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D2D Multi-hop Multi-path Communications in B5G Networks: A Survey on Models, Techniques, and Applications

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Abstract

In 5G networks, device-to-device (D2D) communications have played an important role in enlarging the coverage, relaxing the workload of backhaul links of both macro base stations (MBSs) and small-cell base stations (SBSs), and serving the mobile users (MUs) local applications and services at high capacity. However, beyond 5G (B5G or 6G) networks will require disruptive solutions that can assist D2D communications to meet numerous advanced applications and services requested by dense MUs. One of the most efficient solutions for D2D communications is multi-hop multi-path (MHMP). In this paper, we present a detailed survey of the so called D2D MHMP communications in terms of models, techniques, and applications for B5G networks. We discuss and propose the future research directions of D2D MHMP communications. All the models, techniques, and applications as well as future research directions of D2D MHMP communications provide the useful insights into B5G networks design and optimisation.

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1. Introduction

In every generation of mobile networks, the carriers always face the problems of how to provide the proliferation of mobile users (MUs) with high quality of service (QoS) and high resource efficiency. The emerging 5G technologies have been mostly addressing the problems of high data rate, low latency, ubiquitous and massive connectivity, etc., but expensive deployment due to system architecture changes and upgrades. Therefore, the next generation of mobile networks, i.e., beyond 5G (B5G or 6G) networks will place a high priority on more intelligent solutions that can improve the QoS while do not change the system architecture. One of the most promising solutions, which has been well studied in 5G networks and further developed in B5G networks is device-to-device (D2D) communications [1].

D2D communications enable direct transmission between two MUs over one hop in close proximity. This way not only efficiently mitigates the workload at both the macro base stations (MBSs) and the small-cell base stations (SBSs) but also improves system capacity to meet the high data rate of advanced applications and services. However, D2D communications over one hop cannot exploit the contents already cached at the other MUs around in dense B5G networks for multi-hop multi-path (MHMP) offloading, namely D2D MHMP communications [2, 3].

In D2D MHMP communications, the local applications and services are fully taken to serve the MUs at

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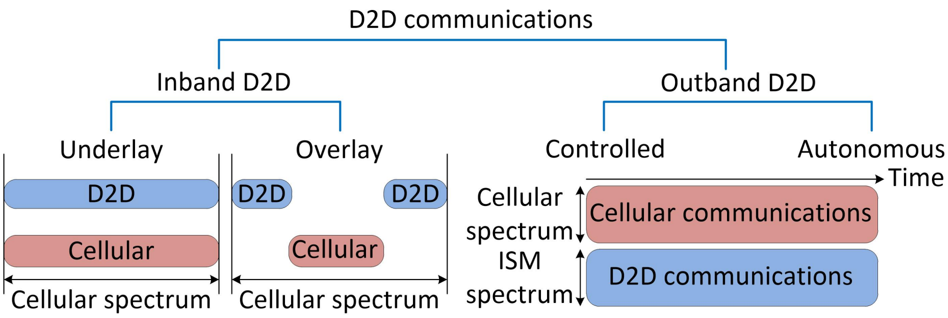

Figure 1. Classification of D2D Communications.

higher quality of experience (QoE[1]) rather than higher QoS traditionally. Thanks to shorter transmission per hop, the D2D MHMP communications reduce the transmission power of each transmitter of a hop. This in turn allows the transmitters to share their power consumption for longer lifetime as well as to mitigate the interference on the other receivers which re-use the same spectrum resource. Importantly, in many applications and services, e.g., emergency scenarios, the D2D MHMP communications expand the coverage of networks from the functional areas to nonfunctional ones, i.e., disaster areas, to serve as many MUs as possible. It is therefore crucial to further study on D2D MHMP communications to make them more powerful for allying to B5G networks.

In this paper, all the aspects of D2D MHMP communications from architectures, models, techniques, to applications are investigated insightfully. They are organised, analysed, and evaluated in a systematic and logical way. Together with the discussions on future research directions, we aim to provide both academic and industrial communities with a full understanding about D2D MHMP communications. This enables us to propose disruptive solutions for D2D MHMP communications to address many challenges raised by the dense MUs with high QoE demand in B5G networks.

The rest of this paper is organised as follows. In Section 2, we introduce an overview of D2D communications and techniques that can be utilised in D2D MHMP communications. Section 3 and Section 4 present the D2D MHMP communications architecture and related models, respectively. The detailed techniques of D2D MHMP communications are shown in Section 5. Section 6 is dedicated to presenting various useful applications of D2D MHMP communications. In Section 7, we discuss and propose some potential research directions of D2D MHMP communications in B5G networks. Finally, we conclude the paper in Section 8.

2. Overview of D2D Communications

In traditional mobile networks, all communications must go through the MBSs or the SBSs if better. This scheme is not quite reasonable for B5G in which dense MUs. The MUs often use high-speed data applications and services (e.g., social networks and e-learning, e-heath, video sharing, and games, etc.), and they may be located in close proximity. In this context, the MUs in short distances from each other can perform direct D2D communications which are expected to be much better than longer distances from MBSs or SBSs [1]. To name but a few, the benefits of D2D communications include: increasing the spectrum, energy, and coverage efficiencies [5, 6]; high connectivity and low transmission time [7–9], and high QoS [10, 11].

D2D communications can be classified based on the spectrum use manner as shown in Fig. 1. D2D communications occur in the licensed band of the cellular mobile networks (inband) or in the unlicensed band (outband). For inband communications, recent studies have focused on how to efficiently distribute the spectrum for D2D communications and cellular mobile networks (underlay inband mode). This research problem mainly focuses on minimizing the interference between D2D communications and cellular mobile communications [12–16]. Other solutions for addressing the interference, the authors suggest that a portion of the licensed band of cellular mobile networks can be devoted to D2D communications (overlay inband mode). In this mode, the spectrum allocation is very important so that the licensed band is pre-specified, but not wasted [17].

Meanwhile, the studies in [18–21] recommend the outband used for D2D communications rather than the inband. In outband communications, the coordination between two radio interfaces can be controlled by the MBSs (controlled outband D2D communications) or between D2D users themselves

[1]Unlike QoS, QoE [4] is more visual and sensitive for the MUs to evaluate the system performance. Some metrics of QoE are used including hit rate, latency, jitter, quality fluctuation, etc.

