OPTIMIZED SPECTRUM SHARING STRATEGIES FOR DEVICE-TO-DEVICE COMMUNICATION IN 5G CELLULAR NETWORKS

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ABSTRACT

Device-to-Device (D2D) communication has become a viable technique to improve cellular networks' overall performance, lower latency, and increase spectral efficiency. While still functioning under the cellular network's management, D2D communication allows user devices to speak with one another directly, avoiding the base station. Effective spectrum sharing between cellular users and D2D pairs is a major difficulty in D2D communication since unmanaged sharing can generate significant interference and impair network performance. Overlay, underlay, and hybrid techniques are some of the spectrum sharing strategies that have been put out to efficiently distribute resources while striking a balance between system throughput and interference control. Spectrum sharing allows cellular users and D2D lines to coexist seamlessly by combining intelligent resource allocation, power control, and interference mitigation techniques. This enhances network capacity, QoS, and energy efficiency. This research emphasizes how crucial spectrum sharing techniques are to facilitating D2D communication in 5G and future cellular networks.

KEYWORDS: 5G networks, spectrum sharing, device-to-device (D2D) communication, resource allocation, interference management, power control, hybrid spectrum access, quality of service (QoS), and energy efficiency.

1. INTRODUCTION

As smart phones gained popularity due to their applications, their use increased without being identified. The sharing of audio, video, images, documents, etc., may be for personal or business purposes, which is why data traffic has increased recently. It quickly reaches the capability of the current 4G cellular networks. Due to the increasing data traffic, there is a large spectrum requirement, making it difficult for mobile users to find a communication channel. Network bulkiness is the common way to increase the spectrum capacity in order to congregate the intense demand, which currently requires a 1000-fold increase. Caching popular material at BSs and user devices is a promising way to lessen the backhaul strain. This way, mobile users can obtain the necessary content from nearby user devices or local BSs without using backhaul links. Local access like this can help increase

energy efficiency and decrease download latency.
Nonetheless, wireless networks' inherent characteristic of user mobility causes network topologies to evolve over time. The user's mobility pattern must therefore be considered. However, because user mobility will improve the options for communication for users who are on the move, it can also be a helpful feature to take use of. Numerous issues in wireless networks have been successfully resolved by mobility-aware design.
Cellular communication has transformed communication by providing users with the convenience of ubiquity. Cellular systems always have a limited amount of accessible bandwidth. In general, cellular systems always experience a channel shortage due to the rise in multimedia applications and the constant demand for wireless devices that allow faster data rate flow. Channel usage, along with power management and position tracking, has been one of the most crucial study topics in cellular systems. Recent studies have placed a great deal of emphasis on the efficient and effective distribution of channels for cellular networks. With more stringent QoS requirements, the various new service types need real-time support and continuous communication.

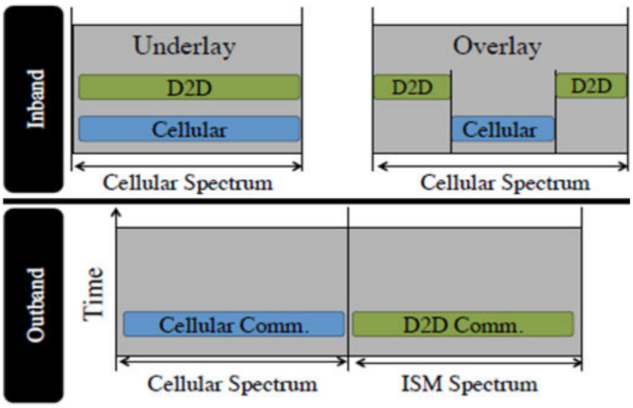

Figure1.1.1: Schematic representations of overlay inband, underlay inband and outbandD2D.

With the advent of 5G technology, Device-to-Device (D2D) communication has become a viable paradigm to improve the performance of contemporary cellular networks. Under the cellular network's supervision, D2D communication allows direct contact between neighboring user devices, in contrast to traditional communication models where data transmission takes place through a base station. This direct link increases spectral efficiency by reusing available frequency resources, lowers communication delay, and offloads traffic from the base station. In order to enable bandwidth-intensive applications like real-time video sharing, public safety communication, and vehicle networks, D2D communication is essential.

