NINEVAH UNIVERSITY
COLLEGE OF ELECTRONICS ENGINEERING
COMMUNICATION ENGINEERING DEPARTMENT

Investigation on Smart Device-to-Device (D2D) Technology for 5G System

By

Maryam Qusai Abdulqadir

M.Sc. Thesis

In

Communication Engineering

Supervised by

Asst. Prof. Dr. Ali Othman Al-Janaby

2023 A.D. **1444 A.H.**

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A Thesis Submitted

By

Maryam Qusai Abdulqadir

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In

Communication Engineering

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بسم الله الرحمن الرحيم

(اقْرَأْ بِاسْمِ رَبِّكَ الَّذِي خَلَقَ* خَلَقَ الْإِنسَانَ مِنْ عَلَقٍ*

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عَلَّمَ الْإِنسَانَ مَا لَمْ يَعْلَمْ)

صدق الله العظيم

سورة العلق، آية: 1-5

Supervisor's Certification

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Committee Certification

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Publications: -

Some of the important results obtained in this work have appeared in the following publications: -

[1] M. Q. Abdulqadir and A. O. A. Janaby, "Capacity and Throughput Enhancement for Minimum Distance Using D2D Scheme with TCP for 5G System," 2022 8th International Conference on Contemporary Information Technology and Mathematics (ICCITM), Mosul, Iraq, 2022, pp. 34-38, doi: 10.1109/ICCITM56309.2022.10031989.

[2] M. Abdulqadir and A. Al Janaby, "Tracking Infected Covid-19 Persons and their Proximity Users Using D2D in 5G Networks," in Journal of Communications Software and Systems, vol. 19, no. 1, pp. 1-8, January 2023, doi: 10.24138/jcomss-2022-0103.

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Abstract

Device-to-device (D2D) is a smart promising technology in 5G that faces many challenges such as mode selection and device discovery.

This thesis identifies two models of D2D communication implemented with the OMNeT++ software and Simu5G simulator. The first is a single-hop D2D communication model is presented and some parameters such as throughput, delay, and received bytes are calculated in infrastructure and D2D mode at different distances. The results show that throughput in D2D mode is higher than in infrastructure mode at all distances, while the delay is lower. Downlink throughput in infrastructure mode is 61.8 kbps with a delay of 0.033s at an 80m distance, while D2D throughput is 186 kbps with a delay of 0.012s. When the distance between devices is reduced to 10m, both modes increase downlink throughput while decreasing delay: infrastructure mode is 219 kbps with a delay equal to 0.004s and D2D mode 248.7 kbps with a delay equal to 0.003s, indicating that D2D mode is better. This model increases total system throughput and capacity, with minimum distance.

The second model proposed a simulation of tracking infected people using D2D communication to detect nearby devices. Five different cases were considered for the number of healthy users X[num(UE)]. The model depicts the number of potentially infected people as well as their location. The model shows that as X[num(UE)] increases, tracking becomes more difficult, and the possibility of infecting an X[num(UE)] increases. In the first case, note the possibility of infecting just one person. The second case involves the possibility of infecting three people. The possibility of infecting a large number of healthy users as in the third and fourth cases. However, if the infected person is moving, as in the last case, the possibility of infecting healthy people is high.

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LIST OF ABBREVIATIONS

Abbreviation	Name
3GPP	Third Generation Partnership Project
4G	Four Generation
5G	Five Generation
6G	Six Generation
ACK	Acknowledgment
AI	Artificial Intelligence
AOA	Angle Of Arrival
BS	Base Station
BSRs	Buffer Status Reports
CCs	Carrier Components
CIC	Centralized Interference Coordination
CN	Core Network
CQI	Channel Quality Indicator
CSI	Channel State Information
CUs	Cellular User Equipments
D2D	Device to Device
DIC	Decentralized Interference Coordination

DL	Downlink
DL	Deep Learning
eNB	evolved Node Base station
eMBB	enhanced Mobile Broad Band
ENDC	E-UTRA/NR Dual Connectivity
EPC	Evolved Packet Core
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FFRA	Fair and Fit Resource Allocation
gNB	Next Generation Node Base station
GPRS	General Packet Radio Services
GTP	GPRS Tunneling Protocol
H-ARQ	Hybrid Automatic Repeat Request
HD	High-Definition
ID	Identity
IEEE	Institute of Electrical and Electronic Engineers
IMSI	International Mobile Subscriber Identity
INI	Initialization

IoT	Internet of Things
IP	Internet Protocol
ISM	Industrial Scientific Medical
ITU-R	International Telecommunication Union Radio Communication
LTE	Long-Term Evolution
LTE-A	LTE-Advanced
M2M	Machine to Machine
MAC	Media Access Control
MCS	Modulation and Coding Scheme
MEC	Mobile Edge Computing
mMIMO	massive Multiple Input Multiple Output
mMTC	massive Machine Type Communication
mmWave	Millimeter Wave
MW	Microwave Band
MN	Master Node
MS	Mode Selection
NACK	Negative Acknowledgment
NED	Network Description

NIC	Network Interface Card
NOMA	Non-Orthogonal Multiple Access
NR	New Radio
NS	Network Slicing
OMA	Orthogonal Multiple Access
OMNeT ++	Objective Modular Network Testbed in C ++
OSI	Open Systems Interconnection
P2P	Peer to Peer
PDCP	Packet Data Convergence Protocol
PDUs	Protocol Data Units
PGW	Packet Data Network Gateway
PHY	Physical Layer
ProSe	Proximity Services
QoS	Quality of Service
RA	Resource Allocation
RAN	Radio Access Network
RBs	Resource Blocks
RFID	Radio Frequency Identification

RLC	Radio Link Control
RRM	Radio Resource Management
SA	Stand Alone
SDN	Software-Defined Networking
SIC	Successive Interference Cancellation
SINR	Signal-to-Interference-plus-Noise Ratio
SL	Sidelink
SN	Secondary Node
SNR	Signal-to-Noise Ratio
TB	Transport Block
TCP	Transmission Control Protocol
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TTI	Transmission Time Interval
UDN	Ultra Dense Network
UDP	User Datagram Protocol
UeRX	D2D Receiver
UEs	User Equipments

UeTX	D2D Transmitter
UL	Uplink
UPF	User Plane Function
URLLC	Ultra-Reliable Low Latency Communication
WHO	World Health Organization
X[num(UE)]	Number Of Healthy Users

Chapter One

Introduction

1.1 Preface

The increasing popularity of bandwidth-intensive applications like live video sharing, games, and multimedia file sharing has increased both the volume of mobile internet traffic and the requirement for faster speed access [1].

Therefore, the increased demand for users to have higher data rates can be addressed through Device-to-Device (D2D) technology [2]. D2D communications in wireless cellular networks allow devices close to broadcast and receive signals without interacting with base stations (BSs) [3]. The advantages of D2D communication are improved spectral efficiency, high data rate, more user capacity, extended coverage, reduced latency, extended device battery life, and enhanced power efficiency [4].

Numerous challenges must be overcome to successfully implement D2D communication that includes resource management, device discovery, mode selection, security, and power control [5]. A mode selection mechanism is critical when communication occurs between nearby devices. It determines whether to use infrastructure mode, which uses UL and DL communications, or D2D mode, in which traffic is directly connected without passing through the BS. Mode selection is essential for improving spectrum efficiency and trying to mitigate interference between D2D and cellular users [6]. One of the most critical processes in cellular D2D communications is device discovery, which detects device discovery [7]. Device discovery occurs when devices transmit a discovery signal to discover neighboring devices through the BS [8]. A device discovery technique is categorized into two types: centralized device discovery and distributed device discovery. Centralized discovery occurs when two devices recognize one another through the assistance of an access point or BS. Distributed discovery involves devices discovering each other and establishing connections without the need for a BS [9].

1.2 Literature Review

Many research articles deal with the D2D schemes and technology through long-term evolution (LTE) as well as 5G to enhance the data rate and improve capacity and spectral efficiency. In this item, many previous articles related to D2D schemes and proposals will be presented:

- In 2019, Petros and Fotis proposed a mode selection (MS) algorithm for mobile networks with D2D capabilities. To guarantee a minimum level of quality of service, MS utilized a threshold that is determined based on the Signal-to-Interference-plus-Noise Ratio (SINR). The new scheme considers interference effects, as well as realistic assumptions about channel information. For the analysis of the performance of a system under the single-user case, a Markov chain-based analytical framework is developed. A joint optimization problem of MS, resource allocation (RA), and scheduling is also formulated using the new method for a multi-user communication scenario. By incorporating SINR awareness into MS, RA, and scheduling algorithms, significant improvements are made in sum rate performance [10].
- In 2019, Han-Ni Su, et al, investigated a cellular mode, D2D mode, and relay mode in their included in their mode selection strategy. All decisions about D2D grouping were made by the User Equipments (UEs) using proximity discovery. In their evaluation, they used a MATLAB simulation;

the results showed that their method improved both system throughput and the impact of adding D2D communication on cellular users [11].

- In 2020, Gang and Lizhu suggested a resource allocation algorithm founded on D2D communications mode selection. The resource allocation was improved by comparing the Signal-to-Noise Ratio (SNR) in multiplex mode, orthogonal mode, and cellular mode. The algorithm can understand the goal of allocating the better communications mode and resources to users with the most throughput as standard [12].
- In 2020, Haiqiao Wu, et al, the authors examined several elements of proximal device discovery. They began by reviewing the foundations of peer discovery, including key ideas, application scenarios, related needs, and the current standardization process. They discussed the problem of device discovery signals and device discovery protocols in centralized and distributed discovery for D2D communications. Also, they addressed the possible solutions for these problems [13].
- In 2020, Yushan Siriwardhana, et al, discussed how 5G, IoT, and related technologies can be used to combat the COVID-19 pandemic. They discussed different cases in healthcare, contact tracing, self-isolation, online learning, and other areas, as well as how they used various elements to create creative solutions suitable for a post-COVID-19 era. The authors also discussed scalability, limited connectivity, societal issues, and legal issues related to security and privacy [14].
- In 2020, Enrique Hernández-Orallo, et al, assessed the efficacy of recent advanced COVID-19 contact-tracing smartphones that use Bluetooth to discover contact details. They investigated how these applications operate to simulate the key factors influencing their performance: accuracy, tracing

speed, and implementation design if it is centralized or decentralized. The authors proposed a pandemic model to assess their effectiveness in central management outbreaks and the amount of effort required. The results indicated that mobile phone monitoring is only effective when used with other measures such as social distancing. They discovered that a centralized model is significantly more efficient than a decentralized model to control the spread of COVID-19 [15].

- In 2021, Yusmardiah Yusuf, et al, proposed a Fair and Fit Resource Allocation (FFRA) algorithm that exploits the path loss by the possibility of D2D Users Equipment (UEs) when it chooses a communication route. The program used for simulation was the OMNeT++ simulator with INET and the SimuLTE framework. Then, they found that the FFRA algorithm increased the overall throughput and achieved excellent fairness implementation as the number of D2D users in the network increased. It also contributed to reducing delays and packet loss between algorithms [16].
- In 2021, Lubna Nadeem, et al, provided a thorough overview of emerging 5G technologies, the solutions they supply, and the impact they have on present cellular networks. They founded on three key 5G concepts: Device-to-Device (D2D), Network Slicing (NS), and Mobile Edge Computing (MEC). By using D2D, spectrum efficiency, energy efficiency, and throughput will be significantly increased. In addition, the system was being enhanced with lower latency, higher throughput, and higher massive connectivity to decrease time to market, increase network efficiency, and lower the complexity of the system [17].
- In 2021, Radwa Ahmed Osman, et al, wireless technologies were used to fight and track COVID-19 users which necessitates receiving data that was

dependable, efficient, and accurate. The authors proposed a model based on Lagrange optimization and a distributed deep learning model to ensure that the received data was efficient and reliable. A reliable transmission of data was achieved by locating the RFID reader in the most appropriate location at the base station. Their study demonstrated that the proposed method, which results in an efficient and simple tracking system, was effective and precise in determining the appropriate transmission distance between an RFID reader and a base station [18].

- In 2021, Domenico Giustiniano, et al, traced contacts of people and provided location-based analytics required in technologies to fight COVID-19. Some technology that is dependent on short distances such as Bluetooth was adopted in some countries but appeared to be hampered by security leaks, and reliability problems. The authors contended that 5G and beyond can play a crucial role in tracking people's movements, location-based analytics, and tracking the movements of groups. For 5G location-based analytics to work, wireless infrastructure has been widely deployed, criteria have been developed over the years for localization and analytics [19].
- In 2021, Hamid Mcheick, et al, showed a COVID-19 contact monitoring application based on wireless communication, where Wi-Fi direct was utilized to trace the region's contacts and explore comparable approaches that are created such as Bluetooth and Wi-Fi Direct with a focus on Google and Apple exposure alerts. An implementation prototype would then be shown along with the architecture of the proposed application [20].
- In 2022, Mirza Anas Wahid, et al, the authors presented COVICT, an IoT-based COVID-19 detection, and tracking system with semi-automated and improved contact tracing capability, with the application of real-time data of

symptoms, gathered from individual people and contact tracing. By imposing a Smart lockdown, COVICT can enhance the prediction of infected people and identify environmental contamination to prevent further virus spread. In developing policies to combat COVID-19, regulatory agencies can make use of the suggested IoT-based design [21].

- In 2023, Ahmed Laguidi, et al, the authors demonstrated how D2D evolved into a promising technology for in-band or out-of-band mobile communication systems. Additionally, they introduced new solutions to enhance the performance of D2D networks by reducing device congestion in the vicinity of a base station. Thus, the proposal reduced financial costs by lowering equipment deployment costs [22].

Compared to the proposed model here, in Ref. [15], the main benefit of D2D communication is to search for nearby devices and connect with them without passing through BSs, offloading congestion from the network. As Bluetooth demands users to keep their devices open and active, the Bluetooth option keeps contacting them constantly so that they remain visible to other peers. In addition, Bluetooth is a wireless communication protocol that transmits and receives data over short distances. Bluetooth's maximum transmission rate can approach 2 Mbps when devices on the same network are within 10 meters of one another, while the D2D technique has a high data rate and a transmission range of up to 100m that gives the exact locations of the devices. In the model, D2D communication can find the exact location of users within a very short distance, less than 3 meters, and take the exact position of the movement of infected people at each moment.

1.3 Aims of the Thesis

1. To investigate the D2D schemes technology, as well as how to increase the throughput, and decrease the delay.
2. To study the mode selection technique in D2D communication that includes D2D mode and infrastructure mode.
3. To calculate the minimum distance possible in D2D mode that gives higher throughput and minimum delay.
4. To design a simulated model based on D2D communication to track the movement of healthy people when moving proximate to an infected COVID-19 person at a distance of 3 meters or less. Five cases of different numbers of healthy users are taken.

1.4 Layout of Thesis

The rest of this thesis will present the chapters.

- **Chapter Two:** presents an overview of the 5G system and discusses D2D communication, classifications, applications, and challenges.
- **Chapter Three:** presents OMNeT++ software description, INET framework, and Simu5G simulator. Then, it explains the performance of D2D communications in infrastructure and D2D modes using OMNeT++ software. Finally, a model is proposed to simulate tracking infected people with COVID-19 using D2D technology.
- **Chapter Four:** presents and discusses the results of a simple model of D2D and infrastructure modes at the different distances between UEs starting at 80m to 10m and measure the throughput of uplink and downlink, delay, and received bytes. Also, model (2) display the

simulated tracking model for possible COVID-19-infected persons, and take different numbers of healthy users for every implementation.

- **Chapter Five:** discusses the conclusions and several suggestions for future works.

Chapter Two

Device-to-Device (D2D) Communications in 5G

2.1 Introduction

Device-to-device (D2D) communication is a radio access method that allows mobile users or user's equipment (UEs) to communicate directly between any two UEs while they are close without passing via network infrastructure. In principle, the advantages of D2D operation include higher spectrum efficiency, increased throughput and capacity per area, decreased latency, and improved power. These advantages stem from the proximity of users utilizing D2D communication, higher spatial reuse of time and frequency resources, and the use of a Sidelink (SL) in D2D mode rather than both the downlink and uplink resource when connecting via the base station (BS) in infrastructure mode. Before reviewing the D2D technologies, this chapter will present a short overview of 5G technology as well as discusses the D2D communication technologies, classifications, benefits, applications, and challenges [1].

2.2 The Fifth Generation (5G)

The launch of 5G enables the beginning of a global digital world with groundbreaking wireless technology standards, notably in terms of data rate, latency, mobility, and even the number of linked devices. 5G is the first cellular generation that uses the mmWave band, a new frequency band technology. Furthermore, 5G is the Internet of Things (IoT)'s central infrastructure, capable of incorporating a slew of emerging technologies such as D2D communication, and Software-Defined Networking (SDN) [23].

2.3 Network Technologies for 5G

The incredible increase in portable devices and associated high-speed applications have increased the ever-increasing flow of cellular data traffic. As a result of this expansion, the need for high data speeds, low latency, and highly reliable wireless communications is skyrocketing. 5G mobile networks have claimed to meet these future applications and service needs, the fundamental technologies necessary to enable 5G cellular networks are as follows [24]:

2.3.1 Millimeter Wave (mmWave)

The use of millimeter-wave (mm-wave) frequencies in mobile communications distinguishes 5G from 3G and 4G. This is due to two factors. First, the limited frequency resources, and microwave frequency bands have become severely crowded and are unable to support the exponential rise in communication capacity. As a result, mmWave is becoming the foundation of 5G cellular networks. At high frequencies, mmWave has a broader bandwidth (ranging from 24 to 300 GHz) as shown in Figure 2.1. Second, the absolute bandwidth at mmWave frequencies is substantially bigger than the relative bandwidth at lower microwave frequencies [24] [25].

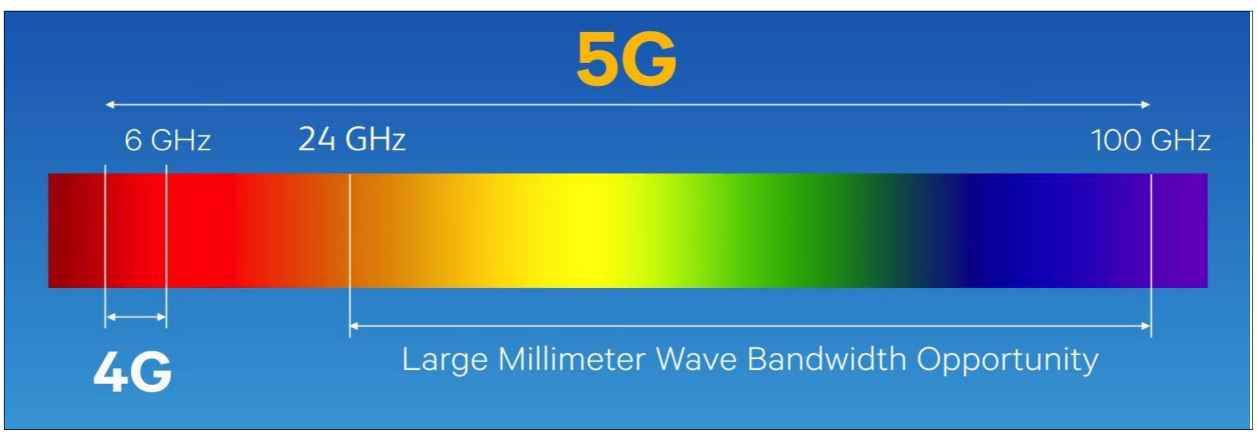


Figure.2.1: The Millimeter-wave Bandwidth [26].

In comparison to microwave band (MW), mmWaves have considerably different propagation circumstances, atmospheric absorption, and hardware limits. These difficulties might be overcome by employing beamforming and a bigger antenna array. To reduce excessive path loss, it is commonly acknowledged that the mmWave spectrum must be employed with a small cell radius (100 m). Fortunately, this behavior is consistent with the current trend of intensive small-cell deployment [27].

2.3.2 massive Multiple Input Multiple Output (mMIMO)

A massive MIMO system is often characterized that employing a large number of independently controlled antenna components, typically 100 or more, at least on one side of a wireless transmission link, usually at the BS side which may offer a wide array aperture as shown in Figure 2.2 [4]. mMIMO has been identified as a high-potential technology for wireless communication with large user capability, which is the main condition for 5G networks and beyond technologies [28]. By analyzing the uplink channels utilizing pilot signals given by the UEs, the BS can estimate the Angle Of Arrival (AOA)s with high precision and little inter-user interference impact.

As a result, huge MIMO will increase the usage of angle-based positioning algorithms in 5G networks, which are not often employed in 2G-4G networks. Also, considerable improvements in dependability, spectrum efficiency, and energy efficiency can be gained [29] [30]. With massive MIMO, a single BS may serve many UEs and receive numerous signals. These signals are often generated by coherent or incoherently dispersed sources, and numerous AOA estimate techniques have been developed, among other things. It should be noted that each UE's position is estimated based on the metrics linked with it. As a result, source association is a critical issue for multiple source locations in huge MIMO systems that has yet to be adequately solved [29].