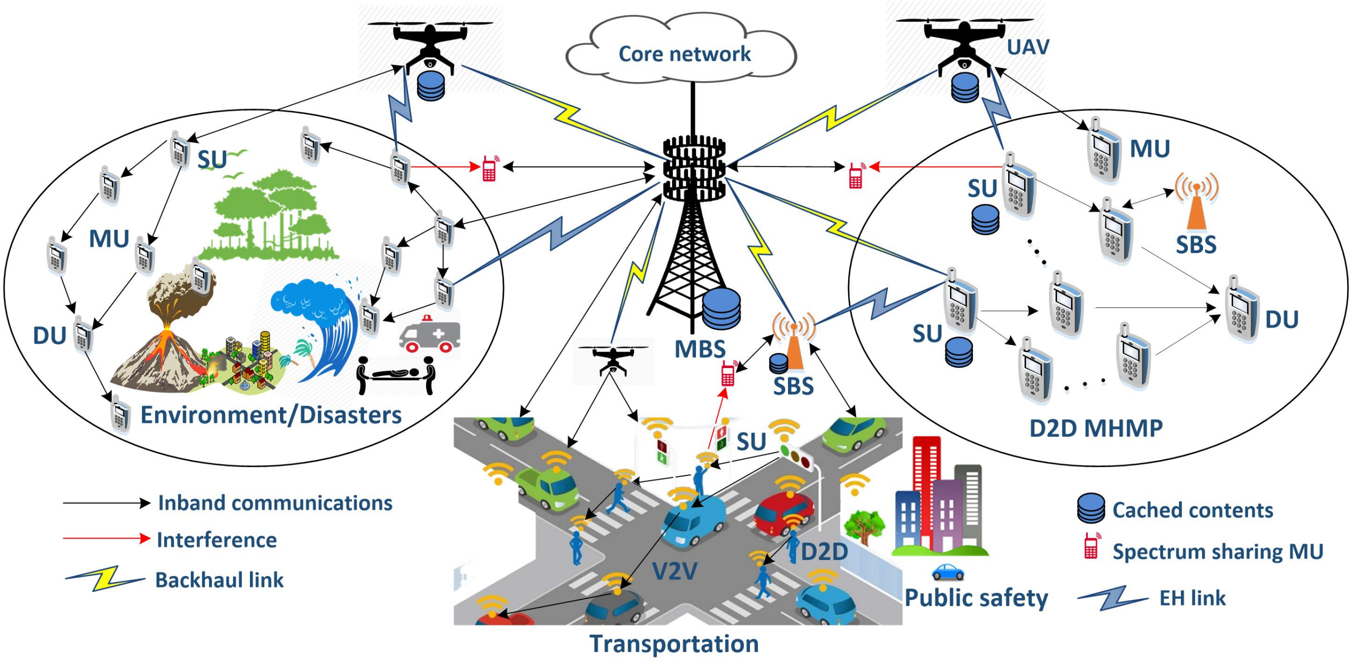

Figure 2. A Typical Architecture of D2D MHMP Communications.

(autonomous outband D2D communications). It can be observed that D2D outband communications face the challenge of complicated coordination between the two bands because D2D communications usually occurs at the secondary radio interface (e.g., WiFi direct and Bluetooth). Therefore, in this paper, all the D2D MHMP communications are in inband applications and services.

In addition, D2D communications can be divided into three typical categories based on the way they communicate with each other including peer-to-peer communications and cooperative communications. Although D2D communications bring many benefits to the network infrastructure and the network core, it is required a disruptive development to become more powerful, and thus can be applied to B5G networks. The promising solution developed for D2D communications is D2D MHMP communications is investigated in detail below.

3. D2D MHMP Communications Architecture

A typical architecture of D2D MHMP communications in B5G networks is illustrated in Fig. 2. It consists of a core network, MBS, SBSs, unmanned aerial vehicles (UAVs), vehicles, and MUs; hereafter, the vehicles and MUs are called end users (EUs). The B5G networks are able to provide advanced applications and services (ASSs) over multiple communication modes, e.g., from MBS, SBSs, and UAVs to EUs, vehicle-to-vehicle (V2V) communications, direct D2D communications, and D2D MHMP communications. In this architecture, the D2D MHMP communications are established based on the key techniques such as routing, relay selection (RS), caching, downlink spectrum resource sharing (DRS), and energy harvesting (EH). The routing and RS techniques play an important role in finding the best D2D MHMP communications from the source EUs (SUs) to the destination EUs (DUs). In addition, the caching, DRS, and EH techniques are applied to further utilising the storage, spectrum, and ambient energy resources to enhance the performance of D2D MHMP communications in B5G networks. In most of the D2D MHMP communications, inband is often used, and thus the interference may occur if using underlay mode.

It is obvious that the B5G networks can serve the dense EUs numerous advanced ASSs like video streaming, social networks, e-learning, e-health, smart transportation, etc. With D2D MHMP communications assisted, the B5G networks can be more efficiently applied to content delivery, public safety, environment and disaster management, IoT networks, and heterogeneous ad-hoc networks (HANETs). The main benefit of D2D MHMP communications is that it can expand the coverage of networks from functional areas to non-functional ones, e.g., in disaster and emergency scenarios [63].

4. D2D MHMP Communications Models

In this section, we introduce some models which are important and mostly used in D2D MHMP communications. Other ones such as wireless channel, transmission models, and energy consumption models

Table 1. D2D MHMP Communications Models

Ref.	Models			
	Delay	Capacity	Coverage	Security
[6, 22–28]			✓	
[2, 13, 29–40]		✓		
[41–44]				✓
[45–51]	✓			
[52–56]		✓	✓	
[3, 57–60]	✓	✓		
[61]	✓		✓	
[62]	✓	✓	✓	

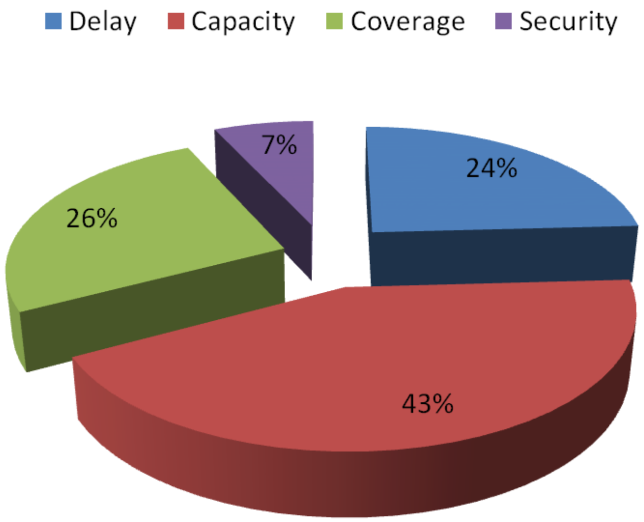

Figure 3. Key models of D2D MHMP communications.

[64–69] are assumed to be well-known and thus they are not considered. The general information of D2D MHMP communications models is shown in Table 1 and Fig. 3. In all systems, the models have to be built first, and then, the system performance can be analysed, optimized, and evaluated. The details of D2D MHMP communications models are discussed as follows.

4.1. Capacity Model

Capacity is the crucial metric used to evaluate the system performance of a proposed architecture, technique, or optimisation design. Most of the capacity models are derived originally from the Shannon-like capacity $W\log_2(1+\gamma_{m,n})$ characterised by the signal-to-noise ratio (SNR) $\gamma_{m,n} = \frac{P_{m,n}}{N_0}$ or signal-to-interference-plus-noise ratio (SINR) $\gamma_{m,n} = \frac{P_{m,n}}{N_0+I_{m,n}}$ [2, 3, 13, 29, 31, 33–40, 52–57, 62]. Here, W is the system bandwidth, $P_{m,n}$ and $I_{m,n}$ are the power of the incoming signal of interest and the power of the co-channel interference signal respectively at the receiving node of the n^{th} D2D hop in the m^{th} path, and N_0 is the power of additive white Gaussian noise. In addition, the capacity can be derived from the incoming data traffic at a relay node [30, 32, 58–60]. In D2D MHMP communications, the capacity of the m^{th} path, $m = 1, 2, ..., M$, consisting of N_m D2D hops, is generally computed as below

$$C_m = \min\{C_{m,n}, n = 1, 2, ..., N_m\}. \tag{1}$$

So, the best path is the one that provides the highest capacity given by

$$C_{\max} = \max\{C_m, m = 1, 2, ..., M\}. \tag{2}$$

It is noted that the above max – min capacity model is equivalent to the min – max inference model given in [13].

