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Assessing a 5G Network's Performance by Modeling and Simulating D2D Multicast Network Communications

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ABSTRACT

Communication between devices (device-to-device(D2D)) in 5G technology allows for direct connections between adjacent devices without the use of a base station. This establishes communication between devices with optimal energy usage and more skillful management of network loads during peak periods. D2D communication in 5G solves the problem of disaster management and emergencies by creating an ad-hoc network in infrastructure places affected by disasters, enabling emergency responders to communicate with one another. The paper aims to achieve smart cities that permit users to exchange large files, such as pictures and videos, between devices in high-risk regions directly to communicate and send their location and distress signals without the need for network infrastructure. This paper contributes to providing wireless networks in rural and remote regions where local devices can connect and share resources, expanding coverage outside the conventional base station's range. The outcomes of the simulations in all scenarios show the possibility of achieving coverage and good Channel Quality Indicator (CQI) if the distance between user equipment (UEs) does not exceed 70 m, and the distance between the base station (ENB) and user equipment (UEs) does not exceed 250 m.

1. INTRODUCTION

Cellular network device-to-device (D2D) data offloading is an effective way to reduce base station congestion, lower energy consumption related to content transmission, and boost spectrum efficiency, to support an increased number of smart devices and a range of applications that 4G is unable to handle [1, 2]. It is anticipated that 5G technology would comprise a vast array of interconnected devices, as sensors, machines, smartphones, and vehicles [3]. Direct links are used to connect D2D users, avoiding the need for an intermediary transfer through a base station [4]. The evolved Node Base stations (eNB) can oversee D2D transmissions in a network-controlled method, where scheduling and resource distribution are still under the control of the eNB but disconnects the data transfer between them [5]. Consequently, by relieving eNBs of excessive relaying, both end user data rates and overall system capacity are improved by D2D communication [6]. The SimuLTE framework and INET in the simulator OMNeT++ are the platforms where the simulation will be run for mode switching and the resource allocation mechanism [7]. Certain D2D communications will be managed by Node Base Stations (eNB), extending cellphone communication beyond its coverage area [8]. Simu5G can be utilized by an application developer by creating an application model with the necessary level of abstraction, then integrating it into Simu5G for performance assessment in non-real time [9]. Multiaccess Edge Computing (MEC) is a communication application in 5G networks that operates as a network emulator [10]. Consequently, the best trade-offs can be achieved between system efficiency and reliability [11]. The central controller attempts to offload the growing intra-cell D2D multicast flows that rely on the User Equipment themselves. This is achieved through resource allocation and routing strategy [12].

D2D communication is employed to avoid problems such as an excessive load of traffic on the source, reduced throughput of multicast, and increased overall transmission duration from the source. This is achieved by allowing the receiver channel to resend the multicast data that was received in the base station via D2D links [13]. A D2D multicast system is proposed, where UE contents are periodically delivered through D2D multicast. Performance for multicast can be improved when guaranteed delay constraints are satisfied [14]. The benefit of D2D communication is its ability to work as relays for each other in a multi-hop sequence, thereby increasing the coverage area [15]. Three modes of operation are intended for the 5G network's D2D communication architecture. They can be classified as in-band (in-coverage), out-band (out-of-coverage), and D2D relay communication [16]. D2D and cellular users sharing the same radio spectrum resource can cause interference in D2D systems. Therefore, optimal resource allocation schemes have been implemented to increase system throughput and the number of D2D users' connections [17]. D2D communications are utilized in emergency services, V2V communication, and IoT [18].

The rest of this paper is organized as follows: Section 2 will provide a Literature Review. Section 3 will give an Overview of the modeling of transmissions between devices and present a description of the LTE Layer 2 functions. Section 4 will detail the Simulation Setup. Section 5 will illustrate the System Model. Section 6 will present the Multicast D2D Network Evaluation and focus on Network Simulation Setup, Simulation Scenarios. Finally, Section 7 will offer the Conclusion.

2. LITERATURE REVIEWER

Nardini et al. [19] displayed the possibility of using SimuLTE to simulate D2D communications within OMNeT++. They provided advice on setting up the simulation parameters to evaluate how different factors affect D2D systems. Virdis et al. [20] described the modeling of D2D integration into the system-level simulator SimuLTE. They evaluated how well D2D communications with frequency reuse function. The results showed a decrease in throughput from 40 to 37 kb/s when the number of D2D flows increased to 100. The interference led to a slight decrease in throughput, with a bound of less than 10%. Additionally, the CQI is effective for close ranges between D2D (less than 30 meters) but becomes unadvisable for distances of 100-120 meters. Virdis et al. [21] described SimuLTE's architecture based on the OMNeT++ simulator, focusing especially on the MAC layer modeling decisions and various models for allocating resources. They concluded that the result of cell throughput is 2250 kbps when the distance from eNB to UEs is 500 m. The cell throughput decreases to 250 kbps as the distance increases to 2000 m. Gupta et al. [22] proposed a new method for locating vehicles and a D2D architecture based on LTE clusters to achieve a high packet delivery ratio using an OMNeT++ simulation model. The simulation results led them to conclude that the proposed approach enhanced the data packet delivery ratio (DPDR) by 10% when increasing the number of clusters from 1 to 8, while also reducing the overall end-to-end delay. Bastos et al. [23] presented an algorithm called NAR (Network Assisted Routing) to expand base station coverage. The results demonstrated an improvement with a 35% increase in energy savings. They assessed the Channel Quality Indicator (CQI) versus the distance between D2D. When the distance is less than 80 meters, it refers to high channel quality.

Kar [24] evaluated D2D communication performance using the OMNeT++ simulator within the SimuLTE framework for both static and mobile devices. The results confirmed an increased throughput for D2D communication at short distances, once the distance exceeds a certain threshold, a relay must be used. The throughput decreased in the direct path for D2D communication without a relay, from 256 to 139 kbps when the distance increased from 20 to 100 meters. They achieved better throughput when using a relay in D2D communication at distances ranging from 40 to 90 meters. Yusuf et al. [25] conducted a preliminary study on resource allocation using packet scheduling through the Best Fit algorithm to address the issue of interference when sharing transmission within the same spectrum among cellular users in D2D. The performance evaluation was carried out in three distinct contexts: varying distances between D2D pairs, different distances between D2D and eNB, and multiple D2D users in the same cell environment. The results indicated that the channel quality starts to deteriorate when there is a distance of 35 meters between two D2D users, and the highest average throughput performance was achieved when the distance from D2D to eNB was less than 200 meters.

