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3GPP Project Based D2D Communication in Cellular Networks

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ABSTRACT

Device-to-device (D2D) communication is rapidly evolving into a viable method of information exchange in a cellular network. It has a very low end-to-end latency and can increase spectral efficiency of a cellular network. The latest releases of 3GPP specification have given considerable attention to standardize this mode of communication and integrate it in the ecosystem of LTE advanced. This will give more impetus to the development of D2D technologies and their adoption by mobile operators. This paper presents a discussion and critical analysis of the main features of D2D communication as defend in Release 12 and subsequent releases of 3GPP specifications.

KEYWORDS: *Device-to-device (D2D), GPP, LTE-direct, LTE-advanced, Cellular network, 5G, mmWave, Group Communication, V2V Communication, V2X Communication*

INTRODUCTION

One of the biggest challenges faced by telecom operators is the continuous increase in demand for high data rate and low end-to-end delay. One way to achieve it is through device-to device (D2D) communication. D2D communication enables direct communication between proximate devices bypassing the base station. As D2D communication promises ultra-low latency for communication among the users, it has attracted great attention from researchers working on the forthcoming 5th generation cellular networks [24, 25]. D2D communication can operate using both licensed cellular spectrum and unlicensed spectrum; the two modes are known as in-band communication and out-band communication, respectively. In the first case, the D2D communication and the cellular communication can both operate over the entire licensed cellular spectrum; this is known as the underlay D2D communication mode. But it leads to heightened interference across the D2D users and the cellular users.

To avoid this problem, a new approach known as the overlay D2D communication mode has been proposed that allows the D2D users to use a certain fraction of cellular resources that is not assigned to the normal cellular users. The overlay mode focuses on the effective resource allocation, so the spectrum wastage can be avoided. In terms of performance, D2D communication, when it is technically feasible, offers more benefits compared to the conventional cellular communication. First, it is a transparent communication technique and is very efficient with a high spectral efficiency and low latency. Therefore, managing local traffic becomes easy for the user equipment's (UEs) communicating directly in a given proximity. Computational of loading is one more benefit of D2D communication. D2D users under a static network environment can use D2D links to of load computation-heavy tasks to nearby D2D users [34]. In D2D communication, the mode selection technique allows the devices to switch from the infrastructure path to direct path easily. This reduces the congestion in the network. From an econometric point of view, D2D communication can play a big role in commercial applications, social networking applications, e-

This paper gives an overview of the standardization of D2D communication based on 3GPP Release 12 and subsequent 3GPP releases. We describe the general features of 3GPP releases in the context of D2D communication in other following sections.

Features of 3GPP Releases

General Features

Standardization of technologies is very important as it ensures their interoperability across products and services manufactured by different vendors. Standardization makes the technology commercially viable [41]. The 3GPP standards organization develops protocols for mobile telephony. It has made monumental contributions in developing and maintaining telecommunications standards from 2G to 5G. Figure 1 shows the current and upcoming 3GPP releases along with their year of release and current status. The initial LTE architecture was standardized as 3GPP LTE Release 8/9. Releases 8 and 9 both used a bandwidth of 1.4 MHz, 3 MHz, 5 MHz, 15 MHz, and 20 MHz to support various deployment scenarios. LTE-advanced or LTE-A arrived with 3GPP Release 10, which focused on enhancing the network capacity using carrier aggregation techniques [20]. It enhanced the overall bandwidth of existing cellular networks by combining two or more component carriers for higher data rates [58]. Coordinated multipoint transmission and reception (CoMP), and heterogeneous deployments (HetNet) are supported since 3GPP Release 11. Network capacity enhancement, increase in coverage area, cell coordination, and cost reduction are some of the important enhancements in 3GPP Release 12. Along with that, 3GPP Release 12 introduced D2D communication in the LTE-A architecture; its major targeted application is public safety. Release 13 added support for other D2D functions and unveiled the frst set of specifications covering mission critical services. Release 14 focused on mission critical enhancements and LTE support for vehicular (V2X) service.