4.2. Coverage Model

Coverage is another important metric that has been mostly studied to evaluate the performance of D2D MHMP communications. The coverage of D2D MHMP communications is modeled based on the quality of the received signal, i.e., SNR or SINR, at the receiving node of a D2D hop. If the SNR (or SINR) is less than a given threshold (θ), it means that the transmitting node of the D2D hop cannot cover the receiving node [6, 22, 23, 25–28, 52, 54, 55, 62]. The coverage outage probability (COP) of the n^{th} D2D hop in the m^{th} path is computed relying on the SNR (or SINR) represented by $\gamma_{m,n}$ and the threshold θ, given by

$$p_{m,n}^{\text{COP}} = \mathbb{P}(\gamma_{m,n} < \theta), \tag{3}$$

where $\mathbb{P}$ presents the probability.

Next, we have the end-to-end (E2E) COP over H_m D2D hops of the m^{th} path, expressed as [24, 53, 56, 61]

$$p_m^{\text{COP}} = 1 - \prod_{n=1}^{H_m}\left(1 - p_{m,n}^{\text{COP}}\right). \tag{4}$$

From Eq. (4), we can select the best path with the lowest COP to guarantee the large coverage of the D2D MHMP communications.

Table 2. D2D MHMP Communications Techniques

Techniques	Ref.
CRR	[9, 22–25, 28, 29, 31, 33, 36–45, 49, 50, 52, 54, 55, 57–59, 62–67, 69–80]
DRS	[2, 3, 34, 43, 52, 55, 58, 68, 69, 81, 82]
Caching	[2, 3, 30, 34, 46]
EH	[36, 54, 64]

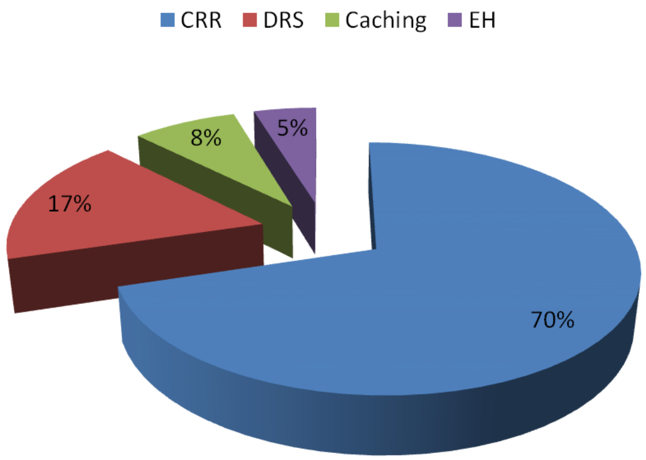

Figure 4. Key techinques of D2D MHMP communications.

4.3. Delay Model

With D2D MHMP communications assisted, the system capacity and coverage can be improved, but it may cause longer delay due to MH communications and the process of MHMP communications establishment. In D2D MHMP communications, E2E delay is often formulated in many forms to be minimised or limited so as to meet the ultra-low delay of B5G networks. Particularly, in [45, 49, 57, 59, 61], the E2E delay is computed based on the time when a packet is transmitted at the SU and the time when it is successfully received at the DU. The E2E delay can be derived from the processing delay per hop, the average waiting delay per hop, and the number of hops [3, 46]; the per-hop parameters of coding delay, propagation delay, and transmission delay [47]; or simply transmission delay [60, 62]. In some delay models, the E2E delay further includes the MHMP control process [48, 50, 51, 58].

4.4. Security Model

Unlike direct D2D communications, D2D MHMP communications are more vulnerable to the eavesdroppers because of more MH transmissions [41]. The secure models for D2D MHMP communications are thus seriously studied. Recently, physical layer security (PLS) has become a promising solution that can efficiently assist the cryptographic technologies done at higher layers of the protocol stack. In [43], an energy efficient secure model has been proposed for D2D MHMP communications. It is known in PLS that the secrecy capacity for the n^{th} D2D hop in the m^{th} path is given by

$$C^{\text{s}}_{m,n} = [C_{m,n} - C^{\text{e}}_{m,n}]^{+}, \tag{5}$$

where $[x]^{+} = \max\{x, 0\}$ and $C^{\text{e}}_{m,n}$ is the channel capacity of the eavesdropping hop associated with the n^{th} D2D hop in the m^{th} path.

From Eq. (5), by taking into account the secrecy capacity constraint C_{c}, the secrecy outage probability (SOP) of the n^{th} D2D hop in the m^{th} path is given by

$$p^{\text{SOP}}_{m,n} = \mathbb{P}(C^{\text{s}}_{m,n} < C_{\text{c}}). \tag{6}$$

Then, we have the E2E SOP over H_m D2D hops of the m^{th} path, expressed as

$$p^{\text{SOP}}_{m} = 1 - \prod_{n=1}^{H_m} \left(1 - p^{\text{SOP}}_{m,n}\right). \tag{7}$$

So far, Eq. (7) allows us to select the best path with the lowest SOP to guarantee the security of the D2D MHMP communications.

Furthermore, in [42], the SOP of a D2D hop can be replaced with the trusted probability to compute the secrecy levels of D2D MHMP communications in a similar vein with the work in [43]. And it is interesting that the PLS combined with cooperative beamforming strategy can improve the secrecy performance of D2D MHMP communications [44].

5. D2D MHMP Communications Techniques

In this section, we investigate the key techniques that have been used in D2D MHMP communications. These techniques mostly focus on establishing the best D2D MHMP communications by using clustering or/and relay selection assisted routing (CRR) techniques and enhancing the resource efficiency by using DRS, caching, and EH techniques to gain higher system performance. The summary of D2D MHMP communications techniques is shown in Table 2 and Fig. 4. The details are presented as below.

5.1. Techniques for establishing D2D MHMP Communications

The clustering or/and relay selection assisted routing (CRR) techniques enable the EUs to access the contents from the SUs located far away over MHMP communications instead of within one hop over direct D2D communications. Depending on the models of D2D MHMP communications, different CRR techniques have been proposed in the literature to establish a D2D MHMP communications session. Under the assumption that the methods to create D2D MH communications, e.g., frequency reuse, frequency synchronization, cross-tier interference mitigation, coded cooperative data exchange, energy efficient relay selection, D2D based clustering scheme, relay selection, bit error rate and fading analysis, etc., within one cell [22, 23, 25, 28, 52, 65, 69–71, 76–80] and cooperative D2D communications across multiple cells [64], can be utilised, the CRR techniques are detailed in the sequel.

In [9], the authors proposed a shortest path routing protocol in which all clustering, RS, and routing techniques are used for effective data dissemination, i.e., larger coverage and higher transmission efficiency. To do so, the target areas of dense EUs are first divided into different clusters for effective advertisement dissemination. Then, the routing path selection process is done to find the shortest path from the SU to the DU for effective data dissemination. During the routing path establishment process, the relay selection technique is deployed to find the set of successive forwarders who can relay the advertisement message successfully from the SU to the DU over the shortest path using geographical user information. In addition, the shortest path routing protocol can be simply done by selecting the set of relay nodes to form the path with minimum number of D2D hops [24], low symbol error rate and outage probability [29], max-min capacity [31], or with energy harvesting [36] and secrecy [42] added to enhance the system performance.

