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Intensive Benchmarking of D2D communication over 5G cellular networks: prototype, integrated features, challenges, and main applications

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Abstract

The evolving Fifth generation (5G) cellular wireless networks are envisioned to provide higher data rates, lower end-to-end latency, and lower energy consumption for devices. In order to achieve 5G requirements, a lot of new technologies are needed to operate in 5G. Device-to-device communication (D2D) is one of the key technologies provided to enhance 5G performance. D2D is direct communication between two devices without involvement of any central point (i.e. base station). It is a recommended technique to enhance the energy efficiency, throughput, latency, and spectrum utilization in cellular networks. This paper provides an intensive benchmarking of the integration of D2D communication into cellular network focusing on the potential advantages, different recent prototypes, classifications, and applications for D2D technology. Finally, the paper addresses the D2D related main topics and indicates the major possible challenges that face most researchers.

Keywords Device-to-Device · 5G cellular networks · Prototype · IoT · Vehicle-to-Vehicle · Green communication · Artificial intelligence

1 Introduction

No doubt those telecommunication systems developments enhance lifestyle in unexpected ways. 5G wireless cellular network deployment is the main key technology of the next wireless cellular network evolution. 5G cellular networks commercial service is estimated to be launch in 2020 [1]. The main target of 5G is to provide ubiquitous connectivity for any kind of device and any kind of application. 5G network should satisfy some needs in order to enhance the performance. It should support data rates up to 10 Gb/s for reality applications (i.e. telemedicine, vehicle-to-vehicle applications, etc.). Also, it is needed to guarantee latency less than 1 ms to support those applications. Tens of millions of devices and hundreds of billions of sensors are vital to be served. Hence, the network has to stand with numerous capacities and extended coverage area especially in airplanes and remote areas. Devices' battery lifetime should be increased as well.

Such mentioned requirements need special technologies to be deployed. The detailed 5G standards are still work in progress and uncertain yet. Carrier Aggregation, massive Multiple Input Multiple Output (MIMO), beamforming, cloud computing, millimeter Waves (mmW), Cognitive Radio (CR), Full-Duplex (FD), Non-Orthogonal Multiple Access (NOMA), green communication, energy harvesting, D2D, and others are potential technologies under research to meet 5G needs and be applied on it [2]. All these previous technologies are outside of the scope of this paper except D2D.

D2D Communication is one of the competent technologies for 5G. In previous mobile generations (i.e. 1G–

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4G), D2D technology did not take much attention; however, it is predicted that applying such a technology will play a vital role in enhancing the era of wireless cellular communication. D2D communication in cellular networks is known as direct communication between two or more terminal devices without involving the Base Station (BS) or any core network [3]. In contrast to a traditional wireless cellular network, D2D technology can provide more power savings due to the close distance among connected devices. Besides, this technology enhances energy efficiency, throughput, and delay. D2D has the availability to offload traffic from the cellular network with high performance. One of the main advantage is its flexibility; so that D2D can be integrated with different technologies to enhance the network's performance such as vehicle-to-vehicle (V2V) technology, mmW technology, Internet of Things (IoT), mode selection, and Artificial intelligence (AI).

Main organizations have co-operated to examine the validation of D2D in cellular networks such as 3GPP (Third Generation Partnership Project) [4]. Release 12 of 3GPP states that such a technology can be applied as a public safety network feature, cellular offloading, V2V communication, and content distribution. Although D2D technology introduces a lot of benefits; on the other side it faces a lot of challenges that should be taken into consideration. Applying D2D technology leads to interference among Cellular Users (CUs) and D2D Users (DUs) due to sharing the same resources in the same area. Other concerns that face D2D technology such as peer discovery, handover, radio resource allocation management and optimization, energy consumption, and security issue. Consequently, D2D has been taking much attention from researchers and mobile operators to enhance the network performance without violating any of the services requirements.

This paper is organized as follows: Sect. 2 provides the potential advantages of D2D technology. Section 3 introduces the D2D classification with its three main categories, while D2D scenarios and applications are provided in Sect. 4. Section 5 discusses the prototypes and experiments. D2D integrated features are laid out in Sect. 6. Section 7 details D2D's challenges. Finally, the paper is concluded in Sect. 8.

2 D2D technology main advantages

D2D technology offers numerous numbers of benefits. From the definition, in the case of devices that near in distance, using D2D technology reduces latency between devices and consumed power. As shown in Fig. 1, devices communicate directly instead of sending data from the source transmitter to Evolved Node B (eNB) then to the destination receiver. Another advantage of applying D2D technology is that it can take some load off of the cellular network in a local area such as big shopping centers or stadiums. This direct transmission among devices enhances system performance.

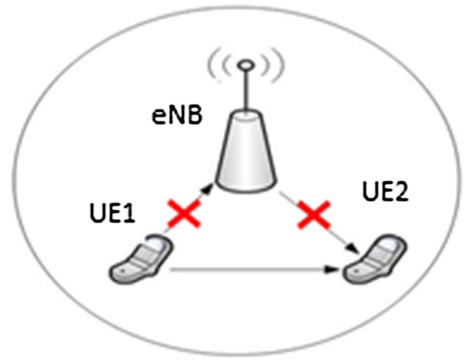

Fig. 1 D2D network layout

Moreover, D2D technology can be an efficient solution in case of emergency networks (an urgent communication network can be established within a short time to replace the damaged infrastructure). This case will be explained in detail later. Another one of the big advantages is that DUs can extend the network coverage area by acting as transmission relays for each other. Figure 2 shows the concept of D2D relay mode that acts as a multi-hop sequence so as to increase the D2D coverage area.

Last but not least, using D2D communications beside cellular communications could raise the spectrum utilization and network capacity. A channel can be reused by multiple D2D pairs in cellular communication if power control is applicable [5]. This feature also leads to an increase in network capacity.

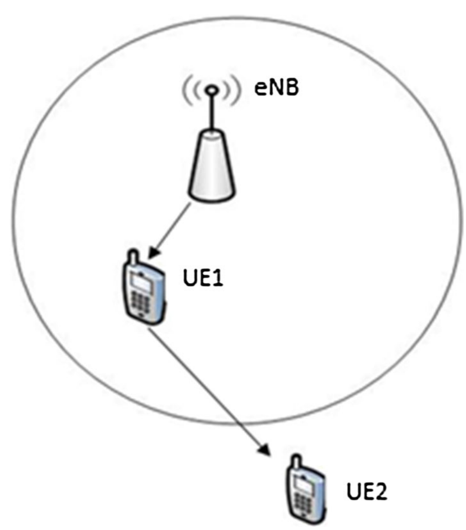

Fig. 2 D2D relay mode

3 D2D main classification

This section introduces a high-level overview of D2D classification. As shown in Fig. 3, this classification is separated into three main categories; D2D control, D2D coverage, and D2D communication mode. Each category is illustrated with details in the following subsections.

3.1 D2D control

D2D control category highlights how deeply the core network is controlling and managing D2D connectivity. This mode can be classified into two types; namely, full control mode and autonomous mode. When devices are managed by a cellular network or operator, the mode is called controlled mode; otherwise it is called autonomous mode. Autonomous mode means that DUs participate in the control. To be clear, Table 1 illustrates the meaning, advantages, and disadvantages of both types.

3.2 D2D coverage

3GPP has classified D2D based on coverage into three types as shown in Fig. 4 [6]. The first one is called "in coverage" which indicates that both DUs are within the cellular network coverage as in Fig. 4a. This means that DUs may access the licensed band. The second scenario is "out of coverage" in which both DUs are out of the cellular network coverage as in Fig. 4b. It is notable that this scenario could be applied in case of an emergency when a failed connection occurs due to eNB abnormal problems. Out of coverage communications means that communication performed in an unlicensed band such as Industrial, Scientific, and Medical radio band (ISM) 2.4 GHz. The most famous standards that implement this type are WiFi direct, Zig Bee, and Bluetooth.