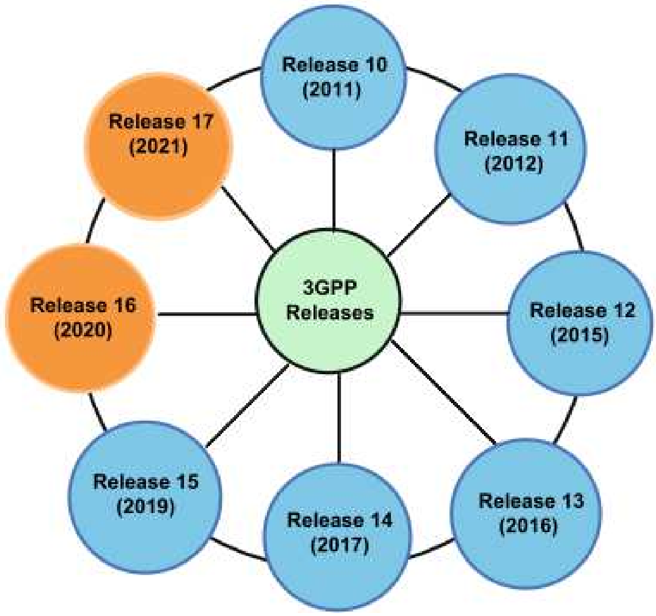

Fig. 1. **3GPP Releases. The circles along the periphery show the 3GPP releases and the year (or tentative year) of publication of the corresponding release. Blue circles indicate frozen releases, while orange circles indicate open ones (color figure online)**

The most important feature of Release 15 is the support for 5G radio systems. Work on Release 16 is in progress; it aims to increase support of vertical industries such as V2X, public safety, and Industrial Internet of Things (IIoT) [37]. Although the 3GPP releases specify a bevy of features for cellular communication, in the subsequent sections of this paper we concentrate on its D2D specifications exclusively.

Specific Features

Key Motivations for D2D Communication: 3GPP Release 12 focuses on developing a communication framework to meet public safety needs that can be used by police, fire fighters, ambulance drivers and other personnel handling emergency situations. The goal is to reduce dependency on network infrastructure that can fail in times and areas of disaster, limit operational costs, and enable broadband communication. It supports two key technologies as explained below [9].

1. *Proximity services (ProSe):* Proximity services in 3GPP Release 12 allow devices in physical proximity to discover each other and communicate in an optimized manner. They are essentially supported with D2D communication that comprises D2D discovery and direct communication. In D2D discovery, a UE discovers another UE in its proximity. D2D discovery may be performed at the EPC level or done directly by the UEs. In direct communication, two UEs that have discovered each other communicate directly via the LTE air interface without routing the signal through the eNodeB (eNB) and the core network. This avoids network congestion and allows devices to communicate even when the network coverage is absent. Note that device discovery is not a prerequisite to direct communication as the latter can also happen through broadcasting. Proximity services can be used for both public safety and commercial applications.

2. *Group communication:* To meet public safety demands, group communication is considered as one of the most important requirements. It provides services like one to-many calling that can easily disseminate messages to a large group of people. 3GPP standardization and releases have focused heavily on the enhancement of group communications techniques. Generally in group communication, all UEs in a group receive a common downlink stream to communicate. Therefore, the overall resource utilization can be optimized. To enable efficient and flexible group communication, 3GPP standardization activities have consistently paid attention to optimized broadcast and multicast techniques. Note that group communication can be achieved with D2D communication, or with existing or enhanced 3GPP multimedia broadcast/multicast services (MBMS) in LTE/ LTE-A.

Scenarios for D2D Communication

3GPP specified the basic functionalities for D2D communications in release 12, where the main motivation was to develop a global standard for public safety communications [37]. However, the application scenario of 3GPP proximity services (ProSe) was not limited to public safety, D2D extension of conventional cellular services was also considered [38]. The basic architecture of the 3GPP ProSe is shown in Figure 1. A UE (user equipment) that wants to use ProSe must first contact the ProSe function through the logical interface named PC3 to get authorization and security parameters. After the discovery request and response message exchange via PC3 is completed, the UE can start the direct discovery process to find other UEs with ProSe cab ability in their proximity using the PC5 interface. When two (or more) Pro Se-enabled UEs have discovered each other, they can start direct communication over the direct link between them.

