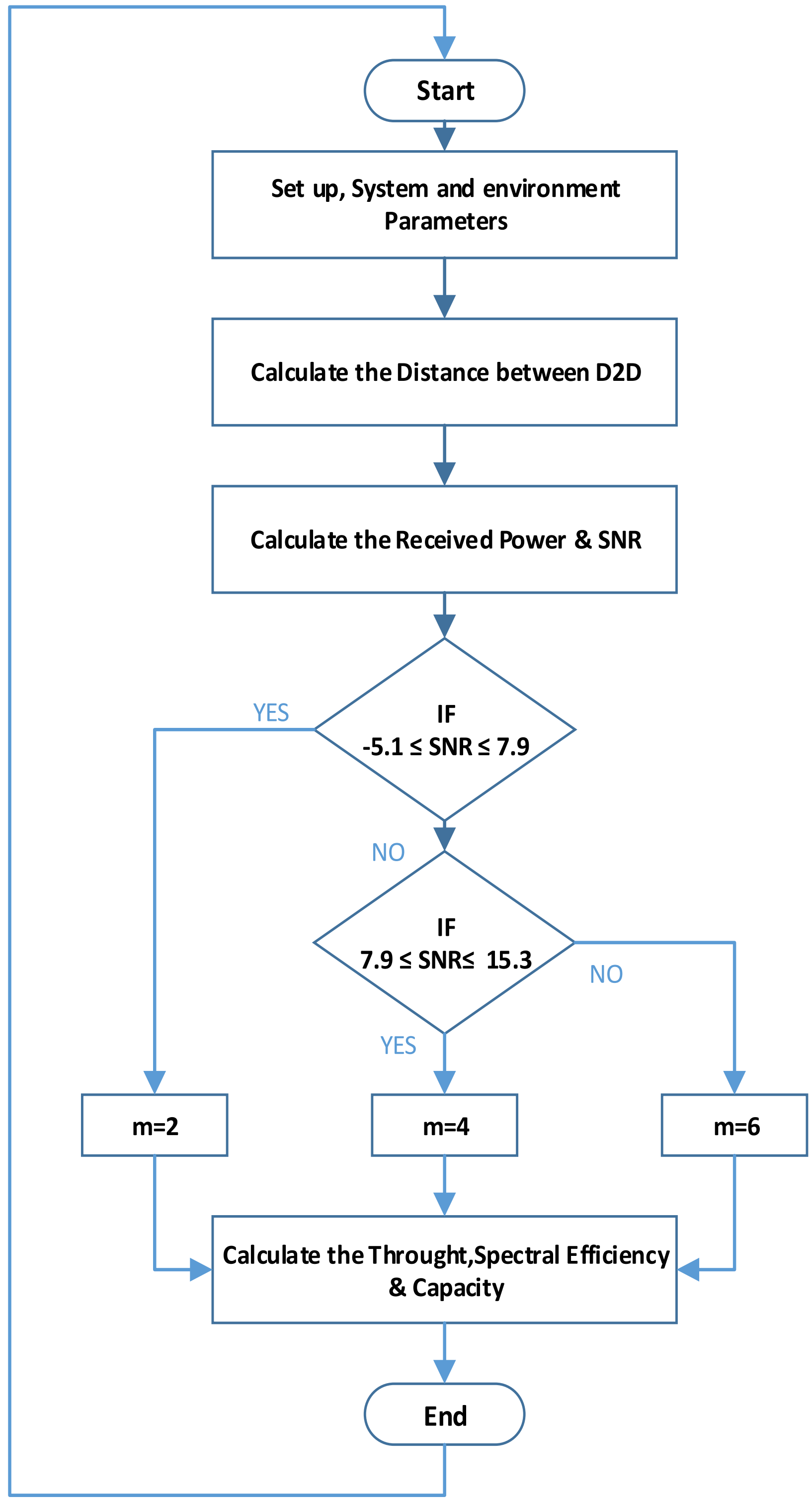


Figure 3.5 D2D Amplify and Forward Relay

3.4 Decode and forward using ARQ Mechanism analysis

In the second scenario, since the AF relaying, just amplifies the received signals without decoding. Due to fading and interference of radio channels, data packets cannot always be transmitted without error. So when data packets are forwarded across multiple AF-RSs, these errors are propagated. This is avoided with DF-relaying, where a DF-RS first decodes the packet and then forwards the re-encoded packet to the next-hop receiver. If a packet is received with error, it cannot be decoded successfully at a DF-RS, and is dropped. Consequently, only error-free packets are forwarded.

To evaluate the performance of our proposed ARQ mechanism, we analyze the delay and the ARQ transmission efficiency. In analysis, we assume that the RS uses the next frame to relay the data received in the current frame and there are no errors in the transmission of ARQ feedback messages.

3.4.1 Delay

In the case of RS ARQ mechanism, when the Packet Error Rate (PER) of the link between the source and the RS is $P1$ and that of the link between the RS and the destination is $P2$, the average delay in the RS receiving the data from the source successfully ($D1$) is calculated as follows.

$$\mathrm{D1} = \sum_{i=0}^{\infty}(T + 2i \times T \times \mathrm{P_f} + R_{\mathrm{T}} \times (1 - \mathrm{P_f})) \times \mathrm{P1}^{i}(1 - \mathrm{P1}) \qquad \textbf{(3.16)}$$

Here, T is the frame duration, $\mathrm{P_f}$ is the probability that the retransmission is triggered by the ARQ feedback message communicating the RS NACK, and R_{T} is the *ARQ* RETRY TIMEOUT period. Hence, $T+2i\times \mathrm{P_f} \times T + R_{\mathrm{T}} \times (1- \mathrm{P_f})$ represents the delay in the RS receiving the data from the source successfully in$(i + 1)^{\mathrm{th}}$ transmission. $\mathrm{P1}^{i}(1 - \mathrm{P1})$represents the probability that the RS receives the data from the source successfully in $(i + 1)^{\mathrm{th}}$transmission. Since we assume no errors in the transmission of ARQ feedback messages, P_f is 1, and hence the following simpler form is derived from Equation (3.15).

$$\mathrm{D1} = \sum_{i=0}^{\infty}(1 + 2i) \times T \times \mathrm{P1}^{i}(1 - \mathrm{P1}) = \frac{1+\mathrm{P1}}{1-\mathrm{P1}}.T \qquad \textbf{(3.17)}$$

The average total delay in the source sending the data to the destination and receiving the ACK from the destination successfully (D_t) is calculated as follows.

$$\mathrm{D\,t} = \sum_{i=0}^{\infty}(2T + 2i \times T \times P\mathrm{f} + R\mathrm{T} \times (1 - P\mathrm{f})) \times \mathrm{P2}^{i}(1 - \mathrm{P2}) + D1 + T \qquad \textbf{(3.18)}$$

Here, 2T + 2i × T × P_f + R_T × (1 − P_f) represents the delay in the RS sending the data to the destination and receiving the ACK from the destination successfully in $(i + 1)^{\mathrm{th}}$ transmission. $\mathrm{P2}^{i}(1 - \mathrm{P2})$ represents the probability that the destination receives the data from the RS successfully in the $(i + 1)^{\mathrm{th}}$ transmission. The last term, T, represents the delay due to the feedback of the RS to the source. Since we assume no errors in the transmission of ARQ feedback messages, Pf is 1, and hence the following simpler form is derived from the Equation (3.17).

$$\mathrm{Dt} = \sum_{i=0}^{\infty}(1 + i) \times 2T \times \mathrm{P2}^{i}(1 - \mathrm{P2}) + D1 + T$$

$$= \frac{4-2(\mathrm{P1}+\mathrm{P2})}{(1-\mathrm{P1})(1-\mathrm{P2})}.\mathrm{T} \qquad \textbf{(3.19)}$$

In the case of the ARQ mechanism in which the RS makes no action, the average delay in the RS receiving the data from the source successfully ($D2$) is calculated as follows.

$$D2 = \sum_{i=0}^{\infty}(T + 4iT \times P\mathrm{f} + R\mathrm{T} \times (1 - \mathrm{Pf})) \times \mathrm{P1}^{i}(1 - \mathrm{P1})$$

$$= \sum_{\mathrm{i}=0}^{\infty}(1 + 4\mathrm{i}) \times \mathrm{T} \times \mathrm{P1}^{i}(1 - \mathrm{P1})$$

$$= \frac{1+3\mathrm{P1}}{1-\mathrm{P1}}.\mathrm{T} \quad \textbf{(3.20)}$$

The average total delay in the source sending the data to the destination and receiving the ACK from the destination successfully (Dt) is calculated as follows.

$$\mathrm{Dt} = \sum_{i=0}^{\infty}(D2 + T + (D2 + 3T) \times i \times \mathrm{Pf} + R\mathrm{T} \times (1 - \mathrm{Pf})) \times \mathrm{P2}^{i}(1 - \mathrm{P2}) + 2T$$

$$= \sum_{i=0}^{\infty}(D2 + T + (D2 + 3T) \times i) \times \mathrm{P2}^{i}(1 - \mathrm{P2}) + 2\mathrm{T}$$

$$= \frac{4}{1-\mathrm{P1})(1-\mathrm{P2})}.\mathrm{T} \quad \textbf{(3.21)}$$

Here, D2+T + (D2+3T) ×i× P_f + R_T × (1− P_f) represents the delay in the RS receiving the data from the source and sending the data to the destination successfully in $(i + 1)^{\mathrm{th}}$ transmission. $\mathrm{P2}^{i}(1 - \mathrm{P2})$ represents the probability that the destination receives the data from the RS successfully in the $(i + 1)^{\mathrm{th}}$transmission. The last term, $2T$, represents the delay for the feedback of the destination to the source by relaying.

3.4.2 ARQ Transmission Efficiency

The ARQ transmission efficiency (ηr) is defined as the ratio of pure data transmission excluding retransmission to total data transmission in the link [28], and it is calculated as follows.

$$\eta r = \frac{\frac{\mathrm{np}}{\mathrm{ttotal}}}{\mathrm{Rlink}} \quad \textbf{(3.22)}$$

Here, n_p is the total number of bits in a packet and t_{total} is the average total time taken to transmit a packet, which is given by $tp(1 + Nr)$, where tp is the transmission time for a packet and Nr is the average number of retransmissions per packet. $Rlink$ is an actual bit rate on the link which is given by n_p / tp. using these relations, ARQ transmission efficiency (ηr) is calculated as follows.

$$\eta r = \frac{\mathrm{np/tp(1+N}r)}{\mathrm{np/tp}} = \frac{1}{1+\mathrm{N}r} \quad \textbf{(3.23)}$$

If the PER of a link is P, Nr of the link is calculated as follows.

$$\mathrm{N}r = \sum_{\mathrm{i}=1}^{\infty} i(1-P)P^i = \frac{P}{1-P} \quad \textbf{(3.24)}$$

Using Equation (3.22) and Equation (3.23), ηr is calculated as follows.

$$\eta r = 1 - \mathrm{P} \quad \textbf{(3.25)}$$

With our proposed ARQ mechanism, the RS has a responsibility to send the data to the destination for the data which the RS receives successfully from the source. So, ηr is calculated separately in each link in the proposed ARQ mechanism. Since, ηr is dependent on the lowest one, ηr of our proposed ARQ mechanism is calculated as follows.

$$\eta r = \min(1 - \mathrm{P1}, 1 - \mathrm{P2}) \quad \textbf{(3.26)}$$

In the case of the ARQ mechanism in which the RS makes no action, the retransmission takes place whenever the data transmission fails in any link. Hence, Nr and ηr are calculated as follows.

$$\mathrm{N}r = \sum_{\mathrm{i}=1}^{\infty} i(1-P1)(1-\mathrm{p}2)\{1-(1-\mathrm{p}1)(1-\mathrm{p}2)\}^{i}$$

$$= \frac{1-(1-\mathrm{P}_1)(1-\mathrm{p}_2)}{(1-\mathrm{P}_1)(1-\mathrm{p}_2)} \quad \textbf{(3.27)}$$

$$\eta r = (1-\mathrm{P}1)\times(1-\mathrm{P}2) \quad \textbf{(3.28)}$$

Chapter Four
Simulation Results and Discussion

Chapter Four

Simulation Results and Discussion

In this section, the results are obtained from the mathematical expressions presented in the previous Section in chapter three based on Matlab simulation. After classifying the device peer discovery algorithms, the D2D will be used as a relay and measure its performance in its two modes (Amplify and Forward, Decode and Forward). The Matlab code can be found in the appendix.

