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Dynamic Transmission Policy for Multi-Pair Cooperative Device-To-Device Communication with Block-Diagonalization Precoding

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ABSTRACT: The proposed system investigates novel methods for D2D communication within cellular networks, aiming to improve efficiency and performance. The model includes two phases: data-sharing and joint transmission. In phase 1, multicast precoders are used. The Lyapunov optimization framework is used to address long-term utility maximization problems. Virtual queues are constructed to record system state evolution, decoupling the problem into optimization problems involving short-term weighted rate adjusted for energy penalties. The NS2 simulation platform simulates and evaluates the proposed multi-paired D2D cellular communication system. The simulation results offer valuable insights into the performance metrics and efficiency improvements obtained by integrating multicast precoders in Phase 1 and coordinated block-diagonalization precoders in Phase 2. These findings illustrate the proposed framework's effectiveness in optimizing long-term utility and efficiently overcoming challenges in cellular networks. The effectiveness of the proposed model is assessed through simulation results, which measure critical performance metrics such as throughput, latency, and packet loss across different scenarios. The results offer insights into the impact of integrating specific frameworks and algorithms on multi-paired D2D cellular communication performance. The proposed system enhances understanding of multi-paired D2D communication through NS2 simulation, framework integration, and advanced algorithms. The cellular network design promotes efficient and reliable communication in dynamic environments and paves the way for future cellular network.

KEYWORDS: Device-to-Device (D2D) communication, Cellular networks, Precoders, Lyapunov optimization framework, NS2 simulation platform

I. INTRODUCTION

D2D communication, or device-to-device communication, is a method wherein devices interact directly without the need for intermediary nodes, utilizing cellular spectrum and infrastructure. This approach presents several advantages: it enables high data transmission rates, minimizes latency, and conserves energy owing to the close proximity of user equipment. Moreover, it facilitates the simultaneous utilization of radio resources by both cellular and D2D links, thereby reducing the demand for uplink and downlink resources. D2D communication has the potential to expand cellular coverage and support new wireless peer-to-peer (P2P) services. Economically, it proves advantageous as it leverages existing cellular infrastructure, thereby enhancing network efficiency. Historically, cellular operators overlooked D2D communication as a means to enhance network performance due to its perceived limited impact on local communication services. However, with the increasing reliance of mobile applications on proximity, operators are now contemplating the integration of D2D communication into their networks.

