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SURVEY

State-of-the-Art Device-to-Device Communication Solutions

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ABSTRACT In recent years, with the spread of IoT services and the amount of data on the network, the importance of D2D communications has emerged in unloading the network, reducing data access time, and improving performance. Due to this importance, in this article, we have reviewed the latest D2D communication solutions in the recent period. Authors proposed categorizing D2D communication solutions into six categories: M2M, V2V, and D2D in cellular networks, D2D with a caching assistant, D2D in socially aware networks, and D2D based on ICN. Writers examined the proposed solutions in each area, elaborating on the methodology employed, the evaluation, the benefits and drawbacks of each proposal. Moreover, based on the study of the presented solutions, we feel that cellular networks and ICN are the most effective for D2D communications, particularly when awareness and social relationships are incorporated into them. We believe that the review presented in this paper will be useful sufficient for developers, researchers as a reference guide to facilitate the design and implementation of D2D communication solutions.

INDEX TERMS D2D, solutions, M2M, V2V, cellular networks, socially aware networks, ICN.

I. INTRODUCTION

Communication between humans and devices have developed a lot in recent years, as different devices interact with humans, or these devices work together for monitoring or automation and control. The ecosystem of the IoT enables these devices to transmit information to each other and humans. These devices include personal electronics, smartphones, laptops, tablets, TVs, smart vehicles, home appliances, industrial sensors, health monitors, and actuators. The ubiquity and use of various devices have increased the importance of D2D communication.

D2D communication is direct communication between things without using any infrastructure node for data traffic. Collaboration and communication between devices through D2D communication are important in global digital transformation. It is one of the most important emerging technology that facilitates the IoT. Wherefore, it is expected to be an essential part of IoT.

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On 8 March 2021, [1] published statistics on the number of devices connected through IoT and non-IoT devices. In 2021, the number of devices connected via the IoT reached more than 13.8 billion and nearly 10 billion non-IoT devices. It is also expected that the number of IoT-connected devices will increase annually by at least 46%, to bring in 2025 the number of devices expected to be connected via IoT to 30.9 billion devices and 10.3 billion non-IoT active devices worldwide. Due to this expansion, IoT will have to configure more devices, and managing these devices for their interactions will lead to the exhaustion of considerable effort with time. A solution to reduce effort and time is data offloading by D2D communication, where the devices take action without human involvement [2].

The D2D approach facilitates work without the essential control, making networks energy-efficient with traffic offloading. For instance, when the network is damaged or out of service in a disaster or emergency, D2D communication can work without existing central infrastructure. Moreover, D2D communication offers autonomous intelligent services or mechanisms without centralized supervision that reduced delay with throughput enhancement [3]. Typical applications include short-range PANs, vehicle networks that connect nearby cars, smart city networks, smart grids, and smart homes. D2D communications are also achieved in wireless cellular networks, BLE, RFID, Zigbee, and NFC.

Given the importance of D2D communications and related key features of the IoT. This paper presents a comprehensive review of the latest D2D communications solutions, specifically, the theoretical background of D2D communications, mentioning D2D technologies, types of control, and major challenges.

To the best of our knowledge, this is the first comprehensive survey to review D2D communications solutions that provides a classification of them with a review of the different characteristics of the proposed solutions. Authors classified D2D communication solutions into six categories: M2M, V2V, and D2D in cellular networks, D2D with cache assistant, D2D in social awareness networks, and D2D based on ICN. We believe that the review presented in this paper will be sufficient as a reference guide for developers and researchers to facilitate the design and implementation of D2D communication solutions. This paper summarizes the most important D2D communication performance metrics, communication protocol, and control type used, and all of this will be beneficial to researchers and developers. It is possible to consider this paper as a reference that saves them effort and time.

The first section introduces a theoretical background to D2D communications, were it reviews the development of D2D communications, with the most prominent technologies that achieve D2D communications. Secondly, we mention the types of control, and the most prominent challenges of D2D communications, which are device discovery, mode selection, resource management, mobility, security, and privacy.

In the second part of the paper, authors propose six approaches to classify D2D communication solutions as M2M, V2V, and D2D in cellular networks, D2D with cache assistant, D2D in social awareness networks, and D2D based on ICN. Authors begin with a simplified explanation of each approach, after that, authors presented sub-classifications for each approach, and examined the proposed solutions in each sub-category, explaining the methodology used in each solution, the evaluation, the features and limitations of each solution.

In section three, the paper presents an analysis and discussion of the proposed solutions. This part contains a table that summarizes the performance measures of D2D communications as mentioned in the reviewed solutions, which are fourteen measures, as well as a table summarizing the D2D communication protocols used. The control methods supported by these solutions, and the technologies used. Finally, the last section dealt with conclusions.

II. AN OVERVIEW OF D2D COMMUNICATIONS

D2D_IoT communication seeks to create a high-reliability, low-latency network that achieves seamless data communication. Many protocols are used; the most common is wireless cellular networks. Wireless cellular networks offer many advantages to D2D networks. The devices will communicate with each other without the control of the BS, which will reduce traffic on the infrastructure. The ability of cellular communication, such as 2G/3G/4G, to cover large areas will benefit IoT applications as most IoT applications operate over longer distances. On the other hand, cellular communication consumes high power and is expensive for many applications.

When cellular networks or WLAN are unavailable, D2D_IoT communication can be achieved through technologies widely used in previous years, such as BT, WFD, and WFH. BT is a short-range communication protocol used on tablets and mobile phones. BT is designed to perform a small set of tasks, while Wi-Fi controls a large amount of data and supports fast data transfer rates. BLE enhances the BT standard to allow wireless communication to low-cost devices with extremely low energy. The devices transmit a small amount of data within relatively short ranges. In work [4], authors compare these communication technologies from transmission performance and energy consumption. This paper concludes that although BT consumes low power, it nevertheless shows poor performance in data transmission.

WFH is roughly the same level as WFD when productivity and energy consumption are considered together. The study finds that the TCP/UDP performance of WFH is slightly better than WFD. However, WFH also consumes slightly more power than WFD.

DECT provides data transmission for local area deployments of low-power and low-bandwidth D2D communications applications. ULE was developed to open the technology to the M2M market.

It is ideal for HAN sensor applications such as home security, automation, home health monitoring, and smart meters. Zigbee and Z-Wave also support two-way connections for many devices in the network with very low energy consumption. It is easy to use with interoperability and reliability. The ZigBee IP determines hardware requirements for D2D_IoT communication. Z-Wave is ideal for home automation applications, and ZigBee is often used for industrial, smart energy applications, retail and healthcare services [5]. RFID technology uses electromagnetic fields and radiofrequency signals to identify objects, although RFID does not require a power supply. Data security is one of the most important challenges. The RFID system is vulnerable to unauthorized access, data traffic analysis and may lead to denial of service. Its most prominent applications are wildlife monitoring, asset tracking, and vehicle identification [6]. NFC is a short-range contactless communication of up to 10 cm, supports a data rate of up to 424 kbps, which connects devices such as smartphones, tablets, and other devices, from its applications eHealth and mHealth [7].

LPWAN: such as Sigfox and LoRaWAN are used in WAN, they support, millions of low-power, low-cost, long-range devices, minimize infrastructure investment, achieve good scalability, simplify devices and protocols to the maximum. They are used in many applications such as smart grid

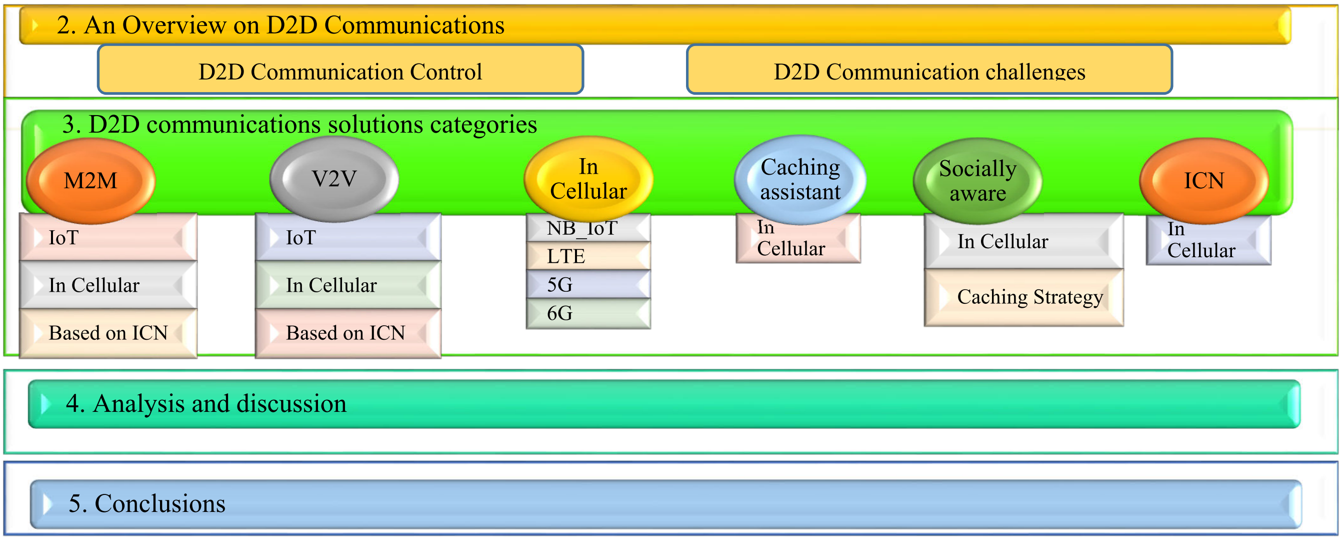

FIGURE 1. An overview of the survey.

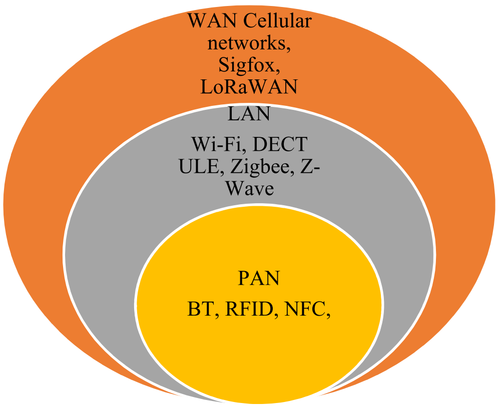

FIGURE 2. D2D communication protocols.

monitoring, smart energy metering, infrastructure, or nature monitoring and may be used in tracking applications [5], [8]. Figure 2 summarizes the traditional protocols used in D2D communications.

A. D2D COMMUNICATION CONTROL

The D2D communication control types are classified as follows [9]:

Centralized: The BS is responsible for managing the UE nodes, even in the case of direct communication between the UES. BS manages all control aspects, such as communication, routing, and interference.

Distributed: There is no central entity to manage the nodes here; thus, there is less control as D2D communications are performed independently by the UES.

Semi-distributed: This type attempts to achieve trade-offs between distributed and centralized schemes.

B. D2D COMMUNICATION CHALLENGES

Many challenges must be faced to support D2D_IoT communications, and the most prominent of these challenges are [5]:

Device discovery: Device discovery is a basic design requirement in D2D communications, enabling devices to discover other devices in their network coverage area and establish direct communication with them. Devices collect information on nearby devices, such as device ID and location. Device discovery can also be centralized or distributed.

Mode Selection: User equipment uses one of the three communication modes they are [2]: Dedicated mode: direct communication between transmitter and receiver. Cellular mode: devices communicate as a conventional cellular communication through the BS. Reuse mode: This mode allows the reuse of the resources already available with the cellular connection. Because of the high mobility of the devices, mode change occurs frequently, and the change of position is the biggest challenge in choosing the mode.

Resource Management: Effective resource management helps reduce communication interference, as it maintains resource management and maximizes productivity. Resource management in a D2D network directly depends on the number of devices. It is difficult to accommodate all devices in a single network when the number of devices increases.

Mobility: D2D communications equipment and devices are highly mobile and often heterogeneous, so handovers are frequent. The focus should be placed on the effective mobility of traffic modes in different life applications, and handover methods to improve D2D network performance and reduce network interference [10].

Security and Privacy: There must be effective security solutions to ensure the reliable exchange of data between devices within a D2D network. These solutions should also move away from the complexity that may lead to more energy consumption and complexity of devices.

There are also many efforts to achieve awareness in D2D communication; [10] used an action link between devices to predict behaviors. According to, G. M. Lunardi and others in [11] used an ontologies solution to establish relationships between devices in the same environment analysis.

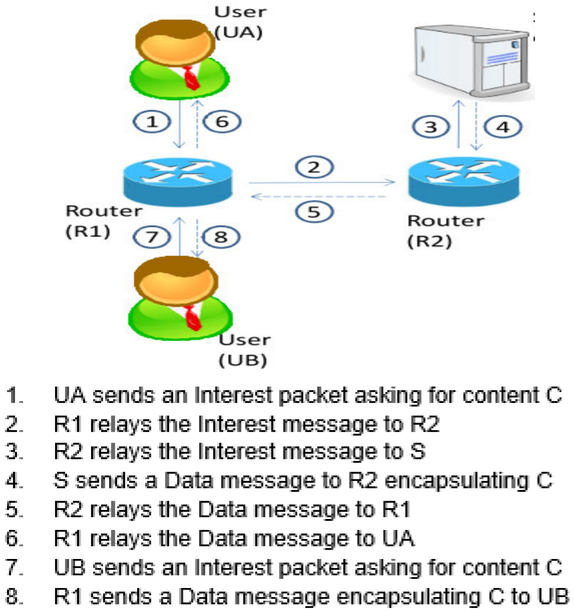

FIGURE 3. Main concept of ICN.

Work [12] used contextual information and previou interactions to propose a neural network-based solution to predict the device's behavior. However, all of these works still depend on host-centric communication (IP protocols).