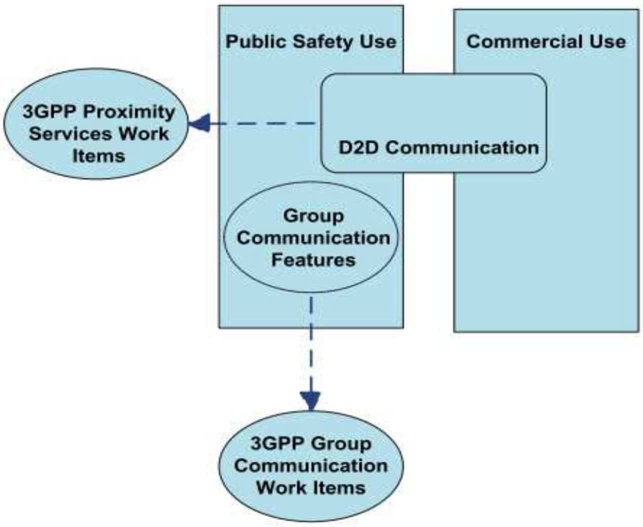

Fig 4 Use cases for D2D communication in 3GPP Release 12

Service requirements related to the 5G system [41] consider D2D in two different ways. The first one uses direct device connection without any network entity in the middle. In the second approach, a relay UE is between a UE and the 5G network. This is called indirect network connection mode. The relay UE may use multiple access schemes such as 5G RAT, LTE, WiFi, and fixed broadband. Service continuity plays a key role when changing from one relay UE to another or to the direct network connection mode. In addition, the 5G system is expected to support the battery consumption optimization of relay UEs.

1. IoT and Wearable's

IoT devices with a very long expected battery lifetime and wearable's with other cellular connected devices in their proximity would especially benefit from short D2D links. Motivated by this, 3GPP opened a release 15 study item "Study on Further Enhancements to LTE Device to Device, UE to Network Relays for IoT and Wearable's" [42]. The primary objective of the study was to improve the power efficiency of the remote UEs (IoT devices and wearable's) by allowing them to form a D2D connection with a UE who is willing to act as a relay [40]. Enhancements were planned to release 13 UE-to-network relaying to support end-to-end security and QoS as well as efficient path switching between conventional and D2D air interfaces. In addition, the needed changes for side link were studied to provide a reliable D2D communication link for low cost and low power IoT devices.

The study considered a diverse group of scenarios that could benefit from UE-to-network relaying. From the coverage point of view, the remote UE could be located within the cell, out of cell, or can be operating in the coverage-enhanced mode [40]. As cellular IoT devices mainly reach enhanced coverage by a high number (up to 2048) of repeated transmissions [43], the power efficiency gain of using short D2D links with minimal repetitions is obvious in this scenario. Relaying using the side link can be bi- or uni-directional, as shown in Figure 2. Bidirectional relaying is more straightforward to implement with minimal signaling from the eNB. However, bidirectional relaying over side link requires UL waveform reception capabilities for the remote UEs. This would mean implementing a UL receiver for low-cost IoT devices, which may not be feasible from the device cost point of view. Thus, many of the open issues in D2D relaying for IoT are related to the question, how to efficiently implement mandatory functionalities, such as discovery, for unidirectional relaying

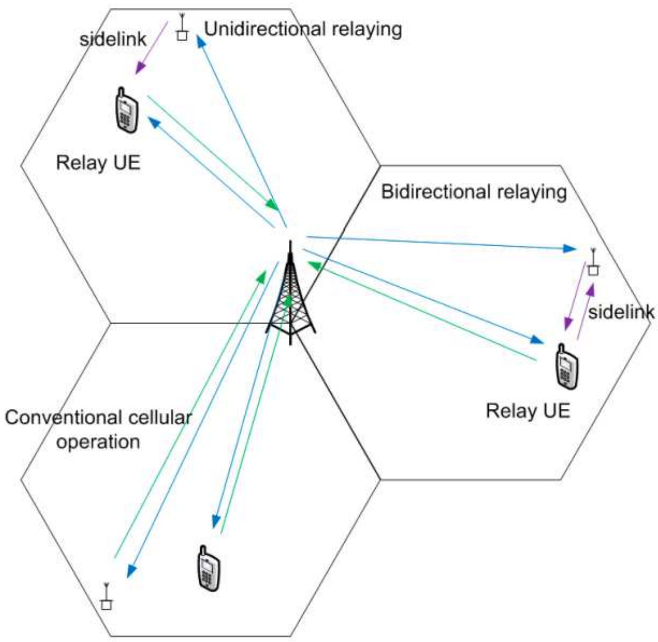

Fig. 2. Device-to-device (D2D) relaying variants for cellular Internet of Things (IoT) devices; UE: user equipment

