Low Latency Device to Device Communications for Sustainable Development

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Abstract: The 5G device to device (D2D) communication is being given impetus as technology for achieving sustainable development goals (SDG) in various fields like health, smart city, education, infrastructure and clean energy. The low latency device to device communications are key enablers for achieving the goals and objectives promulgated as SDG. Network virtualisation, software defined networks, beamforming, artificial intelligence and cognitive methods are facilitating roll out of applications enabling achievement of SDG. The interference mitigation, efficient resource allocation, energy efficiency, mobility management, Quality of Service, scalability, standardisation and interoperability are few challenges being addressed to facilitate implementation of technology and its applications. In this paper existing work on D2D communications, its applications and research challenges has been reviewed. The impetus to D2D and mission critical communications by 3GPP frameworks and releases has been summarized. The SDG applications and research challenges have been analysed to highlight its implications on roll out of technology to achieve the SDG objectives and goals. These SDG applications and technology have the prospective to transform varied fields of health, education, infrastructure and industry for achieving goals.

Keywords:device to device communication, emergency communication, Low latency, SDG

I. INTRODUCTION

5G technology has the ability to significantly contribute to multiple Sustainable Development Goals (SDGs), due to its technical edge, capabilities and envisaged influence on various elements of society and the economy [1]. Device to device (D2D) communication and mission critical push to talk communication has been included as key technologies in 3GPP framework and specifications for 5G. SDG 3 on good health and well-being can be achieved using 5G device to device (D2D) to improve healthcare through telemedicine, remote patient monitoring, and advanced healthcare analytics, making healthcare more accessible and efficient. SDG 4 on quality education is feasible with D2D enabled innovative educational approaches like virtual classrooms, augmented reality (AR), and personalized learning experiences, enhancing access to quality education. D2D is a key enabler of Industry 4.0, supporting the development of smart infrastructure, digital manufacturing, and efficient transportation systems to support SDG 9 on industry, innovation, and infrastructure. SDG 11 (sustainable cities and communities) are being achieved with smart city applications such as efficient resource utilization, smart green corridors and traffic routing, waste management and power distribution leading to more sustainable urban development. 5G can facilitate the monitoring and management of environmental data, helping in order to mitigate and prepare for climate change to support SDG 13 on climate action. 5G and emerging technologies are thus enabling SDG implementation [2]. D2D communication is one such enabling technology supporting SDG.

Low latency D2D communication refers to transmissions between nearby user equipment without the need for routing through centralized network infrastructure [3]. This type of communication is characterized by its low latency, meaning that data can be exchanged quickly between devices, often in milliseconds. An important and key advantage of low latency D2D communication is its technical prowess to support real-time applications and services that require fast and reliable data transmission. Low latency D2D communication can be implemented using various technologies, that allow devices to establish direct connections with each other, bypassing the need for communication through base stations or access points. In addition to supporting real-time applications, low latency D2D communication improves network efficiency by offloading traffic from the central network infrastructure. This can lead to reduced congestion and improved overall network performance. Low latency D2D communication thus, can support a wide range of innovative applications and services, making it an important area of research and development in the domain of next generation wireless communication.

A. Related Work

D2D communication was conceived to allow communications in between user equipment in cellular networks utilizing multiple hops [4]. Research in [5]-[8] looked at the possibilities of D2D communications for spectrally optimized and efficient cellular networks. Other possible D2D applications were suggested in the literature, including peer-to-peer communication [12], video distribution [6], multicasting [10], [11], machine to machine (M2M) communication [12] and cellular offloading [13]. The volumes of the work on D2D communications proposes using the licensed spectrum interference mitigation for both cellular communication (underlay inband D2D) and D2D[14]. A brief summary of D2D related work is collated in Table 1.

B. Motivation and Present Work

As part of the 2030 Agenda for Sustainable Development, the United Nations established a set of 17 global goals known as the Sustainable Development Goals (SDGs) in 2015. The SDGs are an appeal to action to guarantee prosperity for all, eradicate poverty, and safeguard the environment. Each goal has precise targets and objectives to be achieved by 2030, and they are interconnected, recognizing that stimulus and activity in one field will have effect and outcomes in others. The SDGs are critical for addressing a few of the most urgent issues facing the globe today, such as injustice, poverty, inequality, climate change, environmental degradation, and peace. Achieving the SDGs requires a coordinated and integrated approach involving governments, businesses, civil society, and individuals. Emphasis should be laid on the SDGs due to their transformative potential. By addressing key issues such as health, education, equality, justice, poverty and climate change the SDGs can help create a more sustainable and equitable world for future generations. It is essential to track progress towards the SDGs, hold governments and other stakeholders accountable, and ensure that resources are allocated effectively to achieve the goals. D2D communication has varied applications that can facilitate the roll out of applications in support of SDG. In this paper applications of D2D communication with potential deployment in SDG has been discussed in section II. The challenges in implementation and technological enhancements have been emphasised in section III. The road map and future work is covered in section IV.