But one of the main obstacles to D2D communication implementation is effectively managing the spectrum resources that D2D couples and traditional cellular users share. Uncontrolled spectrum reuse can cause significant co-channel interference, which lowers QoS and degrades network performance. In order to solve this problem, researchers have put forth a number of spectrum sharing techniques that strike a balance between limiting interference and increasing throughput, including overlay, underlay, and hybrid approaches. Each strategy makes use of clever strategies including power management, channel selection, and resource allocation to guarantee the best possible use of the spectrum resources while preserving dependable connectivity.

Therefore, in order to fully realize the potential of D2D communication in 5G and beyond, optimized spectrum sharing strategies are crucial. These techniques facilitate the effective coexistence of D2D and cellular communications by combining adaptive interference management and machine learning-based optimization. In addition to improving total network capacity and energy efficiency, this guarantees scalability and flexibility for wireless systems of the future. The current study focuses on creating and assessing efficient spectrum sharing systems that enhance the sustainability, dependability, and performance of 5G cellular networks with D2D capability.

2. LITERATURE SURVEY

The primary factor driving the growth in both wired and wireless data traffic at the moment is video transmission. Currently, 50% of all internet traffic on wired networks occurs during the late hours due to movie streaming, and this percentage is predicted to continue growing. A comparable pattern has been noted for wireless networks. It is anticipated that wireless data traffic would rise by a factor of 40 during the next five years, from the current monthly average of 93 petabytes to 3600 petabytes [1]. Device-to-Device communication as a foundation for LTE-Advanced networks, Doppler et al. As an underlay to LTE-Advanced, D2D is formalized in this seminal study, which also suggests session setup and management procedures and demonstrates how in-network control might allow local services while preventing interference for cellular users. Inband D2D reuse and the fundamental trade-offs between interference and capacity gain are framed.
ResearchGate

The authors, C. Doppler and his associates, were pioneers in D2D research, helping to establish fundamental ideas for the functioning of inband underlays. Their research combines analytical modeling with real-world cellular standards knowledge. Numerous other studies on resource allocation and interference management are built upon the baseline they established.

analysis of 5G spectrum sharing in detail (arXiv, 2022).
In this comprehensive analysis, spectrum-sharing designs and methodologies (overlay, underlay, and hybrid) are categorized, energy-conscious approaches are examined, and open issues for 5G/B5G networks, such as coexistence and dynamic access, are highlighted. beneficial for placing algorithmic contributions in the broader ecology of SS.
ArXiv

Researchers with expertise in wireless resource management and spectrum regulation, the survey's authors synthesize a variety of literature on cognitive radios, cellular D2D, and 5G designs. To direct research goals, they offer a systems-level perspective.

Huang, Nasir, Durrani, and Zhou— "Power control, resource allocation, and mode selection for D2D-enabled two-tier cellular networks"
In summary: provides a centralized decision-making framework for two-tier network power regulation, joint resource allocation, and mode selection (cellular vs. D2D) at the macro base station. It also develops QoS constraints that ensure coexistence. shows the benefits of coordinated optimization.
ArXiv

Description of the writers: The authors are scholars who study stochastic analysis and wireless optimization. They focus on QoS-aware resource rules and tractable optimization formulations for diverse cellular environments.

"D2D underlaying uplink multi-cell networks: resource allocation and dynamic power control" by Fan Jiang et al.
In summary: explores centralized and distributed methods for power dynamic adjustment and uplink resource allocation to safeguard cellular uplink users and allow D2D throughput. demonstrates how simple reuse is made more difficult by multicellular interference.
Fan Jiang et al. concentrate on realistic resource-management algorithms for multi-cell situations, balancing performance under realistic interference coupled with implementation feasibility.

