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Relay Assisted Device-to-Device Communication for Future Generation Wireless Networks: A Review from Architectural and Challenges Perspective

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ABSTRACT

The rapid evolution of wireless communication technologies, along with the increasing demand for efficient and reliable data transfer, has driven the rethinking of traditional cellular network architectures in the context of next-generation networks. In conventional cellular systems, communication between users typically occurs through base stations. However, to improve efficiency, scalability, and spectral utilization, device-to-device (D2D) communication has been introduced, enabling direct data transmission between users without base station involvement. In this paper, we present a comprehensive review of D2D communication from architectural and challenges perspective for future generation networks. Additionally, the study focuses on relay-assisted D2D (RAD2D) communication, examining the role of machine learning (ML) and artificial intelligence (AI) in optimizing relay selection processes. In light of the existing literature, challenges for implementing RAD2D are discussed from different perspectives such as relay selection, energy efficiency, secure communication, resource allocation, and the management of dynamic network conditions.

Key words: Future Generation Networks, Artificial Intelligence, Device-to-Device, Internet of Everything, Machine Learning, Relay Selection.

1. INTRODUCTION

The increasing demand for secure and efficient communications is particularly evident in mobile and wireless communication systems, due to the rapid proliferation of connected devices and the growing complexity of network environments. However, traditional cellular communication systems often face network capacity limitations when operating under certain conditions, such as high traffic volumes, high user densities or stringent quality of service requirements. These limitations can result in reduced performance, congestion and higher operating costs. As a result, these challenges have spurred significant research interest in exploring alternative communication paradigms, such as D2D communication, heterogeneous networks, or advanced relay selection techniques, with the aim of increasing network efficiency, reducing costs, and improving overall system scalability.

The growth in the number of devices and the diversification of usage purposes will result in an increased demand for spectrum resources in fifth generation (5G) networks. This is due to the advancement of mobile applications and the rise in the number of end users. As demand for network resources increases, it is anticipated that traffic load, base station (BS/eNB) and central resource management burdens will rise in proportion. Consequently, the services provided to satisfy the demands of mobile and wireless communication have resulted in an increased requirement for higher bandwidth in cellular networks, more efficient communication, or the necessity for alternative architectural solutions.

The exponential growth in mobile data traffic and the concomitant surge in demand for efficient, reliable, and low-latency communication have propelled the evolution of wireless networks toward 5G and beyond, as evidenced by the increasing prevalence of wireless technologies and the development of new wireless applications. Next-generation networks are designed to support a diverse array of applications, including the Internet of Things (IoT), augmented reality (AR), virtual reality (VR), and ultra-reliable low-latency communication (URLLC). It is therefore imperative that innovative solutions are developed which enhance network capacity, spectral efficiency and energy efficiency while minimising interference and maximising connectivity. In response to these challenges, D2D communication emerges as a promising solution, as it allows devices to communicate directly without routing data through the BS, thus reducing network load, latency, and energy consumption.

