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DEVICE-TO-DEVICE COMMUNICATIONS DIRECTION FOR DISASTER MANAGEMENT: A REVIEW

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Abstract:

Communications in disaster management is crucial and vital to save lives. This study highlights the significant roles and impacts of Device-to-Device (D2D) communications in disaster management. The study utilizes the Web of Science (WoS) and Scopus databases, focusing on literature that explores D2D technology's application in disaster situations. The study reveals that an ample portion of the research concentrates on energy efficiency, underlining its prominence in D2D applications. Maintaining low energy consumption remains a challenge to enable reliable communications in disaster. Future research directions exhibit a promising trend towards integrating D2D with emerging technologies like the Internet of Things (IoT) and Unmanned Aerial Vehicles (UAVs) for enhanced disaster communication. This study underlines the need for continued development and implementation of D2D technologies in disaster management, contributing to saving lives and reducing the impact of disasters.

Keywords:

Disaster, Communication, D2D, Energy Efficiency, Resource Allocation

Introduction

Communication is crucial in saving lives in the event of disaster. However, the breakdown of communication networks can hinder rescue and recovery efforts, thus worsening the disaster situation. In recent years, governments worldwide have developed emergency communications

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networks to deal with disaster situations (Wang et al. 2023). The Malaysian government launched the Government Integrated Radio Network (GIRN) in 2009 to manage communications in disaster events (Anon 2012). The GIRN is based on Terrestrial Trunked Radio (TETRA), which is a digital radio communication standard used by government agencies, emergency services, and the transportation industry (Anon n.d.). Government agencies, including the Royal Malaysian Police (PDRM), the Fire and Rescue Department (JBPM), the Malaysian Armed Forces (ATM) and the Malaysian Ministry of Health (KKM), utilize this GIRN which is coordinated by the National Security Council (MKN). Figure 1 illustrates the GIRN network during disaster events.

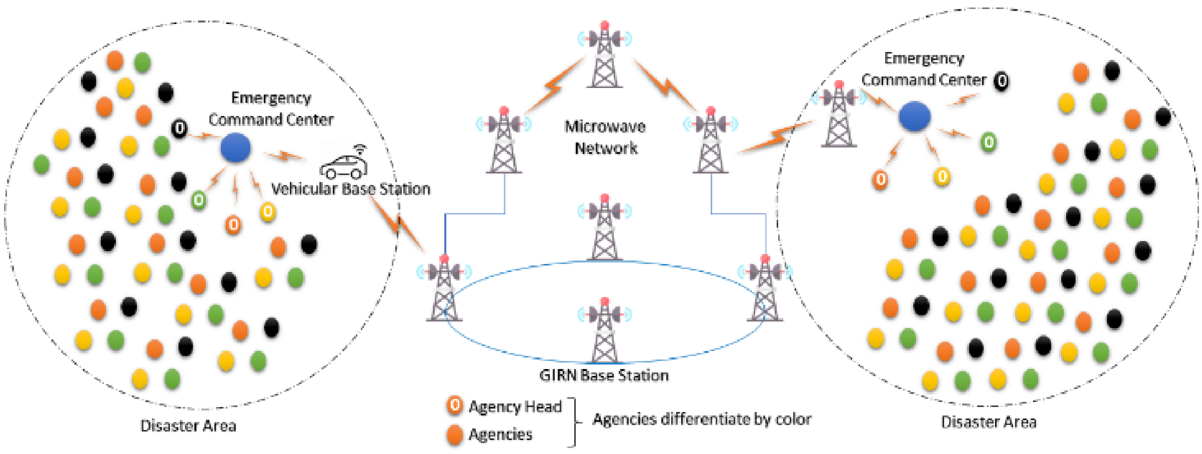

Figure 1: Government Integrated Radio Network (GIRN) in Disaster Management
Source: (Ministry of Health Malaysia 2019)

In GIRN-based communications, each agency uses a handheld device to communicate within its communications channel (talk group). The agency head then communicates with other agencies via the emergency command center set up near the disaster area. The emergency command center will then channel the information to the government office via the GIRN grid using the existing communications tower as the Base Station (BS) or Vehicular Base Station (VBS) as a secondary BS. However, this communication is only possible if the BS is not damaged. Although VBS can be deployed at a damaged BS, not all terrain is accessible via VBS.