4.1 General Environment and Parameters Assumptions

Table 4.1 gives a list of main simulation parameters used through the simulation performances. These parameters are widely used to simulate the wireless cellular networks.

Table 4.1 simulation parameters

Parameter	Values
Carrier Frequency	1.9 GHz
Bandwidth	20 MHz
Maximum total transmitting power of D2D	24 dBm
Number of RN	1
Length and Width of the Area	1500 m
Radius of Hexagon	250 m
Reference distance for the antenna far field	10 m
Path loss exponent according to urban microcell	3.7
Number of RB	1
Additive White Gaussian Noise	1-3 dB
Interference	1-3 dB
Number of D2D Devices	2- 100

4.2 Simulation Results and Discussion

The results and analysis of the two phases will be discussed briefly in the section

4.2.1 Phase 1: D2D Discovery Algorithms Results

A small-scale scenario is considered such as stadiums, theatres or a shopping mall that is covered by 5G macro-cell. The BS are damaged due to environmental disaster or terrorist attacks, the rescue team will try to search and find survivals using different algorithms for peer discovery. Although there is a limit for maximum coverage 500 m for discovery as mentioned in Release 12 3GPP standards, a rebroadcasting of Beacons is assumed which is still an open research. After that, different algorithms for peer discovery and selection of the best D2D pair accordingly will be applied.

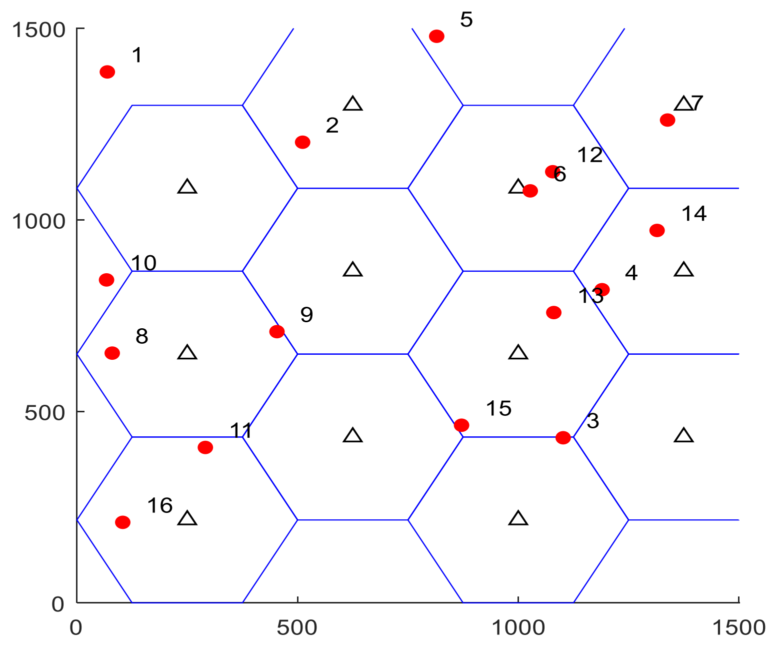


Figure 4.1 D2D Random Distribution.

Figure 4.1 shows a sample of the network distribution; the red dots represents the UE. The system model designed is able to distribute number of D2D devices randomly and calculate the position and the distance between each device and to calculate the main parameter SINR between each D2D device.

On figure 4.2, the distance Algorithm is used where the selecting criteria will be based on the shortest distances between devices with regards to the values of minimum SINR threshold. Each plot represents the number of pairs that is selected using specific number of devices and with respect to minimum distance between devices for pair selection, it is observed that as the number of devices increase the average number of pair increase also as we increase distance threshold between devices the average number of D2D pairs increase.

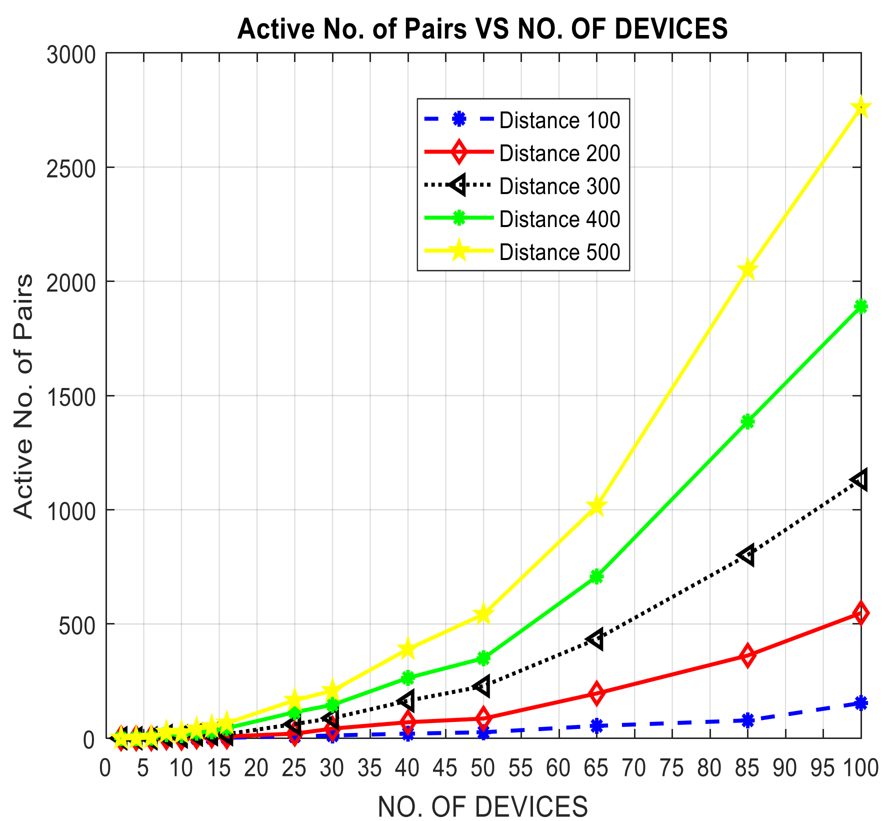


Figure 4.2 D2D Active Pairs according to Distance Algorithm

Continue with the distance algorithm as shown in figure 4.3 the percentage of outage will be in its maximum when the distance threshold is 100 but it starts to decrease as the distance threshold increases. As the number of devices start to increase the percentage of devices seems to be constant.

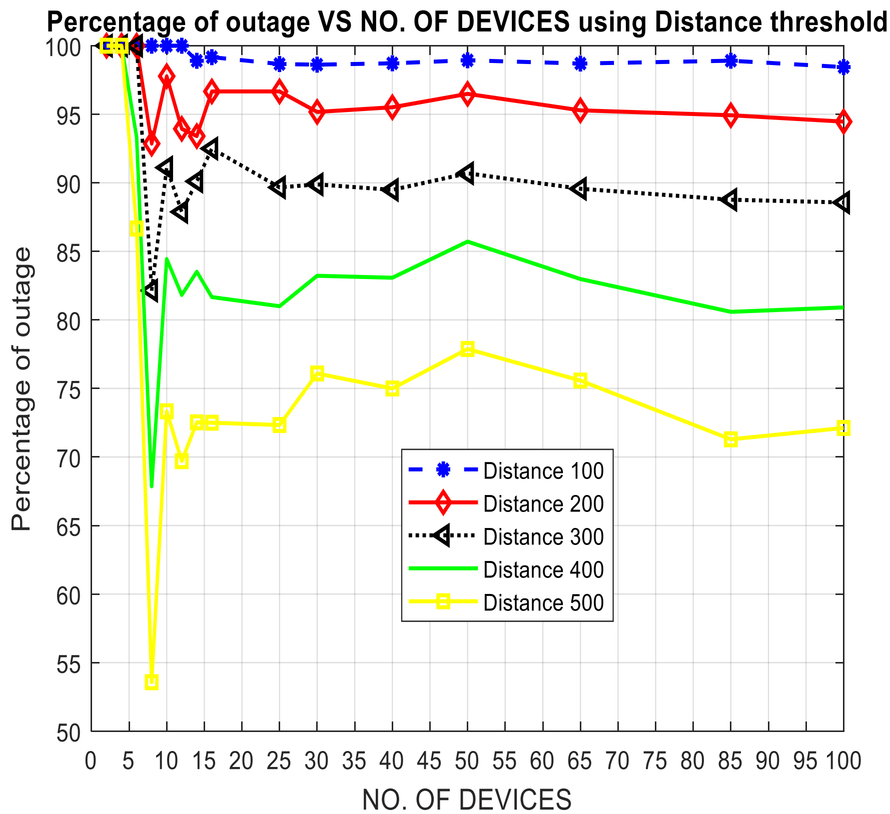


Figure 4.3 D2D Percentage of Outage according to Distance Algorithm

In figure 4.4, the algorithm of discovery was changed to SINR with different threshold the better the SINR the more active pair is discovered and vice versa. The number of devices act directly proportional with the number of active pairs as it increases the number of pair's increases. It's also obvious from the graph that the low SINR will affect the discovery of UE directly.

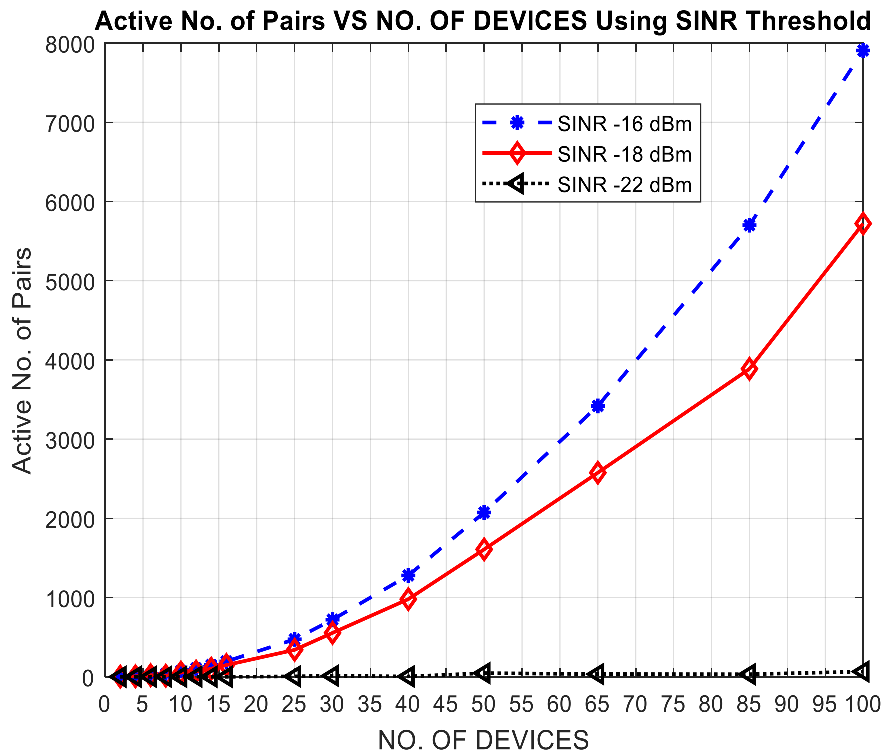


Figure 4.4 D2D Active Pairs according to SINR Algorithm.