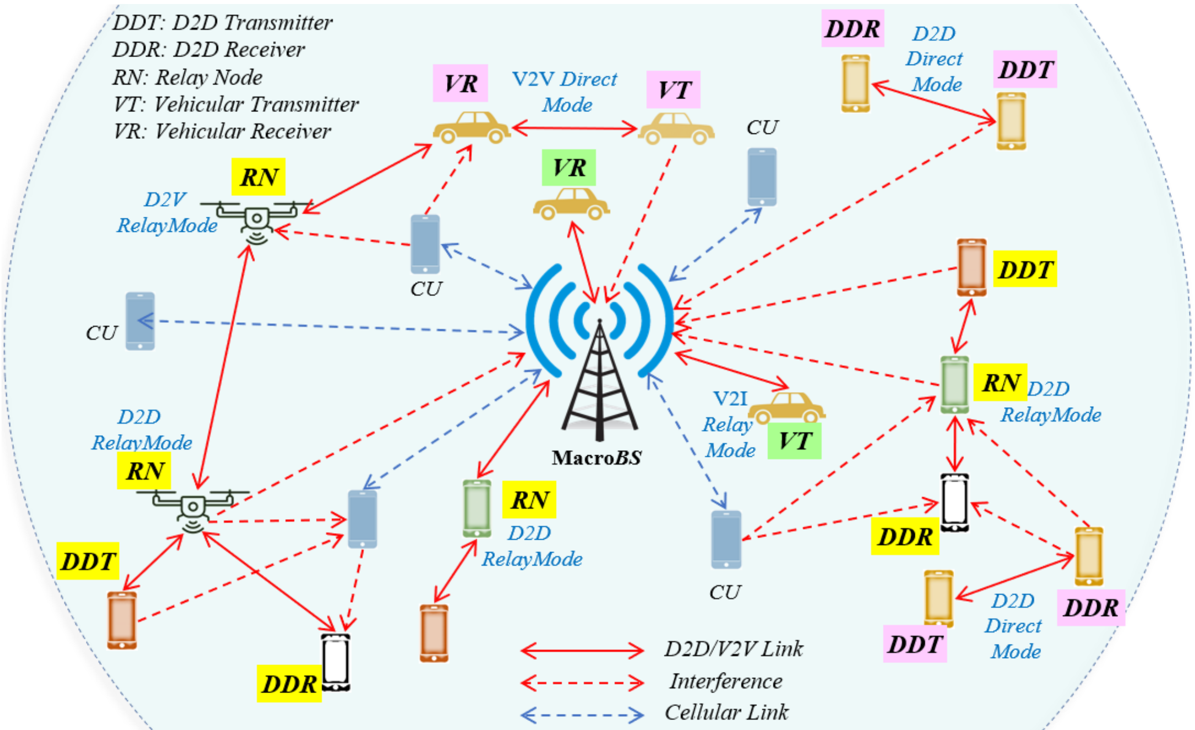

Figure 1: D2D/Vehicle-to-Vehicle/Cellular Communication: Direct, Relay-Assisted, and Base Station Communication

In recent years, D2D communication has emerged as a prominent alternative to traditional cellular communication, particularly in scenarios where direct device communication offers significant efficiency gains. Figure 1 illustrates operation modes of D2D devices in a wireless environment. Proximity-based communication enables D2D to enhance spectrum utilization and performance efficiency, while also facilitating the implementation of applications such as proximity-based services, public safety communication, and machine-to-machine (M2M) interactions. However, the intrinsic characteristics of D2D communication give rise to challenges pertaining to efficient resource allocation, interference management, and connection reliability. One of the most significant challenges is the process of selecting an appropriate relay device, which is essential for ensuring reliable and efficient communication between the source and target nodes. The selection of an appropriate relay device is of particular importance in scenarios characterized by high device density, mobility and dynamic network environments, which are among the anticipated features of next-generation networks. This study presents a comprehensive review of D2D communication with focus on relay selection in D2D, the role of AI in relay selection for RAD2D, and challenges for RAD2D communication.

2. DEVICE-TO-DEVICE (D2D) COMMUNICATION

In contrast to the architecture of conventional cellular networks, in which all devices are connected to the base station, 5G mobile networks are characterised by a growing need for architectural solutions that enhance point-to-point efficiency between devices. This is exemplified by Massive Machine Type Communication (mMTC).

D2D communication represents a pivotal solution that facilitates direct communication between mobile devices, thus preventing the cellular infrastructure from becoming overloaded. The objective of this technology is to reduce the dependence of mobile devices on the cellular infrastructure, thereby enhancing the efficiency of data transmission and increasing the capacity of the network. By enabling direct communication between two mobile devices in proximity, D2D communication alleviates the burden on the BS, enhancing energy and channel efficiency while addressing other issues. D2D communication has the potential to enhance overall network performance, reduce latency and optimize energy consumption. It offers an effective communication solution, particularly in high-density or remote areas. In D2D communication, transmission to distant devices that cannot be accessed directly by the initiating devices is facilitated through intermediate devices (relays), enabling data delivery.

D2D communication can be conducted over either unlicensed or licensed frequency spectrum. The reuse of licensed cellular frequency bands occurs in two distinct modes: underlay in-band D2D and overlay in-band D2D [1]. While reusing resources increases spectral efficiency, it also results in interference between D2D and cellular users. To ensure efficient communication between cellular and D2D devices, it is essential to implement effective governance in key areas such as power usage, resource allocation, channel efficiency gains, connection reliability, and interference prevention.

