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Review

A survey on device-to-device (D2D) communication: Architecture and security issues

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ABSTRACT

The number of devices is expected to radically increase in near future, with an estimate of above 50 billion connected devices by 2020. The subscribers demand improved data rates, with reduced latency and increased system capacity. To endure the rising demands, cellular networks need to undergo suitable changes. For fulfillment of the rising needs of users and efficient utilization of the available scarce resources, device-to-device (D2D) communication is being looked upon as an important emerging technology for present and future cellular networks. It allows peer-to-peer communication between users, with improved spectral efficiency, energy efficiency and system throughput. In this paper, a detailed survey on device-to-device (D2D) communications has been offered, along with the challenges which exist for D2D (like resource allocation, security, interference management etc.) to become a successful paradigm of wireless networks. In order to fulfill the subscriber needs, architecture has been proposed which assures overcoming the various implementation challenges of D2D communication. The paper largely focuses on security in D2D communication and the possible attacks to which the direct links are susceptible to. For ensuring a secure D2D communication, solution has been proposed, based upon Internet Protocol Security (IP Sec).

1. Introduction

The current cellular network technologies tend to be incapable of meeting the rising subscriber demands. This explosion in demand has been due to popularity of various large bandwidth demanding applications like mobile computing, video streaming etc. It is predicted that by 2020, trillions of wireless devices shall be serving billions of people (Doppler et al., 2011). The overcrowded spectrum triggers research for new technologies for efficient utilization of the spectral resources (Hu and Qian, 2014). As a result, the notion of the fifth generation (5 G) networks is being extensively explored, which is essentially an aggregation of a number of technologies. These networks are expected to support the new usage scenarios. One of the promising technologies, device-to-device (D2D) Communication, is expected to meet the technical goals of the next generation networks (NGNs).

D2D communication refers to direct transmission between proximate devices, without relaying information through the base station (BS). Such a direct transmission improves spectral efficiency, system capacity (Chai et al., 2013) and reduces latency. It facilitates proximity aware services in the cellular networks. Although the functionality of Device to Device (D2D) communication has been neglected in the first four generations of wireless communication (1 G, 2 G, 3 G, 4 G), the network operators nowadays are getting attracted towards the D2D technology, due to the advancing trends (Astely et al., 2013). It also provides an efficient offloading solution to the mobile network operators (MNOs).

For a low energy direct communication between the transmitter and receiver, traditionally, Wireless Personal Area Networks (WPAN), and Wireless local area network (WLAN) technologies have been used. These technologies operate in the license exempt band, providing local services at a low cost. device-to-device (D2D) communication, however, allows a direct transmission in cellular spectrum, greatly enhancing the spectrum utilization. Considering the pitfall of interference, the licensed band is much better than the unlicensed band since interference is controllable due to the involvement of a central controlling entity in the licensed spectrum, the Evolved NodeB (eNB). In case of uncontrollable interference levels, the Quality of Service (QoS) of the network deteriorates, which is not desirable. Apart of uncontrollable interference levels in the license exempt bands, the traditional direct communication technologies also consume more energy, causing faster battery drainage. Thus, D2D communication is a desirable technique for direct communication, under a controlled

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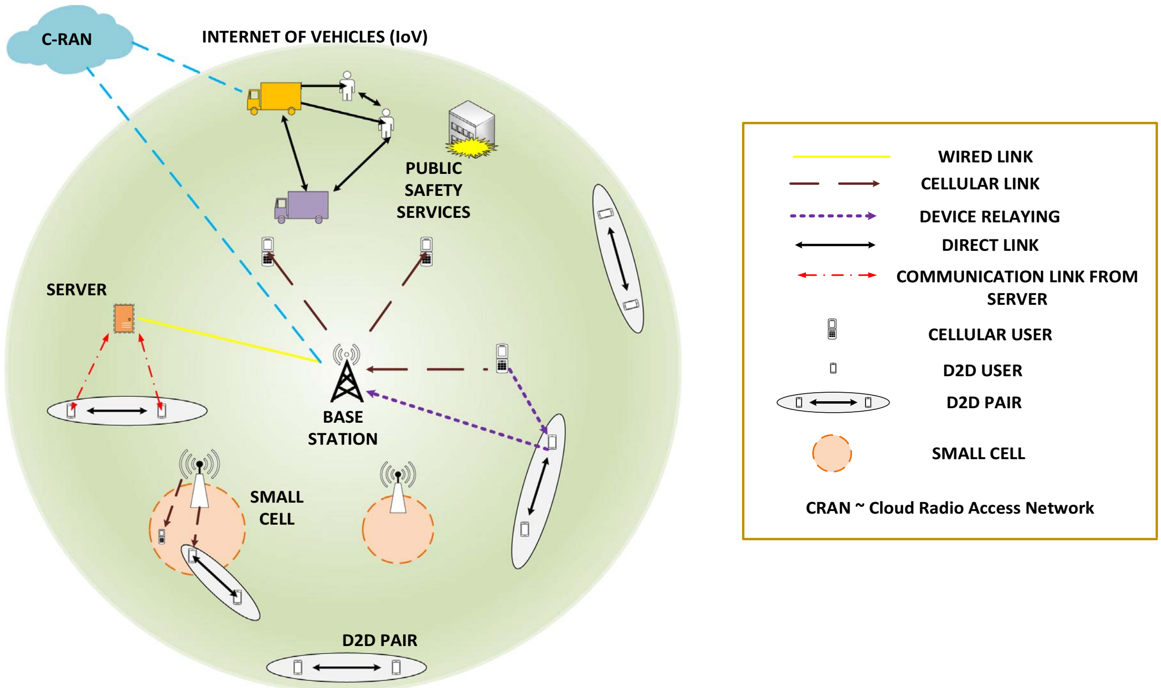

Fig. 1. A General D2D Scenario.

environment, for better network performance.

3GPP is investigating Proximity Service (ProSe) (Jin et al., 2014) for enabling direct communication between proximate devices. Various use cases of D2D and its feasibility is discussed in 3GPP TR 22.803 (2012). Enabling D2D communication in cellular networks requires certain architectural enhancements, which are investigated upon in 3GPP TR 23.703 (2013). FlashLinQ (Wu et al., 2010) from Qualcomm propose PHY/MAC architecture for D2D networks. A comprehensive survey on the standardization of D2D communication (3GPP Release 12) has been provided in Lien et al. (2016), which includes architectures, discovery procedures, mobility, channels and signals.

Numerous services can be associated with D2D communication, like, mobile cloud computing, cellular data offloading, disaster management, etc. A general scenario of device-to-device (D2D) communication in cellular networks is depicted in Fig. 1. The figure depicts various use cases of device-to-device (D2D) communication in a single cell, with the base station at the centre. Vehicle-to-vehicle (V2V) communication with Internet of Vehicles (IoV), public safety services, offloading of cellular traffic from the base station, etc. are depicted in the figure. The Cloud Radio Access Network (CRAN) in the 5 G networks supports flexible network architecture. It centralizes the network functionalities, as per the application to be serviced. For 5 G cellular networks and beyond, small cells in conjunction with D2D communication, can serve as effective means of enhancing coverage and enabling traffic offloading. As D2D communication allows sharing of local content, without multiple base station requests, proactive caching (Pappalardo et al., 2016) has been introduced, to reduce load on the backhaul networks. Caching can be performed at the base station, or at the user terminals, communicating over direct links (Gregori et al., 2016). A careful caching strategy in device-to-device (D2D) communication can greatly enhance Quality of Experience (QoE) (Bai et al., 2016).

Though D2D communication allows direct communication between proximate devices and supports improved network performance, its implementation involves number of concerns. For setting up of direct links, the users need to discover each other. The discovery mechanisms are being widely studied. There is a very high probability of interference between D2D users and cellular users, within the cellular network. Resources must be available to the D2D users for carrying out communication over direct links. Transmission range can be enhanced with the placement of relays in a D2D scenario. Assuring security in the D2D communication thus becomes essential, as relays and rest of the communicating devices, are susceptible to eavesdropping attack, jamming attack, etc. All these issues need special attention.

1.1. Contributions

Existing surveys on D2D communication have been complemented, and the missing pieces of information have been brought up in this survey. An inclusive overview of 5 G technology is provided in Dohler and Nakamura (2016). In Asadi et al. (2014a), an extensive literature is available on device-to-device (D2D) communication, with focus on various under-explored and over-explored areas of research in D2D communication. The authors of Liu et al. (2014) bring about a detailed survey of the existing research in this field, mentioning about the various experimental prototypes, applications of D2D communication and its open research areas. The authors in Mach et al. (2015) present a detailed survey on device-to-device (D2D) communication, primarily focusing on Orthogonal Frequency Division Multiplexing Access (OFDMA) which is being considered for the future 5 G networks. Architectural, business and technical aspects of D2D communication have been explained in Mumtaz (2014) comprehensively. Network assisted multi hop, full duplex and multi-antenna D2D have been reviewed in Fodor et al. (2016). The authors argue that the challenges of the information society beyond 2020 can be effectively met through a proper combination of cellular and adhoc technologies. Architecture has been proposed for the next generation networks in Pimmy and Rakesh (2016).

In this paper, an exhaustive literature on device-to-device (D2D) communication has been studied and thoroughly reviewed. There is a lot of scope in this field for propelling the researchers all over the globe to switch toward the D2D technology. A few important algorithms, pertaining to the various issues in device-to-device (D2D) communication have been discussed. This paper has also shown a suitable network model which is an integral part of basic resource allocation strategy. But the prime focus of the paper is on the proposed architecture for

Table 1
Comparison of wireless technologies.

S No.	Feature Considered	3 G	4 G	5 G
1.	Approach Used	Network centric	Network centric	Device Centric
2.	3GPP Releases	Release 4,5,6	Release 8,10,11	Release 12,13
3.	Access Methodology	CDMA	OFDMA/SC-FDMA	SCMA, BDMA, FBMC
4.	Approx Latency	100–150 ms	Upto less than 5 ms	Less than 1 ms(Zero Latency)
5.	Carrier Frequency	0.8/ 0.85/ 0.9/ 1.8/1.9/ 2.1/ 2.6/3.5/ 5.8 GHz	1.8/2.3/2.5/ 2.6/3.5 GHz	1.8/2.6 GHz, and expected 30–300 GHz
6.	Mobility (in Km/h)	300–350	300–350	500 (Alliance, 2015)
7.	Offloading Technique	Bluetooth, WLAN	LIPA, SIPTO, Small Cells (Yang et al., 2013)	Small Cells, D2D communication
8..	Resource Utilization	Poor	Better	Highly efficient
9.	Support for Energy Harvesting	No	No	Yes
10.	Relay Support	No	Yes	Yes
11.	Carrier Aggregation	No	Yes	Yes

D2D communication in the next generation networks (NGNs). This paper has also contributed towards security by proposing a solution concept for securing D2D communication using Internet Protocol Security (IP Sec). Various security attacks on D2D have been briefed in the survey, with particular emphasis on jamming attack (Section 5).

The paper is organized as follows. Following the introduction, a brief journey through the generations of wireless communication has been presented in Section 2, describing the onset of device-to-device (D2D) communication in the cellular networks. Fundamentals of device-to-device (D2D) communication have been discussed in Section 3, which includes the essential basic architecture, different types of D2D communication, channel models and performance metrics for D2D communication. In this section, architecture has been proposed for D2D communication in next generation networks (NGNs), and it aims to optimally fulfill all the demands of the subscribers and the requirements of the service providers in near future. The key issues in D2D communication are discussed in Section 4. Security in D2D communication, and a proposed solution for securing the direct links is discussed in Section 5. D2D is expected to support a large number of applications in the next generation cellular networks, which are discussed in Section 6. In spite of being such an important technology, few research challenges exist in its implementation, as discussed in Section 7. Eventually, the paper concludes in Section 8.

2. Evolution of device-to-device (D2D) communication through the generations

Wireless communication has evolved from the first generation (1 G) to the fourth generation (4 G), and to counter the demands of the subscribers, the fifth generation (5 G) networks will be soon available. Cellular communication began with the introduction of the first generation (1 G) of wireless communication. In 1 G, only analog cellular technology was used. Digital cellular came into existence in the Second Generation (2 G). Until this time, no direct communication between users had been introduced. It was due to lesser number of subscribers and their demands being limited only to voice and data. Direct communication came with the introduction of wireless personal area network (WPAN) and wireless local area network (WLAN) technologies in the third generation (3 G) networks. These technologies allowed content sharing in the unlicensed band only, at low cost and low energy consumption. However, interference levels were uncontrollable and no Quality of Service (QoS) guarantees could be provided, due to the license exempt band operation. Also, it involved higher power consumption. Due to the massive growth in the traffic and changing trends, direct communication in the licensed band started gaining popularity for the 4 G networks (Long Term Evolution Advanced, LTE-A), and beyond. A detailed discussion on the evolution of the generations of wireless communication has been provided in Akhil and Rakesh Jha (2015).

