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Optimized Mode Selection in D2D Enabled B5G Networks: A Game Theory Approach

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Beyond Fifth Generation (B5G) networks aim to revolutionize wireless communication with unprecedented data rates, extremely low latency, and high throughput. This research is motivated to optimize Device-to-Device (D2D) communication within cellular networks, where the goal is to improve wireless communication gains and performance. This research identifies the key components necessary for ensuring proper Quality of Service (QoS) provisioning for D2D and cellular users, given the challenges to ensuring appropriate QoS for both D2D and cellular users done by a holistic method to ensure the user experience is smooth while the network capability is fully utilized, which aims to improve the efficiency and performance in wireless communication. Leveraging the power of game theory, this study develops practical solutions for the identified challenges. Furthermore, this work presents a proposed solution, goals, architecture, and methodology of the proposed game-theoretic model, paving the way for enhanced D2D communication in future B5G networks.

Keywords: Device-to-Device Communication; Beyond Fifth Generation; Mode Selection; Interference Management and Game Theory.

Introduction

Beyond the Fifth Generation (B5G) wireless technology has emerged as a promising solution aligned with the vision of future wireless networks. It plays a crucial role in addressing evolving requirements and enabling the integration of next-generation technologies. The B5G network is set to incorporate a range of advanced technologies, including Ultra-Dense Networks (UDN), Massive MIMO, Millimeter-Wave (mm-Wave), Device-to-Device (D2D) Communication, Machine-to-Machine (M2M) Communication, Heterogeneous Networks (HetNets), Full-Duplex (FD) Communication, and Cognitive Radio. These technologies will form the foundation of B5G, enabling it to meet the increasing demands and diverse requirements of next-generation users [1].

Device-to-Device (D2D) Communication is anticipated to play a crucial role in wireless networks [2]. D2D communication represents a promising technological advancement that enables the efficient sharing of cellular resources in next-generation cellular networks [3]. It can better meet the transmission needs of services than conventional cellular transmission techniques; this technology is crucial to the development of the B5G networks [4]. By enabling direct communication between nearby devices;either by bypassing the core network or operating independently of it, D2D communication reduces latency, improves spectral efficiency, and enhances overall network performance. This direct interaction between devices also helps reduce traffic load on the base station by offloading data transmissions. Since D2D communication typically operates over short-range links, it minimizes the need for routing data through the core network, thereby enhancing network efficiency and reducing latency [5]. D2D communication provides a variety of advantages to cellular networks, such as enhanced network performance, higher throughput, expanded coverage, faster transmission rates, better energy efficiency, increased capacity, lower energy consumption, the capability to offload traffic from other network layers, enhanced quality of service (QoS), efficient resource allocation, reduced latency and greater spectrum efficiency, as shown in Figure 1 [6].

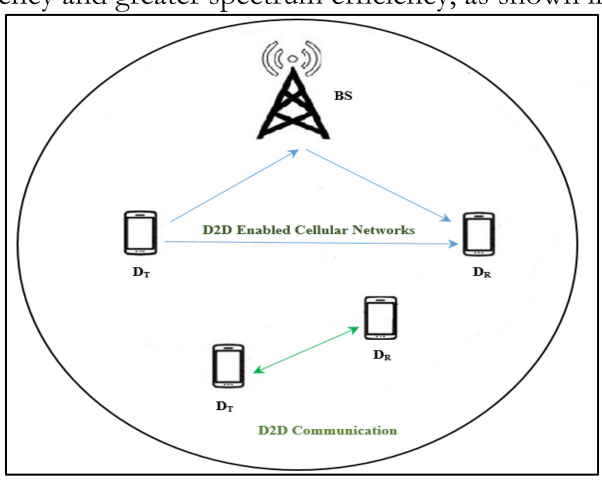

Figure 1. D2D Enabled Cellular Networks

However, D2D communication also comes with its challenges; particularly in selecting the appropriate mode [7], power control [8], resource allocation [9], security measures [10], interference mitigation [11], privacy protection [12], network optimization and addressing various network types [13]. It presents various challenges, each of which has its pros and cons pertaining to mode selection, interference management, resource allocation, and mobility management [14]. However, this research primarily focuses on mode selection and interference management.

One of the key challenges in D2D communication is spectrum sharing, particularly in determining the appropriate method of spectrum allocation. This allocation strategy is primarily influenced by the classification of D2D communication [15]. D2D communication is generally classified into two main categories: In-band and Out-band D2D communication

Inband D2D Communication, includes licensed bands, which have a shared spectrum between D2D and cellular networks [16]. In Out-band D2D communication, an unshared spectrum is used, with a dedicated frequency band allocated separately for both D2D and cellular users. As a result, interference between D2D and cellular transmissions is effectively eliminated in this setup [17]. The major problem in Inband D2D communication is mode selection and interference management.