Yang et al. [26] suggested fixes for issues with traditional mobile device connectivity and algorithms of blockchain consensus. They proposed a D2D communication consensus algorithm and an SBC (Selective Blockchain) system that takes environmental factors into account. They confirmed the data transfer confidentiality of IoT devices, reducing the chance of being overheard, and calculated the security capability by utilizing the mobile devices' resources to register membership in the blockchain. The results indicated that the secrecy capacity increased from 0 to 1 when the received signal strength indicator (RSSI) increased from 1 to 5 dBm. Ioannou et al. [27] proposed using the intelligent approach Belief-Desire-Intention (BDI) with expanded abilities (BDIx) to manage each D2D node independently and autonomously, without the assistance of the base station. They suggested using the DAIS algorithm to apply BDI agents in simulations for decision-making regarding D2D transmission modes, increasing data rates, and decreasing power consumption to solve all D2D challenges. They concluded that when increasing the number of devices from 0 to 1000 with a step of 100, the total power needed increased to 90,000 mW, while the spectral efficiency increased to 20,000 pbs/Hz. Ali et al. [28] highlighted how crucial it is to set up prototyping testbeds for D2D communication in a lab in Pakistan. They used hardware platforms known as Universal Software Radio Peripheral (USRP), LabVIEW Communication, and devices such as RTL-SDR and USRP RIO SDR. They successfully achieved single hop D2D communication without using the Base Station (BS) or other infrastructure, which was then analyzed by OMNeT++ simulation. The received signal strength sharply decreased from -81 dBm to -102 dBm, while the Signal-to-Noise Ratio (SNR) decreased from 21 dB to 4 dB with increasing distance to 10 m in an indoor environment. Yusuf and Mohamad [7] faced challenges while allocating resources in D2D communications, as mobile users share the spectrum with them, causing interference. They proposed an algorithm called Fair and Fit Resource Allocation (FFRA) to select the communication path. They concluded that D2D has high-quality channels (CQI) if the distance between D2D UEs is less than 30 meters. The D2D link began to drop when the distance between D2D UEs is 40 to 100 meters. Farota et al. [29] designed an architecture that included users, a base station (gNodeB), a MEC server, an access network, a central network, and a gateway (UPF) to establish a connection to the Radio Access Network (RAN) of the core network in the simulation program OMNeT. The base station's function is to manage signaling and interference, while the MEC server is positioned near the base station instead of in the cloud to store and supply data to the devices. The results showed that data transfer proceeded smoothly between the MEC server, the antennas, and the end devices with good reliability and low latency.

This paper contributes by presenting a thorough overview of multicast D2D communication in 5G networks, focusing on important performance metrics such as: Performance Assessment, Understanding the CQI, Improved Throughput at MAC and RLC Layers, Analyzing SNR in D2D Multicast, and introducing important applications such as emergency communication, streaming videos in real -time, and synchronization of IoT devices.

3. OVERVIEW OF THE MODELING OF TRANSMISSIONS BETWEEN DEVICES

D2D communication allows for direct communication between two UEs when they are in close proximity to each other without routing their traffic through the CN and BS. This results in quicker communication using a single hop called side link (SL) instead of two (UL leg to the BS and DL leg to the receiving UE). In a D2D network, data is transmitted via SL using resources within the UL spectrum, which is typically less congested and less susceptible to interference than the DL. The BS manages interference and controls resource allocation in this scenario [30].

3.1 LTE Layers

The LTE's Layer 2 functions are classified into the following categories: Physical layer, Medium Access Control (MAC), Radio Link Control (RLC), and Packet Data Convergence Protocol (PDCP) [31].

1- Physical Layer: Once the upper layers have processed data, it is transferred to the physical layer. The physical layer processes radio frequency data such as modulation, demodulation, error detection using techniques like Adaptive Modulation and Coding (AMC), and CQI computation, and then forwards the report to higher layers. The UE and eNodeB physical layer parameters are modeled to assign physical channels such as transmitted power, cable loss, carrier frequency, antenna gain, noise figure, and measure the interference and path loss to provide a realistic simulation of LTE [32].

2- Media Access Control (MAC) Layer: The MAC layer provides connectivity between the RLC's logical channels and the transport channels at the physical layer. The functions of the MAC layer in LTE include multiplexing and de-multiplexing, implementing error correction mechanisms using Hybrid Automatic Repeat Request (HARQ) through a combination of error detection and repair methods with automatic retransmissions, logic channel prioritization, and control. The MAC layer is designed to work with both UE and eNB.

MAC layer parameters are implemented for performance modeling, such as HARQ error rate, throughput delay, MAC packet loss, and buffer overflow [32]. Resource scheduling is handled by the MAC layer at the eNB rather than by UEs [5].

3- Radio Link Control (RLC) layer: RLC is used for the traffic between eNB and UE. RLC provides three reliability modes of operation: transport mode, Unacknowledged mode, and Acknowledged mode [32]. The responsibilities of the RLC layer include: exchanging Protocol Data Units (PDUs) across the upper layer, using ARQ) for error correction, reassembling, separating, and consolidating RLC Service Data Units (SDUs) [33].

4- Packet Data Convergence Protocol (PDCP): The PDCP layer in the LTE stack is positioned beneath the IP (client plane) layer and above the RLC layer. There are pressures that influence the PDCP layer's capacity due to the top layer of the IP piles stack, which is why it is called the Packet Data Convergence Protocol. The functions of the PDCP layer in LTE include supporting security features, confirming and verifying integrity and coding, offering characteristics in defense functions that vary over time, and enhancing radio efficiency in delivery. The PDCP layer on the UE side rearranges PDUs coming from the RLC layer of LTE/RLC before directing traffic to higher levels [31, 32].