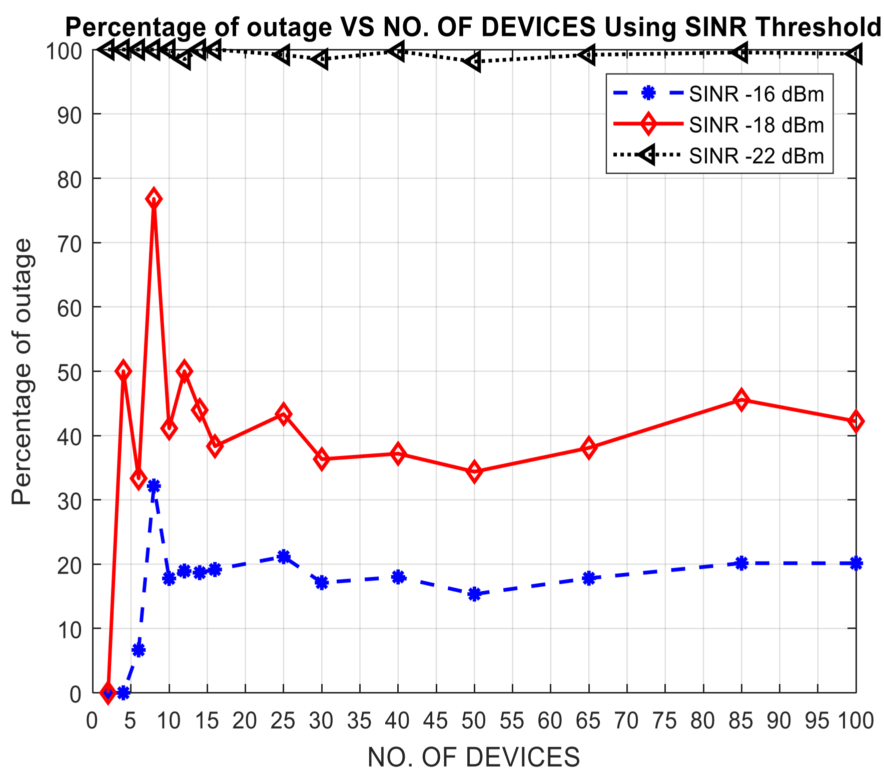


Figure 4.5 D2D Percentage of Outage according to SINR Algorithm

The percentage of outage was about 100 percent for the low SINR threshold as shown above in figure 4.5 above but it starts to decrease as the SINR increase. The lower the percentage of outage the better so in this case the red one is the best this will lead to higher rate of discovered UE.

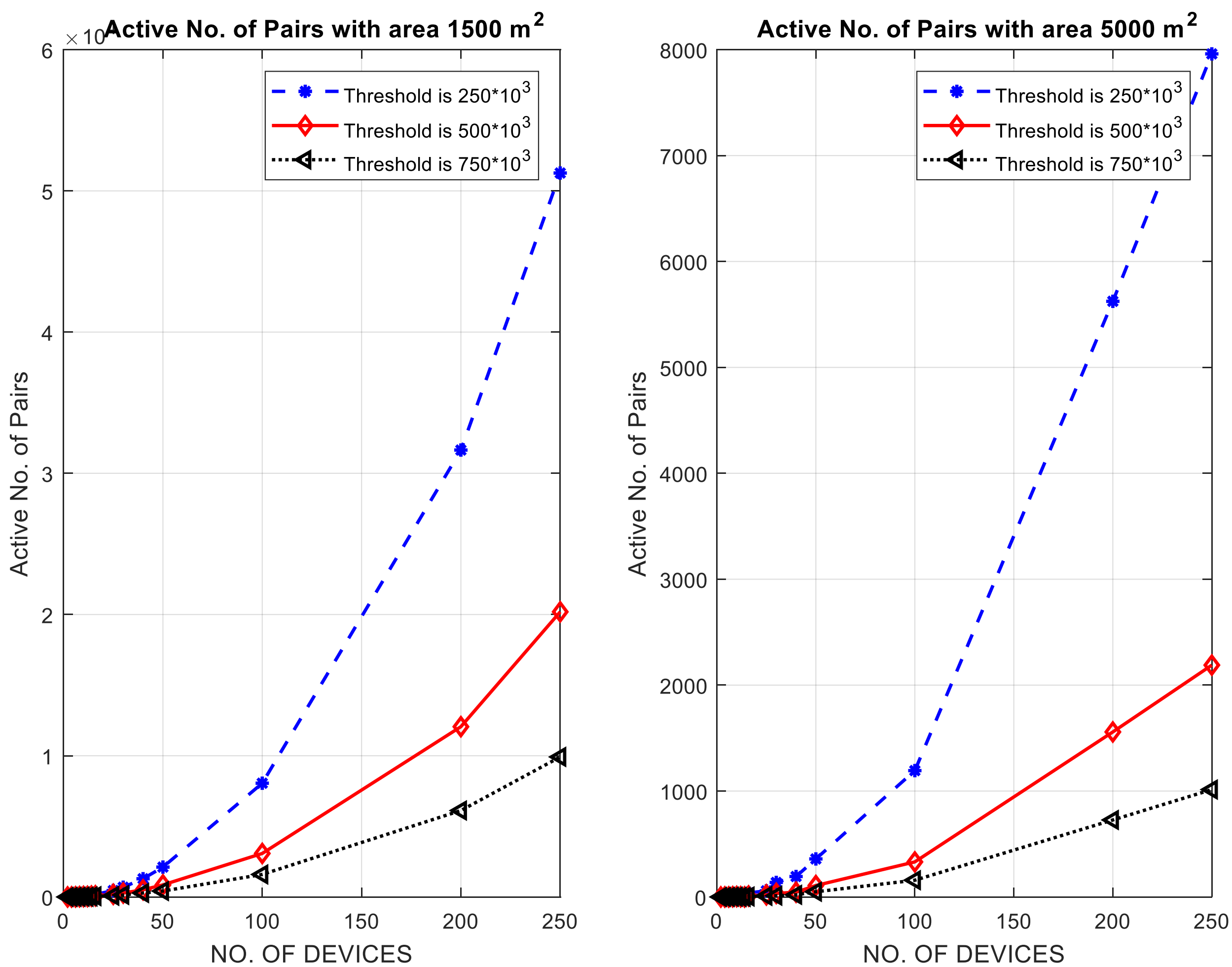


Figure 4.6 D2D Active Pairs according to Data Rate Algorithm.

In figure 4.6 and 4.7 the data rate is used as the main criteria in order for the D2D to be pairs. The algorithm is used twice under the same condition but each time with different area. Figure 4.6 represents the active number of pairs versus the number of devices. Three data rate threshold were chosen and as it appears from the graph, the two graphs looks identical but the active number of pairs is higher in the area of 5000 m^2 than the 1500 m^2 area. It starts to increase as the number of devices increases and vice versa but it depends on the threshold.

In figure 4.8 the same algorithm is used which is the data rates the figure the in the right represent the 5000 m^2 area all of its results are high for the three algorithm but also the higher data rates values will leads to a larger number of active pairs and vice versa.

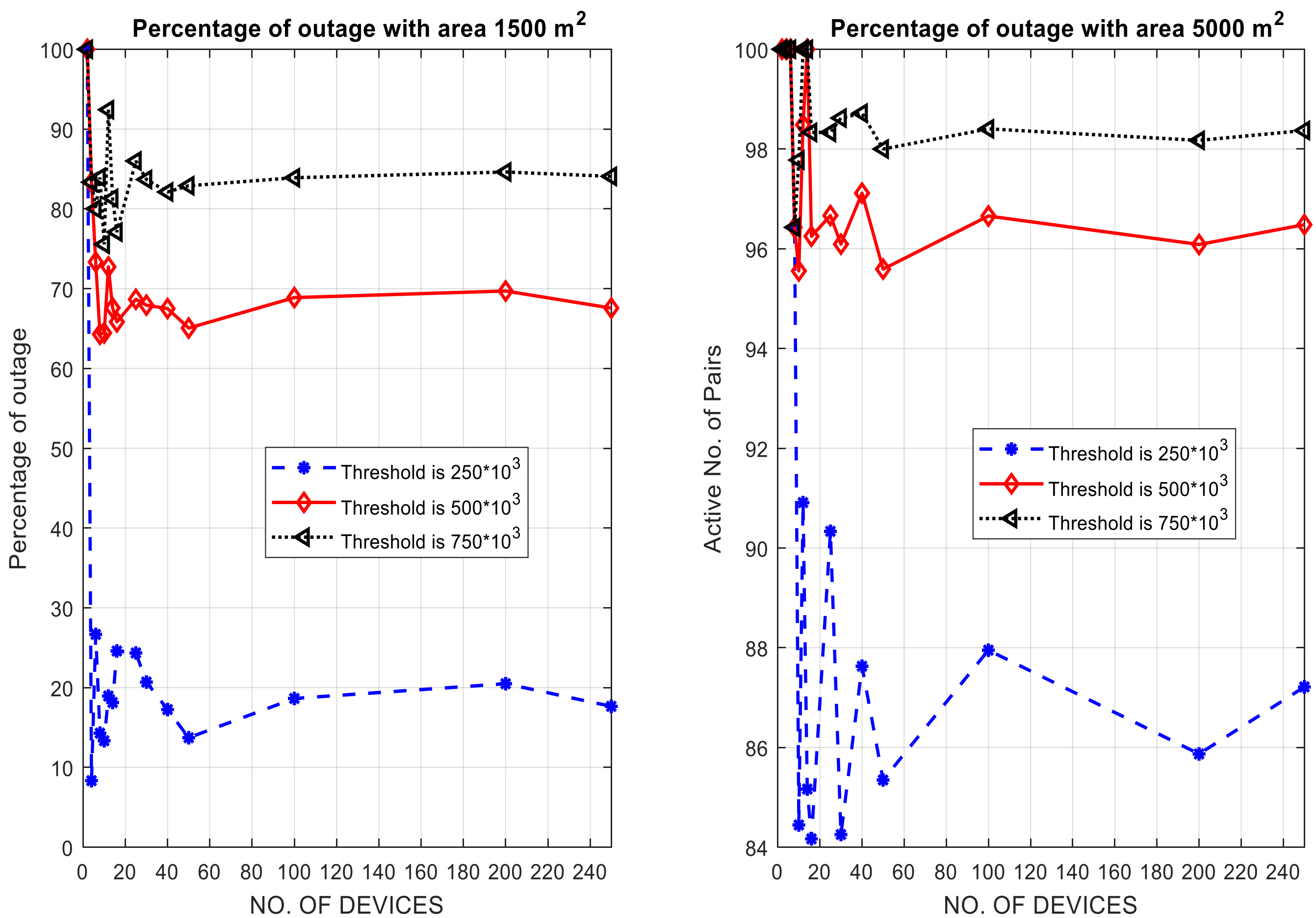


Figure 4.7 D2D Percentage of Outage according to Data Rate Algorithm

As mentioned in the previous graphs three algorithms were used for selecting the D2D pair with different threshold in figure 4.8 and 4.9 the three algorithms were used together at the same environmental conditions

From the results shown below in figure 4.8 using the data rate algorithm will result in a higher number of active pairs almost three times higher than the distance algorithm. The SINR algorithm results were in the middle between the three algorithms. It's obvious from the graphs that when the number of devices are low all of the algorithms acted the same but it started to change from about fifty users the change appeared clearly the number of active pairs started to increase rapidly.