Mode Selection is the process of choosing the best communication channel, whether it be D2D or cellular networks [18]. In wireless communication, choosing the optimal communication mode is crucial. During mode selection, the device decides whether to communicate as a D2D or cellular user. The objective of D2D communication is to select the optimal mode that offers the best quality of service while reducing interference. To achieve specific performance goals;ssuch as high spectral efficiency, low transmit power, and good Quality of Service (QoS), two User Equipment (UE) devices select the most suitable communication mode that optimally meets these requirements. Mode selection can be guided by the Signal-to-Interference-plus-Noise Ratio (SINR), depending on the resource-sharing strategy employed. These strategies may involve either single-hop or multi-hop communication, allowing devices to choose the most efficient path based on network conditions and performance requirements [2]. The transmission modes can be classified as single-hop or multi-hop. In Single-hop Communication, or D2D communication: devices are directly communicating with each other through a direct link. In contrast, in Multi-hop Communication, or Cellular communication: the transmitting device $D_{T\ sends}$ the data to the base station (BS), which then forwards the information to the receiving device D_R.

Interference Management is essential for cellular networks that support D2D communication. It can impact network performance when D2D and cellular communication share the same frequency spectrum. The goal is to reduce interference between D2D and cellular links to ensure dependable and efficient communication while also improving system capacity and QoS [19]. Interference fluctuates due to the shared spectrum between D2D and cellular users, potentially leading to a decline in overall network performance [20]. This research is based on Inband D2D communication, as shown in Figure 2 [21].

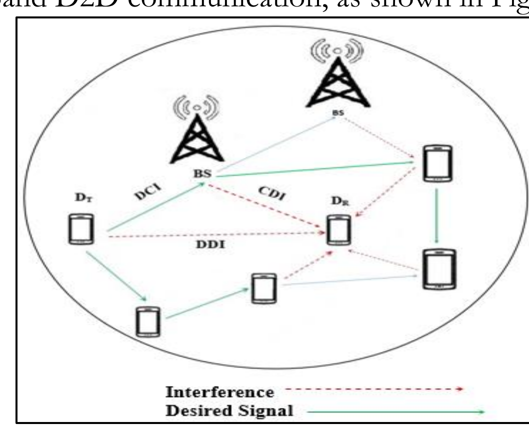

Figure 2. D2D Interference Management

In this research, we explore game-theoretic strategies for mode selection and interference management in D2D-enabled B5G cellular networks, aiming to enhance the QoS for D2D and cellular users. It has extensively tackled the challenges of mode selection and interference management in the realm of D2D communication. Game theory is extensively applied in wireless communication networks [22]. It is a mathematical tool and a suitable tool for making decisions that analyze the behavior or strategies of individual players and is valuable for designing wireless communication systems [23]. It provides a framework for analyzing the complex interactions among independent, rational players. It comprises of three essential components: players, actions or strategies, and utility functions. It enables the prediction of their strategic decisions and behavior in various network scenarios [24].

In a non-cooperative game, each player acts selfishly, aiming to maximize their utility based on the strategy they choose, without collaborating or coordinating with other players [17]. In the context of a non-cooperative game, NE is essential for comprehending game theory concepts [25]. Additionally, the formalism of game theory can be used to develop a non-cooperative game that simulates the decision-making process. Utilizing a game theory approach for mode selection allows devices to make intelligent, strategic choices that enhance communication reliability and reduce interference, even in dynamic and competitive network environments. Factors such as SINR, throughput, latency, and bandwidth, which are crucial for QoS parameters, influence the selection of communication modalities [21].

The existing literature has not examined the use of NOMA in conjunction with In-band communication for mode selection. Previous research did not simultaneously consider both cellular and D2D communication. This research work addresses these limitations by choosing the optimal mode selection, considering both cellular and D2D networks, and utilizing the non-cooperative game theory approach, using NOMA and In-band communication in the presence of interference.

In this context, D2D communication is a key enabling technology for B5G networks, helping to meet user demands. A key challenge in achieving reliable and seamless D2D transmission is developing a management mechanism that can effectively determine how moving devices should adjust their transmission modes. A game theory approach is used to formulate the problem. We addressed the problem of selecting the right mode and mitigating interference issues in D2D-enabled cellular networks. The game theory approach can serve as an effective solution to these issues. In performance evaluations, the proposed approach demonstrates a significant improvement over traditional and game theory techniques, particularly in terms of SINR, throughput, interference, utility function, success probability, and accuracy.

This research identifies the D2D communication integration into cellular networks, presents issues, and proposes potential solutions. Other existing works related to mode selection and interference management are methodically compiled in Table 1, including their approaches, performance indicators, and the issues they tackle for D2D communication.

Table 1. Literature Review

Ref.	Techniques	Contributions	Limitations
[26]	Deep Reinforcement Learning (DRL)	Enhance D2D and cellular communication performance	Does not consider QoS and throughput. Having more complexity.
[27]	Stochastic Geometry-based selection of Full-duplex modes	Maximize D2D network throughput through proper Interference management	However, the impact on the cellular user throughput is negligible.
[28]	Stochastic Geometry Approach for Interference Cancellation	Enhanced network performance for UDN	Used clustering method
[29]	The joint allocation of resources and access to users based on matching iteration	Optimize the sum rate of all users while ensuring their QoS	Considered Outband Scenario, having no interference issue.