4. SIMULATION SETUP

OMNeT++ is a framework for object simulation. It is modular, expandable, and based on a C++ library. Additionally, OMNeT++ offers a GUI library for animation, as well as support for tracing and debugging. The INET framework can be regarded as standard protocol model library for OMNeT++, providing a broad set of Internet protocol models in its package that is maintained by the OMNeT++ team [33]. OMNeT++ can be used for modelling wired and wireless networks, sensors, photonics, and simple or compound modules. It facilitates communication network modeling, including network nodes and communication protocols. Internet stack templates such as UDP, TCP, IPv4, IPv6, IEEE 802.11, OSPF, etc., can be found in INET, and it supports the creation of unique mobility models and Architecture for QoS. Simu5G can simulate LTE/LTE-A, 5G New Radio, and core networks in OMNeT++. It is possible to simulate 5G communications in time division duplexing (TDD) and frequency division duplexing (FDD) modes with heterogeneous gNB, through the X2 interface to support the transfer and coordination of intercellular interference. Additionally, dual connectivity between a gNB (5G NR Base Station) and an eNB (LTE Base Station), as well as D2D communications, are accessible [29].

Simu5G was used to create a simulation model for OMNeT++ version 5.6.2 that makes use of the INET framework 4.2.2. Table 1 contains a list of important simulation parameter settings [34].

Figure 1 Displays a screenshot of the Graphical Users Interface in OMNeT++ network simulations. This display shows how eNB communicate with routers and how many UEs are located near each other.

Table 1. Simulation parameters

Parameter	Value
Transmitted power	20 mw
Alpha (Path loss coefficient)	2
Carrier frequency	2GHz
Number of radio channels	1
Propagation model	Free space model
ENB Transmitted antenna gain	5
UE Receiver antenna gain	5
UE noise figure	5
Cable loss	2
Fading type	JAKES

packet size	1024 bytes
Traffic type	Best-effort data for D2D, Group content delivery for multicast
Traffic generation model	Constant Bit Rate (CBR)
Communication pattern	One-to-one (D2D), One-to-many (multicast)

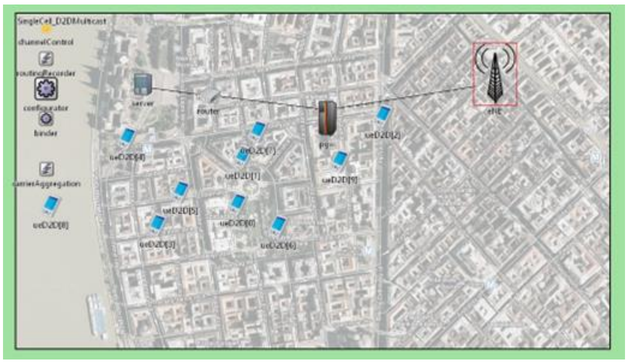

Figure 1. A screen capture shows the GUI window in OMNeT++ network

5. SYSTEM MODEL

Simu 5G presents UE and eNB models to simulate multicast D2D communication on a mobile network. Different parameters are used to evaluate various scenarios. A uniform CQI can be employed for every D2D communication. To allow UEs to communicate in D2D, they have to be recognized as eNBs and UEs with D2D capability, as well as must set up the receiver as a potential D2D pair for the sender. Multicast messages are produced at the application layer in the node and transmitted in the direction of a multicast IP address. Consequently, only UEs that have subscribed to the addressed IP multicast group are able to receive them. Every UE is a part of the group with an address 224.0.0.10. In multicast D2D communications, only fixed mode configuration is possible for CQI (establishing the usage of pre-set TX parameters values). The communication's transmission range is impacted by the selection of CQI. The signal can be received at greater distances with reduced CQIs at the expense of consuming more resources, which requires more RBs to send a message. This impacts the dissemination's performance regarding latency and resource consumption. A resource block (RB) is defined as twelve consecutive subcarriers in the frequency domain [31].

The difference between system models in D2D and multicast communication is presented in Figures 2 and 3. D2D and cellular communication are shown in Figure 2, including D2D relay. A heterogeneous cellular system has been presented in Figure 3, in which a single eNB uses multiple UEs to cover a specific area.

5.1 Network architecture

The LTE model consists of a group of User Equipment (UEs) within the coverage area connected to a single evolved Node B (eNB). In the mobile device cellular network, the D2D multicast network faces a significant challenge in determining how radio resources will be allocated when UEs belong to different cells. Therefore, suggesting a discovery signal scheduling architecture is necessary. The designed architecture includes UEs, eNB, and Cloud or Core Network (CN), as explained in Figure 4.

The multicast and D2D communication architectural layers in 5G consist of Multicast Layers that include the Physical Layer, Data Link Layer, and Network Layer, as well as D2D Layers that include Direct Communication, Proximity Services, and Resource Management. The layers of D2D and multicast architectures are visually separated in the following chart in Figure 5.

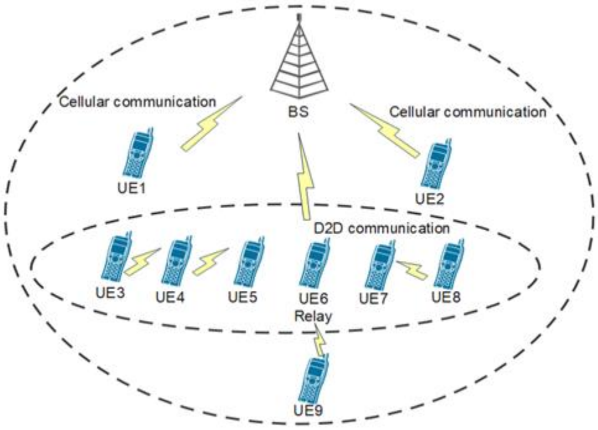

Figure 2. Displays D2D and cellular communication, along with D2D relay [35]