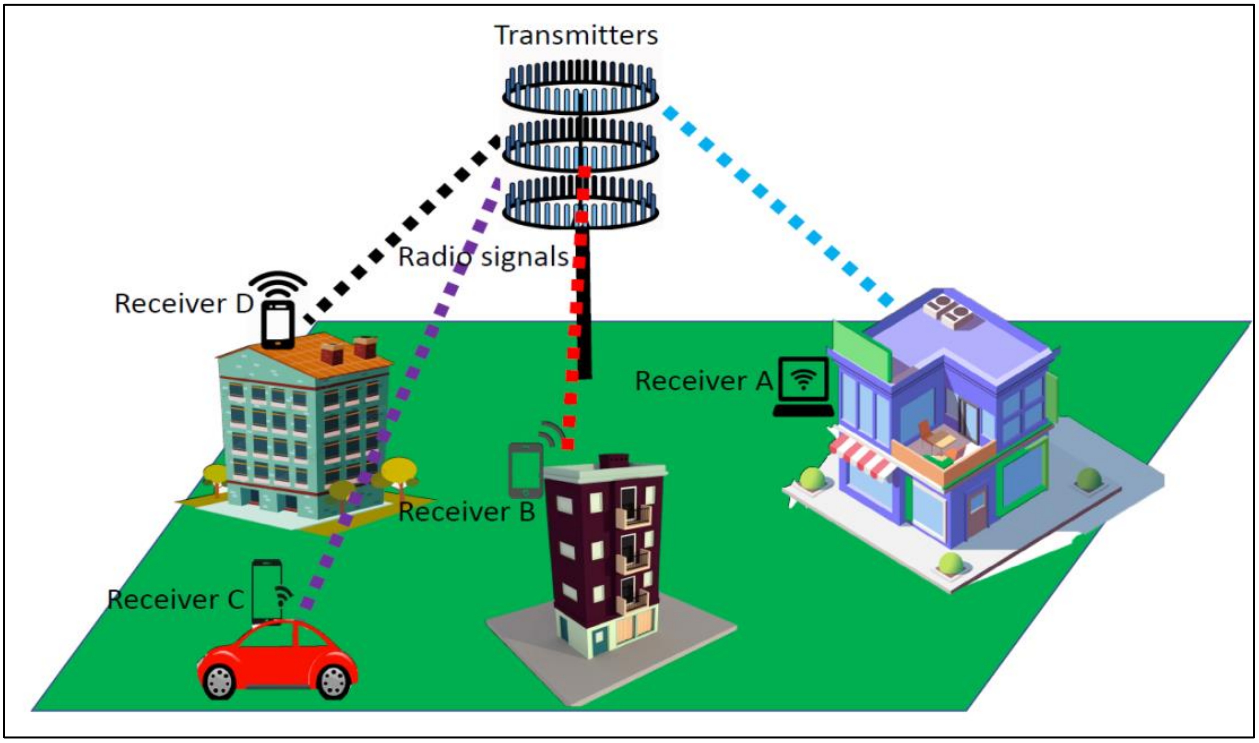


Figure.2.2: Massive Multiple Input Multiple Output (mMIMO) [28].

2.3.3 Non-Orthogonal Multiple Access (NOMA)

Non-Orthogonal Multiple Access (NOMA) techniques have harvested a lot of interest in 5G wireless networks. The capacity of NOMA to serve numerous users utilizing the same time and frequency resources is the major rationale for its adoption in 5G.

There are two types of NOMA: power domain and code domain. NOMA in the power domain achieves multiplexing in the power field, whereas NOMA in the code domain achieves multiplexing in the code field [31]. NOMA initiates superposition coding for multiple streams at the BS and then sends the overlaid signal across the same time-frequency resources through power multiplexing. To remove intra-beam interference and retrieve desirable information, various Cellular User Equipments (CUs) as receivers use the Successive Interference Cancellation (SIC) approach. In contrast, in traditional orthogonal multiple access, each CUE is assigned to orthogonal resources in the (time, frequency, code) domain, or their combinations in conventional orthogonal multiple access (OMA) [24]. The BS, as illustrated in Figure 2.3, provides superposed signals to two users, with user 1 getting greater channel gain than user 2.

In NOMA, the user with the larger channel gain is referred to as the near user, while the user with the smaller channel gain is referred to as the far user. The near user first removes the far user's signals through SIC before decoding its signal, the far user considers the near user's signal to be noise and discovers its signal directly. To maintain justice, the far user is allotted greater power in NOMA when channel gain and interference are lower [31].

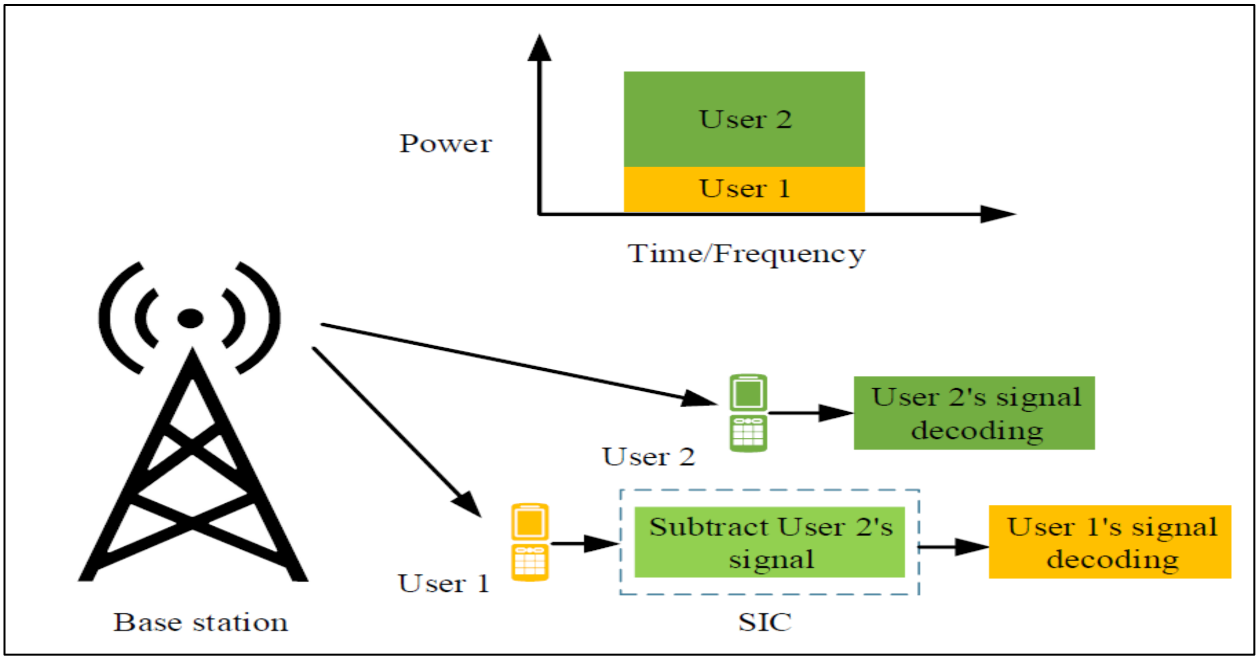


Figure.2.3: Example for downlink power-domain NOMA [31].

2.3.4 Beamforming

Beamforming is the technology of directing the main beam of an antenna in the correct direction while canceling out the unwanted ones at the receiver and transmitter to achieve spatial selectivity [32]. The use of beamforming improves the capacity of the network, coverage, and bandwidth efficiency.

Beamforming employs various radiating elements to determine the direction of a wave front by transmitting the same signal at the same wavelength and phase. The main lobe is the shape of this effective radiation pattern. It is possible to guide the beam in a specific direction by varying the phase of the signal on all radiating elements as shown in Figure 2.4.

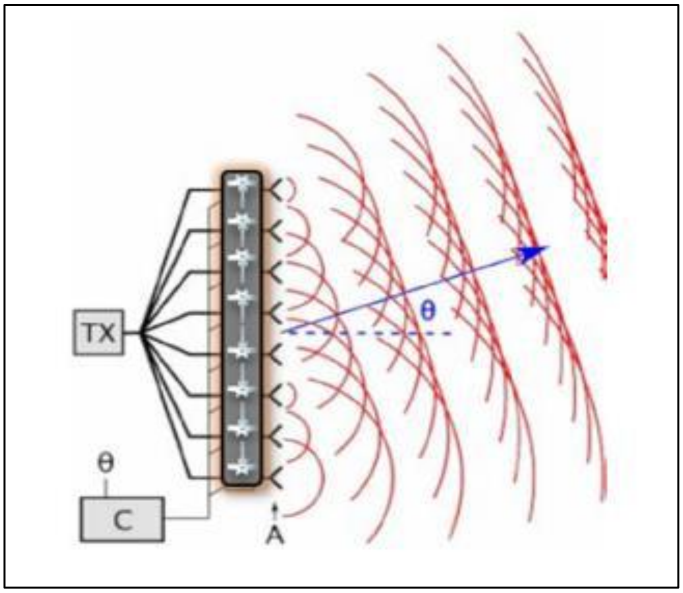


Figure.2.4: The influence of phase shift on eamforming [33].

This allows tracking the UE, effectively reducing interference, and improving the SINR. However, beamforming produces side and back lobes. Also, distributing the transmitted power away from the main lobe is typically associated with unwanted radiation [33]. Beamforming technology is divided into three types: analog, digital, and hybrid beamforming [32] [33].

2.3.5 Mobile Edge Computing

Edge computing is a computational approach that allows edge servers in mini clouds (or edge clouds) to extend cloud services at the network's edge to conduct computation time tasks and store massive amounts of data nearer to user equipment (UEs).

Classical cloud computing has been implemented to permit UEs to offload computation and storage to data centers. Cloud computing is a centralized computing approach that offers continuous access to extremely capable data centers [34].

2.3.6 Small Cells Base Station

As the system uses mmWave, the frequency penetration is decreased, so shrinking the cell size where a cell serves a small number of users is an efficient way to increase the area spectrum utilization. To assist cellular connectivity and meet demand, the third generation communication system includes only macro cellular networks, the 4G system includes small-cell and microcell networks in addition to macro cellular networks, and the 5G system will include ultra-dense small-cells in addition to macro cellular networks. The shrinking allows for more spectra to be provided per user. The beginning of indoor small-cell or femtocell technology has created numerous opportunities. The deployment of small cells is a cost-effective and energy-efficient solution for trying to meet capacity and coverage requirements [35]. The layout of the small cell base station is presented in Figure 2.5.

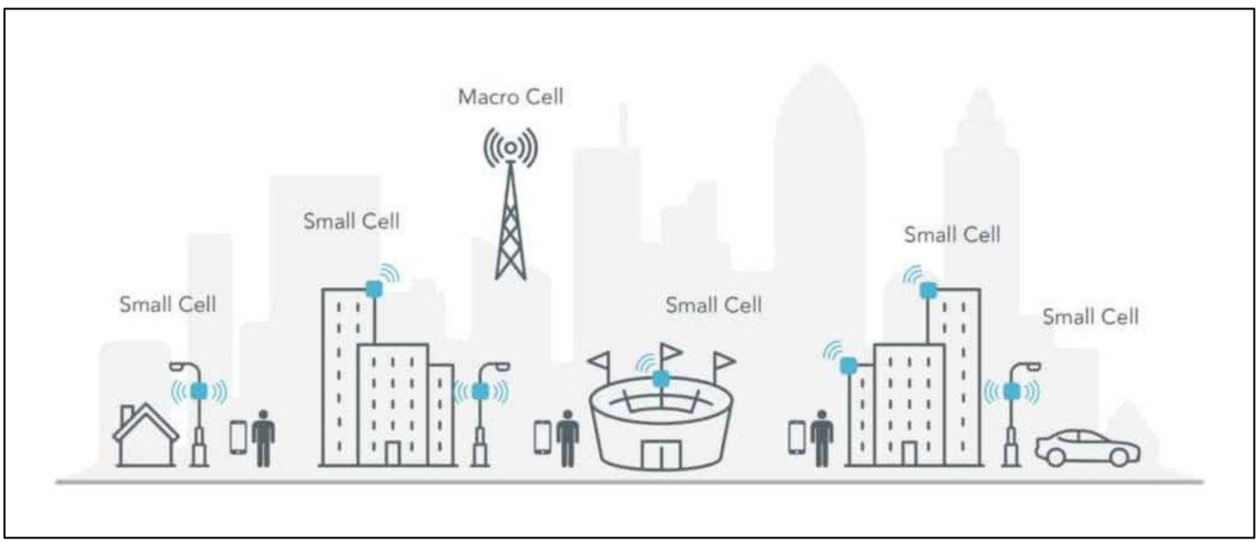


Figure.2.5: Small cell base station[36].

2.4 Ultra Dense Network

Ultra Dense Network (UDN) is a potential solution for meeting the area coverage and capacity demands of 5G networks. Several small cells in a UDN can act as fully functional BSs (picocells and femtocells) or macro-extension access points as shown in Figure 2.6.

In addition to great coverage and capacity, the increased density of small cells can improve UE positioning performance [29]. The reasons for selecting ultra-dense networks are that mmWave technology cannot transmit over 100m as coverage due to propagation deterioration in mmWave. Furthermore, the BSs with mMIMO antennas require a large amount of energy to service all UEs within the macro cell. Small cell networks are the solutions for 5G cellular networks for the reasons stated above. The density of 5G base stations is predicted to reach 40 or 50 BS/km2. As a result, the 5G wireless network is ultra-dense [37].

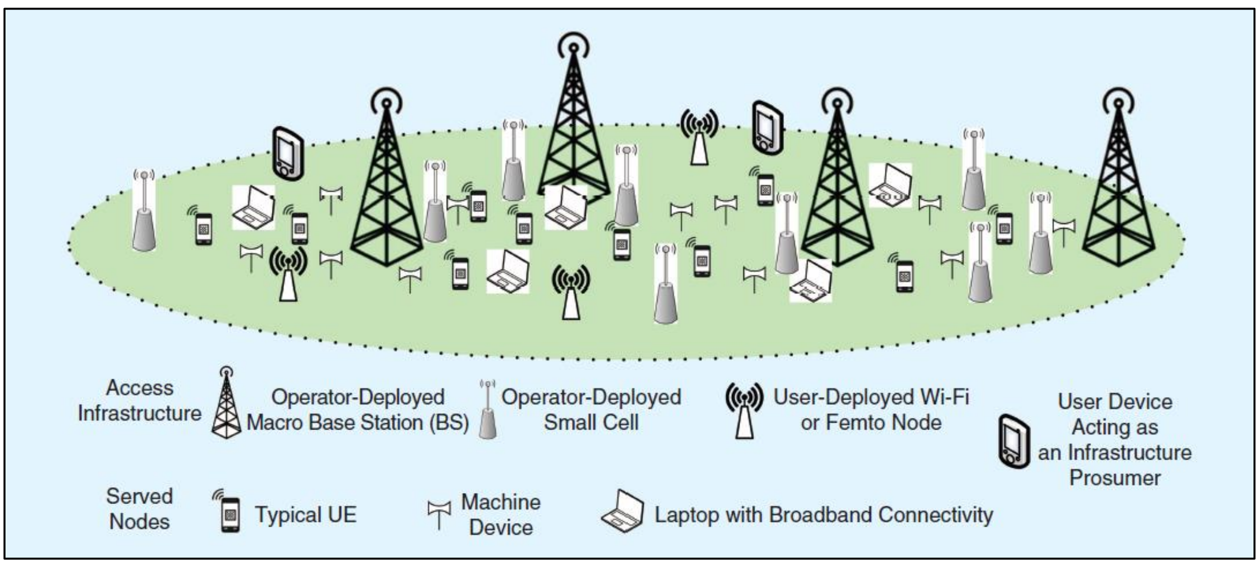


Figure.2.6: Ultra Dense Networks (UDN) in 5G wireless networks [38].

2.5 Device to Device Communication (D2D)

The use of D2D communication techniques is predicted to improve communication aspects such as system throughput, network capacity, spectrum utilization, and latency [39]. D2D communications in wireless cellular networks allow devices in close proximity to broadcast and receive signals without interacting with base stations (BSs) as shown in Figure 2.7 [3].

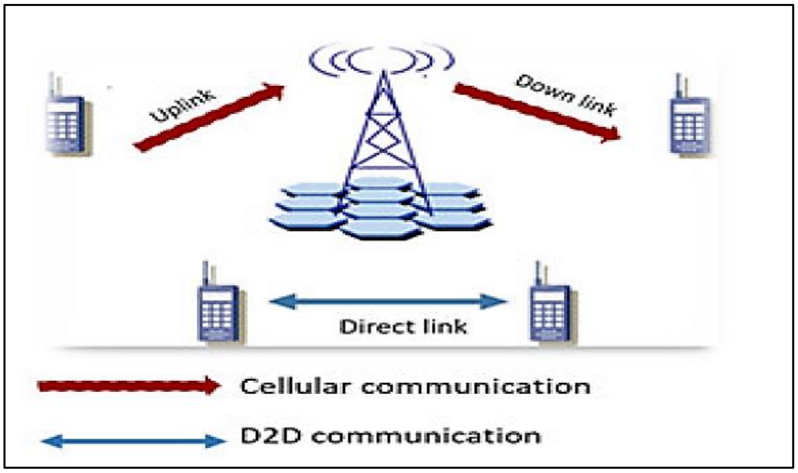


Figure.2.7: Device to Device (D2D) communication [17].

The goal of the 5G mobile network is to integrate underlying solutions to present limits and enhance communication architecture to accommodate additional users, improve throughput, expanded capacity, and decrease control traffic and latency. 5G networks will allow a wide range of services and network deployments, including the IoT, a potential paradigm for combining various technologies and communications solutions. The Third Generation Partnership Project (3GPP) provides an upgraded Long-Term Evolution (LTE) radio interface known as LTE-Advanced to increase the performance of current cellular technology (LTE-A). This comprises several technologies. one of these technologies is D2D communication [40]. Direct connection allows devices to utilize lesser transmission power than cellular communications, which is critical for extending device battery life.

Despite the many advantages of D2D communication, many challenges are encountered, including device discovery, power control, interference, resource allocation, and security. This thesis focuses on device discovery and proximity [41].

2.6 Classification of D2D Communication

D2D communication in a wireless network can be classified as In-band D2D or Out-band D2D depending on the spectrum in which it happens [42]. Figure 2.8 shows a block diagram of the classification of D2D communications.

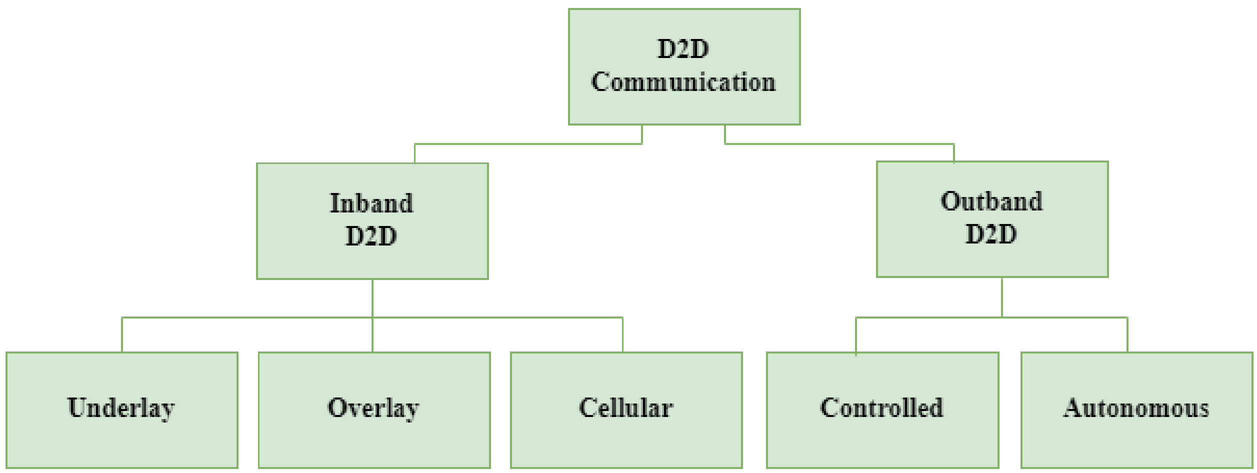


Figure.2.8: Classification of D2D communications [43].

2.6.1 In-band D2D

D2D users, like other cellular users, shared a licensed cellular spectrum, which is controlled by the base station Next Generation Node Base station (gNB). The gNB is in charge of detecting prospective D2D transmission, establishing links based on channel state information (CSI), allocating radio resources to either uplink or downlink and coordinating interference between cellular and D2D users [44]. The In-band is divided into Underlay, Overlay, and Cellular categories.

- **Underlay Mode**

The gNB simultaneously shares the same spectrum of resources with D2D users and cellular users, which has the benefit of obtaining the highest spectrum efficiency. Because both users are accessing the same resource blocks, this kind suffers from interference between D2D and cellular users [44].

- **Overlay Mode**

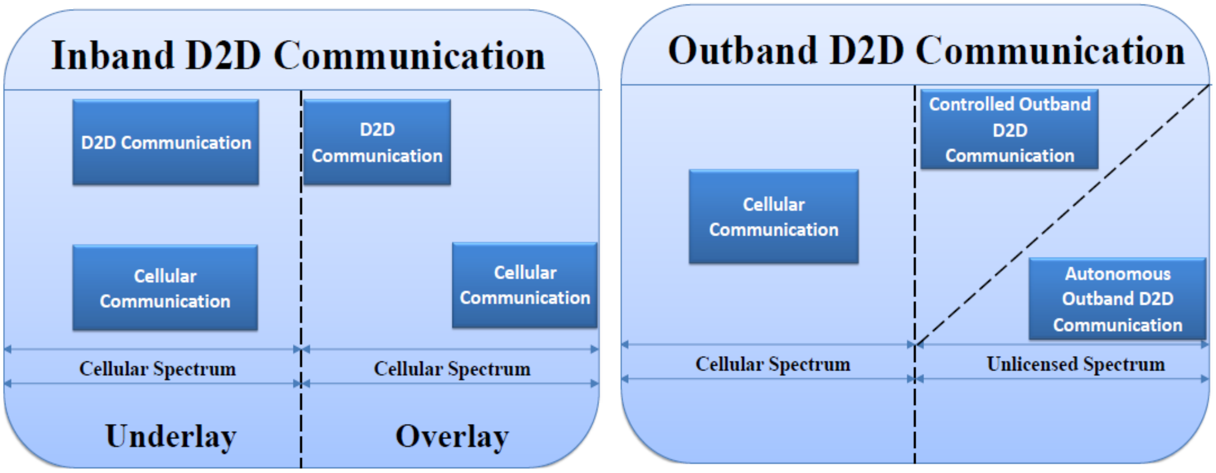
In this type, D2D users and cellular users are granted dedicated cellular resources, which are removed from cellular users, so there is no interference problem between D2D and cellular communications [42].