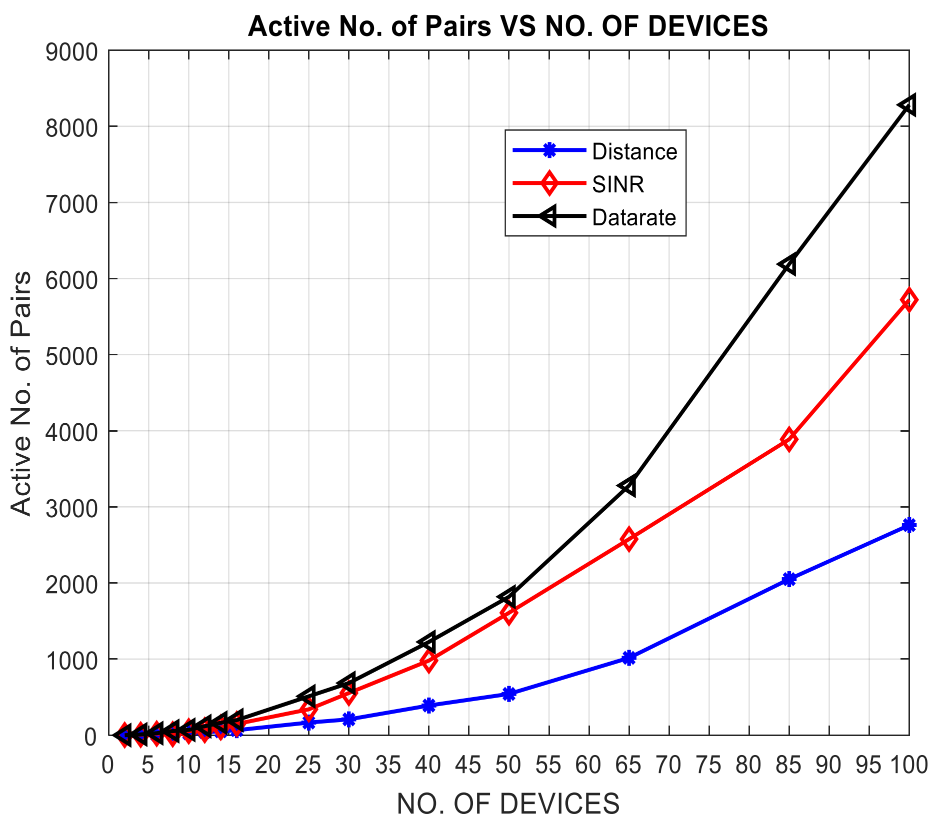


Figure 4.8 D2D Active Pairs according to the three Algorithms.

Figure 4.9 shows the percentage of outage for the three algorithms the distance algorithm has the highest percentage of outage compared to the other algorithms. The SINR algorithm has about 50 % outage but the data rate algorithm showed the best results with the least percentage of outage.

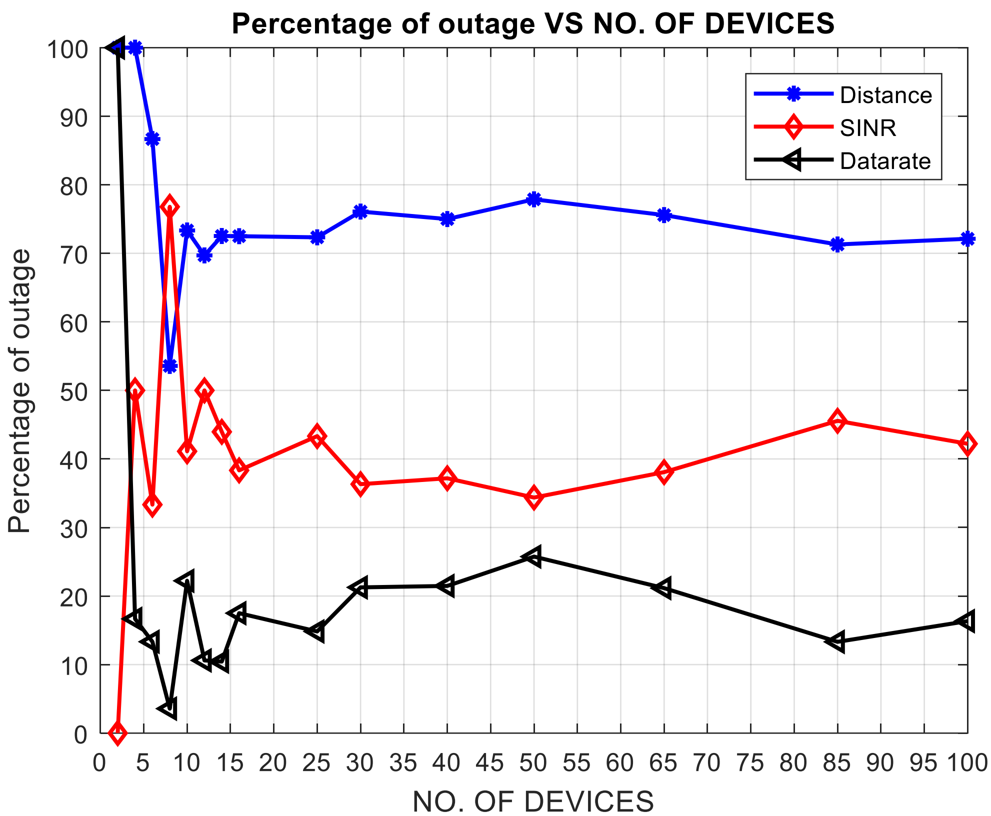


Figure 4.9 D2D Percentage of Outage according to the three Algorithms

After classifying the device peer discovery algorithms, the D2D will be used as a relay and measure its performance in its two modes (Amplify and Forward, Decode and Forward)

4.2.2 Phase 2: Amplify and forward RS Results

In this phase, the system performances had been compared of with-relaying and without-relaying cases. All of the results in this phase are demonstrated against time because most of the wireless channel parameters have random values that is changed with time so if one value is chosen it will not give the right evaluation of the system.

Figure 4.10 illustrates the effects of the different SNR with time. As seen, a much better performance is achieved by using relays in a cell. This is obvious because the signal over the direct link in the no relaying case has to propagate over twice the distance than over the multi-hop relaying case by this the power will be reduced that's lead to a lower SNR. The randomness in the figure is due to the noise at each frame time duration there is a different value for the noise. The result of the simulation illustrated in Figure. 4.1 shows that the use of a relay station in amplify and forward mode give an improvement in SNR by approximately 50%.

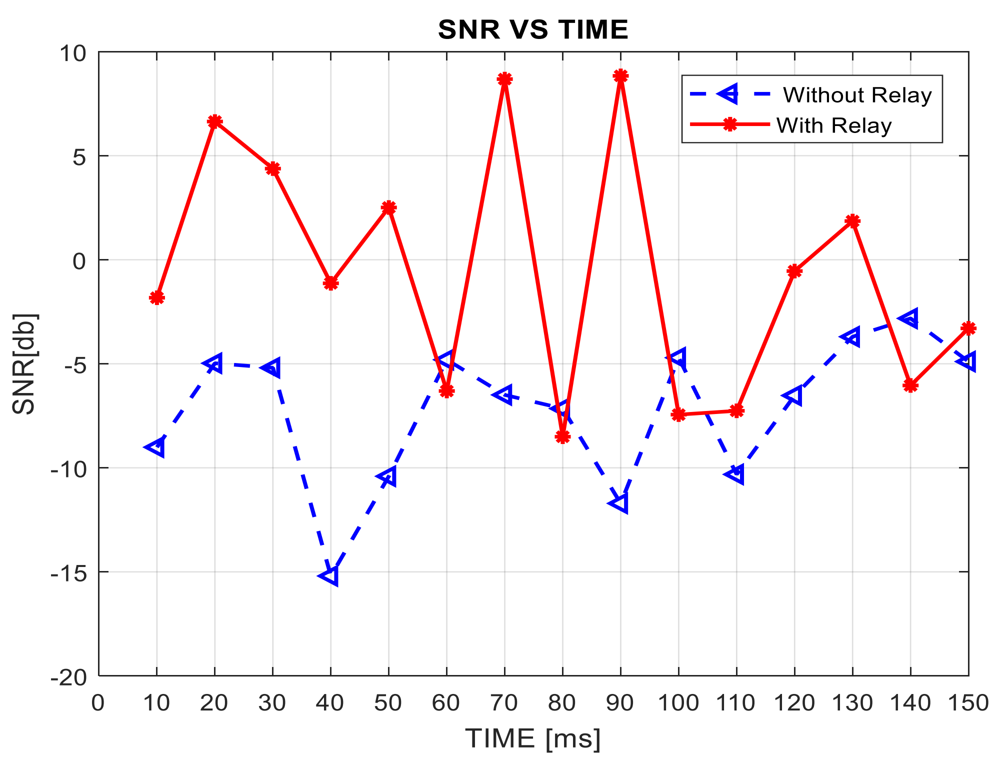
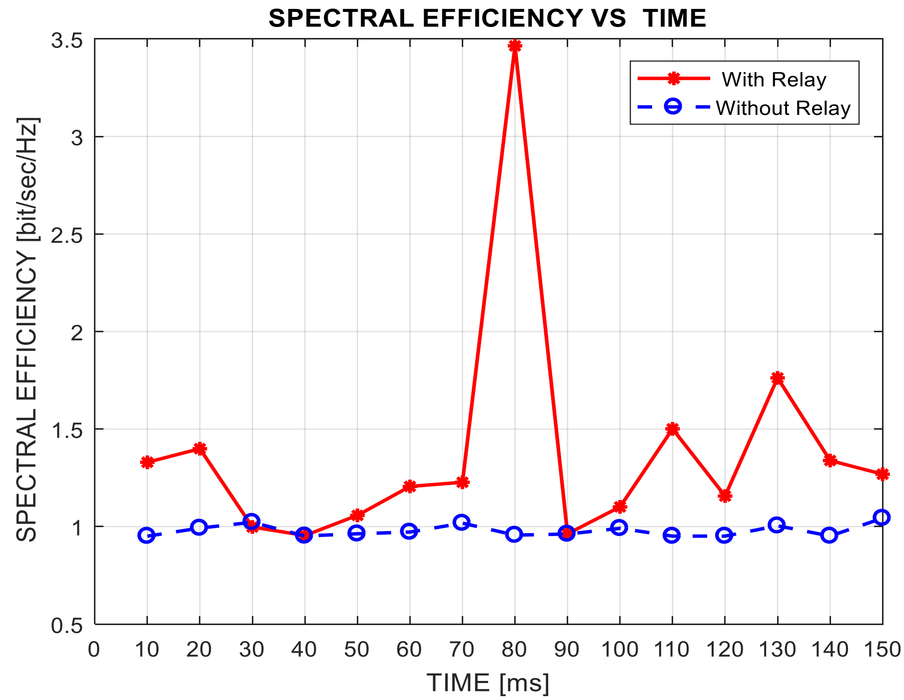


Figure 4.10 SNR versus Time



Figures 4.11 average spectral efficiency versus time

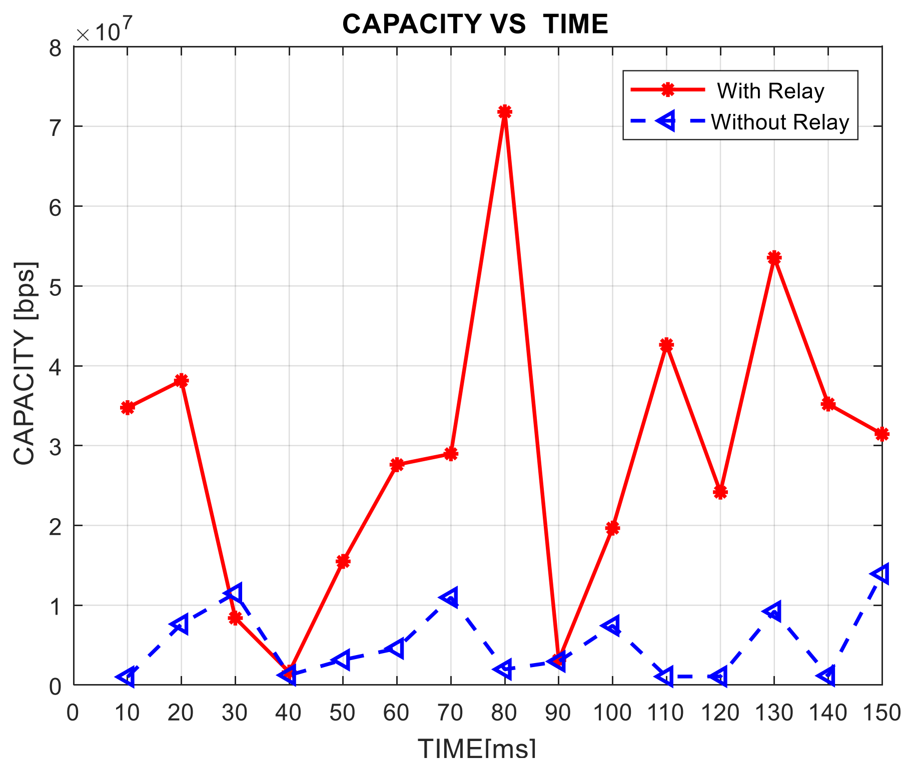


Figure 4.12 capacity versus time

Figure 4.11 illustrate the spectrum efficiency or bandwidth efficiency versus time. From the results obtained it shows that the information rate that can be transmitted over a given bandwidth when using the relay has a better performance than without using the relay due to the increased data rate.