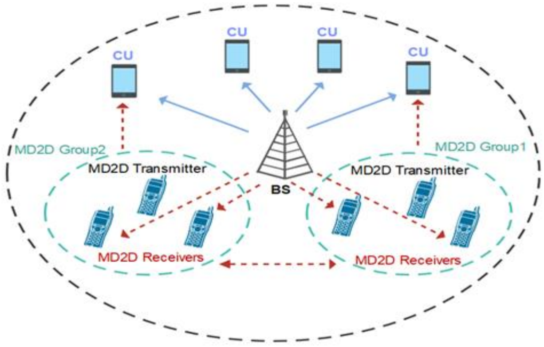

Figure 3. Multicast communication depicts a heterogeneous cellular system where a single eNB employs several UEs to cover a given area [36, 37]

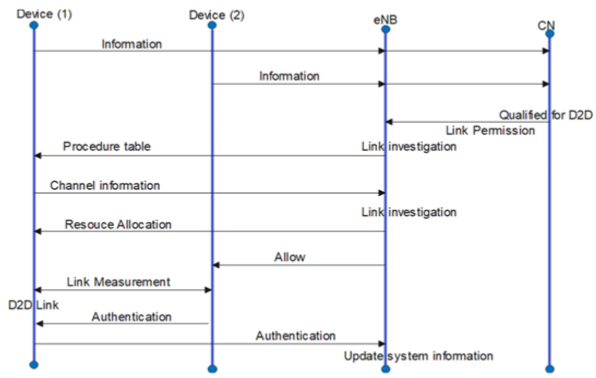

Figure 4. Multi-cell device discovery, the designed architecture consists of UEs, eNB, and Cloud or Core Network (CN) [38]

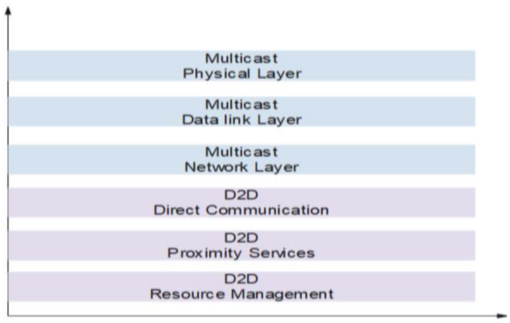

Figure 5. Layers' Architecture of multicast and D2D in 5G network

The D2D and multicast communication architecture in 5G networks is represented as follows:

• Multicast Architecture: In 5G networks, multicast communication is designed to efficiently distribute the same content to multiple consumers simultaneously. Key components include those shown in Figure 6:

- The User Equipment (UE1 and UE2) that receives multicast data.
- Radio Access Network (RAN) responsible for multicast transmission.
- MBSC (Multicast-Broadcast Service Center) managing multicast sessions.
- 5GC: 5GC (5G Core Network) routing and managing multicast traffic.

• D2D Architecture: D2D communication allows direct communication between devices, reducing latency and improving efficiency. This is essential for applications like IoT and public safety.

- UE3 and UE4: User Equipment involved in D2D communication.
- eNB: Developed Node B supporting D2D operation.
- D2D Controller: managing D2D link resource allocation.
- 5GC: 5G Core Network integrating D2D communication.

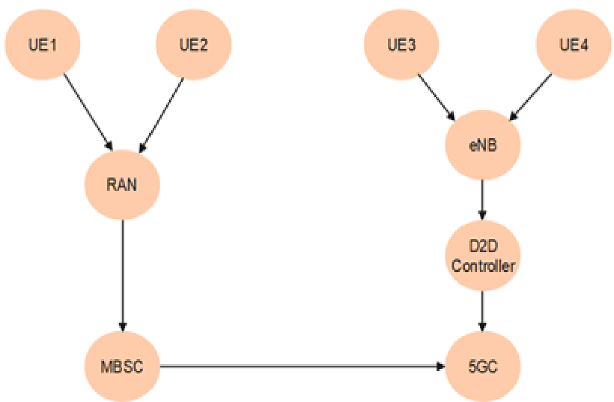

Figure 6. The device-to-device (D2D) and multicast communication architecture

5.2 Algorithm for the minimum discovery distance between multicast D2D devices

The algorithm for determining the minimum distance discovery between multicast D2D devices serves as the basis for the selection process. The optimal D2D pair is chosen by selecting the pair that is closest to each other, provided that the pair meets the minimum SINR threshold. The following algorithm for determining the minimal distance between multicast D2D devices as shown.

Algorithm. D2D Discovery and Adaptive Optimized Multicast

1. Start
2. Initialize system's specifications parameter
   - Noise power, ENB transmit power.
   - User density, Bandwidth.
   - Weighting factors F1, F2, F3.
   - Initial distance thresholds D^{TH}_{D2D}, D^{TH}_{ENB}
3. For each UE_X in the network
4. For each neighboring UE_y
5. Compute distance d_{xy} using Eq. (6)
6. Estimate metrics for link quality:
   - SNR_{xy}
   - CQI_{xy}
   - Interference I_x
7. Calculate pair selection score (UE pair selection that is optimized with a scoring function):

   $$Score_{xy} = (F1 \cdot SNR_{xy} + F2 \cdot CQI_{xy}) / d_{xy} - F3\ I_{xy}$$
8. End For
9. Select optimal UE pair selected for D2D communication (x^{*}, y^{*}) with maximum Score
10. Apply heuristic optimization (Heuristic optimization at low computational costs):

    Update the D2D distance threshold greedily when $d \le D_{D2D}$:

    D^{opti}_{D2D} =arg max Th(d)

    where Th(d) is the estimated throughput
11. If $d_{x^{*}y^{*}} \le D^{opti}_{D2D}$
12. Enable D2D communication
13. Calculate optimized throughput and CQI
14. Else
15. Preserve UE–ENB connection
16. Adaptive multicast decision (Distance thresholds that are adaptive rather than set):
17. Calculate optimized ENB–UE distance:

    D_{ENB}^{opti} =arg $\max_D$ T multicast (D)