II. APPLICATIONS OF D2D COMMUNICATION

D2D communication is a next generation communication standard enabling devices to communicate with each other without the control and management by centralized base station. This technology has garnered remarkable attention in recent years due to its technical edge and ability to enhance the performance of wireless networks and communications transforming systems to enable dynamic services and applications. The various applications of D2D communication have been fielded and are in process of roll out across different industries and domains.

A. Vehicular Communication

V2X (Vehicle-to-Everything) communication has the capability to contribute significantly to many Sustainable Development Goals (SDGs) by improving road safety, reducing traffic congestion, and promoting environmental sustainability. V2X communication can help reduce traffic congestion and improve traffic flow, leading to more efficient and sustainable transportation systems in cities, which aligns with SDG 11. By enabling more efficient traffic flow and reducing congestion, V2X communication can effectively reduce emission of greenhouse gas from vehicles, contributing to SDG 13. D2D communication is transforming the automobile industry by allowing both vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) connection [35]. D2D communication enables vehicles to connect with one another and with roadside infrastructure, resulting in development of intelligent transport systems (ITS). Vehicles in V2V communication can relay information indicating their speed, location, and direction, allowing for cooperative driving and collision avoidance. V2I communication enables cars to connect with traffic signals, road signs, and other infrastructure, resulting in real-time traffic status and optimised traffic flow. Vehicles can use D2D communication to share updates and message their speed, direction, and proximity, enabling them to detect and avoid potential collisions. Further the technology facilitates following applications.

I)Traffic Management: D2D communication can facilitate cooperative traffic management strategies, such as dynamic route optimization, traffic signal coordination, and congestion detection.

II)Emergency Services: D2D communication enables vehicles to quickly communicate with emergency services in case of accidents or other emergencies, improving response times and potentially saving lives.

III)Infotainment and Passenger Services: D2D communication can enhance the in-vehicle infotainment experience by enabling passengers to share media content, play multiplayer games, and engage in social networking activities [31].

TABLE I

LITERATURE REVIEW OF D2D RELATED WORK

Research Paper	**Year**	**Major Aspects Covered**	**Research Gap**
[15]	2022	Survey of D2D communication technologies and applications	Standardized D2D communication protocols and interference management techniques
[16]	2019	Optimization techniques for D2D communication in 5G networks	Methods for energy-efficient D2D communication and QoS provisioning
[17]	2017	Security threats and its mitigation in D2D communication	Need for more robust authentication and encryption mechanisms to secure D2D communication.
[18]	2022	Use of ML for optimizing resource allocation in D2D communication	Studies on the integration of ML with D2D communication and its performance in real-world scenarios
[19]	2017	Applications of D2D communication in public safety scenarios	Comprehensive studies on the integration of D2D communication with existing public safety systems
[20]	2017	Techniques for improving energy efficiency in D2D communication	Practical implementation and evaluation of energy-efficient D2D communication schemes
[21]	2021	Interference mitigation techniques for D2D communication	Need for optimised and efficient interference management algorithms to enhance D2D communication performance.
[22]	2018	Strategies for ensuring QoS in D2D communication	Evaluation frameworks for D2D communication.
[23]	2021	Integration of edge computing with D2D communication	Impact of edge computing on D2D communication latency and reliability.
[24]	2020	Cooperative communication schemes for D2D networks	Need for more practical implementations and performance evaluations
[25]	2020	Techniques for efficient spectrum sharing in D2D communication	Dynamic spectrum sharing models and their applicability in D2D communication
[26]	2023	Applications of D2D communication in IoT networks	Standardized protocols and architectures for integrating D2D communication into IoT networks
[27]	2022	Privacy challenges and solutions in D2D communication	Comprehensive privacy-preserving mechanisms to protect user data in D2D communication
[28]	2021	Use of network slicing for enabling D2D communication	Implementation and performance of network slicing in D2D communication scenarios
[29]	2020	Applications of D2D communication in industrial IoT	Integration of D2D communication with existing industrial IoT protocols and standards
[30]	2023	Cognitive radio techniques for improving D2D communication	Limited research on the practical implementation and evaluation