[30]	Interference coordination based on the Stackelberg Model based in DQN	Solve interference issue	Improve QoS only for Cellular Users.
[31]	Non-Cooperative Game	Improve throughput and spectral efficiency	
[32]	An Efficient Game Theory-based non-cooperative D2D	Eliminate the interference between cellular users and D2D links	Considered only for D2D Communication
[33]	Evolutionary Game Approach	Improve throughput	
[34]	Stochastic Geometry (SWIPT)	Improve system efficiency	
[35]	New Game Theoretic Mode Selection Algorithm	Improve QoS for D2D user	

System Model:

In this research work, we examined D2D-enabled cellular networks, which consist of D2D (D_T and D_R) and cellular networks (BS). This model comprises two hops; the optimal path can be either single-hop or multi-hop. Data is transmitted using the D_T to D_R path in single-hop, while in multi-hop, data is transmitted using multiple paths, i.e., D_T to BS and BS to D_R. D_R is the receiving device, containing data from either D_T or BS. This research focuses on In-band D2D communications, where mode selection and interference are critical challenges because of the shared use of resources and frequencies.

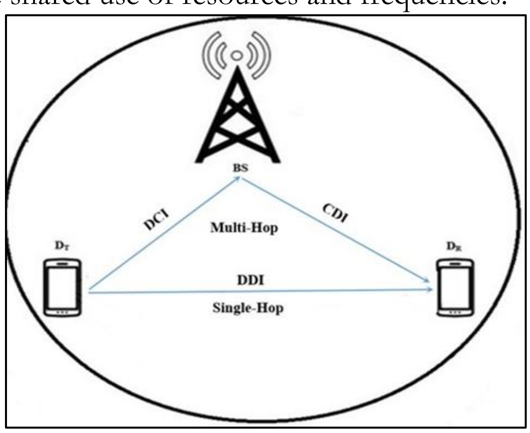

Figure 3. System Model

Network Model:

In our proposed model, we consider two types of devices:

- Set of pairs D2D: denoted D, for each pair of devices, where: $D = \{d_1, d_2, d_3 \dots d_N\}$, where N is the total number of devices. Such that $D \in \{D_T, D_R\}$, where $D_T \in D$ and $D_R \in D$, and base station: denoted BS.

$$\therefore \forall D_i \in \{1, 2, 3 \dots N\}, \text{ where: } D_i \in D_T \text{ and } Di \in D_R.$$

To identify the transmitter and receiver pairs which are as follows:

- x: Transmitter and x ϵ (D and {BS},

y: Receiver and y ϵ (D and {BS})

- The optimal path can be either Single-Hop: D_T to D_R or Multi-Hop: D_T to BS and BS to D_R.

Objectives:

- Researchers had not considered both Device-to-Device and cellular communication simultaneously; this research work is considering both D2D and cellular networks.
- This research delves into the specifications of D2D communication, and the formalism of the game theory approach can serve as an effective solution.
- It explored the application of game theory in mode selection and interference management in the context of D2D communication.
- The proposed solution for optimizing mode selection and addressing interference issues utilizes a game theory approach as a non-cooperative game in in-band D2D communication-enabled cellular networks within B5G networks.

Methodology:

Evaluation for D2D Model:

To evaluate the equation, the SINR and interference experienced by the receiving device (D_R) in a single-hop communication scenario were analyzed.

SINR$_S$:

The SINR$_S$ at D_R is defined as follows:

$$SINR_S = \frac{\rho D_T\ P_{DDI}\ \alpha^{-\gamma/2} \left\| H_{D_T\ D_R} \right\|^2}{I_{D_R} + n_{D_R}} \quad \textbf{(1)}$$

where ρD_T represents transmission power at the transmitter device, P_{DDI} is the path loss of DDI via the channel between D2D users $\left\| H_{D_T\ D_R} \right\|$, α Fading factor (Rayleigh distribution for D2D), ϒ is the path loss exponent, IDR represents interference at D_R, and nD_R represents noise.

Interference:

$$I_{D_R} = \sqrt{\rho BS}\ P_{CDI}\ \beta^{-\gamma/2} \left\| H_{D_R\ BS} \right\| x_{BS} + \sum_{i=0}^{n} \sqrt{\rho DT}\ P_{DDI}\ \alpha^{-\gamma/2} \left\| H_{D_R\ D_T} \right\| D_i \quad \textbf{(2)}$$

Where $I\ D_R$ represents interference at D_R, ρBS represents transmission power at the Base station, P_{CDI} is the path loss of CDI via the channel between the receiver device and Base station $\left\| H_{D_R\ BS} \right\|$, DDI is the channel between the D2D users $\left\| H_{D_R\ D_T} \right\|$, β Fading factor (Rayleigh distribution for cellular), and D_i represents the D2D devices.