The third type is called "partial coverage". It indicates that one DU is within cellular network coverage, while the second DU is out of the cellular network coverage as in Figs. 4c and 2. A D2D enabled device may act as a relay in order to retransmit data from outer DU to eNB or vice versa [7]. A brief look at the advantages and disadvantages of "in coverage" and "out of coverage" are given in Table 2.

3.3 D2D communication mode

This category indicates whether the DUs share the same Resource Blocks (RBs) with other users, whether CUs or DUs. It is also based on deciding if the devices communicate directly in a distributed or centralized manner correct. As such, the D2D communication mode is classified into three types. The first one is dedicated mode which allows the D2D pair to exchange data directly without involving eNB. The allocated RB for this transmission is dedicated only for certain pair without sharing with other users. Shared mode is the second type in which both DUs and CUs can share the same RB; also known as underlay mode. Finally, the third type is a cellular mode as in the traditional cellular communication where all users transmit and receive data through the core network without applying direct communication among users, which is known as overlay mode. Table 3 shows the advantages and disadvantages of each mode.

4 D2D scenarios or applications

Based on D2D advantages, D2D technology is used in several applications as shown in Fig. 5. The following subsections discuss the main scenarios that can have benefits from this technology.

4.1 Local voice and data service

There are many cases where nearby users want to voice chat like but not limited to people in big hall or in cubical arrangement. Using such D2D technology can enhance the

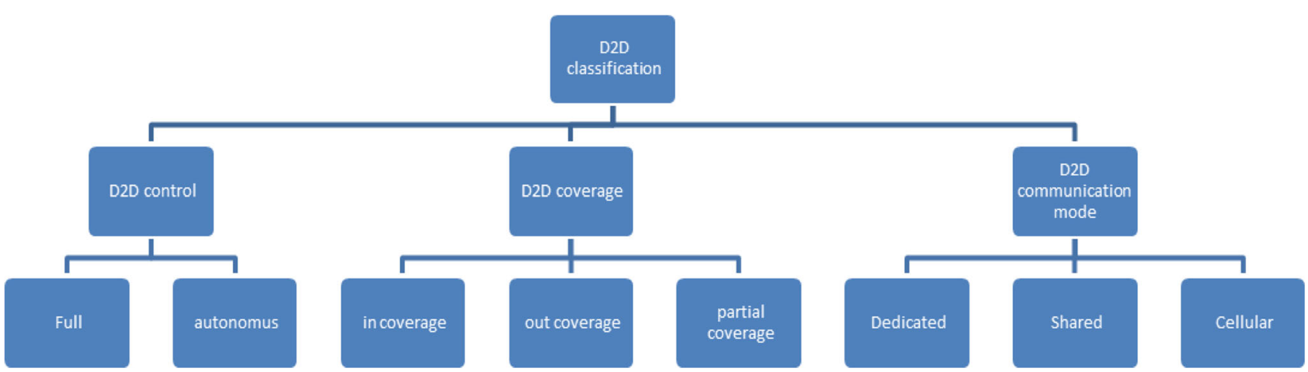

Fig. 3 D2D classifications

Table 1 Main advantages and disadvantages of D2D control types

Type	Full	Autonomous
Meaning	Network is in charge of the following: D2D authentication procedure, D2D pair discovery, D2D initiation procedure, D2D connection, power control, and allocate radio resources	DUs themselves are in charge totally or partially of the following: D2D authentication procedure, D2D pair discovery, D2D initiation procedure, D2D connection, power control, and allocate radio resources
Advantageous	Core network controlling leads to achieving better QoS from user perspective and network perspective.	Negligible signaling overhead
	Less interference among CUs and DUs as core network control interference issues	
Disadvantageous	In order to control D2D communication, high signaling overhead is required	Interference caused by the DUs on the CUs

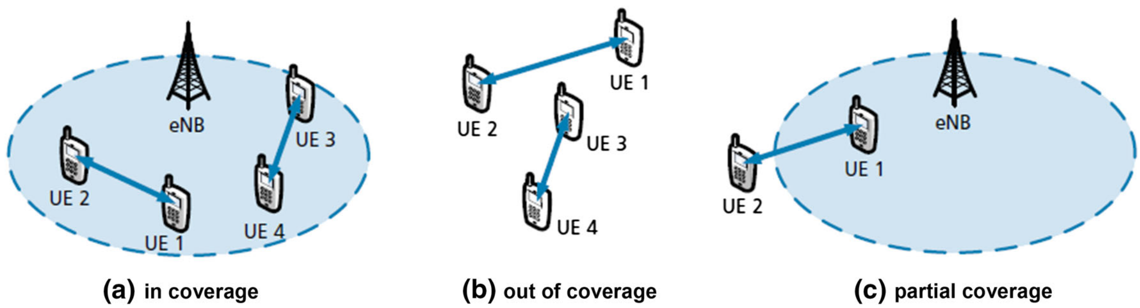

Fig. 4 Release 12 D2D communications are divided into three scenarios

Table 2 Main advantages and disadvantages of D2D coverage

Type	Out coverage	In coverage
Advantages	Easier Resource allocation.	Increased spectrum utilization.
	No interference between cellular and D2D users.	Easier Control of eNB on D2D devices.
	Simultaneous transmission of D2D and cellular devices	No more required additional interfaces
Disadvantage	Additional interface is required for out of band communication and Less spectrum utilization.	High interference between devices due to channels reuse.
	Out of band D2D devices become out of eNB control	Need of smart power control and resource allocation mechanisms

Table 3 Main advantages and disadvantages of dedicated, shared and cellular mode

	Advantages	Disadvantages
Dedicated mode	Easier to manage interference	Less capacity and low spectrum utilization
Shared mode	Higher spectrum efficiency	More interference either among DUs themselves or among CUs and DUs
Cellular mode	Easier to manage interference	Low spectral efficiency
	No need to add new features	Less performance than using D2D technology

network performance especially delay reduce between users to meet the real-time voice constrains. Similarly, local data service can be provided using D2D communication when two collocated users or devices, within D2D coverage area, want to exchange data. It leads also to reducing latency and increasing the data rate between these DUs.

Fig. 5 Application and scenarios for D2D-5G environments

4.2 Video streaming

Video streaming is defined as sending contents in a compressed form over the Internet in real-time. This means it is not necessary to wait until the video had downloaded completely to be watched. As an alternative, video is sent in a continuous stream manner of data and is played back as it arrives immediately. So, video streaming becomes one of the key internet traffic. Cisco stated that in the near future about 90% of the internet traffic will be videos by 2019 [8]. One type of video streaming that can offload the traffic from wireless networks is Point-to-Point (P2P) video streaming. P2P video streaming promotes all users to share their videos with others through direct connection. PPSTREAM and PPLIVE are considered as vital examples of P2P video services. In China, it is reported that there were more than 32,210,000 daily customers on PPSTREAM and more than 60,000,000 overall users on P2P video streaming in September 2012 [9]. D2D technology can provide more performance improvement than normal cellular networks between devices that desire to share video streaming. Similar applications can also be like video chat or video conferences between the devices in the same cell or neighbor cells that are close in distance.

4.3 Machine to machine

Machine-to-Machine (M2M) communication occurs among machines like objects or devices with computing and communication capabilities without human involvement [10]. M2M uses machines to monitor certain events with sensors and to instruct actuation. The captured events are relayed through wireless networks to servers, which extract and process the gathered information and automatically control and instruct other machines. The network provides end-to-end connectivity between machines. Some famous examples of M2M technology are smart homes, monitoring environment, car automation, military, industrial equipment, etc. In many cases, the M2M machines are located close to each other in distance inside a building; therefore D2D technology can be applied. The D2D communications can raise network efficiency by exploiting the high channel quality of short-range D2D links. In addition, by reducing transmission power, machines can have prolonged life battery. Furthermore, overall M2M network delay can be less because of direct routing of D2D traffic. Also, network can have less load distribution of data servers for local M2M traffic [11].