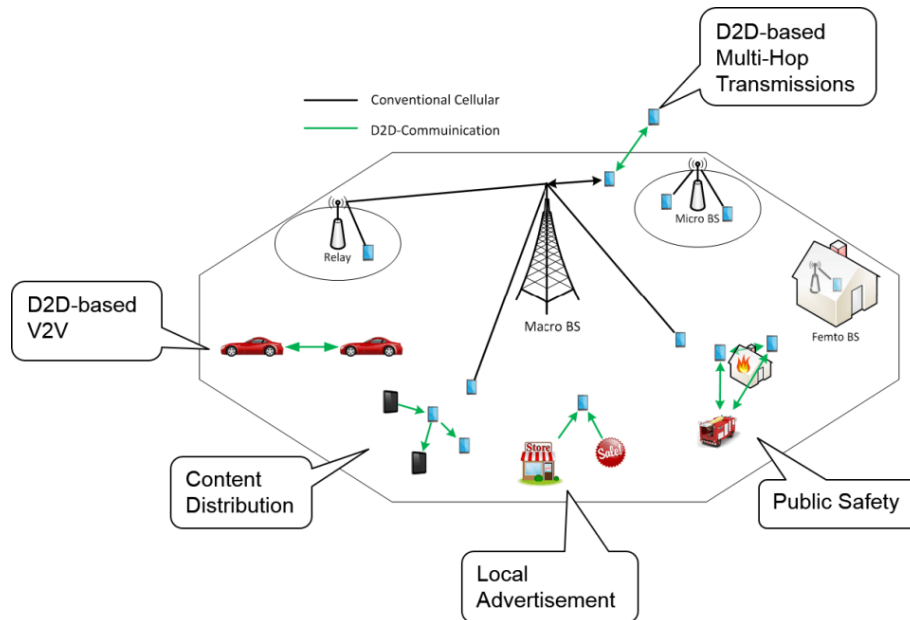


Figure 1 Basic Concept of D2D Communication

Direct-to-direct communication, also known as device-to-device communication, refers to a technique where devices engage directly without relying on intermediary nodes, utilizing cellular spectrum and infrastructure. This method offers numerous benefits: it enables high-speed data transmission, reduces latency, and conserves energy due to the proximity of user equipment. Additionally, it allows for the simultaneous use of radio resources by both cellular and direct-to-direct links, thereby decreasing the need for uplink and downlink resources. Direct-to-direct communication has the potential to extend cellular coverage and support new wireless peer-to-peer (P2P) services. From an economic perspective, it is advantageous as it utilizes existing cellular infrastructure, thereby improving network efficiency. Traditionally, cellular operators neglected direct-to-direct communication as a means to enhance network performance because of its perceived limited impact on local communication services. However, with the growing reliance of mobile applications on proximity, operators are now considering integrating direct-to-direct communication into their networks.

1.1 Objective

- To enable direct communication between devices without intermediate nodes using cellular spectrum and infrastructure.
- For attaining elevated data transfer speeds, minimal latency, and decreased energy usage attributed to the proximity of user devices.
- For enabling concurrent utilization of wireless resources by cellular networks and device-to-device (D2D) connections, thereby diminishing the necessity for separate uplink and downlink resources.
- For expanding cellular reach and enabling the adoption of innovative wireless peer-to-peer (P2P) functionalities.
- To use the same cellular infrastructure economically, increasing network efficiency and enhancing network performance for mobile applications.

II. LITERATURE SURVEY

The research presents an innovative out-of-band device-to-device communication system with high capacity for cellular networks. It employs a medium access control (MAC) protocol to regulate transmissions. The system dynamically adjusts the size of the backoff window depending on network conditions and the appropriate transmission attempt rate. Through the MAC layer protocol, network throughput is improved by adapting CW_{min} according to network settings. Furthermore, the system employs a unique approach to select transmission attempt rate and packet length, ensuring they don't increase with the number of active nodes. Results indicate a throughput enhancement of at least 17.86% and 62.07% with and without the RTS/CTS mechanism, respectively [1].

The D2D-V system, merging Device-to-Device and Vehicle-to-Vehicle communication, provides instant traffic updates, accident alerts, reports on traffic violations, and navigation assistance in foggy conditions. Scientists have devised algorithms for managing messages and verifying the authenticity of Road Side Units and On-Board Units, and have devised an identification scheme for Non-Registered Vehicles. Simulated outcomes confirm the feasibility of the model regarding latency, packet delivery rate, data accuracy, throughput, and spectral efficiency. Adopting D2D-V has the potential to lower construction and upkeep expenses, facilitate smart city initiatives, and enhance spectral efficiency [2].

The suggested architectural design integrates Device-to-Device (D2D) communication with Software-Defined Networks (SDN) technology to optimize mobile network performance. It merges the SDN controller and proximity server for D2D communication within a centralized controller at the core network. This integration offers a streamlined and effective method for administering and facilitating direct D2D communication among mobile devices. Additionally, the system prioritizes efficient energy usage during peer discovery and pairing processes, resulting in increased data throughput and reduced network latency. To tackle interference problems and enhance device battery longevity, the proposed system utilizes out-of-band Wi-Fi technology [3].

The suggested architectural design integrates Device-to-Device (D2D) communication and Software-Defined Networks (SDN) technologies to improve mobile network performance. It consolidates the SDN controller and proximity server for D2D communication within a centralized controller at the core network. This setup offers a convenient and efficient method for overseeing and facilitating direct D2D communication among mobile devices. Energy efficiency is prioritized during peer discovery and pairing processes, resulting in increased data throughput and reduced network latency. Out-band Wi-Fi technology is employed to mitigate interference problems and enhance device battery life [4].

