5G D2D Networks: Techniques, Challenges, and Future Prospects

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***Abstract*—The increasing number of mobile users has given impetus to the demand for high data rate proximity services. The fifth-generation (5G) wireless systems promise to improve the existing technology according to the future demands and provide a road map for reliable and resource-efficient solutions. Device-to-device (D2D) communication has been envisioned as an allied technology of 5G wireless systems for providing services that include live data and video sharing. A D2D communication technique opens new horizons of device-centric communications, i.e., exploiting direct D2D links instead of relying solely on cellular links. Offloading traffic from traditional network-centric entities to D2D network enables low computational complexity at the base station besides increasing the network capacity. However, there are several challenges associated with D2D communication. In this paper, we present a survey of the existing methodologies related to aspects such as interference management, network discovery, proximity services, and network security in D2D networks. We conclude by introducing new dimensions with regard to D2D communication and delineate aspects that require further research.**

***Index Terms*—Device-to-device (D2D) communication, millimeter wave (mmWave), network discovery, proximity services (ProSe), simultaneous wireless and information power transfer (SWIPT), vehicle-to-vehicle (V2V) network.**

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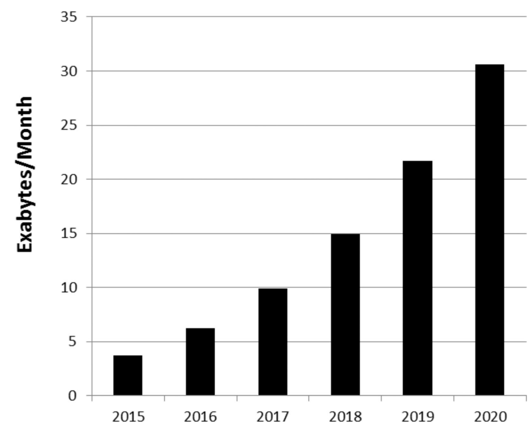

Fig. 1. Mobile data traffic forecast [1].

I. Introduction

The introduction of fourth-generation (4G) wireless technology provided a much needed platform for moving toward higher data rates and reliable communication standards. The ever increasing demand for data services, including internet access on mobile user equipment (UE), led to the development of worldwide interoperability for microwave access and Long-Term Evolution (LTE) wireless communication standards. However, according to recent estimates [1], the use of internet on mobile UEs would experience a sharp rise for years to come. Fig. 1 represents a forecast of global mobile data traffic growth per month in the coming years. Compared to 2015, the global mobile data traffic is expected to grow 727% by 2020. The increase in density of mobile devices would impact the system performance as the data rate requirements would expand, keeping in view various applications, such as live data and video sharing.

The concept of 5G technology was introduced as a futuristic solution for applications involving high data rate peer-to-peer (P2P) links [2]. The proposed technologies, which would undergo standardization under the aegis of 5G network development, include heterogeneous networks (HetNets), machine-to-machine communications, device-to-device (D2D) networks, and internet of things (IoT) among others [3], [4]. 5G standardization activities are aimed at ascertaining the basic architecture of 5G according to the demands of new applications and business opportunities. Network operators have shown keen

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interest in playing a proactive role for the development of 5G. Enhancing mobile broadband is one of the aims of 5G, providing applications such as live video sharing and virtual reality.

5G envisions offloading traffic from cellular networks to P2P networks. The basic idea is to utilize direct links between mobile UEs to soften the burden on base stations (BSs). D2D wireless networks are termed one of the candidates for future 5G networks. Direct communication between mobile UEs augments spectrum efficiency but also poses some challenges, e.g., interference. Intelligent resource allocation schemes could help in efficient spectrum utilization while mitigating the impact of interference [5]. Interference management in networks involving mobile UEs, such as smartphones, could open up a number of opportunities with regard to new applications and services.

Amalgamation of D2D communication networks with cellular deployments such as femtocells has provided an interesting direction for further research. While femtocells allow high capacity network connectivity, the D2D links could enhance cellular reuse [6]. However, the interference issues in an environment involving macrocell, femtocell, and D2D network could impair system performance. The BSs of both macrocells and femtocells could assist D2D pairs in efficient resource allocation and adjust power usages according to the required quality-of-service (QoS) [7]. Research activities undertaken in this regard supplement the claim of better throughput and network sustainability. Energy-efficient network solution for D2D networks is important to ensure network longevity. Resources can be allocated in an energy-efficient manner keeping in view the desired QoS [8]. The utility of D2D networks is of special significance in instances where the backhaul network suffers a failure due to disasters or some other unforeseen events. The D2D networks could provide a reliable solution establishing direct links without the support of Evolved Node B (eNB) [9]. The protocol for establishing D2D pairs is of great significance as it can impact system performance, especially in case of backhaul network failure. A neighbor discovery mechanism could help in establishing D2D links involving the ability of perceiving cellular uplink transmissions [10]. Recently, the concept of multiple-input multiple-output has been explored for D2D networks to increase the network throughput [11].

In this paper, we present a survey of the issues related to D2D communications and highlight the development of protocols, which could be helpful in the context of 5G D2D networks. First, we discuss some works presenting an overview on the aspects related to D2D networks. Cheng *et al.* [12] identify the need for channel measurement and modeling for D2D networks and present an overview of the existing literature by discussing different network environments, e.g., indoor/outdoor, rural, and urban. Mach *et al.* [13] delineates several aspects of D2D communication in a cellular network environment and identifies the need for developing mathematical/analytical models for analyzing D2D networks. Similarly, providing an overview of D2D communication in LTE-Advanced (LTE-A) networks, Liu *et al.* [14] offer an insight into the services, which can be supported by D2D communications and also highlights D2D network deployment scenarios. D2D networks for proximity services (ProSe) have drawn significant attention due to the potential business opportunities. A survey on the issues related to ProSe in the context of D2D network is presented in [15]. The gains achieved through cooperative D2D communication are also highlighted in [16].

The utilization of D2D networks in LTE-A and its related taxonomy is discussed in detail in [17]. The authors have presented an overview of existing works related to D2D networks and have categorized the works into *Inband* and *Outband* D2D to enhance the understanding of the concept behind D2D networks. Moreover, new protocols for realizing ProSe are also presented. The emergence of the futuristic concept of 5G networks has triggered the need for reviewing the D2D network protocols from a 5G network perspective. In this paper, we extend the concepts discussed in the aforementioned paper, provide our insights regarding the shortcomings in existing techniques, and suggest improvements, providing the reader with a broader understanding of how existing techniques need to be evolved for workability in future 5G D2D networks. To apprise the reader of the new research trends in D2D networks, special emphasis is laid on the aspects such as vehicle-to-vehicle (V2V) communications, millimeter wave (mmWave) technology, simultaneous wireless and information power transfer (SWIPT), and social trust based networks, which have not been focused in previous surveys. Our aim is to highlight the several challenges related to 5G D2D networks along with providing future directions and highlighting issues that require further deliberation. The major contributions of this paper include the following.