- **Cellular Mode**

D2D UEs communicate with a gNB, which acts as an intermediary relay instead of directly communicating with one another [43].

2.6.2 Out-band D2D

Out-band D2D communications operate in the unlicensed industrial scientific medical (ISM) frequency band. This mode of communication is compatible with other wireless technologies that transmit in the unlicensed spectrum, such as Bluetooth and Wi-Fi. Out-band communications are further classified as either autonomous or controlled D2D communication [17]. Figure 2.9 displays a diagram of the spectrum of D2D communications in wireless networks.



(a) (b)

Figure.2.9: The spectrum of D2D communications in wireless networks

(a) In-band and (b) Out-band [45].

- **Controlled Mode**

The gNB is responsible for synchronizing D2D users in terms of time, frequency, and phase. It also sends control information signals for device detection, session creation, connection establishment, resource schedule assignment, power management, routing, and so on. In addition, the gNB monitors D2D links to verify that D2D policies are not broken. D2D users provide current status reports on direct links and other control information about the environment to the gNB regularly.

In essence, the gNB has complete control over all D2D connection operations, efficiently executes radio resource management (RRM), and so any unwanted interfering signals from both cellular and D2D communications may be simply coordinated. The benefits of network-controlled D2D include meeting the Quality of Service (QoS) requirements of cellular communication while handling D2D communications effectively and efficiently, to boost total system throughput. It does, however, incur significant signaling overhead to organize and regulate D2D activity [44].

- **Autonomous Mode**

The gNB has some influence over the D2D users or connection's actions. The gNB allocates radio resources on a wide time scale, limits the transmission power allowed to D2D users, and so on. D2D users initiate communication sessions on their own via direct discovery, announcing, and observing the procedure between the D2D pair. Simultaneously, D2D users may control the radio allocation of resources, plan their transmission, and establish power control independently in a distributed manner. One of the primary advantages of autonomous D2D is that the gNB incurs less signaling cost, allowing it to serve additional cellular users. However, among the primary problems for autonomous D2D are interference management among D2D users and significant implementation complexity on the side of D2D users [44].

2.7 Advantages of D2D Communication

D2D communications are one of the major foundations of future networks since it allows for traffic offloading and reduces overall system traffic load. Aside from traffic discarding, the D2D idea may be used to facilitate communication in crisis scenarios where the Macro BS is down due to natural disasters such as earthquakes, floods, and so on. The D2D idea can address such a situation by linking them to the nearest operational ground network or detecting their precise position in the state of multi-hop [46]. Also, D2D communications improve many elements of the system network, for example:

- Reduce the required power or energy for transmission leading to improve power or energy efficiency due to the proximity between the devices.

- Reduce the delay and increases the throughput of the system due to the short distance between the devices.
- Increase the hop gain if they use either the uplink or downlink resources only for the direct communication link [9].

2.8 Applications and services of D2D Communications

There are many applications of D2D communication in 5G as shown in Figure 2.10. The following is a quick explanation of various applications.

Figure.2.10: Applications of D2D communications [47].

2.8.1 Voice and Data

Local services are dependent on proximity-based services. Local D2D services have significant applications, such as proximity-based transmission, in which information is sent directly between two nearby terminals, so it improves system performance, reducing latency and increasing the data rate between users, and evacuation of traffic. In addition, social applications in which the device is identified, a connection is created, and data or online gaming are transmitted, as well as high-definition (HD) video transmission. With the high number of devices, network density, and increased applications in 5G, traffic offloading will become the most important local service [9].

2.8.2 Video Streaming

Video streaming is described as the real-time transport of compressed material over the net. This means that you do not have to wait until the movie has been entirely downloaded before watching it. As a substitute, video is supplied as a continuous stream of information and is played it back as soon as it arrives. As a result, video streaming has become a significant source of internet traffic. Similar apps like video chat or video conferencing between devices within the same cells or neighboring cells that are close together [47].

2.8.3 Machine to Machine (M2M)

Machine-to-Machine (M2M) communications happen between machines such as devices having computation and communications capabilities that do not require human intervention. The collected events are communicated across cellular connections to the server, which collect and analyze the acquired data as well as manages and teaches other units remotely. The network connects machines from beginning to finish. Smart home surveillance settings are well-known instances of M2M technologies.

As a result, D2D technology may be used. D2D communication can improve network efficiency by making use of the excellent channel quality of short-distance D2D connections. Furthermore, by lowering transmit power, machines can now have longer battery life. Additionally, because D2D data is routed directly, overall M2M network latency may be reduced. Furthermore, for local M2M communication, the network may have less load distribution of data servers [47].

2.8.4 Emergency Networks

Natural catastrophes, such as earthquakes, can destroy traditional communication network infrastructure, rendering networks inoperable and necessitating massive rescue operations. This issue might be solved by implementing D2D communications [48]. Even though communication network infrastructures may be irreparably damaged, D2D technology may be built between terminals to fulfill all of these needs. A large number of devices can connect to form a tiny network and immediately relay data to one another [47] [48].

2.9 Proximity Service

The 3GPP specifications in Release 12 add ProSe (Proximity Services). The ProSe is a D2D technology that enables two devices to identify and interact directly with one another. It is based on the concept of leveraging many new functional aspects for LTE standards as well as a customized air interface for direct device interaction (so-called Side-link) [49]. Side-link connection explains the channel topology consisting of logical, transport, and physical channels across an air interface to implement a ProSe application as shown in Figure 2.11 [50].

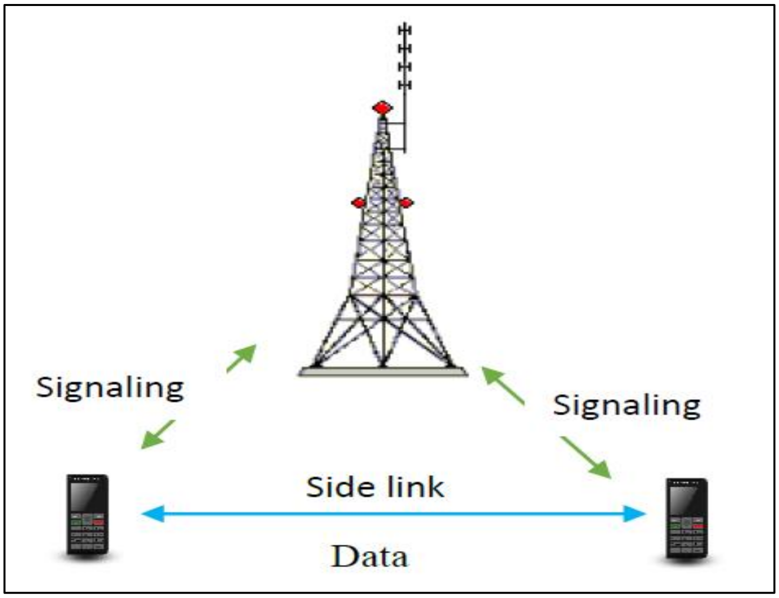


Figure.2.11: Data and control communication lines on the Side-link [50].

The overall benefits of ProSe include increased spectrum utilization, throughput, and energy consumption, as well as the ability to enable new Peer to peer (P2P) and local-based applications and assure enhanced public health and safety network services [11]. The two fundamental functionalities for enabling 3GPP ProSe are D2D discovery and communication. ProSe discovery enables a UE to utilize the LTE air interface to locate other UEs in the vicinity.

There are two types of ProSe discovery: open and restricted; the distinction is whether or not the authorization is required for UE discovery [48]. UE being discovered, whereas limited discovery requires express approval from the UE being discovered [50]. ProSe communication occurs when two UEs that have discovered each other connect directly over the LTE air interface, through the evolved Node Base station (eNB) and the core network [51].

The ProSe architecture consists of three major components that enable D2D communication known as ProSe Application, ProSe Application Server, and ProSe Function as shown in Figure 2.12. It is explained as follows:

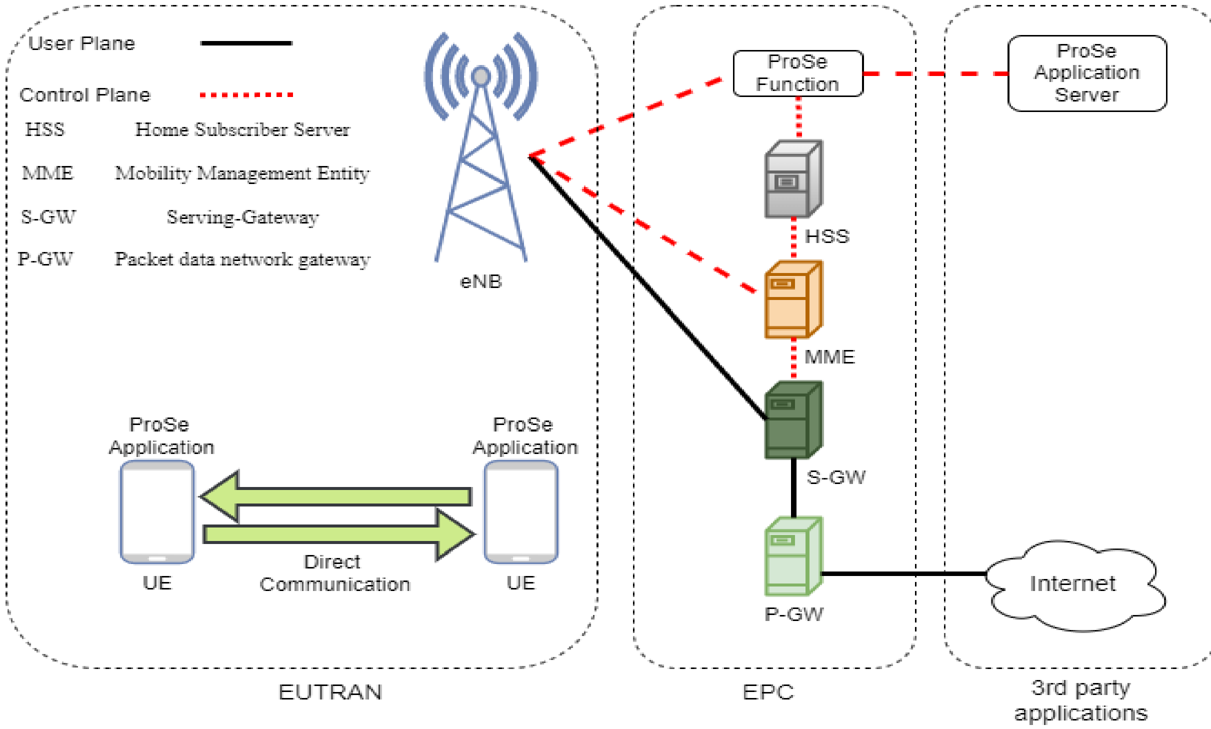


Figure.2.12: D2D communication-based architecture of 3GPP ProSe[52].

2.9.1 ProSe Application

The UE hosts the ProSe Application. This component is responsible for D2D communications both for data and control messages. A ProSe Application can transmit beacons to identify new nodes or submit its position information to the Evolved Packet Core (EPC) and request network help during the discovery phase. Furthermore, following the discovery, the ProSe Application manages the D2D data connection between two UEs [52].

2.9.2 ProSe Function

Acts as a basis of reference for the ProSe App Server, the EPC, and the UE. The features and functionality may include:

(1) Internetworking through a point of reference to third-party applications.

(2) Permission and configuration of UEs for discovery and direct communication.

(3) Enabling EPC-level ProSe discovery, charging, permission, UE configuration, and safety.

2.9.3 ProSe Application Server

The ProSe App server is made up of ProSe's core features (for example, public safety responding points) that are utilized for public safety or other business use cases. The application server can connect directly with a UE-defined application that is normally built outside of the 3GPP framework [52].

2.10 Challenges of D2D Communication

All communication in a classic cellular system occurs via the BS, and direct connection between devices is sometimes not allowed, even if they are within range of one another. D2D communication, on the other hand, allows devices to create a direct link and transfer data without passing via the BS. D2D communication has several advantages over standard two-hop cellular communication. D2D communication enhances spectrum efficiency, extends coverage, reduced latency, and boosts throughput. Despite its many benefits, there are also many issues faced by D2D communications including device discovery, resource management, interference management, power control, security, and mode selection [41].

2.10.1 Security

In mobile communication, the UE is first authenticated, and then the radio connection is encrypted. However, with D2D communications, transmission happens without the aid of the BS. Wireless channels are also transmitted in nature. As a result, they are vulnerable to a variety of threats, eavesdropping, message changing, node impersonation, and other security vulnerabilities, Making security a top priority. Cryptographic solutions are required to protect information while it travels across networks. D2D users can use the security systems supplied by cellular providers if they are inside their service area. However, users outside of the operators' coverage cannot be protected. In this instance, security signals may be transmitted via relays. As relays are generally recognized to be particularly vulnerable to malicious attacks, creating security mechanisms for D2D communication is an essential task to overcome [53].

2.10.2 Resource Management

The goal of incorporating D2D communications into wireless networks was to increase spectrum use, the distribution of frequency resources to D2D pairs inside wireless networks is referred to as resource allocation [53]. The techniques for resource allocation might be centralized, distributed, or semi-distributed. In the centralized approach, the base station is responsible for the allocation and management of resources. The complexity of the centralized approach is more as the base station which is responsible for monitoring the performance of the system, SINR and channel quality calculation, connection establishment, and call setup should also allocate the resources and control the interference in the system. Therefore, the centralized strategy is only appropriate for small cell networks and becomes more difficult for bigger networks [9].

The BS is not involved in resource management in the distributed model. The devices are in charge of resource allocation and management. This form of network is also appropriate for bigger networks with a higher number of connected devices. The devices exchange messages more often to collect information about channel quality, SINR, and the availability of cellular resources of surrounding devices [9].

2.10.3 Interference Management

One of the main issues in D2D communications is interference from CUs. The cohabitation of CUs and D2D pairs that share the same cellular resources causes interference. D2D users will experience intra-cellular and inter-cellular interference based on the operating mode of the D2D network. Interference can endanger transmission performance by lowering the SINR [5]. The interference management strategy is divided into three types:

1. Avoidance of Interference

These strategies are used to prevent interference between D2D users and cellular networks [5].

2. Interference Coordination mechanisms

Offer major benefits in in-band D2D communications. This includes BS control for the Centralized Interference Coordination (CIC) system, Moreover, because D2D nodes participate in the coordination process, control from the BS is reduced for the Decentralized Interference Coordination (DIC) strategy [5][8].

3. Interference cancellation mechanisms

Employ sophisticated decoding and coding strategies to remove interference signals at the D2D users or (CUs). The approaches used can increase the capacity of the wireless networks [5].

2.10.4 Power Control

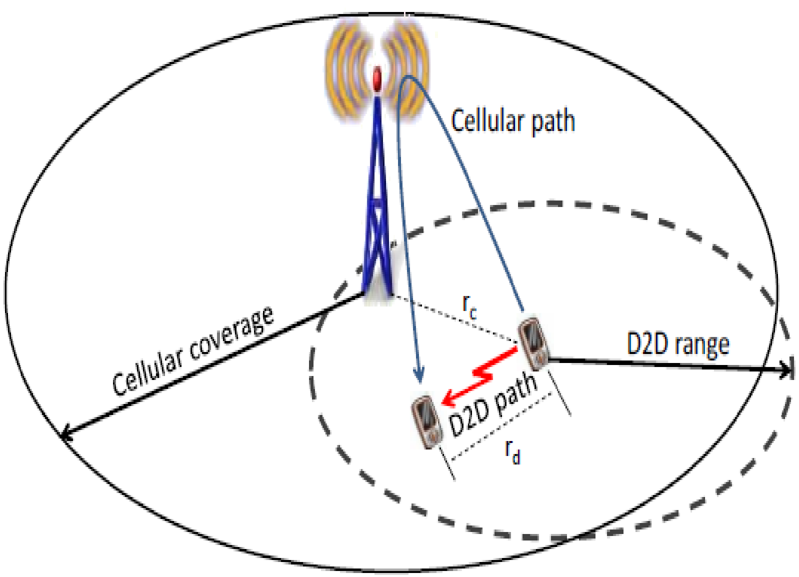
Power control is the method of changing the levels of power of the BS during downlink transmission and the UE during uplink transmission. The requirement to raise a device to transmit power occurs since it can also boost link capacity. This, however, will cause increasing interference among devices that use the same resources. One advantage of power control strategies is that they assist safeguard energy resources.

These strategies distribute radio resources utilized in resource allocation to various users or devices. Time slots in a time division multiple access (TDMA) and frequency bands in a frequency division multiple access (FDMA) are two examples of radio resources. Power control algorithms are classified into two types: centralized and distributed. The BS determines resource allocation and power control choices for centralized algorithms, while the UE is responsible for distributed algorithms [8].

2.10.5 Mode Selection

D2D communication has recently garnered a lot of attention to improve cell throughput and preserve device transmit power [54]. The fundamental idea behind D2D-enabled wireless networks is to allow transmitter-receiver pairs to cohabit nearby to create a direct link connection.

As illustrated in Figure 2.13, if a transmitter has its assigned receiver within its broadcast range, it is permitted to skip the BS and connect in D2D mode (i.e., direct link). D2D communication allows short-range, low-power links to interact alongside wireless links, improving the spatial utilization of the available spectrum [55].



rc: Distance from a generic UE to the nearest BS

rd: Distance from a generic potential D2D UE to its receiver

Figure.2.13: Wireless network with D2D capability [55].

The mode selection planner performs a reconfiguration of whether a user is working in a D2D or infrastructure mode. The mode selection scheme to maximize the network capacity has been explored to enhance the throughput of the cell. Also, the mode selection scheme is to minimize the delay [54].

There are three types of mode selection explained below:

1. **D2D Mode (Direct Mode)**

D2D users connect via a direct link called a Side-link (SL). BS plays no role in this manner of communication.

2. **Infrastructure Mode**

D2D users connect using BS. The BS serves as a link between the D2D receiver and transmitter. Thus, infrastructure mode communicates via two hops.

3. **Relay Mode**

D2D users connect via a relay node. There should be a relay device near each D2D transmitter and receiver.

2.10.6 Device Discovery

One of the most critical processes in cellular device-to-device communications is discovery, which is known as peer discovery [7].

The D2D discovery was motivated by the fact that two devices may connect without utilizing the operator's resources. There are two stages to generic device discovery. The first step is to start the discovery process, and the second step is to manage it. D2D discovery can be initiated by either the device or the network. These two methods are known as a priori and a posteriori discovery. The explicit content is shared among the devices via a priory discovery. Then, a posteriori D2D discovery might be used [56]. There are two forms of device discovery centralized and distributed discovery [9].

1. **Centralized Discovery:** Devices discover each other with the aid of the central system, which is often a base station or access point as shown in Figure 2.14. The equipment lights the BS to connect with nearby devices. The BS initiates the flow of messages between two devices to obtain critical data, such as the Channel quality, position, availability, interference, and power management characteristics. A BSs role in the device discovery process might be complete or partial, depending on the pre-designed set of protocols used. If the BS is completely integrated, the devices are not allowed to begin device discovery with one another. The BS facilitates every device discovery signal. In this case, the devices simply tune in to the BSs discovery signals and emit discovery signals to it, to initiate the device research process. If the BS is only partially integrated, the devices communicate discovery signals to just one another for device discovery without first obtaining permission from the BS. However, the devices contain a BS that exchanges the SINR and path gain of each device. This supports the BS in determining the feasibility of device communication. Finally, the BS requests that both devices commence communication [57].

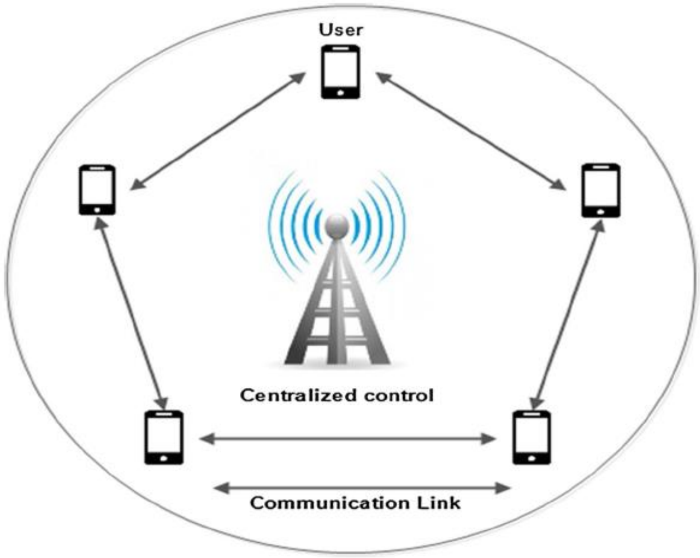


Figure.2.14: Centralized Discovery [56].

2. **Distributed Discovery:** Distributed device discovery approach allows devices to discover one another without the need for a BS as shown in Figure 2.15. The device that wishes to commence communication begins to search for other devices in its vicinity. For D2D communication, beacon signals are delivered, and information about the location, channel state data, and device availability status is transferred between the devices. To discover surrounding devices, the gadgets send control signals sporadically. However, interference, timing difficulties, and the strength of the discovery signal are frequently encountered in the dispersed form [57].