    Where: D denotes the candidate distance between the eNB and UEs, T multicast(D): represents the average multicast throughput measured at distance D, D_{ENB}^{opti}: is the optimal eNB–UE distance that maximizes the multicast throughput, arg $\max_{D:}$ Give me the value of D that maximizes throughput.
18. If d_{ENB}, $x^{*} \le D_{ENB}^{opti}$
19. Turn on multicast transmission.
20. Compute average CQI and SNR
21. Else
22. Preserve unicast transmission
23. For number of UEs N= 0 : 5 : 30
24. Implement heuristic resource allocation
25. Calculate system throughput
26. End For
27. End

The flowchart in Figure 7 illustrates the steps of multicast D2D distance discovery:

D2D connectivity is initiated by the eNB, which then starts to determine the distance between equipment according to Eq. (6). If the distance is less than or equal to 70 m, then it identifies an active pair and computes throughput, CQI, and measures SNR. Otherwise, the UEs stay connected to the eNB and proceed to the next step. If the distance between the eNB and UEs is less than or equal to 250 m, it identifies an active pair and computes the average CQI, measures SNR. Otherwise, the UEs stay connected to the eNB and proceed to the next step. In the case where the number of user equipment is less than 60, increase the number of user equipment by 10 and compute throughput [38, 39].

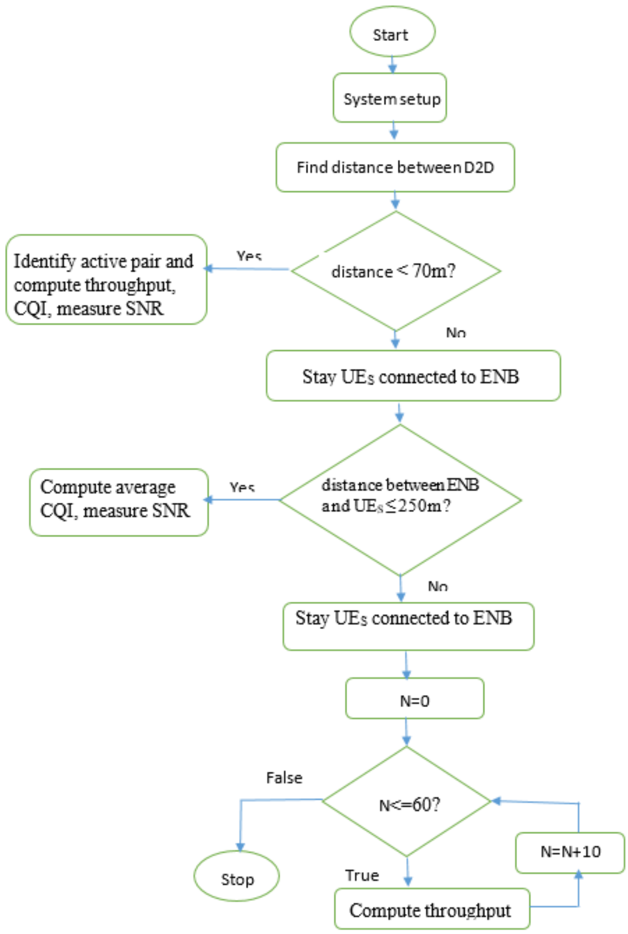

Figure 7. Flowchart explain the steps of multicast D2D distance discovery

5.3 Model equations

In the D2D discovery system model, model equations are used. When a device is successfully detected by D2D communication, UEs can immediately communicate with each other. Let S represent the incoming signal's power, I represent the power interference from other signals in the network, and N represent the noise. The SINR metric (ɣ) of the D2D discovery system model can be computed by applying the formula in Eq. (1) [39]:

$$ɣ = \frac{S}{I+N} \qquad (1)$$

Assume that S is the signal power between two User Equipment. The symbol for transmitting power is PT, the symbols for transmitter and receiver antenna gains are GT and GR, respectively. The symbol for path loss is PL, and the symbol for the distance between these two User Equipment is d, where hi represents the fading coefficient. It is possible to determine the incoming signal power S using Eq. (2) [39]:

$$S = GT\ GR\ PT\ PL(d)^{-1}\ |hi|^{2} \qquad (2)$$

The formula needed to determine interference between two User Equipment, denoted as i and j, is given by Eq. (3) [40].

$$I = \sum_{K=1,k\neq i,j}^{K} GT\ GR\ PT\ PL(d)^{-1}\ h_k^2 \qquad (3)$$

The symbol (I) referring to the interference between the two User Equipment transmitters and the receiver. The computation of the SINR metric involves Additive White Gaussian Noise as the noise factor.

The path loss model includes the Log-Normal Shading model, and constant propagation loss in Eq. (4) [40]:

$$PL(d)\ =\ PL(d0)\ +\ 10nlog\ (d/do)\ +\ X\sigma \qquad (4)$$

In which the random shadowing effect is depicted by $X\sigma$, the symbol d0 represents the reference distance, and the exponent of route loss is n.

The path loss at the reference distance (d0), or PL(d0), is given by Eq. (5) [39]:

$$PL(d0)\ =\ 22.7\ +\ 26log(fc) \qquad (5)$$

where, fc refers to the transmission frequency.

Importance was given to accounting for the distances for each D2D. Within the coordinate plane, the Euclidean distance relation is utilized as follows in order to calculate the distance between two nodes in Eq. (6) [39]:

$$d\ =\ \sqrt{((xT - xR)^2 + (yT - yR)^2)} \qquad (6)$$

where, the UE transmitter and receiver locations are indicated by (XT, XR) and (YT, YR), respectively.

5.4 JAKES fading (channel vanishing) implementation

Small-scale Rayleigh fading brought on by multipath propagation and user mobility is modeled using JAKES fading in wireless communication systems is the JAKES model. Because of this, it can be used to assess D2D and cellular connectivity in practical wireless scenarios.

A sum-of-sinusoids method is used to calculate the channel coefficient, and the carrier frequency and UE speed determine the Doppler frequency. When the instantaneous channel gain becomes close to zero during deep fade occurrences, channel vanishing happens naturally [40].