1) Presenting a summary of issues related to 5G D2D networks and analysis of the techniques reported in literature with regard to performance and different network deployment scenarios.
2) Ascertain the efficacy of 5G D2D networks for ProSe with special reference to scenarios where the D2D networks become inevitable due to destruction or failure of backhaul network infrastructure.
3) New trends in research such as V2V communications, mmWave spectrum band for D2D, SWIPT, and social trust based network for D2D networks are identified, and future directions for the evolution of 5G D2D networks are highlighted.

The remainder of this paper is organized as follows. Section II presents an overview of D2D standardization and classification. In Section III, different interference management techniques reported in the literature are discussed. Network discovery mechanisms and ProSe in D2D networks are discussed in Sections IV and V, respectively. Section VI discusses network coding (NC) in D2D networks followed by network security. In Section VII, we present new dimensions and future directions related to 5G D2D networks, followed by a conclusion given in Section VIII.

II. D2D Standardization Overview

3rd Generation Partnership Project (3GPP) is a joint effort of standard development organizations to review and present new standards. Initially, D2D technology was associated with LTE-A, which forms a part of the 3GPP Rel. 12. Qualcomm, in collaboration with other 3GPP partners, presented its proposals for standardizing D2D communication under a broader umbrella of LTE-direct. 3GPP Rel. 12 and Rel. 13 discussed the ProSe based on D2D communication and also highlighted the evolution of the concept of D2D for V2V communications [18]. Rel. 13 supports multihop relay network for D2D communication and presents standardization with regard to priority control for mission critical push to talk applications. Moreover, the network discovery mechanism was expanded to in-coverage, partial-coverage, and out-of-coverage scenarios.

The discussion under 3GPP Rel. 14 revolved around the enhancements in LTE, which would lead toward the 5G network development. The final specifications of Rel. 14 were issued in June 2017. The work plan developed under Rel. 14 focused on a number of aspects, which include emergency services, LTE for vehicle-to-everything (V2X), location services, and latency reduction techniques. In the next step, 3GPP plans to issue Rel. 15, which would focus on the 5G network deployment. Specifically, Rel. 15 could be considered as the first step toward documenting 5G specifications. International Telecommunication Union Radio Communication Sector initiated research under International Mobile Telecommunication System (IMT 2020) program, paving the way for the introduction of a comprehensive standard for 5G by 2020. The specifications presented under the IEEE 802.11 protocol addressed the concept of D2D network based on the Wi-Fi Direct technology. The Wi-Fi Direct allows the device to dynamically assume the role of an access point and/or a client, which is considered as one of the major advantages for using it in D2D networks [19]. Recently, the inclusion of Wi-Fi Direct technology in mobile devices has gained pace, which would aid the deployment of Wi-Fi Direct based D2D networks.

D2D communication is viewed as an apt technology for proximity-based data sharing services [20], making it a suitable candidate for future 5G networks. Instead of resorting to cellular links, direct links between devices are exploited for providing proximity and diversity gains. D2D communication is further classified into Inband and Outband D2D communication.

1) *Inband D2D:* Communication takes place in the licensed cellular spectrum. Inband D2D provides spectral efficiency due to the sharing of licensed spectrum between D2D and cellular users. The QoS management mechanism is controlled by the eNB, which helps in countering issues such as interference. Inband D2D is further categorized into *underlay* and *overlay* [21]. In *underlay* D2D communication, the cellular and D2D users share the same spectrum resources, whereas in the *overlay* D2D communication, the D2D users are allocated dedicated spectrum resources. Underlay D2D communication poses challenges related to interference management and resource allocation between D2D and cellular users (CUs). Overlay D2D communication overcomes the aforementioned issues, but it does not ensure the efficient utilization of resources due to the rigid resource assignment.
2) *Outband D2D:* Communication takes place in the unlicensed spectrum, e.g., ISM band. Wi-Fi Direct [22] has emerged as a potential candidate for Outband D2D communication. However, Outband D2D requires hardware compatibility between the communicating devices. The eNB provides the control signaling but the actual communication between devices takes place in unlicensed spectrum. Although, Outband D2D avoids the interference from the CUs but the interference between devices exists, which leads to a more complex problem of handling interference. Another deployment scenario related to Outband D2D involves cluster communication, where the burden of signaling is delegated to the cluster head (CH) node.

III. Interference Management

One of the major impairments affecting D2D communication is interference from CUs [23]. Reuse of cellular resources and, hence, the coexistence of D2D pairs and CUs leads to interference issues. D2D users can suffer from both intercell and intracell interference, which depends on the mode of operation of D2D networks, i.e., uplink and downlink scenarios. Interference can hamper successful transmissions by compromising the signal-to-interference-plus-noise ratio (SINR). Several interference management techniques have been proposed in the literature, some of which are discussed in this section. Interference management schemes can be further classified into interference avoidance, interference coordination, and interference cancellation.

A. *Interference Avoidance*

Interference avoidance techniques involve the manipulation of transmissions to avoid interaction between interfering nodes [24]. An interference limited area (ILA) based approach for interference avoidance is presented in [25] and [26]. In the proposed scheme, a geographical area around the D2D user is delimited, and the CUs falling within that area are not allowed to transmit simultaneously with the D2D users [27]. The extant of ILA depends on the comparison of interference-to-signal ratio values at the D2D receiver with a predetermined threshold. It is assumed that the channel state information (CSI) is available at the BS, which is not a practical approach with regard to future 5G D2D networks. A multiple D2D pair and CU scenario is a practical network topology with regard to 5G D2D. Zhang *et al.* [28] elaborate on the interference management based on ILA but provide analysis on a different network setup. Two D2D pairs in the same ILA are not allowed to transmit simultaneously in order to avoid interference. ILA-DP1 and ILA-DP2 represent areas delimited for D2D pairs (DP) 1 and 2, respectively, whereas ILA-C represents the ILA for CUs. It is assumed that perfect CSI is known at the BS. A cumulative distribution function (CDF) of system capacity highlights enhanced performance of the proposed scheme. Transmit power levels can be manipulated to control the magnitude of interference suffered by the communication links [29]. Transmit power of CU and D2D users can be adjusted for reducing interference. An uplink power control scheme based on SINR thresholds (SINR-T) is presented in [30]. The proposed scheme identifies the tolerable SINR-T for D2D and CU, and adjusts transmit power levels to keep the interference levels within desirable limits. CDF curves for throughput signify better performance of the proposed scheme as compared to the conventional power control schemes. The proposed scheme is implemented on a deterministic scenario with very low node density. Interference avoidance techniques for future 5G networks would involve the development of a scenario, which is an interplay between deterministic and stochastic models.