In next-generation networks, the use of D2D communication is faced with several challenges, particularly in scenarios where efficient communication with the target device is only possible through the use of a relay device. These challenges include the efficient allocation of resource blocks (RBs) on the relay, optimizing overall throughput, identifying the relay candidate with the best link suitability among the source, relay, and target devices, preventing interference, and ensuring sustainable and reliable communication. In cases where there is a high density of dynamic relay devices, the complexity that must be overcome for successful relay selection may increase.

Despite the additional overhead introduced by D2D communication in cellular networks, it has a beneficial impact on the overall performance and capabilities of the system. D2D communication enables two user equipment (UE) devices to exchange data either directly or through a BS or an IoT device acting as a relay. In relay-assisted communication, two equal time slots are utilized by a relay device.

Upon becoming active, a UE initiates a connection with the nearest eNB/BS. Each UE transmits channel state information (CSI) to the eNB, which then monitors the quality of the channel. The CSI comprises the signal-to-interference and noise ratio (SINR). If the SINR exceeds a predefined threshold, the UE establishes a direct communication link with the eNB; if it is below the threshold, the UE operates in D2D mode. This assessment of the UE relationship, in the context of uplink (UL) transmission mode, is applicable to Narrowband IoT (NB-IoT) [2].

In D2D communication, two distinct approaches to resource allocation are employed [3]: a centralized approach, whereby resources are controlled by the base station, and a distributed approach, whereby resource control is managed by each UE involved in the D2D connection.

Non-orthogonal multiple access (NOMA) enables the concurrent allocation of a single frequency channel to multiple users within the same cell [4], thereby enhancing spectral efficiency (SE) and facilitating channel feedback. For this reason, it is often the preferred option over orthogonal multiple access (OMA). Furthermore, the self-interference cancellation (SIC) [5] feature serves to reduce interference, thereby enabling a greater number of users to utilise the same frequency simultaneously. Additionally, the deployment of the orthogonal frequency division multiple access (OFDMA) modulation technique allows the available bandwidth to be shared among multiple users.

2.1 D2D Communication Models

A. Inband D2D Communication

The term "spectrum access" is defined in two distinct ways: underlay and overlay. In underlay inband communication, cellular resources are shared between D2D and cellular links (CL), whereas in overlay inband D2D communication, dedicated cellular resources are allocated separately for both D2D and CLs. Inband spectrum sharing has the effect of enhancing the QoS and increasing the SE by providing control over licensed cellular spectrum [1]. Nevertheless, the reuse of resources may result in interference between D2D and CLs, thereby necessitating the implementation of well-designed resource allocation (RA), power allocation (PA), and mode selection schemes to mitigate this issue. D2D links can perform underlay data transmissions by reusing the UL or downlink (DL) resources of cellular users (CUs). Due to the higher downlink speeds, DL spectrum sharing is more frequently preferred and is more suitable for D2D communication at cell edges. Furthermore, in these regions, interference from the BS does not impact D2D links. UL resource sharing, on the other hand, causes less interference in D2D communication because it requires lower transmission power.

In underlay, overlay, and D2D relay communication modes, the cellular spectrum can be reused [6]. These modes facilitate the efficient sharing of spectrum, thereby enabling cellular and D2D communications to utilize the same resources simultaneously.

1. Underlay: The concurrent utilization of the identical spectrum band by both cellular and D2D links is defined as spectrum sharing. In this scenario, both cellular and D2D links communicate via the same frequency band.
2. Overlay: In overlay D2D communication, cellular resources (frequency spectrum and time slots) can be allocated for D2D links. In this mode, interference is avoided; however, due to the limited availability of cellular resources, communication performance may be lower. Resources are shared between cellular and D2D communication over time.
3. Relay: The relay mode is classified into two categories: normal relay and collaborative relay.
   a. In Normal Relay mode, any device assumes the role of an intermediate node between the source and destination, facilitating the transmission of data from a D2D connection.
   b. In Collaborative Relay mode, the D2D relay constitutes an integral component of the cellular connection between the UE and the BS. The data transmission process is comprised of three distinct stages: initially, the CU transmits its data to both the BS and the D2D relay; subsequently, the relay forwards the CU data to the BS; and finally, the relay and the source node engage in a data exchange.