As a result of the 3GPP study, a relaying architecture was proposed. Relaying is done above the radio link control (RLC) layer, i.e., the RLC and lower layers are terminated at the D2D link and higher layers at the remote UE and the eNB [33]. Several solutions for paging and system information transfer for remote UEs as well as path switch and group handover enhancements were also proposed. These layer 2 studies mostly assumed the feasibility of bidirectional relaying; the impact of unidirectional relaying was not fully analyzed in the study item. For example, the discovery procedure for the unidirectional relaying case with remote UEs only capable of receiving downlink (DL) signals was still left open. Another aspect in the 3GPP study was to study the required enhancements to side link physical layer operation. The target was to also enable the side link support for low-cost UEs with a limited bandwidth of one (narrowband IoT) or six (LTE-M) physical resource blocks (PRBs) and potentially with no side link reception capabilities [33]. Enhancements were proposed to the synchronization procedure such that the relay UE can act as a synchronization source for the remote UEs. Also, the needed enhancements for the support of unicast communications over the side link were identified and proposed for resource allocation, semi-persistent scheduling, power control, measurements and feedback for link adaptation. Based on the performance evaluation results presented in [33], especially the adaptive modulation and coding together with the adaptive number of side link transmissions provided a significant energy efficiency gain for the remote UEs.

There are still several open issues regarding D2D and UE relaying for cellular IoT. From the research point of view, the effect on the cell energy efficiency and the battery life-time for all involved devices has not been thoroughly studied. It is clear that with UE relaying, the devices willing to operate as relays consume more power than the remote UEs. However, the device power consumption model used in [33] was rather simplified and no clear view on the spatial distribution of the power consumption was achieved. The 3GPP has plans to continue the normative work on bringing the relaying support for cellular IoT and wearable's into standards. Currently, the corresponding work item has been proposed, but it is yet unclear whether the work will take place in release 15 or 16 [44]. D2D communication support in different 3GPP releases is depicted in Figure 3.

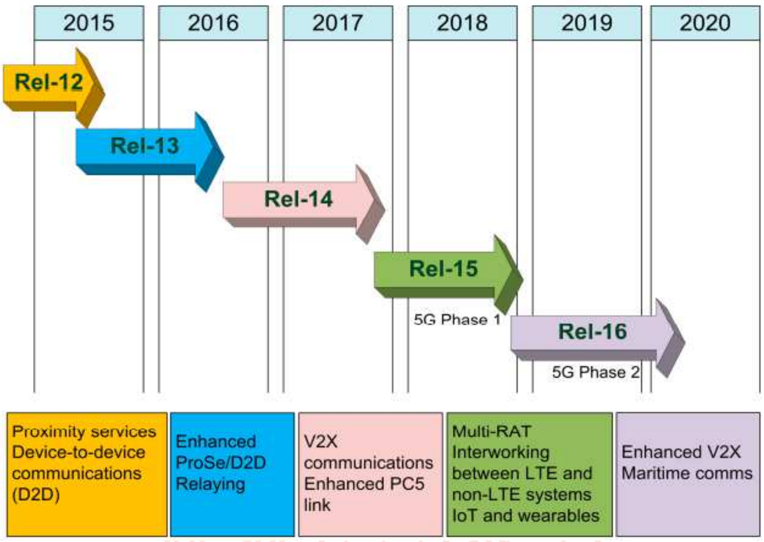

Fig. 3. D2D communications support in 3rd Generation Partnership Project (3GPP) releases; V2X: Vehicle-to-Everything; Rel: Release; RAT: Radio Access Technology.

2. Vehicle-to-Everything (V2X) and Maritime Communications

Another important area for D2D communications is vehicular communications or V2X communications that can be divided into three areas, namely vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-network (V2N) [9]. The V2V and V2I communications towards the other vehicles and roadside units (RSU) are handled through the PC5 interface in 3GPP networks. Connectivity to the network and the cloud (V2N) goes through the Uu interface (Air interface). V2X communications is included first time in Release 14.