Therefore, many researchers believe today's IoT desperately needs to create a new network architecture to meet diverse network services. A promising way to meet the needs of D2D communication is provided by the architecture of ICN. ICN is a part of the future Internet paradigm, where content /data name is the basic element regardless of its location/host (network address). It designs to offer multicast support, inherent mobility, in-network caching, and content-based security. Figure 3 shows that a consumer requests a unique and location-independent content name in ICN. In-network caching stores the content closer to users to reduce network traffic [13], [14]. When D2D uses ICN, devices ask for the content and consume data from the network without any human intervention and without consuming network resources. The integration of ICN with IoT-D2D communications is still in its infancy. However, in recent years, using ICN's advantages, many studies have attempted to meet the challenges of D2D communication, such as heterogeneity, user mobility, and security.

III. CATEGORIES OF D2D COMMUNICATION APPROACHES

In this section, researchers review the proposed solutions, which seek for the device to have the ability to direct data to other devices in exchange of information with them regardless of the infrastructure and away from central communication. Researchers extracted six categories or topics from analyzing these solutions for D2D communications research. Figure 4 below provides a visual representation of these

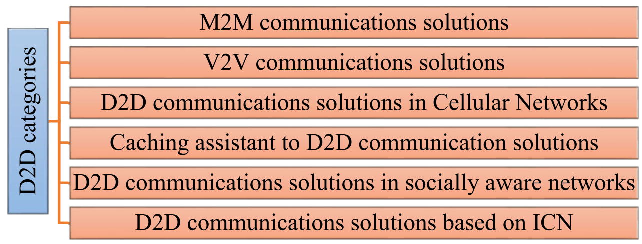

FIGURE 4. D2D communications solutions categories.

topics. This section will describe the proposed solutions under each category, these categories are M2M communications solutions, V2V communications solutions, D2D communications solutions in Cellular Networks, D2D with a caching assistant communication solutions, D2D communications solutions in socially aware networks, and D2D communications solutions based on ICN.

A. M2M COMMUNICATION SOLUTIONS

M2M communications achieve connectivity in automation and have been a focus of research in recent years for several reasons, including [15]:

M2M communications may generate new revenue of profit opportunities for cellular operators. Low-cost actuating and sensing devices.

The researchers suggest the tendency to automate the machine and use it in places that are not desirable for humans to ensure their safety, for the spread of high-speed internet.

Diversity and rapid spread of M2M applications in different fields such as [16]:

- Smart Wearables: These devices provide chances for M2M applications and enhance people's comfort.
- Smart Living: Like smart buildings, smart homes, and healthcare, M2M applications facilitate people's connection, management, and control, saving them time and effort and thus bringing them convenience.
- Smart Farming: M2M applications collect and analyze data, which positively affects agricultural value and food security.
- Smart Mobility: M2M applications provide infrastructure for smart mobility, such as cars/autonomous vehicles.
- Smart Cities: M2M applications develop smart cities by connecting all city services, such as lighting services, transportation, energy, buildings, water management, parking, and waste management; thus, smart cities become an integrated ecosystem organized reliably.
- Smart Manufacturing: M2M applications provide control, measurement, sensing, and energy management that are useful in manufacturing.
- Smart Environment: M2M applications help monitor the environment, such as atmospheric conditions, air quality, noise pollution, and water resource management, which helps protect the environment.

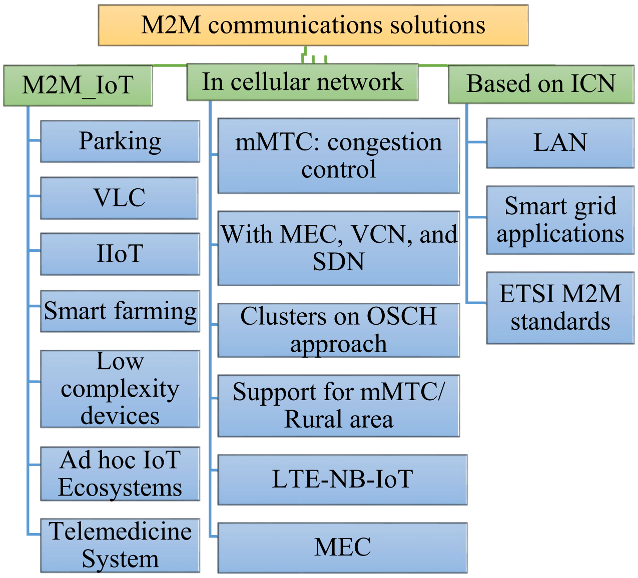

FIGURE 5. M2M communications solutions.

So, here we will review the researches that provided solutions and applications for M2M; M2M communications solutions dealt with three types of networks, as shown in Figure 5; these networks are IoT, Cellular network, and ICN.

1) M2M_IOT COMMUNICATIONS SOLUTIONS

In the IoT context, researchers of [17] proposed a smart parking system with a web application based on M2M communications. The proposed system monitors and indicates the availability of a parking space through a web application and makes it easy for users to reserve a parking space anywhere they want. Based on the SheepIT project that provides solutions for sheep management, where sheep carry a collar with sensors (e.g., ultrasound, accelerometer, and bell).

The researchers in [18] provided M2M communication based on VLC for the IoT. VLC is one possible application of the IoT, which uses visible light modulated at a specific frequency to enable heterogeneous devices to interact and communicate together without human intervention. The proposed system consists of transmitters and receivers with information from the RF link. The transmitter consists of LEDs that produce coded light beams to transmit information to various M2M devices. It may use OFDM. The system can be deployed in an internal or external environment; LEDs connect devices in the indoor environment, while they use LDs in the outdoor environment. Both cases use a peer-to-peer topology.

Also researchers of the work [19] also presented frameworks in the M2M communication. This framework identifies four IIoT business models: systemic business models, corporate business models, value designs, and systemic value designs.

The work [20] proposed a new M2M communications stack for smart farming. This stack consists of four layers: the application layer, transport layer, MAC layer, and physical layer. The data collected in the restricted nodes is transmitted to the end user. By deploying sensors at different locations on the farm, the proposed stack supports various farm monitoring and decision-making applications, such as animal sensing, missing animal detection, and weather monitoring. Furthermore, this stack allows the integration of machine learning and data mining, which are used to predict potential diseases on orchard trees or animals.

Researchers of the work presented [21] ALOHA-NOMA protocols that meet low complexity requirements for IoT devices and are energy-efficient because they reduce retransmission and resolve collisions. It is also scalable so that any nodes can join or leave the network without any interference in network management before connection.

Also, authors in [22] offered a framework for networks dedicated to the IoT for research or ecosystem monitoring. It consists of three components: the M2M learning component of the network, the software that implements the framework itself, and the server.

Drawing on M2M technology, the author's work [23] introduces telemedicine systems to validate cardiovascular patients in rural areas where patients' vital signs are measured and sent to a physician in urban areas. The kNN machine learning algorithm was also used to develop an automatic diagnostic system that helps the doctor make the appropriate decision. The proposed system consists of three parts:

The patient's location, blood pressure, and ECG are measured by a nurse, who interviews the patient to find his basic data, such as age, gender, and medical history. The automatic diagnostic system collects the data, which transmits the diagnosis to the server and, from there, to the doctor.

The server location collects, stores the data. This data displays it on a web page and sends it to the doctor through a mobile application.

The doctor's location looks at the automatic diagnosis, checks the result, and provides consultation or recommendation. Table 2 shows M2M_IoT communications solutions with their advantages, limitations and the method for evaluating the proposed solutions.

2) M2M IN CELLULAR NETWORK SOLUTIONS

Some works have also presented solutions for integrating M2M into cellular networks. For example, the authors of [24] proposed an algorithm for controlling overload in massive M2M networks. This is distributed algorithm that operates during the contention time to allocate uplink resources. Also, it achieves the best use of resources, leading to reduced energy consumption, access delays, and the possibility of blocking.

The authors [25] presented a framework for M2M communication that integrates MEC into VCN and SDN and improves the computing of cellular networks by offloading their servers to a MEC server. Furthermore, the proposed framework also improves power consumption in the

TABLE 1. Summary of abbreviations.

Acronyms	Definitions	Acronyms	Definitions
3GPP	3rd Generation Partnership Project	MEC	Mobile Edge Computing
5G	Fifth generation technology	MH	Mobile Helpers
5GTN	5G Test Network	MME	Mobility Management Entity
6G	Six generation technology	MMFA	Many-to-Many File Allocation
		ML	Machine Learning
AI	Artificial Intelligence	MOIS	Multiple to One
BDI	Belief-Desire-Intention software model	mMTC	Massive Machine Type Communication
Bi2Bi	Bike-to-Bike	MTC	Machine Type Communication
BLE	Bluetooth Low Energy	MRFP	Minimized Redundancy File Placement algorithm
BS	Base station	NB	Narrowband
BT	Bluetooth	NCSD	Network Coding-based Socially-aware D2D
CCN	Content-Centric Network	NDN	Named Data Networking
CDNs	Content Delivery Networks or Content Distribution Networks	NetInF	Network Information
CIoT	Cellular IoT	NFC	Near Field Communication
C-ITS	Cooperative intelligent transport system	NGSIM	Next Generation Simulation
CPs	Content Providers	NSCL	Network SCL
CRs	Content Requesters	OFDM	Orthogonal frequency division multiplexing
CSPC	Community Similarity and Population	OSCH	Optimal Selection of Cluster Heads
D2D	Device-to-device	OSCL	Overlay Service Capability Layer
DAIS	Distributed Artificial Intelligent Systems	OSI	Open Systems Interconnection
DCS	Dynamic Cooperation Scheme	OVF	Optimal velocity function
DECT	Digital Enhanced Cordless Telecommunications	P2P	Peer-to-Peer
DNS	Domain Name System	PaFF	Preference-aware Fast Interest Forwarding
DONA	Data Oriented Network Architecture	PANs	Personal area networks
DSCL	Device SCL	PLC	Power line communication
DSRC	Dedicated short-range communication	ProSe	Proximity-Based Services
EC-GSM-IoT	Extended coverage GSM IoT	QoS	Quality of service
eNB	Evolved Node B (Base stations)	RF	Radiofrequency
ETSI	European Telecommunications Standards Institute	RFID	Radio Frequency Identification
F-AP	Fog Access Points	RL	Reinforcement Learning
FCW	Forward Collision Warning	RSUs	Road Side Units
F-RAN	Fog Radio Access Network	SAA	Smart Adaptation Algorithm
GPRS	General Packet Radio Services	SAMPLER	Social-Aware, Mobility, and Pol Routing
GPS	Global Positioning System	SCL	Service Capability Layer
GSCL	Gateway SCL	SDN	Software-defined networks
GSM	Global System for Mobile	Sod5G	Test track in Sodankylä.
HAN	Home area networks	SV	Surrounding Vehicles
HMM	Hidden Markov Model	TCP	Transmission Control Protocol

TABLE 1. *(Continued.)* **Summary of abbreviations.**

ICN	Information-Centric Network	TM	Transmission method
IIoT	Industrial IoT	TRIAD	Translating Relaying Internet Architecture Integrating Active Directories
IoT	Internet of Things	TVWS	Television white space
IoV	Internet of Vehicles	UDP	User Datagram Protocol
IP	Internet Protocol	UE	User equipment
ISO	International Organization for Standardization	UG-Cache	Utility Gradient Caching
IUs	Important Users	ULE	DECT Ultra Low Energy
kNN	k-Nearest Neighbor	V2I	Vehicle to Infrastructure
LDs	Laser Diodes	V2P	Vehicle-to-Pedestrian
LED	Light-Emitting Diode	V2V	Vehicle-to-vehicle
LoRaWAN	Long Range Wide Area Network	V2X	Vehicle to Everything
LSTM	Long-Short-Term-Memory	VANETs	Vehicular ad hoc network
LTE	Long Term Evolution	VCN	Virtual cellular networks
LPWAN	Low-power wide-area network	VFC	Virtual Fog Community
M2M	Machine-to-machine	VLC	Visible light communications
MaaS	Mobility as a Service	WFD	WiFi Direct
MAC	Medium Access Control	WFH	WiFi Hotspot
MBS	Macro-cell Base Station	WLAN	wireless local area network
MCC	Mobile Cloud Computing	WSN	Wireless Sensor Network

access phase when performing computing tasks. The proposed framework was evaluated by simulating the VCN and SDN.

Drawing on OSCH's approach, the authors in [26] proposed an efficient cluster design for M2M communications in cellular networks. The cells are divided into clusters, and heads are selected for each cluster. Clusters aggregation is an effective way to reduce power consumption, thus extending the life of the network.

Researchers [27] worked to exploit the sideline communication system (sideline in 3GPP refers to a direct link between two devices over an antenna interface) that enables the cellular network to better support mMTC services. Sideline communication occurs by clustering sensors close to each other, allowing communication within the cluster only. With the help of context information (such as battery level and sensor location), a TM is selected within the cluster, and sensors with good cellular connections and sufficient battery capacity are considered relay sensors. The proposed approach allows uplink packets to be relayed from sensors to other sensors with a better propagation channel and sufficient battery level. However, this proposed approach assumes that the mMTC sensors are stationary and can directly make sideline contact with other sensors. Also, it ignores the downlink performance and only checks the uplink performance of mMTC services due to the higher transmit power available at the base station. Hence, mMTC services have better coverage in downlink than in uplink. The performance check and adaptation of the clustering algorithm are only made in a rural area scenario. It does not present scenarios in dense urban areas.

Also, the authors [28] describe an NB-IoT based on the LTE for M2M Communication. This reference describes how NB-IoT supports many devices and reduces device complexity to support IoT applications, providing a long battery life and fast response time.

Authors [29] suggest offloading the core network/ BS and allowing M2M devices to communicate with the nearest MEC. The proposed system offered three levels of offloading: the first level is the cloudlet, and user devices represent it with high computing capabilities. The second level is Micro-cloud edge units, a small data center with limited computing capabilities, and the third is Mini-cloud units, an edge server with computing capabilities on top of the previous units. Also, each level controls the level below it.

Furthermore, in 2015 the authors of [30] reviewed a detailed survey of M2M communications in mobile networks. The paper reviewed the key standardization efforts, M2M service requirements, M2M challenges, and several mobile M2M applications. Table 3 shows M2M cellular network solutions with their advantages and limitations and the method for evaluating the proposed solution.