B. Outband D2D Communication

In overlay outband communication, devices that employ D2D technology can utilize unlicensed spectrum to enable simultaneous D2D and cellular communication (CC), thereby eliminating interference between D2D and cellular networks. However, to utilize these unlicensed bands, devices must be equipped with an interface that is compatible with technologies such as Bluetooth, WiFi Direct, or ZigBee. Furthermore, the management and control of unlicensed spectrum for outband D2D can present challenges. Outband D2D communication is divided into two types: controlled and autonomous [1]. In controlled outband communication, D2D connections are managed by the cellular network, thereby improving overall system performance (e.g. data rates, energy efficiency). In autonomous outband communication, devices can independently establish D2D connections, thereby reducing the load on the base station.

2.2 D2D Models

In general, these modes of communication can be classified as either direct or relay assisted. However, studies have further subdivided the relay-assisted category into two subcategories: one-way relaying (OWR) and two-way relaying (TWR) [1].

A. Direct D2D Communication

In situations where the distance between devices is relatively short, D2D communication may be the preferred option. However, it is important to consider the impact of channel gain (CG) between the devices in such cases. Direct communication can result in lower resource consumption and improved performance.

B. Relay-Aided D2D Communication

The necessity for long-distance communication in next-generation applications has increased the importance of relay-assisted wireless networks. In circumstances where the distance between the source and the destination is considerable, when there are significant disruptive factors present within the communication channel, or when direct communication is not a viable option, the use of relay-assisted D2D communication may be a preferred solution. This type of communication is conducted in accordance with the QoS priority of the relay user. It is essential to consider the consumption of both D2D user pairs and relay users during communication. Furthermore, distance constraints between D2D users and between the transmitter and receiver must be observed. D2D users may encounter interference from other D2D pairs and relay nodes.

C. Cooperative D2D Communication

To enhance efficiency, a relay-assisted cooperative communication mode has been proposed in addition to relay-assisted D2D communication. This mode permits the utilisation of both direct and relay-assisted communication between the source and the destination. The relay device collates and integrates data from two disparate communication pathways through the application of network coding (NC) methodologies, subsequently transmitting the re-encoded packet to the destination [1]. The destination, with the assistance of decoding algorithms, merges the packets received directly and via the relay to reconstruct the original packets.

D. Multiplexing Mode

D2D users communicate by sharing the resources of cellular users and only consider the selection of a single relay node [7]. Orthogonal Frequency Division Multiplexing (OFDM) technology is employed in a single cellular network to multiplex uplink resources in D2D communication, thereby optimising spectrum utilisation.

3. RELAY ASSISTED D2D (RAD2D) COMMUNICATION

The process of one or more devices requesting assistance from one or more relay devices to transmit information is referred to as relaying. In this communication model, there are three principal nodes: the source, the relay, and the destination node. The three-node communication channel has several variations, including the use of multiple relays, multi-antenna relays, and buffered relays. The cooperative communication method can be applied in the links between the source and the destination, as well as between the source and the relay. This method is suitable for scenarios where multiple source devices jointly transfer data, and in such scenarios, the source devices can also function as relays [5].

In a network comprising numerous relays and multi-hop communication, direct communication between the source and destination may be unfeasible. In such instances, it is imperative to implement suitable routing protocols. The relay function may be performed by either network-based or user devices. Network-based relays are typically fixed, such as base stations, whereas user devices may be mobile and perform the relay function randomly and conditionally [5]. The deployment of relays can enhance the reliability of a network, extend the range of coverage, conserve power, and reduce costs. However, the use of relays is not without limitations. In uplink communication, relays consume energy while listening to and transmitting incoming signals. While the use of relays can reduce the transmission power of D2D devices, it also helps balance secure communication and power consumption.

3.1 One-Way Relay Transmission

In the event that communication between the source and the destination is conducted via a relay node (RN), the process of messaging is divided into four distinct stages [1]. The initial two stages encompass the successive transmission between the "D2D Transmitter – Relay Node – D2D Receiver" (DDT – RN – DDR), whereas the subsequent two stages are indispensable for transmission in the inverse direction. OWR serves to extend network coverage when the performance of direct communication between the source and the destination is suboptimal. This mode divides the transmission time interval into two equal parts, thereby reducing the distance. However, in half-duplex communication, the spectral efficiency is reduced by a factor of two in comparison to direct transmission.