5.4.1 Model of channel vanishing

The model for the baseband-equivalent fading coefficient is as follows:

$$h(t) = h1(t) + j\ h_Q(t) \qquad (7)$$

where,

- h1(t) and $h_Q(t)$ are processes of independent zero-mean Gaussian
- the envelope ∣h(t)∣ follows a Rayleigh distribution
- The phase is evenly distributed over [0,2π]

At specific time intervals, this fading coefficient increases the transmitted signal, resulting in channel disappearing (deep fades).

5.4.2 Mobility and the Doppler effect

The following Eq. (8) the greatest Doppler frequency [41]:

$$f_D = (v/c)\ fc \tag{8}$$

where,

c: speed of light

v: UE speed (m/s)

fc = carrier frequency

In order to simulate realistic UE movement, the Doppler frequency regulates the pace of channel variation.

5.4.3 JAKES spectrum generation

A sum-of-sinusoids method is used to create the fading process, in which the Doppler power spectral density is approximated by a number of oscillators with random phases as shown in Eq. (9) [42]:

$$h(t) = \sum_{n=1}^{Ns} an\ cos(2\pi fnt + \phi n) \tag{9}$$

where,

- Ns: number of sinusoids
- $f_n = f_D \cos(\theta_n)$
- θ_n: uniformly distributed angles
- ϕ_n: random phases

The JAKES model's classical U-shaped Doppler spectrum is generated using this formulation.

5.4.4 Implementation of channel vanishing in simulation

- Use the JAKES model to generate the fading coefficient h(t) at each transmission interval.
- Apply fading to the signal that is transmitted as shown in Eq. (10) [43]:

$$r(t) = h(t).s(t) + n(t) \tag{10}$$

- Deep fades ($|h(t)| \approx 0$) generate channel vanishing occurrences organically.

This procedure is used for:

- eNB–UE connections (cellular)
- UE-UE connections (D2D multicast)

5.4.5 Effect on performance measures

The following are directly impacted by JAKES fading:

• SNR (by instantaneous channel gain)

• CQI (mapping based on SNR)

• Throughput (via coding and adaptive modulation)

JAKES fading is therefore included to guarantee that D2D multicast performance increases are assessed under realistic, time-varying channel conditions rather than ideal static channels.

6. MULTICAST D2D NETWORK EVALUATION

In this section, simulation results and performance analysis have been presented to assess the D2D multicast network performance and verify the suggested schemes.

6.1 Network simulation setup

OMNET++ software has been used to simulate a network with dimensions of 1000x500 meters. The network consists of one eNB and a number of UEs. The eNB is connected to the core internet network through a router. The UEs in the simulated network are distributed within a 500-meter radius single cell, where the distribution of CUs and D2D multicast groups is uniform and random. The implementation of the D2D network depends on a combination of complex and simple modules equipped with input and output gates through which messages are transmitted. The Simu 5G model uses algorithms to facilitate communications for the D2D network.

6.2 Simulation scenarios

We employed using a single cell in the simulation with a radius of *R*. The eNB is located in the center, and UEs are uniformly dispersed at a specific density inside the cell.

The first scenario consists of a network size of (1000 × 500) m, with 10 UEs distributed positioned close to one another, and one eNB located far from the edge of the UEs cell at varying distances between 100 to 1000 m in steps of 100 m. Different distances of the eNB to the edge of the UEs cell were considered. UEs receive data, including all terminals inside the multicast group, via D2D connections in worst channel conditions.

The second scenario: consists of a network size of (1000 × 500) m, varying the number of UEs from 10 to 60 in steps of 10, distributed positioned close to one another, and one eNB located far from the edge of the UEs cell at a fixed distance of 150 m. An increase in throughput can be observed with an increase in the number of UEs. UEs can exchange data either through the eNB in infrastructure mode or directly through a D2D connection.

The third scenario: consists of a network size of (1000 × 500) m, with a fixed number of 10 UEs distributed at varying distances to one another from 10 m to 90 m in steps of 10 inside the cell, and one eNB located far from the edge of the UEs cell at a fixed distance of 50 m. The eNodeB's downlink signal quality deteriorates at the cell edge, resulting in poor connectivity between the cell-edge UE and the eNB. In such circumstances, UEs and eNBs with robust downlink and uplink connectivity can act as a "Relay" to forward the downlink and uplink signals in parallel in D2D mode from/to the eNB to/from the cell-edge UE. This technique enables the cell-edge UE to communicate with the eNB through the Relay UE at a higher data rate than when communicating directly with the eNB.

6.3 Analysis of simulation results

This section presents a number of simulation results that we used to evaluate the effectiveness of our proposed scheme. We have utilized OMNET++ software to show the power spectrum of the received signal. Various distances between the eNB and UEs were tested to measure signal strength and evaluate the CQI, as shown in Figure 8.

As shown in Figure 9, the Signal-to-Noise Ratio (SNR) sharply decreases as the distance between the eNB and UEs increases from 100 to 1000 m.

The MAC Cell throughput and RLC Cell throughput in multicast scenarios in 5G technologies are measurements that indicate the data transfer rates of the Medium Access Control (MAC) layer and the Radio Link Control (RLC) layer, respectively. These metrics are influenced by various factors, including user equipment capabilities, channel conditions, and network configuration.

Figure 10 shows the MAC Cell Throughput (DL), which represents the data rate at which multiple UEs are correctly receiving data from the MAC layer in the downlink, based on the number of UEs, with a fixed distance of 150 m between the eNB and UEs.