For the purpose of energy efficiency, the authors in [63, 66] studied an energy-efficient clustering and routing framework. The framework starts with selecting the EUs that have higher remaining energy and computational power to act as the cluster heads (CHs). After that, the other EUs that can communicate with a particular CH is grouped into a cluster. Finally, together with optimal power allocated to the CHs for high energy efficiency, a path optimization problem is formulated and solved for finding the path with minimum end-to-end delay and longer network lifetime. Clustering, RS, and routing techniques have also been studied in [44, 54, 75]. However, the authors in these works further combined with the beamforming technique [44, 75] and EH technique [54] at the relay nodes so as to improve the quality of received signal. In addition, clustering technique can be ignored, i.e., only RS and routing techniques are used to address the issues of delay, energy efficiency, spectrum efficiency, system capacity, green communications, connectivity, and secrecy transmissions [33, 37–41, 43, 45, 49, 50, 55, 57–59, 62, 67, 72–74].

5.2. Techniques for Enhancing D2D MHMP Communications Performance

Downlink Spectrum Resource Sharing. As mentioned in Section 2, inband D2D communications have been often studied in the literature because the inband resource can be controlled and distributed easier than the outband resource can do. In inband, a D2D communication between the two EUs is established by reusing the spectrum resource shared by an arbitrary common cellular user (CU), i.e. underlay mode, or by managing the spectrum resource allocation between the D2D communication and the CU, i.e., overlay mode. The former always yields interference caused by the transmission of the D2D communication to the CU due to using the same spectrum resource, meanwhile the later does not [81, 82].

In [68], the authors have used multiple modes to exploit both inband and outband for D2D MHMP communications. This way can obviously find the best spectrum resource sharing solution, but with very high complexity of radio interface control and management. Meanwhile, the authors in [69] have one utilised inband for D2D MHMP communications for the ease of radio interface control and management.

Despite the co-channel interference, the DRS in underlay mode has been drawn more studies in D2D MHMP communications thanks to its flexible design depending on only the interference limit of the CUs. In a simple sharing manner, a CU can share its spectrum resource with only one D2D hop [34] with less effect of co-channel interference. However, some works in [2, 3, 43, 52, 55, 58] allow multiple D2D hops in different paths to reuse the same spectrum resource shared by a CU as long as the signal to interference-plus-noise ratio (SINR) at the CU is greater than or equal to a given threshold.

Caching. In D2D MHMP communications, the contents can be provided by caching technique at the MBS and the SBSs [34]. However, in dense EUs of B5G networks, many contents are already cached in the EUs. The cached contents in the EUs must be exploited to relax the workload of the MBS and the SBSs as well as improve the QoS of the system [2, 3, 30, 46]. However, the caching techniques in [2, 3, 30, 34, 46] are all proactive caching in which the best SUs are assigned to serve the DU. Further reactive caching techniques that are more efficient are required to study in the context of D2D MHMP communications. It means that

Table 3. D2D MHMP Communications Applications and Services

Ref.	Applications and Services			
	CASs	Public Safety	Disaster Management	IoT, HANETs
[2, 3, 30, 46, 47, 83]	✓			
[52, 67, 69]		✓	✓	
[28, 38, 76, 84, 85]		✓		
[22, 33, 34, 36, 37, 40, 44, 63, 64, 66, 75, 86] [26, 27, 51, 53, 54, 60, 61, 79, 82, 85, 87–92]			✓	
[41–43, 53]				✓

the contents are placed in the best SUs in advance, with a certain caching density based on a prediction model of content popularity. And then, whenever a DU requests the content, D2D MHMP D2D communications are immediately established to serve the DU.

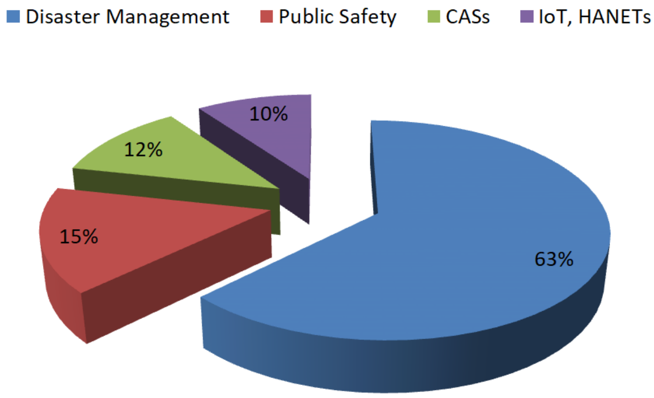

Figure 5. Key applications and services of D2D MHMP communications.

Energy Harvesting. One of the most important problems of D2D MHMP communications is that many EUs agree to join the data transmission session from the SU to the DU. These EUs have to sacrifice part of the remaining energy for D2D MHMP communications. The promising technique to compensate the EUs for their energy consumption is EH. In particular, in [54, 64], a relay EU acts as not only an information transfer (IT) node but also an energy harvesting node (energy harvested from the MBS in functional area) and an energy transfer node (to the next relay node in non-functional area). The process of EH and IT can be repeated over a path from the SU to the DU as studied in [36].

6. D2D MHMP Communications Applications and Services

As we can see from the earlier sections that D2D MHMP communications can efficiently support the MBSs and the SBSs to provide the EUs with many local advanced applications and services. In this section, typical D2D MHMP communications assisted applications and services, i.e., content delivery, public safety, disaster management, and IoT and HANET, as shown in Table 3 and Fig. 5, are presented in the sequel.

6.1. Content Delivery

In most studies, D2D MHMP communications are used for local content delivery applications and services (CASs) [2, 3]. Conventionally, the MBSs or the SBSs are responsible for cooperatively serving the EUs the CASs. In addition, D2D communications are able to do so by direct transmissions over one hop. It is necessary that D2D MHMP communications are applied to enhance the hit rate of CASs, i.e., the success probability to hit a requested content, and thus provide the EUs with better chances to access the contents. To do so, D2D MHMP communications are equipped with proactive caching techniques to bring the contents closer to the EUs or/and passive caching techniques to exploit the contents already cached in the EUs for serving the others around. As a result, the EUs can feasibly access the contents from MBSs, SBSs, direct D2D communications, and D2D MHMP communications, at the highest QoE.

6.2. Public Safety

It is interesting that D2D MHMP communications have been widely applied to B5G networks for public safety purpose [28, 38, 52, 67, 69, 76, 84, 85]. In this scenario, 5G networks may be damaged partially or fully, or the MBSs are overloaded due to the huge traffic requested from the EUs for emergency supports and communications [67]. Such public applications often get the emergency forces and local governments involved to ensure the citizens' safety. In order to meet the requirements of emergency communications like low latency, high data traffic exchange, connectivity maintenance, large coverage; routing algorithms [67], relay and clustering techniques [28, 38, 52, 69, 76], and even using UAVs [84, 85, 91]; have been further studied for D2D MHMP communications. As a result, B5G networks with D2D MHMP communications can assist the emergency forces and local governments in enhancing the performance of public safety activities.