B. Interference Coordination

Interference coordination schemes gain significant relevance in network scenarios with Inband D2D communication. *Centralized interference coordination* (CIC) involves the supervision of the BS. In *decentralized interference coordination* (DIC) schemes, the coordination mechanism involves participation of the D2D nodes with minimal supervision of the BS. Wen *et al.* [31] discuss a CIC technique, combining mode selection, power control, and resource allocation. The proposed multipronged approach could serve as a direction for developing more complex 5G D2D networks. Another CIC technique that employs genetic algorithm (GA) based joint resource allocations and user-matching schemes (GAAM) for mitigating intracell interference in the uplink mode is introduced in [32]. The user-matching scheme ensures allocation of resources to both CUs and D2D users. The GAAM scheme is compared with an exhaustive searching allocation and matching method (ESAM) using CDF versus system throughput plots. GAAM employs far less computational complexity and provides a throughput, which is comparable to the ESAM technique. However, the analysis is limited to the uplink network scenario. It would be interesting to observe how the technique could be modified for applicability in the downlink network scenario.

A DIC scheme is discussed in [33], where the D2D nodes dynamically adjust the allocation of physical resource blocks (PRBs) to mitigate interference. Periodic sensing of PRBs is conducted by the D2D nodes, and the PRBs that experience interference are not chosen for transmissions. The proposed decentralized scheme aligns with the concept of future 5G networks with high D2D node density. Another DIC scheme is discussed in [34], where D2D-to-CU interference is managed by the eNB while the D2D nodes manage the inter-D2D node interference. The inter-D2D interference coordination problem is formulated using a game theory. The proposed scheme provides performance gains in terms of reduced signaling overhead at the eNB.

C. Interference Cancellation

Intelligent cancellation techniques allow the receiver to decode the message by mitigating the impact of interference. A resource allocation scheme based on a greedy algorithm combined with a successive interference cancellation (SIC) scheme is introduced in [35]. The SIC technique is employed at the receiver to cancel the mutual interference between users. The authors have pointed out the shortcomings of the proposed scheme with regard to extra computational overhead and energy consumption. It is envisioned that future 5G networks would be energy efficient and would ensure minimal overhead at the BS. In order to adopt the proposed scheme, the aforementioned limitations need to be taken into consideration while developing future D2D networks.

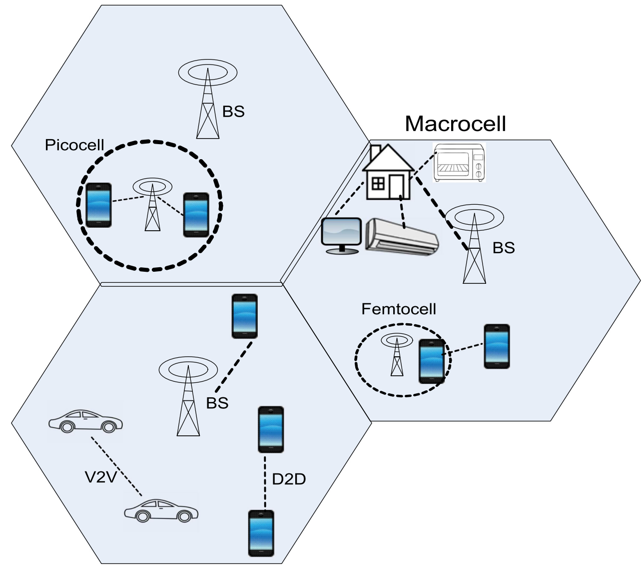

Fig. 2. 5G HetNets (Multitier system) [41].

Coordinated multipoint (CoMP) technology can remove intercell interference between a D2D user and a CU by utilizing the zero-forcing algorithm. In centralized CoMP, a processing unit processes information such as precoding matrix index and rank indicator [36] in order to ascertain the suitability of the D2D operation. The proposed technique is simulated for a multiple CU and D2D pair scenario, which makes it quite relevant with regard to 5G D2D networks. As a future direction, the efficacy of the proposed technique in a heterogeneous environment with dense node deployment could be explored in order to provide an insight into the impact of interference.

A full duplex (FD) communication between D2D users is considered as a new technology being researched as part of 5G D2D communications. The capability to transmit and receive simultaneously could open up new avenues of research [37]. An FD-based interference cancellation technique is discussed in [38]. In the proposed technique, the D2D UE could utilize its FD capability to transmit both the desired signal and the interference (from the BS). Avoiding high overhead required for D2D and CU coordination, this scheme utilizes less resources for interference management. This scheme is specifically suitable for environments where CSI is not known. In [39], Ali *et al.* employ the FD technique for self-interference cancellation. It is observed that for uplink transmission scenarios, lower D2D distance provides better performance due to lower transmit powers. However, a comparison between half-duplex and FD for downlink signifies enhanced throughput achieved through the FD operation.

Future 5G multitier systems would require improvement in existing interference management techniques, especially for HetNets [42]. Fig. 2 depicts a multitier system, involving macrocell, picocell, femtocell, and D2D pairs, presenting a prototype for the future networks [41]. Some solutions are presented in [43], which include relay-aided D2D at cell edges if the deep fading links are observed between D2D and CUs. Different power allocation schemes for uplink and downlink will be required to mitigate the impact of interference.