4.4 Emergency networks

Connection failure may exist due to natural disasters in a certain area for a long time. Unfortunately, huge amounts of local traffic data need to be transmitted. For example [12], the rescuers desire to establish a connection frequently with their rescuers, including sending images and videos. Correspondingly, in the medical sites, nurses and doctors need to have a medical data of patients from their hospital and sometimes need to have remote supports and consultancy for certain operations. Also, journalists and reporters need to report the news fast, etc. D2D technology based on emergency network can afford broadband services temporary for all these requirements. Large numbers of devices can communicate with each other to create a small network and relay data for each other. Some researchers have addressed this scenario and figured out how to solve this issue by applying D2D technology.

Authors in [13] investigated the benefit of exploiting D2D technology in disaster scenarios. A coalition formation method was recommended for energy saving in uplink and downlink to prolong network life time. The recommended method's simulation results show lower energy consumptions, lower latency, and better QoS compared to the non-collaborative case. Another point of view was presented in [14] that also studied the disaster scenario based on D2D. The connectivity between source and destination is established through intermediate nodes act as relays nodes as discussed before. Furthermore, in order to prolong nodes life time, Energy Harvesting (EH) is applied in relays and cluster heads nodes in [15]. Simulation results proved that EH-based D2D protocol performs better nodes life time due to energy efficiency for cluster heads and relay nodes; and also offered extended coverage area.

5 D2D prototypes and experiments

D2D technology can be implemented with operator assisted kike as DataSpotting and Content Aggregator; or autonomous mode like FlashLinQ and Relay by smart phone. As discussed earlier, controlling by operator means full control over D2D links scheduling, security, and connection while autonomous means DUs participate in the control of connection setup and establishing. This section addressed different prototypes for D2D communication and their main experiments. Furthermore, it presents a comparison between them.

5.1 Prototype 1: FlashLinQ

Qualcomm company invented a point-to-point wireless PHY/MAC network architecture called FlashLinQ [16]. FlashLinQ's main purpose is to discover the maximum number of surrounding devices that could connect directly. FlashLinQ is a synchronous TDD/OFDM structure established over the licensed spectrum with carrier frequency of 2.586 GHz and bandwidth of 5 MHz. This structure designed for enabling DUs to realize each other automatically and communicate directly. FlashLinQ can support also link management, rate scheduling, and peer discovery in an autonomous way.

Based on FlashLinQ architecture, the prototype schedules links for devices based on their priorities only in the case of agreement between both transmitter and receiver. This agreement considers that the assigned link doesn't cause more interference on any established links and also considers that the Signal to Interference Ratio (SIR) of the link itself exceeds the threshold level. For peer discovery process, dedicated small time slots are reserved for this process. The system allocates resources fairly among all links by assigning random priority at each time slot. Dedicated small time slots are occupied for peer discovery and each peer discovery slot is also divided into orthogonal resources. The network can support link management by assigning certain channel with Connection ID (CID). Similar CIDs are assigned by the network to those links that are able to transmit simultaneously. It is expected that FlashLinQ will introduce new types of applications like secure mobile payments, content sharing, advertising, etc. A prototype modem of FlashLinQ is implemented on TI DSP chipset TMS-C6482 and XiLinX Virtex-4 FPGA. The main experiments and the results obtained in [16] are as follows:

Experiment 1 It was executed based on four-terminal devices allocated in the same room forming two links. At the begging, both transmitters are initially 3 m away from their receivers then the transmitters get closer to their receivers as close as 1 m.

Results 1 Significant increasing in throughput was shown in the network applying IEEE 802.11 CSMA/CA protocol using RTS/CTS.

Experiment 2 Outdoor and indoor deployments were addressed. For the outdoor scenarios, links are distributed randomly in a square are with side length of 1000 m with link lengths of about 20 m. On the other hand, the indoor scenario links are distributed randomly in a five floors cuboid building with dimensions 50 * 100 * 20 m and 4 m floor height. Link lengths were about 20 m with 60% paired devices were on the same floor, while the remaining pairs devices were one floor apart. In both deployments, only slow fading was taken into account.

Results 2 It displays the capacity gain of FlashlinQ compared to the WiFi protocol for indoor and outdoor scenarios. Throughput of the network has an increase of 450% in spectrum efficiency with 256 links by using FlashLinQ than WiFi for both indoor and outdoor deployments.

5.2 Prototype 2: DataSpotting

"DataSpotting" is a system designed for checking the possibility to offload communication from base station by applying D2D technology. The system was designed by a group of researchers from Alcatel Lucent and Duke University, KAIST [17]. The main target of Dataspotting system is applying peer-to-peer (P2P) highly demand content sharing like videos and pictures. Data spot is defined as a crowded small area that has various numbers of devices requesting data or desire to transfer data to each other. Good cases for this scenario are rush hours, sports stadiums, train stations, concerts, etc. Cellular operator requests to know the locations of all DUs inside the data spot via GPS. The system operates at dual-band, which are 3G band and ISM band. 3G spectrum is assigned for control channel that is used for setup a connection through WiFi ad-hoc mode [17]; while content transmission and receiving is established in the ISM spectrum through WiFi interface.

The procedure of this system to achieve its target is as follows: (1) Dataspotting system activates the content sharing system via the cellular operator in case of crowded areas or rush hours. (2) It gathers all DUs' locations and lists their available contents. (3) The size of each data spot is assigned based on DUs' locations and contents. For example, presume a user Alice exists in a certain data spot; first, it records its location and then asks for the desired content. The cellular operator tries to match DU_1 request based on its location and content. After that, the operator confirms whether DU_2 or WiFi access point exists, that provides Alice's content. If so, the operator allocates a temporary IP to requester Alice and provider Bob and guides Bob to transmit the required content to Alice through WiFi ad-hoc mode. The Dataspotting prototype system has been implemented on Android Nexus One devices. The main important three experiments and their results obtained in [17] are as follows:

Experiment 1 In the Manhattan area, a measurement was derived with Bluetooth and GPS as it is not easy to detect the availability of mobile devices. In their analysis, dumb devices as printers and headphones are discarded and take into consideration mobiles and laptops only. The aim of this experiment is to figure out the available number of devices around a biking user at any time, and also the average expected contact duration between DUs.

Result 1 It showed that, most of the time, there are at least 30 devices around the biking user. Moreover, most of these detected devices stay nearby the user for more than 30 s. Also based on their implementation, the measured data rate is around 1 MB/s, so 30 s is more than enough to transfer a medium-sized file.

Experiment 2 The main purpose of this experiment is to understand how user density changes inside a data spot. They implemented the same previous experiment for two waiting areas in NY Penn Station at rush hours but in a static manner.

Result 2 The outcome measurements indicate that in both different places, the number of nearby DUs is large and stable. Besides, the average contact duration is 80 s, more than enough to transfer multiple files.

Experiment 3 Testing five terminal devices that communicating directly.

Result 3 D2D data rate range varies from 300 Kb/s to 2.5 Mb/s depends on the location of DUs whether it is outdoor or indoor; and also depends on the mobility mechanism.

5.3 Prototype 3: relay by smartphone

Tohoku University academics introduce a system called “Relay by Smartphone” [18] to be a supported system in case of disaster. It supports multi-hop D2D communication unlike “FlashLinQ” and “Data Spotting” which support one-hop D2D communication. This system is designed to transmit a small package of information such as voice, photo, SMS, etc., out of disaster area where the communication infrastructure is either physically damaged or energy lacked. In Relay by Smartphone, each smartphone can operate with one of two routing types either MANET type or DTN type. The routing selection process subjected to mobility, battery power, neighbor density, etc. This system operates in the ISM band and performs WiFi ad-hoc mode for peer discovery and D2D communications.