6.3. Disaster Management

In emergency conditions like natural disasters, the numerous studies suggest that D2D MHMP is a key technology that helps to maintain the connection for rescue activities. The main reason is the mobile infrastructure is often destroyed fully or partially when a natural disaster strikes and D2D communications are proper solution for these cases [22, 27, 88]. The requirement to keep the communications ongoing is a critical matter attracting researches. Due to the damage of mobile networks during disasters, under limited energy and battery life of the mobile nodes, D2D MHMP communications are equipped with some special techniques, such as clustering, energy harvesting, cooperative beamforming [22, 27, 33, 51, 54, 63, 66, 75, 88]. Besides conventionally using the remaining mobile nodes of network infrastructure, UAVs are also deployed to establish D2D MHMP information exchanged for disaster management [53, 85, 89, 91]. The UAVs can help to replace the role of the damaged MBSs in nonfunctional areas by connecting themselves to the MBSs in functional areas. The D2D MHMP communications are then connected to the UAVs to provide the EUs with useful information that may reduce human lost in natural disasters.

6.4. IoT and HANETs

With the proliferation of wireless devices, IoT and HANETs are mentioned frequently in many applications of the fourth industrial revolution. The advantage of D2D communications that allows the mobile nodes to directly communicate with each other plays an important role in IoT networks and HANETs. D2D communications are expanded to D2D MHMP communications for IoT networks by utilising routing algorithms [42, 43, 74]. The objective is to exploit the dense mobile nodes in IoT and HANETs to minimise the energy consumption. Especially, with the help of UAVs, D2D MHMP communications and IoT networks can be efficiently applied to natural disaster management [53]. However, the most important issue of D2D MHMP communications in IoT networks and HANETs is security. The authors in [41] have listed out all the threats related to data transmission over D2D MHMP communications in IoT networks and HANETs. Meanwhile, few of studies have proposed some methods for security in IoT [41, 42].

7. Research Directions and Open Issues

D2D MHMP communications are considered as the promising solution to relax workload at backhaul link, enlarging the coverage and improving connectivity to deal with demand of users in both the number of connection and QoS. The above researches still have to be studied more to improve the QoE and the flexibility in advanced ASSs. Future research directions may focus on routing, energy efficiency, reactive caching, security, and even with UAVs assisted. In fact, there are some studies about UAVs that have been applied to D2D communications, but not many applied to D2D MHMP communications [53, 89].

In routing, selecting paths in D2D MHMP communications in order to increase the reliability of the transmitted data and reduce the latency is an important problem that needs to be studied further. Besides, studying the proper number of hops in routing algorithms is also required to select the path so that latency and energy consumption can be minimized. Related to energy efficiency and reactive caching, only minimizing the energy consumption and deploying proactive caching are not enough. It is more efficient if energy harvesting techniques are added to prolong the lifetime of mobile devices, especially in emergency scenarios, and if reactive caching techniques applied to meet the dense EUs requesting extreme high data rate ASSs in B5G networks.

Importantly, in dense B5G networks, using D2D MHMP communications will still be an important point to be researched in terms of security. The reason is that the data transmitted over D2D MHMP communications is easier to be disclosed. Security for D2D MHMP communications is also a very serious issue. Finally, when D2D MHMP communications applied to emergency scenarios, public safety, transportation systems, and smart cities, the UAVs with optimal trajectories are deployed as intermediate SBSs to support the EUs in quick response without any interruptions.

8. Conclusion

We have witnessed a great achievement in cellular mobile communications that 5G networks have been launched and equipped with many emerging technologies. In B5G networks, besides studying new disruptive solutions that may change the system architecture and require a high cost, it is important to place a high priority on the ones that do not make the system any changes, but are able to ubiquitously serve the ever-high demand of non-stop proliferation of EUs. In this paper, we have made an insightful survey on D2D MHMP communications - a promising solution for B5G networks. The survey presents throughout not only the models, techniques, and applications but also the analysis of D2D MHMP communications to know how it works, what it benefits, and which open issues can be developed in future research directions. Our work can provide the useful insights into D2D MHMP communications design and optimisation to enhance the performance of B5G networks.

References

[1] A. Asadi, Q. Wang, and V. Mancuso, "A survey on device-to-device communication in cellular networks," *IEEE Commun. Surveys & Tutorials*, vol. 16, no. 4, pp. 1801–1819, Apr. 2014.

[2] Q.-N. Tran, N.-S. Vo, T.-M. Phan, M.-P. Bui, M.-N. Nguyen, and A. Kortun, "Downlink resource allocation maximized video delivery capacity over multi-hop multi-path in dense D2D 5G networks," in *Proc. Inter. Conf. on Recent Advances in Signal Processing, Telecommun. & Computing (SigTelCom)*, Ha Noi, Vietnam, Aug. 2020, pp. 72–76.

[3] Q.-N. Tran, N.-S. Vo, M.-P. Bui, V.-C. Phan, Z. Kaleem, and T. Q. Duong, "Resource sharing and segment allocation optimized video streaming over multi-hop multi-path in dense D2D 5G networks," in *Proc. Inter. Conf. on Industrial Networks and Intelligent Syst. (INISCOM)*, Ho Chi Minh City, Vietnam, Aug. 2019, pp. 26–39.

[4] N.-S. Vo, T. Q. Duong, and M. Guizani, "QoE-oriented resource efficiency for 5G two-tier cellular networks: A femtocaching framework," in *Proc. IEEE Global Commun. Conf.*, Washington, DC, Dec. 2016, pp. 1–6.

[5] M. C. Erturk, S. Mukherjee, H. Ishii, and H. Arslan, "Distributions of transmit power and sinr in device-to-device networks," *IEEE Commun. Lett.*, vol. 17, no. 2, pp. 273–276, Feb. 2012.

[6] Z. Zhang, R. Q. Hu, and Y. Qian, "D2D communication underlay in uplink cellular networks with distance based power control," in *Proc. IEEE Inter. Commun. Conf.*, Kuala Lumpur, Malaysia, May 2016, pp. 1–6.

[7] W. Zhibo, T. Hui, and C. Nannan, "Clustering and power control for reliability improvement in device-to-device networks," in *Proc. IEEE Global Commun. Conf.*, Atlanta, GA, Dec. 2013, pp. 573–578.

[8] B. Peng, T. Peng, Z. Liu, Y. Yang, and C. Hu, "Cluster-based multicast transmission for device-to-device (D2D) communication," in *Proc. IEEE Veh. Technol. Conf.*, Las Vegas, NV, Sep. 2013, pp. 1–5.

[9] S. Han, H. Lee, J. Kim, and W. Lee, "On the connectivity in opportunistic D2D networks with hierarchical and non-hierarchical clustering," in *Proc. IEEE Global Commun. Conf. Workshops*, Washington, DC, Dec. 2016, pp. 1–6.

[10] S. Maghsudi and S. Stańczak, "Hybrid centralized–distributed resource allocation for device-to-device communication underlaying cellular networks," *IEEE Trans. Veh. Technol.*, vol. 65, no. 4, pp. 2481–2495, Apr. 2016.

[11] H. Meshgi, D. Zhao, and R. Zheng, "Optimal resource allocation in multicast device-to-device communications underlaying LTE networks," *IEEE Trans. Veh. Technol.*, vol. 66, no. 9, pp. 8357–8371, Sep. 2017.