TABLE I
SUMMARY OF INTERFERENCE MANAGEMENT TECHNIQUES

Network Topology	Ref. No.	Interference Management Technique	Perfect CSI Knowledge	Target
1 CU; 1 D2D pair	[38], [39]	FD-assisted interference cancellation	No	Capacity enhancement in an FD mode
1 CU; 2 D2D pairs	[31]	BS-assisted SIR-based optimization	Yes	Capacity enhancement
	[28]	Power control scheme with D2D and CU transmit power adjustment	Yes	Comparison between the conventional transmit power scheme and the proposed scheme in terms of network capacity
1 CU; multiple D2D pairs	[35]	Radio resource allocation based on the greedy algorithm and SIC	Yes	Throughput maximization
	[40]	Graph-coloring resource allocation algorithm	Yes	D2D user density versus network capacity analysis
Multiple CUs; 1 D2D pair	[25], [26]	ILA-based on SIR	Yes	ILA versus conventional transmit power control scheme
Multiple CUs; multiple D2D pairs	[32]	GA-based joint resource allocation and user-matching scheme (GAAM)	Yes	Algorithm complexity analysis
	[41]	Channel selection and power control	No	D2D network performance in heterogeneous environment
	[36]	CoMP technology	Yes	System power consumption versus throughput analysis
	[27]	ILA-based on SIR	Yes	D2D multicast system analysis
	[29]	Centralized and distributed power control scheme	No	Coverage probability, network capacity

Furthermore, devising cooperative links between macrocells and small cells along with underlay D2D would signify the need for conducting further research on interplay of interference in such scenarios. The presence of different modes of operation in HetNets with dense node deployment would increase computational complexity, which would present a complex interference management problem. The role of BS and the D2D user needs to be assigned in a manner that enhances network capacity and ensures network reliability. Research should be directed toward devising decentralized techniques, which could help in reducing the signaling overhead at the eNB.

Table I presents a summary of interference management techniques when applied to different network topologies.

IV. Network Discovery

Network discovery is an integral part of the D2D communication setup, which allows the D2D users to identify nodes in close proximity. Beacon signals are shared between devices to convey information, such as device IDs. D2D users also share their respective CSI with each other to ascertain the feasibility of being grouped into a pair. Network discovery schemes could be further classified into *network centric* (NC) and *device centric* (DC) [44]. The concept of NC discovery for in-coverage network scenarios was discussed in 3GPP Rel. 12. In 3GPP Rel. 13, the network discovery mechanisms are expanded to include partial network coverage and out of coverage scenarios with special emphasis on public safety networks. The NC and DC schemes are compared in [45]. A time–frequency resource block, denoted by discovery resource block (DRB), is shared by D2D users amongst each other for device discovery.

Previous works show that the DC uniform random performs better than the DC greedy-probabilistic, so the proposed NC schemes are compared with uniform random methods. Path loss versus discovery probability is analyzed for the proposed schemes. It is observed that the location-based method outperforms other methods. However, the NC scheme is not scalable and requires devices to be connected to the network for resource allocation. The DC scheme provides a scalable solution, which could be applied to scenarios where direct outreach of network is not possible. Autonomous D2D networks require a network discovery mechanism, which ensures reliable interconnection between devices. Different modes for network discovery are examined in [46], especially for D2D users in proximity. Network-assisted discovery mode is named network ProSe, whereas the mode involving autonomous operation of UEs for discovery is referred as Open ProSe. It is observed that in high D2D user density scenarios, the NC discovery performs better, whereas in low user density scenarios, the performance of DC discovery is better.

Quick network discovery involves pairing of D2D users, while maintaining the spectral efficiency. Previously, the Hungarian (Kuhn–Munkres) algorithm [49] has been employed for pairing, but Wang and Wu [47] introduce inverse popularity pairing order (IPPO), which is a relatively fast pairing scheme. Latency in network discovery could impact the system performance. In [48], a device discovery mechanism is introduced for both indoor and outdoor network environments. The analysis of the proposed mechanism reveals that spectrum reuse by D2D users augments cochannel interference, which impacts the network discovery.

In the context of 5G D2D networks, quick network discovery is essential for network sustainability. The battery constraints of D2D UEs signify the need for quick network discovery to ensure optimal network lifetime. Moreover, node mobility may lead to the discontinuation of established connection sessions. A dynamic scheme that is able to employ network-assisted and UE-initiated network discovery according to the changing circumstances is important for ensuring quick connection setup. The discovery mechanism can incur signaling overhead, which can compromise the overall network performance with regard to network capacity. Future works should be directed toward devising quick network discovery techniques, which take the

TABLE II
NETWORK DISCOVERY TECHNIQUES

Ref. No.	Network Discovery Technique	Simulation Setup	Objective	Results/Conclusions
[44]	SINR-based D2D discovery	BS distribution homogeneous PPP Receiver sensitivity = −93.5 dBm BS–D2D distance = 600 m, 900 m	Closed-form expressions for the conditional PDF and complementary CDF of the distance between two D2D peers. Finding optimal BS density that maximizes D2D discovery	Location knowledge versus network discovery. D2D discovery probability is unaffected after a certain density of users.
[45]	Cell orthogonal and location based	Uplink: single-cell/multicell QPSK modulation SIR = 3 dB Carrier frequency = 2 GHz	Comparison of network-assisted and device-assisted schemes	Location-aware scheme performs better in a single-cell scenario. DC scheme "uniform random" performs better in multicell scenario.
[46]	Reactive (pull) discovery and proactive (push) discovery	1 cell (radius 1 km), 100 D2D users, maximum D2D distance = 100 m	Analysis of network ProSe NC) and open ProSe (DC discovery)	Control overhead analysis reveals better performance of reactive protocol.
[47]	IPPO	Underlay, cell radius = 300 m, 100 nodes	Reduce computational complexity	IPPO and Hungarian (Kuhn–Munkres) algorithm tradeoff analysis reveals comparable performance of IPPO with low complexity.
[48]	BS-assisted network discovery	Indoor/outdoor nonhomogeneous PPP device distribution Wall penetration loss = 30 dB	Stochastic geometry model for peer discovery	Inband emission hinders network discovery mechanism.

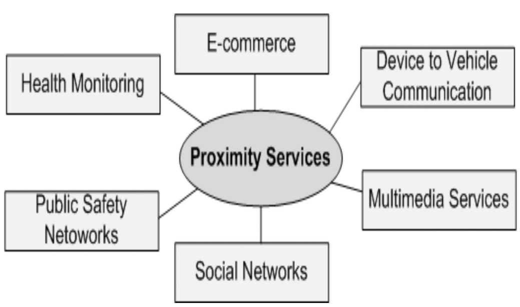

Fig. 3. D2D proximity services.

aforementioned issues into consideration. Table II presents a summary of the network discovery techniques.