To have a stable connection through D2D multihop, several issues should be taken into consideration: (1) Choosing a suitable access interface such as Bluetooth, LTE-A, ZigBee, WiFi, etc. The proper selection is analyzed based on transmission range, data rate and used frequency of each. (2) Selecting the best routing technology whether DTN or MANET as routing is a dominant technology in multihop D2D communication. MANET-type and DTN-type perform in different ways depending on the environment and situation of users. (3) The capability of the network gateway to interconnect with other kinds of networking techniques, such as Movable and Deployable Resource Units (MDRUs) and Unmanned Aircraft Systems (UASs). (4) Ensuring secure information in the procedure of message delivery. (5) Checking the operating systems of the smartphone like Android, iOS, Windows, TIZEN, etc. The system should support emergency operation mode and be compatible with applicable smartphone operating systems.

A number of preliminary experiments have been executed in Sendai city, Japan. The reason behind selecting this city is that it suffered from numerous disasters such as tsunami and the Great East Japan earthquake. The main two experiments and their results obtained [18] are as follows:

Experiment 1 It consisted of 20 smartphones that were distributed along the streets with a mutual distance of around 50–200 m. The main purpose of this experiment is to test the mechanism of message delivery in the urban area.

Results 1 The prototype successfully delivered a message with a total route length of around 2.5 km from a park designated as a refuge area to a railway station.

Experiment 2 It intended to test the interconnection function of the gateway module in the system from the Aobayama campus of Tohoku University to Katahira campus via a UAS flying in the air.

Result 2 It showed that a data package of 100 KB can be efficiently delivered through the mentioned place, resulting in a delivery delay of fewer than 20 s over 3 km distance.

5.4 Prototype 4: content aggregator

In [19], a prototype was addressed that implemented a D2D communication for mobile devices. It aims to ease D2D link establishing among proximate devices with considering the security questions between them without needing any third partner. The main system provider is called Content Aggregator (CA). CA keeps information about device locations and all the data of devices’ demands. The CA’s purpose is to control devices that peers should be connected with which, and what type of data to be transferred.

When a new user joins the network, it logs into CA's database and picks which data it wants to acquire. Then CA offers the new users with a list of neighbor devices that possessing these required data. Now, this user has gained knowledge on which other users to contact for any specific data. In case acquiring data from other devices, the user informs the CA of the completed transfer. Moreover, the process of logging into the CA provides security and authentication to the user. Such messaging media applications can be transfer over the conventional Internet like Facebook, Whatsapp, Telegram, Snapchat, etc. The operating frequency of D2D connections is proposed to be in unlicensed and the operating system of the proposed implementation is Android platform due to its popularity. Finally, WiFi Direct (WFD) is considered as the radio access technique for D2D connectivity since it provides a lager data rate up to 300 Mbps, and extended coverage range up to 70 m. The main experiment and the results obtained in [19] are as follows:

Experiment To prototype the proposed model, a video application is shared among users that close in distance. The experiment's target is to utilize WFD technology to facilitate a D2D connection. The compressed video file was 100 MB shared between two Nexus 5 smartphones. The adopted Wi-Fi technology was the following: 802.11 n in the 2.4 GHz range.

Results The utilization of WFD is compared to cellular networks and WiFi infrastructure. Results may improve the data rate by up to 30% for a given set of users. Results also do not only provide higher data rates but also "frees" the expensive licensed cellular spectrum.

Based on [16–19], Table 4 summarized the features of the different prototypes such as data rate, number of hops, implementation platform, operating band, and application.

6 D2D integrated features

A lot of features could be integrated with D2D technology as shown in Fig. 6 in order to get better performance. A lot of researchers have studied how to integrate this technology with different applications such as mmW, V2V and IoT. This section states other technologies and the potential advantages of combing them with D2D.

6.1 D2D integrated with millimeter wave (mmW)

Unfortunately, most of the recent spectrums below 3 GHz have been occupied with several services as TV, satellite, mobile communication…etc. Millimeter wave's band which included the frequency band from 30 to 300 GHz, introduces a large availability of unused spectrum [20]. Previously, the mmW band has been exploited for rare cases as indoor communication, P2P terrestrial and satellite links. The main advantage of mmW's band is its great bandwidth expansion. It can lead to high data rate and throughput too. Therefore, mmW technology is highly recommended to be applicable in 5G.

Millimeter waves have different characteristics than normal propagation waves [21]. Firstly, the propagation loss of microwave links is much less than the millimeter-wave due to using higher frequencies carriers in mmW. Hence, special antenna design is recommended with high gain to compensate for the fading problem. Secondly, the mmW signals have difficulties in penetrating through solid materials. The limited penetration capability leads to restricting the usage of mmW signals outdoor. For these reasons, it is preferable to use this band inside buildings. Finally, the shortage of millimeter wavelengths leads to some difficulties in diffracting around obstacles. Line-of-sight (LOS) transmissions can easily be blocked by the obstacles as non-LOS (NLOS) transmissions links will suffer from huge shadowing and fading which may cause link failure. There are a lot of challenges will be faced by using this technique such as antennas design, power control, reliability and hardware implementations. Numerous academic researches and industrial hard works are on the way to examine the applicability of the mmW band in the communications process between devices in 5G as it is a very promising topic.

As mentioned before, since mmW has a large fading in transmission and needs a special directional antenna, it is better to be used inside building or for short-distance transmission. By allowing using mmW by D2D links, the transmission data rate and network capacity can be improved due to its large bandwidths. Some challenges may face D2D devices during mmW usages such as special hardware design, additional interfaces, and interference [22].

In [23], applying D2D technology in mmW for 5G cellular networks was studied. First, they describe the advantage of merging both techniques together. Then, network architecture has been imagined and explained. This network consists of 4G base stations, special mmW base stations, and mobile devices, note that all devices together consider as 5G cellular network. It is supposed that mmW transmission/reception depends on directional antennas, which can significantly decrease the mutual interference between mmW base stations. After that, the MAC interface for these devices has been showing by introducing two modules for BSs and devices. These modules are 4G cellular module and mmW module.

Table 4 Technical comparison between different D2D prototypes [16–19]

	FlashlinQ	DataSpotting	Relay by smartphone	Content aggregator
D2D Discovery	Autonomous	Operator assisted	Autonomous via routing protocol	Operator assisted
Peer discovery Range	1 km	~ 100 m	~ 100 m	~ 100 m
D2D communication	Operator controller	Operator controller	Autonomous	Autonomous
Operating band	Dedicated cellular band	Control channel: 3G band Data channel: ISM band	ISM band	ISM band (2.4 GHz)
Radio access	OFDMA	WiFi adhoc	WiFi adhoc	WiFi Direct
Number of hops	single hop	single hop	Multi hop	Single hop
Data Rate	1.5 Mb/s	300 kb/s–2.5 Mb/s	~ 5 kb/s	~ 300 Mb/s
Implementation platform	TI DSP chipset TMS-c6482 Xilinx virtex-4 FPGA	Android Nexus one	Android smartphones	Android Nexus 5
Application and used cases	Advertising, content sharing, secure mobile payments, p2p communications	Peak hours, train stations, sports stadiums	Emergency network	Internet media transfer (e.g. Facebook, Telegram, Whatsapp, Snapshat, etc.)

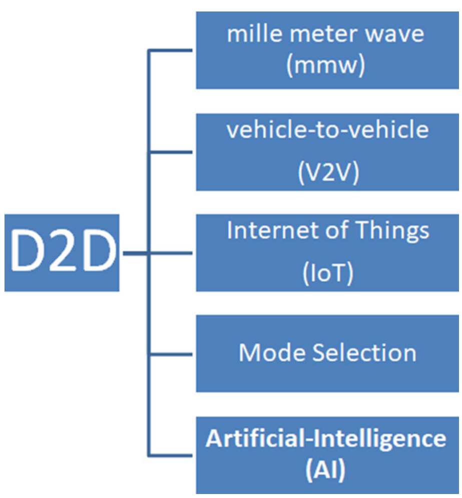

Fig. 6 D2D integrated features

Finally, resource sharing has been proposed. The proposed algorithm shows better results than normal cellular communication and random scheme in terms of capacity and links connectivity.