Throughput:

To calculate the throughput and determine the maximum rate at which information could be transmitted for a single hop, it was calculated using the Shannon-Capacity Theorem:

$$R = B * \log_2 (1 + SINR_S) \quad \textbf{(3)}$$

where, R is the maximum rate, determined by the effective data rate and B represents bandwidth.

Success Probability:

Finally, the success probability Psuc was calculated using the Laplace Transform Theorem, representing the probability of a successful full transmission as:

$$Psuc = Psuc\ (Di).\ Psuc\ (BS) \quad \textbf{(4)}$$

Where, the success probability for single-hop communication, Psucs, was defined as the probability that the received SINR exceeded a predefined threshold θ, and it was expressed as:

Evaluation for Cellular Mode:

To assess the equation, we examined the SINR$_M$ and interference at the receiving device D_R for multi-hop communication.

SINR$_M$:

The SINR$_M$ at D_R is defined as follows:

$$SINR_M = \frac{\rho D_T\ P_{DCI}\ \beta^{-\gamma/2} \left\| H_{D_T\ BS} \right\|^2 + \rho BS\ P_{CDI}\ \beta^{-\gamma/2} \left\| H_{BS\ D_R} \right\|^2}{I_{D_R} + n_{D_R}} \quad \textbf{(10)}$$

where ρD_T represents transmission power at the transmitter device, P_{DCI} is the path loss of DCI via the channel between transmitter device and Base station $\| HD_T \ BS \|$, β Fading factor (Rayleigh distribution for cellular), ϒ is the path loss exponent, ρBS represents transmission power at the Base station, P_{CDI} is the path loss of CDI via the channel between Base station and receiver device $\| HBS \ D_R \|$, I_{DR} represents interference at D_R, and n_{DR} represents noise.

$$P_{Suc_S} \cong P(SINR_S \geq \theta) \quad (5)$$

$$P_{Suc_S} \cong P\left(\frac{\rho_{D_T} P_{DDI}\, \alpha^{-\gamma/2} \|H_{D_T\ D_R}\|^2}{I_{D_R}} \geq \theta\right) \quad (6)$$

$$P_{Suc_S} \cong P\left(\|H_{D_T\ D_R}\|^2 \geq \theta \rho_{D_T}^{-1} P_{DDI}{}^{-1} \alpha^{\gamma} I_{D_R}\right) \quad (7)$$

$$P_{Suc_S} \cong \int_0^{\infty} \left(\|H_{D_T\ D_R}\|^2 \geq \theta \rho_{D_T}^{-1} P_{DDI}{}^{-1} \alpha^{\gamma}.s\right).f_{I_{D_R}}(s).ds \quad (8)$$

$$P_{Suc_S} \cong \int_0^{\infty} F_{DR}\left(\theta \rho_{D_T}^{-1} P_{DDI}{}^{-1} \alpha^{\gamma}.s\right).f_{I_{D_R}}(s).ds \quad (9)$$

Where P_{sucs} represents the success probability for single-hop, P shows the probability ranging between 0 and 1, and F is the channel constant.

Interference:

$$ID_R = \sum_{i=0}^{n} \sqrt{\rho DT}\ P_{DDI}\, \alpha^{-\gamma/2} \| HD_R \ D_T \| D_i \ \mathbf{(11)}$$

Where I_{DR} represents interference at D_R, P_{DDI} is the path loss of DDI, via channel between D2D users $\| HD_R \ D_T \|$, and D_i represents the D2D device.

Throughput:

The throughput was calculated to determine the maximum rate at which information could be transmitted for multi-hop communication using the Shannon-Capacity Theorem:

$$R = B * \log_2(1 + SINR_M) \ \mathbf{(12)}$$

Where, R is the maximum rate, determined by the effective data rate and B represents bandwidth.

Success Probability:

Lastly, the success probability for multi-hop communication, P_{sucM}, was calculated using the Laplace Transform Theorem. It was defined as the probability that the obtained SINR for multi-hop, denoted as $SINR_M$ exceeded a predefined threshold θ, and was expressed as:

$$P_{Suc_M} \cong P(SINR_M \geq \theta) \quad (13)$$

$$P_{Suc_M} \cong P\left(\frac{\rho_{DT} P_{CDI} \beta^{-\gamma/2} \|H_{D_T\ BS}\|^2 + \rho_{BS} P_{CDI} \beta^{-\gamma/2} \|H_{BS\ D_R}\|^2}{I_{D_R}} \geq \theta\right) \quad (14)$$

$$P_{Suc_M} \cong P\left(\|H_{D_T\ BS}\|^2 \geq \theta \rho_{D_T}^{-1} P_{CDI}{}^{-1} \beta^{\gamma}.I_{D_R} + \|H_{BS\ D_R}\|^2 \geq \theta \rho_{BS}^{-1} P_{CDI}^{-1} \beta^{\gamma}.I_{D_R}\right) \quad (15)$$