V. PROXIMITY AND CONTEXT-AWARE SERVICES

D2D networks would allow numerous ProSe, providing the users with a unique connectivity experience. Fig. 3 depicts ProSe related to future 5G D2D networks. Proximity multimedia services are also important from the network provider's perspective as they would open up several new business opportunities. Moreover, the spectrum saved through cellular offloading would allow the BS to accommodate more users and services. Context-aware services are particularly important for smartphone-based networks, where the phones are able to establish local networks for common content sharing.

Physical layer aspects of resource allocation for context-aware services have been discussed by several authors. In [50], Zhu *et al.* studied the problem in a cross-layer perspective. BSs possess the knowledge of the requirements of the D2D users. Information correlation is introduced as a metric for gauging the importance of information for a particular D2D user. The BS prioritizes its transmission according to the information correlation matrix. The D2D users with greater information correlation are given preference. The scheme is simulated for a random distribution of D2D pairs and CUs. The proposed scheme is useful for providing context-aware services in an efficient manner and provides a direction for future 5G context-aware networks. Proximity-based multimedia services require higher data rates along with reliable communications [51]. Ryu *et al.* [52] present an overview of the opportunities offered by D2D communication with regard to proximity multimedia services. The impending capacity congestion due to high data rate multimedia services is highlighted. The criteria for designing future technical specifications for pairing mechanism, device discovery, and interference management in D2D networks are discussed. Along with technical specifications that are common for D2D networks, authors also highlight the need for identifying service-specific requirements. Video would form a major component of future 5G ProSe traffic, which signifies the need for identifying service-specific requirements.

The FD technology is useful in ProSe as it provides self-interference cancellation. An FD model is simulated in [53] in an independent and identically distributed Rayleigh fading environment. The sum throughput (bits/Hz) is analyzed to compare the traditional D2D network with the FD D2D, highlighting the enhanced performance of the FD technology. ProSe, such as live gaming between D2D users, could employ the FD technology for providing the required data rate with the inherent interference mitigation. In [54], the utility of D2D networks is summarized for ProSe, and future challenges are identified. Link selection aided by relaying mode selection based on the QoS metric (data rate threshold) enhances sustainability of the network [55] for ProSe, especially in D2D cluster environments [56]. Another cluster-based approach is discussed in [57], where a CH is chosen for direct communication with the BS. The CH controls the flow of information between the BS and other D2D users, which is a practical approach for 5G D2D ProSe. An apt resource scheduling mechanism is required to ensure fairness and optimal throughput in a cluster-based D2D network [58]. Moiz *et al.* [59] present a mobile cloud (MC) based approach for content distribution in a D2D network, where the nodes in proximity establish a cooperative network by exploiting short-range links. The test bed implementation of the proposed algorithms provides practical results with regard to the network performance. In [60], Huq *et al.* propose an amalgamation of the features of a cloud radio access network and D2D networks to overcome the problem of fronthaul delay. The proposed architecture could go a long way in realizing the performance metrics, such as energy efficiency, cost, and mobility, and seems promising for the application in future 5G networks.

Rise in usage of smartphones will aid 5G D2D network deployment due to the absence of new infrastructural requirements. Video sharing among users is expected to rise to three-fourths of the overall network traffic, as estimated by Cisco [1]. Caching techniques could be quite handy in proximity video sharing service. The most desired video content is stored on priority, and an optimal caching technique ensures content delivery [61]. A popular content caching technique is also discussed in [62], where a popularity matrix is formulated. Recently, the use of Wi-Fi technology has been explored for content dissemination between D2D users in proximity. In [63], Antonopoulos *et al.* present a medium access control (MAC) protocol for D2D content dissemination using the Wi-Fi technology. Sciancalepore *et al.* [64] address the problem of transmission time minimization at the BS for content dissemination to D2D users. Authors observe that interference characteristics of the cell affect the network speed, which in turn impacts the content dissemination time. Information from social networks is exploited to build a social graph, which identifies influential users and devises a caching mechanism. Similarly, context-aware caching based on social networks [65] can exploit trends in user demands for providing backhaul savings. Future research should focus on ensuring secure ProSe, which is essential for persuading devices to cooperate. Developing pricing mechanisms for ProSe would also pose a challenge as the network providers will have to share revenue or incentives with the cooperating devices.

VI. NC and Network Security

A. Network Coding

Cooperative diversity could be exploited by D2D networks for ensuring reliable communication [66], [67]. NC-aided cooperative D2D networks enhance the success probability of end-to-end data delivery. In [68], the NC is employed in BS-assisted D2D communication networks. The proposed mode of operation comprises two D2D users, which use the BS as a relay. The D2D users transmit in the first two time slots, whereas the BS applies exclusive OR (XOR) operation and transmits in the third time slot.

Generally, interference is considered as an impairment, but Jayasinghe *et al.* [69] introduce the concept of physical layer NC (PNC) in D2D communication networks, where interference is maneuvered in a positive manner. The PNC scheme simply superimposes electromagnetic (EM) waves and forms a code. The PNC operation for a two-source and one relay network scenario takes place in two time slots. In the first time slot, the D2D users share their messages $X1$ and $X2$ with the relay. The relay applies PNC and transmits $X3$, the coded message in the second time slot. Traditional two-source relay networks use three time slots for exchanging information but PNC-assisted two-source relay network exchanges information in two time slots, which enhances the network capacity.

Pahlevani *et al.* [70] highlight the use of NC in MC scenarios. Different D2D cluster topologies are discussed. The authors demonstrate diversity gains achieved through NC in scenarios where D2D node density is high. Furthermore, the utility of NC-assisted cooperative D2D is explored for live data transmission. Devices can cooperate by receiving chunks of desired data and then sharing the chunks cooperatively for complete download [71]. The proposed mechanism helps in conserving energy and avoiding delay in transmissions. Datsika *et al.* [72] present an adaptive cooperative NC-based MAC protocol for bidirectional D2D communication, which aids in the sharing of downloaded content between users. The authors also highlight the cellular network parameters that influence the performance of outband D2D by providing a tradeoff analysis. In [73], the gains achieved through joint NC and resource allocation in D2D communication networks are emphasized. Analysis of CDF of spectral efficiency and end-to-end SINR signifies the enhanced performance of D2D networks. Authors conclude by asserting the utility of the proposed scheme in future 5G D2D networks. Maher and Hassan [74] discuss a relaying technique, where inactive nodes are identified and utilized as relays. NC complemented by optimal relay selection yields higher sum rates when compared to the traditional D2D communication networks. In [75], Pyattaev *et al.* highlight the benefits of NC-assisted D2D communication networks combined with caching techniques for ProSe in the context of future 5G communication networks. The proposed scheme is especially useful in scenarios where several D2D users demand similar contents.