[12] P. Janis, V. Koivunen, C. Ribeiro, J. Korhonen, K. Doppler, and K. Hugl, "Interference-aware resource allocation for device-to-device radio underlaying cellular networks," in *Proc. IEEE Veh. Technol. Conf.*, Barcelona, Spain, Apr. 2009, pp. 1–5.

[13] H. Min, J. Lee, S. Park, and D. Hong, "Capacity enhancement using an interference limited area for device-to-device uplink underlaying cellular networks," *IEEE Trans. Wireless Commun.*, vol. 10, no. 12, p. 3995–4000, Dec. 2011.

[14] H. E. Elkotby, K. M. Elsayed, and M. H. Ismail, "Exploiting interference alignment for sum rate enhancement in D2D-enabled cellular networks," in *Proc. IEEE Wireless Commun. and Networking Conf.*, Paris, France, Apr. 2012, p. 1624–1629.

[15] C. Xu, L. Song, Z. Han, Q. Zhao, X. Wang, and B. Jiao, "Interferenceaware resource allocation for device-to-device communications as an underlay using sequential second price auction," in *Proc. IEEE Inter. Commun. Conf.*, Ottawa, Canada, Jun. 2012, pp. 445–449.

[16] N.-S. Vo, T. Q. Duong, H. D. Tuan, and A. Kortun, "Optimal video streaming in dense 5G networks with D2D communications," *IEEE Access*, vol. 6, pp. 209–223, Oct. 2017.

[17] Y. Pei and Y.-C. Liang, "Resource allocation for device-to-device communication overlaying two-way cellular networks," *IEEE Trans. Wireless Commun.*, vol. 12, no. 7, pp. 3611–3621, Jul. 2013.

[18] A. Asadi and V. Mancuso, "Energy efficient opportunistic uplink packet forwarding in hybrid wireless networks," in *Proc. ACM Inter. Conf. on Future Energy Systems*, Berkeley, California, May 2013, p. 261–262.

[19] A. Asadi and V. Mancusoo, "On the compound impact of opportunistic scheduling and D2D communications in cellular networks," in *Proc. ACM Modeling, Analysis and Simulation of Wireless and Mobile Syst.*, Barcelona, Spain, Nov. 2013, p. 279–288.

[20] A. Asadi and V. Mancuso, "WiFi direct and LTE D2D in action," in *Proc. IEEE Wireless Days*, Valencia, Spain, Nov. 2013, p. 261–262.

[21] Q. Wang and B. Rengarajan, "Recouping opportunistic gain in dense base station layouts through energy-aware user cooperation," in *Proc. World of Wireless, Mobile and Multimedia Networks*, Madrid, Spain, Jun. 2013, p. 1–9.

[22] H. Gao, Y. Shen, and B. Yang, "D2D communication for disaster recovery in cellular networks," in *Proc. Inter. Conf. on Networking and Network Applications*, Kathmandu, Nepal, Oct. 2017, pp. 292–295.

[23] K. Lee, D. H. Lee, W. Hwang, and H.-J. Choi, "A multi-hop relay based frequency synchronization for D2D communication in 3GPP LTE system," in *Proc. Inter. Conf. on Ubiquitous and Future Networks*, Sapporo, Japan, July 2015, pp. 766–771.

[24] S. Wang, W. Guo, Z. Zhou, Y. Wu, and X. Chu, "Outage probability for multi-hop D2D communications with shortest path routing," *IEEE Commun. Lett.*, vol. 19, no. 11, pp. 1997–2000, Nov. 2015.

[25] S. Chakrabarti and S. Das, "Poisson point process-based network modelling and performance analysis of multi-hop D2D chain relay formation in heterogeneous wireless network," *Inter. Journal of Commun. Networks and Distributed Syst.*, vol. 22, no. 1, pp. 98–122, Jan. 2019.

[26] G. C. Deepak, A. Ladas, and C. Politis, "Robust device-to-device 5G cellular communication in the post-disaster

scenario," in *Proc. IEEE Annual Consumer Commun. & Networking Conf.*, Las Vegas, NV, Jan. 2019, pp. 1–6.

[27] A. Al-Hourani, S. Kandeepan, and A. Jamalipour, "Stochastic geometry study on device-to-device communication as a disaster relief solution," *IEEE Trans. Veh. Technol.*, vol. 65, no. 5, pp. 3005–3017, May 2015.

[28] S. Gyawali, S. Xu, F. Yey, R. Q. Huz, and Y. Qian, "A D2D based clustering scheme for public safety communications," in *Proc. IEEE Veh. Technol. Conf.*, Porto, Portugal, June 2018, pp. 1–5.

[29] H. A. B. Salameh, L. Mahdawi, A. Musa, and T. F. Hailat, "End-to-end performance analysis with decode-and-forward relays in multihop wireless systems over α–η–μ fading channels," *IEEE Syst. Journal*, vol. 14, no. 1, pp. 84–92, Mar. 2020.

[30] M. Fasil, S. Muller, H. Al-Shatri, and A. Klein, "Exploiting caching and cross-layer transitions for content delivery in wireless multihop networks," in *Proc. Inter. Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks*, Paris, France, May 2017, pp. 1–7.

[31] J. Kim and A. F. Molisch, "Quality-aware millimeter-wave device-to-device multi-hop routing for 5G cellular networks," in *Proc. IEEE Inter. Commun. Conf.*, Sydney, NSW, Australia, June 2014, pp. 5251–5256.

[32] L. Cikovskis and I. Slaidins, "Smart antennas for multi-path routing in ad-hoc wireless networks," in *Proc. Advances in Wireless and Optical Commun.*, Riga, Latvia, Nov. 2017, pp. 268–271.

[33] M. Tanha, D. Sajjadi, F. Tong, and J. Pan, "Disaster management and response for modern cellular networks using flow-based multi-hop device-to-device communications," in *Proc. IEEE Veh. Technol. Conf.*, Montreal, QC, Canada, Sep. 2016, pp. 1–7.

[34] N.-S. Vo, T. Q. Duong, and M. Guizani, "Quality of sustainability optimization design for mobile ad hoc networks in disaster areas," in *Proc. IEEE Global Commun. Conf.*, San Diego, CA, Dec. 2015, pp. 1–6.

[35] S. Kim, "A new cooperative dual-level game approach for operator-controlled multihop D2D communications," *Mobile Information Syst.*, pp. 1–11, July 2019.

[36] S. Ghosh, S. Mondal, S. D. Roy, and S. Kundu, "D2D communication with energy harvesting relays for disaster management," *Inter. Journal of Electronics*, vol. 107, no. 8, pp. 1272–1290, Feb. 2020.

[37] K. Ali, H. X. Nguyen, P. Shah, Q.-T. Vien, and E. Ever, *Internet of Things (IoT) Considerations, Requirements, and Architectures for Disaster Management System*, In: Al-Turjman F. (eds) Performability in Internet of Things. ed. Springer, 2018. [Online]. Available: https://link.springer.com/bookseries/15427

[38] L. Babun, A. İhsan Yürekli, and İsmail Güvenç, "Multi-hop and D2D communications for extending coverage in public safety scenarios," in *Proc. Computer Networks Conf. Workshops*, Clearwater Beach, FL, Oct. 2015, pp. 912–919.