The optimization challenge entails the efficient distribution of resources among cellular users (CUs) and D2D pairs within cellular networks. A four-step resource allocation algorithm, characterized by low complexity, is introduced. This algorithm employs a distance-based approach to construct a graph determining the suitability of resource reuse, delineating three distinct regions. Subsequently, a pairing mechanism is employed to identify the optimal set of D2D pairs for spectrum sharing, thereby maximizing network throughput. The algorithm's efficacy is evaluated based on network throughput, outage probability, and computational complexity. QARA demonstrates near-optimal network throughput with a reduced number of D2D pair candidates, surpassing R-ICA in terms of maximizing network throughput [5].

The article examines the application of network coding in relay-assisted D2D communications, particularly in dual-hop communication scenarios. It introduces an effective relay node selection mechanism, referred to as eNodeB, which oversees spectrum resource management and facilitates streamlined communication among devices within a single cellular cell. The research contrasts relay-based D2D communications without network coding against those employing IDNC and RLNC, focusing on end-to-end loss probability. Findings indicate a notable reduction in loss probability with the utilization of network coding, with RLNC demonstrating superior performance over IDNC. Simulations explore the effects on end-to-end loss probability, coding and decoding durations, and the quantity of decoded packets [6].

The objective of the study is to enhance the capacity of 5G-based networks through the improvement of direct-to-device (D2D) communications utilizing LTE mobile terminals. Utilizing stochastic geometry techniques, the research endeavors to develop a distinctive protocol employing LTE mobile terminals strategically positioned near significant events. Leveraging machine learning, wireless network performance can be optimized by gathering data on the radio environment and constructing a performance model that illustrates the correlation between wireless parameters and throughput. This approach enhances the overall system performance by transmitting wireless parameters to mobile terminals, thereby facilitating enhanced battery life and performance in cognitive radios [7].

The approach introduces a systemic model for multiple sets of Direct-to-Distributed (D2D) users to interact via a single relay, with the goal of alleviating base station burden and tackling communication resource scarcities. Network coding (NC) is implemented to enhance performance, alongside a relay selection approach that integrates factors such as relay proximity, communication payload, remaining energy, and system capability. This streamlined method markedly enhances attainable system capacity post the assistance of network coding in communication and relay selection. The

model is tailored to real communication scenarios, especially in hotspot regions where numerous users concurrently request information [8].

The idea delves into the creation and execution of a Wireless Sensor Network (WSN) in Network Simulator (NS2), a software utilized for analyzing the ever-changing dynamics of computer networks. NS2 furnishes users with an executable command known as 'ns', which requires an input argument. Network Animator (NAM) facilitates the visualization of network simulation traces and real-world packet traces, while scripting languages such as AWK and PERL can aid in performance metric calculations. The energy consumption approach relies on the rechargeability of the battery. A simulation lasting 100 milliseconds was carried out, employing the DSDV routing protocol and 802.11 MAC protocol [9].

The NS2 network module serves as a potent resource for instructing wireless network courses, enriching students' comprehension of network protocols via visualization and problem analysis. It finds application within a multimedia wireless network modularized English teaching platform, facilitating substantial code reuse and minimizing simulation code development duration. The platform's architecture adheres to the B/S structure, while the learning input evaluation index is addressed employing the feedback elite teaching optimization algorithm. NS2 effectively simulates diverse IP network environments and network protocols such as TCP, UDP, and data source generators. It furnishes a cohesive interface, ensures connection isolation, and maintains high security standards through authentication, authorization, and encryption mechanisms [10].

The methodology involves analyzing opportunistic beamforming with random user locations, focusing on outage capacity, a key performance metric in wireless communications, using mathematical models and simulations. Stochastic geometry models random user locations in a cellular network, examining the impact of user distribution on beamforming performance. Analytical expressions for outage probability and capacity are derived and validated through extensive simulations, highlighting the importance of considering user location randomness in beamforming design and optimization [11].

The research examines the efficacy of opportunistic beamforming employing Time Division Multiple Access (TDMA) and Space Division Multiple Access (SDMA). The methodology involves comparing these two schemes under various network conditions, utilizing theoretical analysis and computer simulations to evaluate system performance in terms of throughput and fairness. Models simulate TDMA and SDMA behavior in opportunistic beamforming scenarios, considering user scheduling, channel conditions, and beamforming techniques. Comparative analysis provides insights into the advantages and trade-offs of each access scheme in different deployment scenarios [12].