In the context of OWR D2D communication, a range of resource and power allocation techniques have been proposed with the objective of enhancing data rate and energy efficiency (EE) [1]. These techniques include convex optimisation, Lagrangian duality, the Dinkelbach method, stable matching theory, and greedy algorithms. It has also been observed that optimal relays are selected to maximise data rate and improve EE by geographically identifying the most suitable relays. In socially aware networks, the most suitable relay is selected based on the social ties between the nodes.

3.2 Two-Way Relay Transmission

The system can perform message exchanges in two stages, utilising physical-layer network coding (PNC) technology to enhance the efficiency of this process [1]. In the initial stage, the RN can receive data from two D2D devices concurrently, utilising either the Decode-and-Forward (DF) or Amplify-and-Forward (AF) approach. Subsequently, the received signals are transmitted back to the D2D devices. PNC technology facilitates more efficacious communication by segregating the data from interference. TWR provides enhancements in EE and SE in comparison to direct and OWR methodologies.

In relay-assisted D2D communication, which utilises the spectrum of traditional cellular networks, the two-way communication features have been observed to be employed [1]. Several resource and power allocation mechanisms have been put forth for the management of interference in TWR communication. These mechanisms make use of techniques including coalition game theory, the Lagrangian duality method, the Particle Swarm Optimization (PSO) algorithm, and greedy algorithms. As with OWR, the selection of the optimal relay is of paramount importance in TWR D2D communication in order to enhance system performance.

3.3 Relaying Protocols

The operations performed by relays during signal transmission permit the classification of various relay protocols, as outlined in reference [5].

1. Amplify-and-Forward: In this protocol, the relay retransmits an amplified version of the signal received from the source. The advantage of AF is its ease of implementation; however, it has the disadvantage of amplifying noise and interference along with the signal. Furthermore, this process requires energy consumption by the relay device.
2. Decode-and-Forward: In the DF protocol, the relay initially decodes the received signal, then re-encodes and retransmits it. A fundamental prerequisite for the DF protocol is that the relay must be able to successfully decode the signal. Furthermore, the energy consumption by the relay is an unavoidable consequence of this method.
3. Compress and Forward: In contrast to the DF protocol, the relay transmits a compressed version of the received signal to the intended destination.

The most used relay strategies are AF and DF [5]. Furthermore, the performance parameters and concepts can be summarized as follows:

1. Packet Delivery Ratio (PDR): This parameter assesses the reliability of data transmission. PDR is calculated as the ratio of the total number of packets sent to the total number of packets received.
2. Potential Relay Set (PRS): In D2D communication, the PRS represents a set of N devices situated within the transmission range of the source node, which facilitates the transfer of data packets to the destination node or the eNB.
3. End-to-End Delivery Ratio (EDR): This parameter indicates the performance of multi-hop transmissions. The EDR is calculated based on the PDR. For example, the PDR from the D2D source device to the relay and from there to the destination device yields the EDR.

3.4 Relay Selection

The process of relay selection entails identifying the most suitable relay device from a range of potential options, with the objective of optimizing communication between source and destination devices. This process is based on a set of criteria, which may include factors such as connection quality, power level, delay time, data transfer rate, and reliability. One of the factors that increases the complexity of relay selection is the use of multiple criteria [5].

A. Relay Selection Methods

1. Congregation Selection: The device exhibiting the highest signal-to-noise ratio (SNR) is selected for communication with the destination.
2. Minimum Selection: In the second step, the device exhibiting the lowest SNR value is selected as the relay.
3. Optimal Selection: In consideration of the quality of the connection between the relay-listener and the

relay-destination, the device exhibiting the optimal privacy rate is selected.

4. Suboptimal Selection: The selection is made on the basis of the statistical status of the connection between the relay and the listener, in conjunction with the CSI between the relay and the destination.
5. Selection Based on Social Relationships: With the assistance of a base station, the social trust levels among all potential relays are evaluated. The D2D user is then directed to ensure that a relay with social trust is selected. By choosing relays with social trust above a certain threshold, communication security is enhanced, and the number of relay nodes that need to be investigated is reduced.

B. Security Issue

It is acknowledged that wireless networks may inherently possess security vulnerabilities. However, it is possible to ensure security through the implementation of various methods, including the utilisation of cryptographic functions. In relay communication, it is postulated that malicious relays could potentially impede data transfer and jeopardise data confidentiality. In order to mitigate these risks, it is recommended that physical layer network security and cryptographic key management approaches be employed [5].