$$P_{Suc_M} \cong \int_0^{\infty} \left(\|H_{D_T\ BS}\|^2 \geq \theta \rho_{D_T}^{-1} P_{CDI}{}^{-1} \beta^{\gamma}.s\right) + \left(\|H_{BS\ D_R}\|^2 \geq \theta \rho_{BS}^{-1} P_{CDI}^{-1} \beta^{\gamma}.s\right).f_{I_{D_R}}(s).ds \quad (16)$$

$$P_{Suc_M} \cong \int_0^{\infty} F_{DR}\left(\theta \rho_{D_T}^{-1} P_{CDI}{}^{-1} \beta^{\gamma}.s\right) + \left(\theta \rho_{BS}^{-1} P_{CDI}{}^{-1} \beta^{\gamma}.s\right).f_{I_{D_R}}(s).ds \quad (17)$$

Where P_{sucM} represents the success probability for multi-hop, P shows the probability ranging between 0 and 1, and F is the channel constant.

Proposed Algorithm: GT-OMS:

An algorithm is proposed based on the Game Theory approach GT-OMS and is divided into the following steps. In the first step, the utility function for single-hop communication was evaluated based on the received $SINR_S$ and the level of interference experienced by the receiving device. In the second step, we evaluated the utility function for multi-hop: $SINR_M$ and interference. Lastly, apply the game theory Approach for optimizing results and giving the best possible outcome in terms of best mode and best utility.

Table 2. Algorithm

Algorithm: Game Theory-Optimal Mode Selection (GT-OMS)
1. Input **2. For each device *i*, randomly set its initial mode (D2D or Cellular) and set its initial utility to 0.** **3. Output: Optimized Mode Selection using Game Theory** **4. Step 1: Utility_Function-Single-Hop (i)** **5. Signal to Interference and Noise Ratio for Single-Hop ($SINR_S$).** **6. Calculate interference for Single-Hop at receiving device D_R.** **7. Calculate $SINR_s$ at the receiving device D_R** **8. Evaluate Interference and SINRs for Single-Hop (As in Equation (1) and (2)).** **9. Step 2: Utility_FunctionMulti-Hop (i)** **10. Signal to Interference and Noise Ratio for Multi-Hop ($SINR_M$).** **11. Calculate the interference at the receiving side.** **12. Calculate $SINR_M$ at the receiving device D_R.** **13. Evaluate Interference and $SINR_M$ for Multi-Hop (As in Equation (3) and (4)).** **14. Step 3: Apply the Game theory algorithm** **15. Set equilibrium = false** **16. While equilibrium ==false:** **17.Set equilibrium = true** **18. for each device i ∈ {1, 2, ..., N}:** **19. Calculate Utility Function-Single-Hop (i)** **20. Calculate Utility_FunctionMulti-Hop (i)** **21. If (Utility_Function-Single-Hop (i) > Utility_FunctionMulti-Hop (i) :** **22. Set best_mode = Utility_Function-Single-Hop (i)** **23. Set best_utility = Utility_Function-Single-Hop (i)** **24. Else:** **25. Set best_mode = Utility_FunctionMulti-Hop (i)** **26. Set best_utility = Utility_FunctionMulti-Hop (i)** **27. If M (i)! = best mode:** **28. Set M (i) = best_mode** **29. Set U (i) = best_utility** **30. Set equilibrium = false**

Description of Algorithm:

In D2D Mode, D2D communication enables a direct link between two devices, allowing direct connections: either bypassing the core network or without going to the core network. This approach is advantageous in reducing communication latency and enhancing spectral efficiency, particularly in scenarios where devices are in close proximity.

In Cellular Mode: Cellular Mode, by contrast, involves the base station as an intermediary for communication between devices. In this mode, devices send their data to the base station, which then routes it to the intended recipient. This approach allows for greater control over communication, as the base station can manage network resources, allocate bandwidth, and maintain service quality. Cellular Mode is particularly useful for providing reliable coverage and ensuring smooth communication over long distances.

Utility Function: The utility function plays an important role in optimizing communication in both D2D and cellular modes. It is a mathematical representation that quantifies the reward or benefit each device gains from using a particular communication mode. The utility function aids in determining the most beneficial communication strategy for each device, ensuring efficient network performance and balanced resource distribution.

Goal: The goal of the game was to find a suitable path that allowed users to communicate well in the system.

Step 1: Calculated Interference and SINR for Single-Hop: The network topology with N devices was defined. The initial modes of the devices were set randomly. Interference for single-hop was calculated as in algorithm step 8, and then SINR functions for single-hop were evaluated as in algorithm step 10.

Step 2: Calculated Interference and SINR for Multi-Hop: Interference for multi-hop was calculated as in algorithm step 15, and then SINR functions for multi-hop were evaluated as in algorithm step 17.

Step 3: Game Theory Algorithm: Each device/node was considered a player in the game. Each player could select between D2D mode and cellular mode. The goal of each player was to maximize its utility. For each device, the utility was calculated for both D2D and cellular modes. Each device selected the mode that maximized its utility given the modes of other devices. The mode of each device was iteratively updated based on the current strategies of other devices.