The research focuses on non-orthogonal opportunistic beamforming, examining its performance and implementation. The methodology includes theoretical analysis, algorithm development, and simulation. A new beamforming scheme allows multiple users to share the same beam, enhancing spectral efficiency. Performance metrics such as signal-to-noise ratio (SNR) and throughput are derived, comparing the new scheme with traditional orthogonal beamforming. Simulations validate theoretical findings, demonstrating potential gains in system performance through non-orthogonal beamforming [13].

The conference paper presents a methodology for opportunistic beamforming with superposition coding, using a combination of analytical modeling and simulation to explore the benefits of superposition coding in beamforming systems. Mathematical models describe the interaction between beamforming and superposition coding, evaluating system performance metrics such as capacity and bit error rate. Simulations involve varying the number of users and channel conditions to assess robustness and effectiveness, indicating significant performance improvements over traditional beamforming methods [14].

The research presents a collaborative iterative optimal resource allocation algorithm for non-orthogonal multi-user and multi-weight opportunistic beamforming systems. The methodology combines optimization techniques with iterative algorithms, formulating the resource allocation problem as an optimization problem, employing Lagrangian multipliers and iterative methods to solve it. Simulations evaluate the algorithm's performance in terms of resource utilization, user fairness, and overall system throughput. The iterative approach ensures convergence to an optimal solution, maximizing resource allocation efficiency in beamforming systems [15].

The paper discusses multi-user shared access in massive machine-type communication (mMTC) systems through superimposed waveforms. The methodology involves designing and evaluating superimposed waveform schemes for mMTC, developing mathematical models to describe the waveform superposition process, and analysing its impact on system performance. Simulations compare proposed schemes with traditional access methods, focusing on metrics such as spectral efficiency, error rates, and user capacity. Results demonstrate the effectiveness of superimposed waveforms in enhancing mMTC system performance [16].

The study investigates the utilization of limited feedback unitary precoding for orthogonal space-time block codes (OSTBC). The methodology includes developing precoding algorithms and performance evaluation through simulations. A unitary precoding scheme that requires limited feedback from the receiver to the transmitter is proposed, reducing feedback overhead. Analytical expressions for system performance metrics such as bit error rate and capacity are derived. Simulations validate the theoretical analysis, showing near-optimal performance with significantly reduced feedback requirements [17].

The research centers on optimizing beamforming and time allocation for partially wireless-powered sensor networks, incorporating downlink simultaneous wireless information and power transfer (SWIPT). The methodology involves formulating an optimization problem and developing algorithms to solve it, using convex optimization techniques to determine optimal beam forming vectors and time allocation that maximize the sum rate while ensuring sufficient energy harvesting. Simulations evaluate the proposed algorithms under various network conditions, demonstrating their effectiveness in enhancing SWIPT-enabled sensor network performance [18].

The paper presents a hybrid channel estimation technique for intermittent wireless connections, combining ℓ_1 -norm least squares (ℓ_1 LS) and ℓ_2 -norm minimum mean square error (ℓ_2 MMSE) methods. The methodology involves developing a hybrid estimation algorithm that leverages the sparsity of wireless channels, deriving analytical expressions for estimation error, and evaluating algorithm performance through simulations. The hybrid approach aims to improve the accuracy and robustness of channel estimation in scenarios with intermittent connectivity, enhancing wireless communication system reliability [19].

The conference paper pairing algorithm with successive interference cancellation (SIC) in non-orthogonal multiple access (NOMA) systems. The methodology includes designing and evaluating the user pairing algorithm, developing a mathematical model to describe the NOMA system with SIC, and formulating the user pairing problem as an optimization problem. Simulations assess the proposed algorithm's performance in terms of throughput, fairness, and complexity, indicating effective improvements in NOMA system performance through optimized user pairing and interference management [20].