TABLE 2. **M2M_IoT communications solutions.**

Ref. No	Year	Methodology	Evaluation	Features	Limitations
[17]	2021	The proposed system detects vacant parking spaces and indicates them in the web application, and the user can reserve the place he wants.	Hardware Implementation: sensors detect parking lot vacancies every 5 seconds.	Ensures security by storing the user password as an encrypted password. An LED indicator in the parking slot shows if the place is vacant for the person not using the web application.	There is no flexibility in dealing with potential changes; for example, someone booked a parking slot but did not attend for any reason, such as an accident.
[18]	2020	Authors proposed VLC to enable interaction between heterogeneous devices without human intervention.	They used simulation but did not provide any details about it.	It can be deployed in two main environments (internal and external). Multiplexing (OFDM) can be used. Both LEDs and LDs can be used for illumination.	There are various noise sources (thermal noise from electronic components, reflected light radiation noise, and background light). It is assumed that all sources exist at the same level.
[19]	2020	It is a business model analysis framework for studying IoT business models in an M2M context.	Researchers discussed corporate cases through a conceptual framework to investigate proposed business models.	They proposed a theoretical framework for multiple industries. It added three new concepts, 'value base' and 'value space,' in the context of business models.	They relied solely on their empirical concepts in the automotive and heavy machinery industries. They drew on their experience working in the heavy equipment industry.
[20]	2018	The methodology was deploying sensors in different parts of the farm, including animals. Collecting and monitoring data and making appropriate decisions.	It is a prototype of the proposed M2M communication stack. Their experiment was conducted in a laboratory with an open environment for 127 hours with multiple sources of interference.	The prototype can predict diseases and potential risks because it supports machine learning and data mining.	It is not suitable for agricultural areas that are irregular, rugged, irregularly carved, and large areas where these areas impede the use of radio or cellular-based technologies.
[21]	2018	It is an energy-efficient protocol for low-complexity IoT devices.	Evaluated numerically	This protocol supports heterogeneous devices without performing any network configuration. Also, It is energy efficient, increases throughput, and decreases overhead. Scalable.	It works with low-complexity IoT devices. The increased computational complexity of receptors is due to many nodes.
[22]	2018	It is an ad-hoc IoT ecosystem framework based on M2M Learning.	Theoretical framework	Trusted devices in ad-hoc networks.	Centralized and is not suitable for decentralized systems.
[23]	2018	It is a telemedicine system validating cardiovascular patients in rural areas with an automatic diagnosis system.	They tested and implemented it in four rural locations near Jakarta.	It improves the quality of healthcare services in rural areas. Prediction accuracy is about 76.47 The processing time is one second. Transfer time 8.97 seconds	It is dependent on the staff that enters the data manually. Also needs Quality internet access.

3) M2M SOLUTIONS BASED ON ICN

As the researchers mentioned earlier, in recent years, ICN has gained momentum in future Internet research, and the research community has been addressing the integration of ICN with M2M. For example, authors [31] offered a framework that enables interactions between remote applications and resources in M2M-ICN and ETSI M2M protocols. The proposed framework used the ICN for local M2M communications. It also uses hierarchy to name resources in the local network and supports multi-source communication (more resources simultaneously with a single Interest). Nevertheless, to connect the remote devices used, the ETSI M2M protocols.

Authors in [32] offered an architectural framework for M2M data delivery in smart grid applications based on publish/subscribe ICN architecture. ICN can support real-time state estimation in the medium voltage power grid while overcoming potential power grid component failures. Also, the proposed framework considers a hybrid network using optical fiber and PLC.

Authors of [13] presented a development of ETSI M2M standards. ETSI M2M standards consist of the M2M SCL, and each SCL exchanges information over the defined reference points. Furthermore, SCL is defined as the DSCL, the GSCL, and the NSCL. This standard is centralized, which the NSCL uses as a relaying point for all messages because all devices and gateways must be authenticated at the NSCL. They proposed to design an OSCL that depended on NDN (related to ICN). OSCL eliminates the centralization found in the ETSI M2M standards, which increases scalability.

TABLE 3. M2M in cellular networks solutions.

Ref. No	Year	Methodology	Evaluation	Features	Limitations
[24]	2019	It is a distributed network overload control algorithm to access the MTC and efficiently use available resources	Simulation using MATLAB.	Low power consumption. Low cost. It reduces delay.	It assumes that there is no undo interval so that failed devices will retry in the next time interval. Its traffic is based on demo distribution only.
[25]	2019	It is a framework for M2M communication with MEC, VCN, and SDN to improve system performance.	Simulating with VCN and SDN.	It improves the overall computing power of the system. Low costs. Low energy consumption. It reduces delays.	It did not mention any solutions for potential failures, such as packet loss with M2M communication.
[26]	2018	Authors designed effective clusters for M2M communications in cellular networks based on the OSCH approach	They using MATLAB programs in terms of performance measures	Reduce energy consumption. Extend network life, thus reducing cost. Low computational complexity.	It is assumed that all machines consume the same amount of energy.
[27]	2017	Uplink packets are transmitted from the sensors to other sensors. The sensors cluster close to each other and communicate only within the clustering. Sensors with good cellular coverage and battery capacity are used as relay sensors.	They used simulation at the system level, and they did the following: Deployed one base station in a rural area with a cell radius of 2500m They deployed one hundred thousand uniformly distributed sensors inside the cell at the height of 0.5 m with a maximum transmission power of 20 dBm per sensor. The frequency of the wave is 900 MHz. Send periodic reports, one report per 150 seconds, with a payload of 1000 bits. Send periodic reports, one report per 150 seconds, with a payload of 1000 bits.	It gathers the required context information without significant signal overload. It improves service availability. Longer battery life.	This approach assumes that: Sensors are stationary. Also, it Ignores the downlink performance. Adaptation of the proposed approach only in a rural area scenario.
[28]	2016	They described an overview of NB-IoT for M2M Communication.	They analyze performance in Stand-alone and In-band scenarios. Performance analysis includes capacity, coverage, battery life, and latency.	Operating in standard LTE networks without the need to add any devices or cost, low-cost device connections, long battery life, and high coverage are achieved in all the scenarios mentioned.	Describe the NB-IoT based on LTE only.
[29]	2016	They proposed a system that used MEC for cellular offloading.	Network performance experience with MEC and without MEC. They concluded that the applications are distributed among the local MEC.	They are improving QoS. They are increasing network performance by offloading channels in the core network.	It is a complex system to manage due to offloading levels.

OSCL connects many SCL without referring to NSCL, which leads to increased response time and access to resources in a distributed way. However, this work does not ingest potential failures. When failure occurs, the system is used the ETSI-M2M standard until a new link is set up in the OSCL. Table 4 shows M2M_ICN communications solutions with their features and limitations and the method for evaluating the proposed solutions.

B. V2V COMMUNICATION SOLUTIONS

Transportation affects our daily lives directly, so it is an important aspect of our lives, like water and food. Recent research is directed toward creating a vehicle infrastructure that includes V2V technologies and is managed by intelligent systems [33]. V2V includes three common aspects of its applications which are:

- Environment environmental V2V applications include dynamic environmental routing (vehicles, charging, and light), smart parking, traffic monitoring, turn traffic analysis, and traveler information.
- Smart road, V2V applications for smart roads and mobility include communication and vehicle protection systems in emergency and evacuation, cruise control, radio checks, emergency guidance, and others.
- V2V safety includes various warning systems (collision warning system, blind-spot warning, no-traffic warning, crossing warning, speed-curve warning) and the intersection, cornering, lane change assist systems, and electronic emergency brake lights.

Authors [34] presented surveys of vehicle communication systems and their classes in 5G. These categories are:

- V2X, this category refers to the technologies and standards that enable vehicles to communicate with

TABLE 4. M2M solutions based on ICN.

Ref. No	Year	Methodology	Evaluation	Features	Limitations
[31]	2016	Authors proposed a framework for local M2M communications using M2M-ICN and ETSI M2M protocols.	Evaluation is a testbed for home automation with an IEEE 802.15.4 interface.	It is easy to interoperability with ETSI M2M because of the hierarchical naming scheme. There is the easiness of implementation and good consumption of device resources in local M2M communications. It fits the requirements of group-based M2M communications and information-centric applications.	This framework is used only for local M2M communications while using the ETSI M2M protocol for global resource access.
[32]	2014	They proposed an ICN-based framework for emerging smart grid communications.	It is the simulation of a prototype that focuses on the topological properties of an entire power distribution network in the Netherlands.	It Supports heterogeneous smart grid applications and applications with strict requirements in real time.	They consider a hybrid network using both optical fiber and PLC.
[13]	2014	They designed a Layer (OSCL) depended on NDN that connects many of the SCL without referring to NSCL.	System-level simulator in Matlab.	This proposed layer increase scalability of ETSI-M2M systems, response due to reducing connection with NSCL, and access to resources in a distributed way.	This layer does not ingest potential failures. When failure occurs, the system uses the ETSI-M2M standard until a new link is set up in the OSCL.

infrastructures such as roads and their users. It is also interested in exchanging information between other classes. V2X reduces pollution, manages traffic, reduces congestion, reduces vehicle crashes and associated fatalities, and helps lower fuel costs and produce environmentally-friendly vehicles. The authors mentioned that Latency and Security are this category's most prominent network challenges.

- V2V, this category represents the interaction between two devices directly without the need for central control so that each vehicle can receive and transmit data to other vehicles within a radius of 70 meters. V2V offers many applications, especially for future cars, such as autonomous driving, highway safety services, and information dissemination like road entertainment services.
- V2I, Communication in this category occurs between vehicles and the communications infrastructure, i.e., roadside devices. Vehicle and infrastructure data are used to set speed limits and traffic flow and reduce fuel consumption. This infrastructure includes fog networks, clouds, and servers.
- V2P, in this category, the vehicle interacts with a mobile phone or computer carrying an individual/a passenger, a cyclist, or a pedestrian. It provides warnings to both pedestrians and drivers. Where these systems implement pedestrian detection in the infrastructure or vehicles or with pedestrians, for example, warnings to drivers of the presence of a pedestrian in the blind spot; also, it may be a pedestrian warning system connected to mobile devices.

Furthermore, the authors [35] review recent research trends in V2V communications. The authors mention the architectural requirements, communication protocols, and security requirements that must be supported to achieve reliable and secure V2V communications. It also mentions the challenges facing the deployment of V2V communications and the role of fog computing in its deployment and empowerment. The most important requirements are the sensors and the processor. Sensors collect traffic, safety-related information, and recreational information, and are directly connected to a processor that receives data from different devices, analyzes it, and uses it to make decisions to improve the road network. Also, storage units that store driver information, application data, and more are required. Also, architectural requirements are the GPS, Interfaces connected to the driver, which sends him the relevant warnings, and radio communication that uses antennas to exchange data between vehicles. Security mechanisms and requirements must be implemented in all system components. Here the researchers will review the research papers that provided solutions and applications for V2V solutions. Researchers in this paper reviewed these solutions with three types of networks, as shown in Figure 6. These networks are the IoV, the Cellular Network, and the ICN.

1) IOV COMMUNICATIONS SOLUTIONS

Researchers in this paper mentioned earlier, the density of vehicles increases due to users' need for transportation that leads to traffic congestion and may cause road accidents, property loss, and lives. The term IoV has emerged with the surge in Internet-connected vehicles, as modifications have been made to the concept of VANETs [36]. The hope is that IoV will enhance traffic safety, reduce traffic accidents and control their damage. In this context, here the researchers review the solutions that dealt with IoV.

The paper presented [37] mechanisms for collaborative video transmission of accidents in the V2V communications highway, which helps reduce accidents and increase traffic safety. This mechanism works on a two-way cooperative transmission, forming groups that communicate with each

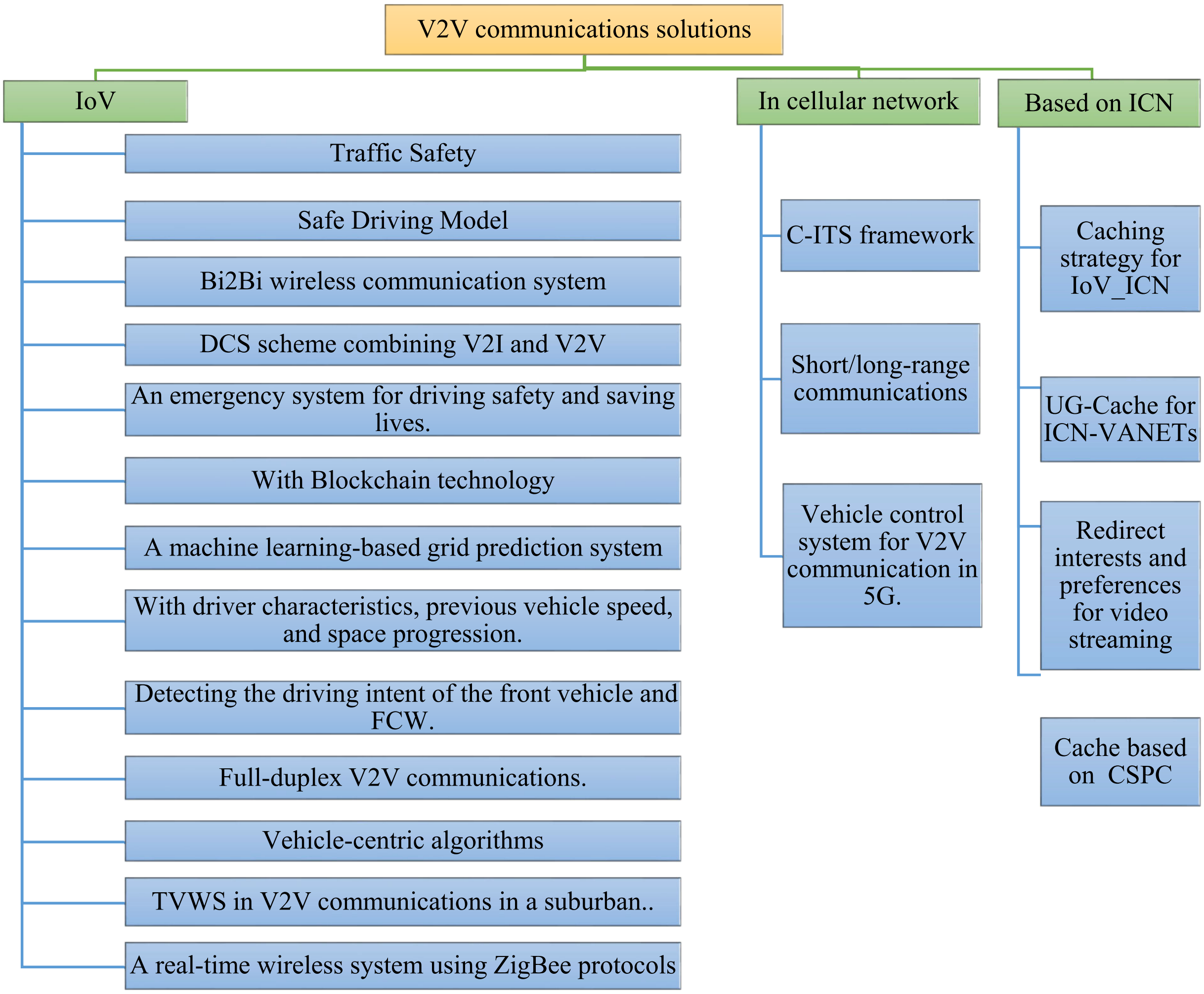

FIGURE 6. V2V communications solutions.

other and publish the video of the accident in the same direction as the accident vehicle, and in the opposite direction, the relay vehicles are chosen to spread the video quickly and reliably.