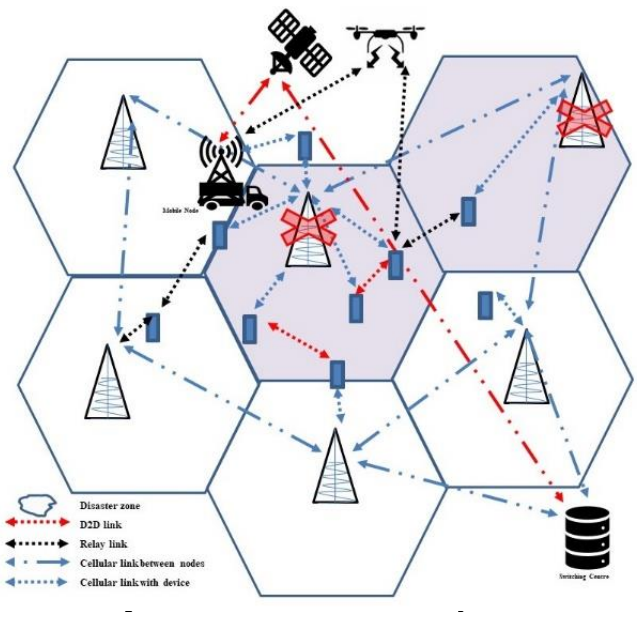
B.Public Safety and Emergency Services

One of the most critical applications of D2D communication is in public safety and emergency services [32]. D2D communication allows first responders and emergency personnel to communicate directly with each other, even when the cellular network is congested or unavailable. In emergency situations such as natural disasters, accidents, or terrorist attacks, D2D communication can be a lifesaver, enabling quick and efficient coordination of rescue efforts. D2D communication can also be used to improve the safety and efficiency of emergency services. For example, firefighters equipped with D2D-enabled devices can communicate with each other inside buildings, where traditional communication methods may not work effectively. Similarly, police officers can use D2D communication to share real-time information about suspects or dangerous situations, improving situational awareness and response times.

*I) Mission critical communication:*Major new features that improve the capabilities and quality of critical communication have just been introduced in a new version of the Third Generation Partnership Project (3GPP) [33]. The relevance of 3GPP to MCPTT and Releases throughout time is seen in Fig. 1. Reliability and public safety communications are enhanced by the published proximity service specifications in Release 12 of 3GPP. D2D communication is included as a means of using proximity services (ProSe) in 3GPP Release 12, which was released in

2015. It also outlines the steps that must be taken to roll out. Mission critical push-to-talk (MCPTT) functionality was added to Release 13 in 2016 along with comparable features. Data and video functionalities were included in Release 14 in 2017 for mission-critical communication. Release 15, which included internetworking and connectivity technologies, improved specs in 2019 to handle mission-critical communications. 2020's Release 16 brought functionality for multicast and multimedia broadcasting—essential services—to the table. The scope of Release 17 is expanded to include proximity services in 5GS and mission critical services support for 5G. Plans call for enabling critical communication applications in Release 18.

II) Application: An application for D2D communication during catastrophes is mission critical push to speak emergency communication. In these situations, just-in-time contact between rescue troops and their bases is crucial, as is backward communication and connection. There are several uses for Mission Critical Push to Talk Communication (MCPTTC) in emergency, disaster, and public safety communication [34]. A scenario of MCPTT communication application is shown in Fig. 2. In addition to being a vital technology for public safety, disaster relief, and military communications, applications including LTE Radar, Land Mobile Radio (LMR), LTE integration, and push-to-talk via cellular gateway have already been deployed and have shown a sizable user base and commercial viability. The reach of communication has been expanded by LMR integration with cellular technology, which also makes it easier to integrate military and commercial communications.



C. Healthcare

D2D communication has revolutionised healthcare delivery by transforming the techniques for remote patient monitoring and telemedicine. D2D-enabled wearabledevices have technical capability to track vital signs, blood glucose levels, and other medical health metrics in real time, enabling for early diagnosis of health concerns and remote patient monitoring. D2D communication can also improve communication between healthcare doctors and patients, allowing for virtual consultations and increasing access to healthcare services, particularly in distant locations. In addition, enhanced D2D features can be fielded to track the location of medical equipment and supplies, improving efficiency in healthcare facilities. Few SDG implementations are listed below.