Survey: Using AI to Facilitate D2D Communications in 5G/B5G
In summary: reviews machine learning strategies used to solve D2D challenges, particularly in complicated settings (mmWave, mobility), like relay selection, channel assignment, and power regulation. demonstrates how ML can pick up policies in dynamic spectrum settings.

Researchers that are interested in the nexus between machine learning and wireless networks, the authors support data-driven strategies for adaptive spectrum and interference control.

The use of reinforcement learning in D2D spectrum sharing (TNSM, 2024)
In summary: Targeting URLLC requirements, it suggests an RL-based spectrum sharing solution that shows how agents can learn power control and channel selection rules that adhere to latency and reliability limitations. better than static heuristics in terms of coexistence.

Experts in networked learning and wireless QoS, the authors of the research apply contemporary reinforcement learning to highly limited D2D settings where traditional optimization is inadequate.

3D Spectrum Exchange for Mixed D2D and UAV Systems
In summary: extends the analysis of spectrum sharing to hybrid networks, which include aerial (UAV) links and ground D2D pairs. It proposes 3D-aware allocation methods and adds spatial/altitude dimensions for modeling interference. beneficial for D2D's interactions with non-terrestrial systems.

The authors are combining their knowledge of spectrum management and UAV communications to investigate novel geometric interference patterns that emerge in 3D deployments.

Joint power control and resource allocation for D2D-assisted heterogeneous networks that is energy efficient

In summary: develops cooperative energy-aware power regulation and resource allocation to satisfy throughput/QoS goals and reduce energy consumption in networks with D2D underlay. shows that for battery-limited UEs, energy optimization is essential.

The author's description In D2D-enabled heterogeneous deployments, researchers here concentrate on green communications and optimization, putting forth techniques that compromise spectral efficiency for energy savings.

SC-FDMA-based power control and resource distribution for D2D (Glasgow ePrints)
In summary: investigates how to allocate resources in a way that is appropriate for SC-FDMA uplink (as used in LTE) to support D2D, suggesting power and allocation schemes that respect single-carrier limitations and lower PAPR while managing interference.

Described as wireless systems engineers, the authors' practical focus is on translating theoretical allocation algorithms onto the limitations of the cellular physical layer.

Allocating resources in D2D-enabled 5G using multi-agent reinforcement learning (2024)
For distributed resource allocation among numerous D2D pairs and cellular users, multi-agent RL (using PPO) is used. This approach demonstrates scalability and adaptability in dense areas where centralized control is not practical.

The authors are at the intersection of wireless networking and distributed learning, advocating for scalable AI solutions that can manage non-stationary dynamics and sizable user populations.

Strategies to Reduce Interference in Wireless Systems Beyond-5G (MDPI)
In summary: argues that hybrid or adaptive methods frequently outperform static allocation and reviews interference mitigation strategies that are pertinent to D2D, such as spectrum partitioning, dynamic mode selection, interference cancellation, and hybrid partitioning.

Author description: The authors of the research examine B5G system trends by fusing theoretical mitigation strategies with real-world deployment considerations for D2D coexistence.
Overview: SSRN and LTE-A examinations of the various forms of device-to-device communication and their architecture
Gives a taxonomy of D2D modes (underlay/overlay, inband/outband), weighs the advantages and disadvantages of each mode, and lists the protocol and architectural adjustments required for cellular integration. Good source for matching 3GPP conceptual models with a D2D SS strategy.

Author description: In order to make clear how D2D fits into developing LTE/5G designs, contributors to this overview compile standardized viewpoints and scholarly findings.
An extensive examination of energy-related topics and spectrum-sharing structures (ScienceDirect)
In summary: examines the effects of sharing on energy, cognitive methods, and hybrid spectrum access. For reliable D2D spectrum sharing, the focus is on cross-layer and combined design (MAC + PHY + network).

The writers emphasize energy considerations in shared spectrum utilization and realistic system design. They are experts in spectrum economics and architecture.