C. Mobility Issue

The deployment of mobile relays may result in a deterioration of both the quality of the connection and the performance of the system, due to changes in the location of the relay. The exit of relay devices from coverage areas or their unavailability as suitable options can result in communication interruptions and the unnecessary storage of data. It is therefore essential to monitor the quality of the connections and the data transmission performance of mobile relay devices with great care.

D. Relay Selection in IoT Networks

The utilisation of relays in the context of IoT networks offers a number of benefits with regard to the enhancement of communication between source and destination devices. However, the erratic movements of mobile relays can result in IoT devices being situated outside of designated coverage areas, thereby increasing the probability of communication interruptions. In cellular networks, fixed or mobile relays can be allocated to utilise D2D and M2M technologies [5]. The utilisation of relays has the potential to enhance energy efficiency and diversity gains, whilst simultaneously prolonging the lifespan of the IoT network. The selection of relays in IoT networks can be classified under two main approaches: (a) physical layer selection algorithms and (b) cross-layer selection algorithms. Physical layer selection algorithms rely on connection parameters, whereas cross-layer algorithms utilise additional parameters. Physical layer parameters, such as channel gain, data rate, and privacy capacity, play a significant role in relay selection.

4. ARTIFICIAL INTELLIGENCE FOR RAD2D COMMUNCATION

The exponential growth in demand and the pace of technological advancement have led to a notable increase in the complexity of next-generation wireless networks. This situation has resulted in the inadequacy of classical mathematical methods in the context of network design, deployment and resource optimization [5]. It is therefore anticipated that ML and AI technologies will assume a prominent role in the entirety of the wireless network design process. Solutions based on ML and AI are being explored in several areas, including radio propagation, wireless signal identification, access control, routing protocols and radio resource management. In the context of IoT networks, the application of machine learning and AI-supported transmission methods has emerged as a prominent area of research. This has led to the development of a range of ML algorithms aimed at addressing the challenges associated with relaying in IoT networks.

The four main learning strategies that underpin machine learning models are supervised, unsupervised, semi-supervised, and reinforcement learning (RL). In contrast to supervised learning, unsupervised learning does not utilise labelled training data [8]. Semi-supervised learning, conversely, incorporates both labelled and unlabelled data [5]. Illustrative supervised learning algorithms include K-Nearest Neighbours (K-NN), Multi-layer Perceptron (MLP), and Gradient Boosting Classifier (GBC).

The design of next-generation networks must consider the necessity of supporting critical requirements, such as secure and low-latency communication. For these networks to meet the diverse requirements of various applications, they must be dynamic and adaptable. The application of machine learning and artificial intelligence provides a significant solution to this problem. The use of these technologies is particularly essential for coordinating devices and activities that generate large amounts of data [5]. In this context, ML and AI techniques hold great potential for addressing fundamental issues such as relay selection, resource allocation, and interference management.

A. Optimization in Relay Selection

The selection of the optimal relay in D2D relaying systems is of critical importance for communication performance. Traditional methods may prove inadequate for dynamic environments. In this context, ML algorithms, particularly RL, can adaptively select the optimal relay by analysing the network environment. Factors such as signal quality, energy level, and user mobility are taken into consideration in relay selection.

RL algorithms model relay selection as a decision-making process, thereby enabling the system to learn optimal strategies through interaction with the environment. For example, Q-learning can assist the device in selecting the most appropriate relay based on historical communication success rates, signal strength, and interference levels.

B. Channel State Prediction

AI techniques, particularly those based on deep learning, can be employed to predict the conditions of communication channels (e.g. signal-to-noise ratio, interference levels) in D2D communication. Accurate prediction of channel states enables the dynamic optimisation of the network's resource allocation and relay selection.

The use of deep neural networks (DNNs) allows for more accurate prediction of channel behaviour by modelling the intricate relationships between environmental factors and channel conditions. This facilitates the formulation of more effective communication strategies.

C. Power Control and Resource Allocation

In D2D relaying systems, the control of power and the allocation of resources are of critical importance to ensure energy efficiency while simultaneously minimising interference. The use of machine learning algorithms enables the dynamic adjustment of power levels and the real-time allocation of frequency resources for different D2D connections.