In [76], a comparison is presented between traditional D2D communication networks, D2D aided by analog NC and D2D aided by space-time analog NC (STANC). The proposed topology consists of three D2D pairs with a two-antenna relay, which amplifies and forwards the received signals. Zero-forcing detection takes place at the receiver to recover the desired information. The average sum rate versus the SNR is analyzed, which reveals benefits of STANC over other techniques. In our work on NC [77], we presented the idea of a relay-aided network-coded technique with priorities assigned to users according to the channel conditions. It was observed that the NC mechanism could be employed in order to enhance the end-to-end success of D2D pairs suffering from adverse channel conditions.

B. D2D Network Security

Network security for D2D networks has gained significant importance due to the nature of information shared on the network. D2D nodes in proximity can share sensitive information related to identity of the users and other personal details. Any eavesdropper could exploit such personal information for illegal purposes. Therefore, network security protocols in D2D networks were developed, which allow the users to avoid any information leakages. The major issue in building secure D2D networks is the dynamic readjustment required due to the mobility of D2D users. New users may join the coalition while the old users can leave the coalition, triggering the need of an adaptive mechanism for D2D network security.

A novel technique of exploiting the interference signals for security is discussed in [78]. Generally, interference is considered as an impediment, but it could also be exploited for providing security by blocking the eavesdropping node [79], [80]. It is difficult for CUs to identify the eavesdropping node perfectly on the basis of channel gains. In case a CU is able to sense the eavesdropping, it could switch to the D2D mode, which provides considerable interference to the eavesdropper. The D2D user interferes with the listening capability of eavesdropper, hence providing security. Secrecy outage probability is measured, and D2D users transmit power for blocking the eavesdropping node is determined. Similarly, nodes can also switch their modes of operation and discontinue cooperative communication in order to avoid revealing transmissions to the eavesdropping node [81].

Analysis of previous communication links can help in building trusted networks. Coon [82] presents two trusted network formation concepts.

1) *Proximity based*: Trust is developed on the basis of spatial distance between UEs.
2) *Experience based*: Trust is developed on the basis of previous network links.

Such networks are particularly useful in scenarios where transmission reliability is desired. D2D users can learn from the experience gained from previous transmissions to avoid information loss. Security in ProSe is of prime importance, especially with regard to public safety networks. Abd-Elrahman *et al.* [83] discuss a group key management technique for ensuring user privacy. Only the users with the relevant key are allowed access to the transmissions. The proposed technique is modeled for a multicast scenario. Authors have highlighted the performance gains achieved over other techniques in terms of computational overhead.

From a future 5G D2D network perspective, it is important that D2D security is ensured with minimum overhead. Ensuring security in dense node deployment is of prime importance. Physical layer security techniques could help in blocking eavesdropping nodes. Jayasinghe *et al.* [84] discuss a physical layer security technique based on physical layer NC. Imperfect CSI estimation is assumed, which makes the technique quite suitable in terms of practicality. However, a simplistic scenario with low node density is taken into consideration. The initial work on physical layer security techniques [85] require further research in order to devise a mechanism, which is consonant with the needs of future 5G networks. Moreover, the security mechanism should be dynamically adjustable according to the present state of the network.

VII. New Research Aspects and Future Directions

In this section, we discuss some emerging aspects related to D2D networks and delineate some under explored research avenues for future research.

A. D2D in Vehicular Communications

V2V communications have opened up numerous opportunities for new applications, such as traffic updates and road safety systems. V2V communication based on 802.11p standard was introduced to enable V2V *ad hoc* communications. Another approach that has been followed for providing V2V connectivity is to leverage the existing LTE cellular infrastructure. A comparison between V2V communications based on 802.11p standard and LTE is presented in [86]. A highway environment is considered for simulation and a comparison is drawn on the basis of scalability of the network for beacon transmission. V2V communications based on LTE are shown to utilize less resources for beacon transmission. Beaconing allows the vehicles to develop context awareness, which helps in applications such as intimating neighboring cars about any unusual activity, e.g., emergency braking. However, the need for strict QoS constraints triggered the need for exploring new concepts for V2V communications. Recently, V2V communications based on the concept of D2D networks has drawn significant attention as a key enabler for future 5G networks. The concepts developed for D2D networks can be transformed for use in V2V communications.

The resource management techniques developed under the purview of D2D networks cannot be directly adopted for V2V communications. The mobility of vehicles leads to instantaneous changes in channel conditions. The resource management techniques assuming perfect CSI knowledge at the BS are not suitable for V2V communications. Sun *et al.* [87] present a resource allocation and power control scheme for realizing V2V communications. Latency and reliability are identified as the critical performance metrics for V2V communications [88]. The simulation model consists of CUs operating concurrently with vehicles. A comparison is drawn between the proposed scheme and existing resource allocation schemes for D2D networks. It is shown that the proposed scheme provides optimal data rates for CUs and low latency for V2V communications. A backhaul cellular network failure could severely compromise the V2V safety applications. It is imperative that the network connectivity is maintained by developing an *ad hoc* V2V network. Gutierrez-Estevez *et al.* [89] present a self-organizing time–frequency division multiple access scheme for developing an *ad hoc* network in case of backhaul network failure. The proposed scheme incorporates the rapidly changing channel conditions and provides the desired QoS in terms of reduced transmission delay.

Recently, the concept of V2X [90] has been introduced, which is an amalgamation of vehicle-to-network, vehicle-to-infrastructure, V2V, and vehicle-to-pedestrian communications. Standardization with regard to V2X communications is being pursued by the 3GPP, as V2X communication is considered a key aspect of 5G network. V2V for safety applications can greatly benefit from the techniques developed for D2D communication. The futuristic concept of autonomous driving vehicles can be realized by establishing D2D-enabled links between vehicles and the infrastructure in close proximity. Vehicle positioning information can be relayed by the infrastructure through D2D links, leading to numerous new services and applications. Some of the applications envisioned through V2V network include collision warning, blind spot warning, pedestrian movement warning, and emergency braking system. Moreover, the road-side equipment could issue warnings to vehicles for any impending danger and speed limits.