The need for the next generation networks arouse given that the network society of 2020 and beyond is expected to undergo an explosion in the data traffic (Cisco, 2014). Mobile video traffic is expected to account for more than 70% of the total data traffic by 2018. A key component technology of the fifth generation (5 G) networks is device-to-device (D2D) communication. The first four generations have been network centric, but 5 G is heading towards device-centric network architecture. Network centric means base station was the sole controlling entity in the network. With the advancement in wireless industry, there has been an increase in the small cell deployments. The trend is thus shifting towards user-centric (device centric) networks, in which the user is expected to actively perform storage, relaying, computation and content delivery, which was earlier being performed by the network (the base station (BS)). D2D communication enhances coverage, cost efficiency, reliability, capacity density and spectrum efficiency. A brief comparison of the generations of wireless communication supporting direct communication has been presented in Table 1. Efforts are on the run to integrate D2D communication to the existing cellular networks.

3. Fundamentals of device-to-device (D2D) communicaion

Traditional cellular communication allows communication between user equipments (UEs) through the base station (BS), but the UEs may be in range to carry out direct communication. It means communication between the UEs is possible without traversing the core network. Such a communication results in improved spectral efficiency, energy efficiency, reduced delay and enhanced throughput. Additionally, data traffic is drastically increasing due to the content being shared by the users, demanding large bandwidth, and high data rates. To serve the requirements of the subscribers, D2D communication plays an essential role. D2D enables merging ad hoc and centralized networking. Taking benefit of ad hoc network, D2D communication can be used in conjunction with other technologies like cooperative communication, cognitive radio, Internet of Things (IoT), to enhance the spectral efficiency. With centralized networking, D2D communication helps in overall enhancement of the network performance, having the control from the operator.

From the architecture point of view, D2D networks look similar to Mobile Ad-hoc Networks (MANETs), and Cognitive Radio Networks (CRNs), but in actuality, there exist some differences. Numerous issues related to MANETs and CRNs can be resolved in D2D communication, as a result of the presence of a central controlling entity, the base station (BS). Distinguishing users as primary or secondary is possible with D2D communication and CRNs (Cheng et al., 2012), as a result of which both can be treated as similar technologies but, CRNs function autonomously and use cognitive sensing (Ejaz et al., 2011), which is not supported by D2D communication. Machine-to-machine (M2M) communication also seems to be similar to D2D communication but it is application oriented, unlike D2D, which primarily focuses on proximity connectivity services. The M2M communication does not contribute towards enhancement of spectral efficiency, however D2D communication does.

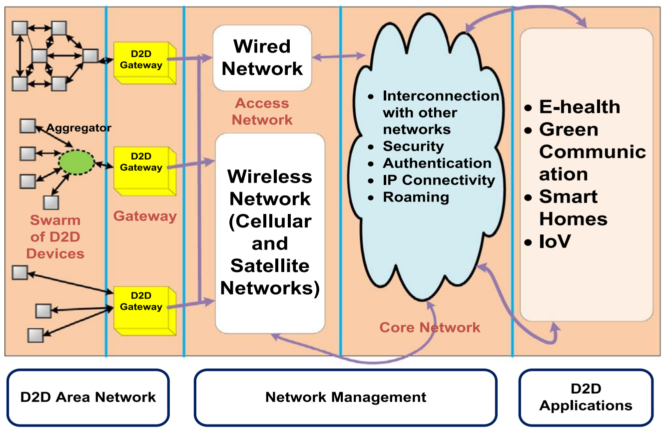

Fig. 2. Fundamental Network Architecture for D2D communication.

With D2D communication underlaying cellular networks, content sharing by a large number of users is possible by setting up of local caching and sharing zones. This supports network management in a distributive manner. Also, relaying of data is possible with device-to-device (D2D) communication. Device-to-device (D2D) communication has been identified as a key enabler for various 5 G services, by the METIS research project. As identified by METIS (Li et al., 2014), device-to-device (D2D) communication can be utilized in a number of scenarios, depending upon the requirements. These have been listed below as per the needs:

- For backhaul applications, D2D-B
- For critical applications, D2D-C
- For direct D2D, without involvement of the core network D2D-D
- For direct M2M communication, D2D-M
- For non-critical applications, D2D-N

A complete overview of the METIS project is available in Dohler and Nakamura (2016) and Fodor et al. (2016). METIS 5 G concepts are evaluated in detail and their significance with D2D communication is presented.

3.1. Fundamental network architecture

The basic network architecture of D2D communication is divided into three parts (Alkurd et al., 2014): area network, network management and D2D applications. The fundamental architecture is depicted in Fig. 2. A large number of devices, communicating with each other via direct links form a part of the D2D area network. Aggregators are available in the network architecture, which collect the data from all the D2D devices and after aggregation, connect to the core network. Thereafter, the data is sent to the gateway, which connects to the access network. The access network can be wired or wireless. The devices are connected to the service providers from the core network.

In order to enable working of D2D communication in the cellular networks, new functionalities need to be added to the existing structures. Certain enhancements in the LTE-Advanced (LTE-A) architecture (Technical Specification Group Services, 2014) can enable the functioning of D2D communication in the existing cellular networks. Architecture supports for the next generation networks is described in Lien et al. (2016) and (Yang et al., 2013). Another modified LTE-A network, to support D2D communication has been discussed in Raghothaman et al. (2013), with the introduction of D2D server in the system. But security of communication must be ensured.

3.2. D2D types

Device-to-device (D2D) Communication enabled 5 G cellular networks are considered as a two-tier network, where the tiers are the macro cell tier and device tier. The macro cell tier involves the conventional cellular communication, through the base station (BS). The device tier, on the other hand, involves direct communication between the devices (D2D communication). The base station can have different levels of control in the device tier network, which maybe full or partial, or no control at all. As a result, device to device (D2D) communication can be categorized into four types, depending upon the degree of involvement of the base station in assisting the communication between devices (Tehrani et al., 2014), and are discussed below.

Case (i) ***Device Relaying with base station assisted controlled link***.

A device in an area of poor coverage or at the cell edge can communicate with the base station by relaying information through other devices. The allocation of resources and setting up of call in such a scenario is done by the base station (BS). Also, interference can be avoided between devices as a result of the centralized control. This enhances the battery life of the device.

Case (ii) ***Direct communication between devices with base station assisted controlled link***.

The source and the destination devices communicate with each other directly, with the base station (BS) assisting them for link establishment by providing the control links. The BS primarily deals with access authentication, connection control, resource allocation and interaction between devices.

Case (iii) ***Relaying device with device assisted controlled link***.

The source and destination communicate with each other via relays. The entire communication is controlled and managed by the devices themselves, thus eliminating the role of the base station in the communication process.

Case (iv) ***Direct D2D with device assisted controlled link***.

The source and destination devices communicate directly, without provision of any control links from the base station at all. Thus, these devices must be careful with respect to the management of interference within the device tier and, also with the macro cell tier. Before starting the transmission of data, the devices need to find each other (device discovery) and then communicate. All these types are depicted in Fig. 3.

Another classification of D2D communication is on the basis of the spectrum (licensed/unlicensed) accessed by the D2D users. When device-to-device (D2D) communication occurs on the licensed spectrum, it is referred to as inband D2D and on the unlicensed spectrum, outband D2D (Asadi et al., 2014a, 2014b). The inband D2D can be categorized as underlay or overlay. Underlay D2D uses the cellular spectrum for cellular communication as well as for device-to-device (D2D) communication, while, in overlay, a dedicated portion of the entire spectrum is used for device-to-device (D2D) communication. Outband D2D communication can be autonomous or controlled. It is said to be controlled when the radio interfaces are coordinated by the base station, even though the direct communication is occurring in the unlicensed band. For autonomous D2D, these interfaces are coordinated by the users themselves. For outband D2D communication, devices thus need two wireless interfaces, like LTE and Wi-Fi. The interfaces can be Wi-Fi Direct (Alliance, 2010), Bluetooth (Bluetooth, 2001), Zigbee (Alliance, 2006). This categorization of D2D is shown in Fig. 4. Coexistence of number of modes increases complexity of the system (Asadi et al., 2014b). As a result, the mode i.e. spectrum accessible by the D2D devices should be decided, taking into consideration the overall system conditions. Different types of D2D communication (inband/outband) have their pros and cons. A comparison between these has been given in Table 2.

Majority of the available literature on device-to-device (D2D) communication is based on underlay inband D2D. It is efficient for enhancing spectral efficiency, coverage area and other targets for better performance of cellular networks.

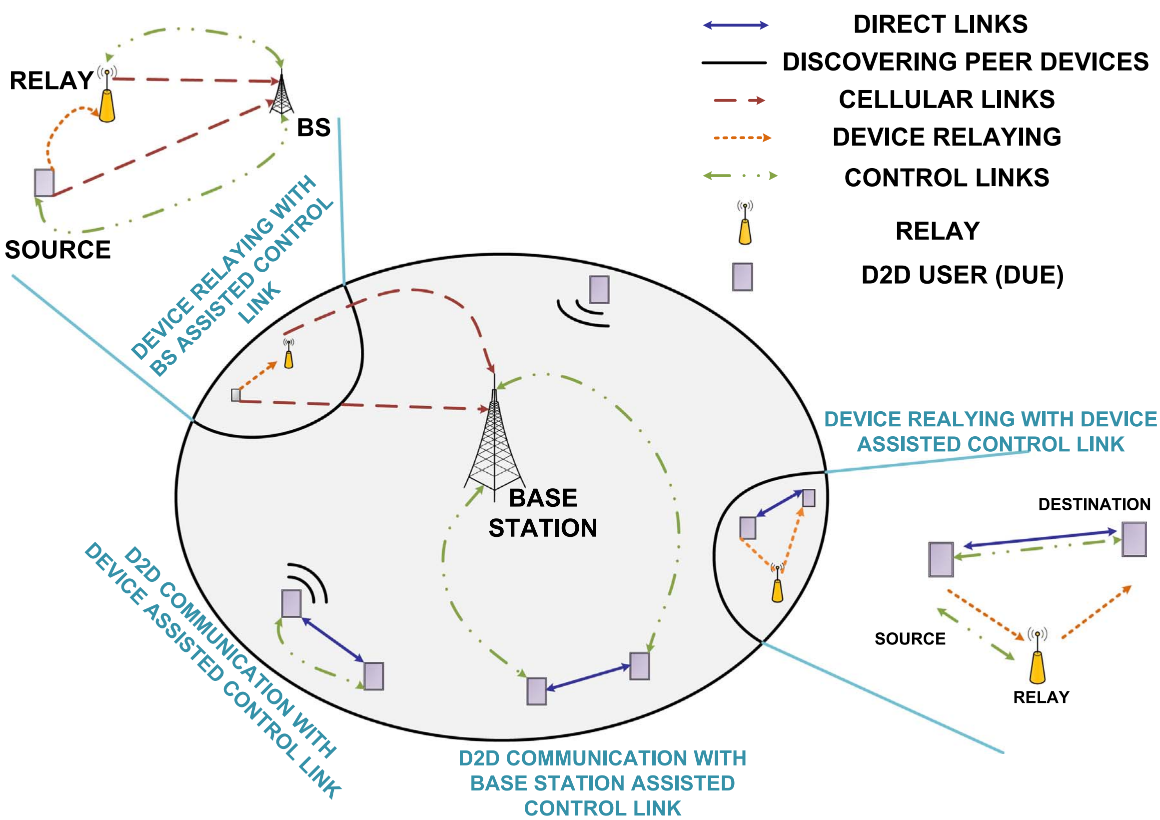

Fig. 3. Types of D2D Communication, on the basis of involvement of base station.

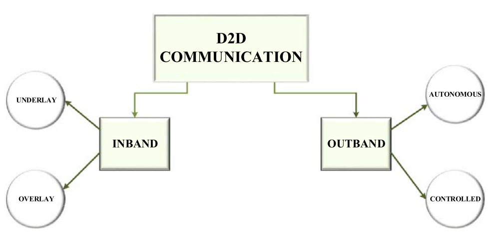

Fig. 4. Types of D2D Communication (based on spectrum access).

Table 2
Comparison between inband and outband D2D.