I) Telemedicine (SDG 3): Telemedicine enables remote diagnosis, consultation, and treatment, reducing need for patients to travel long distances to access healthcare services. 5G D2D communication enhances telemedicine by enabling real-time video conferencing, vital signs remote monitoring and access to e-health records.

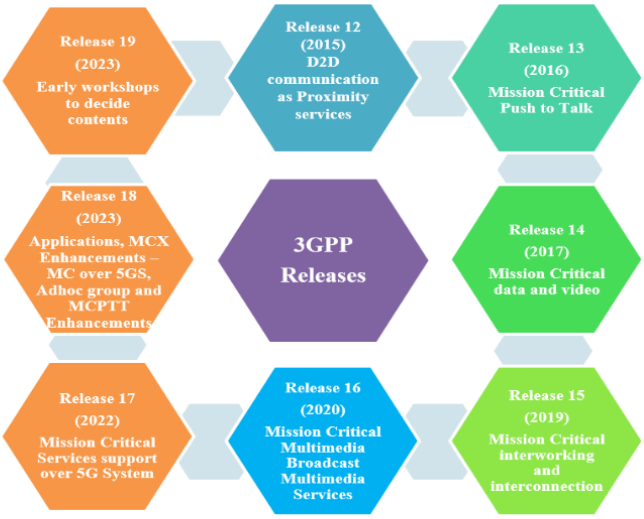


Fig. 2. D2D communications with break in network infrastructure during catastrophe.

Fig. 3. Application Scenario for SDG

*II) Emergency Response (SDG 3):*In emergency situations, such as natural disasters or accidents, 5G D2D communication can facilitate communication between first responders and healthcare providers, enabling faster response times and better coordination of care.

III) Remote Patient Monitoring (SDG 3): It facilitates continuous remote vital signs monitoring, allowing healthcare warriors to detect and take immediatecorrective measures to changes in health status in near real time. This is particularly beneficial for patients with chronic conditions requiring regular monitoring.

IV) Health Information Exchange (SDG 3): It enables secure exchange of health status updates to healthcare providers, improving care coordination and patient outcomes.

*V) Health Education and Awareness (SDG 3):*It is essential to deliver health education and awareness messages to communities, promoting healthy behaviors and disease prevention.

*VI) Medical Training and Education (SDG 4):*5G D2D communication enables remote medical training and education, allowing healthcare professionals to access high-quality educational resources and collaboration with medical experts remotely anytime to anywhere.

VII) Resource Optimization (SDG 9): D2D connectivity, allows for remote monitoring and administration of healthcare resources. It and can also ensure optimised allocation of resources, lower healthcare costs, and increase overall efficiency.

D. Internet of Things (IoT)

IoT communication has the technical prowess to achieve several SDGs by enabling smart and efficient solutions that improve health, energy efficiency, infrastructure, and sustainability. IoT can help create smart cities with efficient transportation, energy, and waste management systems, leading to more sustainable urban development, which aligns with SDG 11. D2D technology facilitates IoT devices to establish communication seamlessly amongst each other with or without access point or base station. D2D-enabled IoT devices can exchange data and information, enabling smart cities, smart homes, smart applications and industrial automation. In smart homes, D2D-enabled devices like smart thermostats, lights, and appliances can communicate to optimize energy usage and enhance convenience. In smart cities, D2D communication can be used for traffic management, waste management, and environmental monitoring, leading to more sustainable and efficient cities.

E. Entertainment and Social Networking

Entertainment and social networking platforms can contribute to several Sustainable Development Goals (SDGs) by promoting education, raising awareness, and fostering community engagement. Educational platforms and apps that provide accessible and affordable learning resources contribute to SDG 4. For example, online courses, educational videos, and interactive learning tools can help improve access to quality education for people around the world. Social networking platforms can help promote gender equality (SDG 5) by providing a platform for women to share their experiences, connect with others, and access information and resources. For example, women-focused networking groups and forums can help empower women and promote gender equality.It can help reduce inequality (SDG 10) by connecting people from different backgrounds and providing a platform for marginalized groups to share their stories and experiences. This can help raise awareness about inequality and promote social inclusion. Social networking platforms can promote peace and justice (SDG 16) by providing a platform for dialogue and discussion. For example, platforms that promote civil discourse and respectful debate can help build stronger institutions and promote peace. D2D communication is also finding applications in the entertainment and social networking industries. D2D-enabled devices are used for multiplayer gaming, augmented reality (AR) applications, and location-based services, creating immersive and engaging experiences for users. In social networking, D2D communication is used to share photos, videos, and other content directly between devices, without centralized server. This leads to faster and more efficient sharing of content, especially in crowded or congested environments.