Enhanced support for V2X services (eV2X) in 3GPP release 15 will include safety-related V2X scenarios, such as automated and remote driving and platooning, where vehicles form a platoon or a line travelling together [45]. It will also enable extended sensors where vehicles could exchange sensor information locally. A relevant aspect of advanced V2X applications is the level of automation (LoA), which reflects the functional aspects of the technology and affects the system performance requirements. The levels of automation are defined as: 0—No Automation, 1—Driver Assistance, 2—Partial Automation, 3—Conditional Automation, 4—High Automation, 5—Full Automation.

At lower automation levels a human operator is primarily responsible for monitoring the driving environment, whereas in higher layers an automated system is responsible for operations. Similar types of work are going on in the development of automated drones and autonomous and remote-controlled ships [8]. Currently 3GPP is considering and developing systems specifically for maritime communications for release 16 and beyond to support the needs of future maritime users [46]. One of the requirements of this "LTE-Maritime" system is to support 100 km coverage. It will also support the interworking between the 3GPP system and the existing/future maritime radio communication system for the seamless service of voice communication and data communication between users ashore and at sea or between vessels at sea.

3. System Model and D2D Use Cases for Combined LTE/5G and WiFi

Figure 4 presents our high-level system model for D2D communications in a 5G network. There are many types of users that are connected to the base stations using cellular interfaces. Nodes can also communicate directly using D2D communication links between nodes that are in proximity to each other. Direct links between user devices such as phones and laptops may use several RATs, including 3GPP evolution, as described in Section 2, Bluetooth, or WiFi standards. Cars also use a dedicated 802.11p standard in the intelligent transport system (ITS) band in 5.9 GHz for V2X communications. In the future, autonomous and remote-controlled ships will also use more and more ship-to-ship communications, possibly also radios specifically developed for these purposes. Both in the V2X communications among cars and in maritime communications, integrated 5G satellite-terrestrial systems will be needed [8,9].

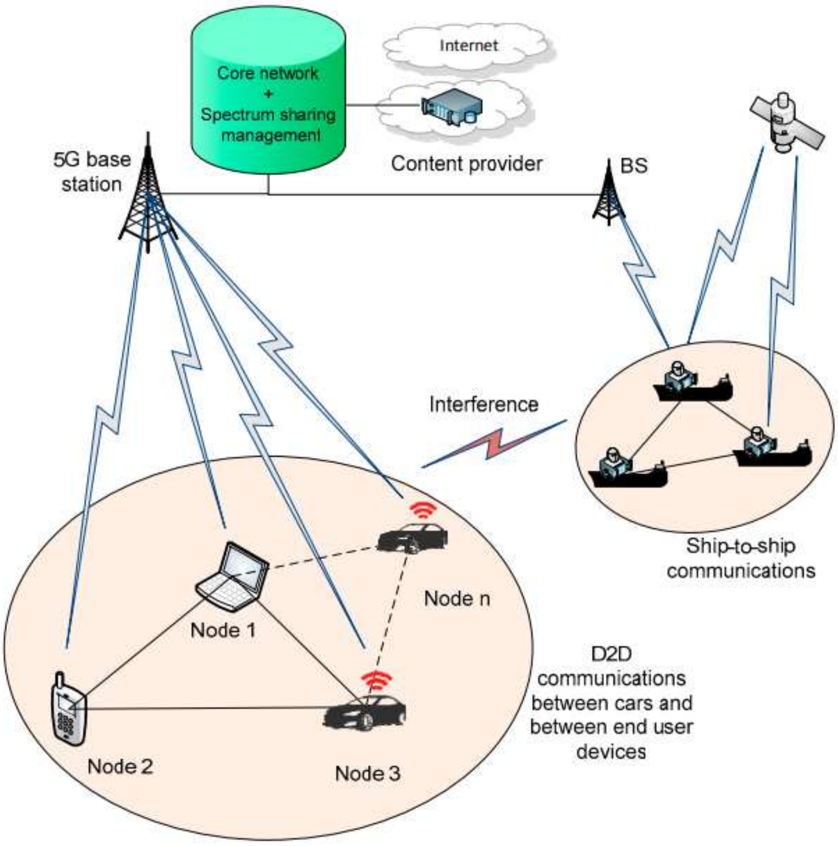

Fig. 4. High-level system model for D2D communications in 5G; BS: Base station.