Authors in [38] proposed a safe non-linear driving model has been proposed to describe the variance and factors affecting the vehicle speed, including the distance, the type of vehicle in front of the vehicle to make the acceleration or deceleration decision, and the road factors affecting the vehicle speed such as road friction and bends, and driver behavior.

In the smart city region, authors of [39] proposed a Bi2Bi wireless communication system in different urban scenarios and integrated it into the smart city. The data exchange in the proposed system is based on LPWAN technologies, specifically ZigBee. Authors also developed a sustainable mobility mobile app Pamplona CityApp where users can organize their itineraries according to their interests. The services are aimed at all stakeholders, such as bicycle platform services, cyclists, local and regional authorities, and the city's general population.

Authors [40] proposed a DCS scheme to address network connectivity problems by combining V2I and V2V. V2I provides continuous file download and connection service for any vehicle within its coverage area without needing a V2V connection. RSUs are installed uniformly and intermittently along a two-way highway, and all RSUs are connected to a central server containing all needed files. The proposed scheme selects a dynamic forwarder to create a multi-hop V2V communications path to improve vehicle connectivity and throughput outside RSU's coverage.

Authors [41] believe that most accidents and collisions are due to a lack of lighting at night and foggy weather, so authors proposed an emergency system that alerts, warns, and prevents vehicle collision, especially in off-balance conditions such as potential closing barriers, especially in foggy weather, or night or any conditions other. The proposed system uses GPS and GSM to locate nearby rescue platforms, such as hospitals or police stations, and send alert messages to family members registered in the system. It is also possible to report collisions to insurance companies to obtain vehicle-related reports. Several sensors deploy and specialize, and modern technologies are developed to alert vehicles when needed. Vibration and ultrasonic sensors estimate the distance between vehicles to vehicles, and nearby obstacles. Sensors are connected to the Arduino Uno controller, and a buzzer sound accompanies the alarm system. The vibration sensor detects the unbalanced condition so that if the vibration exceeds the threshold limit, it means an accident has occurred. The data is sent to the cloud server, which searches for the nearest police stations, hospitals, and insurance companies. Then an ambulance is sent to him, with a police officer, in addition to submitting a report to insurance companies.

In [42], authors present a framework based on the existing V2V architecture and use block chain technology to achieve lightweight and secure V2V communications. The proposed framework uses data-sharing mechanisms in the block chain to exchange data and achieve authentication between vehicles. Vehicles send the information to the servers registered on them and from there to the cloud, and after authentication, the vehicles receive the required data from the cloud.

To maintain traffic safety, the research community provides solutions based on predicting the lanes of the surrounding vehicles to prevent collisions or at least mitigate their damage. In this context, the authors [43] presented a system based on machine learning in V2V communications that predicts the trajectory of vehicles. The system predicts the SV trajectory by sensors mapping the area around the target vehicle, and the future trajectory of the target vehicle is determined using Random Forest (RF) algorithm, decoder architecture, and LSTM. Traffic safety is affected by many factors, including environmental characteristics, the road, the vehicle, and collision, in addition to the characteristics of the driver.

Authors [44] presented models of vehicle tracking in a V2V communication environment taking into account the drivers' characteristics and the driver's response to the previous vehicle's speed. Authors also introduced a new OVF, which better describes the characteristics of drivers than a conventional OVF. New OVF also correlates with the speed of the previous vehicle and the space advance (the distance between the two vehicles). Where the vehicles exchange their operating information under the V2V or V2I communication environment, each vehicle is affected by the vehicle speed that precedes it.

Among the prediction-based solutions, authors [45] introduced a system based on detecting the driving intent of the front vehicle (FCW) and providing early warnings via V2V communication to the next vehicle, ensuring quick response and giving it enough time to brake smoothly and avoid a frontal collision. The system consists of a unit that recognizes the driving intent, which is the driver's behavior and the expected movement of the vehicle, for example, walking at a constant speed, acceleration, normal braking, and emergency braking. Driver behavior is analyzed using a dual-layer HMM. Then, using a V2V communication, the information is sent to the next vehicle to prevent a frontal collision.

Authors [46] proposed deploying a V2V transmitter and receiver in one channel simultaneously, enabling dual use of the spectrum by separate antennas distributed over the vehicle body, increasing the degree of freedom in the spatial domain. In dual channels, each vehicle receives independent signals from itself and from all surrounding vehicles, which means better use of resources and lower latency.

Authors [47] proposed vehicle-centric algorithms. They proposed an algorithm that addresses a heterogeneous network composed of V2V and V2I networks.

Vehicles located at a short distance and in a straight line are grouped and called a platoon and driven by the main vehicle (the first vehicle in a platoon). The compounds in the platoon compose a virtual V2V network and coexist with V2I.

In one platoon, information about vehicles, such as speed and location, is exchanged periodically. The V2I network then provides communications for fast-moving vehicles.

Using IEEE 802.11af-compliant devices, authors [48] implemented TVWS in V2V connections in a suburban environment. The University of San Carlos Talamban Mountain was considered an experimental environment due to the similarity of its terrain with that of the suburbs due to the infrastructure of the buildings, the existing vegetation, and the terrain. The experiments were conducted in three cases, first, if the vehicles were moving towards or away from each other, and finally if they were moving in the same direction.

In the context of traffic safety, authors [49] proposed a real-time wireless system using ZigBee protocols for V2V communications. Through GPS technology included in today's cars, vehicles can know each other's locations. Also, the authors proposed a communication system consisting of a receiver and a transmitter in the vehicle to communicate with other vehicles to warn drivers, communicate with each other, and act to clear lanes in traffic congestion and emergency. Furthermore, the proposed system contains various sensors related to the possible causes of accidents, such as the distance traveled by the vehicle, its speed, humidity, temperature, and the distance of the nearest vehicle to it. Table 5 summarizes these solutions.

2) V2V IN CELLULAR NETWORK SOLUTIONS

Various wireless technologies, particularly cellular networks, can enhance the operational performance of roadside V2V communication. Here, researchers review solutions that use cellular networks. In [50], the authors present a complete collaborative intelligent transportation system consisting of a framework shared between different components in C-ITS, which realizes the communication between vehicles in V2I and V2V networks when exchanging traffic and road weather information in cellular networks. Experimental networks 5GTN and LTE were used for performance analysis. It helps to reduce traffic jams, increase safety, and design environmentally friendly systems. It consists of four components. First is the central server that manages C-ITS services and applications, collecting data from different vehicles and then

TABLE 5. IoV communication solutions.

ref. No	Year	Methodology	Evaluation	Features	Limitations
[37]	2022	They proposed a mechanism for two-way collaborative video transmission of accidents on the highway.	Simulation of the proposed mechanism.	It reduces accident damage and enhances traffic safety. It improves performance. Improve transmission efficiency and reliability.	The proposed mechanism enables vehicles to share video within the group, which cannot be sent to vehicles from outside the group.
[38]	2022	Safe Driving Model	Numerical simulation using MATLAB 2018a	They studied more than one-factor affecting vehicle speed/distance, vehicle type, road factors, and driver characteristics.	Communication reaction time and its effect on drivers
[39]	2022	Authors proposed a Bi2Bi wireless communication system in an urban scenario for the smart city.	It 3D simulation technology implemented in Pamplona, Spain.	They develop a special application for all stakeholders.	Only deal with urban scenarios in smart cities.
[40]	2022	They proposed a DCS scheme combining V2I and V2V.	Simulation using MATLAB (version 2016b)	This scheme improves communication. High throughput of target vehicles.	They assumed only a one-dimensional network topology. Also, they assumed that all vehicles traveled in the same direction and at the same speed.
[41]	2021	An emergency system that alerts and prevents vehicle collisions, and when the collision occurs, it communicates with hospitals, police stations and sends alert messages to the injured's family.	Theoretical comparison with other systems.	It helps save lives in a short time. Before the accident occurs, alert the driver and nearby vehicles. After the accident: Communicate with the police, the hospital, the insurance company, and the injured family. It works in different climates, including day and night.	The system works in different climates and locations, which makes it difficult to manage. It does not contain any solutions or alternatives if any part of the system is broken.
[42]	2021	They proposed a framework based on V2V architecture and Blockchain technology to achieve lightweight and secure V2V communications.	Simulation using MATLAB R2020a.	The proposed framework achieves Lightweight and secure V2V communications.	The proposed framework needs an investigation of the encryption solutions used.
[43]	2021	They proposed a machine learning-based grid prediction system using Random Forest (RF) and LSTM decoder architecture.	It is a highway-like test environment (test car, 932 different tracks)	It depends on differential GPS (DGPS) applications to overcome the problem of GPS accuracy in urban areas.	Prediction decreases with increasing speed and changing lanes.
[44]	2020	They proposed a tracking model in V2V communications that correlate with driver characteristics, driver response to previous vehicle speed, and space progression.	The NGSIM project performed numerical simulations.	It avoids traffic jams and collisions. Optimizing vehicle fuel consumption.	No solutions are guaranteed for cases of transmission delays or packet losses.
[45]	2020	They proposed a system to predict the front vehicle's driving intent and send warnings to the next vehicle.	They use simulation with PreScan (commercial software provided by TASS international). Also, they used real tests of vehicles with a 5 km long, 3.5 m wide, two-lane test road and a dry asphalt surface.	Increase safety. The proposed system accurately detects the driving intention of the front vehicle. It provides early warnings.	It does not take into account sudden changes. It just works: In the low to medium speed range. The vehicle is traveling at a constant speed and in one lane. Traffic flow is low. Asphalt road.
[46]	2020	They deployed a dual transceiver in V2V communication by separate antennas distributed over the vehicle body.	They used simulation and numerical comparisons with traditional methods. They have not mentioned the software used in the simulation.	It achieves good performance in high-density V2V communication and low latency. It uses resources efficiently.	They assumed the absence of any frequency offsets. It works efficiently in nearby vehicles only.

TABLE 5. *(Continued.)* **IoV communication solutions.**

[47]	2019	They proposed vehicle-centric algorithms composed of V2V and V2I networks.	Mathematical analytic.	Low latency V2V. These algorithms effectively operate the network.	They assumed that: The effect of white noise is minimal, and therefore the interference is ignored. There are all the packages.
[48]	2018	They proposed TVWS in V2V communications using IEEE 802.11af-compliant devices in a suburban environment.	They did experiments in Cebu City, Philippines, on the San Carlos Talamban University Mountain Campus, whose environment mimics the suburbs due to the buildings, terrain, and vegetation present.	It received signal strength. Increase productivity.	It contains acknowledgment after the start of transmission, which may result in lost packets
[49]	2018	They proposed a real-time wireless system using ZigBee protocols for V2V communication.	It is a mathematical analysis of the sensors, in addition to flowcharts explaining the functioning of the various parts of the proposed system.	It helps avoid accidents. It improved traffic management.	The system depends on the model of the vehicle, which means that it is difficult to install in old vehicles.

sharing it with them. Secondly, an individual unit is a transportation unit/such as a smartphone or similar, that hosts and assists C-ITS applications in communication between vehicles/road users/and with road infrastructures. Third, the car unit shall be equipped with units or devices that create a LAN network on the side of the road between the infrastructure, nearby vehicles, and means of transportation. It works on exchanging information, processing it, and transferring it to either other units or the main server. Fourthly, the roadside unit contains variable message indicators such as traffic lights and other warnings. It can communicate and send messages to other components. Finally, the references protocol stack contains communication protocols based on the ISO/OSI reference model.

Authors in [36] proposed a protocol to facilitate efficient communication in IoV, consisting of two technologies: DSRC for short-range communications, which is suitable for delay-sensitive security applications, and LTE networks for long-range communications, where the LTE environment is utilized, such as wide coverage, as well as QoS.

Authors [51] proposed a vehicle control system for V2V driverless communication by GSM towers in 5G mobile technology. The GSM tower works to receive and transmit information in a coverage range. In real-time, communicate with vehicles, transmit information that helps them to avoid collisions and exercise caution. The proposed system provides vehicle owners with vehicle-related information such as speed, track, and others. Table 6 presents a summary of these solutions.

3) V2V SOLUTIONS BASED ON ICN

Many authors provide solutions to use ICN for IoV. ICN's reliance on data dissemination makes it a promising solution for video streaming in IoV. Also, ICN speeds up content retrieval based on caching of different nodes. In this context, authors [52] offered a strategy to place content proactively at the right nodes based on ICN in IoV retrieval based on caching of different nodes. In this context, authors in [52] offered a strategy to place content proactively at the right nodes based on ICN in IoV.