Inband D2D	Outband D2D
Exploits spatial diversity, resulting in enhanced spectral efficiency	Does not result in improved spectral efficiency
Base station control results in better QoS management	No control from the base station, thus, no support for better QoS management
High level of interference between D2D communication and cellular communication and among D2D users	Interference problem overcome due to operation of cellular and D2D communication in different bands
No extra interface like Wi-Fi needed by the device	Devices require an extra interface, thus two interfaces needed by a device for its successful operation
High possibility of resource wastage	Easier resource allocation, and no wastage caused
No coding/decoding involved, as only a single interface is used	Coding and decoding of packets is essential as different interfaces use different protocols

1) Proposed Architecture

Due to increase in the number of subscribers and their demand for high data rates, channels available in a cell become insufficient. This requires more number of channels proportionate to the coverage area. Cells are split into sectors, with the use of directional antennas at the base station. Sectoring may divide the cell into three 120° sectors or six 60° sectors. This makes them more efficient and greater number of calls can then be handled at the same time. It is an effective technique for initiating improved signal-to-interference-plus-noise ratio (SINR) and reducing co-channel interference. Architecture consisting of directional antennas at the base station, dividing the coverage area into three sectors of 120° each is proposed (Fig. 5). This architecture is proposed in view of the rising traffic scenario and deployment considerations of the next generation networks (NGNs).

It is a suitable architecture for servicing users that are located in congested areas or at the cell edges. The users within each sector are distinguished as cellular users (CUEs) and D2D users (DUEs). The distance constraint, $D \leq d_0$ determines whether two user equipments (UEs) form a valid D2D pair or not. Here, D is the distance between the D2D transmitter and D2D receiver and d_0 is the threshold distance. Resource allocation to the D2D users and cellular users is addressed, in this proposal.

As shown in the figure, we explain its working by considering a single sector only. The total scheduling period of the base station is given by Ts, in which time slots shall be allocated to both, the D2D users and the cellular users. Prior to allocating time slots to the users within a sector, the number of D2D users and cellular users are determined. As the number of D2D users will be less than the number of cellular users within a network, time slots are first allocated to the D2D users. In the proposed architecture, we consider three D2D pairs and six cellular users in a single sector, which are being considered for time slot allocation. The resource allocation is adaptive. Adaptive time slots are allocated to the D2D users, on the basis of the application demanded by them, which may be video, voice or text application. Of these applications, maximum length of time slot will be required by video application, followed by voice and text, respectively. As depicted in Fig. 5, the adaptive time slot allocation is made to the D2D pairs, on

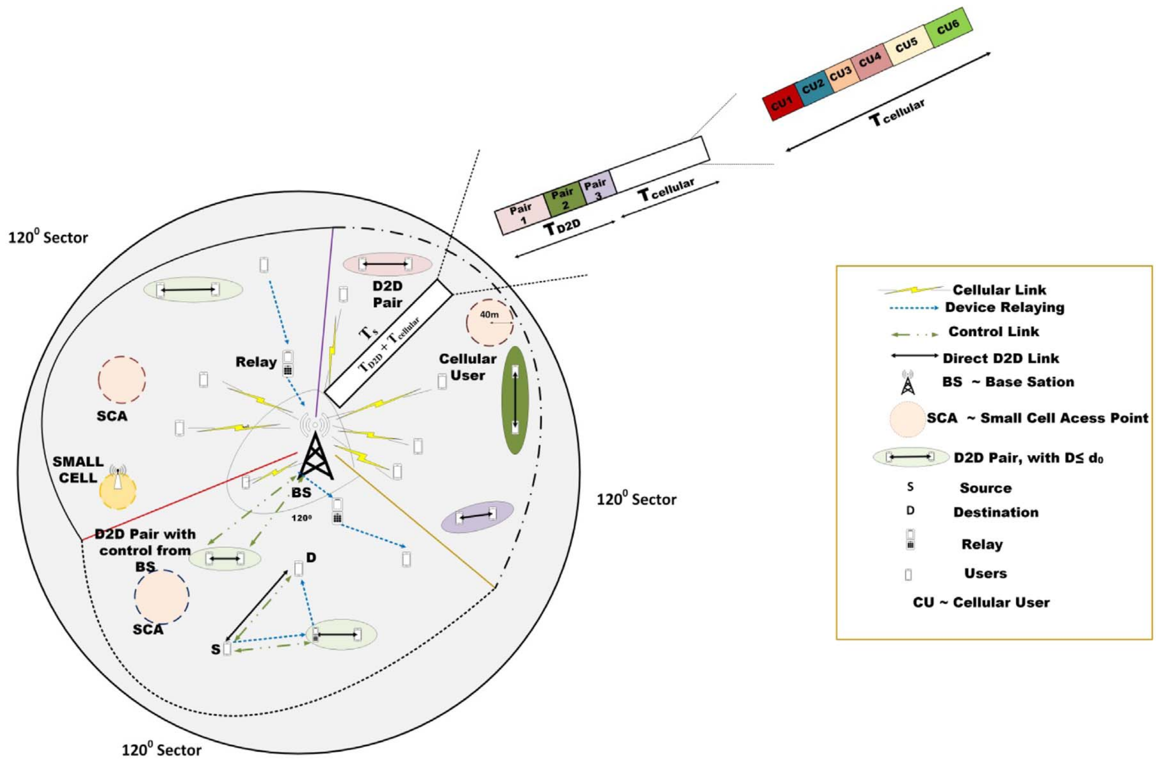

Fig. 5. Proposed aArchitecture.

the basis of the applications demanded by them. Pair 1 demands a video application, being allocated the largest size time slot of all the three. Pair 2 demands voice application, allocated a comparatively smaller sized time slot. Pair 3 demands a text application, allocated with the minimum sized time slot. This time, used by D2D pairs is denoted by $T_{D2D.}$ At another instant, these pairs may demand a different application, thus, will be allocated suitable sized time slots then. Such an adaptive time slot allocation is performed using the Hidden Markov Model (HMM). After allocating time slots to the D2D users, time slots are adaptively allocated to the cellular users from the remaining time duration. This allocation of time slots to the cellular users is also adaptive, based on the applications (video, voice and text) they demand. The simulations for such a resource allocation can be performed in MATLAB. The time allocated to cellular users is denoted by $T_{Cellular}$.

The architecture targets throughput maximization, latency minimization, and better Quality of Service (QoS). It is an effective solution for overcoming the various open issues in D2D communication. With the proposed approach, resources are shared between the two types of users (CUEs and DUEs). Since D2D communication allows direct communication between proximate users, power consumed is less. As a result, this architecture can optimize the overall power of the network. This proposed architecture is capable of performing direct communication between devices efficiently, thereby improving the overall network performance and satisfying subscriber demands. The primary focus of the architecture remains optimal resource allocation, so as to meet the subscriber demands in the most efficient manner. No single possible architecture can be clearly defined for D2D communication. This fact becomes clear from Jin et al. (2014), Asadi et al. (2014b) and Rêgo and da (2012). Choice of architecture is dependent on a number of factors like, coverage extension, energy efficiency, Quality of Service, and other architecture related issues.

3.3. Channel models for D2D communication

As discussed, there are different types of D2D communication and on the basis of these types, different channel models exist. Channel modeling and measurements includes three steps: channel measurement, raw data processing and channel modeling and simulations. The existing channel models of cellular networks cannot be used in D2D communication directly. The suitability of channel models, in D2D scenarios are discussed in Cheng et al. (2015) and different channel models for D2D have been presented in Table 3. These consider indoor-to-indoor (I2I), outdoor-to-outdoor (O2O), line-of-sight (LOS) and non-line-of-sight (NLOS) scenarios. The authors categorize the channel models as deterministic or stochastic. The need for new channel models in D2D communication is the fact that in D2D communication, both the transmitter and receiver can be mobile and they may be shadowed by human body.

D2D channel modeling is affected by path loss and shadow fading. A fast fading channel generation method has been proposed in Kim and Oh (2014), based on Doppler frequency response and, the InternationalTelecommunication Union-Radio(ITU-R) channel model is extended to the D2D channel. The Doppler effects and scattering are taken into consideration on both the sides, the D2D transmitter as well the D2D receiver. Double ring channel models have been proposed for direct communication in Patel et al. (2005), and depicted in Fig. 6. This model assumes use of an Omni directional antenna at the transmitter as well as the receiver. The model considers the existence of uniformly spaced scatters at both the ends, i.e. transmitter as well as receiver. This is a mathematically convenient model. Such a model is particularly useful for simulating scattering environments, but computational load is high. A D2D model with Rician fading channel has been investigated in Peng et al. (2014). In Li et al. (2015), a three-dimensional two-cylinder model has been proposed for D2D communication. From this model, more realistic results can be achieved. New channel models need to be evaluated, in order to realize the complete potential of D2D communication. A number of challenges related to channel modeling for D2D communication have to be dealt with, and is an area of open research.

Table 3
D2D channel models (Cheng et al., 2015).

S. No	Scenarios/Properties	Authors/ Organizers	Channel Models
1.	Indoor to Indoor (I2I)	3GPP COST IEEE 802.11 Berg Recursive	InH Mode lDual stripe model (MBPGM) COST 231 model (MBPGM) 802.11 model (MBPGM) I2I model (MBPGM)
2.	Outdoor to Outdoor (O2O)	3GPP ITU-R P.1411-6 Berg recursive	ITU UMi Model Xia model (MBPGM) O2O model (MBPGM) O2O model (MBPGM) I2O model (MBPGM)
3.	Vehicle to Vehicle (V2V)	D. W. Matolak, M. A. Ingram etc. J. Maurer etc. X. Cheng etc. A. F. Molisch etc.	MBPGM Geometry-based deterministic models Regular-shaped geometry-based stochastic models Irregular-shaped geometry-based stochastic models
4.	Line of Sight/Non Line of Sight (LOS/NLOS)	3GPP ITU-R P.1411-6	ITU UMi Model InH model (MBPGM) O2O model (MBPGM)

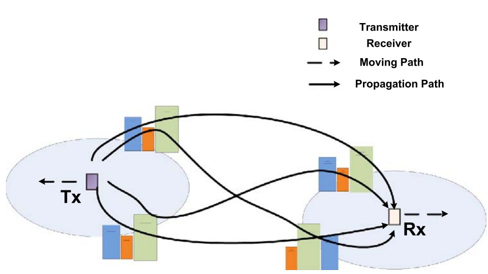

Fig. 6. Double Ring channel model for D2D communication.

3.4. Performance metrics

In this section, a set of commonly used performance metrics for D2D communication have been briefly discussed. These are mostly related to the SINR (Signal-to-interference-plus-noise).

1. **System throughput**: It is defined as the overall throughput of all D2D pairs and cellular users within a cellular system. A higher value of throughput signifies better performance of the algorithm. It is measured in bits/sec. It is an indicator of successful information transfer between the pairs.
2. **D2D User Capacity**: For any resource allocation algorithm, D2D user capacity is the number of DUEs that can be accommodated for a given set of cellular users in the network, subject to the maximum data rate constraint. A higher user capacity value is always desirable.
3. **Fairness**: This is a very critical indicator of evaluating how fair a given scheme is (generally resource allocation), for D2D communication. Measurement of fairness is decided by the fairness index.
4. **Secrecy Rate:** It is an important parameter to evaluate the secrecy performance of a network. It can be seen as analogous to the traditional channel capacity, subject to secrecy constraints. Secrecy rate maximization is a prime agenda in cellular networks.
5. **Mean Opinion Score (MOS):** It is used to evaluate the performance of a cellular network, in terms of the Quality of Experience. The range of MOS lies between 1 and 5. Values close to 5 are desirable. It signifies excellent quality of information.
6. **Latency:** It is an indicator of the delay between transmission and reception of information. D2D communication generally results in lower latency, due to transmission over a small distance.
7. **Energy Efficiency:** It is the ratio of the system throughput to the power consumption per unit area. It is an indicator of the efficient energy (Battery power) utilization within a cellular network.
8. **Spectral Efficiency:** The number of bits transmitted per unit bandwidth indicates the spectral efficiency. It is essential for quantification of the D2D network performance.

This section touches upon various essential aspects of D2D communication. These fundamentals are essential for any researcher, for investigating various research aspects of D2D communication. This new emerging technology is paving way for a very efficient cellular architecture, but, redressing some of the issues is critical, for its practical implementation. These have been discussed in the next section. Of all the open challenges, security in D2D communication is a rising concern at present, and has been extensively studied in Section 5.

4. Key issues in D2D communication

In order to enhance the network performance by using D2D communication, a number of issues have to be dealt with. Some important issues have been discussed in this section, each using a different analytical tool and evaluation method to support efficient D2D communication in cellular networks. The methods proposed for resolving the open issues mostly have a limited scope and achievable performance. The challenges which have been listed below include peer discovery and mode selection, radio resource management, interference management, power control, and security.