D2D Communication and Disaster Management

On the other hand, Device-to-Device (D2D) communication is an emerging alternative enabling direct communication between devices without relying on network infrastructure such as BS (Ali et al. 2017). D2D communications offer potential advantages compared to other technologies like Long Term Evolution (LTE), Software Defined Radio, Cognitive Radio, and indoor positioning systems (Rawat, Haddad, and Altman 2015). D2D communication in disaster is underlined by its ability to maintain connectivity when cellular networks are unavailable. Furthermore, it improves spectrum efficiency by allowing devices to communicate directly over short distances. The advantages of D2D communication in such situations are included in Table 1.

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Table 1: The Advantages of D2D Communication

D2D advantages	Key Points
Resilience to Infrastructure Damage	Do not rely on fixed infrastructure, such as BS, which is susceptible to damage during natural disasters (Rihan et al. 2019).
Enhanced Connectivity	Enables devices to connect directly with each other. Maintain communication even when network services are down (Masood et al. 2020).
Rapid Deployment	It can be quickly set up and used in emergency situations without the need for extensive setup or configuration (Joseanne Viana et al. 2021).
Energy Efficiency	D2D is energy-efficient, which is vital in preserving the battery life of devices (Srideepa and Babydeepa 2023).
Support for Public Safety	Emergency responders can communicate with each other and with victims when BSs are unavailable (Joseanne Viana et al. 2021).
Low Latency	Direct communications lower latency, which is critical for time-sensitive communications during rescue operations (Joseanne Viana et al. 2021).
Flexibility and Adaptability	It can be adapted to the need for robust and reliable communication under challenging conditions (Masood et al. 2020).
Interoperability	Facilitate interoperability among different agencies and services involved in disaster response, improving coordination and collaboration (Anjum, Noor, and Anisi 2017).
Support for Emerging Technologies	D2D can be integrated with other technologies like the Internet of Things (IoT), Unmanned Aerial Vehicles (UAVs), and sensor networks to create comprehensive disaster management solutions (Srideepa and Babydeepa 2023; Joseanne Viana et al. 2021).

Agencies communicate directly with each other via direct communications using D2D technologies from their smartphones. D2D communications use Wi-Fi frequencies, which are 2.4GHz and 5GHz, to communicate with each other (Shen 2015). Additionally, agencies that are in proximity (< 50-100 meters) form a group called a cluster and elect a member as a leader or Cluster Head (CH) to communicate with another cluster. D2D communication offers several benefits in disaster situations when other communication networks are compromised or completely fail. Therefore, D2D can potentially be used for disaster communication management when the BS is unable to be used as illustrated in Figure 2.

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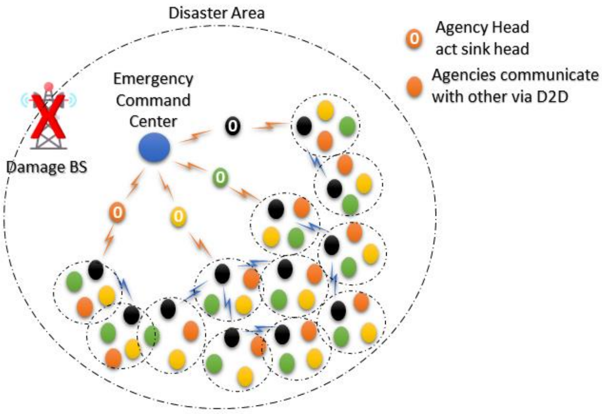

Figure 2: D2D Communications in Disaster Management

However, the use and integration of D2D communication in disasters is still under study and research. Despite its potential, several challenges are hindering its effective implementation. These challenges include efficient energy consumption (Ali et al. 2018), interference (Iqbal et al. 2023), resource allocation (Waqas et al. 2020), reliability (Nadeem et al. 2021) and security (V and Satyanarayan Reddy 2022). The main challenge in improving D2D communication for disaster is energy efficiency (Mumtaz et al. 2016). Several studies have focused on addressing the energy efficiency challenge in D2D communication for disaster. Thus, studies on clustering techniques in D2D have been identified as efficient methods to improve energy efficiency and extend network communication (Saif et al. 2021). This study aims to understand the current state of D2D communication in disaster situations. Therefore, this study aims to provide the scope and research direction for developing D2D communications in disasters.

Methodology

The main aim of this review is to contribute to the development of resilient communication systems that can support effective response and recovery operations in disaster situations. This study relied on the Web of Science (WoS) and Scopus database for data search. Tables 2 and 3 describe the details of the search.