F. Retail and Marketing

Retailers can promote conscientious consumption and production aligned to SDG 12 by offering sustainable products, providing information about product sustainability, and encouraging customers to make environmentally friendly choices. For example, retailers can promote products that are made from recycled materials or are produced using sustainable practices. It can contribute to economic growth (SDG 8) by creating job opportunities and supporting small businesses. For example, retailers can source products from local artisans and small producers, providing them with a market for their goods and helping to create sustainable livelihoods D2D communication may be used to deliver personalized promotions and discounts to customers based on their location and preferences. D2D enabled devices are also used for mobile payments, enabling secure and convenient transactions without requirement for a traditional payment terminal.

G. Industrial Applications

D2D communication is also being explored for its potential in industrial applications, like smart manufacturing and the Industrial Internet of Things (IIoT). D2D-enabled sensors and devices can communicate directly, enabling real-time monitoring and control of industrial processes. This leads to increased efficiency, reduced downtime, and improved safety in industrial environments. Industrial applications can promote responsible consumption and production (SDG 12) by implementing sustainable practices and reducing waste. For example, industries can recycle materials, use eco-friendly packaging, and minimize water consumption in their operations. It can also help protect terrestrial ecosystems by minimizing deforestation, preventing soil degradation, and promoting biodiversity (SDG 15). Thus, industries can implement sustainable forestry practices and restore degraded land to support ecosystem health. SDG applications of D2D communication is summarized in Fig.3.

III. CHALLENGES AND TECHNOLOGICAL ENHANCEMENTS

D2D communication is a promising technology that enables direct communication between nearby devices, bypassing the traditional cellular network infrastructure. While SDG implementations of D2D communication offers many benefits, such as improved spectral efficiency, reduced latency, and enhanced coverage, it also poses several research challenges that merits attention and technological prognosis to realize its full potential. Some of the key research challenges and technological enhancements in D2D communication, potential solutions and future directions are:

A. Interference Management

One of the primary challenges in D2D communication is identification and mitigation of interference. Since D2D devices share the allotted spectrum with cellular users, as well as other D2D pairs, interference can degrade the performance of the communication system. Managing interference is crucial to ensure reliable and resilient communication and efficient spectrum operation. Artificial intelligence based Intelligent reflective surfaces, successive interference cancellation and non-orthogonal multiplexing access techniques are being implemented to facilitate roll out of applications.

B. Resource Allocation

Another challenge in D2D communication is resource allocation. D2D devices need to compete for resources like frequency bands, transmit power and time slots. Efficient resource allocation algorithms ensure fair allocation of resources and optimize system performance. Dynamic Spectrum Access (DSA) allow D2D devices to utilize available spectrum efficiently. Cognitive radio techniques may also be employed to dynamically allocate spectrum based on dynamic usage and interference conditions. Power control algorithms adjust the transmission power depending on distance between devices and the channel conditions, minimizing interference and conserving energy. Resource sharing algorithms allocate resources depending on factors such as proximity, channel conditions, and application requirements, ensuring fair distribution and optimal utilization. QoS-aware resource allocation ensures that resources are allocated based on specific needs of each D2D communication, ensuring a satisfactory user experience. Dynamic resource allocation techniques adapt to changes in network conditions in near real-time. These techniques continuously monitor channel conditions, traffic loads, and interference levels to adjust resource allocation dynamically, ensuring optimal performance under varying conditions.