Figure 4.12 shows the capacity of channel versus time. The channel capacity is the tightest upper bound on the rate of information that can be reliably transmitted over the communications channel in bits per second (bps). This figure demonstrates that when using the relay, the capacity of the system can approximately be twice better than without using the relay due to the improvement in SNR. Also the use of UEs as relay increases the system capacity due to shorter communication paths which led to better channel conditions.

Figure 4.13 shown below represents the BER obtained from table 3.3 in chapter three, according to the modulation type and SNR. The BER can be defined as the percentage of bits that have errors relative to the total number of bits received in a transmission. As expected, the BER is increased when the relay is not used and decreased when it is used this improves the system performance by approximately 70%.

Simulation results shown in figure 4.14 demonstrates that with the increment of number of hops, EE increases, for the same UE transmission power and bandwidth utilization. Another important metric is reducing the UE transmission power for different numbers of hops. In public safety communications, reducing the UE transmission power is vital, since that will contribute in extending the UE battery life in situations where power outages can be present by using UE power more efficiently. Also, reducing UE transmission power will reduce the interference of D2D to cellular network along with the interference with other D2D communications.

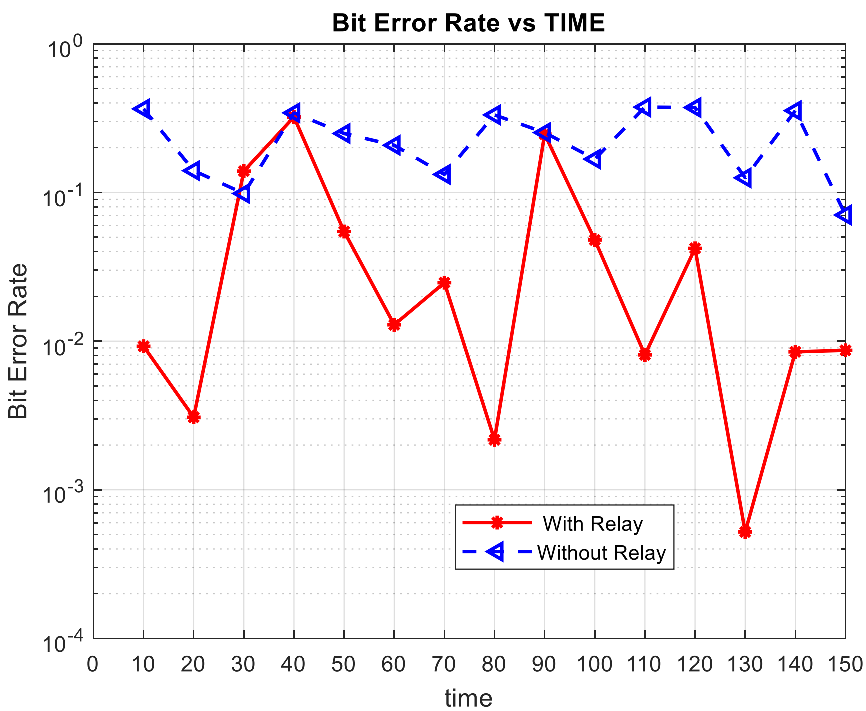


Figure 4.13 Bit Error Rate versus Time

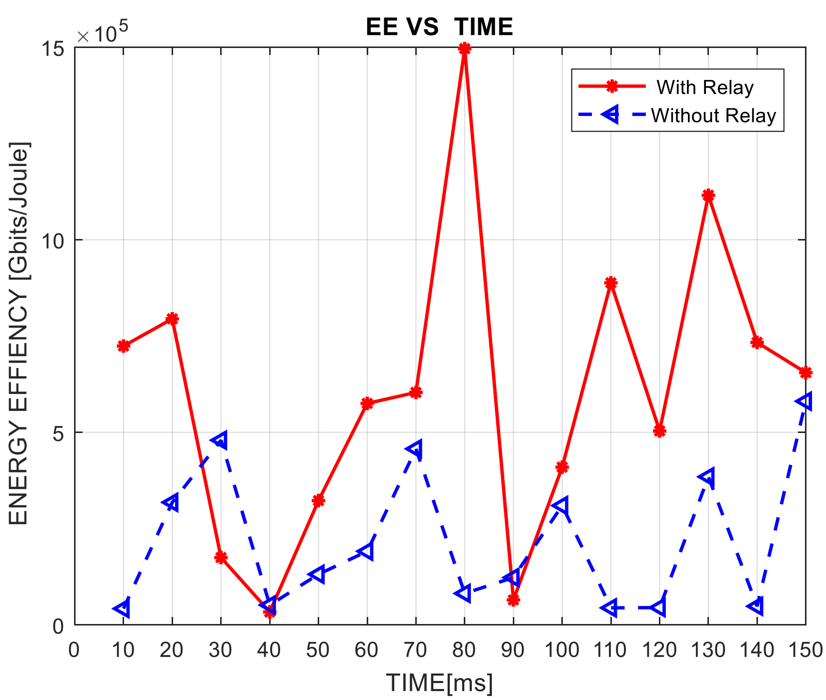


Figure 4.14 Energy Efficiency versus Time

4.2.3 Phase 2: Decode and forward using ARQ Mechanism Results

In order to evaluate the ARQ mechanism, we assume that the link capacity between the source and the RS is enough to transmit 10 packets in a frame and that the link capacity between the RS and the destination is the same. Also, we assume that the RS uses the next frame to relay the data received in the current frame and there are no errors in the transmission of ARQ feedback messages. The analysis of the results had been represented in two different ways, first the packet size is assumed to be constant, while varying the bit error rate as shown in figure (4.15, 4.16 and 4.17). Second the bit error rate is constant and varying the packet size as shown in figure (4.18, 4.19 and 4.20).

Figure 4.15 shows the analysis and simulation results of the average transmission delay versus bit error rate. According to Figure 4.15 the average transmission delay is reduced with the relay station ARQ mechanism due to the fast retransmission triggered by the ARQ feedback message of the RS. As a result the ARQ mechanism using RS has a better performance than using E2E, as $P1$ and $P2$ increase.

Figure 4.16 shows the analysis and simulation results of the ARQ transmission efficiency according to P1 and P2, setting the packet size constant while varying the bit error rate. This figure illustrates that the RS-ARQ mechanism increases the ARQ transmission efficiency by preventing the source from retransmitting the data which RS already receives successfully and that the RS-ARQ mechanism has a better performance than E2E-ARQ mechanism, as P1 and P2 increase.

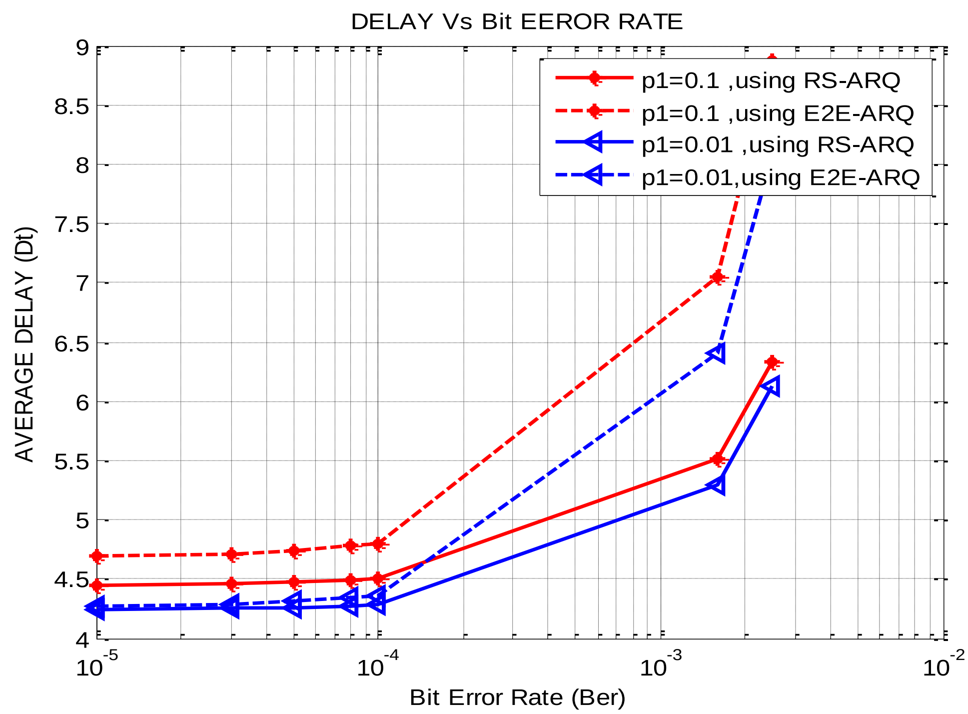


Figure 4.15 Delay versus Bit Error Rate

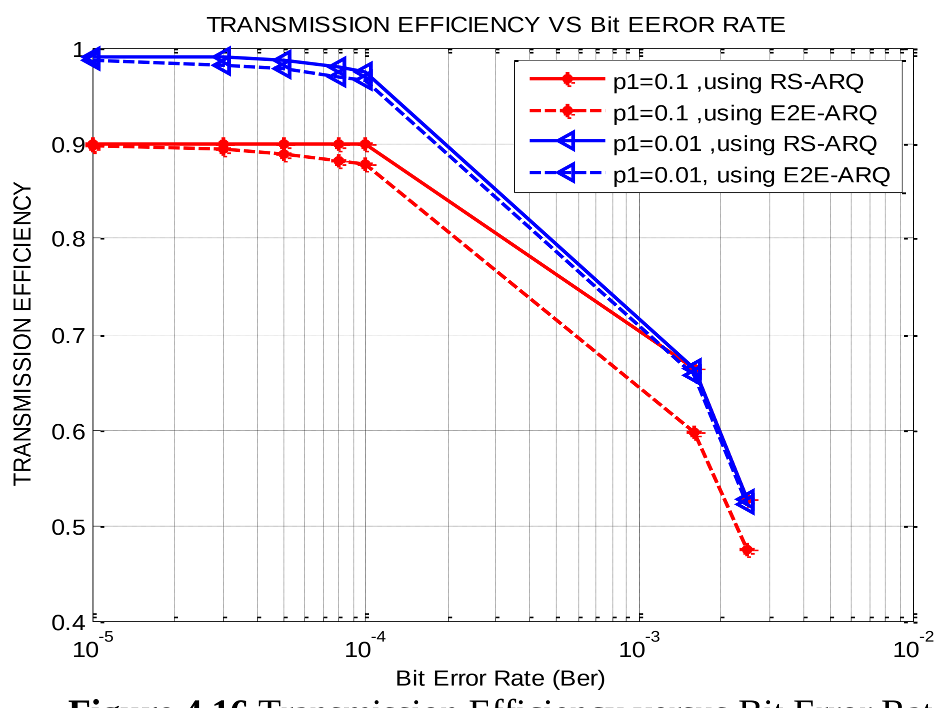


Figure 4.16 Transmission Efficiency versus Bit Error Rate

Figure 4.17 represents the relation of the packet error rate with bit error rate in which the bit error rate increases as packet error rate increases. For bit error rates less than 0.0001 the error values are small that can even be negligible as shown in figure (4.17). But above that value the curve start to raise rapidly which refers to more error in the packet that reflects directly to the performance of the system.