Nash Equilibrium (NE): The Nash equilibrium is a fundamental idea in the realm of non-cooperative game theory. In an NE, the strategy chosen by each player represents the optimal reaction to the strategies of the other participant. This equilibrium reflects a set of strategies where no individual player can enhance their payoff by unilaterally altering their strategy. Each player's goal is to reach this equilibrium, thereby maximizing their utility function without the need for collaboration. This state of stability can be characterized as follows:

$$U_n(S^*_n, S^*_{-n}) \geq U_n(S_n, S^*_{-n}) \quad \textbf{(18)}$$

where, U_n represents the utility function, the reward gain obtained by the game player after making the decision, S^*_n represents the best strategy for player 1 and S^*_{-n} represents the best strategies for other players.

Check if the network has reached a Nash equilibrium, where no device can increase its utility by unilaterally changing its mode. The final mode selection for each device in the network. The utilities are associated with the chosen modes. If equilibrium is reached, terminate the algorithm. If not, continue the iterations. The following are the parameters that can be considered:

- **SINR**: Higher SINR means good QoS, enhanced data rate, and low latency.
- **Throughput**: Higher in D2D mode due to direct communication.
- **Interference:** Lower in cellular mode, as the base station manages the interference.

Experimental Design:

In this study, the experimental design was conducted using Google Colab for the graphical representation, which is a free and open-source platform. The programming language used for coding was Python to produce the results. A comparative analysis is performed to evaluate the efficiency of the proposed algorithms against the existing techniques. Additionally, various optimizing parameters were used in this experiment.

Consider a single-cell network scenario in our simulation where the D2D pairs and base station are in the initial state and randomly distributed in a 500-meter radius with the base station in the center. The base station is represented by a red circle, while D2D pairs are presented by a blue circle, as shown in Figure 4.

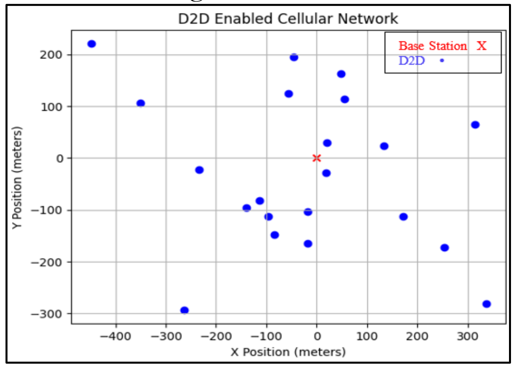

Figure 4. Environment Setup

Parameters:

The parameters for the simulation are outlined in Table 3.

Table 3. Simulation Parameters

Parameters	Values
Cell Layout	Circular
Cell Radius	500m
Noise(N_0)	-100dBm
Bandwidth	50MHz
BS-Height	30
UE-Height	1.5
SINR Value	50dB
SINR Threshold (θ)	30dB
Path loss Exponent	5
No. of Base Station (BS)	1
No. of DUEs (D2D)	10 pairs
Transmission Power (T_X)	23dB

Results:

The result of the research highlights the effectiveness of the GT-OMS algorithm in optimizing B5G communication systems using a game theory approach. The analysis shows that GT-OMS outperforms existing techniques in key performance metrics such as SINR, interference, throughput, success probability, and accuracy. GT-OMS achieved the highest SINR, lowest interference, and highest throughput, along with an accuracy rate of 91%. In contrast, other methods like GT-D2D, SIC, and PPP performed significantly worse. Overall, GT-OMS is the most efficient and reliable method for B5G communication systems. This advancement represents a crucial step toward achieving a sustainable and high-performance wireless communication environment. The simulation results demonstrate the proposed scenario and also compare the result with the state-of-the-art schemes. The evaluation results were conducted as presented in Table 4.

Table 4. Improvement Factors

Techniques	**SING**	**Interference**	**Throughput**	**Success Probability**	**Accuracy**
GT-OMS	0.03 dB	4.44e-07 W	16427192.84 Mbps	0.65	91%
PPP	-64.14dB	2.59e-02 W	621499.24 Mbps	0.51	89%
Game-theoretic MS	-72.34dB	7.51e-01 W	42.06 Mbps	0.40	82%
SIC	-5.11dB	2.58e-02	1.35 Mbps	0.36	77%

Sing:

The graph in Figure 5 illustrates a comparison of SINR for four different communication systems. The x-axis indicates the devices in the system, while the y-axis indicates the SINR in decibels (dB).

The graph in Figure 5 demonstrated that as the number of devices increased, the SINR generally decreased across all systems. However, the proposed system, GT-OMS, consistently achieved the highest SINR values up to 0.03 dB, particularly at higher device counts, outperforming other techniques. In terms of performance, it was followed by PPP, Game-Theoretic MS, and SIC, as shown in Table 4.