1. Supervised Learning: The application of supervised learning models to historical data on power levels and communication quality enables the prediction of optimal power control strategies.
2. Unsupervised Learning: In the context of resource allocation, unsupervised learning can facilitate a more efficient utilisation of resources by grouping devices based on their communication requirements or interference levels.

D. Interference Management

D2D communication has the potential to create interference for traditional cellular users. Machine learning models can be trained to predict interference and mitigate this situation by adjusting transmission parameters. Furthermore, the selection of relays that cause the least interference can enhance network performance.

AI-Based Scheduling: Artificial intelligence algorithms have the potential to optimise the scheduling of D2D transmissions by facilitating more effective coordination between D2D and cellular connections.

E. Mobility Management

In D2D networks, the mobility of devices introduces a challenge to maintaining stable communication connections. AI algorithms can predict user mobility and adjust the network configuration (e.g., relay selection, power control) accordingly to accommodate this mobility.

Machine Learning Models: Models trained on mobility data can predict when a user will exit the coverage area of a specific relay, thus enabling a smooth transition to an alternative relay based on this information.

F. Energy Efficiency

Given the typically limited battery life of devices engaged in D2D communication, energy efficiency represents a critical concern. The deployment of AI and ML algorithms can facilitate optimisation of energy usage, through the minimisation of unnecessary transmissions, the selection of energy-efficient relays and the dynamic adjustment of power levels.

5. CHALLENGES FOR RAD2D COMMUNICATION

The reviewed literature addresses a range of challenges, including relay selection, energy efficiency, secure communication, resource allocation, and the management of dynamic network conditions.

A. Relay Selection and Optimization Challenges:

1. Relay Selection in Dynamic and Complex Environments: [9] and [10] address the issue of optimal relay selection under dynamic conditions. [9] focuses on blockage in mmWave communication, while [10] emphasizes energy-harvesting ad-hoc networks with interference constraints. [7] and [11] emphasise the significance of minimising the complexity and computational delays inherent to the selection of relay nodes. [7] addresses socially aware filtering in V2V communication, whereas [11] focuses on the optimisation of broadcast relay selection in urban vehicular networks. [8] addresses the complexities of optimal relay selection in the context of energy consumption, routing overhead and coverage issues in D2D communications.
2. Joint Relay Selection and Resource Allocation: [6] and [3] address the challenges of resource allocation without the joint optimization of energy-efficient power and relay selection, specifically in the context of missing CSI. [12] discusses optimal relay selection in conjunction with resource allocation, focusing on reducing interference and maximizing overall data rates in D2D communications. [13] encounters challenges related to relay selection and power allocation specific to mmWave vehicular networks, which require solutions that are not overly reliant on connection quality data.

3. Relay Selection for Secure and Reliable Communication: [14] and [15] address the complexities of secure relay selection in multi-hop networks with multiple listeners, with a particular focus on enhancing physical layer security. [16] emphasizes the challenges of improving communication reliability by integrating social and physical interactions in reliable peer selection in D2D networks. [2] aims to achieve a balance between reliability and reducing electromagnetic field exposure by highlighting low EMF exposure in relay selection for energy-efficient NB-IoT systems.

B. Energy Efficiency and Power Management:

1. Energy Constraints in IoT and D2D Networks: [5] and [17] address the challenges of energy efficiency in relay-assisted IoT and NB-IoT networks, with a particular focus on the management of energy consumption and relay participation. [18] seeks to enhance connectivity while sustaining efficient power utilization in D2D-based blind spot reduction by analyzing energy consumption in industrial IoT networks. [3] confronts the challenge of guaranteeing energy efficiency in power allocation for relay-assisted D2D communications, where the objective is to strike a balance between optimizing energy efficiency and maintaining QoS.
2. Relay-Assisted Communication in Energy Harvesting Networks: [10] presents difficulties in achieving an equilibrium between energy consumption, interference, and the probability of disruptions associated with relay selection in energy-harvesting ad hoc networks. [19] concentrates on enhancing energy efficiency in D2D networks, particularly through optimizing MPR selection in OLSRv2 to forestall sudden power outages and disconnections.