4.1. Peer discovery and mode selection

To establish potential direct links between the devices, the user equipments (UEs) need to identify their neighbors. Exploring opportunities for peer discovery within the cellular networks is essential for the sustenance of D2D communication underlaying cellular networks. Prior to setting up of the communication link, the UEs can detect each other by transmission of beacons. A number of approaches exist in literature, for device discovery and link set up between the D2D users. In Feng et al. (2014), the authors propose two techniques of device discovery: restricted discovery and open discovery. In case of restricted discovery, the UEs cannot be detected without their prior explicit permission thus maintaining user privacy. In case of open discovery, UEs can be detected during the duration for which they lie in proximity of other UEs. Device discovery may be controlled by the base-station tightly or lightly as discussed in Fodor et al. (2012) and Lei et al. (2012). Peer discovery can furthermore be either distributed, or centralized. In distributed approach, a UE broadcasts beacons to the other devices in the network (Corson et al., 2010). In Centralized approach, the process of discovery is managed by a single entity or many entities, which check for devices in proximity and authenticate the setup of direct links (Lei et al., 2012). Both have their merits and limitations.

From the perspective of the User Equipment (UE), energy requirement for supporting D2D communication is more. The authors of Hong et al. (2013) propose an energy-efficient technique for discovering devices in proximity and establishing D2D links. The simulation results

Table 4
Different methods of peer discovery for D2D communication and their comparison.

Reference No.	Technique for device discovery	Objectives			
		Easy discoverability	Reduced latency	Energy efficiency/ power efficiency	Throughput enhancement
(Feng et al., 2014)	Restricted or Open Discovery	×	✓	×	×
(Hong et al., 2013)	Energy-efficient device discovery	×	×	✓	×
(Tang et al., 2014)	Sound Referencing Signal for neighbor discovery	✓	✓	×	×
(Zou et al., 2014)	• Bluetooth Discovery • WiFi Device Discovery • WiFi Direct Device Discovery • IrDA Device Discovery • Network Assisted Discovery • Packet and Signature-based Discovery • Request Based Discovery • Direct Discovery	✓	×	✓	×
(Nguyen et al., 2014)	Network Assisted Discovery Technique	✓	×	×	×
(Chao et al., 2013)	Bio-inspired Proximity Discovery	✓	✓	×	×
(Pratas and Popovski, 2015)	Network assisted proximity discovery	×	✓	×	✓
(Ngo and Kim, 2015)	Time Advance proximity discovery	✓	×	✓	×

show trade-off between the delay and energy consumption of the network. The energy consumption in idle state of the UEs is less than in the connected state. After discovery, though, the delay across the link is longer in the idle state, than in the connected state, with a maximum value of 5 msec in the connected state. The authors of Tang et al. (2014) address the neighbor discovery problem. Using the sounding reference signal (SRS) channel, neighbors are discovered. Uplink transmissions of cellular users play an important role in finding the neighbors. Neighbor discovery under unknown channel statistics is also considered. Maximum delay in a single discovery cycle is computed as 4 μsec. The authors in Zou et al. (2014) provide a review of the techniques for proximity discovery. Existing techniques have been discussed like Bluetooth discovery, Wi-Fi (AD Hoc) Device Discovery, IrDA Device Discovery, following which Request based discovery, Direct Discovery, Packet and Signature-based Discovery and Network-Assisted discovery have been identified as different discovery mechanisms for device-to-device (D2D) communication in cellular networks. An effective network-assisted technique for device discovery has been proposed in Nguyen et al. (2014) for the support of device-to-device (D2D) communication in LTE networks. The results show that a very high probability of device discovery exists in this technique for a certain discovery interval. Yet, network assisted D2D communication can take place without device discovery at the device side, as network itself can detect the presence of a device in proximity.

A bio-inspired discovery technique is proposed in Chao et al. (2013), where proximity signals are transmitted and detected by the devices to accomplish proximity discovery. Firefly spanning tree algorithm has also been proposed in Chao et al. (2013), in order to overcome problems associated with various other topologies, for device discovery. The authors in Pratas and Popovski (2015) propose a network assisted proximity discovery protocol in which cellular users act as monitors or announcers to listen to, or broadcast the information of interest within the proximity region. This protocol is highly efficient in terms of energy. Another device discovery mechanism has been proposed in Bagheri et al. (2015), considering the near far effect. An efficient time advance method for peer discovery has been proposed in Ngo and Kim (2015) which compute the distance between the UEs in the cellular network. As a result, this method is based on simple geometry. A novel peer selection approach to assign a direct link to a D2D pair has been proposed in Namvar et al. (2015), exploiting context information about user mobility and size of data demanded. A summary of these methods is with a comparative analysis is given in Table 4. A sequence of steps involved in the setup of direct links is depicted in Fig. 7.

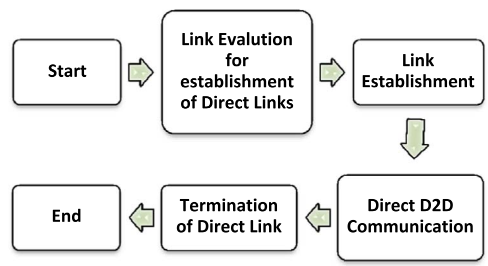

Fig. 7. Steps Included in Direct Link Setup and direct communication.

After the completion of peer discovery, the UEs need to set up sessions. There are two methods for session set up, named IP based detection and dedicated D2D signaling. D2D users require optimal amount of resources for supporting the communication over direct links. The links must not interfere with the ongoing cellular communication also. As seen, in this section, a number of peer discovery techniques for device-to-device communication have been discussed. The objective of discovery not only remains finding the communicating partners, but energy efficiency, security, interference should also be taken care of. Optimal resource allocation and interference management are discussed next.

4.2. Radio resource allocation

The objective of introducing D2D communication in cellular networks has been to improve the spectrum utilization. Resource allocation deals with allocation of frequency resources to the D2D pairs, within the cellular networks. This allocation must be optimal for functioning of D2D networks underlaying cellular networks, and meet the objectives of this emerging technology. Once device discovery is complete, using a comprehensive discovery mechanism (Mumtaz, 2014), resource allocation has to be performed. Different modes of resource allocation exist for D2D communication: cellular mode, dedicated mode, mode supporting reuse of resources of a single cellular user (CUE) and mode supporting reuse of resources of multiple cellular users. There is no interference problem in the first and second mode as they involve utilization of orthogonal resources, but these two modes maybe inefficient to maximize the overall network throughput. The other two modes suffer interference because of resource sharing with cellular users. Yet, maximum resource utilization is achieved through reuse mode only. The radio resources are allocated using centralized or distributed techniques, in D2D communication. Centralized techniques result in increased complexity in case of large networks, supporting a large number of UEs. In these techniques of resource allocation, resources are allocated to the D2D users and cellular users by the base station (BS). Distributed techniques, on the other hand, decrease the device complexity, and reduce interference with the cellular networks. Some distributed techniques of resource allocation in D2D communication is studied in Zhang et al. (2013), Song et al. (2014), Kuang et al. (2015), Zhang et al. (2013), and Mohammed and Hossain (2014). In cellular networks, information like channel gains, SINR measurement etc. are uncertain and time-varying. Robust resource allocation can then deal with optimization problems under such circumstances, and can model the uncertainties by ellipsoids, polyhedrons and D-norm methods (Kai et al., 2008). A number of resource allocation algorithms have been proposed by the researchers for efficient utilization of the spectrum. Hybrid solutions can also be provided and are an open area of research. An effective hybrid technique is discussed in Lee et al. (2014).

In Zhou et al. (2013), intra cluster retransmission scheme has been proposed for efficient resource utilization A Heuristic Location Dependent Resource Allocation Algorithm has been proposed in Botsov et al. (2014) and resource pooling in Fodor et al. (2012). Taking into consideration the spectral efficiency of LTE-A networks, (Phunchongharn et al., 2013) proposes a resource allocation technique. It minimizes the transmission length of the D2D links on increased power consumption. An NP-Complete problem is formulated (Garey and Johnson, 1979) as a Mixed Integer Programming problem and a column generation method allocated resources optimally, supporting low complexity. In Koskela et al. (2010) and (Hakola et al., 2010), the authors target the Signal-to-Interference-plus-Noise ratio (SINR). The authors (Feng et al., 2013) provide a method for overall throughput improvement and enhancement in spectral efficiency through power allocation and admission control. A general resource scheduling problem is investigated in Asadi et al. (2014b).

In Gjendemsjo et al. (2006), Chandrasekhar and She (2008), non-orthogonal resource sharing is discussed, considering the maximum transmit power constraint of the user devices. The authors of Wang et al. (2011) propose an optimal resource allocation technique that is able to significantly improve the sum throughput of D2D communication as well as the cellular communication, in a network. In order to improve the overall network throughput and user satisfaction ratio, the authors of Chen et al. (2015) introduce a time-division scheduling algorithm for efficient utilization and allocation of resources, using non-orthogonal sharing mode. In Liu et al. (2013), the authors propose a semi-persistent resource reuse algorithm in inter cell as well as intra cell scenarios for improvement of throughput of the network. The authors of Yu and Tirkkonen (2012) introduce a rate splitting based resource sharing algorithm, in which the message being transmitted is divided into a public part and a private part. The private part of the message can be decoded only by the receiver for which it is intended. The public part is available to all receivers. In comparison to other algorithms, it is possible to achieve higher sum rate with rate splitting mode. A dynamic resource allocation scheme has been proposed in Liu et al. (2015) with joint beamforming, routing and flow control. It is an efficient method for reducing the signaling overhead, and the overall latency.

The authors of Lin et al. (2013) aim at maximization of the system throughput, considering the minimum data rate requirement. To obtain the solution, particle swarm optimization (Kennedy, 2010) method is used. D2D communication underlying cellular network is considered, and the results show that the system performance can greatly improve with this technique of mode selection and resource allocation. A two-phase resource allocation scheme for D2D communication underlying cellular networks has been proposed in Le (2012). The first phase performs optimal resource allocation, on the basis of the technique used in Kim et al. (2006). The second phase uses a heuristic sub channel allocation scheme, which takes into consideration, the minimum data rate constraint for resource allocation. The incentive resource allocation scheme is proposed in Sun et al. (2015). It introduces energy efficiency, as an incentive parameter and stimulates cooperation among users. For the users needing cooperation, DUE relays maximize the received signal-to-noise ratio (SNR) first. Then, the resource allocation problem is formulated for two users and finally solved using a two-dimensional search method. A semi-control resource scheduling algorithm has been proposed in Wang et al. (2013), in which the boundary of the resource-assignment and resource-contention area is adjusted dynamically. A proportional fair scheduling (PFS) technique is used for resource allocation, and maintaining overall fairness of allocation. The simulation results show that the performance of this algorithm is far better than round-robin scheduling. The authors of Zheng et al. (2015) propose an adaptive time division scheduling algorithm which also is based on proportional fairness algorithm for adaptively scheduling D2D pairs. For reduction of delay, wireless caching with D2D is a smart choice. A resource allocation scheme, based on social interaction is addressed in Wu et al. (2016), for improvement of the system efficiency. Heuristic algorithms for dynamic resource allocation have been investigated upon in Belleschi et al. (2015).

A radio resource management scheme for V2X communications has been formulated in Sun et al. (2016). As V2X communications adhere to strict latency and reliability requirements, an NP hard optimization problem is formulated, to enable robust resource allocation. Optimal resource allocation for improving the delay performance of VANETs has been discussed in Cao et al. (2016). Packet lifetime is checked periodically by each vehicle, and D2D links are setup, if needed. An optimal receiver vehicle is selected for the establishment of D2D links. The effectiveness of the proposed algorithm is validated by simulation results. Resource allocation techniques for applying D2D communication in VANETs have been discussed in Weijun et al. (2014) also, which support high density of vehicles.

The authors of Ciou et al. (2015) propose a Greedy Throughput Maximization plus (GTM+) algorithm for resource allocation. It considers multi-sharing resource allocation in cellular networks containing D2D links. GTM+, which is an iterative algorithm, maximizes throughput by taking into consideration conflict graph and maximal weight independent set. The system performance is better with the GTM+ algorithm, compared to other algorithms, in terms of system throughput, percent D2D pairs permitted, and running time. The authors of Chen et al. (2014) propose a distributed resource allocation and power control strategy for resource allocation to enhance the system capacity. A brief overview of some of the mentioned algorithms has been given in Table 5. Different algorithms proposed by the various researchers target optimization of various parameters. This has been depicted in Table 6, which clearly depicts the particular parameter maximized for every algorithm.

On the basis of a comparative analysis of the various algorithms discussed so far, we have observed that compared to other well known schemes, (Lin et al., 2013; Liu et al., 2013) (Particle Swarm optimization and Semi-Persistent Scheduling) have provided the best performance. Taking throughput as the parameter of comparison, a comparison of some of the discussed algorithms has been shown in Fig. 8. Other parameters for comparison of the algorithms can be: D2D access rate, user satisfaction ratio, spectral efficiency, energy efficiency etc (as shown in Table 6). From the graph, it is clear that for the same simulation parameters, maximum system throughput is achieved by Lin et al. (2013).

Hence, it is one of the most efficient resource allocation algorithms of available in literature.