This strategy is simulated in highway scenarios that do not have frequent turns. The proposed strategy provides a mechanism to disseminate safety messages on time.

As mentioned earlier, caching capacity is a major benefit of ICN and is necessary for mobile networks such as V2V. In [53] authors have proposed an implicit utility gradient caching function, UG-Cache, for ICN-VANETs. In UG-Cache, caching decisions are made based on request frequency and cache distance. The content is distributed over the network, taking into account the spatial distribution of copies where the distance between the content provider and the node is proportional to the popularity of the element to avoid placing duplicate copies next to each other.

Authors [54] suggest guidelines that are aware of user preferences and interests that allow video streaming in information-centric VANETs (PaFF). In PaFF, a preference content table is created for each user to store these preferences in nearby nodes to reduce latency.

Authors [55] proposed Cache based on CSPC in the ICN V2V scenario. A dynamic caching scheme is designed by classifying the specificity of vehicles based on community similarity and the popularity of the content the caching vehicle is selected. Also, the authors put a mechanism to replace this cache CSPC over a while to reduce overhead for the cache replacement. Nevertheless, this work did not explain strategies for dealing with failure in caching vehicles. Table 7 shows the solutions in ICN.

C. D2D COMMUNICATIONS SOULATIONS IN CELLULAR NETWORKS

Cellular networks are well organized and have an integrated, secure ecosystem. Also, have multiple advantages such as community acceptance, wide coverage, meeting the requirements of QoS, and scalability. Therefore, it is possible to reuse the huge infrastructure of the operators and provide Internet of Things services through it, including D2D solutions [56] Especially there are standards and technologies dedicated to the IoT in the licensed spectrum, cellular IoT (CIoT) refers to IoT solutions in the licensed spectrum. These

TABLE 6. V2V in cellular network solutions.

Ref. No	Year	Methodology	Evaluation	Features	Limitations
[50]	2022	Authors offered the C-ITS framework to realize communication between vehicles in V2I and V2V networks to exchange traffic and weather information.	It is a field test using LTE and 5GTN networks. They used the 1.7 km "Sod5G" route. The Python programming language, iPerf, Wireshark, and a Samsung Galaxy S7 smartphone.	It is reducing traffic jams. Increasing safety. It designs environmentally friendly systems.	It must have sufficient bandwidth available. It needs to observe hardware requirements to achieve connectivity. It only meets some vehicle communication needs.
[36]	2022	They proposed an efficient protocol to facilitate short-range and long-range communications in the IoV.	Simulation using MATLAB 2019a software.	It guarantees solutions for short and long-term communications. Improved response time, especially in short-range communications.	This protocol did not mention solutions or alternatives to problems associated with LTE networks, such as those associated with handover or network congestion.
[51]	2019	They proposed a system for controlling vehicles in V2V communications by GSM towers in 5G mobile technology. The GSM tower works to receive and transmit information in a coverage range.	It is a simulation using MATLAB 2017 and testing various road patterns in Pakistan, such as square, line, and triangle.	It works in different ways and patterns.	It needs additional towers on the straight roads. Therefore an additional cost.

TABLE 7. V2V solutions based on ICN.

Ref. No	Year	Methodology	Evaluation	Features	Limitations
[52]	2021	They use caching strategy for IoV based on ICN.	They built IoV based on ICN using SUMO and NS-3 simulator in highway scenarios.	It improves IoV performance. Through proactive data delivery, It reduced the delay times of interest data.	The proposed strategy does not work in the following ways: Vehicles on highways that have frequent turns. The vehicle is moving at high speed.
[53]	2017	They proposed implicit caching of utility gradients for ICN-VANETs.	They used SUMO, Veins, and OMNet++. They set up a simulation environment from a road network in a city center with dimensions of 2 km x 1 km. The network consists of 300 vehicles, 10% of which act as servers, while the rest act as clients.	Increase delivery rates. It reduces the average number of hops for UG-Cache content delivery. Higher cache access ratio.	The size of each content object is 100 KB. The caches are configured to store 50 items at any given moment. The proposal needs mechanisms to increase the diversity of the cache.
[54]	2017	They proposed guidance that understands user preferences and interests that allow video streaming in VANETs.	Network Emulator (NS-3) with IEEE 802.11p WAVE Network Interface	It improves in startup time. Increase the number of hits.	They consider splitting the video where each clip is 30 seconds, and its size is about 720KB only. They study urban areas only.
[55]	2017	They proposed a cache based on community and population similarity.	Using OMNeT++ simulator	It reduces overhead and time delay. It increases the number of hits.	They should have explained strategies for dealing with failure in caching vehicles.

standards allow long-range, low-power connections to a large number of devices spread over large geographical.

Areas at an unprecedentedly low cost [57]. Spectrum solutions licensed by 3GPP were published in 2015. It is part of LPWA Technologies. These technologies are:

- EC-GSM-IoT provides enhanced data rates for GSM enhancements.
- LTE-M provides further LTE enhancements for MTC.
- NB-IoT provides performance and integration with legacy GSM, GPRS, and LTE technologies.

Also, telecom operators have various strategies for providing IoT services [58]. Operators possible to provide:

- Connectivity as a service, telecom operators, provides reliable, high-quality, and economical packages.
- General platforms, an application hosting environment that meets the requirements of the IoT to store, manage, process and share data in multiple sectors.
- End-to-end solutions, the operator provides all components of IoT solutions from applications, middleware, connectivity, and sensors, including billing and support, such as healthcare applications.
- The sensor as a service, in this strategy, data is directly dealt with as it is presented as an option to enable IoT solutions by operators.

D2D communication in a cellular system is not new, as it was first proposed in 2000 to enable multiple relays in cellular networks [59]. The researchers later demonstrated the possibilities of D2D communication in improving the

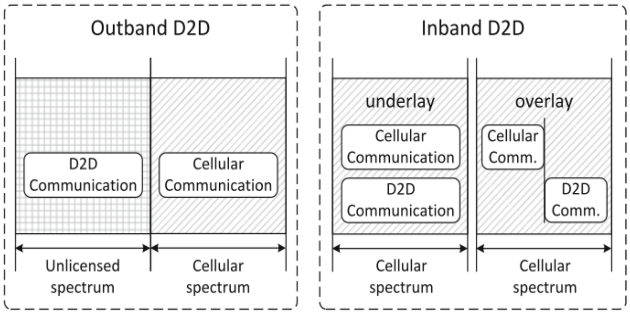

FIGURE 7. Inband and outband D2D communications.

spectral efficiency of cellular networks, peer-to-peer communication, multicasting, video dissemination, M2M communication, content capture, and cellular offloading. The primary motivation for enabling a cellular network for D2D communication is to maintain the local connection locally. The UEs are very close to each other and thus communicate directly rather than their radio signal traveling through the BS or backbone network, and due to the short distance, the response time will be very low. D2D communication will help operators offload traffic from the backbone network, thereby increasing spectrum efficiency and reducing power consumption [60]. It is also possible that D2D connections share the same cellular system resources and are under the control of NodeB [61]. The spectrum used by D2D communications, as shown in Figure 7 [62], is categorized into:

- D2D Inband: The spectrum is used by both D2D and the cellular network; thus, interference occurs. This communication avoids the problem. A portion of the cellular resources is allocated to D2D communication, which means that the allocated cellular resources are wasted. In-band D2D communication is categorized into two modes. D2D underlay/non-orthogonal mode which both cellular users and D2D users share the radio resource of a cellular system. Also, in overlay/orthogonal mode, D2D users are granted a dedicated cellular resource in this mode.
- D2D Outerband: Unlicensed spectrum was used to eliminate interference between cellular linkage and D2D. It relies on wireless technologies such as Bluetooth, Wi-Fi Direct, or ZigBee. Furthermore, the unlicensed LPWA technologies like Sigfox or the LoRa. It faces challenges in coordinating communication across different domains, and the coordination is done either by the BS or the users themselves.

Moreover, based on the mechanism of interaction of the UE with the BS, the D2D communication mode is defined, which are [9], [62]:

- Direct D2D or duplex D2D: Two UEs communicate using either unlicensed or licensed spectrum.
- D2D single-hop relay: only one D2D UE communicates with an access point or BS and provides access to the rest of the UEs.

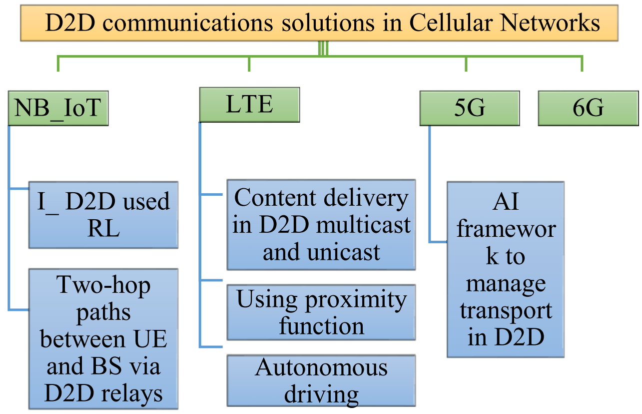

FIGURE 8. D2D in cellular Networks solutions.

- D2D multistage relay: The idea of a single hop is extended so that a group of UEs acts as a chain of relay nodes and controls more other UEs.
- D2D cluster: This type is suitable for high user density, where a group of UEs connects to a relay node that acts as a cluster header, and that node acts as a router for the network through an access point.

In this section, the researchers will review solutions from D2D in cellular networks, according to Figure 8.

1) D2D COMMUNICATIONS SOLUTIONS IN NB_IOT

NB-IoT was designed to improve the efficiency of extended coverage and the spectrum. NB-IoT is from the licensed techniques for LPWA that provides a transmission range of up to 15 km in open areas and 3 km in urban areas, with a battery life of up to 10 years [63]. NB-IoT is deployed in one of three ways:

- Guard-band mode: This mode utilized the guard band of the LTE spectrum for NB-IoT deployment without affecting LTE channel capacity.
- In-band mode: NB-IoT is deployed within existing LTE channel carriers, meaning that the total spectrum resources are shared between LTE and NB-IoT.
- Stand-alone mode: NB-IoT can be deployed in the idle spectrum resources of GSM networks.

In this context, the authors [63] proposed intelligent, effective, and simple D2D communication based on RL for NB-IoT UE. RL is used to find the optimal solution in real-time networks because the full dynamics of the network are unknown. The agent has to figure out what action to take through the experiment's methodology. The proposed I-D2D methodology operates on two steps NB-IoT UE follows to determine the best relay for D2D communications. First, NB-IoT equipment transmits a test signal within its range, the UE system analyzes this signal and sends a response signal to the NB-IoT UE, or it will withdraw from the selection process. NB-IoT UE models the selection process and then solves it by exploiting RL.

The scenario proposed in [64] enable D2D communication services over two-hop paths between an NB-IoT UE and a BS via a set of D2D relays. The UE relays that enable D2D

TABLE 8. D2D communications solutions in NB_IoT.

Ref. No	Year	Methodology	Evaluation	Features	Limitations
[63]	2021	They proposed intelligent and efficient D2D communications for NB-IoT UE, which uses RL to select the best relay for D2D communications.	Authors used simulation without stating what tools.	Reduce overhead. It improves end-to-end delay, the performance of the NB-IoT system, and the rate of delivery of packages.	It dealt Interference across levels with either by ignoring or assigning a unique subcarrier to each UE.
[64]	2018	They proposed two-hop paths between NB-IoT UE and BS via D2D relays.	They used simulation without stating what tools.	Improve QoS. It improves system performance.	Two-hop link states must be known in advance in the D2D_UE link, which is costly in practice.

communication are specified by a work schedule. At first, each UE is recorded at its nearest BS, and then the UE sends a test signal to the BS to test the channel quality. If the signal strength of the BS is higher than the specified threshold, it establishes a connection with the BS and uploads its data directly to it. Otherwise, the UE establishes a connection with a contiguous single-hop UE, whereby the single-hop UEs act as D2D relays. The researchers summarize these solutions in Table 8.

2) D2D COMMUNICATIONS SOLUTIONS IN LTE

3GPP defines 12 LTE-Advanced standards that support direct communication between UEs using spectrum licensed in the LTE Ecosystem. LTE Direct or ProSe is based on convergence, with which nearby devices can detect themselves and communicate directly [2]. There are three scenarios for D2D communication in cellular networks [65]:

- All UEs are participating in D2D communications within network coverage.
- Only some UEs are involved in D2D communications within the network coverage.
- There are no UEs in D2D communications within network coverage.

Authors in [66] proposed a strategy for content delivery in D2D multicast and unicast communication situations based on the content access characteristics. In the proposed strategy, the UE determines the BS it serves based on the strength of the received signal and transmits data to it. The UE transfers the data directly to the BS or via D2D communications to nearby UEs. Researchers studied two transmission modes for D2D communications, unicast and multicast. The researchers randomly selected one of these cells and studied the performance of content delivery with it, taking into account the possible interferences from other cells. The content demand statistics were modeled and studied mathematically.

In [67], authors present a solution to depressurize the cellular network by enabling D2D communications within the network, with the help of the proximity discovery service provided by the network, users can detect the presence of other users near them. The proximity function determines the distance between UEs that want to communicate directly. D2D communications begin by sending an initiation request to the MME, which uses an interface to generate a D2D radio carrier and delivers an IP address to the D2D receiver. Finally, the proximity function passes information to the applications and communicates between the mobile network and the application servers.

Authors [68] proposed D2D strategies for autonomous driving, this strategy spreads collaborative awareness messages within a platoon where the platoon's front vehicle sends periodic messages that aid in the spatial reuse of LTE resources. The proposed strategy is based on an ancestor-leader control algorithm in which spatial reuse is carried out within the platoon. A platoon is a group of vehicles with fixed distances between them, and information is exchanged through a control unit inside the vehicle. Researchers in this paper summarize these solutions in Table 9.