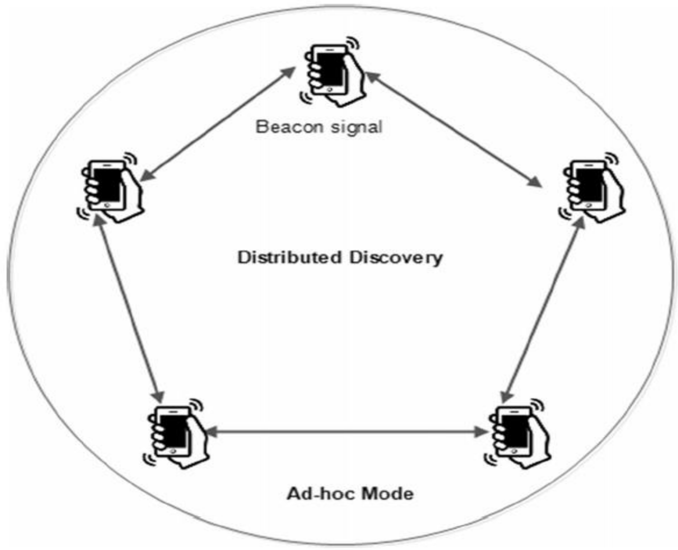


Figure.2.15: Distributed Discovery [56].

A beacon or pilot signal is sent to locate other nearby devices. The pilot signal includes scheduling information, which might be problematic if the information it transmits is incorrect. Unless an acceptable device is located, the beacon signals are sent often and again. This repeated transmission of beacon signals may create interference with other network devices. The beacon broadcasts cannot also be infrequent, since this may delay the finding process when the neighboring device state changes owing to device movement. Synchronization is another key challenge in D2D communication. All network devices are synchronized with the BS. The scheduled time is set by the BS. When two devices are transmitting data and one of them is detected to be out of range of the BS, the network must continually search for additional nearby devices [9].

As a result, in-band device discovery is effective in all aspects of D2D design. Many additional device discovery strategies for in-band and out-of-band have been developed based on the centralized and distributed categories, as illustrated in Figure 2.16. The network-assisted discovery, direct discovery, and beacon-based discovery are for in-band devices, whereas the others are for out-of-band devices.

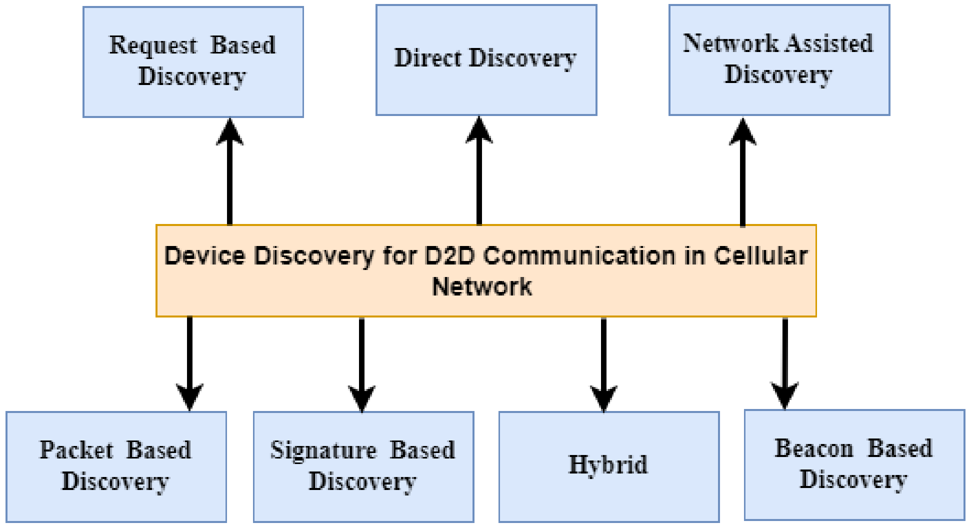


Figure.2.16: Situations involving In-Band and Out-of-Band device detection in D2D communication[56].

Chapter Three

Modeling and Simulation of D2D Communications

3.1 Introduction

Most of the current research in the 5G has often focused on D2D communication. It is seen as one of the cornerstone technologies in 5G networks. This chapter investigates the mode selection process between two communication modes D2D mode and infrastructure mode and compares them.

The COVID-19 pandemic exploded at the beginning of 2020, several national governments decided to adopt containment measures, such as lockdowns, social distancing, and quarantine. Among these measures, contact tracing can contribute to bringing under control the outbreak. D2D communication can be useful for COVID-19 contact tracing applications. As a result, a simulation model was used to track potential COVID-19-infected individuals and their proximity. It is possible to identify the number of potentially infected people and track their movements as well as the location of each user.

3.2 OMNeT++ Framework

Objective Modular Network Testbed in C ++ (OMNeT++) is an open-source framework for discrete-event simulation that is expandable, modular, and component-based in C++. Simulators for networks are primarily built using this technology. A large community of academic and corporate users uses it free of charge. Researchers can assess the effectiveness of networking systems using OMNeT++-based models, such as Simu5G, Veins, and the INET framework [58][59]. The parameter values, description, and behavior of a model are all maintained separately in OMNeT++. C++ is used to code the behavior of a model. In contrast, the description (i.e., gates, connections, and parameter definitions) is coded separately using the Network Description (NED) language. Inheritance and interfaces are exploited in NED, a declarative language. Using NED, one can write parametric simulation scenarios. Last, but not least, parameter values are written in Initialization (INI) files. At runtime, INI files are read and used to initialize the model. A parameter can have multiple values or intervals specified, making simulation studies easier to run [59].

The common mechanisms for recording statistics from simulation results are signals and declared statistics, i.e. using @statistic properties in NED files. However, the simulation library also includes some classes for programmatic result collection, such as:

- Scalar values can be recorded in the output scalar file using the module or channel's record Scalar() method. Use the cStdDev and cHistogram classes to gather statistic summaries such as mean, min, max, etc... The module's recordStatistic() method can record their contents into the output scalar file.
- Declarative (@statistic-based) result recording can also be extended through the cResultFilter and cResultRecorder classes.

3.2.1 INET Model Library

INET is a well-known model library designed for OMNeT++. It contains a plethora of computer network element models, such as hosts, protocols, switches, connections, and so on. Notably, INET models many TCP/IP suite protocols, including TCP, UDP, IPv4, IPv6, and others, as well as both wired and wireless layer-2 protocols (Ethernet, IEEE 802.11, etc.). A user can incorporate the INET library into an OMNeT++ simulation scenario and then run an experiment in which an application on a host communicates with some other end-point via a network of IP routers, each of which has Ethernet cards and PPP WAN links. It is not an issue if the two end devices use different entry technologies, such as 802.11 and 802.15 [60].

3.2.2 Simu5G Simulator

Simu5G is founded on the OMNeT++ simulation framework and progresses a collection of models with defined interfaces. Also, Simu5G includes all models from the INET library, a new 5G emulator based on the known SimuLTE library, used by manufacturers and academia. Simu5G boasts a wide set of models for UE navigation, including D2D connections [60]. 5G Simulator is made up of Radio Access Network (RAN) and Core Network (CN). The RAN is made up of cells that are managed by a single base station, known as gNB and is based on 3GPP terminology, which assigns radio resources to some User Equipment (UEs), and User Plane Function (UPF) or Packet Data Network Gateway (PGW) as shown in Figure 3.1. The gNB of 5G is a developed evolved node base station (eNB) of 4G. UEs are connected to a BS and can vary the serving BS over a handover procedure.

The BSs communicate via the X2 interface, which is a logical connection on a wired network. The CN's data plane is composed of one or many UPFs that connect the RAN to the data network. The General Packet Radio Services (GPRS) tunneling protocol (GTP) is used for forwarding in the CN. Each node can connect the binder's data structures that included network-wide data via method calls (both UEs and gNBs). Multicast group membership, frequency resource usage, and so on are among the data contained in this binder. This form-based option has two advantages. First, having a central repository of relevant information simplifies managing distributed tasks. Second, it allows the user to abstract control-level functions and elements, and replace them with Binder queries to obtain the necessary information [61].

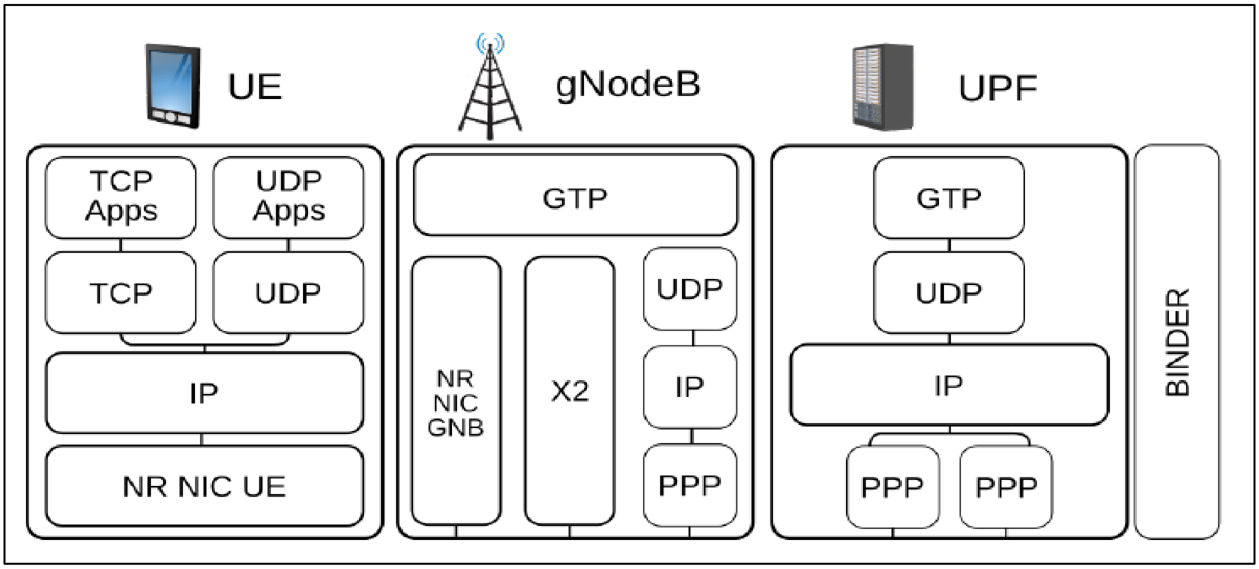


Figure.3.1: The architecture of the 5G system [61].

Communications between the BS and the UE take place at layer 2 of the Open Systems Interconnection (OSI) model in the RAN. Layers 1 and 2 are implemented on both the BS and the UE utilizing a stack of four protocols.

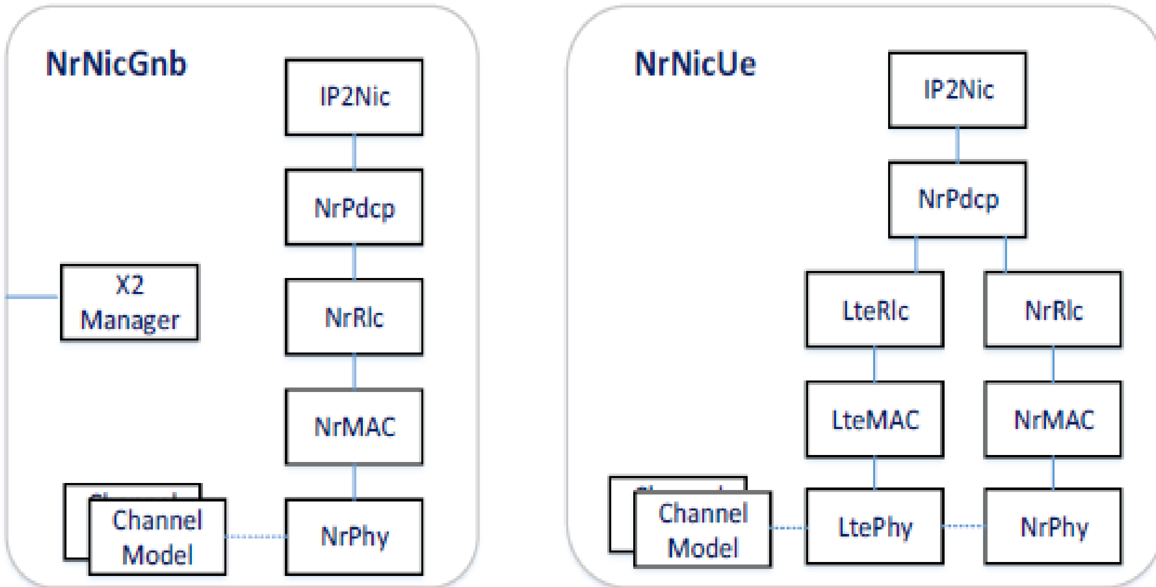
Starting at the top is the Packet Data Convergence Protocol (PDCP), which accepts IP datagrams, ciphers, and numbers, and transmits them to the Radio Link Control (RLC) layer.

When the underlying Media Access Control (MAC) layer needs to compose a transmission, it fetches RLC Service Data Units from the RLC buffer. The MAC assembles the Protocol Data Units (PDUs) into Transport Blocks, adds a MAC header, and transmits everything across the physical layer (PHY) [61]. The BS schedules resources regularly, for every Transmission Time Interval (TTI). According to its scheduling rules, the BS assigns a vector of Resource Blocks (RBs) to backlogged UEs on each TTI. The amount of RBs occupied by Transport Blocks (TB) varies depending on the Modulation and Coding Scheme (MCS) used for transmission. The BS chooses the MCS based on the Channel Quality Indicator

(CQI) given by the UE. The latter reflects the UE's perceived SINR, quantified on a scale of 0 (extremely bad) to 15. (i.e., optimal) [61].

The CQI implicitly determines the MCS, hence limiting the number of bits that a single RB may carry. The BS transfers the TB to the scheduled UEs on the allocated RBs during the DL. The BS sent the transmitting grants to UEs in the UL, clarifying which RBs and MCS to use. UEs, notify the BS of UL accumulation by transmitting Buffer Status Reports (BSRs) after a scheduled transport, or by initiating a random access process to obtain a try to schedule grant from the BS if they are not scheduled. UL and DL transmissions and scheduling are separate. Frequency Division Duplex (FDD) and Time Division Duplex (TDD) are both methods of fragmenting UL and DL resources. In FDD, each direction has its spectrum. The DL and UL use the same spectrum in TDD, and the two transmission directions alternate over time. Hybrid-Automatic Repeat orders protect MAC transmissions (H-ARQ) [61].

The receiver transmits an ACK/NACK to the sender after a formal number of TTIs, which can then reschedule a failed transport [60]. Modeling a UE and a gNB with New Radio (NR) capabilities, the NrUe and gNodeB compound modules, are the Simu5G library's main components. A UE model encompasses all protocol layers, from physical to application. Also, it contains the IP and TCP/UDP protocols and TCP/UDP application vectors. The UE's NR capabilities are applied in its Network Interface Card (NIC), known as NrNicUe. A gNB compound module, in contrast, contains protocols up to layer 3 (IP) and has two network interfaces: one NR, implemented in the NrNicGnb module, and one running the Point-to-Point Protocol [61]. Figure 3.2 depicts the inner structure of both NICs.



(a) (b)

Figure.3.2: The structure of NIC modules in NR

(a): for gNB, (b): for UE [61].

This feature allowed designers to combine LTE 4G with 5G. In a model network setup, the gNB is connecting with PGW to communicate on the internet. This condition is called Stand Alone (SA) state as can be seen in Figure 3.3 (a). Alternatively, as shown in Figure. 3.3 (b) a gNB can operate in an E-UTRA/NR Dual Connectivity (ENDC) deployment. In the initial stages of 5G deployment, this last deployment is expected to become the most popular. In this case, the gNB serves as a Secondary Node (SN) for an LTE eNB, which serves as a Master Node (MN) connected to the CN. The X2 interface connects the eNB and the gNB, and all NR traffic passes through the eNB first.

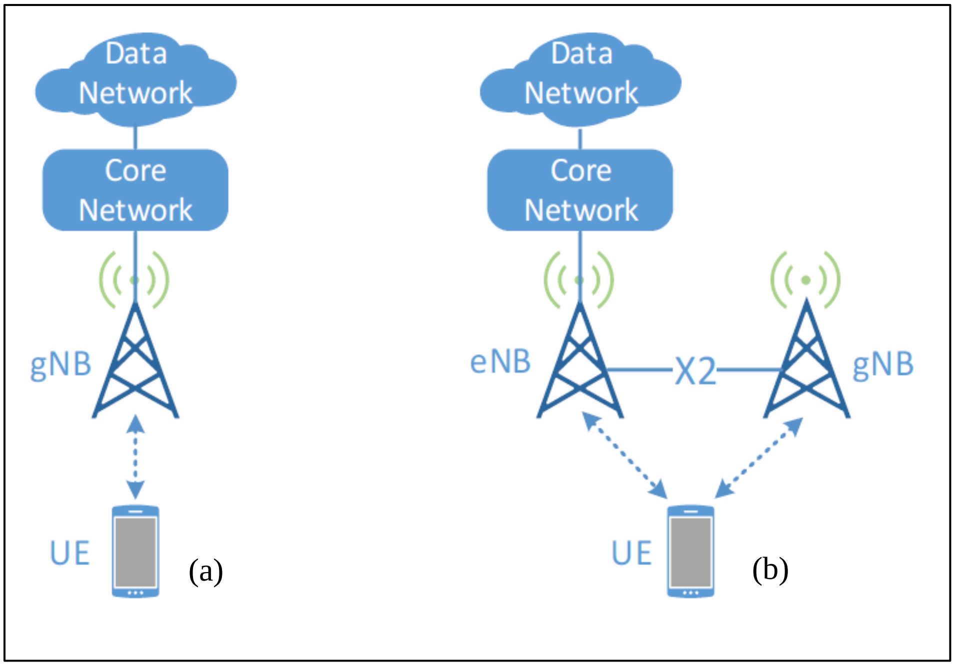


Figure.3.3:(a) The SA, (b) The ENDC [62].

3.3 The D2D Mode Selection Modeling in 5G

For the simulation, a very simple single hop D2D communication model in 5G is presented and implemented using OMNeT++ simulator version (5.6.2), the INET framework version (4.2.5), and the Simu5G software version (1.1.0). some basic parameters are analyzed in different network conditions; such as uplink and downlink throughput, delay, and received bytes. The model consists of a pair of UEs D2D transmitter (UeTX) and UEs D2D receiver (UeRX) are connected via two states, the first state via gNB as an infrastructure mode, and the second directly without gNB as the D2D mode (Direct mode) as shown in Figure 3.4.

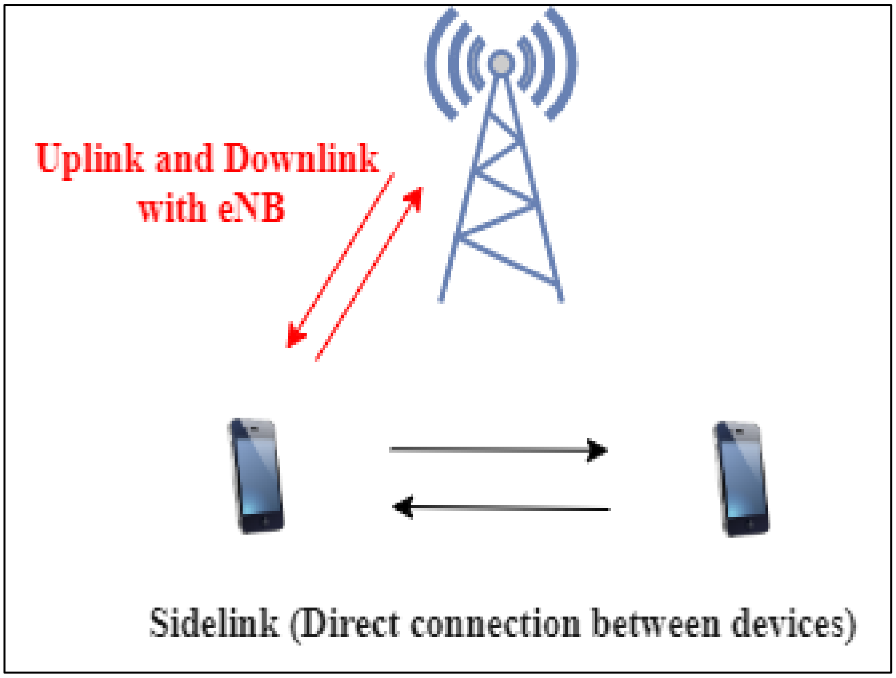


Figure.3.4: Sidelink Control and Data communication links.

As mentioned before, the performance tested and the evaluation analyzed for the D2D communication model using the OMNeT++ program simulator. The cell simulation area is 100m x 100m, and the initial distance between D2D modules for communication is 80m as shown in Figure 3.5.

Figure.3.5: Simulation D2D communication in OMNET++ in NED file.

The Channel Control is in charge of establishing the channel of communication as specified in the channel deterministic model and monitoring the channel state throughout the simulation. OMNeT++ also used the Configurator and Routing Recorder entities for sending signals in the 5G network's control plane. The binder is the oracle module in Simu5G that needs to perform resource allocation and observes RBs, has total transparency of all nodes, and can be arrived at by any entity to achieve common data [63].

The Carrier Aggregation module records all information that relates to the network's carrier components (CC). CCs are discontinuous frequency portions defined by a carrier frequency and some available RBs. Like the Binder, which is represented as a global module that is viewable to all gNBs and UEs in the simulated world, the visualizer integrates all canvas visualizers into a single module. It supports disabling any submodule visualizer by providing an empty string as its type [61].

The description of the parametric simulation is written in The Network Description (NED) files as shown in algorithm 1 below:

Algorithm 1: NED File

1. Define the network.
2. Input: the parameters of the model such as (users, gNB, router, server, etc…).
3. Define the gates of the model and their positions for each element.
4. Make the connection between the elements.

It is assumed that the variables defined in NED files are fixed. However, some variables must be adjusted for various experiments. In the proposed models, for example, the UE's position must be changed to experience varying distances with the gNB. As a result, the variables can be stored individually in the.ini file to override their default values.