Any resource allocation strategy needs to follow a sequence of steps, for optimal allocation of resources and throughput maximization. These have been depicted below, by using a simple network model

Table 5
Algorithms for resource allocation in device-to-device (D2D) communication.

Ref. No.	*Algorithm*	*Description of algorithm*	*Objective met*
(Zhou et al., 2013)	Intra cluster D2D retransmission scheme	A D2D retransmission scheme (intra cluster) where cooperative relays are adaptively get selected through multicast retransmissions, exploiting the multichannel diversity	Optimal resource utilization and enhancement of retransmission throughput
(Botsov et al., 2014)	Heuristic Location Dependent Resource Allocation algorithm	A cellular offloading and capacity enhancing solution for D2D communication underlaying cellular networks, by application of persistent resource allocation a vehicular network supporting D2D communication; the algorithm involves strict QoS requirements	Reduced signaling overhead and minimal interference with the primary network
(Phunchongharn et al., 2013)	Column generation method	A heuristic algorithm that Detection of maximum number of active D2D links, using a heuristic approach; The links must be capable of transmitting simultaneously in every time slot and satisfy the constraints of the access pattern	Enhanced spectral efficiency and reduced transmission length of the D2D links on increased power consumption
(Feng et al., 2013)	Admission control and power allocation	Admission control performed followed by power allocation to admissible D2D pairs and its cellular user partners. Then maximum weight bipartite scheme for finding suitable D2D pair for each CU	To improve spectral efficiency, and overall throughput of the network
(Chen et al., 2015)	Time Division Scheduling (TDS) Algorithm	Base station's entire scheduling time divided into fixed number of time slots, with a balanced allocation of the D2D pairs in the slots using a location dispersion principle in order to avoid interference	Improve system throughput and D2D user satisfaction ratio
(Liu et al., 2013)	Semi-Persistent Scheduling (SPS) Resource Reuse Algorithm	Uplink resources are utilized by the D2D users, to minimize interference within the cellular networks(inter cell as well as intra cell interference)	Reduced interference levels with improved system throughput
(Yu and	Rate Splitting	Han-Kobayashi rate	High per user

(continued on next page)

Table 5 *(continued)*

Ref. No.	*Algorithm*	*Description of algorithm*	*Objective met*
Tirkkonen, 2012)	Based Resource Sharing Algorithm	splitting is used and the algorithm coordinates communication between the UEs when the distance between them is large. The interfering links in the transmission between DUEs are coordinated using Successive Interference cancellation (SIC)	spectrum efficiency is achieved.
(Lin et al., 2013)	Particle swarm optimization resource allocation	Joint mode selection and resource allocation for enabling flexible reuse of cellular resources by DUEs, based on particle swarm optimization (PSO-MSRA), guaranteeing minimum rate requirements of UEs	To maximize system throughput, while guaranteeing minimum data rate requirement
(Le, 2012)	Two-phase resource allocation Scheme	Takes into consideration sub channel allocations for cellular flows in the first phase and D2D flows in the second phase	Optimal resource allocation with efficient exploitation of the spectrum
(Sun et al., 2015)	Incentive resource allocation algorithm	Three step resource allocation scheme: relay selection, setup of two-user case, and finally solving resource allocation problem by two-dimensional search	Optimization of energy efficiency, with cooperation among UEs
(Wang et al., 2013)	Proportional Fair Scheduling Resource Allocation Scheme	A scheme considering central-controlled D2D network in which boundaries of resource-assignment and contention areas are dynamically adjusted	To increase system throughput and maintain fairness among D2D pairs
(Zheng et al., 2015)	Adaptive Time division Scheduling Algorithm	Fixed length time are considered in which D2D pairs are scheduled adaptively on the basis of proportional fairness algorithm	Higher system throughput and better fairness in comparison to other existing algorithms.
(Ciou et al., 2015)	GTM+ Algorithm for resource allocation	Multi-sharing resource allocation algorithm which allows any CUE to share its resources with multiple DUEs	To maximize system throughput, and number of permitted D2D pairs
(Chen et al., 2014)	Distributed resource allocation and power control algorithm, with stackelberg game	Resource allocation and power control are jointly optimized. A stackelberg game model is used to	Significant improvement in system capacity, with high convergence of the distributed

(continued on next page)

Table 5 *(continued)*

Ref. No.	*Algorithm*	*Description of algorithm*	*Objective met*
	framework	solve the optimization problem	algorithm
(Fodor et al., 2012)	Resource Pooling Algorithm	Allows resource reuse between D2D and cellular users, taking advantage of hop gain	Enhanced throughput and better spectrum utilization

Table 6
Comparative analysis of resource allocation algorithms (Comparing Performance Metrics).

Ref No.	Parameter optimized			
	System throughput	Spectral efficiency	Energy efficiency	Fairness ratio
(Fodor et al., 2012)	✓	✓	×	×
(Zhou et al., 2013)	✓	×	×	×
(Botsov et al., 2014)	✓	×	×	×
(Phunchongharn et al., 2013)	×	✓	✓	×
(Feng et al., 2013)	✓	✓	×	×
(Chen et al., 2015)	✓	×	×	×
(Liu et al., 2013)	✓	×	×	×
(Yu and Tirkkonen, 2012)	×	✓	×	×
(Lin et al., 2013)	✓	×	×	×
(Le, 2012)	×	✓	×	×
(Sun et al., 2015)	×	×	✓	×
(Wang et al., 2013)	✓	×	×	✓
(Zheng et al., 2015)	✓	×	×	✓
(Ciou et al., 2015)	✓	×	×	×
(Chen et al., 2014)	✓	×	×	×

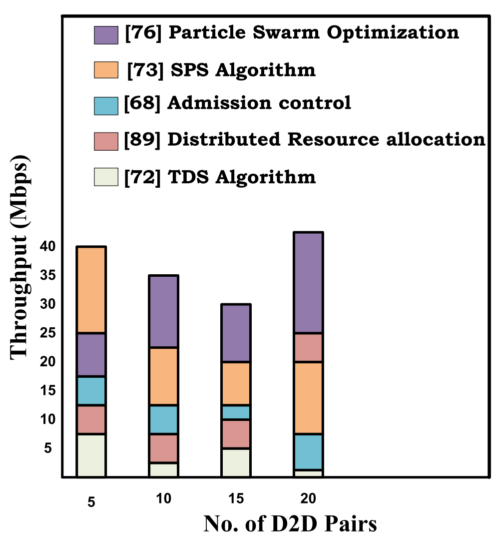

Fig. 8. Comparison of Throughput of Different resource allocation algorithms.

and mathematical equations.

1) Network model

A single cell scenario with the base station at the centre is considered having n number of D2D pairs and m number of cellular users (Fig. 9). In D2D underlaying cellular communication networks, interference between the CUEs and DUEs is high. This is controlled by the base station, acting as a controlling entity. A path loss model is

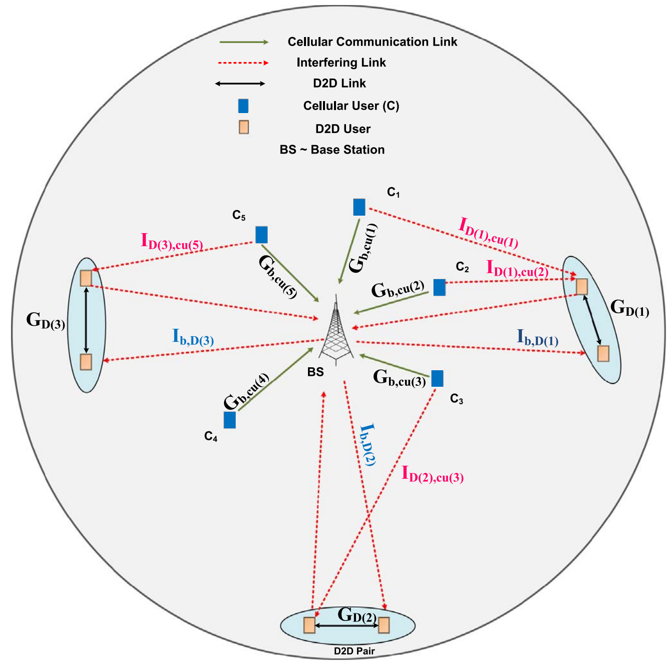

Fig. 9. Network Model.

considered with fast fading as a result of multipath propagation and slow fading as a result of shadowing. All D2D pairs have a cellular reuse partner, for sharing of resources. *Rij* represents the resource reuse indicator, having a value 0 or 1. The system is assumed to have the same number of resource blocks as the number of cellular users.

Taking the channel gain between base station and *ith* cellular user as $G_{b,\ cu(i)}$; channel gain between a D2D transmitter and receiver (pair *j*) as $G_{D(j)}$; the interference link gain from the base station (BS) to *jth* D2D pair as $I_{b,D(j)}$, and gain of interference link from *jth* D2D pair's receiver to *ith* cellular user be $I_{D(j),\ cu(i)}$, the network model is characterized by the following set of equations. The transmission power of the i^{th} cellular user and *jth* D2D pair are denoted by $P_{cu(i)}$ and $P_{D(j)}$, respectively.

For setting up of D2D pairs in a cellular network, the minimum SINR requirements need to be fulfilled. The interference caused to the cellular users must be less than the threshold, to ensure a balanced cellular network performance. The SINRs of i^{th} cellular user and j^{th} D2D pair are given as

$$_{cu(i)}=\frac{P_{cu(i)}\quad G_{b,cu(i)}}{\sigma_0 + \quad P_{D(j)}\quad R_{ij}I_{D(j),cu(i)}} \tag{1}$$

$$_{D(j)}=\frac{P_{D(j)}\quad G_{D(j)}}{\sigma_0 + \quad P_{cu(i)}\quad R_{ij}I_{D(j),cu(i)}} \tag{2}$$

where *Rij* € {0,1}, such that.

Rij=1 when *jth* pair shares resources with *ith* cellular user, otherwise 0.

The minimum SINR requirements for the D2D pair and cellular user within a network are stated as,

$$_{D(j)} \quad \geq \quad ^{min}_{D} \tag{3}$$

$$_{cu(i)} \quad \geq \quad ^{min}_{cu} \tag{4}$$

In order to ensure fulfillment of these SINR conditions, when no resources are shared between D2D users and cellular users, minimum transmission power of the cellular users must be

$$P^{min}_{cu(i)} = \frac{^{min}_{cu}\sigma_0}{G_{b,cu(i)}} \tag{5}$$

Similarly, for the D2D user, the minimum transmission power is

Table 7
Symbols used in network model.

Symbol	Meaning
$G_{b,\ cu(i)}$	Channel gain between the BS and cellular user
$G_{D(j)}$	Channel gain between the D2D pair
$I_{b,D(j)}$	Channel gain of interference link between BS and D2D pair
$I_{D(j),\ cu(i)}$	Channel gain of interference link between i^{th} Cellular user and j^{th} D2D pair
$\acute{\varepsilon}_{cu(i)}$	SINR at *ith* CU
$\acute{\varepsilon}_{D(j)}$	SINR at *jth* D2D pair
${}^{min}_{D}$	Minimum SINR required for a D2D pair
${}_{cu(i)}$	Minimum SINR required for a cellular user
$P^{min}_{cu(i)}$	Cellular user's minimum transmission power
$P^{min}_{D(j)}$	D2D pairs minimum transmission power
$\Gamma_{cu(i)D(j)}$	Throughput of *ith* cellular user after sharing resources with *jth* D2D pair
$\Gamma_{cu(i)}$	Throughput of *ith* cellular user not sharing resources with D2D pair
Γ_{D2D}	Overall System throughput
σ_O	Noise Power on each channel

given as

$$P^{min}_{D(j)} = \frac{{}^{min}_{D}\sigma_0}{G_{D(j)}} \tag{6}$$

When a cellular user does not share any resources with the D2D pair, then throughput is represented as,

$$\Gamma_{cu(i)} \quad = \quad \log_2\ (1 + \ {}_{cu(i)}) \tag{7}$$

When *ith* cellular user share resources with j^{th} D2D pairs, the throughput is given by,

$$\Gamma_{cu(i),D(j)} \quad = \quad \log_2\ (1 + \ {}_{D(j)}) + \quad \log_2(1 + \ {}_{cu(i)}) \tag{8}$$

Thus, overall system throughput is given by

$$\Gamma_{D2D} \quad = \quad \Gamma_{cu(i),D(j)} - \Gamma_{cu(i)} \tag{9}$$

Optimal resource allocation to the D2D pairs underlying cellular network can be achieved by maximizing the throughput gain of the system, which can be stated as the following optimization problem

$$\mathbf{argmax}\,\Gamma_{D2D} \tag{10}$$

for all i € m and j € n.

The various symbols used in the described model are given in Table 7.