Explainability, data efficiency, and safety in radio environments are some of the open difficulties and strengths and limitations of a recent, targeted survey that maps machine learning techniques (supervised, RL, and federated) to spectrum sharing issues. crucial for the study directions of ML-driven D2D SS.

The survey's authors are contemporary ML and communications experts who assess algorithmic development and pinpoint areas in need of more study for AI deployments in spectrum sharing.

D2D communication resource management from an optimization standpoint (ScienceDirect review)

Analyzes optimization frameworks for D2D, such as convex/non-convex programming, game theory, and matching theory; contrasts distributed and centralized methods; and emphasizes tradeoffs between complexity and performance in real-world systems.

Description of the writers: The authors are specialists in game theory and optimization who use exacting mathematical frameworks to resource allocation, demonstrating which strategies work for actual networks.

3. EXISTING METHOD

3.1 Formulating the problem and the system model:

We shall outline the caching placement problem in conjunction with the caching method and file transmission model.

3.1.1 The Model of User Mobility:

In wireless networks, the inter-contact model has been extensively studied and is capable of capturing the connectivity information in the user mobility pattern [32], [38]–[40]. Therefore, it is used in this study to model mobile consumers' patterns of movement. According to this paradigm, when mobile users are within transmission range of one another, they can make contact. Accordingly, two biliary users' contact time is the amount of time they can communicate with one another; that is, they may trade files at that period. It is crucial to describe the connections between nodes while assessing mobile opportunistic networks. The most often used method for characterizing inter-contact periods is to examine the aggregate distribution of contacts between individual node pairs, presuming that the network is homogeneous and that node contact patterns are comparable. This aggregate distribution has the drawback of not necessarily being indicative of the distributions of individual pairs, particularly in the short term and when the network has a large number of nodes. Inaccurate performance evaluation results may therefore arise from drawing conclusions from this characterisation. The distribution of inter-contact times is more representative, which raises the accuracy ofthe outcomes of the derived performance. Furthermore, a temporal adjustment of traffic traces can be performed because these new characterizations only need a moderate number of encounters to be representative. Since contact patterns in real-traces can vary greatly over time, this is a crucial problem for improving accuracy. The results demonstrate that even with short-time contact traces, the new characterizations are more accurate than the established one.

4. PROPOSED METHOD

Mode selection, channel assignment, and power control are the three components of resource allocation. In addition to determining whether to use dedicated channels or repurpose CU channels, mode selection determines whether two users in close proximity should talk directly. D2D systems can communicate in three different ways.

• Cellular mode: If two users choose this option, they will use eNB to communicate like regular CUs. Generally speaking, this option would use the greatest channel resources. Use it solely in the event that the other two options are unavailable.

• Dedicated mode: Two DUs speak to each other directly over a channel that CUs do not presently use. Because they are closer to the user, DUs in this mode utilize less channel resources than those in the cellular mode and can increase energy efficiency.

• Reuse mode: Two DUs can speak to each other directly by sharing a channel that CUs are currently using. This mode has the potential to significantly increase spectrum utilization; however, co-channel interference must be appropriately controlled to prevent DU or CU performance from being negatively impacted. According to the aforementioned, mode selection is crucial for D2D communications. As a result, there have been some works on the subject.

4.1. SYSTEM MODEL

The combined mode selection, channel assignment, and power control problem for D2D systems is formulated in this part after the system model and different D2D communication modes have been introduced.

System Model

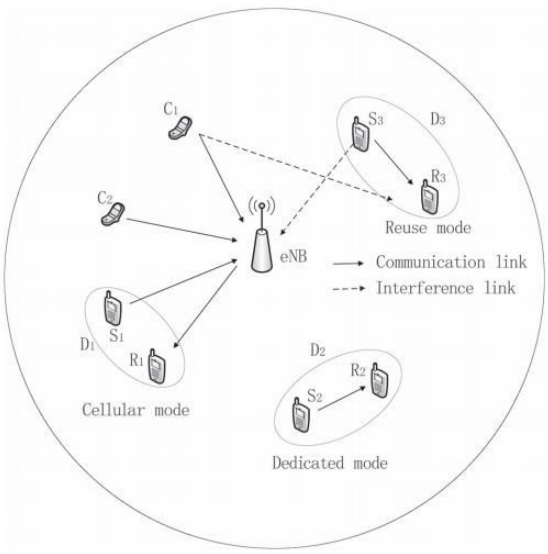

Fig. 1. System model for D2D communications.