[39] A. Das and N. Das, "Multihop D2D communication to minimize and balance SAR in 5G," in *Proc. Inter. Conf. on Commun. Syst. & Networks (COMSNETS)*, Bengaluru, India, Jan 2020, pp. 590–593.

[40] K. Ali, H. X. Nguyen, P. Shah, Q.-T. Vien, and E. Ever, "D2D multi-hop relaying services towards disaster communication system," in *Proc. Inter. Conf. on Telecommun.*, Limassol, Cyprus, May 2017, pp. 1–5.

[41] F. E. Mahdi, A. Habbani, B. Bouamoud, and M. Souidi, "Bootstrapping services availability through multipath routing for enhanced security in urban IoT," in *Proc. Inter. Conf. on Smart City Applications*, New York, NY, Oct. 2019, pp. 1–9.

[42] B. Hammi, S. Zeadally, H. Labiod, R. Khatoun, Y. Begriche, and L. Khoukhi, "A secure multipath reactive protocol for routing in IoT and HANETs," *Ad Hoc Networks*, vol. 103, pp. 1–19, June 2020.

[43] S. Basak and T. Acharya, "On energy efficient secure routing in multi-hop underlay D2D communications for IoT applications," *Ad Hoc Networks*, vol. 108, pp. 1–9, Nov. 2020.

[44] J. Z. Moghaddam, M. Usman, F. Granelli, and H. Farrokhi, "Cognitive radio and device-to-device communication: A cooperative approach for disaster response," in *Proc. IEEE Global Commun. Conf.*, Washington, DC, Dec. 2016, pp. 1–6.

[45] S. Othmen, S. Asklany, and A. Belghith, "A fuzzy-based delay and energy-aware routing protocol for multi-hop cellular networks," in *Proc. Inter. Wireless Commun. & Mobile Computing Conf.*, Tangier, Morocco, June 2019, pp. 1952–1957.

[46] N.-S. Vo, T. Q. Duong, and L. Shu, "Bit allocation for multi-source multi-path p2p video streaming in vod systems over wireless mesh networks," in *Proc. IEEE Inter. Commun. Conf.*, Ottawa, ON, Canada, Nov. 2012, pp. 5360–5364.

[47] Y. Zhao, Y. Li, H. Mao, and N. Ge, "Social community aware long-range link establishment for multi-hop D2D communication networks," in *Proc. IEEE Inter. Commun. Conf.*, London, UK, June 2015, pp. 2961–2966.

[48] S. Wang, O.-S. Shin, and Y. Shin, "Social-aware routing for multi-hop D2D communication in relay cellular networks," in *Proc. Inter. Conf. on Ubiquitous and Future Networks*, Zagreb, Croatia, July 2019, pp. 169–172.

[49] S. Othmen, S. Asklany, and W. Mansouri, "Fuzzy logic based on-demand routing protocol for multi-hop cellular networks (5G)," *Inter. Journal of Computer Science and Network Security*, vol. 19, no. 12, pp. 29–36, Dec. 2019.

[50] X. Ge, L. Pan, Q. Li, G. Mao, and S. Tu, "Multipath cooperative communications networks for augmented and virtual reality transmission," *IEEE Trans. Multimedia*, vol. 19, no. 10, pp. 2345–2358, Oct. 2017.

[51] M. A. Hossain, S. K. Ray, and J. Lota, "SmartDR: A device-to-device communication for post-disaster recovery," *Journal of Network and Computer Applications*, vol. 171, pp. 1–12, Dec. 2020.

[52] K. Ali, H. X. Nguyen, P. Shah, Q.-T. Vien, and N. Bhuvanasundaram, "Architecture for public safety network using D2D communication," in *Proc. IEEE Wireless Commun. and Networking Conf. Workshops*, Doha, Qatar, Apr. 2016, pp. 206–211.

[53] J. Gui and J. Deng, "Transceiver design and multihop D2D for UAV IoT coverage in disasters," *IEEE Internet of Things Journal*, vol. 6, no. 2, pp. 1803–1815, Apr. 2019.