6.2 D2D integrated with vehicle to vehicle (V2V) communication

Nowadays, Vehicle-to-Vehicle (V2V) communications [24] have taken more concerns. Vehicular communication systems are networks in which vehicles and roadside units are the communicating nodes, providing each other with certain information and data, such as speed, location, the direction of travel, braking, loss of stability, safety warnings and traffic information….etc. These data can be effective in avoiding accidents and traffic congestion. Consequently, V2V communications become one of the main topics of wireless communications that have already been the focus for several years. For example, IEEE has already launched a standard called 802.11 p for wireless communication between vehicles. Basically, Intelligent Transportation System (ITS) applications is essential depends on Dedicated Short Range Communication (DSRC) technology that applied on IEEE 802.11 p [24]. Unfortunately, applying DSRC technology to support vehicle communication leads to poor network performance as less reliability due to shortage in data rate and transmission range.

Other proposed technologies for V2V are ad-hoc communications, Bluetooth, Ultra-Wide Band (UWB) and WiFi Direct. The following Table 5 states these protocols names and their specifications. From the mentioned table; it is clear that the main problem with all mentioned communication systems is that they basically assigned for a wireless LAN environment. Hence, the main drawbacks are weaker mobility support and lower coverage area that may degrade network performance. For all previous reasons, finding a better solution to backing V2V communications becomes a vital issue. Due to Table 5 LTE-A and 5G

Table 5 Comparison between DSRC, ZigBee, Bluetooth, UWB, WiFi Direct and LTE-A

Technology	DSRC	ZigBee	Bluetooth	UWB	WiFi Direct	Next generation (LTE-A/ 5G)
Standardization name	IEEE 802.11p	802.1504	Bluetooth SIG	802.1503a	802.11a	3GPP LTE-A Rel12
Transmission distance (max)	~ 200 m	~ 100 m	~ 100 m	~ 10 m	~ 200 m	~ 1 km
Data rate (max)	~ 27 Mb/s	~ 1250 kb/s	~ 24 Mb/s	~ 480 Mb/s	~ 250 Mb/s	~ 1 Gb/s
Frequency band	5.86–5.92 GHz	868/915 MHz–2.4 GHz	2.4 GHz	3.1–10.6 GHz	2.4/5 GHz	Licensed Band
Supporting mobility	Up to 60 km/h	Low	Very low	Very low	Low	Up to 350 km/h
V2I	Available	Available	Available	Available	Available	Through eNB
V2V	Ad hoc	Ad hoc	Ad hoc	Ad hoc	Ad hoc	Through D2D

systems offered better transmission range, massive data rate and support high speeds. That is why most researchers tend to studying applying V2V on LTE-A or 5G system. 5G network supports licensed spectrum, higher data rate up to 5 Gb/s, higher mobility up to 350 km/h, higher coverage region around 1 km, and lower latency around 1 ms.

From V2V communication perspective, it usually occurs among vehicles that close in distance such as vehicles in the same roadside. Furthermore, V2V depends on real-time requirements. Hence, V2V communication requires low latency about 1 ms approximately and high reliability around 99.99% approximately. These QoS are necessary for V2V communications to be achieved by exploiting the offered advantages of D2D technology. Thus, D2D technology can be a strong candidate for achieving V2V's requirements [25]. The main challenges that face V2V communication are mobility, interference and resource allocation. The notion of extending D2D technology in V2V communication scenario is cleared in LTE-a band in [24]. Simulation results proved that D2D is one the suitable solutions in order to eliminate latency concerning IEEE 802.11 p. A different topic is covered in [25–27]. They tend to optimize SINR for cellular users while optimizing latency and reliability for communicating vehicles.

6.3 D2D integrated with internet of things (IoT)

The Internet of Things (IoT) holds the promise to improve our lives by introducing innovative services conceived for a wide range of application domains [28]. IoT defines new kind of connectivity that introduces free flowing transferring information among human and machine, software and hardware. It is expected that will be 30 billion connected devices in the market by 2020 and the economic value of IoT to be around $1.46 trillion in 2020, while Ericsson expected that will be 24 billion to 50 billion total connected devices in the market by 2020 [29].

In order to enhance the performance of IoT, some requirements need to be fulfilled [30] as minimizing energy consumption, supporting massive Machine-Type Communication (MTC) without degradation in network performance, supporting interoperability and Handling Big Data for complicated IoT applications like as storage and analysis of the huge amount of data that generated by IoT devices. In addition, IoT should have a high-level network recovery capacity, quickly identify connectivity failures, and automatically establish alternative communication paths. Smart multimedia devices shall be properly included to sustain multimedia services in IoT networks. Some of the multimedia services such as patient monitoring, military surveillance, smart home integrated monitoring systems for security, ambient multimedia services….etc.

By applying D2D, it will meet previous IoT requirements [31]. Performance of IoT network will be enhanced by achieving larger data rate and low delay which could sustain Internet of Multimedia Things, minimizing energy consumption for IoT devices, extending both coverage area and capacity increasing to fund MTC and supporting interoperability in Multi-RAT heterogeneous networks.

The resource multiplexing has been investigated in the multi-cell D2D communication scenario [32]. Cross-cell Frequency Resource Multiplexing (CFRM) scheme has proposed to maximize the network throughput and to decrease the interference between CUs and DUs. CFRM allocates resources to CUs according to the cell region division and provides efficient resource multiplexing for DUs. The simulation results demonstrate that CFRM can enhance the stability of the cellular network and increase the network throughput for IoT by exploiting D2D.

6.4 D2D integrated with mode selection technique

Mode selection is the problem of choosing whether two users should communicate through a direct link (D2D) or via eNB [33] in order to optimize network performance. The optimal mode selection depends on the performance measure to enhance network output such as sum rate, transmit power, energy consumption, and system capacity; and on the state information available when making the decision such as physical distance, the channel quality of the links, and interference level. Static and dynamic selections are two types of mode selection [34]. The first one is the simplest that study one parameter. This type assumes that such a parameter is static and does not change with time. However, dynamic selection is more complicated. It is more accurate than the other. As it takes into account the dynamicity nature of the wireless network, where mobility could occur or even channel quality may change in time among connected nodes.

The joint optimization problem of mode selection and eNB selection in multi eNB cellular concepts have been formulated in [33]. They adopted a centralized graph approach to solving the problem globally optimally in polynomial time. To reduce the complexity and signaling overhead, a distributed algorithm had been proposed which solves the original problem in the dual domain via Lagrangian dual decomposition. Simulation results demonstrate that the distributed algorithm acts with very closely way as the centralized algorithm. The authors in [34, 35] defined the problem joint mode selection and the problem of allocating resources as a Mixed-Integer Non-linear Programming (MINLP) problem. Heuristic algorithms were proposed as a solution for mode selection problem, channel assignment problem, and power control problem.

In [36, 37] authors study mode selection based on energy efficiency in case of dedicated resources or shared resources. They used heuristic suboptimal solution and Bound & Branch (B&B) optimal solutions. It has been proved that the second solution is more complicated compared with the first solution. However, they didn't show the performance of the network in the case of using mode selection. All these papers depend on static mode selection while [38, 39] depends on dynamic mode selection. In [38], a framework was developed which opportunistically executes mode selection under the nature of the channel dynamicity. The authors take into consideration two connections scenarios, which are the cellular connection and the direct connection. The aim of the paper is to utilize either the uplink or the downlink cellular resources. Paper's results are compared with the traditional connection and the situation when the D2D is applied nevertheless of the distance between the devices. It is obvious that for the entire available distances among the devices; the average sum rate for the proposed technique always achieves the highest results. However the paper highlights the dynamic mode issue, it does not take into account the mobility of devices but it states the best mode according to the device's position within the cell. Paper [39] addresses both connection types that are cellular connection and D2D connection, in the case of semi-static mode selection and dynamic mode selection. The paper demonstrates that dynamic mode selection is better than the semi-static mode selection.