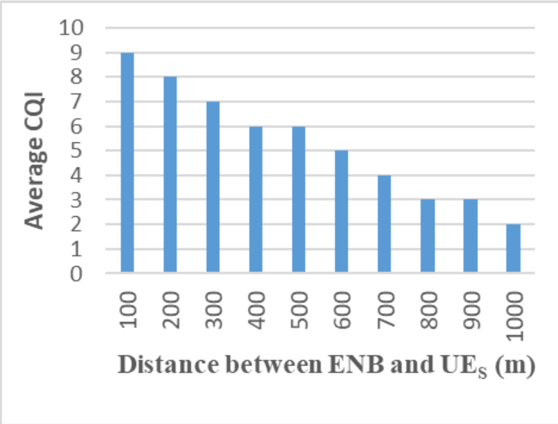

Figure 8. Display CQI vs. various distances between the eNB and UEs

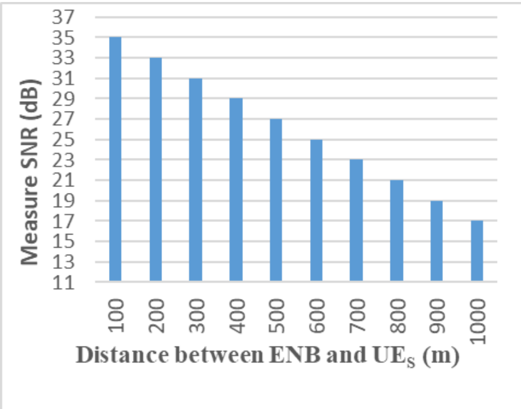

Figure 9. Display measure SNR vs. various distances between the eNB and UEs

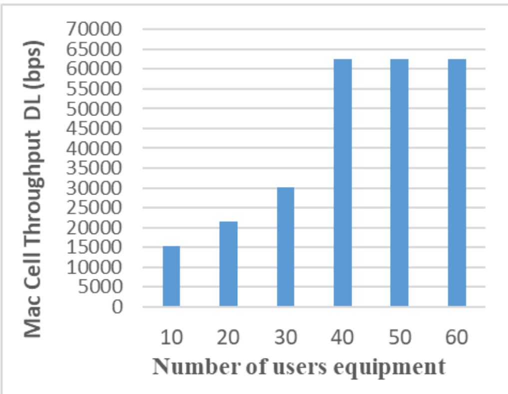

Figure 10. Display Mac Cell Throughput DL vs. number of UEs

Figure 11 refers to RLC Cell Throughput (DL), which represents the data rate at which the MAC layer is properly receiving data from the RLC layer for downlink transmission versus the number of UEs when the distance between the eNB and UEs is fixed at 150 m.

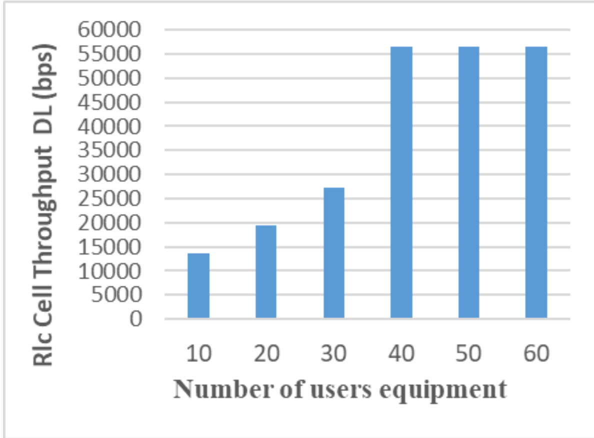

Figure 11. Display RLC Cell Throughput DL vs. number of UEs

Figures 12, 13, 14, and 15 illustrate average CQI, measured SNR, MAC Cell Throughput DL, and RLC Cell Throughput DL when the distance between the eNB and UEs is fixed at 50m, the number of UEs is fixed at 10, and different distances between UEs inside the cell.

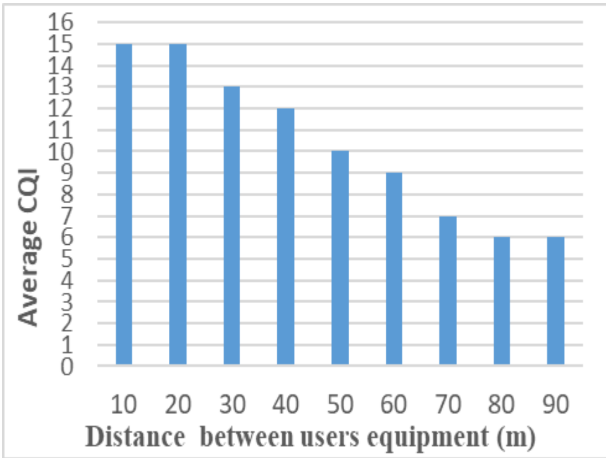

Figure 12. Display CQI vs. distances between UEs

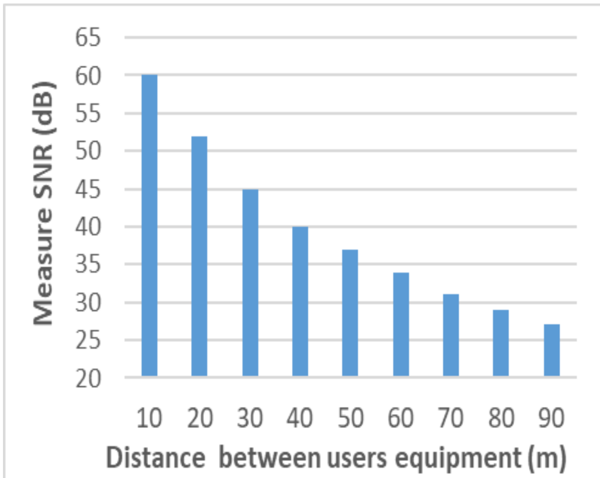

Figure 13. Display measure SNR vs. distances between UEs

6.4 Performance evaluation and discussions

A simulation model was created to evaluate the effectiveness of the suggested algorithm. The propagation model in the simulations represented a wide range of fading intensities. Initially, the eNB announces the multicast service and invites interested users to sign up for the network and form the multicast group (MG). One of the main requirements to ensure the security of both parties is reciprocal authentication between the network and the user equipment. In this stage, UEs send the necessary information about their channel conditions to the eNB to determine which devices to serve through multicast transmission and which through D2D communications. Each UE that is a member of the MG sends its CQI values to the eNB, indicating its connection to the eNB and neighboring D2D links.