Overall, the proposed method GT-OMS yields the highest SINR value and retains a considerable gain over the other techniques. The proposed method offers the best performance, suggesting that it is more efficient in utilizing resources and higher SINR values indicate good quality signal, and better throughput compared to the other systems, as in Figure 5.

Interference:

The graph in Figure 6 illustrates a comparison of interference for four different communication systems. The x-axis indicates the devices in the system, while the y-axis indicates the interference in watts (w).

The graph in Figure 6 demonstrates that as the quantity of devices increases, the interference generally increases for all systems. However, the proposed system consistently exhibits the lowest interference, followed by SIC. The Game-theoretic MS and PPP show similar interference levels, with PPP slightly higher than the new game model at higher device counts.

Overall, the low interference with the proposed model GT-OMS indicates the superiority of this model in terms of interference control in contrast to the other techniques. The proposed model is very effective in minimizing the level of interference, which is acceptable and has the least interference along with other techniques, as in Table 4. The proposed method GT-OMS offers the best performance in terms of minimizing interference, suggesting that it is more effective in managing interference between devices compared to the other systems, as shown in Figure 6.

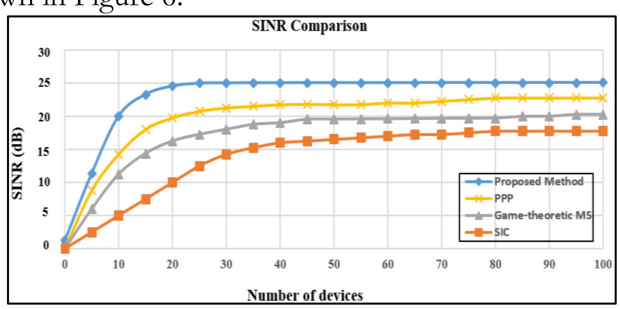

Figure 5. SINR comparison with other existing techniques

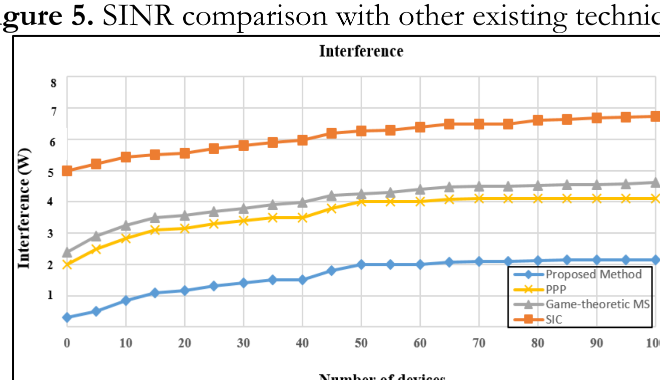

Figure 6. Interference comparison with other existing techniques

Throughput:

The graph in Figure 7 illustrates a throughput comparison of four different techniques. The x-axis indicates the number of devices in the system, while the y-axis indicates the throughput in Mbps.

The graph in Figure 7 demonstrates that as the quantity of devices increases, the throughput generally increases for all systems. However, the proposed method consistently achieves the highest throughput. In terms of performance, it was followed by PPP, Game-Theoretic MS, and SIC, as shown in Table 4.

Overall, the proposed method GT-OMS yields the highest throughput and retains a considerable gain over the other techniques. The proposed method offers the best throughput performance, suggesting that it is more efficient in utilizing resources and handling interference compared to the other systems, as shown in Figure 7.

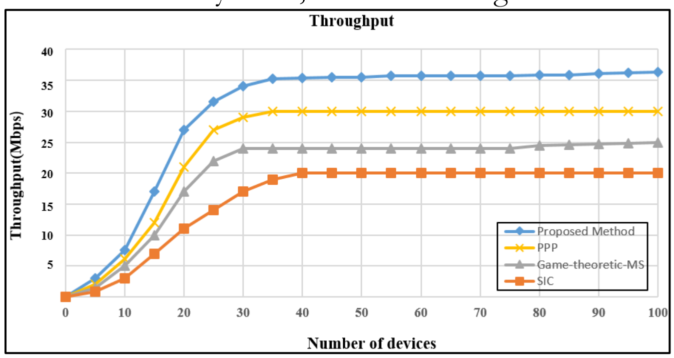

Figure 7 Throughput comparison with other existing techniques

Success Probability:

The graph in Figure 8 illustrates a success probability comparison of four different techniques. The x-axis indicates the SINR value, while the y-axis indicates the probability, which ranges from 0 to 1.

The graph in Figure 8 demonstrated that as the SINR increased, the success probability generally decreased across all systems. However, the proposed method consistently achieves the highest success probability up to 65%. In terms of performance, it was followed by PPP, Game-Theoretic MS, and SIC, as shown in Table 4.

Overall, the proposed method GT-OMS yields the highest success probability; it outperformed the Game-theoretic MS, SIC, and PPP. The proposed method demonstrated the highest success probability performance and maintained a significant gain over the other techniques, indicating greater efficiency in link quality, as shown in Figure 8.