Let {C1, C2,..., CM} be a single cell that connects to the eNB and has M cellular users. There are K possible DU pairs, represented by {D1, D2,...,DK}. Let Sk stand for the D2D pair k's transmitter and Rk for its receiver. One of the neighbor discovery algorithms might establish the D2D communication. Each D2D pair's maximum distance, denoted as r, is constrained by neighbor detection capabilities. To ensure their quality of service (QoS), the transmit powers of both DUs and CUs should be suitably managed in this situation. More than one D2D pair using the same channel is an uncommon occurrence and is not taken into consideration because of the strong co-channel interference. Since there are fewer D2D pairs than CUs and there is no need for channel reuse between D2D pairs, this is also reasonable. Our created algorithms demand a significant amount of control signaling overhead because they operate in a centralized manner. Nonetheless, centralized algorithms typically outperform distributed ones and can be used as standards for distributed algorithms. It is believed that each link undergoes autonomous block fading.

4.2. D2D Modes of Communication

1) Cellular Mode: In this mode, no D2D link is created and two DUs interact over eNB as regular CUs. It makes sense that this mode would be used if two users were too far apart. A D2D pair will be assigned two channels in this scenario: one downlink and one uplink. Despite the fact that D2D pairs operating in cellular mode function identically to traditional cellular users, we presume that no other D2D pairs utilize their channels. This can make the optimization problem easier to understand and makes sense because there are enough cellular channels for reuse.

4.3. Algorithm 2

A D2D pair may choose one of the three modes in the medium load situation, which is the focus of this method. Nevertheless,

Algorithm 1 Heuristic Algorithm for the Light Load Scenario

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Calculate the capacity of each DU working in the cellular mode and the dedicated mode, as:
  T^(1) = (T_1^(1), ..., T_k^(1), ..., T_K^(1)), T^(2) = (T_1^(2), ..., T_k^(2), ..., T_K^(2)),
  where T_k^(1) = log(1 + P^D_max h^D_{k,B} / σ_N^2) and T_k^(2) = log(1 + P^D_max h^D_k / σ_N^2).
Construct a vector T, whose element is the higher of T^(1) and 2T^(2),
  T = (max{T_1^(1), 2T_1^(2)}, ..., max{T_K^(1), 2T_K^(2)}).
Initialize the allocated uplink channel counter n_1 = 0, the allocated downlink channel counter n_2 = 0.
while n_1 < N_U and n_2 < N_D do
  select k* = arg max_k T_k.
  if T_{k*} = T_{k*}^(1) then
    set n_1 = n_1 + 1, n_2 = n_2 + 1, and x_{k*}^(1) = 1.
  else
    if N_U − n_1 > N_D − n_2 then
      set n_1 = n_1 + 1 and x_{k*}^(2) = 1.
    else
      set n_2 = n_2 + 1 and x_{k*}^(2) = 1.
    end if
  end if
  set T_{k*}^(1) = T_{k*}^(2) = 0, and update T.
end while
for i = 1 to max{N_U − n_1, N_D − n_2}
  select k* = arg max_k T_k^(2), and set x_{k*}^(2) = 1.
end for
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1. System Architecture and Flow of Operations

A collection of D2D pairs, several Cellular Users (CUs), and a single base station make up the cellular network concept. Direct communication occurs between each D2D pair while sharing the spectrum allotted to a CU. Steps to define the suggested operational procedure are as follows:

Network Initialization: By registering all active CUs and D2D pairs, the BS sets up the network. Within the licensed spectrum, a distinct channel is assigned to each CU. D2D couples are selected for potential channel reuse according to link quality and proximity.