III. PROPOSED METHODOLOGY

A. Multicast Precoders

Multicast precoders enhance wireless communication by optimizing multicast transmissions, where one source sends data to multiple destinations simultaneously. They improve system performance by considering factors like signal quality, interference, and energy efficiency. Typically associated with multiple antenna systems such as MIMO (Multiple Input, Multiple Output), multicast precoding uses spatial multiplexing to transmit independent data streams from multiple antennas to different users. Linear precoding methods such as zero-forcing (ZF) and minimum mean square error (MMSE) precoding are widespread. ZF eradicates interference among streams, whereas MMSE reduces the mean square error between transmitted and received signals. Dirty Paper Coding pre-cancels interference at the transmitter, enabling simultaneous interference-free transmissions to multiple users. Network coding mixes information at intermediate nodes, boosting multicast communication efficiency. These techniques also aim to enhance energy efficiency by optimizing resource use, especially with multiple antennas.

B. Multicast Precoders In D2d Wireless Communication

In wireless communication, especially in D2D, multicast transmits data from one sender to multiple receivers simultaneously. Precoding optimizes this transmission through specific signal processing at the transmitter. In D2D communication, multicast precoders are algorithms designed to enhance transmission by mitigating interference, improving spectral efficiency, and ensuring reliable communication. The precoding process relies on accurate Channel State Information (CSI) to adapt the transmission strategy. Multicast precoding algorithms use this CSI to optimize

signal quality and minimize interference, considering the spatial characteristics of the wireless channel. Managing interference, such as through beamforming or nulling, ensures successful multicast signal reception. Improving spectral efficiency, multicast precoders allow multiple D2D devices to communicate concurrently without significant performance loss. Researchers use the network simulation tool NS2 to evaluate the impact of multicast precoders on performance metrics like throughput, latency, and reliability.

3.1 Multiple Input Multiple Output (MIMO)

MIMO technology amplifies wireless communication by employing multiple antennas at both the transmitter and receiver to concurrently transmit and receive multiple data streams. Key in Wi-Fi, LTE, and 5G, MIMO's main advantage is spatial multiplexing, allowing multiple data streams to occupy the same frequency channel. This leverages the multiple antennas for different spatial channels, improving performance by reducing fading and increasing link reliability.

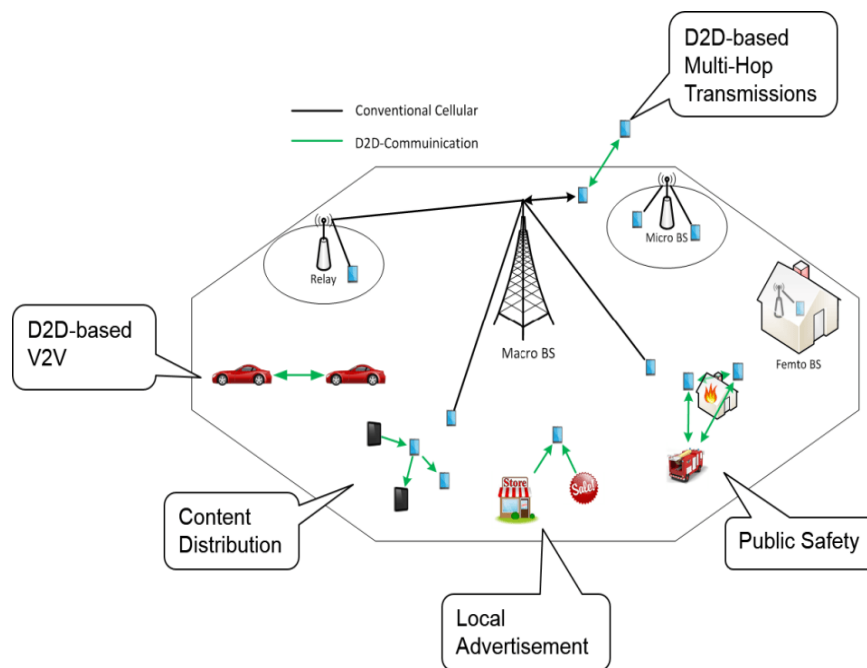


Figure 2 shows synchronized multicasting for massive MIMO across multiple cells

MIMO systems also use beamforming to direct energy towards the receiver, enhancing signal strength and overall performance. Precoding optimizes the signal before transmission, while postcoding processes the received signal to accurately extract the transmitted data.