4.3. Power control and optimization

As stated in the network model, controlling power of UEs is essential for efficient resource utilization. Blindly applying D2D communication to cellular networks can result in degradation of system performance. The D2D users need to limit their power so that the SINR requirements of the cellular users can be effectively met. Controlling power is the key to mitigating interference between the users in a cellular network (Min et al., 2011). The overall system capacity can be enhanced by limiting the transmit power, as discussed in Nguyen et al. (2014), in case of D2D communication in MIMO networks. Due to limited battery capacity, energy efficiency is critical to be achieved. For improved system performance, few power control methods have been reviewed in Wen et al. (2012), Dongyu Wang and Wang (2013). A low complexity algorithm has been proposed in Wang et al. (2014), which considers game-theory as its basis. The source selection and controlling power levels of the links are decided using the game theory. In this, the Stackelberg game model is used to demonstrate the impact of improvement in the quality of D2D transmission quality. For a multicast D2D communication, joint power and channel allocation is proposed in Meshgi and Zheng (2015), using a maximum weight bipartite matching scheme along with a low complexity heuristic algorithm. Efficient spectrum utilization is not addressed in this technique and needs further investigation. For context aware resource allocation, an energy efficient algorithm has been proposed in Zhou et al. (2016), based on nonlinear fractional programming and Lagrange dual composition. A number of power control strategies, applicable to D2D communication are studies in Fodor et al. (2013). LTE power control scheme is applied to a hybrid cellular D2D network and then compared with a distributed power control scheme. The LTE power control scheme is highly flexible, as stated by the simulation results. A distributed power control scheme, aiming utility maximization, is proposed in da Silva et al. (2014). Mode selection and resource allocation constraints are taken into account for balancing spectral efficiency and energy efficiency. It is an important algorithm for maximization of proximity, reuse and hop gains, as well as for extending cellular coverage. The proposed algorithm is efficient for D2D networks which do not employ traditional mode selection schemes and power control schemes.

A near optimal low complexity scheme for power control has been proposed in Song et al. (2015). In Lee et al. (2015), two types of algorithms are proposed for power control: centralized and distributed. These are effective for coordinating the interference in D2D underlaid cellular networks. A distributed scheme for controlling power in D2D communications has been proposed in Fodor and Reider (2011). It considers a D2D underlay scenario and is an efficient technique for minimizing the overall power consumption. Using Augmented Lagrangian Penalty Function (ALPF) method, optimal SINR targets are achieved in this algorithm. For energy efficient D2D communication, a power control algorithm has been framed as a non-convex optimization problem in Jiang et al. (2015). Remarkable improvements are attained with this algorithm, in terms of energy efficiency. In Tang et al. (2015), power control is considered in a D2D scenario in which the entire problem is divided into two parts: mitigating co-channel interference by allocating channel from graph perspective; link assignment (LA) and power control (PC) are jointly optimized. For optimization of LA, genetic algorithm (GA) is used. A single cell scenario resulting in an optimal power control is considered and evaluated in Yu et al. (2009). A binary power control (BPC) scheme is proposed in da Silva and Fodor (2015), in which the resources of a single CUE are shared by multiple DUEs. BPC does not involve any iteration and is much simpler, providing optimal transmits powers. A power control scheme for supporting vehicle-to-vehicle (V2V) communication in D2D networks has been proposed in Ren et al. (2015). Mobility of devices affects the efficiency of the system, in terms of energy, and is addressed in Wu et al. (2014). For maximizing energy efficiency, a distance based mobile association algorithm is proposed in Xiao et al. (2016), for D2D enabled HetNets. This scheme effectively meets the trade-off between energy efficiency and complexity. A hybrid power control scheme has been proposed in Belleschi et al. (2015) which interference to the cellular users, by the D2D users is limited by utility optimal scheme. The sum transmission power is minimized, while maximizing the spectral efficiency. A summary of different power control techniques in D2D communication is given in Table 8.

Since the UEs are battery operated, energy efficiency is also a major concern. A survey of energy optimization in the next generation networks has been presented in Abrol and Kumar Jha (2016), focusing upon the rising need for green communication. The tradeoff between saving the device battery and achievable QoS of the network must be maintained. Efficient power optimization can be achieved using massive MIMO (Gupta and Kumar Jha, 2016). A fast converging power control scheme for D2D Massive MIMO systems has been evaluated in Xu et al. (2016). Some guidelines for energy efficient D2D architectures have been provided in Zhang et al. (2015), in which energy efficient technologies have been discussed from different aspects, and provide a good platform for researchers to ahead in the direction of energy efficient D2D networks.

In Fig. 10, the graph depicts a comparison between the transmis-

Table 8
Power control algorithms in D2D communication.

Reference No.	Algorithm	Description	Objective
(Wang et al., 2014)	Game theory based power control scheme	Stackelberg game model is used for selecting source and controlling the power	Improvement in the D2D transmission quality
(Song et al., 2015)	Joint Power and Rate control for D2D communication in cellular networks	Maximize the sum rate of the cellular users in the network, guaranteeing Quality of Service (QoS) of D2D communication at the same time	Coexistence of both cellular and D2D users contributing towards improving system throughput
(Lee et al., 2015)	Centralized and distributed power control algorithms using stochastic geometry	Centralized power control ensures sufficient coverage probability of cellular users and distributed method maximizes sum rate of D2D links	Improved throughput performance of cellular users achieved
(Fodor and Reider, 2011)	Distributed Power Control Scheme	ALPF method is used , with optimal SINR target, to control the user equipment power	Minimize the overall power consumption of the network
(Jiang et al., 2015)	Joint resource allocation and power control technique	Penalty function approach is adopted for power control in the network; the problem is formulated as a non-convex optimization problem, and solved using a two-layer scheme	Maximizing energy efficiency of the network
(da Silva and Fodor, 2015)	Binary Power Control Scheme	A simple algorithm achieving near optimal utility , efficiently supporting a large number of D2D pairs in the cellular network	Improve spectral efficiency and power efficiency
(Xiao et al., 2016)	Distance based mobile association Scheme	Access point selection, mode switching, relay selection and power control, all are considered and basis of this technique is the location of UEs in the network	Better tradeoff achieved between energy efficiency and complexity, in comparison to other techniques
(Xu et al., 2016)	Revised Graph coloring based pilot allocation	A fast converging algorithm proposed to overcome pilot contamination by limiting D2D transmission power. It is an optimal choice for practical considerations.	Considerable reduction in pilot overhead

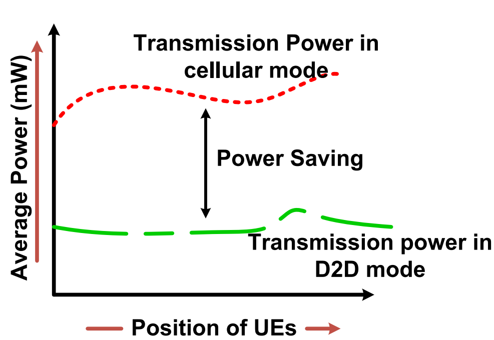

Fig. 10. Power saving in D2D mode.

sion power of UEs in cellular as well as D2D modes, with respect to their positions within a cellular system. With D2D communication underlaying cellular networks, there is considerable power saving in the cellular network, as depicted. This benefit of D2D communication has been investigated upon by the various algorithms discussed above. Thus, overcoming the challenge of power control in device-to-device (D2D) communication is essential for the overall power optimization in the network.

4.4. Interference control

Device-to-device (D2D) communication, a competent technology for the next generation networks (NGNs) promises lower delay, lower transmission power, increased system capacity, etc. Integration of D2D technology with cellular networks results in interference, due to the sharing of same resources between them. When the cellular downlink resources are shared by the D2D users, the cellular users and their neighbors suffer interference. The receiver of the D2D pair is also susceptible to counter interference by the base station.

When sharing cellular uplink resources, the base station suffers interference by the D2D users. Interference between D2D users and cellular users may be intercell or intracell and needs to be mitigated for proper functioning of D2D communication in cellular networks. The existing interference management schemes are not capable of interference mitigation in the next generation networks. A survey, along with a comparison of various existing schemes has been provided in Hossain et al. (2014), suggesting guidelines for modification of the various schemes and efficiently deal with the next generation networks.

Interference mitigation is possible through proper mode selection, optimum resource allocation and power control of the devices. The various approaches for interference mitigation are categorized into three types:

- *Interference Cancellation Techniques*, which use advanced coding and decoding methods for cancellation of interference signals at the CUE or DUE. Interference cancellation techniques have the ability to enhance the capacity of cellular networks.
- *Interference Avoidance Techniques*, which avoid interference between cellular links and D2D links by using orthogonal time-frequency resource allocation techniques.
- *Interference Coordination Techniques*, which mitigate interference between D2D and cellular links with power control schemes and proper scheduling.

A number of algorithms have been proposed to overcome the problem of interference in D2D underlaid cellular networks. Interference management is studied in Guo et al. (2015), by considering the Interference suppression area's range. Adjusting the interference suppression area adequately provides an optimal system performance. Interference aware interference mitigation methods in D2D communication have been discussed in Kwon et al. (2014), where the interference information is known to the UE by the base station or through a blind estimation. It is an efficient technique for improving the system throughput. Another interference aware scheme has been proposed in Janis et al. (2009), based on Hungarian algorithm and aims at maximization of the number of permissible D2D pairs. The authors in Yin et al. (2015) propose an interference coordination scheme by joint spectrum allocation and power control. This scheme guarantees Quality of service to the D2D users as well cellular users. An interference cancellation technique has been proposed in Zhou et al. (2015), where authors maximize the utility of the network by considering transmission powers of users in the network. In Xiao et al. (2011), the authors propose a technique for interference reduction by a power optimization scheme.

Most of the existing literature on D2D communication exclusively focuses on single-antenna systems. However, in the next generation networks, multi-antenna deployment will gain importance. MIMO transmission schemes are introduced for interference avoidance, in Jänis et al. (2009), which results in a considerable SINR improvement. In Ni et al. (2016) D2D system underlaying cellular networks is analyzed for interference cancellation, as well as beamforming, with the base station equipped with multiple number of antennas. The users however are equipped with a single antenna. Ergodic process is adopted for analysis of such a system, along with some suitable approximations. The results of ergodic achievable rates are very close to Monte-Carlo results.

In order to achieve the required cell edge capacity in the next generation networks, advanced interference management schemes are crucial. With inter cell inference becoming common in D2D underlaid cellular networks, a promising approach to overcome this are cooperative communication. This fact is exploited in Shin et al. (2013), which propose an interference mitigation scheme, D2D communication assisted interference alignment. A realistic multi-cell scenario has been considered in Batista et al. (2015), to propose an interference mitigation technique for D2D communication. A large amount of literature is thus available on interference management in D2D communication. An extensive survey on interference management in device-to-device (D2D) communication has been presented in Mach et al. (2015), Noura and Nordin (2016). If the interference is not managed properly, it can hamper the performance of cellular networks. Effective interference management strategy can result in enhancement of the overall capacity of cellular networks (Min et al., 2011). Advanced D2D receivers can be used to mitigate interference. However, some challenges exist for interference cancellation (Halperin et al., 2007). Forward error correction (FEC) decoding and error recovery can cancel interference in D2D networks and are an efficient technique for interference management in the future networks. The heuristics related to interference need to be explored. An overview of some of the important existing algorithms for managing interference in D2D scenarios has been provided in this section. Still, this issue remains an open challenge for the researchers. There is a promising future research direction in this field.

4.5. Security in D2D

In conventional cellular communication, the UE is first identified, authenticated and then encryption of the radio link occurs. The core network is a trusted party. But this is not the Case in D2D communication as transmission occurs without the assistance of the core network. Also, wireless channels are broadcast in nature. As a result, they are susceptible to a number of attacks, making security an important concern. Cryptographic solutions are needed to secure the information, when it passes through the wireless channels. The security schemes provided by the cellular operators can be used by the D2D users if they are under their coverage. But, users outside the coverage of the operators can't be secured. In such a case, security signals may be passed on through relays. It is well known that relays are highly susceptible to malicious attacks; therefore, designing security schemes for D2D communication is an important challenge to be addressed. Cha et al. (2009), Yue et al. (201), Perrig et al. (2004), Zhou et al. (2008), Muraleedharan and Lisa (2006) discuss about the security concerns in D2D communication. Security in D2D has been discussed in detail in the following section (Section 5).

5. Securing D2D communication

Facilitating D2D communication in cellular networks is beneficial, in terms of throughput enhancement, energy consumption, etc. In spite of the extensive ongoing research in the field of D2D communication, security aspects are less addressed. An attacker can attack the core network, or the user applications, and extract useful information, thereby hindering the information exchange over the direct links.

Table 9
Possible security attacks in D2D communication.