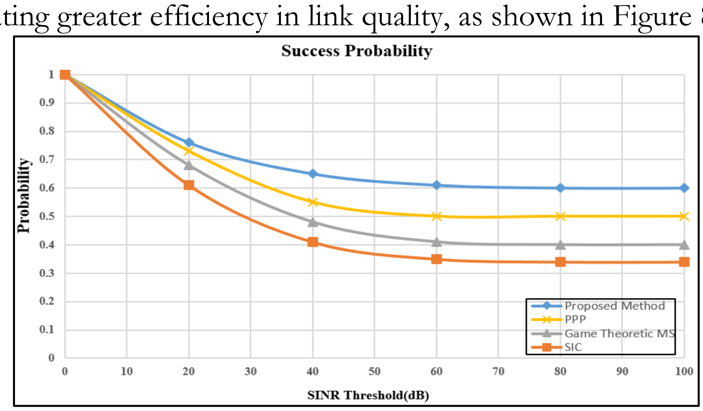

Figure 8. Success Probability comparison with other existing techniques

Accuracy:

The graph in Figure 9 illustrates an accurate comparison of four different techniques. The x-axis indicates the number of devices, while the y-axis indicates network accuracy in percentage.

Figure 9 illustrates that accuracy tends to decline for all systems as the number of devices increases. However, the proposed method consistently achieves the highest accuracy throughout and appears to be the most effective of all other methods, as in Table 4.

Overall, the proposed method GT-OMS yields the highest accuracy as the number of devices increases. The proposed work attained 91% accuracy; it outperformed the Game-theoretic MS, SIC, and PPP. The suggested approach demonstrated a high level of accuracy while delivering efficient and reliable communication quality, as shown in Figure 9.

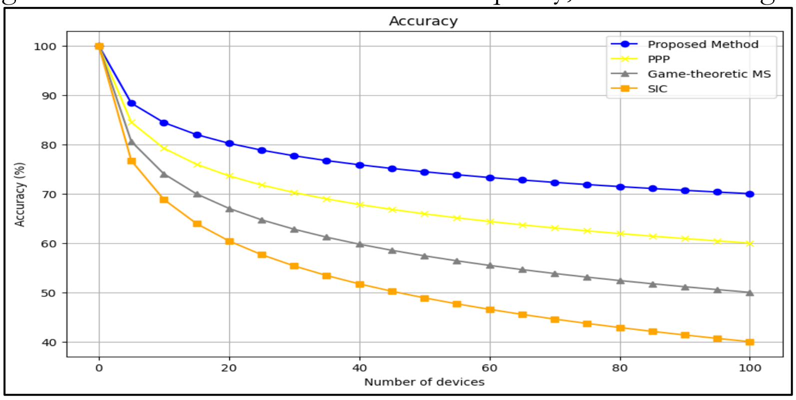

Figure 9. Accuracy comparison with other existing techniques

The development of an optimal mode selection policy and addressing interference issues through a game theory approach. It emphasizes the significance of developing effective solutions to enhance wireless communication systems, particularly in the context of emerging technologies B5G networks. The proposed work has proven effective in identifying the most efficient data delivery routes to end-users, significantly optimizing mode selection and mitigating interference in the network. This advancement is a critical step towards ensuring a sustainable and high-performance wireless communication landscape. The proposed method results in the highest SINR followed by other techniques and would be suitable for high-density networks. It also offers the best SINR performance, and achieved the highest SINR value, suggesting that it is more efficient in managing interference and noise compared to the other systems. Lowest interference and highest throughput, along with an accuracy rate of 91%. This advancement represents a crucial step toward achieving a sustainable and high-performance wireless communication environment and also comparing it to other existing schemes using simulation.

Conclusion:

This research focuses on optimizing mode selection and mitigating interference in D2D-enabled B5G cellular networks through a game-theoretic approach. The primary objective is to identify the optimal mode utilizing game theory techniques that minimize interference within the network while enhancing data rates, QoS, and throughput and reducing energy consumption at the base station by effectively selecting transmission modes. A non-cooperative game framework is employed to model the interactions between devices, facilitating optimal mode selection and addressing interference issues in D2D-enabled cellular networks within the context of B5G. Through simulations using various parameters, demonstrated the effectiveness of our proposed model, such as SINR, throughput, interference, success probability, and accuracy, comparing it to other existing schemes.

Future Work:

- This research outlines potential research directions, including the exploration of cooperative models, advanced algorithms, and the integration of cutting-edge technologies such as edge computing, federated learning, machine learning, and the Internet of Things. Additionally, sophisticated game theory techniques are highlighted as important areas of study.

- A key aspect of sustainable solutions involves efforts to reduce energy consumption, increase the number of base stations, and enhance scalability and network management, particularly in intricate environments.
- Emphasizing advancements in machine learning and artificial intelligence will be crucial for network optimization. Enhancing the user experience and investigating bands with higher frequencies, such as terahertz frequencies, also offer substantial opportunities. To ensure that technological advancements lead to effective, reliable, and user-centered wireless communication systems.

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