In this program simulation procedure in a model (1), there is a set of values for each parameter, we decided to choose those parameters that gave us the best results. The TCP protocol is used for communication, the D2D transmitter sends 1 GB of data to the receiver. The D2D UEs are stationary (no mobility) and the distance between the D2D UEs and gNB is supposed to be 50m while the initial distance between the D2D UEs is 80m. The maximum transmission power of D2D UEs and gNB is 22 dBm and 46 dBm respectively. Simulation of fading effects, JAKES fading model, and ITU Urban Macro path loss model are used to model the effects of fading. The total simulation time is in the 30s, and the number of

Resources Blocks (RBs) is equal to 50. In Table 3.1, the setting of the main parameters as well as the characteristics of the D2D model is explained.

Table 3.1: Main Parameters Setting

Parameters	**Value**
Carrier Frequency	2 GHz
Bandwidth	10MHz
Tx Power of gNB	46 dBm
Antenna Gain of gNB	8 dBi
Tx Power of UEs	22 dBm
Noise Figure of gNB	5 dB
Antenna Gain of UE	0 dBi
Noise Figure of UE	7 dB
Antenna Type	Directional Antenna

The BS schedules resources regularly, for every TTI. According to its scheduling rules, the BS assigns a vector of RBs to backlogged UEs on each TTI. The amount of RBs occupied by a TB varies depending on the MCS used for transmission. The BS chooses the MCS based on the CQI given by the UE. The CQI carries the information sent from the UEs in the UL direction to the gNB to recommend a suitable transmission data rate for the best available MSC value. CQI is a 4-bit integer number based on SINR noticed at the UE. Quantified on a scale of 0 (extremely bad) to 15. (i.e., optimal). The CQI implicitly determines the MCS, hence limiting the number of bits that a single RB may carry. For this model, a CQI value equals 15.

3.3.1 Scenarios for Simulation

For analysis, the following are the two primary modes of mode selection:

3.3.1.1 Infrastructure Mode

The infrastructure mode denotes the D2D communication technique, which is the same as the classic cellular mode. The communication is done through the base station. The licensed spectrum will be used for both D2D and cellular links, so the interference will be increased, which is worse than in D2D mode.

3.3.1.2 D2D Mode (Direct Mode)

The D2D user pair communicates directly without the base station (gNB) and the data is transmitted in a direct link. The direct link between D2D users is known as the SideLink (SL), to avoid the hop path over gNB, and it should be distinguished from the Uplink (UL) and Downlink (DL). The SL frequency resources are carved away from the UL frequency resources. Thus, it will reduce interference with cellular users, reduce delay, and increase spectrum and capacity, so this mode is better than the infrastructure mode.

Algorithm 2, below, depicts the omnet.ini file's essential parameters to the gNB and UEs, like the number of UEs and gNB, positions, limits of the region of simulation, mobility state of UEs, and the selection mode of D2D communication.

Algorithm 2: The Mode Selection of D2D Communication

1. Input: the AMC parameters.
2. Input: the Users and gNB configurations.
3. Input: the range of simulation area, mobility, and positions of users.
4. Define the type of data communication like TCP, or UDP.
5. Define the properties of simulation like frequency, power, path loss…
6. Disable D2D for the gNB and the UEs in infrastructure mode.

7. Enable D2D for the gNB and the UEs involved in direct communications (D2D Mode).
8. Output: calculate the throughput, delay, and bytes received.

3.3.2. Performance Measures of Results

A single-hop D2D communication model is presented and some basic parameters are analyzed in different network conditions, this model is focusing on the performance evaluation of users that are connected at two modes, infrastructure mode, and D2D mode by examining the following metrics:

Throughput: is the amount of data that is successfully transmitted between two places in a specified period, it is measured in kilobits per second (Kbps).

$$\text{Throughput} = \frac{\text{Total Received bits}}{\text{simulation time}} \qquad (3.1) \quad [63]$$

The throughput of the MAC layer is calculated in D2D mode and infrastructure mode at different distances.

Capacity: the maximum amount of data that can be transmitted reliably between different locations across the network.

Delay: the time it takes for data to be sent from the transmitter to the receiver.

3.4 D2D Communication Simulation Model for Tracking COVID-19 Infected persons

This D2D communication can play a primary role in contact tracing and group movement monitoring such as metal buildings, and crowded areas such as stadiums, hospitals, and others...

The COVID-19 pandemic has suddenly raised the need for technological solutions capable to trace contacts of people and provide location-based analytics[19]. So, the technology of D2D communications is used to present a model for simulation tracing a possibly COVID-19-infected persons.

3.4.1 Overview of COVID-19

A new coronavirus was identified in December 2019 in Wuhan, Hubei Province, China, and labeled COVID-19 by the World Health Organization (WHO). WHO designated the COVID-19 outbreak to be a pandemic in March 2020. Similar to earlier coronaviruses. Both humans and animals are susceptible to this disease. It causes dry cough, scratchy throat, diarrhea, and fever are among the symptoms of the illness[64]. As nations dealing with COVID-19 have discovered, to treat and contain infections, it is crucial to detect positive people as soon as possible [65].

COVID-19 is combated by tracking, testing, diagnosing, and treatment of the illness. The COVID-19 test works best when used in conjunction with a rigorous path of contacts, and tracking works best when used in conjunction with a suitable communication system that gathers and disseminates information about the whereabouts of possibly infectious individuals, among other things. To accomplish this, in high-risk areas, 5G technology could enhance diagnostic capabilities by allowing us to locate infected individuals faster, swiftly tracing their contacts, and identifying the source of the infection, thereby preventing further viral spread through interactions subsequent [66]. To limit the break-out of COVID-19, it is very important to perform massive tests, inform the infected persons, and lock them down. Sometimes, a person will not follow the authority’s precautions and leaves home, and consequently, he/she infects others. In this case, it is urgent to assign each infected person and broadcast their names in order not to allow the virus to break out and cause a disaster.

Tracking people wirelessly starts by creating an account for them, whether they are infected or not. Giving each person their unique identity (ID), internet protocol

(IP), and international mobile subscriber identity (IMSI) address of their mobile operator. The user ID is usually random according to a predefined random number generator in the user's device, thus maintaining the confidentiality of the user's ID. Information and data are stored on the server either centrally or in a distributed form. In the centralized model, the user uploads their data to the cloud server, and health authorities can track and check their contacts. In the distributed model, data is stored locally and allows users to check if they are in contact with people nearby or not. The second type is characterized by giving more privacy to people. As for the first type, it gives health authorities more information about the spread of the disease and is faster in detecting the infection spread. If someone shows signs of illness like temperature, cough, etc. If takes a COVID-19 test and the test result is positive, the operator will send the result of his tests to the cloud server. The server sends his data to all the governmental organizations and alerts people who are less than a 3m distance from him/her. The health authority asks them to quarantine, in this case, will prevent the spread of the Coronavirus further [67].

3.4.2 Contact Tracing

Contact tracing is regarded as an important public health precaution for limiting COVID-19 spread. It is a critical part of comprehensive COVID-19 prevention strategies because it assists in identifying persons who may have been exposed to a confirmed COVID-19 case (s). The tracking of those contacts aids in trying to break the chain of COVID-19 transmission from person to person. Contact tracing is typically accomplished when some person meets infected persons at a short distance of fewer than 3 meters by health authorities [68]. There are two ways of performing contact tracing: manual and digital. During the infectious period of a person who has tested positive for COVID-19, A manual contact-tracing solution entails authorized individuals, such as police officers or health professionals, identifying the contacts of that individual or identifying the locations visited by that individual. In a digital contact-tracing process, individuals or wearable devices are used to identify people who were in the same place at the same time, using GPS, Wi-Fi, mobile phones, Bluetooth, and wearables [69]. Smartphones now have intelligent sensors, GPS, connectivity (Bluetooth, Wi-Fi), and other capabilities that make them ideal for contact tracing. Because most people have it with them all the time, it can be used to take advantage of mobile characteristics and aid in contact tracing. A contact-tracing app can be created using one of two methods: centralized or decentralized. Between decentralized and centralized architectures, the primary differences are the amount of data that is stored on a cloud server and how decisions are made. Table 3.2 below shows the comparison between centralized and decentralized [69].

Table 3.2: The Comparison Between Centralized And Decentralized

Centralized	Decentralized
A large amount of data is stored on a single cloud server.	The minimum amount of data is stored on nodes .
The server makes the decision.	User devices make the decision.
The efficiency of the centralized application especially if the central server is a reliable entity. The ability to gather data from all users using a specific contact-tracing app is called efficiency.	The efficiency is less than centralized.
Governments and healthcare providers can use the app to access such data to monitor people in a specific area effectively. When a user recently reported testing positive for COVID-19, data is uploaded to a centralized app.	Only an anonymous identifier of the user who reports testing positive for COVID-19 is uploaded by decentralized apps This identifier is then broadcast to all app users, who compare it to on-phone contact-event documents. If there is a match on a given user's mobile app, that app will alert the user.

Generally, the system architecture of tracing is divided into four basic steps as shown in Figure 3.6.

1. **Registration:** registers a user on a cloud server and gives data and details including timestamps and a user-specific ID. The user-specific ID is usually generated at random by a predefined random number generator in the user's device, preserving the user's confidentiality.
2. **Contact information:** when a registered user is close to another user, they contact each other through D2D communication, thus, it is possible to distinguish their locations and the distance between them. The type of contact of infected people by using D2D technology is important to offloading the network, also D2D technology works with short distances due to direct links between users.
3. **Update data:** nothing occurs with the details provided above if user A is never tested. However, if user A is tested and receives a positive COVID-19 result, the positive test data is sent to the cloud server, either automatically from the authorized health service provider or with the user's assistance.
4. **Contact tracking:** the server processes the information and searches for users in contact with the infected user within a distance of less than 3m through D2D technology. Then, the health authority alerted them, which in turn warned the users and asks them to quarantine. In addition, the server sends an exposure alert signal to all users who were in the proximity of the infectious user during the infectious period.

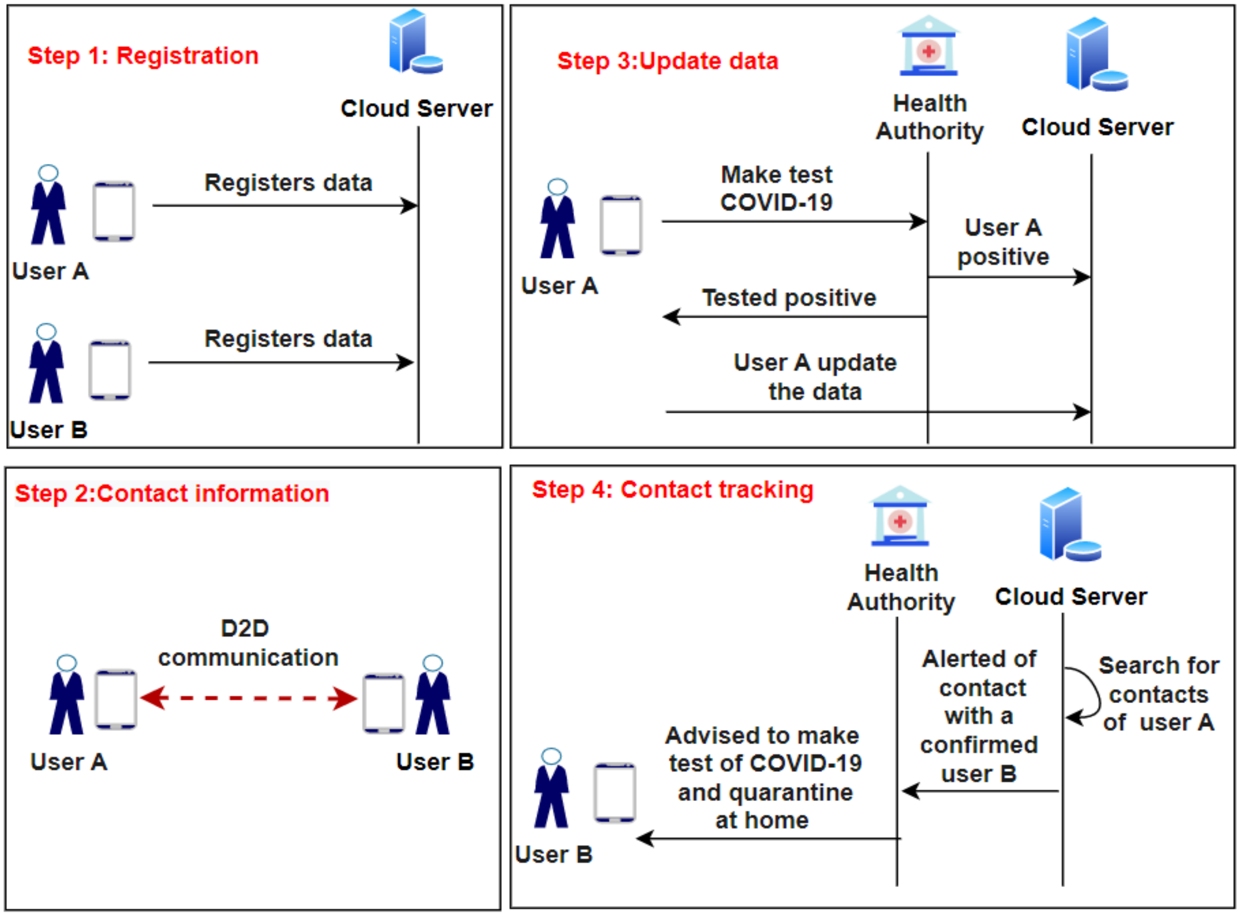


Figure.3.6: COVID-19 contact tracking.

In the presence of the contagious disease COVID-19, social distance is a non-pharmaceutical method of limiting disease transmission. Social distancing refers to measures for limiting the physical proximity of humans, such as closing public venues (workplaces, hospitals) and keeping an appropriate space between persons. Sufficient social distance can greatly minimize disease spread by lowering the likelihood that infected people can transmit the virus to healthy individuals. The primary premise of social distancing is to increase the distance between individuals by more than 3 meters. Techniques to establish the locations of people and measure the distance may play an essential part in aiding social distancing measures.

Many social distancing scenarios could help reduce the spread of infections. These often include distance keeping, tracking people's mobility, identifying the people who are close to the infected person at a short distance, tracking their movements, and alerting them to the necessity of sanitary isolation.

In this chapter, design a simple model as a method to simulate tracking the movement of people using D2D technology and tracking the movement of persons. If any person is close to another infected one at a distance less than three meters away, the infection may be transmitted to him/her without his knowledge. As he/she keeps moving he/she, there is possible to infect other people. In the simulation, it is possible to identify the location of each person constantly, follow his movements, recognize the possible infected people, and inform them of the necessity of quarantine to limit the spread of the Coronavirus, as shown in Figure 3.7.

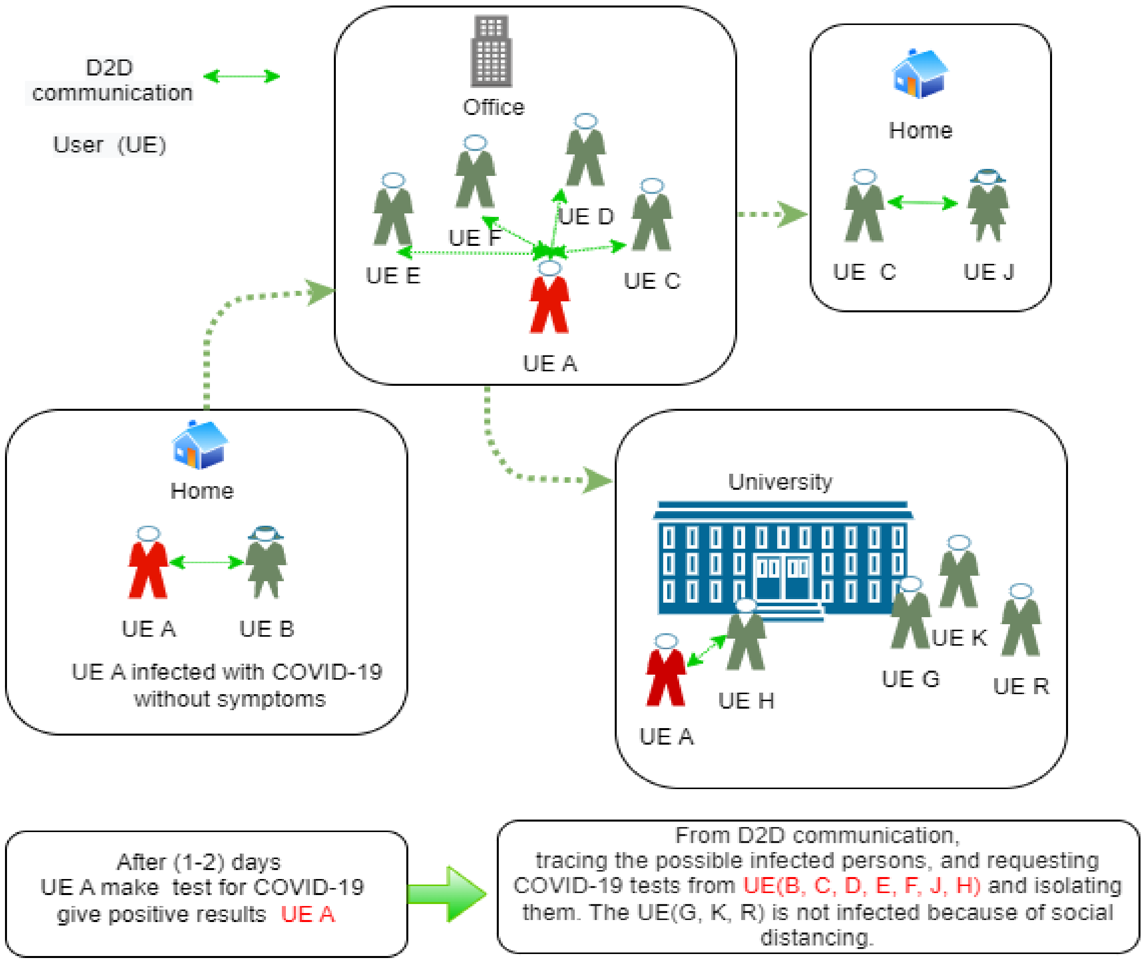


Figure.3.7: Tracking the movement of one person and monitoring the people in contact with him/her.

As shown in Figure 3.7, users UEs (A, B) are in the same indoor environment, the distance between them is less than 2m and mobile devices can connect via D2D communication, and know the location and distance between them. After that, UE A move to the office and meet other UEs (C, D, E, F), the distance between UE A and other users is less than 3m, which is less than the safe distance. After that, UE A moved to the university and approached UE H for 2m, which is less than the safe distance, and the distance between UE A and the other UEs (G, K, R) is more than 3m, which is greater than the safe distance. After infecting UE A with COVID-19, UE A can upload data to the cloud server. The server search for the persons approached with UE A, and know the distance between them if it is less than safe distance or not, track their movement, and know the persons who meet. Like UE C after coming back home, approach UE J, which is less than a safe distance. The server found all the possible infected users, their positions, and the distance between them through D2D communication. Because UEs (B, C, D, E, F, J) were within 3 m of user A, they will be notified as a close contact. Consequently, appropriate measures can be taken to reduce the spread of COVID-19.

3.4.3 The Architecture Of Model (2)

The COVID-19 pandemic has heightened the demand for technical solutions that are capable of tracking people's contacts and providing location-based data. Therefore, model (2) tries to use D2D technology to simulate tracking COVID-19 infection persons. In the simulation, the beginning of model (2) is based on the state of D2D mode in model (1), while model (2) starts when a person is infected, makes a test for COVID-19, and the result is positive, so he/she sends the result to the cloud server to inform it. The system will track the device and gets the minimum distance using a D2D communication with the infected person.

Anyone close to the minimum detection proximity will be set to be infected as well, and the model will track his device. Assume that a UEs D2D, an infected UE(TX) transmitter, and a healthy UE(RX) receiver are connected using D2D technology directly without the need for a base station (gNB) inside a building, the UDP protocol is used for communication. In addition, the number of healthy people X[num(UE)] is 10,20,30 and 40 randomly distributed each time on the cell simulation area of 100m x 100m, the time of simulation is 50s, users of D2D communication initially communicate 40m apart, and users and base stations initially communicate 50 meters apart, before moving closer together. The model was tested and analyzed using OMNeT++ simulation, INET framework, and Simu5G software, as shown in Figure 3.9.

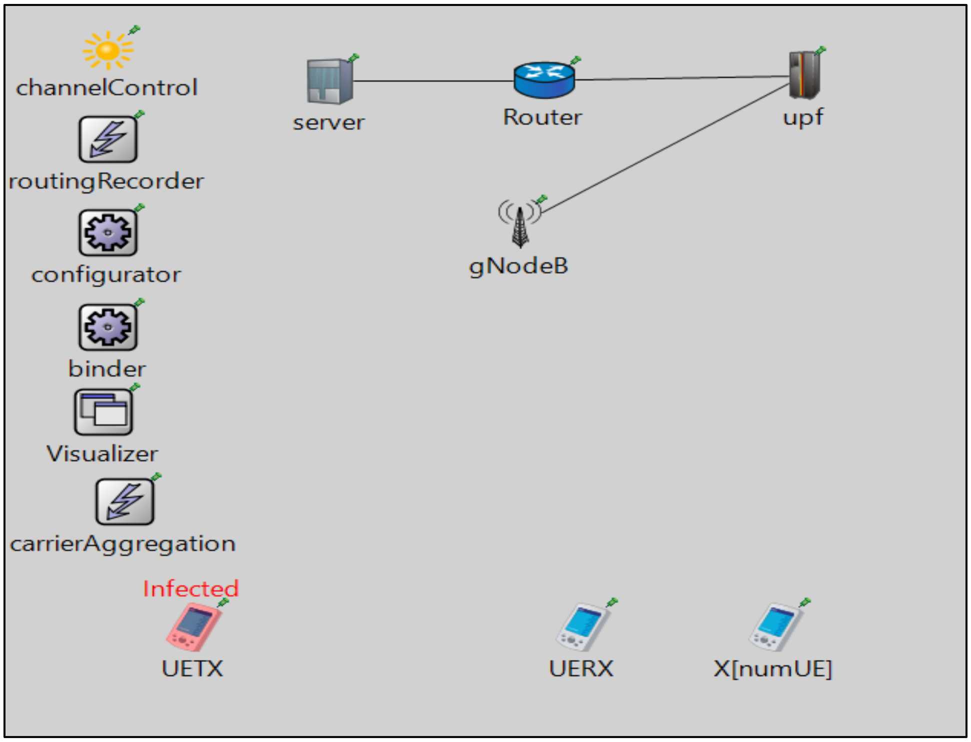


Figure.3.8: Simulation D2D communication in OMNeT++.