S.No	Security attack	Description
1.	Eavesdropping	Unauthorized interception of the confidential data between the DUEs
2.	Denial of Service (DoS)	Attempt to make resources unavailable for authorized UEs
3.	Man-in-the-Middle Attack (MITMA)	The malicious node acts as a client for the server and a server for the client, i.e. a D2D receiver to the D2D transmitter and vice-versa
4.	Free-riding attack	Selfish UEs receive data from their pairs, and at the same time are not willing to share their own resources with other UEs because of energy consumption in the process, resulting in reduced system availability for D2D communication
5.	Node Impersonation	Malicious node acts as a legitimate node, posing threat to D2D communication
6.	Malware Attacks	Hostile software, targeting the D2D pairs to gather sensitive information
7.	IP Spoofing	Manipulation of IP packets, particularly the headers, by the malicious nodes
8.	Bandwidth Spoofing	Unauthorized access to the bandwidth of the legitimate user, by the malicious node
9.	Inference Attack	Privacy is attacked, by studying either logically or statistically, transmission patterns between devices
10.	Trust Forging Attack	Intruder forges its trust value for attracting D2D transaction requests
11.	Location Spoofing (GPS Spoofing)	Fake GPS Signals sent by the attackers, causing arbitrary location s to be chosen by a subscriber

Possible attacks on the direct links and some algorithms for securing them are discussed herein.

1) *Possible Attacks in D2D*

In wireless communication, D2D is susceptible to a number of security attacks, like, eavesdropping, data fabrication or alternation, denial of service attack (DoS), free-riding attack. Some possible attacks are briefed in Table 9. The eavesdropping attack in D2D communication is depicted in Fig. 11, where an eavesdropper is present in the network, trying to take up information from the senders. This figures depicts a general attack on a D2D network.

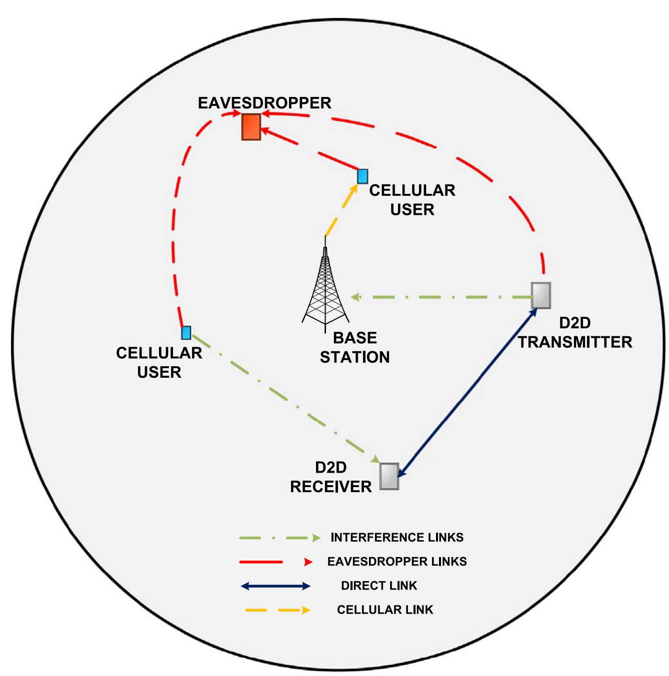

Fig. 11. A D2D scenario, with eavesdropper.

2) *Secrecy Algorithms in D2D Communication*

To make D2D communication secure, physical layer security plays a key role. The concept of physical layer security came into picture to describe the physical characteristics of wireless channels. Sensitive information may be retrieved by the eavesdropper, in a communication system. Physical layer security employs techniques which exploit the characteristics of the wireless channel, modulation, coding, and multiple antennas to avoid eavesdropping. Physical layer security is investigated in Zhang et al. (2016) to improve secrecy performance of the system. The authors in Zhang et al. (2015) investigate physical layer security in Cooperative D2D networks. Cooperation among cellular users and D2D users is formulated as a coalition game, based on Max-Coalition order for an efficient cooperation, along with guaranteed secrecy in the network. The physical layer security is proposed, considering an energy-constrained D2D transmitter. Wireless power transfer (WPT) model is used to ensure secrecy of transmissions. In order to ensure secure D2D communications, certain security requirements need to be fulfilled.

Another concept is secrecy capacity, which quantifies the security of transmission. It defines the maximum rate of faithful information sent from transmitter to receiver, in the presence of threat from eavesdropper. In Zhang et al. (2014), secrecy capacity in cellular networks with underlaying D2D communication has been explored. A graph-based model is used for radio resource allocation problem and formulated as a matching problem in a weighted bipartite graph. To obtain maximum secrecy capacity for DUEs and CUEs, the Kuhn Munkres (KM) algorithm has been considered. This algorithm provides better performance, in comparison to random or greedy spectrum sharing.

For ensuring secure D2D transmissions, encryption of messages by cryptographic techniques is required. A secure key agreement protocol has been presented in Shen et al. (2014), enabling establishment of a shared secret key between UEs, and is based on Diffie-Hellman key agreement protocol. The main advantage of this protocol is low computation and communication overhead. The simulation results show that a higher level of usability is possible with this protocol. With the increase in the number of eavesdropper, the D2D performance degrades. A solution is proposed in Abd-Elrahman et al. (2015) to secure D2D discovery and D2D communication in cellular networks, based on Identity Based Encryption (IBE). Ensuring security in cellular networks with D2D communications is an open research area. This scheme is not useful, for multi-domain networks. As a result, Abd-Elrahman et al. (2015) investigate upon ensuring security in discovery and communication phases of D2D communication in multicast group communication. Group Key management has been studied, for ensuring the security. This mechanism ensures high security, in comparison to other methods. In Liu et al. (2016), security in cognitive D2D networks is considered. Authors in Wang and Yan (2015) propose security architecture for D2D communication and the requirements to ensure security have also been suggested. Various applications and use cases of D2D communication have also been discussed.

Since security is a major concern for device-to-device (D2D) communication, for D2D assisted cellular networks, secure throughput optimization solution has been proposed in Ometovy and Orsino (2016). Public safety D2D communication over LTE Hetnets have been investigated in Tata and Kadoch (2014) for addressing the issue of secure network coding. Using data splitting mechanism, an algorithm is presented, and named as Secure Network Coding based Data Splitting Algorithm. It avoids passing of information to the eavesdropper, without increase in overhead of the system. The sequence of the sent packets is known only to the source and destination, thus, not allowing any useful data to be known to the attackers. A technique to prevent eavesdropping in MIMO D2D communication is investigated in Jayasinghe et al. (2015). A relay in the network performs physical layer network coding (PNC). The devices communicate through this trusted relay, via a secure beam forming design, which provides high level of secrecy. The DUEs are not powerful enough to prevent attacks from eavesdroppers, and fighting for attacks upon them. Wang et al. (2015) present a heuristic genetic algorithm to select jamming partners for DUEs in the network. The secrecy rate has been maximized, by a two step approach: power allocation for worst case eavesdropper and best jamming partner selection, which is clearly depicted in the simulation results. Using a cryptographic approach, Zhang et al. (2015) introduce a secure data sharing protocol. This uses symmetric encryption, along with public key based signature to achieve security. Security goals fulfilled by this protocol are data confidentiality, integrity, transmission and reception non-repudiation, entity authentication and free riding resistance. Accounting social relationships and proximity between devices, a game theoretic approach is used in the proposed solution to improve the system performance, in terms of throughput and latency. It is also efficient in enhancing network coverage. The work in Wang and Wu (2015) investigates upon selection of jamming partners for D2D users by taking into consideration full and partial channel state information (CSI). Heuristic genetic algorithm and low complexity optimization problems have been proposed for maximizing the worst case eavesdropping in D2D communications.

Trust and social aware cooperation is mandatory for adoption of D2D communication on a large scale (Ometovy et al., 2016). For ensuring secure D2D communications, sociality of users and trust factors play an essential role. The trustworthiness of a device is given in terms of its trust value, adjusted by the BS, as per the last transaction over the D2D link. For any user, m^{th} transaction of D2D pair, it is given by using the Gompertz function (Kenney and Sydney Keeping, 1954), as,

$$t_{a(m)} = \left(\; ^{-1} t_{a(m-1)} \right) + \Delta t_{a(m)} \tag{11}$$

where g(z) denotes the Gompertz function, for a vector z, denoted by

$$(z) = \quad e^{-e^{-CG(z)}} \tag{12}$$

where

CG(z) determines sensitivity of the trust value variation, along time. Also $\Delta t_{a(j)}$ denotes the device's behavior at m^{th} transaction. Relationships based on trust among users have been extensively studied, of which an important one is discussed in Urama et al. (2016). D2D communications require a sophisticated control to resist eavesdropping and other security attacks. Malicious behavior of devices in a D2D environment resulting in data loss is studied in Militano et al. (2016) and 86% reduced data loss is achieved with the proposed trust bases coalition game. Another technique to limit the impact of malicious nodes has been proposed in Militano et al. (2016), and is based on trust solutions. Simulation results show how filtering of malicious nodes is done with the proposed scheme, thereby increasing successful cooperative interactions in small-scale IoT environments. Security of direct communication is a key concern, which determines ultimate adoption of this technology. Spatial and social notions of proximate users are addressed in Ometov et al. (2016) for improving the system performance using game-theoretic mechanisms. Although there was increased overhead, but seamless connectivity was provided to users outside the network coverage as well. This clearly depicts the impact of social and spatial notions, on the performance of D2D networks.

The various security algorithms for device-to-device (D2D) communication have been listed in Table 10. Security algorithms allow transmission and reception of the information among intended users only. Algorithms in Zhang et al. (2015) and Wang et al. (2015) prove to be highly efficient for securing D2D links. A comparison of achievable secrecy capacity by different algorithms has been shown in Fig. 13. From the above discussion, it is quite clear that a very challenging task for the research community still remains securing the direct links. Possible attacks on the links are becoming more threatening with the

Table 10
Security algorithms for D2D communication.

Reference No.	Algorithm	Description	Objective
(Shen et al., 2014)	Diffie-Hellman Secure Key Establishment using	A key agreement protocol is designed, based on Diffie-Hellman key agreement protocol, and is integrated to Wi-Fi Direct protocol. It is also implemented using Smartphone	Secure key setup between two mobile users , with low computation cost and overhead; maximum probability of attack is 2^{-k}, where k is the no. of bits used for authentication strings
(Tata and Kadoch, 2014)	Secure Network Coding based Data Splitting Algorithm	Data Splitting mechanism is applied over a butterfly network, to ensure confidentiality of the transmitted information	No important information received by the eavesdropper; low computation overhead
(Jayasinghe et al., 2015)	Securing MIMO D2D Communication	Using a beam forming technique, information passing through a relay is secured by ensuring the presence of a trusted relay in the network. The trusted relay is safe as it performs PNC	A fast converging algorithm, providing high secrecy levels for D2D communication
(Abd-Elrahman et al., 2015)	Securing D2D communication using Identity-based Encryption	Investigates security in D2D discovery and communication phases to enhance the level of security of the network	Less overhead with the use of a single hash function, thereby enhancing overall security of the network
(Abd-Elrahman et al., 2015)	Group Key Management (GKM) Mechanism	Dynamic approach to Secure messages on direct links, during discovery and communication phases by building a strong protocol for group key management	Ensure high security
(Zhang et al., 2015)	Merge and split based coalition formation algorithm	Physical layer security is investigated In D2D communication from a cooperative perspective, with the formation of a coalition formation game, to ensure cooperation between cellular users and D2D pairs	Improved secrecy rate of the system and social welfare
(Liu et al., 2016)	Wireless Power Transfer (WPT) Policy for securing Cognitive D2D communication	Investigate physical layer security in D2D communication using three wireless power transfer policies: cooperative power beacons, best power beacon and nearest power beacon, to ensure secure cognitive D2D communication in cellular networks	Improved values of secrecy throughput, secrecy outage probability and power outage probability, but demands more overhead
(Wang et al., 2015)	Genetic Algorithm for maximizing secrecy rate	An optimal jammer selection scheme is proposed with optimized power allocation ; based on the social trust policy of the jammer with minimum social trust index threshold being 0.4	Increase in secrecy rate with increase in the number of jammers, resulting in better system performance
(Zhang et al., 2015)	Secure Data Sharing Protocol	Detects free-riding attacks by maintain record of the UEs in the network with the use of digital signature and symmetric encryption	Maintain data confidentiality, integrity, provide free-riding resistance, entity authentication
(Urama et al., 2016)	Proof of Concept Application Development	In absence of availability of a cellular link to the D2D users, secrecy can be ensured , the proposed technique assures security to the D2D users by establishment of dynamic connections	Helpful in evaluating social trust in D2D communication

(continued on next page)

growth of technology. The next generation networks are becoming denser, making easier for intruders to spoof information and the disrupt overall functioning of the networks. A proposal for securing direct links using IP Sec has been given in the following sub-section.