6.5 D2D integrated with artificial-intelligence (AI)

AI methodologies have been widely deployed in an extensive range in several fields of researches, such as computer vision, prediction models, natural language processing, wireless communications, etc. Swarm search, neural network, fuzzy logic, bio-inspired, genetic algorithm and machine learning are the most well-known mechanisms of AI that deployed for wireless communication field. A special interest of AI in 5G cellular networks grows due the necessities of 5G networks. AI mechanisms have the capability to deploy nonlinear approximations data driven, manage resources for massive capacity, optimize networks' QoS, and mitigate interference and nonlinearities of radio frequency (RF) components, such as High-Power Amplifiers (HPAs). Furthermore, AI algorithms can provide relevant network operator with the capability to create a cognitive and comprehensive data repository by splitting, scheduling resources, processing and signal classification, link adaptation, and interpreting the operational data [40].

Due to higher capacity needs of next generation networks, 5G Radio Access Network (RAN) has multiple tiers of heterogeneous networks (HetNets) which are macro cell and small cells and D2D. However, D2D communication in that case adds to another tier. So, D2D makes interference mitigation and resource allocation more complex. Thus, applying AI acquires these kinds of networks the capability of self-configuration, self-healing, and self-optimization [41].

A cooperative Reinforcement learning (RL) algorithm was imposed in [42] to allocate power level and RBs for DUs and CUs. The reason behind selecting this algorithm as it is seen as a suitable one for adaptive resource allocation which contributes to improving system throughput and D2D throughput. A single tier network model with macro BS is suggested, while both CUs and DUs operate under this BS. The authors proposed cooperation between the learning agents DUs by sharing their value functions to jointly increase the overall throughput of the system. Moreover, the set of states with the appropriate number of system-defined variables was performed, which raises the observation space. Consequently, the accuracy of the learning algorithm was enhanced. Results from this model were compared to the distributed reinforcement learning models and random allocation of resources. Results proved that the proposed algorithm has better performance in terms of network throughput and D2D throughput, and network QoS.

Another RL algorithm was investigated that based power control mechanism for underlying D2D connectivity in cellular networks [43]. The main purpose of this investigated algorithm was maximizing system capacity while keeping the level QoS of CUs. In order to realize the purpose, two RL based power control algorithms were investigated that are distributed-Q learning and team-Q learning. Team-Q learning algorithm is implemented to achieve global optimal policy while distributed-Q learning algorithm is applied to accelerate convergence speed. Numerical results proved that compared to the open-loop power control algorithm. Q-learning based power control performs better.

7 D2D challenges

D2D technology gets more consideration thanks to its numerous advantages. However, it copes with a lot of challenges such as energy consumption, interference management, peer discovery, handover, radio resource management and security. Following subsections highlight these challenges.

7.1 Energy consumption

Abundant numbers of devices will be served in future cellular networks. It is estimated to be 50 billion devices. Regrettably, rising number of communication devices leads to increasing the amount of consumed energy. Because of that CO2 level in the atmosphere will increase that harms the environment and global weather. Moreover, BSs and access points need a huge amount of energy and emit large amount radiation [44] that effect on human health and the global economy. As a result, wireless communication networks are made an enemy of the environment. For these reasons, 5G network has a tendency to deploy green communication networks. Green communication is to reduce energy consumption as possible and to prolong devices' batteries. It is expected to raise energy efficiency up to $\times$ 1000 time in next 5G cellular networks [45]. Green network can be supported with different aspects to achieve its main purpose such as power control, energy harvesting, femto-cells, and cloud RAN. One of the main technologies that assist green networks is D2D technology. It is able to offload some energy from BS. Also short range connectivity between proximate devices leads to less consumer power for devices. D2D eliminate BSs' radiation. Besides, relays applicability using DUs will enhance energy efficiency also.

One of the main challenges that face cooperative D2D networking is energy consumption problem; because of evolved DUs in such networks are battery-powered devices. In [46], authors demonstrated this challenge in the case of the influence of social characteristics. A social-aware cooperative D2D MAC protocol was outlined in order to solve the energy efficiency challenge. This protocol is referred to as a green D2D MAC protocol. It permits the use of neighbors as relays to introduce a green communication. In addition, social awareness of green D2D cooperative network's practical issues was highlighted. Results of the simulation have provided better energy efficiency than other protocols. Results also showed the importance of green social-aware D2D cooperative networks.

To make a smart green city, energy consumption and gas emission for high data rate services should be eliminated. D2D communications have made recommendations in [47] to tractable these issues and support real-time services. Single-cell D2D underlying cellular network was planned. In order to reduce consumer energy and guarantee throughput for all devices either CUs or DUs, joint optimization of uplink subcarrier assignment and power allocation were highlighted. Generally, this optimization problem is viewed as a Mixed-Integer Nonlinear Programming (MINLP) problem. To manage this optimized problem, a heuristic algorithm is suggested. The effectiveness of the applied algorithm has been verified through simulation results.

Three layers of architecture is supposed in [44] to save prolonging battery lifetime of devices and terminal energy for a single BS-cell network. Layer1 represents terminal devices that close in distance to BS up to 3 m. Layer 2 represents terminal devices that are intermediate up to 35 m while the third layer represents the most far terminal devices in the cell. Terminal devices in the first layer communicate directly with the BS without excessive energy while terminal devices in third layers communicate directly together via D2D. In layer2, cell may have relayed to prolong battery lifetime in case of faraway devices. It is expected that this network will have better lifetime and lower energy consumption than other networks.

7.2 Peer discovery

One of the main challenges that face researcher is a D2D discovery peer process. D2D discovery process defined as the way to gain knowledge about surrounding devices that may communicate directly together. Discovery initiation and discovery control are the main two stages of this discovery process [6]. The D2D discovery initiation stage may be priori or posteriori process [48]. Priori process means initiating D2D discovery before the DUs start to communicate by sharing certain information between devices. On the other hand, the posteriori process occurs during ongoing communication. The common use of this kind of process could happen when mobile devices change their locations. The second stage is D2D discovery control that can be fully controlled via eNB, or autonomously by the DUs themselves.

Utilizing allocated resources for D2D discovery discussed in [49]. UEs execute procedures in order to discover surrounding nodes. The first state is search/listen period; the second one is discoverable interval state and finally frequency multiplexed discovery channel. Paper's results show that the suggested procedures are capable of raising the amount of discovered devices during one discovery period.

The time-division multiplexing (TDM) technique based on the synchronous OFDM system applied for a fully distributed D2D discovery network has been suggested in [50]. Each allocated radio resource has a discovery period, which includes the process of transmitting or receiving discovery signals. This period permits each device to acknowledge its presence and to discover other proximity devices. The main target for [51] is to minimize discovery process overhead. This could happen by assign a minor part form frames of the physical layer for the D2D discovery process.

7.3 D2D handover

Unfortunately, there are very fewer literatures are available on handover for D2D communication. In the case of enabling D2D connection, when both communicating devices or one of them are moving toward the neighbor cell, they enter into this cell at some point then a joint handover happens. In the case of only one of the communicating devices moves to the neighbor cell, it is called half handover or partial handover [52]. A general handover scenario has been clarified in Fig. 7, showing the handover scenario of UE1 from source to target eNB.

Several solutions for mobility management issues have proposed in [53]. Two smart algorithms for handover execution have provided which are D2D triggered handover and D2D aware handover. These algorithms presented lower signaling overhead and latency in simulation results. However, in [54], horizontal and vertical handover are represented in order to eliminate consumed energy in 5G heterogeneous networks.

7.4 Interference management

Interference between DUs and CUs is one of the main challenges that face D2D technology. Most D2D researchers try to minimize interference between links as possible as can. In the case of in-band shared resource communication, interference among cellular and D2D devices can exist. There are four interference scenarios. The first scenario studies interference from DUs to CUs while the second scenario studies interference from CUs to DUs. The third scenario combines both previous models in the study. Finally, the fourth one studies interference between D2D pairs themselves.