The system has a connection to the Internet and the connectivity provider to make all the required services available to the end users. The 5G core supports seamless cooperation between different RATs and the terrestrial and satellite segments. It also enables QoS management of data transmission e.g., by dedicating part of the resources to applications with higher priority. There could even be end-to-end network slices dedicated to autonomous driving and other use cases so that QoS requirements can be met in any circumstances via proper resource allocation and isolation mechanisms. Network virtualization and slicing techniques enable different operators to share network resources with other (virtual) operators and to provide end-to-end connectivity across operator boundaries.

As far as D2D communication scenarios are concerned, various new terminologies are defend under 3GPP Release 12 [4, 51]. Some of the most important terms are:

- *ProSe-Enabled UEs:* ProSe-enabled UEs are the UEs which support the requirements and procedures for proximity services as defend in 3GPP Release 12. They may be associated with both public safety and non-public safety applications. The ProSe-enabled public safety UEs can be used for both public safety and other ProSe services, whereas ProSe-enabled non-public safety UEs cannot be used for public safety ProSe services.
- *ProSe discovery*: ProSe discovery is a mechanism in which a UE discovers other UEs in a given proximity using Evolved UMTS Terrestrial Radio Access Network (E-UTRAN). This ProSe discovery can be either open discovery or restricted discovery. In open discovery mechanism, UEs discover each other without any authorization. In restricted discovery mechanism, UEs need to acquire permissions to discover the nearby devices. Similarly, network-assisted ProSe discovery is a mechanism where the mobile network operator verifies if the UE is authorized to discover another UE or not. The assistance is provided by the Evolved Packet Core (EPC) and the mechanism called EPC-level ProSe discovery since the EPC determines and informs the ProSe enabled UEs about their proximity. 3GPP Release 12 also allows network-independent discovery of UEs where they perform the discovery procedure autonomously, without assistance from the network. Therefore, it is useful when both UEs lie outside the network coverage.
- *Switching between two different communication paths*: This is a very important use case of 3GPP Release 12. In this case, the operator can easily switch the user trafc from an infrastructure path to a ProSe communication path. Therefore, all the proximity criteria can be dynamically controlled by the operator.
- *ProSe-Based WLAN and WiFi-Direct*: In this use case, there is a direct communication between ProSe-enabled UEs and WLAN under WiFi-Direct communications. Here, the operator can switch the network session between infrastructure path and WLAN ProSe communication path.

- Apart from public safety, various other use cases for D2D communication are envisaged in the 3GPP standards. We enlist some of them below:
- *Multiuser cooperative communication (MUCC) in HetNets*: a simplified diagram of MUCC is given in Fig. 5. In this case, there are two users categorized as the benefited user and the supporting user. The benefited user lies under a weak network signal, whereas the supporting user is under a strong network signal; the latter helps the former in improving its signal. There are two paths defined, one is from the benefited user to the eNB and another from the supporting user to the small cell. The benefited user and the supporting user communicate with each other using LTE-A D2D communication.
- *D2D offloading*: D2D provides opportunistic data offloading facility that can reduce the overall network overhead. This also allows the network operators to save the spectrum resources and optimize the downlink transmission overhead for the network operators. If one UE with a poor channel conditions identifies a neighboring UE in its close proximity with a good channel condition, the former can offload its data to the latter using D2D communication and data can be relayed further with the help of cellular communication [43, 44].
- *V2V communication and V2X communication (LTE-V):* In 3GPP standardization, D2D-based V2V network is an active area of investigation. A feasibility study has been conducted in Release 13. A vehicle running at high speed can warn nearby vehicles using D2D links before it changes the lane. Depending on the received message, the nearby vehicles can slow down and avoid accidents. Based on the Release 12 side-link communication protocols, Release 14 specified V2X communication in the year 2017. V2X in 3GPP release 14 supports vehicle-to-vehicle (V2V), vehicle-to-pedestrian (V2P), vehicle-to-infrastructure (V2I) and vehicle-to-network (V2N) communication [14]. Both cellular communication and D2D communication are part of LTE-V services. Vehicle platooning, automated and remote driving are some of the extended features of V2X communication supported by 3GPP release 15. In comparison to conventional cellular communication, the LTE-V is somewhat different in terms of deployment and traffic characteristics. Interference coordination, collision avoidance, and efficient resource allocation are some of the biggest challenges in LTE-V communication.
- *Security in data communication:* D2D communication allows uses to receive data that are saved in the nearby trusted UEs. This avoids accessing potentially insecure links to third-party databases like those in the cloud. Hence, it can provide a great deal of security.
- *Machine type communication or MTC*: D2D communication protocols specified in LTE-A 3GPP standards provides a promising solution for MTC. 3GPP Release 13 and above allow cellular operators to multiplex the bandwidth between MTC devices and regular devices [45].
- *Indoor installation and positioning:* Indoor positioning is one of the key features in 3GPP Release 13. Earlier the accuracy level of indoor positioning was low and it was a great concern for the operators. Basically, in indoor conditions multipath propagation is difficult. Therefore, 3GPP is consistently working to facilitate both location service and mission critical voice service on LTE devices based on the ProSe D2D standard.
- *Enhancement of D2D for UE-to-network relaying*: The 3GPP release 15 focuses on the enhancements of D2D communication for network relaying. The main aim is to retain the connectivity between the remote devices like sensors or smart wearable's and the network through a relay-assisted D2D communication.
- *Maritime communication:* Activities on 3GPP Release 16 focus on the development of a maritime communication system known as LTE-Maritime. The overall coverage area will be up to 100 kilometers and there will be seamless communication between the existing 3GPP system and the maritime radio communication system. It will also support voice communication and data communication between different vessels at sea [19]. This inter-vehicular communication can occur using D2D communication technology.