3) *Security concern for UDNs and Proposed Solution for Securing direct links*

In the next generation networks, densification of networks is essential for meeting the needs of the subscribers. This densification results in ultra dense networks (UDNs). In such heterogeneous networks (HetNets), with UDNs and D2D communication, there are high chances of jamming attack (Grover et al., 2014). The jammer emits a radio signal causing a continuous interference mostly in the form of noise, in the network. A scenario of jamming in UDNs with D2D communication underlaying the cellular networks is depicted in Fig. 12. When devices communicate through direct links, the distance between devices for information exchange is less (proximity devices). As a result, it becomes easier for the jammer to hamper the communication. The jammer (intruder) can attack the network by inserting an interference signal (single-carrier jamming) in the entire system or jamming selective carriers (multi-carrier jamming). This issue needs a special attention.

In order to ensure integrity, confidentiality and authentication of data, security mechanisms are applied at the internet protocol (IP) layer. This is referred to as IP Security (IP Sec). It supports two encryption modes: Transport and Tunnel. The transmitted data contains the header and payload. Transport mode encrypts only the payload, while Tunnel mode encrypts data as well as the payload. Thus, Tunnel mode is of more importance. A solution for securing D2D networks from eavesdropper has been proposed and depicted in Fig. 14, which is based on IP Security. The figure depicts ongoing communication between a D2D pair, which is hindered by an intruder by spoofing the bandwidth. Without a security mechanism applied to the communication, the intruder would obtain the information from the channel, between the D2D transmitter and D2D receiver. Using IP security, the information can be prevented to be sent to the unauthorized user, with both transmitter and receiver sharing a public key. Thus, the transmitted information can be safeguarded. The D2D pairs have a small distance between D2D transmitter and D2D receiver.

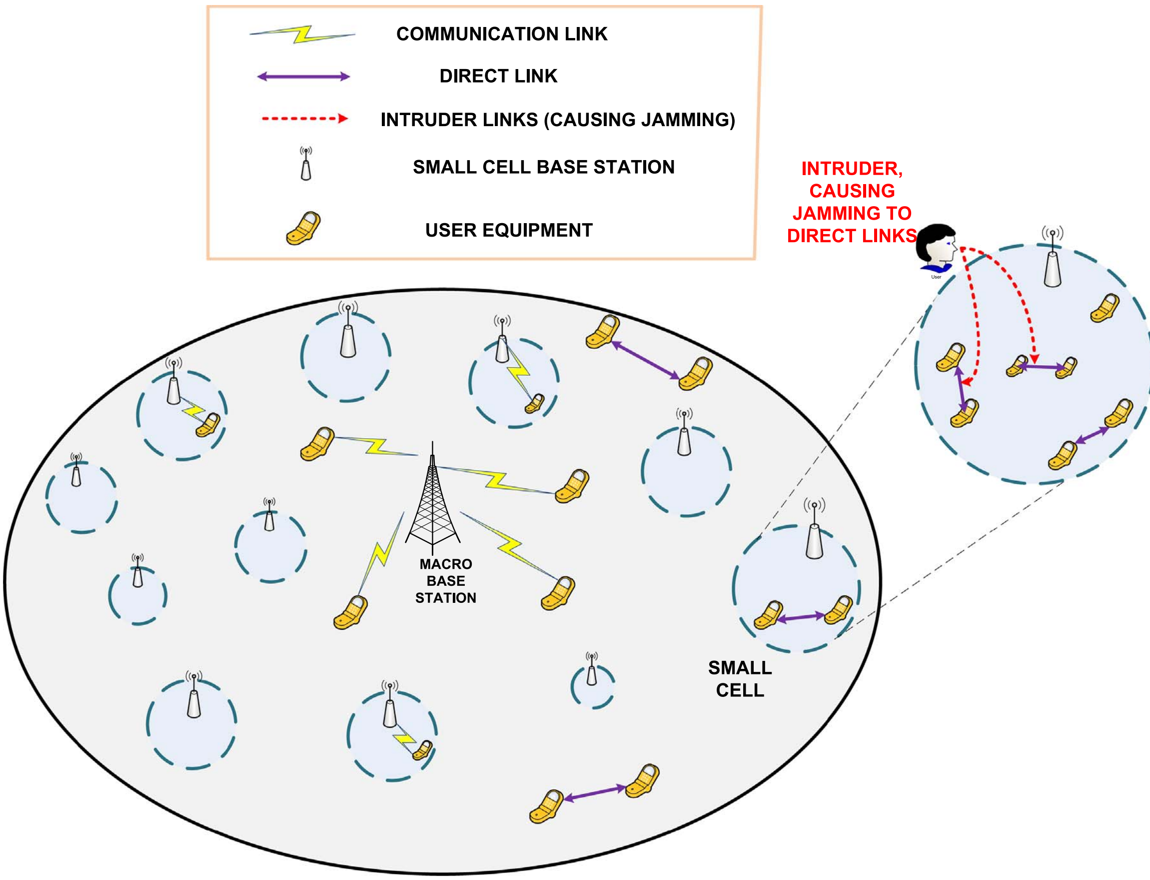

Fig. 12. Jamming in Ultra dense networks with D2D communication.

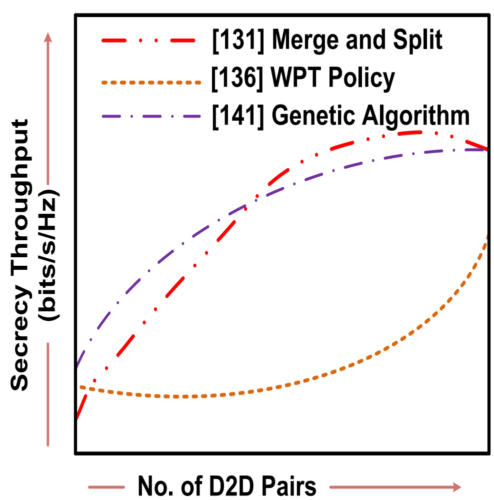

Fig. 13. Comparison of secrecy capacity from different security algorithms in D2D.

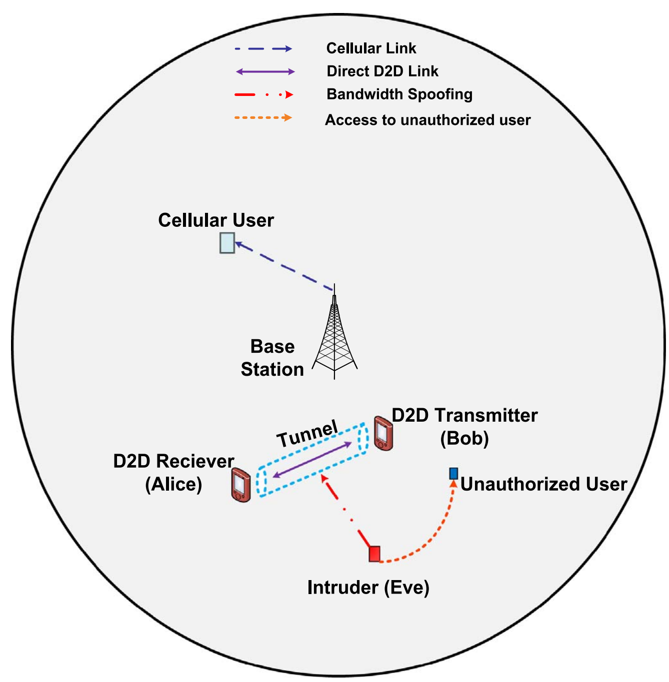

Fig. 14. Proposed solution for security in D2D, using IP Sec.

Thus, IP Sec can prove to be an efficient technique for securing the short direct links. The effect of mobility on security in D2D communication is yet to be further studied. D2D security concerns require significant research, for assuring secrecy over direct links.

The various aforementioned issues in D2D need to be critically addressed, prior to the implementation of device-to-device (D2D) communication in cellular networks.

6. Use cases of D2D communication

In D2D communication, two devices can communicate either directly or via relays, independent of the control from the base station. As a result, device-to-device (D2D) communication has the ability to support a large number of use cases like cellular offloading (Bao et al., 2010), multicasting (Zhou et al., 2013; Du et al., 2012), video dissemination (Golrezaei et al., 2012), (Li et al., 2012), M2M communication (Pratas and Popovski, 2013), public safety services (Usman et al., 2015), V2V communication, location-aware services, social networking, smart grids (Fey et al., 2012), D2D for e-health, D2D for smart city etc. Some use cases of D2D communication have been addressed in Lei et al. (2012). D2D communication has the ability to support a number of telecommunication applications as well.

In case of multiuser cooperative communication (MUCC), device-to-device (D2D) communication can provide innovative ideas for enhancement of the network performance. Device-to-device (D2D) communication is an optimal choice for provision of energy efficient communication within cellular networks. If a group of users request the same services from the base station (BS), they can collectively form a cluster. The content requested will be served by the base station to the cluster head only, which can then be multi casted to the rest of the users. This supports energy efficiency within the network and also reduces unnecessary overhead.

D2D communication, in conjunction with Internet of Things (IoT) results in a massive interconnected wireless network (Bello and Zeadally, 2014) which has the ability to support numerous applications. Achieving intelligent D2D communication in the IoT is overviewed in Bello and Zeadally (2016). Device-to-device (D2D) communication assures low energy consumption, thus supporting energy efficiency in the Internet of Things (IoT). The remarking potential of D2D communication in IoT, for the next generation networks is studied in Militano et al. (2015). A distinctive application is Vehicle-to-Vehicle (V2V) communication, playing a vital role in car crash warning systems (Hayami et al., 2015; Bohmländer et al., 2015), brake coordinating systems, intelligent transport systems (Warabino et al., 2005). Device-to-device (D2D) communication has the ability to serve as an important component for assuring public protection and disaster relief (PPDR) and national security and public safety services (NSPS). The network requirements to support these are discussed in Fodor et al. (2014). Therefore, D2D communication is an important emerging technology of the future networks.

7. Research challenges in D2D communication

Although D2D communication is an open research field for academicians, as well as industrialists, but still there exists wide range of challenges in its implementation. Modification is needed on the part of the user equipments (UEs). This includes: UEs supporting device discovery; Proximity Services (ProSe); and relay functionality in the relay scenario. The protocols for device discovery in D2D must consider reduction of energy consumption by the UEs. The issue of UE discovery and its power consumption is an open research problem. For efficient utilization of the limited available spectrum, optimal resource allocation is required. While allocating the resources to the DUEs in the cellular networks, for enabling them to communicate, care must be taken that the same resources are not shared by the nearby CUEs. If it is so, chances of interference are very high. Interference management is being studied by the researchers but the nature of the interference is not completely exploited and understood. Interference management and avoidance involves addressing issues like collision issues, congestion, and power control. All these issues need to be addressed in an accurately balanced manner.

For enabling any type of communication, channel information must be precisely available. This is a challenging perspective for implementation of D2D communication, as, for the direct communication, extra channel information is required, resulting in an increased overhead. Controlling and charging for D2D services is a vital concern for the service providers. The service providers may charge for security. The modulation format for D2D communication is yet to be addressed. Addressing these critical problems thoughtfully will help in practical implementation of D2D communication, in cellular networks.

A critical research challenge, considering the practicality of D2D communication, is security of the direct links. The D2D links are highly susceptible to various security attacks (listed in Table 8). As a result of densification of the cellular architecture, jamming in Ultra dense networks (UDNs) is posing serious threat to the integrity, confidentiality and authenticity of the information transfer over direct links. This needs special attention from the research community. Measures have been proposed, yet, it remains a vital challenge, seeking further investigation. After this extensive survey on D2D communication, it is quite eminent that security remains an exclusive research field for practicable implementation of D2D communication. The proposed solutions and architectures may not be the only one, but are an efficient means to target and solve the research challenges.

8. Conclusion

In this paper, device-to-device (D2D) communication has been comprehensively outlined. It is a promising technology of the next generation networks, which ensures increased system capacity, enhanced throughput, reduced latency and efficient spectrum utilization. Fundamentals of D2D communication have been discussed in depth, including the basic D2D architecture. A number of key issues in D2D communication have been discussed. Architecture for D2D communication has been proposed, considering the scenario of NGNs, using directional antennas at the base station, dividing the cell into three sectors. Such a scenario provides better coverage, high spectral efficiency and enhanced network capacity, overcoming the various open challenges of D2D communication. Possible security attacks on D2D communication have been described. The future networks contain dense deployments, resulting in Ultra dense networks (UDNs), causing high risk of jamming attack in them. A solution for securing D2D communication has also been proposed, which is based on IP security (IP Sec). A few examples have been quoted, where D2D communication plays a crucial role. Thus, D2D communication is an integral technology of the future networks, motivating the researchers to overcome the associated challenges in order to completely take advantage of its utility.

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