Cellular communication and multicast D2D communications share the same resources. In a D2D call, a UE contacts the eNB to request a channel and is assigned a resource block in return to establish a connection with another UE. Channel measurements are used for channel estimation, based on the CQI values provided by the equipment. These CQI values are sent to the eNB, which uses them to define D2D routes. Both uplink and downlink frequency bandwidth can be shared by D2D communications and cellular links. Channel estimation can also be performed using the reference signals from the cellular uplink. To increase the number of connected UEs, these routes may share the same spectrum as cellular communications. An eNB providing cellular data services must monitor all D2D communications within its coverage area for allocation and routing.

Low computational complexity is a feature of the suggested D2D multicast discovery and selection algorithm. Threshold-based decision making, CQI/SNR evaluation, and distance calculation are all done once per user equipment (UE). The suggested method avoids repeated optimization and combinatorial searches, in contrast to exhaustive or graph-based D2D pairing strategies that necessitate evaluating every potential UE pair and usually display quadratic or higher-order complexity. Because of this, it is computationally effective and appropriate for real-time application in real-world cellular systems. Table 2 shows a numerical comparison of traditional cellular communications and D2D multicast.

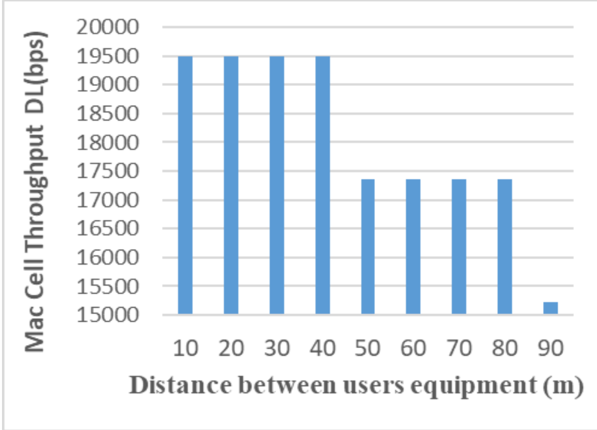

Figure 14. Display Mac Cell Throughput DL vs. distances between UEs

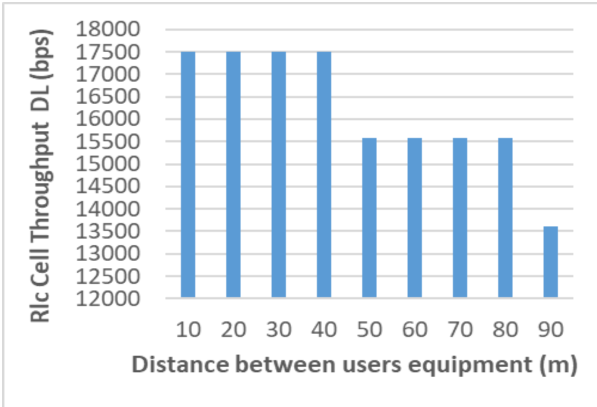

Figure 15. Display RLC Cell Throughput DL vs. distances between UEs

Table 2. A quantitative comparison between D2D multicast and traditional cellular communications

Metric	Traditional Cellular	D2D Multicast	Improvement
Average CQI	Degrades from 9 to 2. At increase distance eNB–UE from 100 to 1000 as shown in Figure 9.	15 at the same distance eNB–UE when the distances between UEs = 20 m as shown in Figure 13 (connected via local links).	Higher
Measure SNR at cell edge	Drops to 17 dB as shown in Figure 10.	Improved via D2D to 60 dB as shown in Figure 14.	Higher
Throughput for (40 UEs)	The throughput is19.5 kbps for ≈ 16 UEs when the distance between devices is 10 meters as shown in Figure 11&15. in Cellular, resource fragmentation and scheduling overhead cause throughput to grow slowly.	The throughput ≈ 24 kbps for ≈ 16 UEs when the distance between devices is 10 meters. D2D multicast increases spectrum efficiency by serving several UEs with a single transmission.	Significant
Scalability	Weak at high UE density.	Effective multicast.	Better

6.5 Limitations and discussion

In high-mobility scenarios, rapid channel fluctuations may not be adequately captured by the suggested simulation framework's quasi-stable CQI within each scheduling interval, which could result in less-than-ideal link adaptation. Furthermore, the assessment is restricted to a single-cell setting, ignoring handover effects and inter-cell interference that may affect cellular and D2D multicast performance in dense deployments. Additionally, D2D pairing and discovery are idealized, assuming perfect knowledge of channel conditions and distances without taking discovery delays or signaling overhead into consideration. Therefore, rather than being absolute assurances for large-scale, real-world networks, the observed performance enhancements should be seen as optimistic estimations under controlled settings.

7. CONCLUSIONS

In this paper, we assessed the performance of multicast D2D communication using the OMNeT++ simulation framework in

5G networks. The main emphasis was on key performance metrics such as the Signal-to-Noise Ratio (SNR), MAC and RLC cell throughput, and CQI. The CQI findings showed that D2D multicast communication consistently maintained good channel quality in different network circumstances. This is crucial to ensure effective resource allocation and preserve high data rates. The throughput at the MAC layer showed significant improvements when using D2D multicast. The decrease in hop count and direct connection between end users led to high throughput, optimizing the usage of the available spectrum resources. The SNR measurements showed that D2D multicast maintained a strong signal quality. Even with a higher number of users in scenarios, the direct communication route in D2D multicast reduced signal deterioration and interference, enhancing signal integrity. Overall, the incorporation of D2D multicast into 5G networks led to promising enhancements in network performance to support services and applications that are in high demand in upcoming 5G networks, paving the way for more reliable and efficient 5G networks.

Future work can expand on this research by investigating the effects of different mobility models, various traffic patterns, and applying cutting-edge interference control methods to further improve D2D multicast performance.

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NOMENCLATURE

D2D	device-to-device
CQI	Channel Quality Indicator
UEs	user equipment
eNB	Node Base Stations
MEC	Multi-access Edge Computing
IoT	Internet of Things
RSSI	Received signal strength indicator
RAN	Radio Access Network
SL	side link
MAC	Medium Access Control
RLC	Radio Link Control
PDCP	Packet Data Convergence Protocol