[54] K. Ali, H. X. Nguyen, Q.-T. Vien, P. Shah, and Z. Chu, "Disaster management using D2D communication with power transfer and clustering techniques," *IEEE Access*, vol. 6, pp. 14 643–14 654, Jan. 2018.
[55] J. Gui and J. Deng, "Multi-hop relay-aided underlay D2D communications for improving cellular coverage quality," *IEEE Access*, vol. 6, pp. 14 318–14 338, Jan. 2018.
[56] E. M. Mohamed, B. M. Elhalawany, H. S. Khallaf, M. Zareei, A. Zeb, and M. A. Abdelghany, "Relay probing for millimeter wave multi-hop D2D networks," *IEEE Access*, vol. 8, pp. 30 560–30 574, Feb. 2020.
[57] S. Madabhushi and C. R. Murthy, "Delay-aware routing and data transmission for multi-hop D2D communications under stochastic interference constraints," in *Proc. Asilomar Conf. on Signals, Syst., and Computers*, Pacific Grove, CA, Apr. 2018, pp. 1079–1083.
[58] S. Alwan, I. Fajjari, and N. Aitsaadi, "Joint routing and wireless resource allocation in multihop LTE-D2D communications," in *Proc. Conf. on Local Computer Networks*, Chicago, IL, Feb. 2018, pp. 167–174.
[59] V. Tilwari, R. Maheswar, P. Jayarajan, T. V. P. Sundararajan, M. N. Hindia, K. Dimyat, H. Ojukwu, and I. S. Amiri, "MCLMR: A multicriteria based multipath routing in the mobile ad hoc networks," *Wireless Personal Commun.*, vol. 112, p. 2461–2483, Feb. 2020.
[60] L. Murry, R. Kumar, T. Tuithung, and P. M. Shakeel, "A local decision making technique for reliable service discovery using D2D communications in disaster recovery networks," *Peer-to-Peer Networking and Applications*, vol. 13, p. 1131–1141, Dec. 2019.
[61] X. Zhou, S. Durrani, and J. Guo, "Drone-initiated D2D-aided multihop multicast networks for emergency information dissemination," *IEEE Access*, vol. 8, pp. 3566–3578, Dec. 2019.
[62] K. Zhou, J. Gui, and N. Xiong, "Improving cellular downlink throughput by multi-hop relay-assisted outband d2d communications," *EURASIP Journal on Wireless Commun. and Networking*, vol. 2017, pp. 1–23, Dec. 2017.
[63] A. Masaracchia, L. D. Nguyen, T. Q. Duong, and M.-N. Nguyen, "An energy-efficient clustering and routing framework for disaster relief network," *IEEE Access*, vol. 7, pp. 56 520–56 532, Apr. 2019.
[64] Z. Chu, T. A. Le, H. X. Nguyen, A. Nallanathan, and M. Karamanoglu, "A stackelberg-game approach for disaster-recovery communications utilizing cooperative D2D," *IEEE Access*, vol. 6, pp. 10 733–10 742, Nov. 2017.
[65] R. I. Ansari, S. A. Hassan, and C. Chrysostomou, "Energy efficient relay selection in multi-hop D2D networks," in *Proc. Inter. Wireless Commun. and Mobile Computing Conf.*, Paphos, Cyprus, Sep. 2016, pp. 620–625.
[66] A. Thomas and G. Raja, "FINDER: A D2D based critical communications framework for disaster management in 5G," *Peer-to-Peer Networking and Applications*, vol. 12, p. 912–923, Oct. 2018.
[67] D. B. Arbia, M. M. Alam, R. Attia, and E. B. Hamida, "ORACE-Net: A novel multi-hop body-to-body routing protocol for public safety networks," *Peer-to-Peer Networking and Applications*, vol. 10, p. 726–749, Oct. 2016.
[68] E. Arribas and V. Mancusobe, "Achieving per-flow satisfaction with multi-path D2D," *Ad Hoc Networks*, vol. 106, pp. 1–16, Sep. 2020.
[69] K. Ali, H. X. Nguyen, P. Shah, and Q.-T. Vien, "Energy efficient and scalable D2D architecture design for public safety network," in *Proc. Inter. Conf. on Advanced Commun. Syst. and Information Security*, Marrakesh, Morocco, Oct. 2016, pp. 1–6.
[70] G. Luo, X. Wang, J. Li, and F. Yang, "Coded cooperative data exchange in multi-channel multi-hop wireless networks," *IEEE Internet of Things Journal*, vol. 7, no. 4, pp. 3013–3025, Apr. 2020.
[71] H. Yuan, W. Guo, and S. Wang, "D2D multihop routing: Collision probability and routing strategy with limited location information," in *Proc. IEEE Inter. Conf. on Commun. Workshop*, London, UK, Sep. 2015, pp. 670–674.
[72] R. C. Voicu, J. A. Copeland, and Y. Chang, "Multiple path infrastructure-less networks a cooperative approach," in *Proc. Inter. Conf. on Computing, Networking and Commun.*, Honolulu, HI, Feb. 2019, pp. 835–841.
[73] S. Madabhushi, G. R. Gopal, and C. R. Murthy, "Optimal routing and data transmission for multi-hop D2D communications under stochastic interference constraints," in *Proc. National Conf. on Commun.*, Chennai, India, Mar. 2017, pp. 1–6.
[74] G. Chen, J. Tang, and J. P. Coon, "Optimal routing for multihop social-based D2D communications in the Internet of things," *IEEE Internet of Things Journal*, vol. 5, no. 3, pp. 1880–1889, June 2018.
[75] J. Z. Moghaddam, M. Usman, and F. Granelli, "A device-to-device communication-based disaster response network," *IEEE Trans. Cognitive Commun. and Networking*, vol. 4, no. 2, pp. 1–11, June 2018.
[76] G. Fodor, S. Parkvall, S. Sorrentino, P. Wallentin, Q. Lu, and N. Brahmi, "Device-to-device communications for national security and public safety," *IEEE Access*, vol. 2, pp. 1510–1520, Dec. 2014.
[77] D. Dixit and P. R. Sahu, "Exact closed-form BER for multi-hop regenerative relay systems over $\kappa - \mu$ fading," *IEEE Wireless Commun. Lett.*, vol. 6, no. 2, pp. 246–249, Apr. 2017.
[78] S. Ghofrani-Jahromi, A. Zolghadrasli, and M. Neinavaie, "Performance analysis of multihop decode-and-forward relay networks with diversity in Nakagami fading channels," *AEU - Inter. Journal of Electronics and Commun.*, vol. 113, pp. 1–21, Jan. 2020.
[79] E. Ever, E. Gemikonakli, H. X. Nguyen, F. Al-Turjman, and A. Yazici, "Performance evaluation of hybrid disaster recovery framework with D2D communications," *Computer Commun.*, vol. 152, pp. 81–92, Feb. 2020.
[80] S. Atapattu, N. Ross, Y. Jing, Y. He, and J. S. Evans, "Physical-layer security in full-duplex multi-hop multi-user wireless network with relay selection," *IEEE Trans. Wireless Commun.*, vol. 18, no. 2, pp. 1216–1232, Feb. 2019.
[81] M. Jo, T. Maksymyuk, R. L. Batista, T. F. Maciel, A. L. de Almeida, and M. Klymash, "A survey of converging solutions for heterogeneous mobile networks," *IEEE Wireless Commun.*, vol. 21, no. 6, pp. 54–62, Dec. 2014.

[82] G. C. Deepak, A. Ladas, Y. A. Samb, H. Pervaiz, C. Politis, and M. A. Imran, "An overview of post-disaster emergency communication systems in the future networks," *IEEE Wireless Commun.*, vol. 26, no. 6, pp. 132–139, Nov. 2019.

[83] N.-S. Vo, T. Q. Duong, L. Shu, X. Du, H.-J. Zepernick, and W. Cheng, "Cross-layer design for video replication strategy over multihop wireless networks," in *Proc. IEEE Inter. Commun. Conf.*, Kyoto, Japan, June 2011, pp. 1–6.

[84] S. Shakoor, Z. Kaleem, M. I. Baig, O. Chughtai, T. Q. Duong, and L. D. Nguyen, "Role of UAVs in public safety communications: Energy efficiency perspective," *IEEE Access*, vol. 7, pp. 140 665–140 679, Sep. 2019.

[85] S. Zhang and W. Chengn, "Statistical QoS provisioning for UAV-enabled emergency communication networks," in *Proc. IEEE Global Commun. Conf. Workshops*, Waikoloa, HI, Dec. 2019, pp. 1–6.

[86] N. Saxena, M. Agiwal, H. Ahmad, and A. Roy, "D2D-based survival on sharing: For enhanced disaster time connectivity," *IEEE Technol. and Society Mag.*, vol. 37, no. 3, pp. 64–73, Sep. 2018.

[87] S. Abdellatif, O. Tibermacine, W. Bechkit, and A. Bachir, "Service oriented D2D efficient communication for post-disaster management," in *Proc. Inter. Wireless Commun. and Mobile Computing*, Limassol, Cyprus, June 2020, pp. 970–975.

[88] P. Rawat, M. Haddad, and E. Altman, "Towards efficient disaster management: 5G and device to device communication," in *Proc. Inter. Conf. on Information and Commun. Technologies for Disaster Management (ICTDM)*, Rennes, France, Dec. 2015, pp. 79–87.

[89] N. Zhao, W. Lu, M. Sheng, Y. Chen, J. Tang, F. R. Yu, and K.-K. Wong, "UAV-assisted emergency networks in disasters," *IEEE Wireless Commun.*, vol. 26, no. 1, pp. 45–51, Feb. 2019.

[90] M. Hunukumbure, T. Moulsley, A. Oyawoye, S. Vadgama, and M. Wilson, "D2D for energy efficient communications in disaster and emergency situations," in *Proc. Inter. Conf. on Software, Telecommun. and Computer Networks*, Primosten, Croatia, Sep. 2013, pp. 1–5.

[91] E. Christy, R. P. Astuti, B. Syihabuddin, B. Narottama, O. Rhesa, and F. Rachmawati, "Optimum UAV flying path for device-to-device communications in disaster area," in *Proc. Inter. Conf. on Signals and Syst.*, Sanur, Indonesia, May 2017, pp. 318–322.

[92] S. Ahmed, M. Rashid, F. Alam, and B. Fakhruddin, "A disaster response framework based on IoT and D2D communication under 5G network technology," in *Proc. Inter. Telecommun. Networks and Applications Conf.*, Auckland, New Zealand, Nov. 2019, pp. 1–6.