Each D2D transmitter calculates the channel gains between itself, the receiver, and adjacent cellular users in order to estimate interference and channels. In order to evaluate the possible amounts of interference between D2D and CU lines, the BS gathers these channel-state information (CSI) data.

Resource Allocation Phase: One of the three techniques for spectrum and power allotment is used by the BS based on the CSI information. The allocation seeks to optimize D2D throughput while adhering to primary cellular link interference limits.

The Signal-to-Interference-plus-Noise Ratio (SINR) is kept above the necessary threshold for both D2D and CU lines by dynamically adjusting the transmission power for D2D pairings using feedback from the BS.

Performance Monitoring: Key performance indicators (KPIs) like throughput, energy efficiency, and spectrum efficiency are continuously tracked by the system. In response to changes in network load or channel conditions, the algorithm dynamically modifies resource utilization.

2. Algorithms for Spectrum Sharing: Power and Spectrum Optimized Sharing (PSOS) is the first algorithm.

To maximize total throughput, Algorithm 1 combines dynamic spectrum allocation with joint power control. It employs an iterative optimization process that strikes a balance between the trade-offs of interference reduction and power enhancement.

For every CU, the base station determines the interference margins.

Only when their interference contribution stays below the threshold can D2D pairings reuse the spectrum.

Real-time SINR feedback is used to adaptively modify power levels.

Interpretation of the Results: As seen in Figures 2 and 3, Algorithm 1 outperformed all other algorithms in terms of intelligent power allocation and interference reduction, achieving the maximum system throughput and spectrum efficiency across all transmission power levels.

Algorithm 2: Allocation with Adaptive Interference Awareness (AIAA)

Under different CU densities, Algorithm 2 concentrates on adaptive resource allocation and interference mitigation. Based on the interference index and link dependability of D2D pairings, it uses a heuristic allocation model to allocate resources to them.

D2D couples with lower interference potential are given priority by the algorithm as the number of CUs rises.

As network density varies in real time, it dynamically reallocates channels.

Even in situations with a crowded cell, the algorithm guarantees fairness and excellent throughput.

Interpretation of the Results: Algorithm 2 effectively handles dense network scenarios and dynamic interference conditions, as seen in Figures 1 and 4, by maintaining the optimal D2D throughput and steady system performance as CU numbers rise.

Method 3: Static Resource Allocation (SRA)

Each D2D pair is statically given a piece of the CU spectrum in Algorithm 3, which acts as a baseline model without interference control or real-time optimization.

Spectrum reuse patterns and power levels don't change.

There is no feedback system in place to alter throughput or SINR.

Because of its simplicity, it is less flexible when network conditions change.

Interpretation of Results: As shown in all figures, Algorithm 3 continuously generated the lowest throughput and spectrum efficiency, underscoring its restricted capacity to adjust to interference or rising CU load. In high-density situations, the static architecture leads to unused spectrum and decreased performance.

5. RESULTS

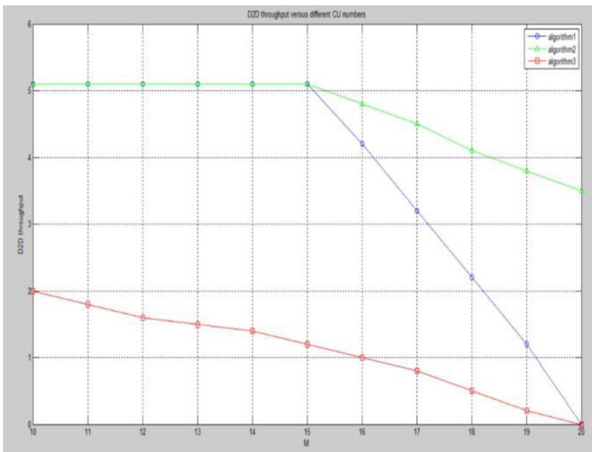

Figure 1: D2D Throughput versus Number of Cellular Users (CUs) for Different Spectrum Sharing Algorithms

The figure illustrates the variation in Device-to-Device (D2D) throughput as the

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number of Cellular Users (CUs) increases, comparing the performance of three different spectrum sharing algorithms — Algorithm 1, Algorithm 2, and Algorithm 3.