Suppose a user UE(TX) is COVID-19 infection with no mobility in the first four cases, the UE(RX) and X[num(UE)] are uninfected moving randomly. At the same time, the location of each healthy user is followed at every moment. As he/she is close to UE(TX) at a range of distance three meters or less around the UETX, the infection will be possibly transmitted to him/her without his knowledge. Therefore, it would be possible to know if he/she causes any possible infection in other people or not. In the last case, UETX is also moving with X[num(UE)].

Algorithm 3: Simulation model for tracking a possible COVID-19 Infected People Using D2D Communication

1. process all steps of algorithm 2.
2. Set all users inside the building (indoor).
3. Define the position of infected user UETX in the cell size.
4. Define the position of UERX in the cell size.
5. Define the type of mobility for the receiver UERX (random mobility).
6. Input the number of healthy users X[num(UE)] and the type of distributed (randomly).
7. Define the type of mobility of X[num(UE)] (random mobility).
8. In the last case, make UETX move randomly in addition to X[num(UE)].
9. Output: The simulation model used for tracking healthy people that have possible to be infected with COVID-19 by using D2D communication. With each implementation in the program, the X[num(UE)] is entered, after which the implementation begins. The movement of users is monitored. The person who approaches the UETX and enters within the limits of 3 meters around him, has the possibility of infection being transmitted to him.

Chapter Four

D2D Models Evaluation and Results Discussions

4.1 Introduction

This chapter presented a D2D model that is displayed in Chapter 3, also calculated the throughput, delay, and received bytes for the model, and explained why D2D mode is better than infrastructure mode. Also, display the simulated tracking model for a possible COVID-19-infected persons, and take different numbers of healthy users for every implementation. This chapter describes the outcomes of the sections presented in Chapter 3, as well as discussions and the evaluation of simulation results.

4.2 OMNET++ Evaluation Metrics

As mentioned before, the OMNeT++ simulator was built from the ground up to assist large-scale network simulation. The simulation software should make it easier to visualize and debug simulation models to decrease debugging time, which traditionally consumes a large portion of simulation projects.

There are two methods for collecting and recording results:

1. Using declared statistical data by the signal method.
2. Straight from C++ code using the simulation library.

In this thesis, depending on the first method, OMNeT++ provides support for recording simulated data as output vectors and scalars. Time series information from simple modules or channels is used to generate output vectors. The researcher can use output vectors to record throughput, end-to-end delays, and so on. Any information will help to understand what occurred in the model during the simulation process. Output scalars will evaluate the results that are calculated during the simulation and written out when it is finished. A scalar result can be an (integer or real) number or a statistical summary with several fields such as packet count, delay, minimum, maximum, and so on.

4.3 D2D Mode Selection Modeling and Configuration in 5G

As mentioned before, D2D mode selection selects either the D2D mode or infrastructure mode. In section 3.3, which presented Model (1), the model will analyze a single-hop implementation of D2D communications in mobile networks. In model (1), the UEs are stationary (no mobility), and the distance between D2D (two UEs) and the gNB is set to be 50m.

The initial distance between the D2D UEs is proposed to be 80m, the UEs are allocated at a single cell within the minimum possible domain for direct communications and have a chance to choose the D2D mode. When the separation between the two D2D UEs is too large for direct communication (The receiver's data rate is below a certain threshold, for instance), the mode of communication switches from direct to infrastructure mode, which is known as D2D communication mode selection. In this model, the mode selection scheme is maximizing the network capacity and has been investigated to improve cell throughput. In addition, the mode selection scheme is designed to minimize delay. The key parameters of implementation, such as throughput, delay, and capacity are investigated and analyzed to reduce the distance between D2D UEs as minimum as possible. The throughput for Uplink (UL) and Downlink (DL) of the MAC-layer is calculated in D2D and infrastructure modes at different distances between UEs, beginning from 80m decreased to 10m. Figure 4.1 shows the uplink throughput for D2D mode which is depicted in red color, while infrastructure mode is depicted in blue color at different distances.

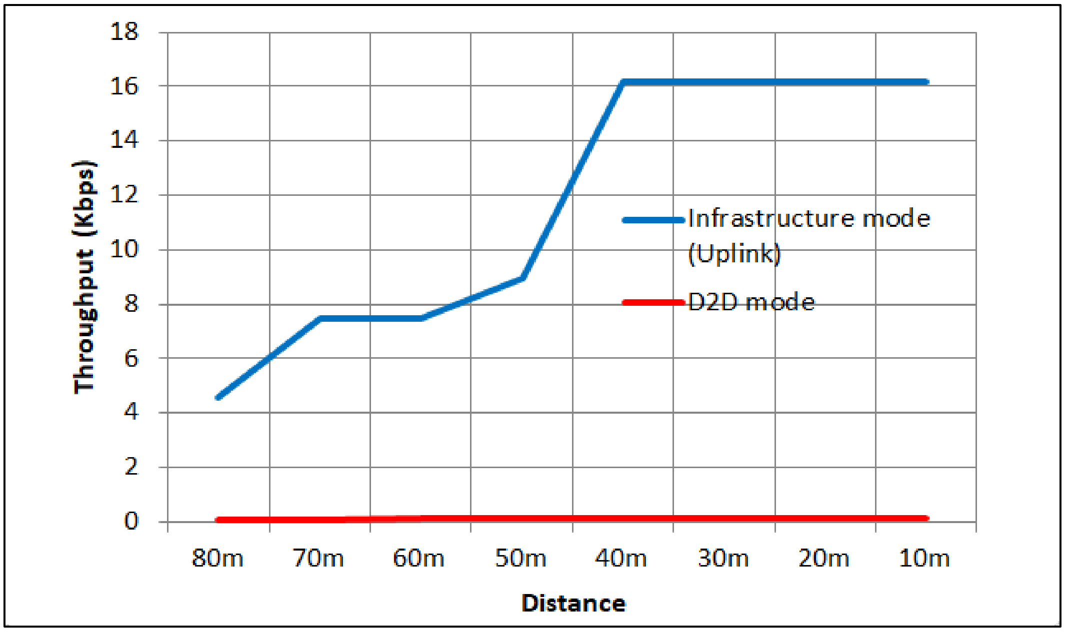


Figure.4.1: Uplink Throughput versus Distance.

From Figure 4.1, it can be noticed that the uplink throughput in D2D mode is approximately zero as there is no uplink from D2D to BS (the D2D uses the SideLink between D2D users to avoid the hop path over gNB) only, while the infrastructure used the uplink and downlink so the infrastructure performs more throughput. The UEs in D2D communication consume less transmitted power than that used in traditional mobile networks caused extending the UE's battery life. D2D mode improves energy efficiency since the UEs use less transmitted power. So, the D2D mode is better than the infrastructure mode.

Now, for the downlink, Figure 4.2 shows the DL throughput for D2D mode depicted in red color while infrastructure mode is depicted in blue color at different distances for a range of 80 m to 10 m.

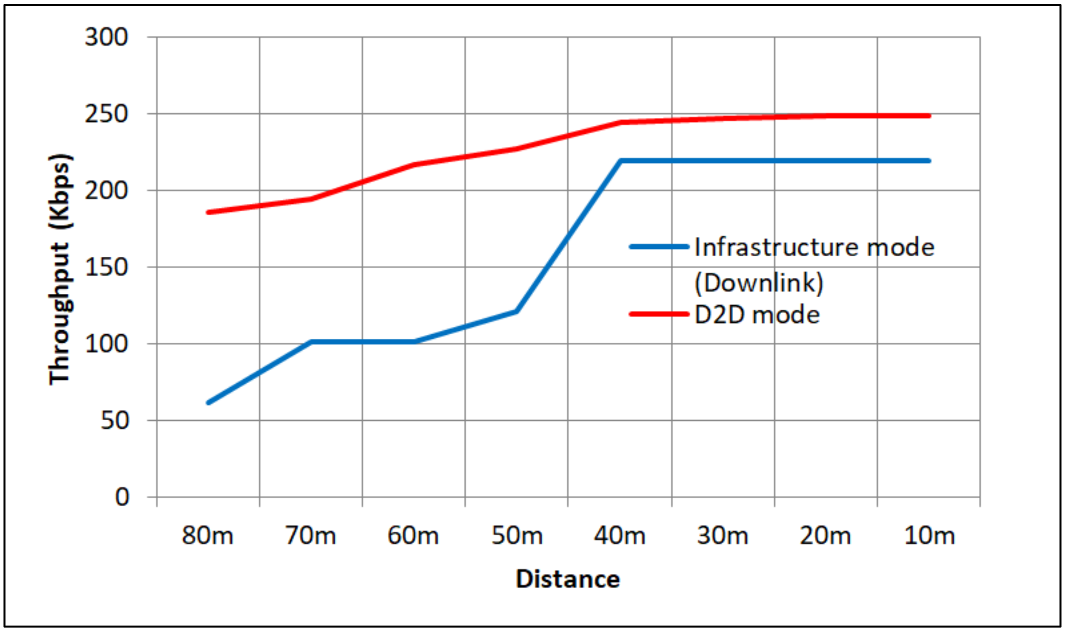


Figure.4.2: Downlink Throughput versus Distance.

According to Figure 4.2, it can be noticed that the downlink throughput in the infrastructure mode is lower than the D2D mode at all distances because it uses two hops, and the data transmitted for a long distance between the TX and RX via the BS, such as at distance 80m, the data transmitted for a double distance 160m. so in Figure 4.2, double the values of distances in case of infrastructure for the axis of distance. While the D2D uses a single hop only, the data transmit a short distance between TX and RX (Direct link), so the D2D mode reduces communication delay and increases network throughput.

As the distance decreases in both infrastructures and D2D mode, it will lead to an increase in throughput because the throughput is dependent on latency, which represents the required period for data to transmit from TX to RX.

Starting with a distance between UEs of 80m and gradually reduced to 10m as a minimum distance, which has a higher DL throughput, minimum delay, and maximum capacity. The results of throughput, bytes received, and delay in D2D mode and infrastructure mode were presented in Table 4.1. For the two modes, the received bytes were calculated and compared together at all distances as tabulated in Table 4.1. Figure 4.3 represents the bytes received against distance.

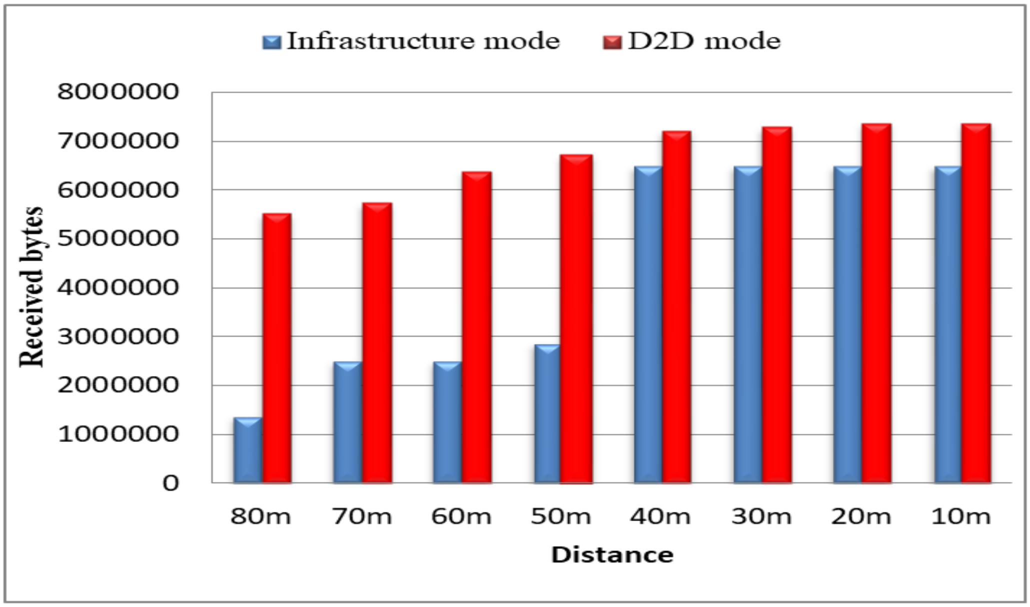


Figure.4.3: Received bytes versus distance.

From Figure 4.3, it can be noticed that the received bytes in D2D mode are higher compared to that in infrastructure mode. This is due to the connection between UEs being a direct link in D2D mode (SideLink) at either uplink or downlink with resource availability, so the gain is increased. Whereas for infrastructure mode, the network used both links (uplink and downlink). By reducing the distance, the received bytes will be higher due to the short distance. So, the D2D mode is better because it increases system capacity by increasing the total throughput of system output and capacity with a minimum distance. The delay is calculated, too, in D2D mode and infrastructure mode at all distances as tabulated in Table 4.1.

Table 4.1: Performance Metrics For D2D Communication

Distance	INFRASTRUCTURE MODE				D2D MODE			
	Throughput UL (kbps)	**Throughput DL (kbps)**	**Bytes received**	**Delay (sec)**	**Throughput UL (kbps)**	**Throughput D2D (kbps)**	**Bytes received**	**Delay (sec)**
80m	4.556108	61.81517	1376200	0.033	0.1041107	186.06085	5518120	0.01273
70m	7.457606	101.20999	2496086	0.014	0.1056335	193.90793	5735736	0.00975
60m	7.457606	101.20999	2496086	0.014	0.1188865	216.53311	6385904	0.00777
50m	8.932514	121.266	2862209	0.0117	0.1154909	226.69677	6697856	0.00684
40m	16.20033	219.37407	6491496	0.004	0.1225683	243.94182	7212952	0.00498
30m	16.20033	219.37407	6491496	0.004	0.12358	246.55542	7283704	0.00426
20m	16.20033	219.37407	6491496	0.004	0.1248712	248.70243	7361960	0.00399
10m	16.20033	219.37407	6491496	0.004	0.1248712	248.70243	7361960	0.00399

Figure 4.4 shows a comparison of delay across direct (D2D) and infrastructure modes.

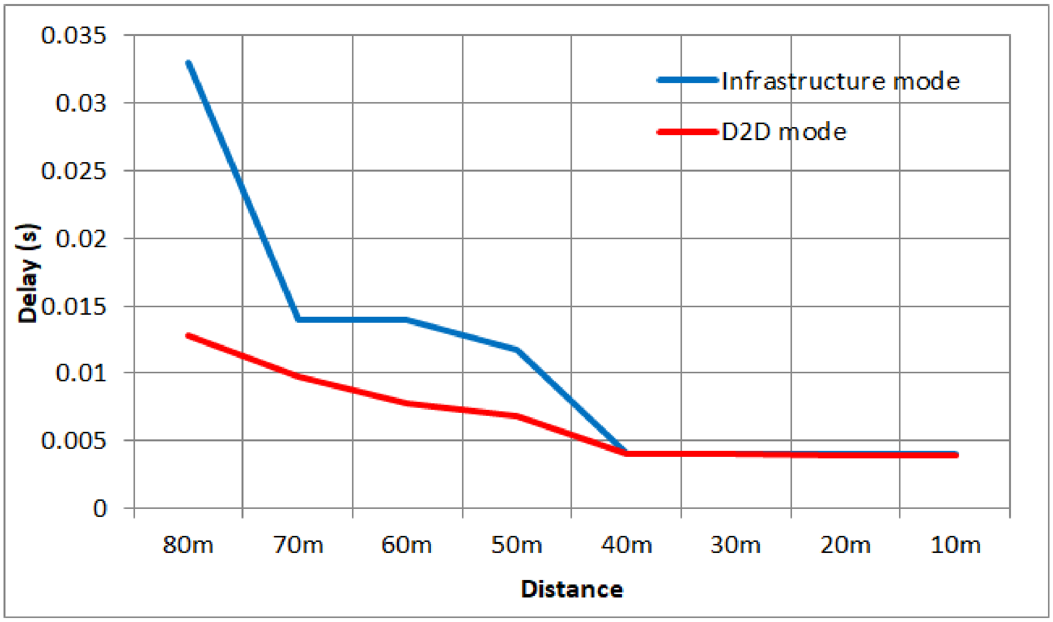


Figure.4.4: Distance versus delay.

As presented in Figure 4.4, it can be noticed that the delay in D2D mode is lower than in infrastructure mode due to the direct link in D2D mode. This is due to data transmission in D2D mode, which is faster between TX and RX than in infrastructure mode due to the shorter distance. As the distance between TX and RX is reduced, the delay in both modes decreases. For a very short distance, the system performs equal delay for both modes. So, D2D mode minimized the delay more than infrastructure mode at distances of more than 40 meters. The model shows that throughput in D2D mode is higher than in infrastructure mode because of the short distance and information transmitted in a single hop (direct link). So D2D mode is better. This model improves spectrum utilization by increasing total system output and capacity with the least amount of distance to enhance the research for proposes a new model exploited the focusing on the shortest distances between D2D with a minimum delay to be used to simulate tracking a possible COVID-19-infected individual. The D2D scheme can be used for a short distance (less than 10 meters).

4.4 Simulation Model for Tracking COVID-19 Infected Persons Using D2D Communication

When a person is COVID-19 infected and the positive result is uploaded to the cloud server to inform the network about the infected persons. The model will simulate tracking the people by using D2D communication with the infected person. The infected UE(Tx) is stationary at points (20,80)m, while the other user UE(RX) is randomly moving at points (60,80)m. In addition, the number of healthy people X[num(UE)] is added, which are moving randomly and random distributions in the cell with a dimension of 100 m x 100 m. The simulation was run multiple times for different X[num(UE)] values. As shown below, num(UE) is taken as 10, 20, 30, and 40.The simulation time is 50s.

- **For X[num(UE)] =10**

The 10 healthy users are distuributed randomly at the begging of simulation as shown in Figure 4.5.

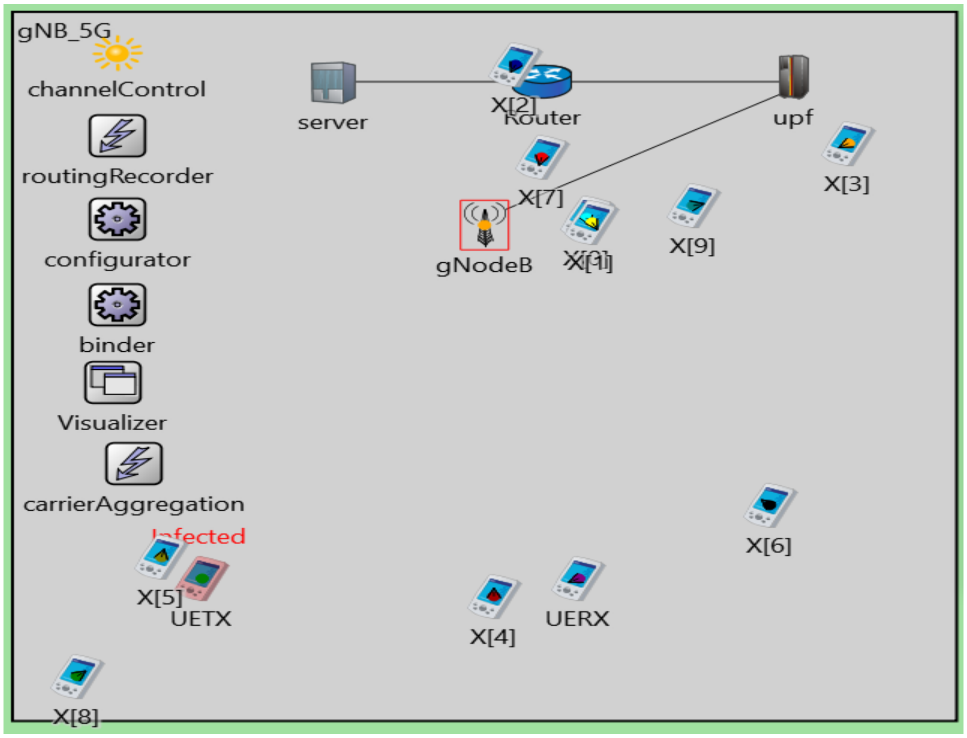


Figure.4.5:The random distribution for 10 of healthy users.

The position of each user can be found in the simulation of OMNeT++ by two ways, the first is from a graphical view of user, or from the details for user.

In the simulation, only one healthy user X[8] close to UETX within the range of 3 m around the position of UETX , the position of X[8] is (19.01,84.1)m as shown in Figures (4.6).

In this case, only X[8] is at risk of becoming infected.