3) D2D COMMUNICATIONS SOLUTIONS IN 5G

As mobile phone subscribers are increasing and advanced Internet applications are rising, subscribers are looking for these services anytime and anywhere, increasing the pressures on the current technology, such as the 4G, to produce a higher communication speed. Therefore, the urgent need for a new generation of communications, the fifth generation (5G), has emerged. D2D communication is the design and further development of a 5G network, where intelligence will be harnessed to design device-centric systems. These devices are mostly UEs [62]. 5G supports device centralization as it uses direct communication between devices. D2D in 5G creates a local communication network without communicating with BS, leading to efficient use of available resources, improving communication energy efficiency, and increasing communication speed and cellular discharge [69].

Regarding spectrum, D2D in 5G communications are designed to operate in three modes, the indoor and outdoor bands, previously discussed, and D2D relay communications. In D2D relay communication mode: The devices within the BS coverage can act as sub-base stations and allow the devices outside the BS coverage to be connected through it, thus increasing and extending the coverage of the BS. Despite the many advantages of D2D communication in 5G, including increased throughput, energy efficiency, cellular discharge, and low latency. However, it faces many challenges, such as interference management, because it is recommended to

TABLE 9. D2D communications solutions in LTE.

Ref. No	Year	Methodology	Evaluation	Features	Limitations
[66]	2018	They proposed a strategy for content delivery in D2D multicast and unicast communication.	Authors used a mathematical model and a simulation but did not mention the tools.	It improves minor performance. It improves energy efficiency in unicast. Multicast mode is better when multicast content is popular.	Nodes consume more power in multicast to compensate for the interference caused by multiplexers.
[67]	2018	D2D communication using proximity function in cellular networks	They used OMNET++ in the D2D simulation. First, the researchers established a direct connection to the wires and tested it. Then they established D2D communications wirelessly.	It is a more efficient direct connection Low energy consumption. It reduces resource usage, achieving higher spectrum usage due to cellular network emptying.	Overlap is ignored.
[68]	2017	They proposed D2D strategies for autonomous driving in dedicated LTE resources.	They used simulation by MATLAB.	Very reliable. Low latency.	This strategy wastes cellular resources because D2D connections are made over licensed LTE frequency bands. They assume there are no errors (perfect channels).

TABLE 10. D2D communications solutions in 5G.

Ref No	Year	Methodology	Evaluation	Features	Limitations
[9]	2020	They proposed an AI framework to manage transport in D2D communication.	They used simulation by Matlab and Java. They assume BS at the center of the network and UEs ranging from 10 to 1000 on an area of 1000 x 1000 meters.	It increases the data transfer rate and reduces power consumption in the network. High spectral efficiency.	Authors assume that the devices have GPS, interconnection frequencies between BDIx agents, no interference, and an unused resource block is selected. It works when signal quality is guaranteed / no solutions are suggested when errors occur. The UE uses two mobile interfaces for uplink and downlink.

deploy D2D communication in the licensed spectrum of 5G, appropriate resource allocation, efficient mode selection, device synchronization, and effective peer discovery.

To address these challenges, authors [9] proposed a framework that uses AI to manage transport in D2D communication independently, without the aid of a BS. The framework uses BDI agents and the DAIS algorithm to choose the appropriate node transfer mode to achieve this. The proposed framework has many limitations and assumptions, as shown in Table 10.

4) D2D COMMUNICATIONS SOLUTIONS IN 6G

As applications continue to evolve, wireless communication system is being developed almost every decade. It is expected that 5G cannot meet the requirements of modern emerging applications such as virtual reality, augmented reality, mixed reality, and any other applications that require convergence, compatibility, sensing, and communication. In addition, other new services are expected to be developed, such as high-precision manufacturing, smart environments, sustainable development, and 3D communications [70].

6G is expected to be a smart, dynamic, and heterogeneous network, with high data transmission speeds 100 to 1,000 times faster than 5G and low latency of less than one millisecond. To achieve this, 6G will use higher frequency bands, such as terahertz (THz) and VLC. The data transmission distance will be very short, so the 6G network is very dense.

Moreover, 6G will be built on AI technologies, as AI will manage and maintain the 6G networks. 6G is described as a space-air-land-sea integrated network, and 6G architecture enables efficient connectivity of objects at the marine, terrestrial, air, and even space levels domain.

Therefore, D2D communications are envisioned to be an important component of 6G. D2D takes advantage of the density of the network and the interconnection of all things, and D2D communications will achieve very high speeds.

The capacity of UEs is expected to be equivalent to mobile workstations. It is expected that UEs will witness significant development, starting with the processor, storage capacity, battery, and smart operating systems and ending with their potential applications, such as sensing capabilities like environmental sensing, healthcare monitoring, body scanning, gesture detection, 3D imaging, and mapping. It will be possible to integrate multiple antennas into UEs and thus be combined with different wireless systems.

Based on the above characteristics, the UE will drive AI, which means it can predict, route content, learn, enable proactiveness, and assist in automated network configuration.

D. D2D WITH A CACHING ASSISTANT COMMUNICATION SOLUTIONS

Caching is a promising technology for achieving D2D communication, as the integration of a D2D assistant allows devices to communicate directly without central control.

In [71], authors provide detailed reviews of approximately 97 proposed solutions to improve the performance of D2D communication using the auxiliary cache. Authors categorized auxiliary caching strategies into three categories in this reference and reviewed previous work after their proposed classification. These categories are the integration of a D2D helper into a network architecture that includes CDNs, P2P networks, cellular networks, and VANETs. Second, the use of a D2D assistant in MCC computing, fog computing, and MEC computing. Finally, in the trait of social consciousness. Despite this momentum in integrating caching to aid and achieve D2D communications, authors in [71] review several important challenges that must be addressed before expanding the use of caching systems in D2D communications. These challenges are:

- Heterogeneity: With the further development of cache usage, its heterogeneity becomes an important and major issue. The devices are supposed to communicate directly and seamlessly in different network structures and achieve high performance.
- Realtime analysis: The demand for information in D2D real-time communication is increasing, so we need to reduce the latency.
- User Mobility: Achieving communication under the conditions of mobility is one of the most prominent challenges of D2D communications, as well as one of the challenges of choosing a D2D assistant, as the researchers want to achieve high-efficiency communication with the random movement of users.
- Extensibility Scalability is one of the most important advantages of D2D communications. With the diversity of applications and the increase in users, the number of connected devices is expected to increase continuously. Therefore caching must have the ability to work efficiently in this constantly expanding environment.
- Security: This cache may be a vulnerability and access point for devices. So, new challenges arise from using D2D assistants, and they need to be met.

In the same vein, the authors [72] also surveyed more than 100 proposed content caching technologies as a solution for D2D communications in a 5G environment. This study included a review of the proposed solutions with their results and comparing them with the limitations and challenges each. The comparison was made between resource consumption, power, bandwidth, and response time. The techniques used for caching are big data-enabled caching, collaborative caching, edge caching, hierarchical caching, and cryptographic caching.

In the context of cellular networks, the authors [73] proposed an intelligent model for proactive caching in D2D communications. The SAA algorithm has been proposed that selects users with the potential to share data and then proactively puts common files into their cache. The proposed SAA algorithm considers many aspects, such as user location, file size transmitted through a D2D connection, speed, and bit rate.

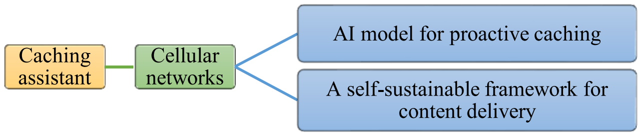

FIGURE 9. **D2D with a caching assistant communication solutions.**

Authors [74] propose a framework that integrates D2D networking and wireless caching. The proposed framework analyzes the performance of power-based content delivery in the presence of mobile aids that support a self-sustaining cache. In the proposed framework, the UE makes multimedia requests to nearby MHs. MHs then make independent decisions to respond to UE requests based on the state of the content cache and the immediate battery. Whereas, if the requested file is in the cache and the power harvested in the battery is equal to the transmission power, MH is enabled to deliver the content to the UE; otherwise, it is delayed.

As previously reviewed, all D2D communication solutions with caching assistant were in cellular networks, as shown in Figure 9. Also, Table 11 presents a summary of these solutions.

E. THE SOCIALLY AWARE D2D COMMUNICATION SOLUTIONS

In recent years, social networks such as Instagram, Facebook, and Twitter have spread widely. This diffusion led to the generation of huge amounts of data and encouraged the scientific community to apply centralization and social connections in their work. The community of researchers is beginning to use social awareness networks to increase the performance of D2D communications [75]. In social awareness networks, patterns are created for social interaction between people or things based on the rules and. social relationships imposed by their owners. By scanning a network of relationships and friends, a social network can discover and manage information faster and more consistently. With social activities and relationships, devices create a social network and help improve D2D communications. By [76]:

- Social networks define the relationships, communities, and structures between UEs. Thus peer selection and relay discovery, when a D2D communication is established, peer selection must first be performed, where peers used as relays are found. Based on the social connections, the devices are grouped into groups, and then the block or relay that communicates with the BS is selected.
- The best communication mode can be selected, and resources allocated based on awareness and different social connections to manage network load, channel status, and potential D2D pairs.
- Managing and allocating spectrum resources, resource allocation, data dissemination efficiency, efficient scheduling, and reduced latency can all be improved by

TABLE 11. Caching assistant to D2D communication solutions.

Ref. No	Year	Methodology	Evaluation	Features	Limitations
[73]	2020	They proposed an intelligent model for proactive caching in cellular networks for D2D communications that considers user location and file size.	They used simulation by the Ahuman model that predicts different human mobility behaviors.	It reduces the download time delay and energy consumption. They identified users according to their regions and then grouped them according to their interests. They take the required file size into account.	They assume one cellular BS and several mobile phone users; each user has a 1 GB proactive cache, and the transmitting power is fixed for all mobile devices; also, each device has a GPS, no interference, and SAA verified for low and medium-speed movements only.
[74]	2019	They proposed a framework for content delivery in a self-sustaining cache-enabled mobile assistant.	Numerous analytical results. They verified results through simulation. However, the authors did not mention the simulation program.	Network spectrum efficiency. It reduces data delay and energy costs.	They assumed the D2D network consists of UES and MHS dedicated, a limited library of multimedia files the same size, each MH can store one file with equal power, and unlimited battery capacity.

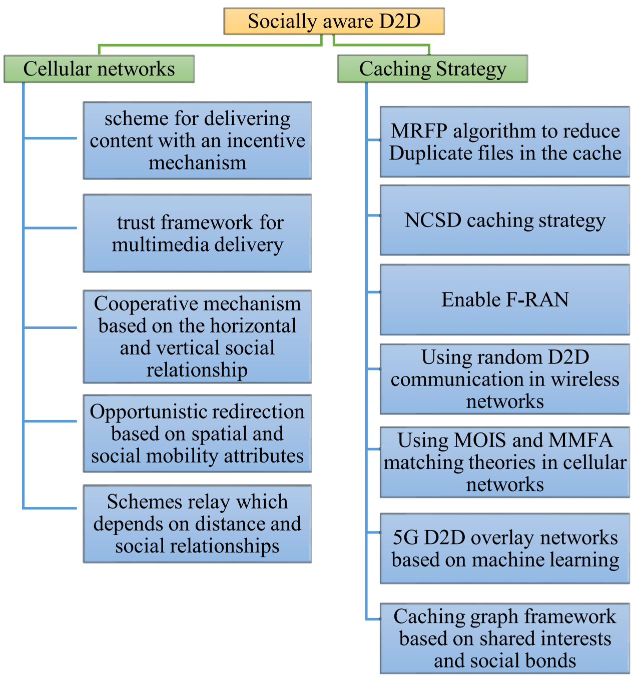

FIGURE 10. Socially aware D2D communication solutions.

considering social and physical features such as channel state, network load, and potential D2D pairs.

Researchers classified socially aware D2D communication solutions into two categories, as shown in Figure 10: socially aware D2D communication solutions in cellular networks and socially aware caching strategy in D2D communication solutions. In this section, these solutions will be reviewed.

1) SOCIALLY AWARE D2D COMMUNICATION SOLUTIONS IN CELLULAR NETWORKS

There are many solutions proposed for embedding social awareness within cellular networks. Researchers in [77] proposed a content delivery scheme based on the social link between CPs and CRs. The proposed scheme includes an incentive mechanism to encourage CP to provide the service, and the incentives are modeled as a Stackelberg game. At Stackelberg, each CP's percentage of required content and the price per content unit are calculated.

Authors in [78] proposed multimedia delivery through a socially aware trust framework for selecting trusted, collaborative D2D relay users. Two types of trust identify the trusted users: 1) the ability to trust from the BS to the relay user. BS selects users through objective evaluation, the user's ability to process, analyze and store data, transfer, and cache to determine the service's ability to the user. 2) Social trust from sender to relay user. Based on the historical interactive\e behaviors of users.

In the context of IoT applications in a cellular network, the authors propose [79] collaborative transmission mechanisms for D2D communication based on the horizontal social relationship, i.e., within the community, and the vertical social relationship, i.e., between communities, to improve the use of network resources. The BS records the user's appearance times at different points of interest, and a matrix of interests can be obtained for each user. By comparing the interest matrices of all users, the social relationship between the communities can be obtained, and then the network can be divided into a VFC based on the societal areas of interest.

Authors [80] proposed the SAMPler algorithm, designed for opportunistic redirection based on human spatial and social mobility traits, to achieve increased delivery. Based on community awareness, areas of interest are identified, and fixed relay points are deployed in the most common areas. These relay points only forward messages to nodes within the community to which they belong, reducing the burden on the network.

Also, to improve the performance of collaborative cellular networks, authors [81] presented socially aware relay schemes in D2D communications. The scheme identifies a relay near the source's midpoint and with which it is socially

TABLE 12. Socially aware D2D communication solutions in cellular networks.