The techniques that have evolved under the umbrella of D2D networks can serve as a basis for developing mechanisms, which satisfy the performance constraints in V2V networks. Although the concept of V2V communications is developed for transmissions between vehicles in proximity, the mobility of vehicles presents numerous challenges. The dynamic environment poses challenges, such as network discovery, interference management, power control, and radio resource allocation. Moreover, the techniques need to be distinguished on the basis of the network environment, i.e., as an underlay to cellular LTE or *ad hoc* based network. *Ad hoc* V2V networks lack a central authority to provide signaling and control, which signifies the need for establishing a mechanism for distributed control that could maintain transmission synchronization. The use of FD technology for V2V communication [91] presents an interesting avenue for further research as it could allow simultaneous beacon transmission and reception thereby conserving radio resources. New techniques need to be introduced for scenarios where perfect CSI is not available [92]. Network sustainability needs to be ensured through failure recovery mechanisms [93]. Research should focus on developing quick failure recovery mechanisms for avoiding transmission disruption.

B. mmWave Spectrum Band

Providing connectivity in dense node deployment scenarios has signified the need for spectrum management. mmWave spectrum band (30–300 GHz) is being considered as a viable option for future 5G D2D networks. mmWave technology promises gains in terms of low interference and high data rates [94]. Moreover, low antenna dimensions could help in miniaturization of devices. There is also a need for further standardization with regard to frequency range of the unlicensed mmWave band. The benefits provided by mmWave technology for D2D networks could only be leveraged if design issues are identified and standard specifications are determined.

Al-Hourani *et al.* [95] present an analysis of path-loss characteristics of mmWave technology in an Outband urban network environment. The performance of the technology is evaluated for both line-of-sight (LOS) and non-LOS environments. The authors highlight the need for developing antennas with beam forming and beam switching techniques. The beam forming is important for avoiding interference, especially in implementation scenarios involving dense D2D node deployment. In an urban environment, the high-frequency mmWaves undergo reflections and refractions, which allows transmission in NLOS environments. The high data rate links and highly directional coverage provided by mmWave networks make them a preferable choice for ProSe services in future 5G networks [96]. The directional coverage provides the advantage of interference avoidance, which leads to the coexistence of several D2D pairs

Niu *et al.* [97] present an overview of opportunities offered by mmWave technology for the deployment in future 5G networks. However, several challenges are also identified, which include high propagation losses and low communication range. Moreover, it is also emphasized that the mobility of users would impact the network performance due to the need for frequent handovers, channel quality monitoring, and interference management. The implementation of mmWave in D2D networks would involve hardware changes, such as directional antennas [98]. Similarly, a comprehensive overview of mathematical models for mmWave technology is presented in [99]. The blocking of mmWave transmission due to physical objects, such as buildings and human bodies, is identified as an impediment to successful transmissions. The analytical model for SINR distribution is devised to characterize the network performance from a theoretical perspective. The authors identify the need for antenna arrays at mobile devices and the BS for realizing cellular communications. The analysis of indoor-to-outdoor network coverage and the impact of mobility on handover mechanisms are identified as potential research areas that require further deliberation.

The impact of human body on mmWave transmissions in D2D networks based on hand-held devices is also an aspect that requires further research. The human density in a particular area impacts the mmWave transmissions [100] due to transmission blockage. However, it is also important to analyze if the use of mmWave technology conforms the regularity standards regarding impact on human health. Conventionally, Federal Communications Commission regulations regarding specific absorption rate (SAR) are considered as a guiding principle for quantifying the exposure of EM waves on human body. However, power density is considered as a suitable metric to quantify exposure in scenarios involving high frequency. Wu *et al.* [101] propose a new temperature-based approach instead of the power density based approach for determining the impact of mmWaves on human body. The temperature changes on human tissues are observed to ascertain the impact of mmWave exposure. The analysis is conducted at 60 GHz, and it is shown that the proposed temperature-based approach is an effective tool for evaluating the impact of mmWaves on human body. The use of mmWave technology for providing new services for D2D networks could open up new revenue streams for network operators [102]. ProSe services in mmWave-based D2D networks could lead to a development of numerous applications, which can create new business opportunities. However, there is a need to further explore the compatibility of mmWave technology with existing resource management schemes. The peer discovery mechanism will also be difficult to manage, viewing the range constraints of mmWave technology. The coexistence of mmWave network with conventional cellular networks would require offloading traffic from one frequency band to another. New offloading and resource management techniques would be required for realizing mmWave D2D and cellular communications. Several hardware changes in existing hand-held devices seem inevitable for realizing mmWave communication in D2D networks. Future research should be directed toward hardware interface design for hand-held devices to support dual mode of operation, D2D and cellular communication. The capacity enhancements that can be achieved through mmWave technology make it a strong candidate for future 5G D2D networks.

C. Social D2D Networks

A D2D network could exploit social networks for providing secure connection setup [103], [104]. Building trusted networks with the aid of relationship trace gathered from social networks could enhance sustainability of the network. Social trust based networks could encourage the potential cooperators to participate in information exchange. Moreover, the devices demanding common content could cooperate in order to utilize the spectrum resources efficiently. The major challenge related to social D2D networks is the network readjustment in the case of change in node locations. A self-adjusting mechanism needs to be devised, which exploits social connections between devices to establish links dynamically. The information gathered from social networks could also help in common content sharing. The devices with similar interests can cooperate among themselves for sharing content. The BS has to transmit the content to one D2D user, and then the D2D user initiates a dissemination mechanism to share content with interested users in vicinity. The BS is relieved of the burden of redundant transmissions, which helps in saving spectrum resources as the traffic is offloaded to D2D network. Zhang *et al.* [105] utilize the Indian Buffet learning process to model the social relationships between devices. The purpose is to attain maximum traffic offloading in situations that represent real-time mobility-based models. The proposed model is validated by conducting simulations on real social network traces. The limited battery resources and processing capabilities of hand-held devices can lead to selfish behavior of nodes. The nodes that possess the desired content in their cache need to be provided with some incentive for their cooperation. An incentive mechanism based on caching is discussed in [106]. A relationship in both social and physical domains is considered by using social ties and the distance between devices for determining the cost of caching. A relaying mechanism based on social ties between D2D users is discussed in [107]. A simplified and energy-efficient probing mechanism for identifying relay nodes is presented. The proposed technique provides advantages in terms of incentives for users. D2D MAC designs based on social awareness can lead to energy efficiency in cooperative D2D networks, as observed in [108]. The authors also highlight some design challenges, which need to be addressed to realize a social awareness based D2D cooperative network.