D2D Communication in 5G Networks

Since 3GPP Release 12, 3GPP is publishing a release roughly once a year. As far as 5G mobile systems are concerned, 3GPP is working according to the timeline of International Telecommunication Union—Radio Communication (ITU-R) to complete the standardization process. Currently, 3GPP is focusing on the Radio Access Network (RAN) and the core aspects of 5G. The standardization phase of 5G is divided into two parts. The first part focuses on the deployment requirements and second part focuses on enhancing the capabilities of 5G wireless communication systems. After significant efforts, the first complete set of 5G standards was published in 3GPP Release 15 in the year 2018. It covers the 5G New Radio (NR) system. 3GPP's focus has now shifted to the first stage of Release 16 because Release 15 is mature and near closure. Release 17 work will proceed mainly through the years 2020 and 2021. Some important areas of interaction between 5G and D2D communication are the following.

1. *mmWave communications*: In upcoming 5G cellular networks, mmWave communications is a promising and one of the most emerging technologies. It can operate between 30 GHz and 300 GHz frequency band and thereby offer higher data rate to 5G enabled mobile devices. One of the major demerits of mmWave communications is its shorter wavelength. Due to the shorter wavelength, the difficulty in penetrating the nearby obstacle increases. In such a scenario, however, relay assisted D2D communication can be very helpful. Establishment of a D2D relay between two mobile devices and between mobile devices and a mmWave enabled base station can be done to extend the overall coverage area even if these devices do not have a clear connecting line of sight (LOS) [49]. If D2D communication can be integrated properly with mmWave communication, the overall network capacity can be enhanced.
2. *D2D communication in social networks*: The volume of mobile data will be way higher in 5G communication as of now. The majority of data will be carried on by social networks. Analysis of the social ties, users' similarities and their interest can be helpful in identifying their geographical locations [5]. D2D communication together with the social network can ensure a trusted connection

setup [57]. Data dissemination which is one of the important features of D2D communication can be used in social networks for effective content sharing between the users with similar interest. This can weigh down the load of the BS and can increase the spectral efficiency as well [57]. The combination of D2D networks and social networks can be a great boon for the proximity services in 5G cellular communication [3]. For that purpose, D2D discovery mechanisms could be designed exploit social networks at the application layer.

3. *D2D communication in ultra-dense networks*: Ultra-densification of nodes is expected in 5G cellular networks. Hence, it is considered as one of the major paradigms of 5G communication. In an ultra-dense network, a large number of active small cells will be deployed to increase communication efficiency. To have convenient traffic offloading, D2D communication can be integrated with small cells to reduce the load on the eNB [49].

Conclusion

D2D communication is going to play a major role in the upcoming 5G cellular network. In this article, we have presented a brief overview on the standardization of D2D communication. The standardization is based on 3GPP Release 12 and subsequent releases. We have discussed in detail the architecture, discovery procedure, synchronization, and direct communication technique of D2D communication. We have also highlighted some critical issues in D2D communication. It is expected that D2D communication will play a pivotal role in both public safety and various commercial use cases in future cellular networks.

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