Ref. No	Year	Methodology	Evaluation	Features	Limitations
[77]	2020	Authors proposed a scheme for delivering content based on social awareness in cellular networks, which includes an incentive mechanism.	They used simulation without stating what tools.	It is suitable for practical applications and includes a mechanism for incentives.	Communications are centralized. BS carries the required content from the Internet. They assume that CP applies an equal power distribution to multiple content requests.
[78]	2019	They proposed a socially aware trust framework for multimedia delivery in D2D communications.	They used simulation without stating what tools.	It provides real-time multimedia service. The evaluation results were accurate.	It is an indirect D2D communication where the BS and the user provide recording and computing. They assumed that the cellular user's uplink channel is shared by only one D2D pair.
[79]	2018	Authors proposed a D2D communication cooperative transmission mechanism based on the horizontal and vertical social relationship to optimize the use of network resources.	They used simulated Infocom06 human mobility tracking collected by Cambridge Haggle Projects.	It improves the efficiency of data forwarding and increases delivery rates. Reliability.	The proposed mechanism is influenced by physical features such as transmission rate, connection time, and user density because it has a large role in the collaborative user selection. Data transmission efficiency decreases when the user speed is high.
[80]	2018	They proposed the SAMPler algorithm for opportunistic redirection based on spatial and social mobility attributes.	They used NCCU and SWIM simulation programs to simulate mobility and social communities.	It increases delivery performance and reduces network load. Redirect has an awareness of individual navigation.	This algorithm did not specify a location strategy, as the current strategies are not energy efficient. Community discovery is a difficult task in the proposed algorithm.
[81]	2017	Authors proposed a scheme relay that depends on the distance and social relationships in cellular networks.	They used simulation without stating what tools.	It improves throughput.	This scheme relays consume energy.

connected. Table 12 summarizes these solutions with their features and limitations.

2) SOCIALLY-AWARE CACHING STRATEGY IN D2D COMMUNICATION SOLUTIONS

The caching strategy effectively empties traffic and reduces the delay in accessing the content in cellular networks that support D2D communications. The social relationship between users also has a very significant impact on file caching.

However, caching the most common content in the UE may cause cache redundancy in D2D networks. In this context, the authors [82] proposed MRFP algorithms for distributed cache in cellular networks to solve the problem of file redundancy with lower computational complexity. The proposed algorithm works based on multi-party matching to achieve lower buffering frequency. Initially, the authors modeled the users' navigation as a continuous-time Markov chain, using the user's connection time and the inter-user communication time to estimate the probability of encountering the user. Then, a social graph is created between users based on integrating social relationships with users' mobility. Based on this data, the problem of reducing redundancy in caching is converted to multi-to-many matching, and then user preference lists are defined.

Based on users' social relationships and geographic proximity, authors [83] proposed a D2D caching strategy based on network encoding (NCSD). First, a network consisting of devices for D2D communications is established according to geographical proximity. Then the devices are divided into communities according to the social relationship between users. BS is responsible for arranging the devices according to their contribution within the same community, and according to this contribution, it decides to cache the user. Devices store encrypted blocks, not the entire content, to improve caching efficiency.

Authors [84] presented a scheme for socially conscious caching in D2D communications to enable F-RAN wireless access. In the proposed scheme, fog communities are created based on the content. Then divide and direct access points within the F-RAN to the appropriate fog community based on content. Finally, the most appropriate UE or F-AP is chosen to cache the contents.

Authors [85] proposed a socially aware caching method on users' devices using random D2D communication in wireless networks. The proposed method preemptively caches chunks of data in the users' cache. Then D2D communication enables people close to each other to exchange cached information. Often only parts of the data are stored on users' devices (distributed), and BS helps download and transfer the remaining parts of the data (centralized). The proposed method enables users to control the sharing of their data, as they may want to share data according to social relationships, and sometimes they may avoid interaction due to their resource restrictions or for fear of suspicious devices.

In underlaid cellular networks, authors [86] proposed an approach for selecting IUs, thus obtaining D2D nodes for file caching and transmission based on content popularity and social relationships. The proposed approach uses MOIS to select IUs that are D2D nodes, and MMFA uses to customize content based on users' preferences to reduce average latency within the network. The proposed approach only transfers files and assumes they have the same size. Also, authors suggest that there is a physical incentive for users to prefer D2D communications over downloading files from MBS.

Based on a decentralized learning and social interaction approach, authors [87] developed content caching algorithms. The proposed approach works in 5G cellular networks and is based on a D2D overlay. There is no overlap between cellular and D2D communications. If the required files are available from nearby users and there is a D2D link, the data will be downloaded from them. Otherwise, the data will be downloaded from the BS. The decentralized learning approach puts the content into different international units and thus optimizes the cache according to local requirements.

Authors [88] also proposed a new graph-buffering framework for D2D communication based on shared interests and social bonds. Three layers are represented in the graph: the physical layer, the social ties layer, and the common interest layer. D2D devices communicate with each other and create a physically connected graph based on distance, shading, and path loss. The social bond formation can be predicted by analyzing the duration and times of contact. Trusted relays or caching servers are selected through social trust, and the proposed framework uses incentives to encourage users to use their resources to share content. A shared interest layer creates a group and requests the same content, these solutions, with their features and limitations, summarizes in Table 13.

F. D2D COMMUNICATIONS SOLUTIONS BASED ON ICN

As mentioned earlier, because ICNs are data-centric, they naturally support D2D communication. Among the most prominent features of ICN that support these communications are [89]:

- Content-Centric Network: ICN Content is the main entity in the network. When the user needs data, it sends a packet of interest to the network containing the name of the requested content. Based on the name, the packet is routed to the node containing the data, and then the node sends the content to the user. Thus, ICN is content-centric in contrast to the traditional TCP/IP protocol centered on the host.
- Naming instead of location: With the changing patterns and applications of the Internet, users are more concerned with the content than its source. The ICN interest packet does not contain addresses associated with the source or destination sites. ICN communication depends on the data's name, which mainly expresses its content. Therefore, ICN is independent of the location because it is data-centric.
- In-network Caching: In caching, each intermediate router in the network caches a copy of the data it previously routed. When an interest packet arrives with the same content it has, it sends the content directly from its cache and does not need to be routed back to the requested data source. The caching reduces network traffic and also reduces data delivery time, thus, it improves the overall performance of the network.
- Content Name-Based Routing: At ICN, routing is based on content rather than location. Each time the router receives interest packets and forwards them, it creates a reverse path for the next content delivery, as the router keeps the content in its cache.
- Unique naming of the content: Since the ICN is based on content and routing based on content name, it is important that the naming is unique and independent of its location. Various naming systems have been proposed, for example, flat or hierarchical. This naming is also validated at the level of routers spread across the network, which contain copies of the data in their cache.

ICN research is still in its infancy. There is no general ICN architecture, but many proposed ICN architectures exist. Such as [90]:

- TRIAD, TRIAD is the first formal content-based architecture and proposal introduced by Stanford University in 1999. The architecture supports a naming mechanism and provides name-content communication over IPv4 infrastructure. It is compatible with traditional network Internet protocols such as TCP and DNS. Based on the unique names of the content, data is requested and delivered.
- DONA, built on TRIAD design principles and introduced in 2007. DONA publishes and hierarchically retrieves objects. DONA has modified the TCP/IP network's naming scheme to work with a content-centric environment. The names are made available to the user via trustworthy mechanisms such as search engines.
- CCN proposed in 2011 to develop TCP/IP and make it simple, where CNN is an overlay network with IP. It also provides heterogeneous communications and security features on content rather than secure communications, as in an IP network.
- PURSUIT, Publish-Subscribe architecture has also been proposed, where the source publishes the information, and the client requests the content according to his need. Instead of the traditional IP protocol stack, PURSUIT contains a full subscription protocol stack. The data naming is also more general than the previous architectures and is hierarchical.
- NetInF, In 2013 NetInF architecture has proposed, which enables data caching and replicas everywhere in the network. Data is the most vital component and is called a balanced approach for naming rather than an organizational or structured approach. The balanced approach allows for name resolution before the request is forwarded to provide a hint for routing. Once the content is found, it is returned and cached in the reverse path for future use. These routing hints are done over the traditional IPv4 network. However, it does have limitations in routing based on name resolution.

TABLE 13. Socially-aware caching strategy in D2D communication solutions.

Ref. No	Year	Methodology	Evaluation	Features	Limitations
[82]	2020	Authors proposed an MRFP algorithm to solve the problem of file redundancy with lower computational complexity in cellular networks.	They used simulation without stating what tools. They collected real contact data for 15 users for five days. Each user has a demo device that uses Bluetooth to perform device discovery within a 10m range.	It improves performance and traffic movement efficiency and reduces redundancy for cached data. It achieves a higher data rate and lower latency.	The proposed algorithm only works for users with strong social relationships.
[83]	2020	Authors proposed a socially aware caching strategy based on network coding in D2D communication.	They studied the performance of the proposed strategy compared to three other strategies. They create a network over 79 days from 27 mobile devices. They used simulation without stating what tools.	It reduces traffic and improves network performance. Higher cache rates.	D2D communication links are in the same band as cellular communications.
[84]	2019	Authors proposed a scheme for socially conscious caching in D2D communications to enable F-RAN wireless access.	They used MATLAB to simulate. They compare the proposed scheme with the two previous strategies.	The scheme takes into account appropriate UE hardware and reduces content delivery delays. Scheme dynamically updates the Fog community structure.	The proposed scheme reduces redundancy only when the cache size is large. It only characterizes some types of traffic in real-world networks.
[85]	2019	They presented a socially aware caching method on users' devices using random D2D communication in wireless networks.	Authors used simulation without stating what tools. Numerical results.	It reduces power consumption and network traffic.	There may be delays due to its dependence on the centralized and distributed method. There is no incentive to encourage users to share their resources. During peak hours, redundant links are dropped randomly.
[86]	2019	They proposed an approach to socially aware caching of cellular networks with MOIS and MMFA matching theories for D2D node selection and content assignment, respectively.	They used simulation by MATLAB. Analytical results.	It reduces latency, maximizes social welfare, and provides better performance.	The proposed approach assumes the following: Users prefer a distributed network, where data is dumped from trustworthy friends rather than MBS. In different communities, there needs to be more communication between users. All files have the same size.
[87]	2018	They proposed a socially aware approach based on machine learning for optimizing cache positioning in 5G D2D overlay networks.	They used simulation by MATLAB.	Different cache sizes. This approach assigns D2D users radio sources, so there is no interference. They studied performance in the worst cases of interference. It reduces download delay.	They assume that all downlink channels are independent and distributed symmetrically. All cached files have the same size, BS has enough memory, and it can store the files needed by all users within its coverage.
[88]	2016	Authors presented a framework for graph caching D2D communications based on shared interests and social bonds.	They used simulation without stating what tools.	It improves spectrum efficiency, the quality of user's experience and reduces energy consumption.	This framework only creates D2D links between users if there are close social ties.

- NDN, NDN was proposed in 2014 to enhance CNN, but NDN is self-contained and does not operate on a traditional IP network. NDN removes IP dependency and is replaced by named objects. NDN uses a hierarchical nomenclature that does not contain DNS names or IP addresses. With this naming, the user sends a packet of interest to request content from the network. The interest is sent to the content router and then forwarded. The actual producer also creates a signature on the data to ensure its authenticity.

This part reviews ICN's D2D communication solutions. It is divided as shown in Figure 11.

1) D2D COMMUNICATION SOLUTIONS IN CELLULAR NETWORKS BASED ON ICN

Based on CCN, authors proposed [91] decentralized schemes to enable D2D communication in the millimeter wave band to offload the cellular network. The proposed solution consists of D2D requesters (DRs) and D2D transmitters (DTs).

TABLE 14. D2D communication solutions in cellular networks based on ICN.

Ref. No	Year	Methodology	Evaluation	Features	Limitations
[91]	2021	Authors proposed a decentralized scheme based on CCN to enable D2D communication in the millimeter wave band for cellular network offload.	They used Monte Carlo simulation by MATLAB, where they built a D2D environment in an area of 10 km x 10 km.	It improves network throughput and performance.	They assumed that all DTs have the same transmitter power, If D2D cannot retrieve the required contents, it uses the traditional cellular network, and D2D links have a short stability time.
[92]	2021	Using the NDN architecture, the authors presented a framework for creating a wireless network with different links.	They tested the system in a real environment with LoRa and Raspberry Pi devices.	Interoperability of heterogeneous wireless links. It achieves long-distance communications.	Overlap can occur in small areas.
[93]	2018	The authors propose dynamic caching in 5G D2D systems based on ICN.	Numerical results. The authors used simulation without stating what tools.	They reduce the access time to content, system load, spooling cost, and redundancy in caching.	They assumed that every mobile device has a 5G D2D interface. The content is divided into parts of equal size.
[94]	2018	Authors presented the caching strategy considers the social relationships of D2D communication in cellular network	Theoretical performance analysis	It improves performance.	This strategy is centralized, caching is managed by BS, and users are not incentivized to share their resources.
[95]	2017	Authors presented a framework that provides mobility as a service for D2D devices in mobile networks based on the ICN.	They used a mathematical model for measuring performance. Also, Realistic modeling and simulation, but the authors used simulation without stating what tools.	It offloads network traffic, improves User-oriented performance.	D2D communications are central, relying on eNBs for mobile assistive devices.
[96]	2017	They proposed video communication in cellular network with D2D communication using ICN	They used simulation by MATLAB.	Reduce download delay. Improve the performance.	Communication is centralized, and BS manages D2D communications. There is interference because they use the same frequency band. Video download only.
[97]	2016	Authors proposed D2D communications in virtualized cellular networks based on ICN	They used simulation without stating what tools.	It improves the performance	The framework works in the single-cell scenario only.
[98]	2015	They proposed a framework for caching mobile content in D2D communications based on ICN.	They used simulation by SPMBM and WDMM. SPMBM simulates the commuting characteristics of users on the weekend. WDMM simulates human commuting behaviors on a workday basis.	There is an incentive mechanism to encourage users to be helpful. It reduces overheads, energy consumption, and access delays.	One-hop content delivery only.