A. Multiple Input Multiple Output (MIMO) In D2d Communication

Multiple Input, Multiple Output (MIMO) technology, widely used in wireless communication, enhances spectral efficiency and performance. In device-to-device (D2D) communication, MIMO offers benefits like spatial multiplexing for simultaneous data streams, boosting data rates, and spectral efficiency, making it ideal for high-throughput applications. It improves link reliability by exploiting spatial diversity and mitigating fading effects. MIMO reduces interference through strategic designs and enhances signal quality with beamforming. Efficient resource allocation is vital for optimizing D2D performance. Additionally, MIMO improves energy efficiency and enables cooperative communication among D2D pairs, where multiple antennas collaboratively enhance system performance.

3.2 LYAPUNOV Optimization Framework

Lyapunov optimization is a control technique using a Lyapunov function to ensure system stability. In control theory, these functions measure system states, growing large in undesirable states. Control actions aim to reduce the Lyapunov function towards zero, stabilizing the system. To optimize queueing networks, minimizing the deviation of a quadratic Lyapunov function leads to the implementation of the backpressure routing (max-weight) algorithm. Adding a penalty term yields the drift-plus-penalty algorithm for joint stability and performance optimization. In D2D communication, this framework maximizes link sum rates under power constraints and interference management using Lyapunov optimization techniques.

3.3 NS2 Simulation

NS2, known as Network Simulator 2, serves as a discrete event simulator extensively employed for both research and educational purposes within the realm of computer networks. It provides users with the capability to replicate intricate networking scenarios and assess the efficacy of diverse network protocols and algorithms within a regulated setting. NS2 is primarily used for modeling wired and wireless networks, including protocols such as TCP/IP, UDP, routing algorithms, and traffic management mechanisms. Its flexibility and extensibility make it a valuable tool for network researchers and engineers to test new ideas, compare different approaches, and analyze the behavior of network systems under diverse conditions. With its open-source nature, NS2 encourages collaboration and the development of novel solutions to address challenges in network design, optimization, and security.

IV. RESULT AND DISCUSSION



Figure 3 Fixed Network Grid with 20 nodes

The Figure 3 shows the simulation focuses on experimenting with a specific type of grid system, aiming to assess the performance of systems across various scales and types. The grid network comprises 20 nodes arranged in a 5×4 matrix configuration. The default packet size used in this simulation is 512 bytes, and the time interval ranges from 0.1 to 0.2 seconds. The simulation duration spans 2 seconds, providing a comprehensive evaluation of the systems under consideration.



Figure 4 Fixed Network Grid with 20 nodes and Yellow colored Node are ready to Send Data

Figure 4 depicts a simulation of wireless Device-to-Device (D2D) communication utilizing NS2, where the nodes are differentiated by distinct colors. The node highlighted in yellow is identified as the sender, while the remaining nodes, represented in green, function as receivers. Notably, the red-colored node received a significant amount of data.

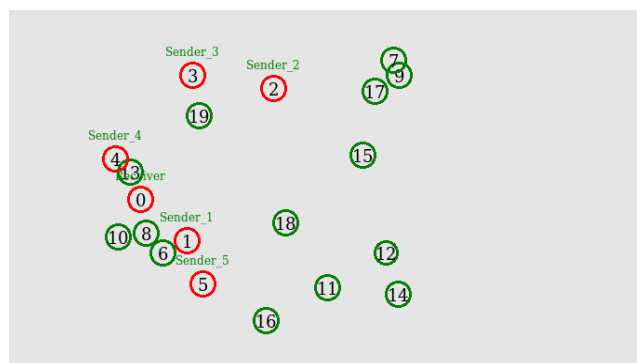


Figure 5 Fixed Network Grid with 20 nodes

Figure 5 demonstrates a simulation of wireless Device-to-Device (D2D) communication using NS2, where nodes are represented by distinct colors. The nodes receiving high data are highlighted in red, while those in green are designated as receivers.