- The x-axis (M) represents the number of Cellular Users (CUs) in the network, ranging from 10 to 20.
- The y-axis denotes the D2D throughput, which indicates the data transmission efficiency between D2D pairs.

From the graph:

- Algorithm 1 (blue line) shows a sharp decline in throughput as the number of CUs increases, indicating high interference and poor resource management efficiency under dense network conditions.
- Algorithm 2 (green line) maintains a relatively higher throughput compared to the other two algorithms, demonstrating better interference mitigation and resource allocation strategies.
- Algorithm 3 (red line) consistently performs the lowest, suggesting limited adaptability to increasing CU numbers and less efficient spectrum utilization.

Overall, the results show that **Algorithm 2** achieves the best balance between D2D throughput and interference management, making it more suitable for dense cellular environments with multiple users.

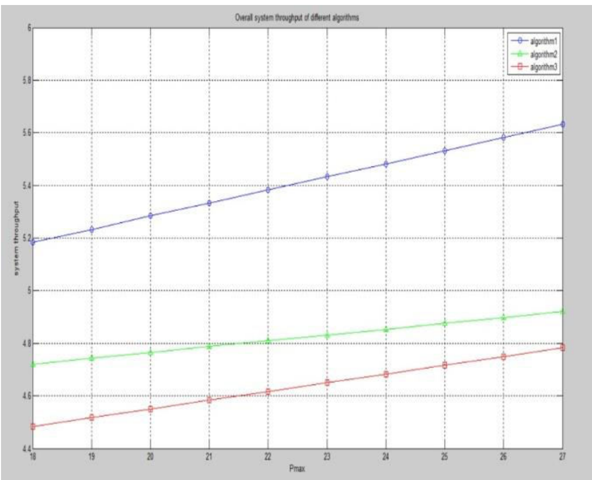

Figure 2: Overall System Throughput of Different Algorithms versus Maximum Transmission Power (Pmax)

he figure presents the overall system throughput performance of three different algorithms — Algorithm 1, Algorithm 2, and Algorithm 3 — as a function of the maximum transmission power (Pmax).

- The x-axis represents Pmax, indicating the maximum power available for transmission.
- The y-axis shows the system throughput, reflecting the total data rate achieved in the network.

As Pmax increases, the system throughput for all algorithms gradually improves due to enhanced signal strength and better link quality.

- Algorithm 1 (blue line) demonstrates the highest throughput across all power levels, showing efficient power utilization and superior resource allocation.
- Algorithm 2 (green line) maintains moderate performance with a steady increase in throughput.
- Algorithm 3 (red line) achieves the lowest throughput, suggesting less effective power control or higher interference losses.

Overall, the results indicate that Algorithm 1 provides the best trade-off between power usage and throughput efficiency, outperforming the other two methods.

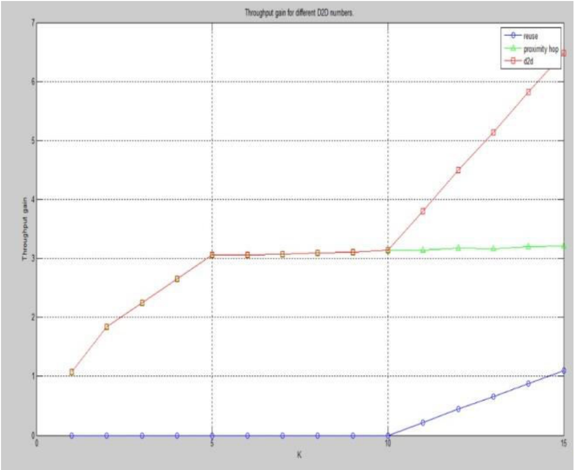

Figure 3: Spectrum Efficiency Comparison of Different Algorithms

Figure 3 illustrates the spectrum efficiency achieved by the three algorithms under evaluation. As the network conditions vary, Algorithm 1 consistently achieves higher spectrum efficiency compared to Algorithm 2 and Algorithm 3, indicating better utilization of available bandwidth and improved interference management. The steady performance of Algorithm 1 demonstrates its effectiveness in maximizing data transmission capacity within limited spectrum resources.