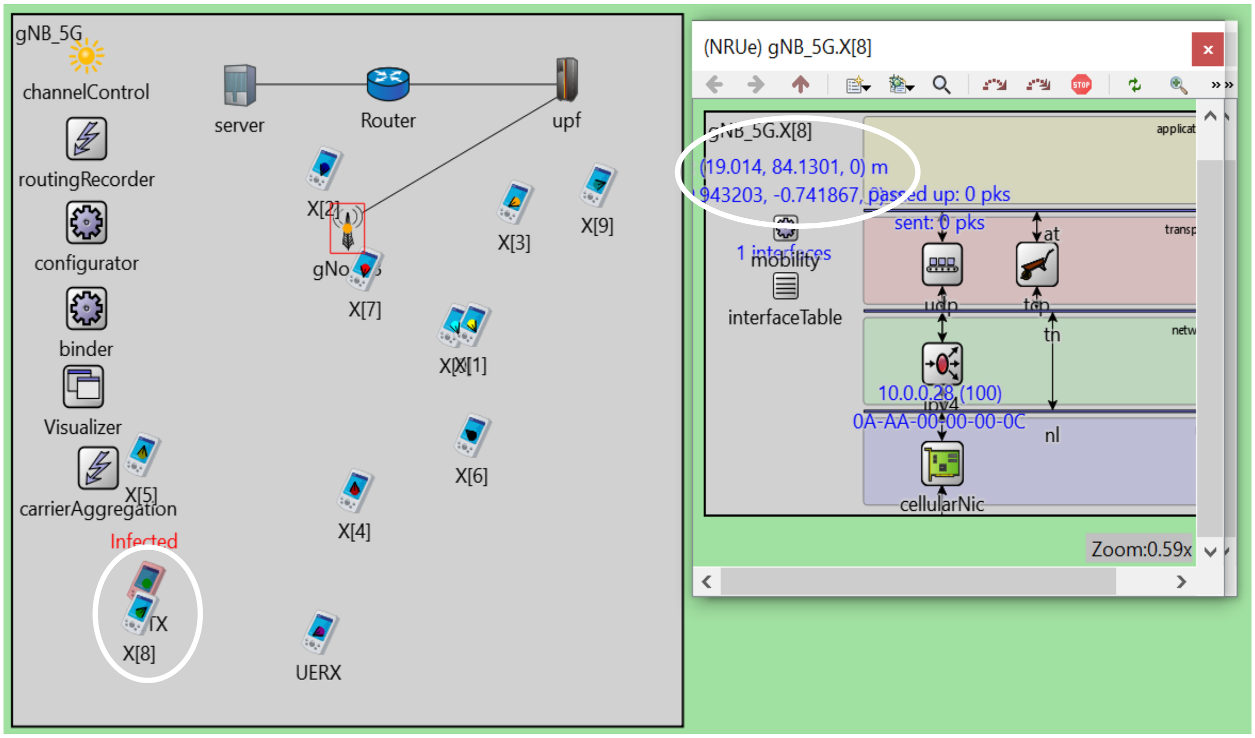


Figure.4.6:X[8] closed to UE(TX).

- **For X[num(UE)] =20**

The healthy people are increased to 20, and they are randomly distributed for the same cell size as shown in Figure 4.7.

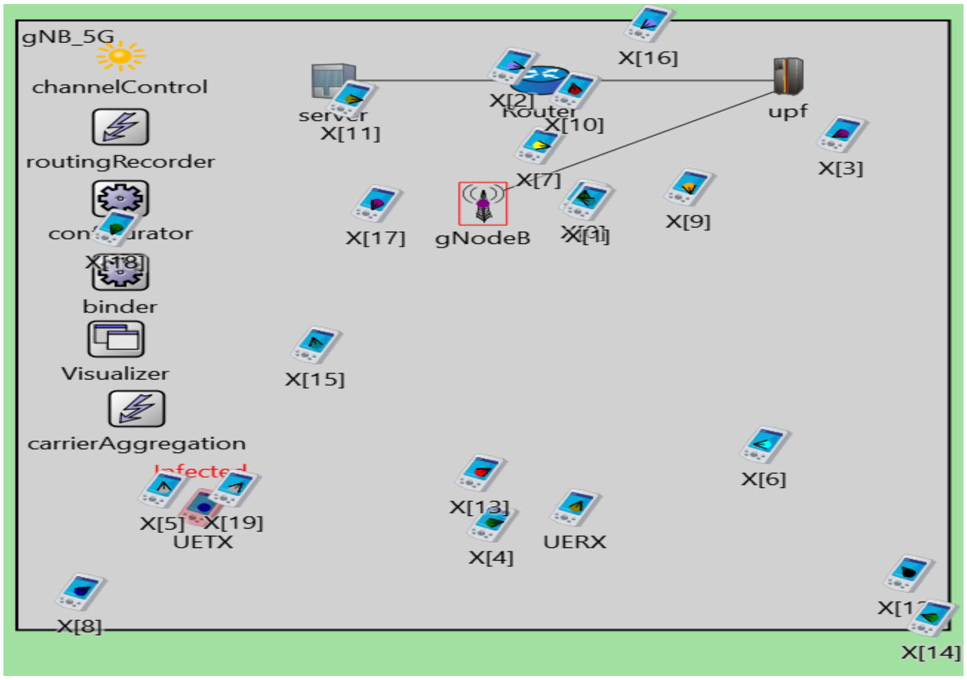


Figure.4.7: The random distribution for 20 of healthy users.

After the simulation begins, the X[8] is close to UETX at position (22.7,82.4)m, as shown in Figure 4.8. As a result, he is at risk of contracting the infection.

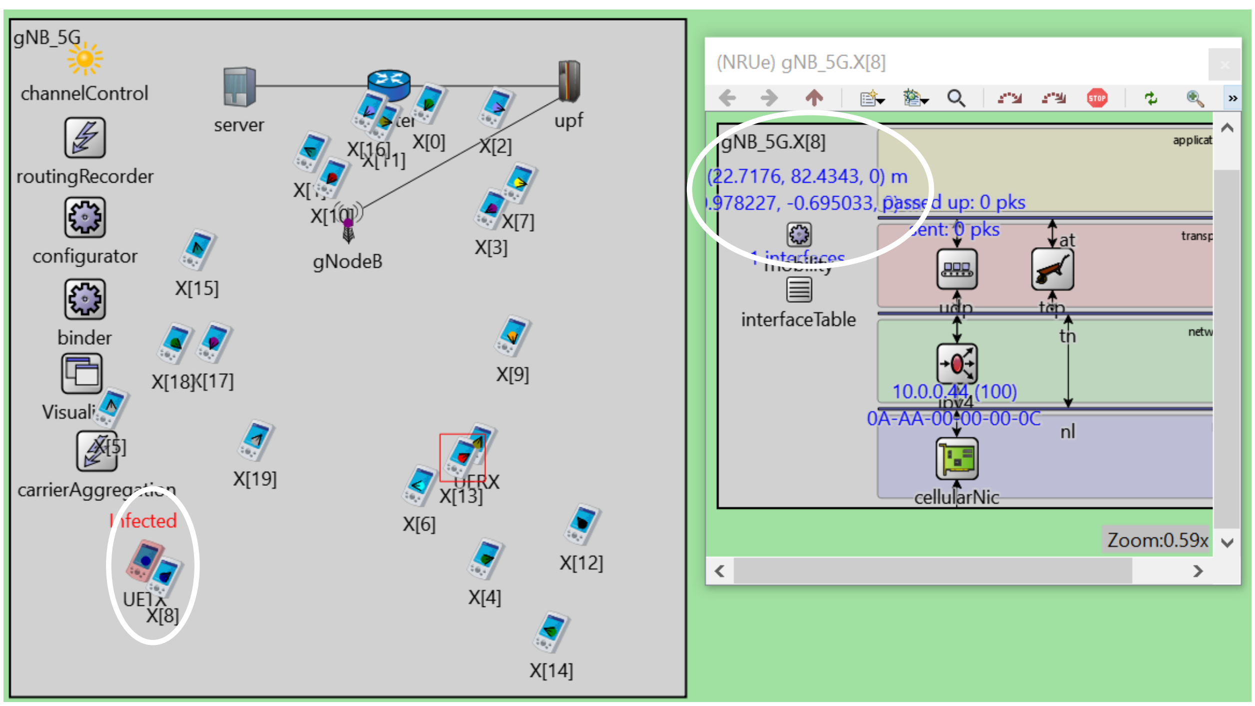


Figure.4.8:X[8] close to UETX.

Following that, X[8] continues his movement, approaching X[6] and X[18] at positions (40.2,68.1)m and (41.9,64.9)m, respectively, as shown in Figures (4.9) and (4.10).

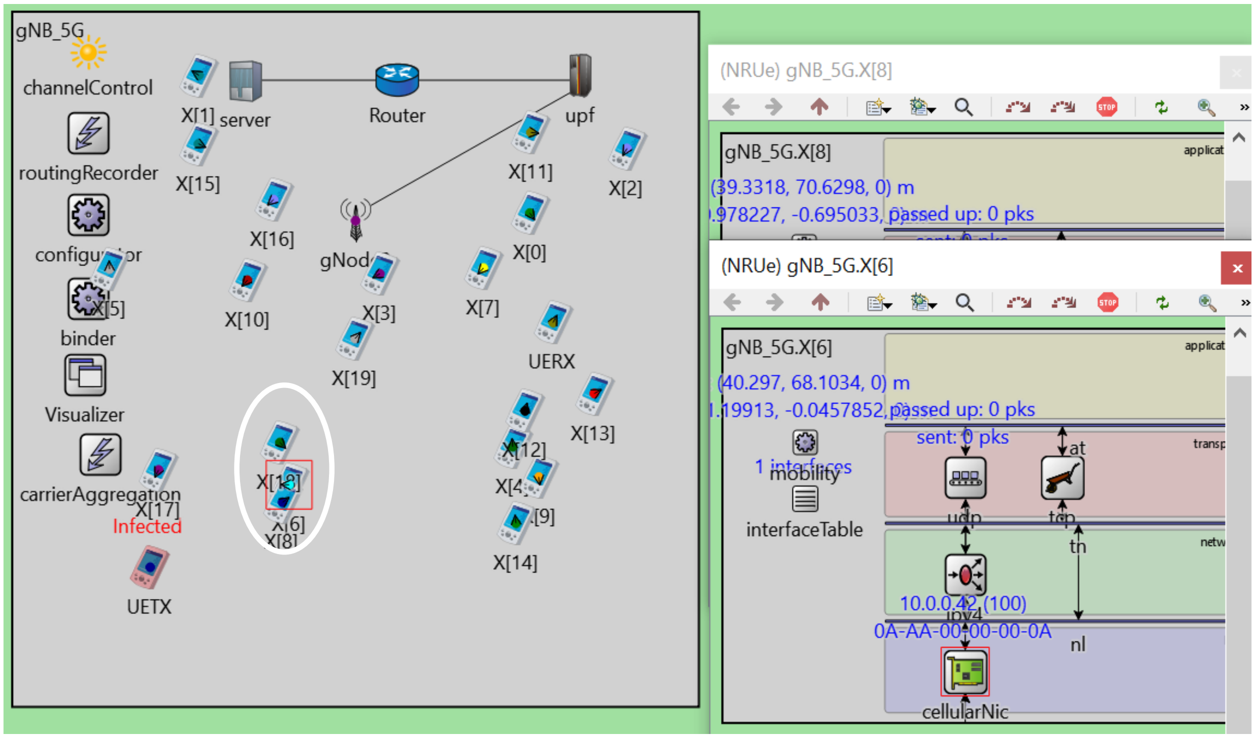


Figure.4.9:X[6] close to X[8].

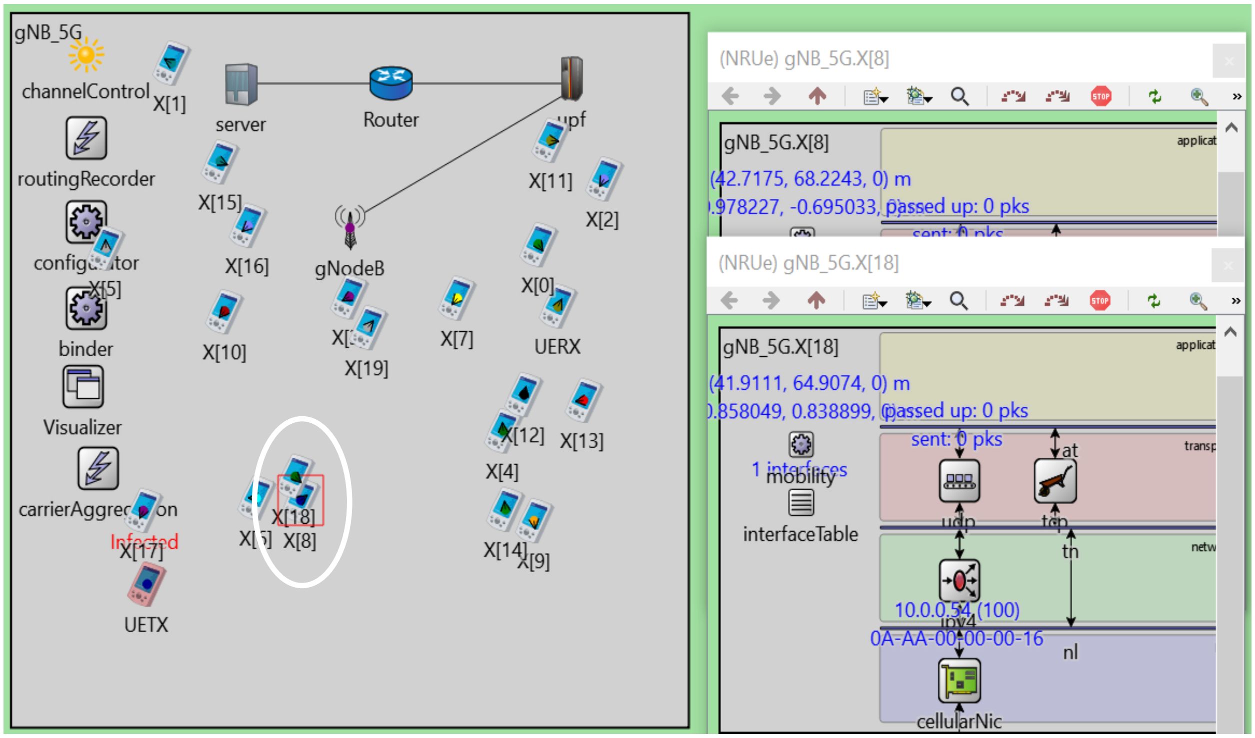


Figure.4.10:X[18] close to X[8].

In this case, three of the healthy users may be infected, particularly X[8], who came within a short distance of an infected person UETX.

- **For X[num(UE)] =30**

The number of healthy users has risen to 30. Due to the density of users in the simulation at the same cell size, it is difficult to track people. Figure 4.11 depicts the random distributions for healthy users.

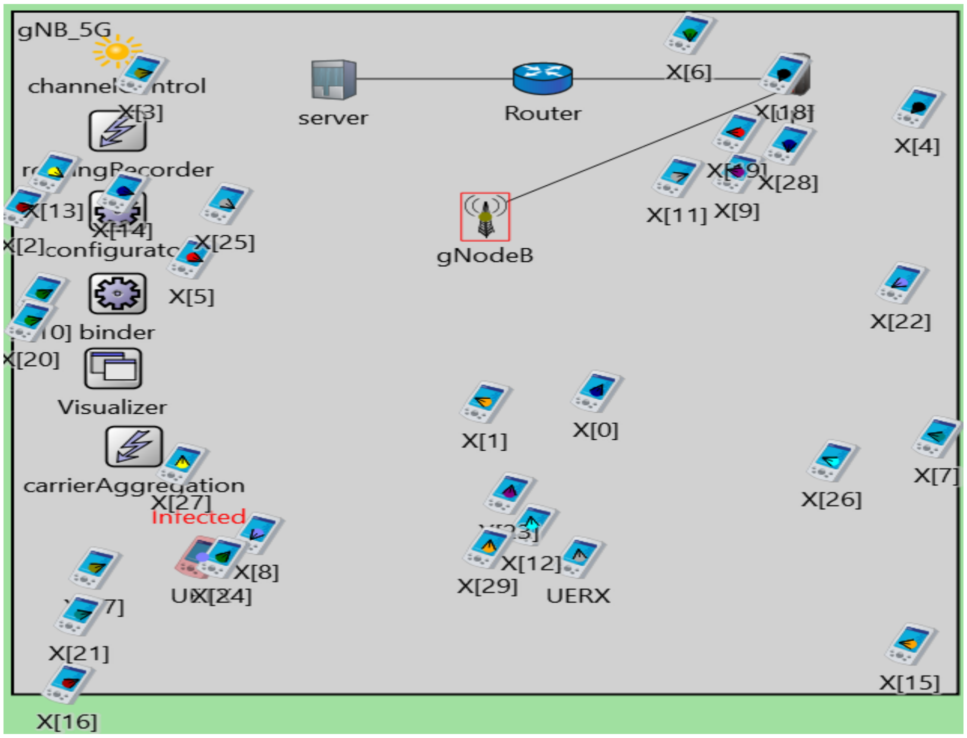


Figure.4.11: The random distribution for 30 of healthy users.

After starting the simulation and tracking the movement of healthy users in case an infected UETX is approached. The X[24] is close to UETX at a site (22,80.1)m as shown in Figure 4.12, so he could have been infected. Also, all X[8] at site (22.2,81.07)m, X[17] at site (18.3,78)m, and X[21] at site (18.8,85)m have approach to UETX and have a possibility to be infected. The X[26] is close to X[24] at site (49.2,51.2)m as shown in Figure 4.13.The X[14] is close to X[26] at site (45.6,47.2)m.

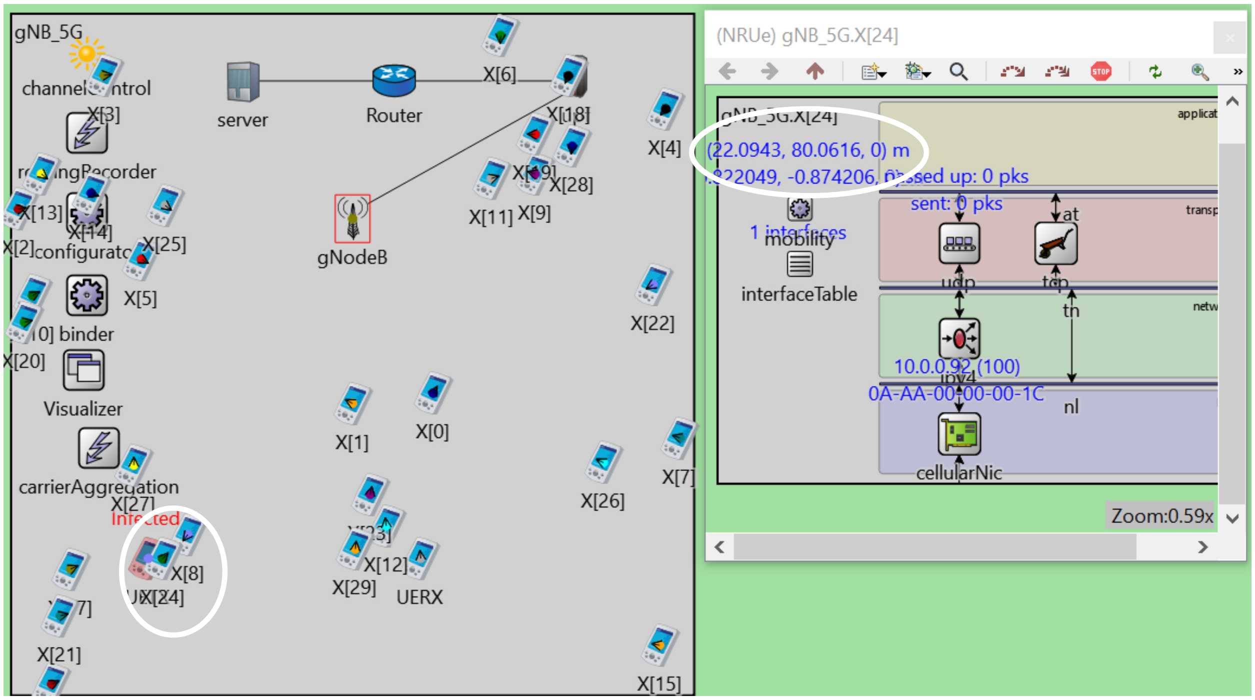


Figure.4.12:X[24] close to UETX.

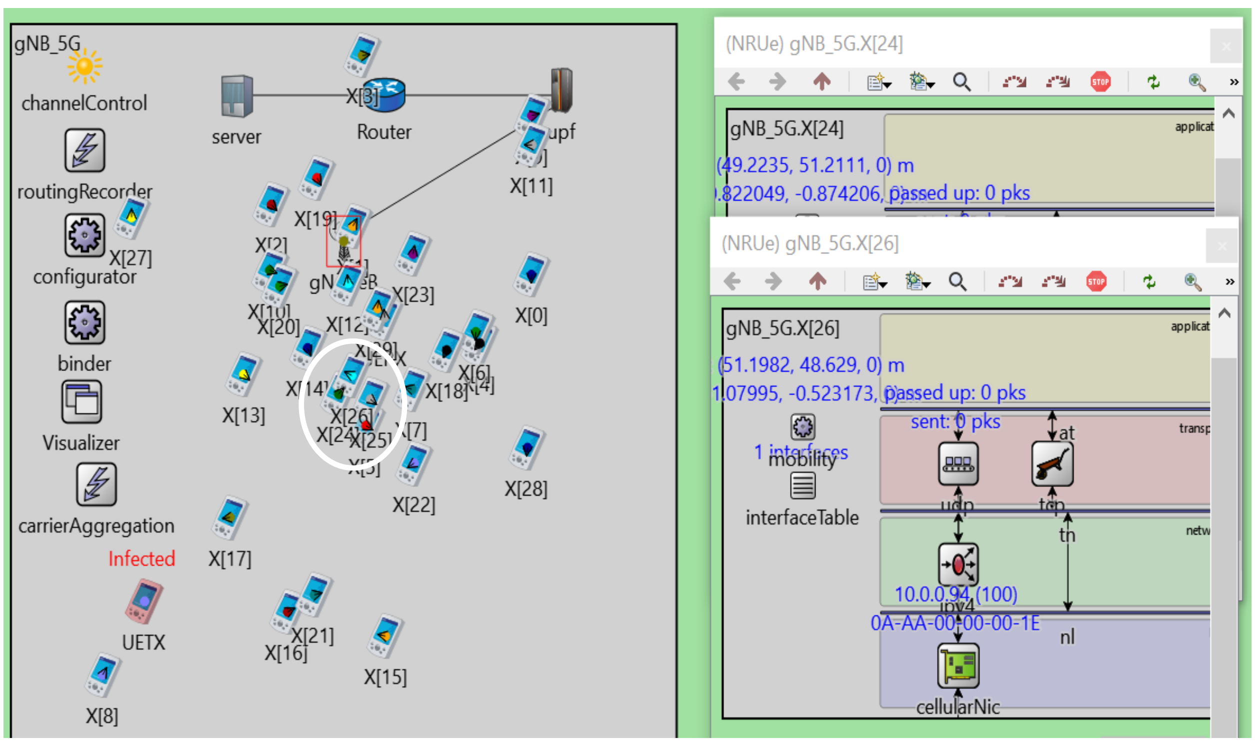


Figure.4.13:X[26] close to X[24].