C. Secure Communication and Privacy Issues:

1. Ensuring Secure D2D Relaying and Communication: [20] and [21] address the question of achieving an appropriate balance between security and performance in D2D networks. [20] makes use of token-based incentives, while [21] employs multi-agent deep Q-learning to optimise the selection of relays and jammers. [22] outlines the challenge of designing efficient and secure relay and jammer selection algorithms that operate without the need for complete CSI, thereby overcoming traditional optimisation limitations.
2. Physical Layer Security and Multi-Hop Privacy: [14] and [15] address the issues of ensuring secure multi-hop communication, with a particular focus on physical layer security and the complexities of selecting optimal relays in the presence of eavesdropping threats. [23] presents a case for resource allocation that not only maintains quality of service but also minimises EMF exposure, thereby considering health and privacy concerns.

D. Communication Efficiency and Spectrum Utilization:

1. Efficient Spectrum Allocation and Utilization: [24] and [25] elucidate the challenges of efficient channel allocation and spectrum efficiency in beyond 5G (B5G) supported IoT networks, emphasizing the necessity of dynamic channel conditions and predictive channel allocation. [4] and [1] address interference management and efficient resource allocation in D2D networks, focusing on spatial-temporal optimization and spectrum sharing challenges in relay-assisted communication.
2. Communication Optimization for Vehicular and URLLC Networks: [7] and [11] address the issue of efficient communication in vehicular networks, with a particular focus on high communication speeds, spectrum utilization, and the dynamic nature of vehicle movements. [26] considers the challenges of meeting URLLC requirements in multi-hop D2D networks over 5G sidelink, emphasizing decentralized scheduling and resource allocation.

E. Dynamic Topology and Network Management:

1. Adaptive Network Management in Dynamic Environments: [27] addresses the challenge of ensuring reliable communication with UAV swarms in dynamic topologies, which requires decentralized decision-making and low-latency D2D communication. [28] deals with the optimal placement of relays and deployment of UAVs in D2D networks, addressing the complexities of active user forecasting, route planning, and coverage maintenance.
2. Resource Allocation and Relay Selection Without Complete CSI: [6] and [22] address the issues of resource allocation and relay selection in environments with unknown CSI, emphasizing the difficulties of optimizing performance in the absence of detailed channel information. [12] employs adaptive MLP and hybrid meta-heuristic algorithms to achieve a joint optimisation of relay selection and resource allocation, with consideration of energy efficiency and data rates.

F. Real-Time Decision Making and Scalability:

1. Real-Time Learning and Scalability in D2D Communication: [26] emphasises the necessity for robust and scalable solutions for real-time scheduling and resource allocation in decentralised URLLC multi-hop D2D networks. [29] addresses the complexities of relay vehicle selection in VANETs during critical mission communication, with a particular focus on efficient clustering and relay selection under dynamic vehicle movement.
2. Maintaining a Balance Between Performance Metrics: [21] and [22] address the issue of achieving a balance between privacy and reliability in secure communication, examining the challenges of optimising both objectives simultaneously in the context of rapidly evolving network

conditions. [13] considers the necessity for a balance between performance and complexity in mmWave vehicular networks, with the objective of developing efficient relay selection algorithms that do not rely on comprehensive connection quality information.

G. Incentive Mechanisms and User Participation:

1. Token-Based Incentives for Relay Participation: [20] addresses the challenges of encouraging self-interested users to participate in relay services by employing token-based mechanisms to reconcile relay service optimization and network fairness. [5] examines the difficulties of motivating mobile IoT devices to act as relays in non-cellular networks, particularly where voluntary participation is essential.

H. Network Stability and Reliability:

1. Maintaining Network Stability in High Mobility and Dynamic Conditions: [29] and [11] elucidate the difficulties inherent in maintaining stable communication in vehicular environments, with a particular emphasis on cluster formation and the selection of efficient relays despite the inherent volatility of the underlying topologies. [10] addresses the challenges of managing interference and conserving energy sources in multi-hop D2D communication within energy harvesting networks.

6. CONCLUSION

The objective of this study was to provide a comprehensive overview of D2D communication from various aspects for future wireless networks. The general architecture of different D2D communication scenarios has been given. The relay assisted D2D (RAD2D) communication and the roles of AI in this communication scenario have been addressed with key highlights. The challenges for implementing RAD2D have also been presented. The research challenges addressed by these studies encompass a wide range of topics, including relay selection in dynamic and interference-prone networks, energy efficiency in IoT and D2D systems, secure communication in multi-hop and multi-user environments, spectrum utilization, and resource allocation, as well as network stability and scalability in vehicular and URLLC networks.

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