C. Energy Efficiency

Energy efficiency is a critical consideration in D2D communication, aiming to reduce power consumption and prolong device battery life. Several techniques are employed to enhance energy efficiency in D2D communication networks. Power control is a fundamental technique that adjusts transmission power depending on distance between devices and channel conditions, minimizing power usage while maintaining communication quality. Sleep mode operation allows devices to enter a low-power state when not actively transmitting or receiving data, conserving energy by turning off unnecessary components. Dynamic power management dynamically adjusts the power consumption of various components based on network conditions, optimizing energy usage. Efficient protocols reduce overhead by minimizing control packet exchange, reducing energy consumption. Cross-layer optimization optimizes parameters across protocol layers, such as transmission power and packet size, to reduce overall energy consumption. Cognitive radio enables devices to dynamically adjust transmission parameters based on available spectrum, reducing energy consumption by accessing unused spectrum. Context-aware techniques consider the environment and user behavior to optimize energy consumption, further enhancing energy efficiency in D2D communication. These techniques collectively contribute to reducing energy consumption, extending device battery life, and improving the sustainability of D2D communication networks.

D. Security and Privacy

Security, privacy, and key management are major concerns in D2D communication. Since D2D devices communicate directly amongst each other, they are more vulnerable to security threats such as eavesdropping, interception, and spoofing. Robust security mechanisms are required to protect D2D communication from these threats. Various techniques are employed to enhance security and privacy in D2D communication networks. Authentication mechanisms validate the identities of devices prior to establishing communication, preventing access by unauthorized and blocked users. Encryption techniques such as Advanced Encryption Standard (AES) encrypt data to protect it from eavesdropping and unauthorized access. Key management ensures that encryption keys are securely distributed and updated, maintaining the confidentiality of data. Intrusion detection and prevention systems (IDPS) scrutinise network packets and sniff traffic for skeptical activity and avert potential attacks. Privacy-enhancing technologies such as anonymization techniques and differential privacy protect user identities and sensitive information. Trust management establishes and maintains trust relationships between devices, ensuring secure communication. Secure routing protocols prevent routing attacks and ensure data is transmitted through trusted paths. Security and privacy thus are vital in ensuring the integrity, confidentiality, and availability of D2D communication, safeguarding sensitive data, and maintaining user privacy.

E. Mobility Management

Managing mobility is a challenge in D2D communication, especially in dynamic environments such as vehicular networks. D2D devices need to maintain seamless connectivity as they move, which requires efficient handover and routing mechanisms. Handover management ensures uninterrupted communication when a device moves between different cells or coverage areas. Handover assessment are made depending on signal strength, quality, and other network parameters to minimize disruption. Location management keeps track of the current location of mobile devices, enabling efficient routing and resource allocation. Location updates are performed periodically or when a device enters new location. Context-aware mobility management considers the context of device movement, such as speed, direction, and predicted trajectory, to optimize handover decisions and resource allocation. This ensures efficient mobility management while minimizing signaling overhead. Predictive mobility management anticipates the future movement of devices based on historical data and patterns. By predicting future locations, handover decisions can be made proactively, reducing latency and improving overall network performance.

F. QoS Provisioning

Ensuring Quality of Service (QoS) is a challenge in D2D communication, particularly for mission-critical applications. D2D devices need to meet strict QoS requirements such as low latency, high reliability, and high throughput, in dynamic and interference-prone environments.

G. Scalability

Scalability is another challenge in D2D communication, especially in densely populated areas with a large number of devices. Efficient protocols and algorithms are needed to manage the scalability of D2D communication networks and ensure optimal performance.

H. Coexistence with Cellular Networks

Coexistence with cellular networks is a research problem statement in D2D communication, as D2D devices coexist in the same wavelength as mobile phone users. Efficient spectrum sharing mechanisms are needed to ensure fair coexistence and minimize interference between D2D and cellular communications.

I. Standardization and Interoperability

Standardization and interoperability are important challenges in D2D communication. Standardized protocols and interfaces are needed to ensure compatibility and interoperability between different D2D devices and networks.

J. Social and Economic Factors

Social and economic factors also play a vital role in the implementation and deployment of D2D communication. Issues such as user acceptance, regulatory policies, and business models need to be addressed to promote the widespread adoption of D2D communication.

IV. CONCLUSION

D2D communication has the potential to revolutionize various industries and domains by enabling direct and efficient communication between devices. As this technology continues to evolve and mature, we can expect to see even more innovative applications and services that will transform the way we live, work, and communicate. D2D communication offers many benefits but also poses several research challenges and problem statement that needs deliberation. By addressing these challenges, the full potential of D2D communication can be exploited and pave the way for a new era of wireless communication. Roll out of applications to implement SDG is being achieved with enhancement in technology.

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