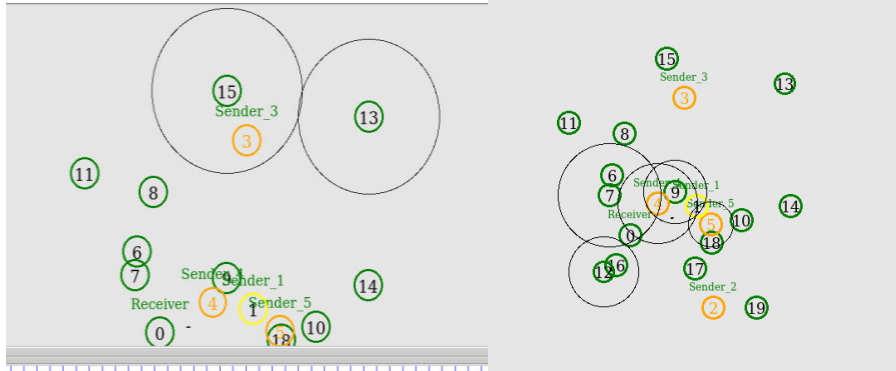


Figure 6 Data Transmission between nodes and Data transmission between multiple nodes

Figure 6 illustrates the data transmission process between nodes in the NS2 simulation output. In network simulations, NS2 (Network Simulator 2) is a widely used tool for modeling and analyzing the performance of communication networks.

In Figure, we observe multiple nodes connected in a network topology, each represented as a distinct point or entity. The circle between these nodes illustrate the transmission of data between them.

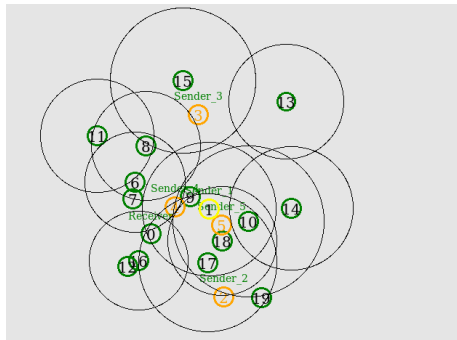


Figure 7 the activity modes of neighbor nodes of Node by transmitting packets in a time slot

The figure 7 represents xgraph-in-ns2 output screen displays performance metrics from simulations, allowing for analysis of D2D wireless communication systems. It shows throughput, delay, packet loss, signal strength, and potential bottlenecks. Analyzing these graphs helps identify bottlenecks, optimize network parameters, and enhance performance. The results also assess scalability and network planning.

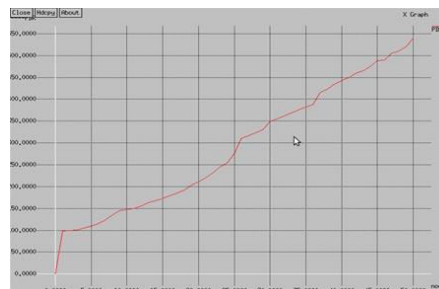


Figure 8 xgraph-in-ns2 output-screen

V. CONCLUSION

The intended system seeks to enhance the effectiveness and performance of multi-pair cooperative Device-to-Device (D2D) communication within cellular networks. The framework comprises two stages: multicast Precoders in Phase 1 and coordinated block-diagonalization precoders in Phase 2. The Lyapunov optimization framework addresses long-term utility maximization challenges, while virtual queues decouple the optimization problem into manageable short-term components. The NS2 simulation platform evaluates the proposed system, providing valuable insights into performance metrics and efficiency gains. Simulation outputs show improvements in throughput, latency, and packet loss under various scenarios, highlighting the framework's ability to optimize long-term utility while efficiently addressing cellular network challenges. Methods such as zero-forcing, minimum mean square error, dirty paper coding, and network coding are investigated for their possible roles in spatial multiplexing, interference mitigation, and energy efficiency in multicast scenarios. The simulation results highlight the importance of understanding network dynamics and neighbor node activities, and the role of ns2 simulation software in modeling and simulating complex network scenarios. The proposed dynamic transmission policy advances the field of multi-paired D2D communication, offering a comprehensive framework to address key challenges in cellular networks. In future clearly define the problem you aim to address with a dynamic transmission policy for multi-pair cooperative communication. Highlight the importance and potential applications of such a policy in improving network performance, resource utilization, or other relevant metrics.

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