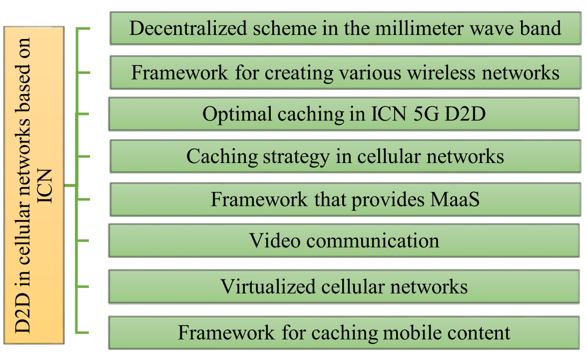

FIGURE 11. D2D communication solutions in cellular networks based on ICN.

Contents are cached in DTs and based on messages of interest transmitted to DRs, DRs Retrieve content from the nearest DTs. These links are established in the millimeter wave range.

In [92], authors designed a framework for creating a global multi-hop wireless network to create various links with different protocols using NDN architecture. This proposed framework uses the NDN architecture, and each device in the proposed framework has two wireless interfaces, WiFi and LoRa. WiFi and LoRa links redirect through interest messages used in NDN networks.

Author [93] proposed D2D communication models. The proposed model integrates 5G specifications and ICN functions to achieve optimal caching. The user requests the data by the name of the requested content. The network locates UEs that contain copies of the requested content, after which the network prepares a D2D path and returns the requested content to the user. Caching is done dynamically, considering mobile node parameters, system parameters, optimal time limit control, and trade-offs to optimize the caching decision.

TABLE 15. D2D communications performance metrics.

Ref. N	Year	D2D categories		Performance Metrics: Security	Availability	Battery life/ energy	Capacity	Coverage	Latency/ Delay	QoS	Performance	Reliability	Cost /overhead	Throughput	Scalable	Efficiency	Safety
[17]	2021	M2M solutions	IoT	√													
[20]	2018					√										√	
[21]	2018					√							√	√	√		
[22]	2018			√													
[23]	2018								√								
[24]	2019		Cellular network			√				√		√	√				
[25]	2019					√			√		√		√				
[26]	2018					√							√				
[27]	2017				√	√											
[28]	2016					√	√	√	√								
[29]	2016								√	√							
[32]	2014		ICN						√		√						
[13]	2014										√						
[37]	2022	V2V solutions	IoV	√								√				√	
[38]	2022																√
[39]	2022													√		√	
[40]	2022										√			√			
[41]	2021												√				√
[42]	2021			√								√					
[43]	2021								√								√
[44]	2020					√					√						
[45]	2020								√								√
[46]	2020								√		√					√	
[47]	2019								√		√						
[48]	2018										√			√			
[49]	2018												√				√
[50]	2022		Cellular network						√		√	√		√			
[36]	2022								√	√							
[51]	2019								√							√	√
[52]	2021		ICN						√		√						
[53]	2017								√							√	
[54]	2017								√								
[55]	2017								√				√				
[63]	2021	Cellular network solutions	NB IoT						√		√		√	√			
[64]	2018									√	√						
[66]	2018		LTE			√					√						
[67]	2018					√										√	
[68]	2017								√			√					
[9]	2020		5G			√								√		√	
[73]	2020	Caching assistant solutions	Cellular networks			√			√								
[74]	2019					√			√				√				
[77]	2020	Socially aware D2D solutions	Cellular networks													√	
[78]	2019								√							√	
[79]	2018											√				√	
[80]	2018										√					√	
[81]	2017													√			
[82]	2020		Caching Strategy						√		√					√	
[83]	2020										√					√	
[84]	2019								√							√	
[85]	2019					√										√	
[86]	2019								√		√						
[87]	2018								√		√			√			
[88]	2016					√										√	

TABLE 15. ***(Continued.)*** **D2D communications performance metrics.**

[91]	2021	ICN D2D solutions	Cellular networks								√			√			
[92]	2021					√					√	√				√	
[93]	2018								√				√				
[94]	2018										√						
[95]	2017			√					√		√						
[96]	2017								√		√						
[97]	2016										√						
[98]	2015					√			√				√				

They have provided many solutions to integrate ICN networks with social networks and temporarily store data in network caching based on social relations. In this context, and based on the local popularity of the content, authors [94] proposed a strategy for caching D2D communication in cellular networks that considers social relations. The BS shall manage the data caching reactively or proactively in the UEs.

Based on content-aware networks, authors [95] proposed frameworks that provide MaaS navigation for D2D devices in mobile networks. Common content is distributed across several assistive devices, thus enabling D2D communications. Assistants are selected according to analyze of human behavior based on historical mobility data since the behavioral patterns of users are repetitive, regular, and, therefore, predictable. Each eNB maintains information about the availability of content in the assistive devices to serve customers effectively, especially when the assistive device is moved to multiple places where the eNBs are coordinated and synchronized to update information about the availability of the content. Because GPS performance is degraded in dense areas and high power consumption, location is determined and tracked by MEC's participation in the 5G cellular network.

Authors [96] suggested that the video be cached in UEs unused memory and made available using a D2D link to nearby users. D2D communications use the same frequency band as a cellular network. BS manages D2D communications within its coverage areas. If the content is at the UE, the BS allocates resources to the D2D communications; otherwise, the BS supplies the requested content from its memory or the server.

Authors in [97] also proposed a framework for virtual resource allocation and caching in ICN-based virtual cellular networks for D2D communications.

Authors [98] suggested a framework in cellular network environments for caching mobile content in D2D communications based on ICN. The content is cached in UEs called assistants. They are chosen based on interests. BS manages content delivery, where BS receives content requests from users, analyze them, and resolves them to nearby assistants. Then, based on the D2D communications, the helper presents the content directly to the user. Table 14 summarizes these solutions.

IV. ANALYSIS AND DISCUSSION

As mentioned earlier, the researchers in this paper have categorized D2D communications solutions into M2M solutions, V2V solutions, and D2D solutions in cellular networks, D2D with a caching assistant, D2D in socially aware networks, and D2D based on ICN.

Researchers noticed that these solutions have various performance metrics are summarized in Table 15. According to their recurrence in the proposed solutions, these metrics are latency, performance, efficiency, battery life/energy, cost /overhead, throughput, reliability, safety, security, and QoS, respectively. In addition, there are metrics mentioned only once: availability, capacity, coverage, and scalable.

In Table 16 researchers also summarized each of the communication protocols used in the reviewed solutions, the type of control whether it is centralized or distributed, and the use of AI or ML in solutions.

Although the term M2M is well-known in the industry, some authors in 3.1 used this term as an application of D2D, such as [17], [23], and [32]. As researchers mentioned, these solutions were in IoT networks, cellular networks, and ICN. The performance metrics in this category were energy, latency, cost, and performance, respectively. As it is known that energy occupies an important part of industries, it was on the list of interest of researchers in the previously reviewed solutions.

In V2V communications, most of the solutions focused on IoV, where the vehicle body is exploited, and IoT devices are added that efficiently achieve IoV communication, such as sensors and antennas. The performance metrics improved by this category are latency, performance, safety, efficiency, throughput, and reliability, respectively. Table 15 shows that safety was considered only in V2V solutions because the reviewed solutions primarily aimed at the safety of vehicles and those inside or around them. V2V communications are characterized by the speed of movement of vehicles, especially on highways and extending between cities over long distances. Cellular networks can only cover part of the road with the same efficiency if reinforcement towers are added along the road, which means an additional cost. Therefore, the previously reviewed solutions focused on adding devices to the body of vehicles that support V2V according to demand and used wireless communication protocols to achieve this as shown in Table 16. It also adopted central control type, where drivers' behavior is monitored and analyzed, and the road is monitored, then the appropriate decision is taken to reduce accidents and ensure safety.

The reviewed solutions in cellular networks focused on integrating D2D communication with them, where D2D communication is a basic application in cellular networks.

TABLE 16. Communications protocol, control type, AI utilisation in D2D.

Ref N	Year	D2D categories		Communication protocol				Control type		AI Utilisation
				WSN	Wireless protocol	Cellular networks	GPS	Centralized	Distributed	
[17]	2021	M2M solutions1q	IoT	√				√		√
[18]	2020				√			√		
[20]	2018			√				√		√
[21]	2018				√			√		√
[22]	2018				√			√		√
[23]	2018					√		√		√
[24]	2019		Cellular network			√			√	
[25]	2019					√			√	
[26]	2018					√			√	
[27]	2017					√			√	
[28]	2016					√		√		
[29]	2016					√			√	
[32]	2014		ICN		√				√	
[13]	2014				√				√	
[37]	2022	V2V solutions	IoV		√				√	
[38]	2022				√				√	√
[39]	2022				√			√		√
[40]	2022				√			√		
[41]	2021			√			√	√		
[42]	2021				√			√		
[43]	2021						√	√		√
[44]	2020				√			√		√
[45]	2020				√			√		√
[46]	2020				√				√	
[47]	2019				√			√		
[48]	2018				√			√		
[49]	2018				√		√	√		
[50]	2022		Cellular network			√		√		
[36]	2022					√		√		
[51]	2019					√		√		
[52]	2021		ICN		√				√	
[53]	2017				√				√	
[54]	2017				√				√	
[55]	2017				√				√	
[63]	2021	Cellular network solutions	NB IoT			√		√		√
[64]	2018					√		√		
[66]	2018		LTE			√		√		
[67]	2018					√		√		
[68]	2017					√			√	
[9]	2020		5G			√			√	√
[73]	2020	Caching assistant solution	Cellular networks			√		√		√
[74]	2019					√		√		
[77]	2020	Socially aware D2D solutions	Cellular networks			√		√		
[78]	2019					√		√		
[79]	2018					√		√		
[80]	2018					√		√		
[81]	2017					√		√		
[82]	2020		Caching Strategy			√			√	
[83]	2020					√		√		
[84]	2019					√		√		
[85]	2019				√			√	√	
[86]	2019				√			√.		
[87]	2018					√			√	
[88]	2016					√		√		
[91]	2021	ICN D2D solutions	Cellular networks			√			√	
[92]	2021				√				√	
[93]	2018					√			√	
[94]	2018					√		√		
[95]	2017					√		√		
[96]	2017					√		√		
[97]	2016					√		√		
[98]	2015					√		√		

We mentioned earlier in 3.3.3 that 5G supports direct communication between UEs, furthermore, it is expected that D2D communication will be a basic application in 6G. Researchers see the need for an incentive mechanism for users to share their resources. This mechanism may count the number of times the content is downloaded or shared. As for incentives, they may be financial incentives, additional data allowance, or QoS from the mobile operator. The performance metrics improved by this rating are energy, performance, latency, throughput, and efficiency, respectively. The reviewed solutions also focused on QoS, cost, and reliability, which are important metrics in cellular networks. Most of the solutions in this category relied on central control type, where D2D communications are managed by BS.

Authors introduced caching assistant solutions as an enable D2D communications in various networks. The cellular communication structure is exploited, such as BS or UEs, in caching. As mentioned in 3.4, the authors [71] reviewed 97 caching solutions in various types of networks. The performance metrics optimized by caching are energy, latency, and cost.

With increased social media, the idea of integrating social relationships into D2D communications has recently emerged. Users often share content they like with their relatives or friends. Therefore, the authors presented solutions based on social relationships in caching or cellular networks.

Naturally, efficiency is the most important performance metric improved by this classification, followed by performance and latency, energy, and throughput.

Although most solutions rely on IP networks, where communication is from host to host, however, the researchers expect that ICN is enabling D2D communications because the purpose of D2D communications is to transmit content, and therefore the consumers do not need to know the location of this content. Table 15 shows performance metrics performance, latency, energy, and cost. Caching solutions can be included in ICN because in-network caching is a core feature of ICN. In addition, it is possible to integrate solutions based on social relations with ICN simply, where the content is caching in the ICN contract based on the social relations between users.

As shown in Table 16, socially aware D2D and ICN D2D solutions are enabled in cellular networks to take advantage of the infrastructure that already exists. It rely heavily on central control as well as the distributor. Copies of the content are distributed near to the consumers.

In general, researchers note that most of the solutions depend on cellular networks due to the huge ecosystem and the advantages of cellular networks [57], [58]. Therefore, cellular networks are considered promising to enable IoT services in general and D2D communications in particular.

As for AL solutions, they are relatively few, but we expect that they will be addressed in the future.

V. CONCLUSION

D2D communications are promising because they reduce latency and unload the network. This paper has provided a review of the solutions offered for D2D communications.

This paper first deals with an overview of D2D communications, it explains the communication techniques used and the challenges that D2D communications face. This paper discussed the solutions provided for D2D communications, and we divided them into six categories: M2M solutions, V2V solutions, D2D solutions in cellular Networks, D2D with caching assistant solutions, D2D solutions in socially aware networks, and D2D solutions based on ICN. The paper reviewed the solutions under these classifications, with an explanation of the methodology used for each solution, methods used by authors to evaluate their proposed solutions, with strengths and weaknesses. The paper presented performance metrics in each solution. The paper analyzed these solutions with an explanation of the performance measures for each of the reviewed solutions. We have noticed that the most important performance metrics are energy and latency in M2M, V2V, and D2D with a caching assistant. As for cellular networks, the most important performance metrics were also energy and performance. In socially aware networks, efficiency appeared first, followed by energy and performance. In ICN, performance and latency are the most important metrics improved by the proposed solutions.

Moreover, we noticed that most solutions focused on integrating D2D communications in cellular networks to exploit their infrastructure. The control of most solutions is centralized in the nodes, and it also allows the unloading of the main network.

Enabling awareness and social relations increases efficiency. So, ICN offers an excellent alternative to D2D communications as it is concerned with content rather than location as it is with IP.

In future research, further study on which ICN architectures are best for enabling D2D communications, the possibility of integrating social awareness with it, and the incentives that may encourage users in cellular networks to share their resources. Also, the 6G standards for D2D communications

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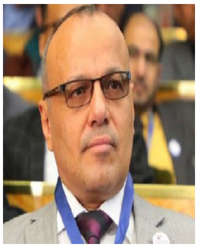

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