Scenario 1: interference from DUs to CUs is the most important one and it needs to be mitigated, as cellular networks consider CUs as licensed users or primary users while DUs considered as unlicensed users or secondary users. The power control mechanism is the most appropriate and used technique in this scenario.

Radio Resource Allocation (RRA) technique is one of the power control techniques used for interference elimination [55]. The eNB determines an acceptable level for interference caused by DUs then this information has broadcasted by eNB to all D2D devices. Based on this information, DUs fill those RB only that does not cause harmful interference. Simulation results introduce throughput rising in the case of the cellular receiver from 2.65 to 3.33 Mb/s. Unfortunately, this achievement happens at the cost of D2D receiver throughput which decreases from 3.02 to 2.83 Mb/s.

More complicated RRA techniques have been suggested in [56] which successfully assigns time slots for cellular and D2D users. Licensed users are categorized into two main categories: near-far risk and non-near-far risk. Also, time slots are categorized into shared and dedicated time slots. Where cellular users from the first category access both types of time slots; while the second one access dedicated time slots only without additional interference from D2D transmitters. This technique denotes the network's lower signaling overhead, DUs have been considered as autonomously controlled, where DUs themselves allocate RBs. The results introduce that CUs and DUs average throughput depends on a certain value for threshold (from − 5 to 13 dB). In the case of higher values for threshold, the overall gain has been raised. Some researchers combine the RRA technique with a power control mechanism to get better results as in [57–59].

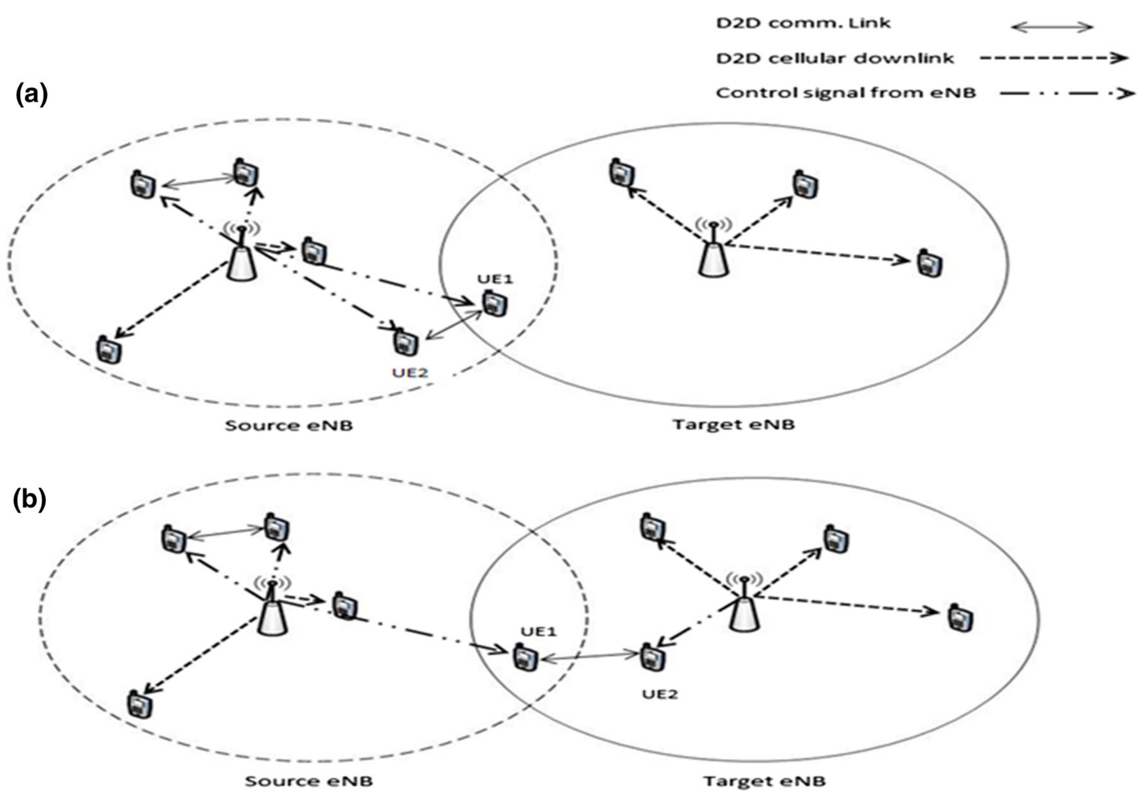

Fig. 7 Handover scenario case, **a** before handover; **b** after handover

Scenario 2: although scenario 1 has the priority, scenario 2 also takes more attention in order to enhance D2D users' performance. The novelist in [60] stated that interference from CUs to DUs can be reduced easily by a simple distance-based resource allocation algorithm. In the case of DUs close in distance desire to have direct communication, a request is transmitted to the eNB by the transmitter. The eNB allocates specified resources to DUs in order to reduce the outage probability. The main advantage of this method is lower signaling overhead as the resource allocation process is executed only with respect to the mutual distance of CUs and DUs, not due to channel state information. Therefore, the accurate positioning technique is essential requires in order allowing the eNB to allocate resources properly.

Scenario 3: previous two scenarios concern on addressing interference elimination from DUs to CUs or vice versa, while this scenario concerns on addressing both interference issues simultaneously. Mutual interference among the CUs and DUs could be reduced by utilizing the Fractional Frequency Reuse (FFR) scheme [61]. The FFR grouped the whole band into four sub-bands (f1, f2, f3, and f4). Each cell is assumed to be divided into two regions which are inner region and outer region. The first subband (f1) is reused in each cell by overall CUs that existed in the inner region. While remaining sub-bands (f2, f3, and f4) are exploited by CUs that existed in the outer region. The overall four sub-bands are used by all DUs with smart technique to eliminate interference with CUs. For example, if DU exists in the inner region of the cell, in this case CUs use f1. DU can access other sub-bands that assigned for the outer region of other eNBs (f2, f3, and f4). While if the DU locates in the outer region, it may exploit f1 from the inner region. Simulation results of this scheme show higher SINR for CUs and DUs both with respect to assigning resources for DUs randomly. The main drawback of this scheme that it has a lower spectrum utilization ratio, as 25% of the overall band can be allocated for one user. In addition, the scheme requires having a very accurate localized approach for users, which may affect the network performance.

The previous method has an enhancement version in [62], where accessible and reusable regions are specified next to the previous regions either outer or inner regions. So, only DUs that exist in the accessible region is able to exploit CUs' resources where exist in the reusable region. For example, in the case of the D2D pair that exists in the inner region, the outer region of neighbors cells becomes the accessible region. Correspondingly, DUs can exploit the cellular inner region resources in case of they exist in the outer region. The simulation presented that the CUs and the DUs have more SINR than [61]. But, in this case, the need for accurate localization technique becomes more challenging as the different categories for regions become much smaller in area.

Scenario 4: This scenario addresses the interference between DUs that use non-orthogonal radio resources. Interference between DUs could be avoided by allocating spatial, frequency, and time orthogonal resources. The graph coloring approach is used in [63] to be capable of sharing similar resource blocks. In this paper, DUs are categorized into two groups. The first group of DUs that do not suffer from interference is assigning the same color in the created graph. While DUs that may interfere together represent the second group. For example, one of D2D users at least exists in the region of transmission of the other user. The region of transmission is specified by transmitted power value by DUs that have the same color. This region is considered a circular area. To raise utilization probability, similar resources are exploited by the DUs that exist in the same region. It also indicates the issue of allocating available RBs D2D reuse groups. The allocating unfilled RBs processes for DUs are executed by a fair assignment mechanism or opportunistic mechanism. The paper shows high network throughput. Paper's disadvantage is assuming that the transmission region is circular; while in reality, the obstacles lead to deformation in the cellular area.