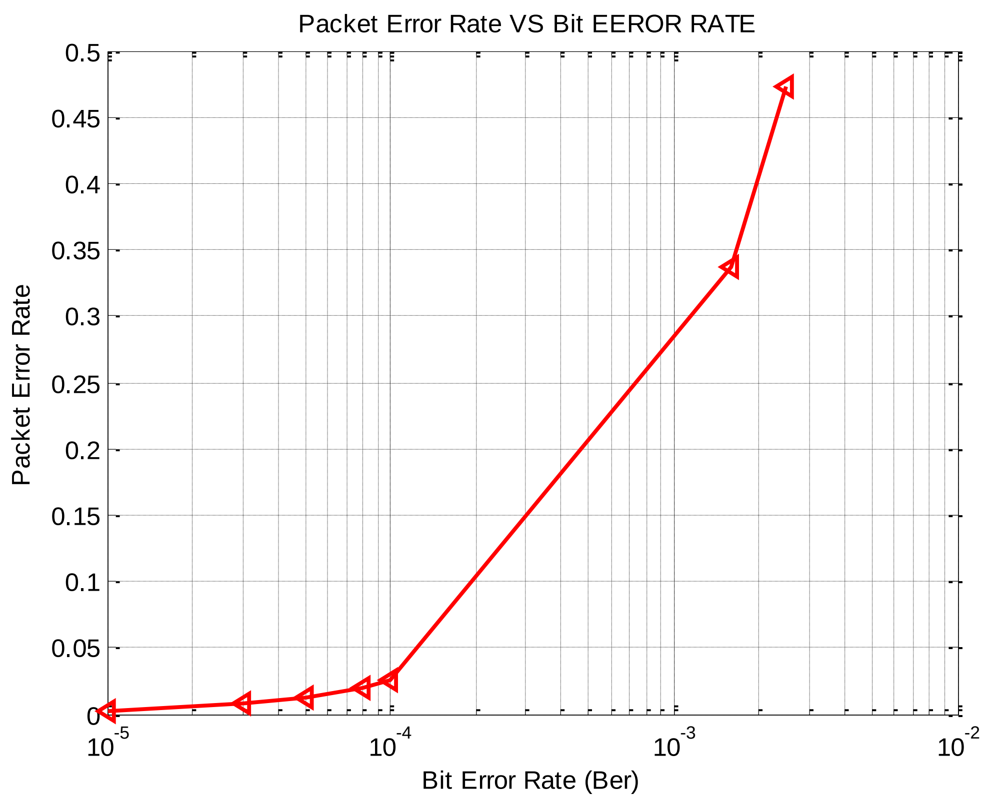


Figure 4.17 Packet Error Rate versus Bit Error Rate

Figure 4.18 demonstrates how the packet size and packet error rate will affect the system performance. From the figure when the packet size increases the average transmission delay gets higher. It is also observed that when the value of packet error rate increases the average transmission delay increases which makes RS-ARQ has a better performance over conventional E2E-ARQ mechanism.

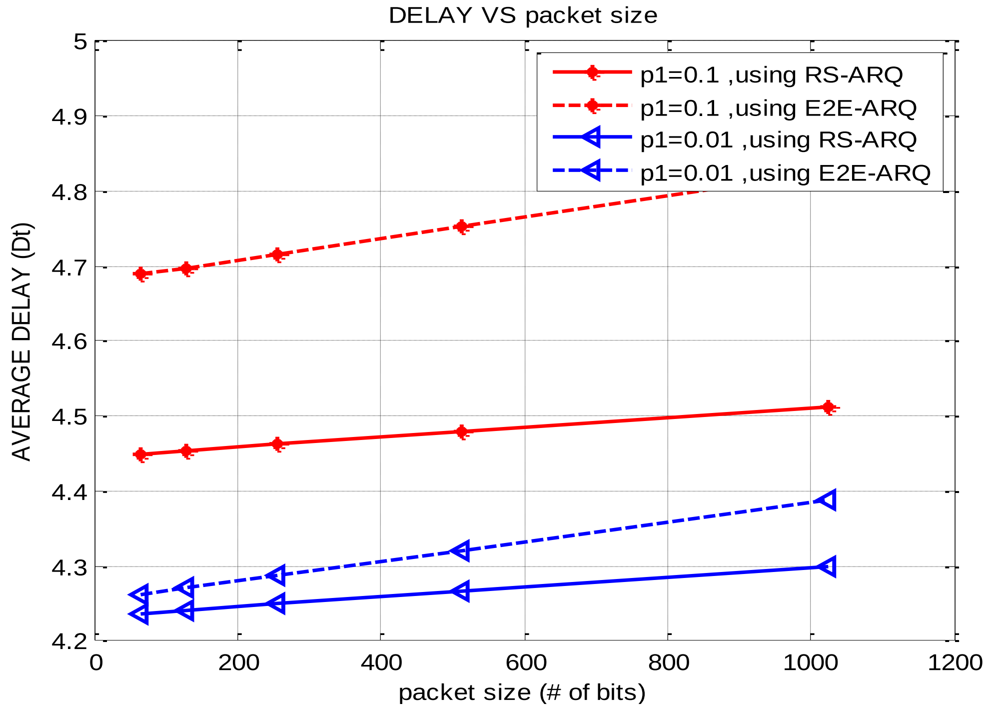


Figure 4.18 Average delay versus Packet size

In figure 4.19 by changing the packet size and making the bit error rate constant a comparison between the transmission efficiency of the RS-ARQ and the E2E-ARQ mechanisms had been performed. The results shows that RS-ARQ mechanism has a better performance than conventional E2E-ARQ mechanism, in which the packet size and the packet error rate are inversely proportional to the transmission efficiency of the system.

Figure 4.20 illustrates that the relation between the packet size and packet error rate which they are directly proportional to each other and vice versa.

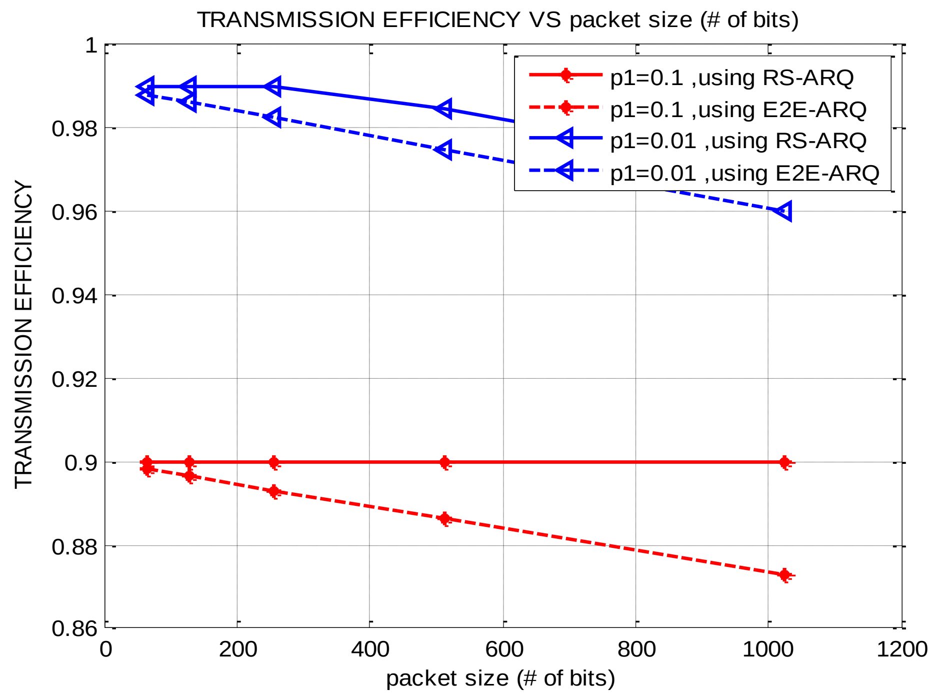


Figure 4.19 Transmission Efficiency versus Packet size

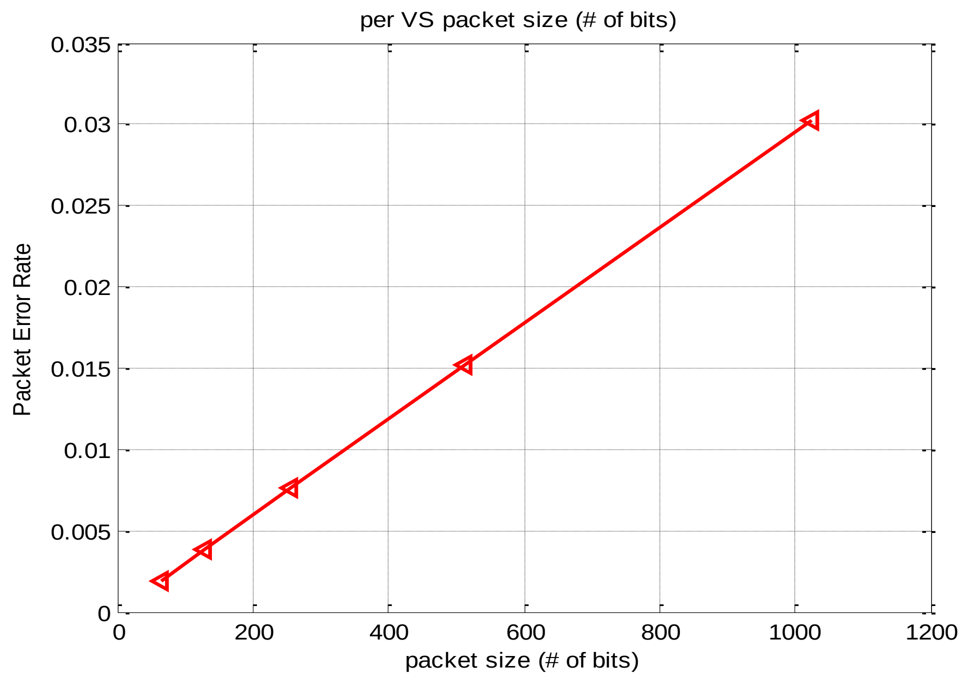


Figure 4.20 Packet error rate versus packet size

Chapter Five

Conclusion & Recommendations

Chapter Five
Conclusion and Recommendations

In this chapter, the main results of this projects are summarized. And some possible future studies are suggested to extend this research.

5.1 Conclusion

In this thesis the Performance Evaluation of Device-to-Device Communication with Discovery Methods for the Fifth Generation Systems has been compared and evaluated in two phases. Device peer discovery phase and using the D2D as a Relay

In the First phase, Device peer discovery with three main algorithms for selection of D2D pair has been introduced based on the emergency scenario. The algorithms were evaluated using Matlab simulation and the results showed that the outage probability can be decreased to 33% using the data rate algorithm.as overall the data rate algorithm was the best algorithm in this scenario related with the distance and SINR algorithm.

In the Second phase, the d2d were used as a Relay and operated in two modes Amplify-and-Forward (AF) and Decode-and-Forward (DF) relaying. When the relay operates as Amplify and forward, the performance of the system had been investigated when using the relay and without using the relay and the results showed that relaying can improve the system performance significantly in terms of SNR by approximately 50% by this ratio a higher modulation scheme can be used that's leads to a better data rate and a larger capacity. Then, the performance of error control mechanism E2E-ARQ and RS-ARQ had been compared and analyzed in terms of the delay and the ARQ transmission efficiency. The numerical analysis and simulation results indicated that the RS-

ARQ mechanism has a better performance in view of the delay and the ARQ transmission efficiency than the E2E-ARQ mechanism in which the RS makes no action, because the source can retransmit data quickly and avoid meaningless retransmission by introducing the ARQ feedback message made by the RS.

5.2 Recommendations

This research explored the use of fixed multi-hop relay in 5G Systems However, there are some remaining issues that can be continued in further research activities that includes:

- A basic model for simulating a small emergency scenario were constructed. Further development can be carried out to introduce a larger area where Relays with multi User scenarios for multiple cells can be used.
- Future study is required to learn more on the rebroadcasting of beacons and the time frame used. The simulated model has been performed with the parameters stated in chapter three and four by changing these parameters different results can be obtained.
- For simplicity of the simulation, we considered two types of relay: The Amplify and Forward relay and Selective Decode and Forward Relay. In future research, Demodulation and Forward Relay can also be involved.
- In order to reduce the complexities, scheduling and interference controlling are not focused in this thesis work. Therefore, a more detailed study of relay nodes considering the scheduling and the impact of the interferences can be included in the future further research.
- Lastly, the mobility of the UE and even the RS can be considered for further research.