- **For X[num(UE)] =40**

The number of healthy users has increased to 40, making simulation tracking extremely difficult due to the high density of users in the same cell size. Figure 4.14 depicts the random distributions of healthy users.

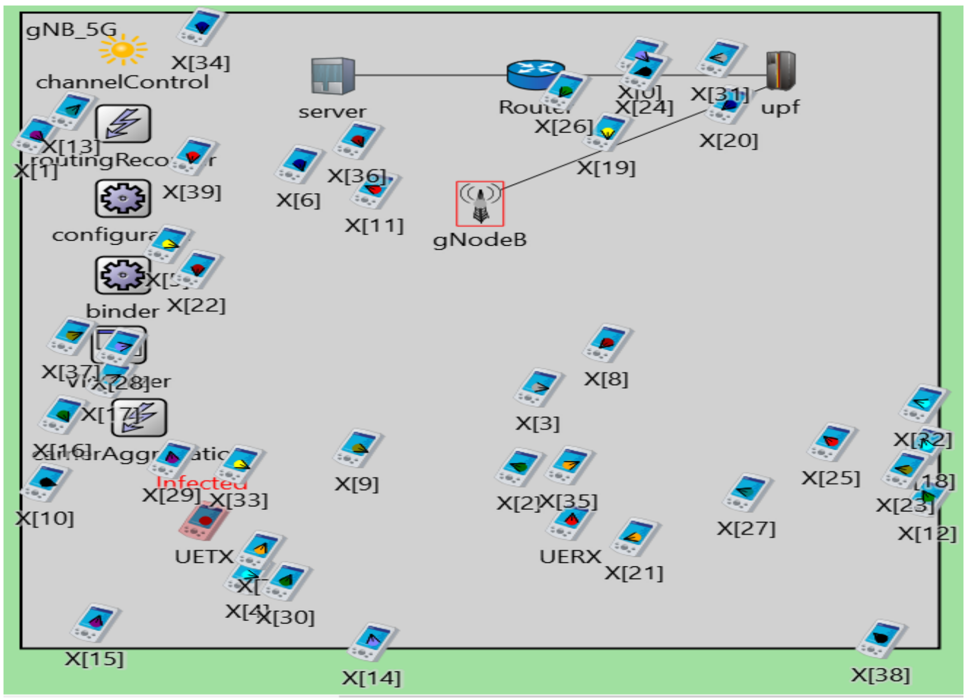


Figure.4.14: The random distribution for 40 of healthy users.

In this case, high number of healthy users have a possibly to be infected due to high density.

Based on the instances mentioned above, we conclude that as the number of healthy users increases, tracking becomes more difficult, and a large number of healthy people may become infected as shown in table 4.2.

- **The UETX is move and X[unm(UE)] equal 30**

In this case, there are 30 healthy users, UETX and X[num(UE)] are moving randomly with random distributions, as shown in Figure 4.15.

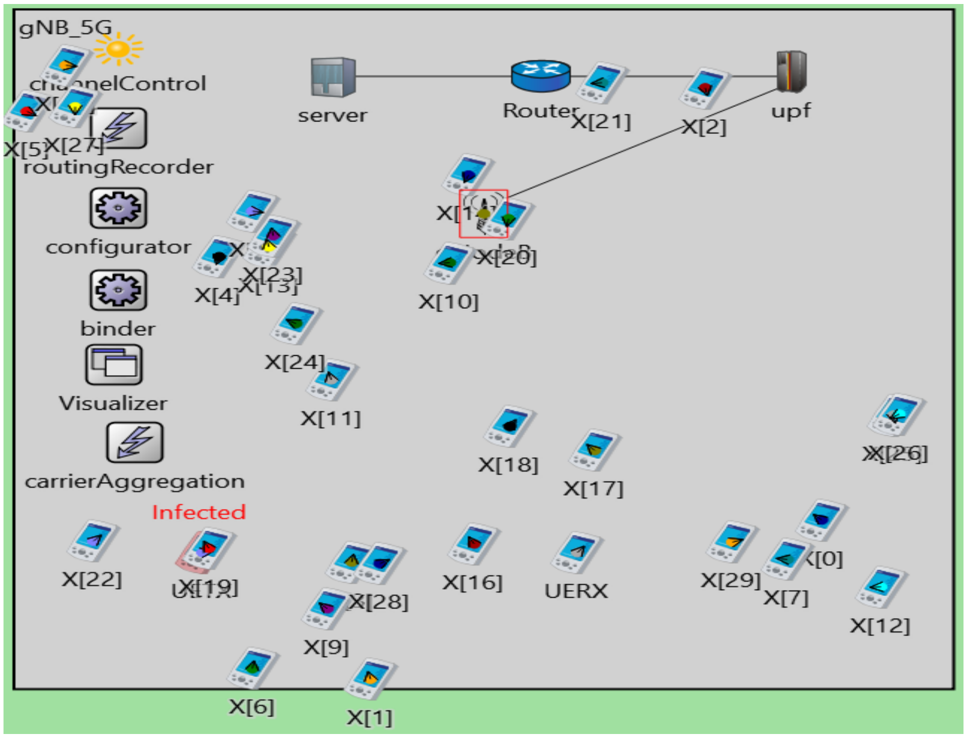


Figure 4.15: The random distribution for UETX and X[num(UE)].

At the beginning of the simulation, the X[19] is close to UETX at site (20.1,78.3)m, after that, The X[9] is close to UETX at site (28,82.9)m, at the same time X[19] at site (17.2,72.6) is close to X[22] at site (14,72.8)m as shown in Figure 4.16. The X[9], X[19], and X[22] have a possible to be infected.

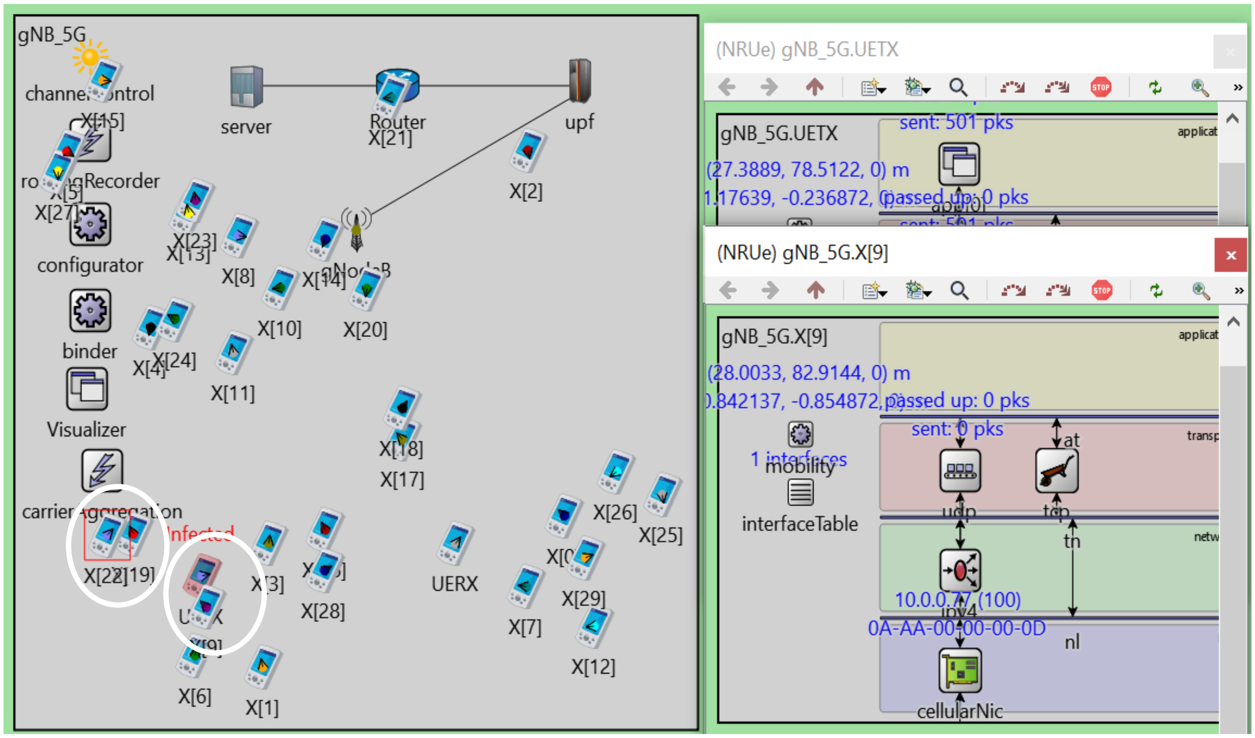


Figure.4.16: X[9] close to UETX, X[22] close to X[19].

After that, X[4] at site (14.6,63.6)m is close to X[9] and have a possible to be infected as shown in Figure 4.17.

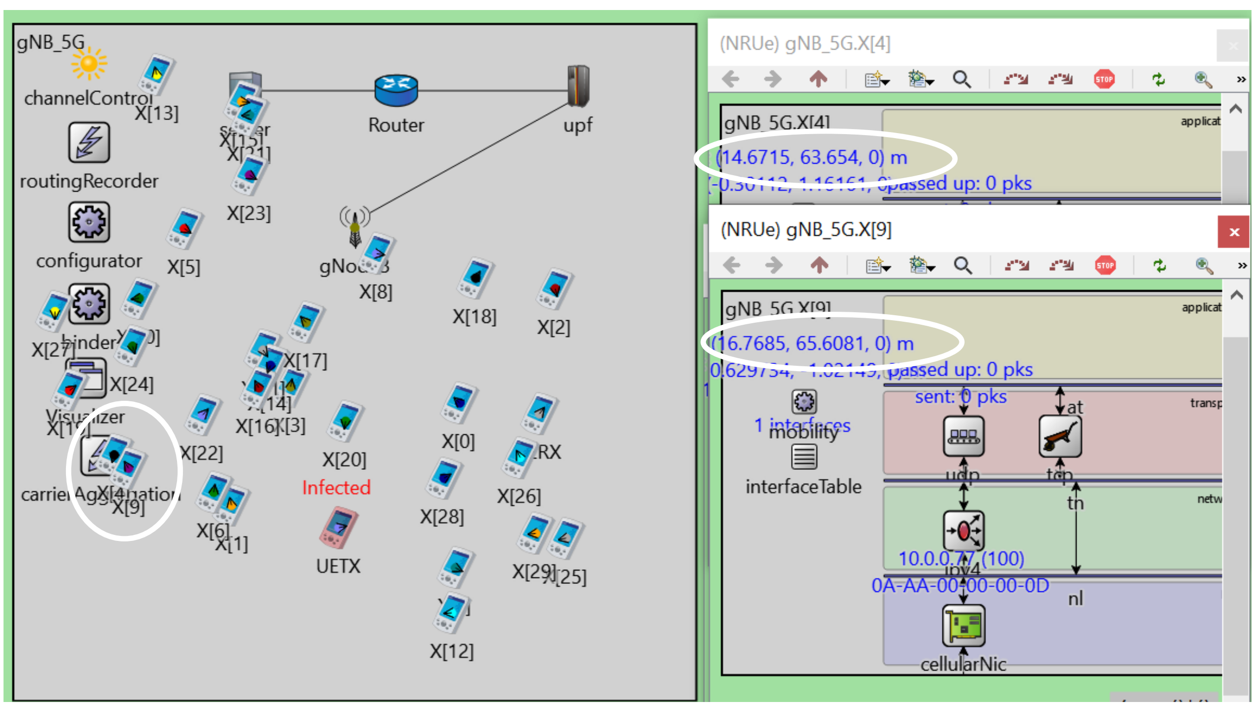


Figure.4.17: X[4] close to X[9].

Constantly moving, the X[5] at site (40.5,40.1)m and X[0] at site (47,38.8) are close to X[22] and have the possibility of infection. As a result for this case, when a person becomes infected and continues to move, the possibility of infecting a large number of healthy people is high, especially if the area is congested.

Table 4.2 shows the number of potentially infected persons in each case.

Number of Healthy Users X[num(UE)]	**Persons Who Could Be Infected**
X[num(UE)]=10	X[8].
X[num(UE)]=20	X[8], X[6], X[18].
X[num(UE)]=30	X[24], X[8], X[17], X[21], X[26], X[14].
X[num(UE)]=40	High number of healthy users have a possibility to be infected.
X[num(UE)]=30, and UETX is move	X[19], X[9], X[22], X[4], X[5], X[0].

As a result, the model simulates tracking healthy people via D2D communication and monitoring if any user is close to an infected person; if he enters a range of 3 meters or less around the infected person, he may be infected. then the server requires him to take a test and be quarantined.

The benefits of D2D communication in this model are the offloading of cellular network congestion, and D2D communication works with very small distances so it is difficult for other technologies to work with these distances.

Chapter Five

Conclusions and Suggestions for Future Works

This chapter summarizes the major points of the work completed during this thesis and proposes some future work.

5.1 Conclusions

The following are the main conclusions that can be depicted from the study:

- Uplink throughput for the D2D mode is close to zero.
- For downlink throughput and bytes received, the D2D mode is higher than the infrastructure mode at all distances
- as at 80m the D2D throughput is equal 186 kbps while the infrastructure downlink throughput is equal to 61.8 kbps when decreases the distance the throughput for both modes are improved, as at 10m the D2D throughput become 248 kbps while infrastructure mode become 219 kbps.
- For delay, D2D mode performs better than infrastructure mode, the delay in both modes decreases to 0.004s at 10m.
- D2D mode increases throughput, capacity, and minimize the delay.
- A model is proposed to simulate tracking infected people with COVID-19 using D2D communication, to track the movement of people when approaching an infected person, at a distance of 3 meters or less.
- Based on the simulation results for the five cases taken, The model can track the movement of users and know the position of each user, and know who healthy users have a risk to be infected.
- As the number of healthy users grows, tracking becomes more difficult, and a large number of healthy users may have been infected.

5.2 Future works

A future release may include the following features:

- Support multi-cells and multiple D2D pairs for mode selection and added the relay mode addition to D2D mode and infrastructure mode which depend on the ratio of the SINR threshold.
- Some packets are lost due to mode selection. Resolving packet loss issues in mode selection and packet size's effect on D2D communication performance are the open issues in D2D communication.
- The proposed model required people's data, such as location and health condition/data. These data, if not secured properly, can be vulnerable to cyber-attacks and expose users to criminal activity, financial loss, and privacy invasions. It is essential to create privacy-preserving and cyber-security solutions to guarantee that users' private information is used and secured properly.
- Developing the proposed model's idea into a mobile application supported by the government and large telecom companies, and adding many features to the application, where mobile phone users can install the official app on their smartphones.

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الخلاصة

من جهاز إلى جهاز (D2D) هي تقنية ذكية واعدة في شبكة الجيل الخامس تواجه العديد من التحديات مثل اختيار الوضع واكتشاف الجهاز.

تحدد هذه الرسالة نموذجين لاتصالات D2D تم تنفيذهما باستخدام برنامج ++ OMNeT ومحاكي Simu5G. الأول هو نموذج اتصال D2D ذو قفزة واحدة يتم تقديمه وحساب بعض العوامل مثل الانتاجية والزمن والبايتات المستلمة في الشبكة الخلوية وأسلوب D2D على مسافات مختلفة. تظهر النتائج أن معدل النقل في وضع D2D أعلى منه في وضع الشبكة الخلوية في جميع المسافات ، بينما يكون الزمن أقل. يبلغ معدل نقل البيانات للوصلة الهابطة في وضع الشبكة الخلوية 61.8 كيلوبت في الثانية مع زمن قدره 0.033 ثانية على مسافة 80 مترًا ، بينما يبلغ معدل نقل البيانات في وضع D2D 186 كيلوبت في الثانية مع زمن يبلغ 0.012 ثانية. عندما يتم تقليل المسافة بين الأجهزة إلى 10 أمتار ، يعمل كلا الوضعين على زيادة معدل نقل البيانات للوصلة الهابطة مع تقليل الزمن: وضع الشبكة الخلوية هو 219 كيلوبت في الثانية مع زمن يساوي 0.004 ثانية ووضع D2D 248.7 كيلوبت في الثانية مع زمن يساوي 0.003 ثانية. مما يشير إلى أن وضع D2D أفضل. يعمل هذا النموذج على زيادة إنتاجية وقدرة النظام الإجمالية ، مع الحد الأدنى من المسافة.

اقترح النموذج الثاني محاكاة لتتبع الأشخاص المصابين باستخدام اتصال D2D لاكتشاف الأجهزة القريبة. تم النظر في خمس حالات مختلفة لعدد المستخدمين السليمين [X[num(UE. يصور النموذج عدد الأشخاص المحتمل إصابتهم بالإضافة إلى موقعهم. يوضح النموذج أنه مع زيادة عدد المستخدمين السليمين [X[num(UE ، يصبح التتبع أكثر صعوبة ، ويزداد احتمال إصابة عدد اكبر من المستخدمين السليمين [X[num(UE. في الحالة الأولى ، نلاحظ إمكانية إصابة شخص واحد فقط. في الحالة الثانية إمكانية إصابة ثلاثة أشخاص. ايضا إمكانية إصابة عدد كبير من المستخدمين السليمين كما في الحالتين الثالثة والرابعة. في حالة كان الشخص المصاب يتحرك ، كما في الحالة الأخيرة ، فإن احتمال إصابة عدد كبير من الأشخاص السليمين مرتفعة.

إقرار لجنة المناقشة

نشهد بأننا أعضاء لجنة التقويم والمناقشة قد اطلعنا على هذه الرسالة الموسومة **(التحقيق في تقنية من جهاز إلى جهاز الذكية في نظام الجيل الخامس)** وناقشنا الطالبة **(مريم قصي عبدالقادر)** في محتوياتها وفيما له علاقة بها بتاريخ / /2023 وقد وجدناها جديرة بنيل شهادة الماجستير/علوم في اختصاص هندسة الاتصالات.

التوقيع:

رئيس اللجنة: أ.م.د. محمد حازم الجماس

التاريخ: / /2023

التوقيع:

عضو اللجنة: أ.م.د. زياد خلف فرج

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عضو اللجنة: أ.م.د. ضياء محمد علي

التاريخ: / /2023

التوقيع:

عضو اللجنة (المشرف): أ.م.د علي عثمان الجنابي

التاريخ: / /2023

اجتمع مجلس كلية هندسة الالكترونيات بجلسته المنعقدة بتاريخ: / / 2023
وقرر المجلس منح الطالبة شهادة الماجستير علوم في اختصاص هندسة الاتصالات

مقرر المجلس: أ.م. د. ضياء محمد علي

التاريخ: / / 2023

رئيس مجلس الكلية: أ.د. خالد خليل محمد

التاريخ: / /2023

إقرار المشرف

أشهد بأن هذه الرسالة الموسومة **(التحقيق في تقنية من جهاز إلى جهاز الذكية في نظام الجيل الخامس)** والمعدة من قبل الطالب **(مريم قصي عبدالقادر)** تحت اشرافنا في قسم هندسة الاتصالات / كلية هندسة الالكترونيات / جامعة نينوى، وهي جزء من متطلبات نيل شهادة الماجستير/علوم في اختصاص هندسة الاتصالات.

التوقيع:

الاسم: أ.م. د. علي عثمان الجنابي

التاريخ: / /2023

إقرار المقوم اللغوي

اشهد بأنه قد تمت مراجعة هذه الرسالة من الناحية اللغوية وتصحيح ما ورد فيها من أخطاء لغوية وتعبيرية وبذلك أصبحت الرسالة مؤهلة للمناقشة بقدر تعلق الأمر بسلامة الأسلوب أو صحة التعبير.

التوقيع:

الاسم: م.د. لطيف احمد محمد

التاريخ: / /2023

إقرار رئيس لجنة الدراسات العليا

بناءً على التوصيات المقدمة من قبل المشرف والمقوم اللغوي أرشح هذه الرسالة للمناقشة.

التوقيع:

الاسم: أ.م.د. محمود احمد محمود

التاريخ: / /2023

إقرار رئيس القسم

بناءً على التوصيات المقدمة من قبل المشرف والمقوم اللغوي ورئيس لجنة الدراسات العليا أرشح هذه الرسالة للمناقشة.

التوقيع:

الاسم: أ.م.د. محمود احمد محمود

التاريخ: / /2023

التحقيق في تقنية من جهاز إلى جهاز الذكية في نظام الجيل الخامس

رسالة تقدمت بها

مريم قصي عبدالقادر

إلى

مجلس كلية هندسة الالكترونيات

جامعة نينوى

كجزءِ من متطلبات نيل شهادة الماجستير

في

هندسة الاتصالات

بإشراف

أ.م.د. علي عثمان الجنابي

1444 هـ　　　　　　　　　　　　　　2023م

جامعة نينوى

كلية هندسة الالكترونيات

قسم هندسة الاتصالات

التحقيق في تقنية من جهاز إلى جهاز الذكية في نظام الجيل الخامس

مريم قصي عبدالقادر

رسالة ماجستير علوم في هندسة الاتصالات

باشراف

أ.م.د. علي عثمان الجنابي

1444 هـ   2023 م