Social D2D networks could serve as a platform for peer discovery and ProSe in 5G networks. The future research must be aimed at devising a joint mechanism, which takes both social connections and channel conditions into consideration. The social connection type may also vary from occasional interaction to frequent interaction between devices. Moreover, the selfish nodes also need to be identified to avoid transmission blockages as some nodes may avoid cooperation. The social network discovery must be cheat proof, disallowing users to generate false information regarding social connection status. All the aforementioned performance metrics need to be taken into account with regard to social D2D networks.

D. Energy Harvesting and SWIPT for D2D Networks

The battery constraints of hand-held D2D devices impact the sustainability of the network. The D2D networks are considered to be a part of a wider concept of IoT, and the D2D network deployment should be compatible with the futuristic concept of green IoT [109]. The development of energy-efficient communication protocols is important to conserve energy [110]. Xu *et al.* [111] present a solution to jointly optimize the relay selection, spectrum allocation, and power control. The proposed resource management protocol leads to energy savings for the D2D links.

Energy harvesting [112], [113] could help in allowing the devices to operate autonomously in situations where instant access to power infrastructure is not possible. The dynamic spectrum allocation scheme combined with energy-harvesting capability of D2D devices allows efficient spectrum utilization and enhances network lifetime [114], [115]. The issue of opportunistic D2D communication band selection along with energy harvesting is important [116] as a joint solution that could help in achieving the optimal transmission mechanism with regard to information transfer and energy harvesting. SWIPT [115], [117] is an emerging concept with regard to D2D networks. Zhou *et al.* [115] present a joint power control and spectrum resource allocation problem in SWIPT-based D2D underlay networks. The performance gains achieved through the proposed algorithm are highlighted by providing a comparison with existing heuristic algorithms. The authors also highlight future directions, which include the joint optimization of power-splitting ratio and power control to enhance energy efficiency of the network. SWIPT in a cluster network environment [118], [119], such as D2D clusters, could open up new avenues of research but could also lead to some challenges, such as interference. Exploiting the EM sources in the environment as an energy source is a potential area of research that requires further deliberation. The suitability of multiantenna SWIPT systems for D2D networks needs further analysis, and a cost-benefit analysis needs to be presented for SWIPT techniques, such as time switching, power splitting, and antenna switching. The energy-harvesting circuit properties could impact the D2D network performance providing variation in harvesting efficiency [120]. Simultaneous signal and power transfer could prove to be quite helpful in multihop cooperative D2D networks.

E. Pricing and Incentive

The D2D networks will introduce numerous multimedia services, which signifies the need for developing new business models [121]. The main challenge for the operators is to persuade users to benefit from the operator-controlled D2D link establishment. A comprehensive pricing and incentive mechanism needs to be devised for D2D networks. The multihop D2D relay networks require the proximity devices to cooperate

TABLE III
ADVANTAGES AND DISADVANTAGES OF D2D NETWORKS

Advantages	Disadvantages
Interoperability between Autonomous D2D networks and commercial networks	Additional hardware required to support multiple radio access (D2D and cellular)
Enhanced capacity	Transmission delays due to resource sharing
Low transmission power	Limited range
Spectrum sharing	Cellular resources might be underused/wasted
ProSe public safety networks	Battery constraints of UE may compromise network sustainability
Relay networks providing network diversity	Complex billing system
Cellular offloading	Dual wireless interfaces for D2D and cellular network

in information transfer. The potential cooperators participate in the relay network at the cost of their resources, such as battery and processing. Viewing the battery constraints and limited processing capabilities of hand-held devices, it is important that the cooperators are provided with incentives for their participation in information exchange [122]. Participation metrics, such as the amount of data flow and the connection period, could help in determining suitable incentives for the cooperators. Incentives may include free data services, priority access to network in case of contention due to overloading, and priority in resource allocation.

Tian *et al.* [123] present an incentive mechanism for relays to cooperate in transmissions. The relays are encouraged to move to regions, where they can achieve data dissemination to maximum users. This technique allows mutual benefits: BS achieves cellular offloading, while the D2D users can enjoy the monetary incentives for their collaboration. Li and Guo [124] signify the need for persuading users to switch to D2D communication. An auction mechanism is proposed, where the D2D users submit their bids to the BS. The bids include the monetary incentive the devices are expecting for switching their mode of operation from cellular to D2D. The BS decides the winner from all the received bids, which marks the end of the bidding process. However, such a bidding process is prone to security issues due to unwarranted access by the eavesdropping nodes.

Similarly, a pricing mechanism is also necessary to ensure that the D2D receivers are charged appropriately for the services they have availed. Furthermore, the economic perspective with regard to cellular network providers also needs further consideration. The techniques related to pricing and incentives could lead to extra computational overhead, which might influence the overall network capacity. Therefore, there is a need for further research to develop pricing and incentive mechanisms for D2D networks in order to converge to a win–win situation for all participants.

Table III identifies a number of advantages and disadvantages of D2D networks. The major advantages of D2D networks include spectrum efficiency, ProSe applications, and enhanced network capacity. Although, low transmit power is required for D2D communication, the limited range provided by D2D networks may render them unsuitable for node distribution scenarios with higher spatial distance. The impact of mobility of D2D users on the overall network performance need to be analyzed. Several analytical models for analyzing user mobility exist, but it is important to identify a mobility pattern, which best suits a particular application or the D2D network deployment. For example, the group mobility models can help in analytically analyzing the D2D communication in public safety networks, where the rescue teams work in groups and have similarities in their mobility patterns [125]. Cellular spectrum sharing will allow significant gains in terms of network capacity, but high dependence on D2D networks might lead to underutilization and wastage of cellular resources. Moreover, D2D networks promise a number of ProSe, but the battery constraints of D2D networks based on hand-held devices cannot be overlooked. Multihop D2D networks will enhance network diversity, while, on the other hand, a complex billing system will be required for facilitating the cooperation. The requirement of extra hardware for providing dual wireless interface at the UE will increase deployment costs. The UEs might switch to D2D or cellular mode, depending on the service requirements, but the security issues might dissuade the cooperators from participating in D2D cluster communications.

VIII. CONCLUSION

In this paper, we presented an overview of the issues related to D2D networks and explained how they could be developed for meeting the demands of future 5G communication networks. A survey of existing techniques related to major aspects of D2D communication has been presented, which includes interference management, network discovery, proximity and context-aware services, and NC and security. The techniques are explored in the context of providing a reliable and resource-efficient D2D network. Furthermore, some emerging aspects related to D2D networks, such as V2V communications, mmWave technology, social D2D networks, energy harvesting and SWIPT, pricing and incentive, have been discussed along with future directions in the context of 5G D2D networks.

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