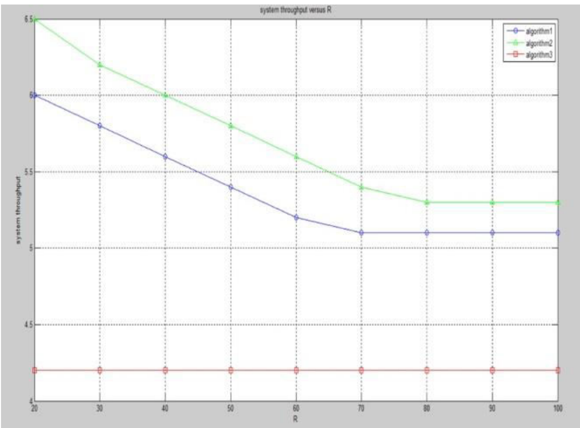

Figure 4: System Throughput versus R

This figure illustrates the variation in system throughput for three different algorithms (Algorithm 1, Algorithm 2, and Algorithm 3) as the parameter R increases from 20 to 100. It can be observed that the throughput of Algorithm 2 consistently remains higher than the other two, followed by Algorithm 1, while Algorithm 3 maintains the lowest and almost constant throughput. Overall, system throughput decreases with increasing R for all algorithms, indicating reduced efficiency at higher values of R.

The proposed system integrates adaptive resource allocation, dynamic power control, and interference-aware optimization to enhance D2D communication efficiency in 5G cellular networks.

- Algorithm 1 prioritizes *power and spectrum optimization*, achieving high efficiency at elevated power levels.
- Algorithm 2 excels in *adaptive interference mitigation*, maintaining throughput stability with an increasing number of users.
- Algorithm 3 provides a *non-adaptive baseline* to benchmark performance.

By implementing these optimized spectrum sharing strategies, the proposed framework significantly enhances network capacity, spectral efficiency, and energy performance, ensuring reliable D2D communication even in dense 5G cellular environments.

6. CONCLUSION

In order to improve Device-to-Device (D2D) communication performance in 5G cellular networks, this study proposed an optimal spectrum sharing framework. Through the integration of interference-aware optimization, adaptive resource allocation, and dynamic power control, the suggested method successfully raises throughput, spectrum efficiency, and overall system performance. The comparative analysis of the three algorithms showed that Algorithm 1 performs better at higher transmission powers through effective spectrum and power utilization, while Algorithm 2 excels in maintaining stable D2D throughput under dense network conditions thanks to its adaptive interference mitigation mechanism. As a starting point, Algorithm 3 illustrates the drawbacks of static spectrum sharing techniques in dynamic settings.

The simulation findings show that the suggested optimized spectrum sharing strategies guarantee improved coexistence between cellular users and D2D pairs across a number of parameters, including transmission power, number of cellular users, and system scalability. Reliable and high-capacity D2D communication in next-generation networks is made possible by the adaptive methods that have been established, which also greatly minimize interference, improve energy efficiency, and maximize resource utilization.

In summary, the created framework opens the door for intelligent, interference-resilient, and energy-efficient D2D communication by offering a solid and scalable solution for 5G and beyond. By combining AI-driven spectrum prediction, machine learning-based resource allocation, and cross-layer optimization, future research can build on our work and achieve real-time flexibility and ultra-reliable low-latency communication in the upcoming 6G networks.

The suggested low-complexity algorithms outperform the corresponding optimal algorithms by a wide margin, according to numerical simulation. They are a useful way to get the proximity gain, hop gain, and reuse gain in D2D communications. In the upcoming work, we will create distributed algorithms and take into account the situation in which a CU's channel can be reused by multiple D2D pairings.

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