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Appendix A

D2D Matlab Code

%Constants:-

```
R=250;    R2=500;                 % Hexagon Raduis
len=1500; len2=5000;              % lenght of the whole area
wid=1500; wid2=5000;              % Width of the whole area
pt=24;                            %Transmit Power(dbm)
Bw=20*10^6;                       %Total Bandwidth (Hz)
f=1.9*10^9;                       %Carrier frequency (Hz)
d0=10;                            %Reference distance in m
y=3.7;                            %Path loss Exponent
c=3*10^8;                         %Speed of Light
lammda=c/f;                       %Wavelenght  (m)
k=20*log(lammda/(4*pi*d0));       %Constant Depend on antenna (db)
a1=-110; b1=-135;                 %Noise Range upper and lower limits (dbm)
W=1 ; E=3;                        %Interferance Range upper and lower limits(dbm)
for p= 1:15
 b= [2:2:16 25 30 40 50 100 200 250];
 D2D=b (p);                          %no. of D2D devices
```

% Drawing the Hexagon

```
nx11=len/(2*R);  nx=round(nx11)     % x size
ny1=wid/(2*R);  ny=round(ny1);      % y size
grid on;
```

% one hexagon coordinates

```
al=0:((2*pi)/6):2*pi;
xh=R*cos(al); yh=R*sin(al);
xcell=[]; ycell=[];
hold on;
```

% First rectangular spaced hexagons set

```
x0=R;    y0=sqrt(3)*R/2;   x=x0;     y=y0;
for nxc=1:nx
  for nyc=1:ny
    plot(x+xh,y+yh,'b'); plot(x,y,'k^');
    grid on;
    xcell=[xcell x];   ycell=[ycell y];         %recording cell coordinates
     y=y+sqrt(3)*R;
  end
 x=x+3*R;   y=y0; end;
```

% Second Rectgular Spaced Hexagons Set

```
 x0=2.5*R;    y0=sqrt(3)*R;  x=x0;   y=y0;
for nxc=1:(floor(nx11))
  for nyc=1:(floor(ny1))
    plot(x+xh,y+yh,'b');   plot(x,y,'k^');    grid on;
    xcell=[xcell x];     ycell=[ycell y];      %recording cell coordinates
    y=y+sqrt(3)*R;
  end
 x=x+3*R;   y=y0;end
axis equal; axis([0 len 0 wid]);    grid on;
```

%Generating the Users Randamly and Uniformaly

```
D2Dxuser=rand(1,D2D).*len;         D2Dyuser=rand(1,D2D).*wid;
D2Dxuser2=rand(1,D2D).*len2;     D2Dyuser2=rand(1,D2D).*wid2;
subplot (3,5,p) , scatter(D2Dxuser,D2Dyuser,'red','filled');
for i=1:1:D2D
text(D2Dxuser(i)+50,D2Dyuser(i)+50,num2str(i));  %giving each of D2D user a number
 end
```

% Calculating SINR

```
for i=1:1:D2D
```

```
 for j=1:1:D2D
 DIST(i,j)=sqrt((D2Dxuser(i)-D2Dxuser(j)).^2+(D2Dyuser(i) D2Dyuser(j)).^2);
Pr_dbm(i,j)=pt+k-y*log((DIST(i,j)/d0));            %Received Power (dbm)
n1_dbm(i,j)=(a1+(b1-a1).*rand);                    % Noise Range(dbm)
INT_dbm(i,j)=(W+(E-W).*rand);                       %Interferance(dbm)
SINR_dbm(i,j)=Pr_dbm(i,j)-n1_dbm(i,j)-INT_dbm(i,j);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
 DIST2(i,j)=sqrt((D2Dxuser2(i)-D2Dxuser2(j)).^2+(D2Dyuser2(i)-D2Dyuser2(j)).^2);
%Calculating the distance between each user
  Pr2_dbm(i,j)=pt+k-y*log((DIST2(i,j))/d0);              %Received Power (dbm)
  n12_dbm(i,j)=(a1+(b1-a1).*rand);                          % Noise Range(dbm)
 INT2_dbm(i,j)=(W+(E-W).*rand);                             %Interferance(dbm)
 SINR2_dbm(i,j)=Pr2_dbm(i,j)-n12_dbm(i,j)-INT2_dbm(i,j);  % SNIR(dbm)
  end
 end
 distD2D= DIST;
 Received_power= Pr_dbm./100;
 SINR= SINR_dbm./100;


 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
 distD2D2= DIST2;
 Received_power2= Pr2_dbm./100;
 SINR2= SINR2_dbm. /100;
```

<u>% Best D2D Pair According to Shortest Distance</u>

```
active_pair1=0; active_pair4=0; active_pair5=0; active_pair6=0; active_pair7=0;
for i=1:1:D2D
  for j=1:1:D2D
      if (distD2D(i,j)<500 && distD2D(i,j)~= 0 )
       active_pair1=active_pair1+1;
```

```
       l=i; KL=j;  kj=distD2D(i,j);
       X = sprintf('%d AND %d will be pair. threshold is 500m and distance between them is %d \n',l,KL,kj);
       disp(X)
    else
        active_pair1=active_pair1;
      end
      if (distD2D(i,j)<100 && distD2D(i,j)~= 0 )
       active_pair4=active_pair4+1;
       l4=i; KL4=j;   kj4=distD2D(i,j);
       X = sprintf('%d AND %d will be pair. threshold is 100m and distance between them is %d \n',l4,KL4,kj4);
       disp(X)
    else
        active_pair4=active_pair4;
      end
      if (distD2D(i,j)<200 && distD2D(i,j)~= 0 )
       active_pair5=active_pair5+1;
       l5=i;  KL5=j;  kj5=distD2D(i,j);
       X = sprintf('%d AND %d will be pair threshold is 200m and distance between them is %d \n',l5,KL5,kj5);
       disp(X)
    else
        active_pair5=active_pair5;
      end
      if (distD2D(i,j)<300 && distD2D(i,j)~= 0 )
       active_pair6=active_pair6+1;
       l6=i;  KL6=j;   kj6=distD2D(i,j);
       X = sprintf('%d AND %d will be pair. threshold is 300m and distance between them is %d \n',l6,KL6,kj6);
       disp(X)
```

```
   else
       active_pair6=active_pair6;
     end
     if (distD2D(i,j)<400 && distD2D(i,j)~= 0 )
      active_pair7=active_pair7+1;
      l7=i;  KL7=j;  kj7=distD2D(i,j);
      X = sprintf('%d AND %d will be pair. threshold is 400m and distance between them is %d \n',l7,KL7,kj7);
      disp(X)
   else
       active_pair7=active_pair7;  end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
all_possible_pairs (p) = (D2D * D2D ) -  D2D
active_no_of_pairs_according_to_distance_500(p)=active_pair1
percent_of_acive_pair_according_to_distance_500(p)=(active_no_of_pairs_according_to_distance_500(p)/all_possible_pairs(p))*100
percentage_of_outage_according_to_distance_500(p)=100-percent_of_acive_pair_according_to_distance_500(p)
active_no_of_pairs_according_to_distance_100(p)=active_pair4
percent_of_acive_pair_according_to_distance_100(p)=(active_no_of_pairs_according_to_distance_100(p)/all_possible_pairs(p))*100
percentage_of_outage_according_to_distance_100(p)=100-percent_of_acive_pair_according_to_distance_100(p)
active_no_of_pairs_according_to_distance_200(p)=active_pair5
percent_of_acive_pair_according_to_distance_200(p)=(active_no_of_pairs_according_to_distance_200(p)/all_possible_pairs(p))* 100
percentage_of_outage_according_to_distance_200(p)=100-percent_of_acive_pair_according_to_distance_200(p)
active_no_of_pairs_according_to_distance_300(p)=active_pair6
```

```
percent_of_acive_pair_according_to_distance_300(p)=
(active_no_of_pairs_according_to_distance_300(p)/all_possible_pairs(p))* 100
percentage_of_outage_according_to_distance_300(p)=100-
percent_of_acive_pair_according_to_distance_300(p)
active_no_of_pairs_according_to_distance_400(p)=active_pair7
percent_of_acive_pair_according_to_distance_400(p)=
(active_no_of_pairs_according_to_distance_400(p)/all_possible_pairs(p))* 100
percentage_of_outage_according_to_distance_400(p)=100-
percent_of_acive_pair_according_to_distance_400(p)
   end; end
```

%Best D2D Pair According to SINR

```
active_pair2=0;  active_pair8=0;  active_pair9=0;
for i=1:1:D2D
  for j=1:1:D2D
    if (SINR(i,j)<-18 && SINR(i,j)~= Inf )
       active_pair2=active_pair2+1;
       l2=i; KL2=j;   kj2=SINR(i,j);
       X = sprintf('%d AND %d WILL BE PAIR. Threshold is -18 dBm and SINR between them is %d \n',l2,KL2,kj2);
       disp(X)
    else
        active_pair2=active_pair2;
      end
    if (SINR(i,j)<-22 && SINR(i,j)~= Inf )
       active_pair8=active_pair8+1;
       l8=i;   KL8=j;   kj8=SINR(i,j);
       X = sprintf('%d AND %d WILL BE PAIR. Threshold is -22 dBm and SINR between them is %d \n',l8,KL8,kj8);
       disp(X)
    else
```

```
        active_pair8=active_pair8;
    end
    if (SINR(i,j)<-16 && SINR(i,j)~= Inf )
       active_pair9=active_pair9+1;
       l9=i;   KL9=j;   kj9=SINR(i,j);
       X = sprintf('%d AND %d WILL BE PAIR. Threshold is -16 dBm and SINR between
them is %d  \n',l9,KL9,kj9);
       disp(X)
    else
        active_pair9=active_pair9;
      end; end; end;
all_possible_pairs(p) = (D2D * D2D ) -  D2D
active_no_of_pairs_according_to_SINR_18(p)=active_pair2
percent_of_acive_pair_according_to_SINR_18(p)=
(active_no_of_pairs_according_to_SINR_18(p)/all_possible_pairs(p) ) * 100
percentage_of_outage_according_to_SINR_18(p)=100-
percent_of_acive_pair_according_to_SINR_18(p)
active_no_of_pairs_according_to_SINR_22(p)=active_pair8
percent_of_acive_pair_according_to_SINR_22(p)=
(active_no_of_pairs_according_to_SINR_22(p)/all_possible_pairs(p) ) * 100
percentage_of_outage_according_to_SINR_22(p)=100-
percent_of_acive_pair_according_to_SINR_22(p)
active_no_of_pairs_according_to_SINR_16(p)=active_pair9
percent_of_acive_pair_according_to_SINR_16(p)=
(active_no_of_pairs_according_to_SINR_16(p)/all_possible_pairs(p) ) * 100
percentage_of_outage_according_to_SINR_16(p)=100-
percent_of_acive_pair_according_to_SINR_16(p)
```