7.5 D2D resource allocation optimization and management

Radio resource management optimization issue indicates how to optimally allocate frequency resources to overall DUs so as to optimize some performance parameters such as SINR, latency, power consumption, reliability, QoS, interference, channel utilization, energy efficiency …etc. Resource blocks should be distributed among DUs depending on certain rules based on cellular network design. Optimization procedures may be executed by eNB or by D2D pairs themselves. Basically, CUs should have a priority than DUs in optimizing procedures. One of the technical challenges in optimization procedures comes from the nature of dynamicity of the network where DUs and CUs always have variable states and locations. Heuristics, fuzzy logic, and game theory are some examples of solution types used to solve optimization problems relating to D2D communication. Various papers supposed [64–66] simple scenarios that include a single CU and a single D2D pair. Optimization of resource allocation in terms of SNR had highlighted in detail with certain restrictions that are maximum transmit power and energy limitation [64], spectral efficiency restrictions boundaries [65], and average Channel State Information (CSI) [66].

Another network scenario is introduced in [67, 68] where there is one DU pair and multiple CUs. The mode selection technique is applied in order to optimize SINR based on DU pair distance and number of users [67]. Also, the mode selection example for selecting optimal relay nodes mentioned in [68]. While the opposite scenario is investigated in [69], where there are multiple DUs accessing the same channel with a single CU. An optimization problem is addressed to minimize total power consumption for both CUs and DUs subjected to users' QoS. The property of the Z-matrix is examined to be exploited by a power allocation mechanism.

Multiple DUs/multiple CUs scenario is remarked in [70–72] to allocate appropriate resources that optimize a certain parameter(s) under specific constraints. Maximizing the system energy efficiency is proposed in [70], which based on searching all possible mode combinations of overall DUs and CUs to achieve this target. A list-coloring theory-based resource allocation algorithm is highlighted in order to increase utilization probability [71]. In this algorithm, additional tasks were supposed for DUs to report their desired UL resource block to the eNBs. The eNB constructs a Node Contention Graph (NCG) to overall DUs based on their desired UL resource block and then completes an interference-free allocated resource. Finally, the main target of authors in [72] is to maximize spectrum utilization and throughput of the network. A Stackelberg game framework was settled for multiple CUs and DUs to form a leader–follower pair where CUs are the leader while others are followers. A joint scheduling and resource allocation algorithm was proposed to solve the optimization problem due to interference constrains.

A comparison of different related works can be found in Table 6. This table classifies the research works based on their network scenario, main objective(s), main restriction(s), and finally a proper tool or solution that fits the problem.

7.6 Security

Assuring security of D2D connectivity considers as one of the main challenging topics. Because of the nature of D2D networks, DUs become less secure than CUs under eNB control. Different security attacks can face communication channels like node impersonation, message modification, and eavesdropping. In the case of DUs that are in coverage, they may exploit the security algorithms providing by the cellular network. However, DUs that are out of coverage couldn't be secured [73]. Thus, designing security algorithms for DUs consider a vital challenge to be studied.

One of the important papers that highlighting this issue is [74]; it offers three simplified techniques. It suggested a shark key algorithm to manage authentication for D2D connectivity in the LTE network. However, many other algorithms of attack, as replay attacks, distributed denial of

Table 6 Comparison between resource allocations related works

Scenario	Related works	Objective(s)	Restrictions(s)	Solution/tool
1 D2D/1 CUE	[64]	Maximize SINR	Maximum transmit power and energy limitation	Linear optimization
	[65]		Minimum and maximum spectral efficiency restrictions	
	[66]		Average Channel State Information (CSI)	
1 D2D/M CUs	[67]	Maximize SINR	D2D pair distance and number of cellular users	Basic math derivation and mode selection
	[68]		Number of relay nodes	Basic math derivation
M D2D/1 CUs	[69]	Minimize power consumption	Users' QoS	Z-Matrix
	[25]	Maximize SINR and reliability	Minimize outage probability, maximize transmit power	Hungarian method
M DUs/M CUs	[24]	Maximize SINR, reliability and minimize latency	Maximize transmit power, resource blocks orthogonally, guarantee of users QoS	Heuristic two-stage scheme
	[26]	Maximize SINR and reliability	Minimize outage probability, maximize transmit power and reuse channels	weighted 3-dimensional matching problem
	[70]	Maximizing energy efficiency	Guarantee of users QoS and maximize time frame	Basic math derivation and mode selection
	[71]	Maximize spectrum utilization	Minimize interference among DUs and CUs	List coloring graph theory
	[72]	Maximize spectrum utilization and throughput	CUs fairness and DUs interference	Stackelberg game
	[47]	Minimize energy consumption	Guarantee throughput for CUs and DUs	Heuristic two-stage scheme

service, denial of service, and man-in-the-middle attack which not studied at all. In reality, it is a mandatory issue to have a secure algorithm for D2D connectivity even in case of complex scenarios. A D2D communication protocol was suggested for m-health application in [75]. This protocol is called a Light-weight and Robust Security-Aware (LRSA) D2D-assist. In order to establish a secure link for this application, the protocol needs to have a mutual authentication for sensors. Thus, it provides a new efficient Certificate-Less Generalized Sign-Cryption (CLGSC) scheme which can adaptively work as one of the three cryptographic primitives: sign-cryption, signature, or encryption, but within one single algorithm. Based on the paper's analysis, CLGSC proves to be secure, simultaneously achieving confidentiality and unforgeability. The outcome of the performance evaluation shows that the LSRA protocol succeeded in achieving the design objectives and outperform existing schemes in terms of computational and communication overhead.

To provide security scoring system (SeS) for D2D networks, continuous authenticity with legitimacy patterns is lectured in [76]. SeS is used to prevent, react, and detect attacks at the physical layer without necessitating computations at upper layers of the software stack. The feasibility of implementing the proposed security-scoring using legitimacy patterns is proved by Simulation results. It offers less secure attacks compared to static and random allocation of legitimacy patterns. Besides, executing security at the lower layer improves the overall system security.

A D2D connection between two DUs in a cellular network is proposed in [77]. Both DUs are in the network coverage. A key exchange protocol based on the standard Diffie-Hellman (DH) is also proposed. Moreover, the Authors analyzed three key exchange protocols for D2D communication. A thorough threat and defense analysis of the proposed protocol has been presented for the common brute force and man-in-the-middle attacks. Compared to other existing key exchange protocols, numerical results verified that the proposed protocol has lower computational overhead and time. The proposed protocols are practically implementable and highly suitable for D2D communications in 5G cellular networks.

Another protocol was proposed called eCMS-SD2D (enhanced Conventional Multicast Scheme with Secure D2D communications) [78]. The main target of this protocol is to establish a D2D secure connection of a multicast service in the 5G network, while also increasing the network utilization. Therefore, to establish this secure connection, mechanisms as signature and encryption were applied to ensure the privacy and protection of the transmitted data. The outcome of this protocol performs that, it is possible to eliminate data losses caused by malicious users. At the same time, it also ensures an acceptable users' data rate.

8 Conclusion

In this paper, an intensive overview is provided about D2D communication technology with the existence of infrastructure cellular network. The D2D communication technology underlying mobile network provides numerous benefits such as raising overloaded cellular network efficiency to reduce latency and minimize consumed energy. Moreover, current D2D's prototypes and experiments, such as FlashLinQ, Data Spotting, Relay by Smartphone, and content aggregator was laid out and explained with details about their architecture, implementations, and results. Also, an intensive comparison between these prototypes was outlined. Major research topics such as IoT, V2V, mmWave, AI, and mode selection were explained to show the importance of attaching D2D technology with these different features. Besides that, the paper highlighted the vital challenges that D2D technology faces such as handover, energy consumption, interference, resource allocation, and security.

Finally, applying D2D technology in 5G becomes a very richly material for investigation. Till now, most researches and prototypes are still in the initial study stages of D2D technology performance in case of simple scenarios or under certain conditions.

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