% Best D2D Pair According to datarate

```
active_pair3=0; active_pair10=0; active_pair11=0;
active_pair12=0; active_pair42=0; active_pair52=0;
```

```
for i=1:1:D2D
  for j=1:1:D2D
      m=2;
     w(i,j) = 2 * m + 1;
     s(i,j) = 0.95 - 0.08 * mod(m,2);                    % The scale factor
     MIshannon(i,j) = log2(1 + 10^(SINR(i,j)/10));
     MI(i,j) =1/((s(i) *MIshannon(i,j))^-w(i,j) + m^-w(i,j))^(1/w(i,j));
     data_rate(i,j)=Bw*MI(i,j);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

   MIshannon2(i,j) = log2(1 + 10^(SINR2(i,j)/10));
     MI2(i,j) =1/((s(i) *MIshannon2(i,j))^-w(i,j) + m^-w(i,j))^(1/w(i,j));
     data_rate2(i,j)=Bw*MI2(i,j);
     if (data_rate(i,j)> 250000 && i~= j )
       active_pair3= active_pair3+1;
       l3=i;   KL3=j;    kj3=data_rate(i,j);
       X = sprintf('%d AND %d WILL BE PAIR. Threshold is 250*10^3 Data Rate between
them is %d \n',l3,KL3,kj3);
       disp(X)
     else
        active_pair3=active_pair3;
     end
     if (data_rate(i,j)> 500000 && i~= j )
       active_pair10= active_pair10+1;
       l10=i; KL10=j;  kj10=data_rate(i,j);
       X = sprintf('%d AND %d WILL BE PAIR. Threshold is 500*10^3 Data Rate between
them is %d \n',l10,KL10,kj10);
       disp(X)
     else
        active_pair10=active_pair10;
```

```
     end
     if (data_rate(i,j)> 750000 && i~= j )
       active_pair11= active_pair11+1;
       l11=i;    KL11=j;  kj11=data_rate(i,j);
       X = sprintf('%d AND %d WILL BE PAIR. Threshold is 750*10^3 Data Rate between
them is %d \n',l11,KL11,kj11);
       disp(X)
     else
        active_pair11=active_pair11;
     end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

 if (data_rate2(i,j)> 250000 && i~= j )
       active_pair12=active_pair12+1;
       l12=i; KL12=j;   kj12=data_rate2(i,j);
       X = sprintf('%d AND %d WILL BE PAIR. Threshold is 250*10^3 Data Rate between
them is %d \n',l12,KL12,kj12);
       disp(X)
    else
        active_pair12=active_pair12;
      end
      if (data_rate2(i,j)> 500000 && i~= j )
       active_pair42=active_pair42+1;
       l42=i;  KL42=j;  kj42=data_rate2(i,j);
       X = sprintf('%d AND %d WILL BE PAIR. Threshold is 500*10^3 Data Rate between
them is %d \n',l42,KL42,kj42);
       disp(X)
    else
        active_pair42=active_pair42;
      end
```

```
    if (data_rate2(i,j)> 750000 && i~= j )
     active_pair52=active_pair52+1;
     l52=i;  KL52=j;   kj52=data_rate2(i,j);
     X = sprintf('%d AND %d WILL BE PAIR. Threshold is 750*10^3 Data Rate between them is  %d \n',l52,KL52,kj52);
     disp(X)
   else
      active_pair52=active_pair52;
    end;  end; end ;
Data_Rate= data_rate;
all_possible_pairs(p) = (D2D * D2D ) -  D2D
active_no_of_pairs_according_to_datarate_3(p)=active_pair3
percent_of_acive_pair_according_to_datarate_3(p)= (active_no_of_pairs_according_to_datarate_3(p)/all_possible_pairs(p))* 100
percentage_of_outage_according_to_datarate_3(p)= 100 - percent_of_acive_pair_according_to_datarate_3(p)
active_no_of_pairs_according_to_datarate_10(p)=active_pair10
percent_of_acive_pair_according_to_datarate_10(p)= (active_no_of_pairs_according_to_datarate_10(p)/all_possible_pairs(p))*100
percentage_of_outage_according_to_datarate_10(p)= 100 - percent_of_acive_pair_according_to_datarate_10(p)
active_no_of_pairs_according_to_datarate_11(p)=active_pair11
percent_of_acive_pair_according_to_datarate_11(p)= (active_no_of_pairs_according_to_datarate_11(p)/all_possible_pairs(p))* 100
percentage_of_outage_according_to_datarate_11(p)=100- percent_of_acive_pair_according_to_datarate_11(p)

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

all_possible_pairs(p) = (D2D * D2D ) -  D2D;
active_no_of_pairs_according_to_datarate12(p)=active_pair12
```

```
percent_of_acive_pair_according_to_datarate12(p)=
(active_no_of_pairs_according_to_datarate12(p)/all_possible_pairs(p))* 100
percentage_of_outage_according_to_datarate12(p)=100-
percent_of_acive_pair_according_to_datarate12(p)
active_no_of_pairs_according_to_datarate42(p)=active_pair42
percent_of_acive_pair_according_to_datarate42(p)=
(active_no_of_pairs_according_to_datarate42(p)/all_possible_pairs(p))* 100
percentage_of_outage_according_to_datarate42(p)=100-
percent_of_acive_pair_according_to_datarate42(p)
active_no_of_pairs_according_to_datarate52(p)=active_pair52
percent_of_acive_pair_according_to_datarate52(p)=
(active_no_of_pairs_according_to_datarate52(p)/all_possible_pairs(p))* 100
percentage_of_outage_according_to_datarate52(p)=100-
percent_of_acive_pair_according_to_datarate52(p)
end; figure
```

%Plotting Active Pair VS No. of Devices

```
plot(b,active_no_of_pairs_according_to_distance_500,'b-*','LineWidth',1.5);
    hold on
plot(b,active_no_of_pairs_according_to_SINR_18,'r-d','LineWidth',1.5);
plot(b,active_no_of_pairs_according_to_datarate_3,'k-<','LineWidth',1.5);
    grid on
    legend ('Distance ', 'SINR  ', 'Datarate ');
    xlabel('NO. OF DEVICES');  ylabel('Active No. of Pairs');
    title('Active No. of Pairs VS NO. OF DEVICES');
     set(gca,'XTick',0:20:250); figure
```

% Plotting Percentage of outage VS No. of Devices

```
plot(b,percentage_of_outage_according_to_distance_500,'b*','LineWidth',1.5);
    hold on
 plot(b,percentage_of_outage_according_to_SINR_18,'r-d','LineWidth',1.5);
```

```
plot(b,percentage_of_outage_according_to_datarate_3,'k<','LineWidth',1.5);
      grid on
 legend ('Distance ', 'SINR  ', 'Datarate ');
      xlabel('NO. OF DEVICES');
      ylabel('Percentage of outage');
      title('Percentage of outage VS NO. OF DEVICES');
       set(gca,'XTick',0:20:250); figure
```

<u>% Plotting Active Pair VS No. of Devices Using Distance Threshold</u>

```
plot(b,active_no_of_pairs_according_to_distance_100,'b-*','LineWidth',1.5);
      hold on
 plot(b,active_no_of_pairs_according_to_distance_200,'r*','LineWidth',1.5);
 plot(b,active_no_of_pairs_according_to_distance_300,'k*','LineWidth',1.5);
 plot(b,active_no_of_pairs_according_to_distance_400,'g*','LineWidth',1.5);
 plot(b,active_no_of_pairs_according_to_distance_500,'y*','LineWidth',1.5);
  grid on
legend ('Distance 100 ', 'Distance 200 ', 'Distance 300 ' , 'Distance 400 ' ,'Distance 500 ');
      xlabel('NO. OF DEVICES');
      ylabel('Active No. of Pairs');
title('Active No. of Pairs VS NO. OF DEVICES using Distance threshold and area 1500');
      set(gca,'XTick',0:20:250); figure
```

<u>% Plotting Percentage of outage VS No. of Devices Using Distance Threshold</u>

```
plot(b,percentage_of_outage_according_to_distance_100,'b*','LineWidth',1.5);
      hold on
plot(b,percentage_of_outage_according_to_distance_200,'r*','LineWidth',1.5);
plot(b,percentage_of_outage_according_to_distance_300,'k*','LineWidth',1.5);
plot(b,percentage_of_outage_according_to_distance_400,'g*','LineWidth',1.5);
plot(b,percentage_of_outage_according_to_distance_500,'y*','LineWidth',1.5);
     grid on
legend ('Distance 100 ', 'Distance 200 ', 'Distance 300 ' , 'Distance 400 ' , 'Distance 500 ');
      xlabel('NO. OF DEVICES');    ylabel('Percentage of outage');
```

```
title('Percentage of outage VS NO. OF DEVICES using Distance threshold');
    set(gca,'XTick',0:20:250)
figure
```

% Plotting Active Pair VS No. of Devices Using SINR Threshold

```
plot(b,active_no_of_pairs_according_to_SINR_16,'r-d','LineWidth',1.5);
    hold on
plot(b,active_no_of_pairs_according_to_SINR_18,'b-d','LineWidth',1.5);
plot(b,active_no_of_pairs_according_to_SINR_22,'k-d','LineWidth',1.5);
    grid on
    legend ('SINR -16 dBm ', 'SINR -18 dBm  ', 'SINR -22 dBm ');
    xlabel('NO. OF DEVICES');  ylabel('Active No. of Pairs');
    title('Active No. of Pairs VS NO. OF DEVICES Using SINR Threshold');
    set(gca,'XTick',0:20:250);  figure
```

% Plotting Percentage of outage VS No. of Devices Using SINR Threshold

```
plot(b,percentage_of_outage_according_to_SINR_16,'r-d','LineWidth',1.5);
    hold on
plot(b,percentage_of_outage_according_to_SINR_18,'b-d','LineWidth',1.5);
plot(b,percentage_of_outage_according_to_SINR_22,'k-d','LineWidth',1.5);
    grid on
    legend ('SINR -16 dBm ', 'SINR -18 dBm  ', 'SINR -22 dBm ');
    xlabel('NO. OF DEVICES');  ylabel('Percentage of outage');
  title('Percentage of outage VS NO. OF DEVICES Using SINR Threshold');
    set(gca,'XTick',0:20:250);  figure
```

% Plotting Active Pair VS No. of Devices using data rate Threshold

```
subplot (1,2,1),plot(b,active_no_of_pairs_according_to_datarate_3,'b- *','LineWidth',1.5);
 hold on
subplot (1,2,1),plot(b,active_no_of_pairs_according_to_datarate_10,'r-d','LineWidth',1.5);
subplot (1,2,1),plot(b,active_no_of_pairs_according_to_datarate_11,'k:<','LineWidth',1.5);
    grid on
```

```
legend ('Threshold is 250*10^3 ', 'Threshold is 500*10^3', 'Threshold is 750*10^3');
      xlabel('NO. OF DEVICES');    ylabel('Active No. of Pairs');
      title('    Active No. of Pairs with area 1500 m^2');
subplot(1,2,2),plot(b,active_no_of_pairs_according_to_datarate12,'b--*','LineWidth',1.5);
  hold on
 subplot(1,2,2),plot(b,active_no_of_pairs_according_to_datarate42,'r-d','LineWidth',1.5);
 subplot (1,2,2) ,  plot(b,active_no_of_pairs_according_to_datarate52,'k:<','LineWidth',1.5);
      grid on
 legend ('Threshold is 250*10^3 ', 'Threshold is 500*10^3', 'Threshold is 750*10^3 ');
      xlabel('NO. OF DEVICES');     ylabel('Active No. of Pairs');
      title('    Active No. of Pairs with area 5000 m^2');  figure
```

% Plotting Percentage of outage VS No. of devices using data rate Threshold

```
subplot(1,2,1),plot(b,percentage_of_outage_according_to_datarate_3,'b-*','LineWidth',1.5);
  hold on
subplot(1,2,1),plot(b,percentage_of_outage_according_to_datarate_10,'r-d','LineWidth',1);
subplot(1,2,1),plot(b,percentage_of_outage_according_to_datarate_11,'k:<','LineWidth',1);
      grid on
legend ('Threshold is 250*10^3 ', 'Threshold is 500*10^3', 'Threshold is 750*10^3');
      xlabel('NO. OF DEVICES');   ylabel('Percentage of outage');
      title('    Percentage of outage with area 1500 m^2');
      set(gca,'XTick',0:20:250)
subplot(1,2,2),plot(b,percentage_of_outage_according_to_datarate12,'b--*','LineWidth',1);
    hold on
 subplot(1,2,2),plot(b,percentage_of_outage_according_to_datarate42,'r-d','LineWidth',1);
subplot(1,2,2),plot(b,percentage_of_outage_according_to_datarate52,'k:<','LineWidth',1.5);
      grid on
 legend ('Threshold is 250*10^3 ', 'Threshold is 500*10^3', 'Threshold is 750*10^3 ');
      xlabel('NO. OF DEVICES');  ylabel('Active No. of Pairs');
      title('     Percentage of outage with area 5000 m^2');
     set(gca,'XTick',0:20:250)
```