Table 2: The Search Strings

WoS	((“device to devic” OR“device-to-devic” OR d2d) AND (disaster OR emergency OR safety) AND (communicat*)
Scopus	TITLE-ABS-KEY ((“device to devic” OR“device-to-devic” OR d2d) AND (disaster OR emergency OR safety) AND (communicat*)

Table 3: The Search Selection Criterion

Criterion	**Inclusion**	**Exclusion**
Language	English	Non-English
Timeline	2021-2023	<2021
Literature type	Journal Article	Proceeding, Book, Review

The search for articles is limited to those published between 2021 and 2023 to set the focus of the study in this period. These articles were then filtered to include purely research articles,

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excluding reviews and non-English language papers, leading to a robust selection of current research directions.

Results

Technologies Enhancement in D2D

D2D communication applications have become increasingly prominent, especially in situations where cellular communication networks fail. The integration of communication technologies in disaster management and applications has been the focus of recent research. It aims to improve the reliability and efficiency of communication in challenging situations.

A throughput-based discovery algorithm (TDA) was introduced by (Marttin et al. 2021) for D2D communication in public safety networks. TDA outperforms other algorithms, such as the Shortest Distance Algorithm (SDA) and Maximum SINR with and without distance limitations (MSNA, MSLA). Moreover, TDA has proven highly effective in environments where traditional communication infrastructure is compromised, displaying its potential as a robust solution for connectivity in emergencies. Another innovative approach is the Tactful Opportunistic Communication Strategy (TOOTS) proposed by (Costa et al. 2022). TOOTS leverages human mobility characteristics to deliver content effectively, especially in challenging environments such as emergencies. In addition, TOOTS stands out by incorporating a deep analysis of human mobility in its operational strategy. It is distinguished by its ability to reduce overhead, improve delivery rates, and minimize delivery latency, thereby offering a comprehensive guide for future advancements in opportunistic communication strategies.

Integrating UAVs with D2D users offers another dimension to this field. A method proposed by (Aslam, Harris, and Siddiq 2023) suggests clustering D2D users on the ground and using UAVs to deliver content to selected CHs. Figure 3 illustrates the UAVs' communications approach with D2D users. This approach clusters D2D users (ground nodes) and then elects a user as the CH, colored red in Figure 3. Each cluster communicates via UAV through its CH. This method addresses the energy constraints of UAVs and demonstrates improvements in throughput, energy efficiency, and content delivery timeliness.

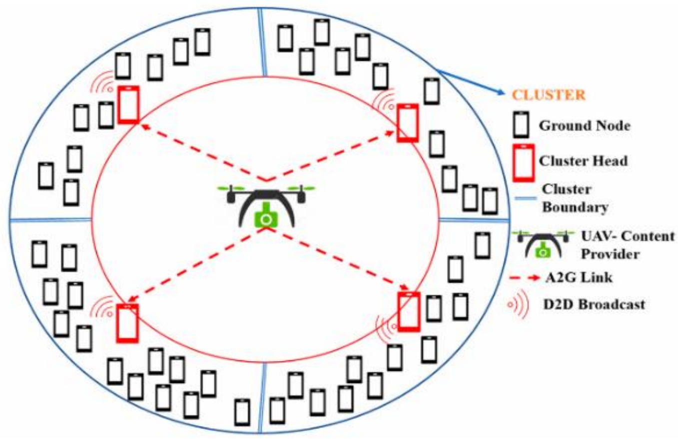

Figure 3: D2D Communication Underlaying UAV-Enabled Network

Source: (Aslam et al. 2023)

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The role of UAVs in enhancing D2D communication is also research by (Grinewitschus et al. 2021) and (J. Viana et al. 2021). The work by (Grinewitschus et al. 2021) introduced a Large Dynamic Communication Network (LDCN) that integrates D2D communication with drones, enhancing network relay and reducing latency in emergency scenarios. Conversely, (J. Viana et al. 2021) explored the impact of UAVs in 5G public safety communications, focusing on their mobility and line-of-sight advantages. The findings from this study revealed the complex relationship between UAV speed and communication efficiency, underscoring the need for optimized UAV-assisted communication strategies in emergency situations.

In the context of the IoT, studies by (Kamalov et al. 2023), (Attar 2023) and (Cheng et al. 2022) highlighted IoT's role in enhancing D2D communication. Meanwhile, (Kamalov et al. 2023) focused on the importance of efficient routing algorithms in IoT ecosystems, which are essential for managing the surge in data and internet service usage. This study offered a comprehensive guide to IoT routing solutions, addressing key aspects like safety and data flow control. The role of Machine Intelligence (MI), Deep Learning (DL), and Machine Learning (ML) in enhancing IoT security is further explored by (Attar 2023), highlighting the shift towards more sophisticated security mechanisms in IoT devices. The paper emphasizes using MI, ML and DL technologies to enhance IoT device security and tackle existing and emerging threats.

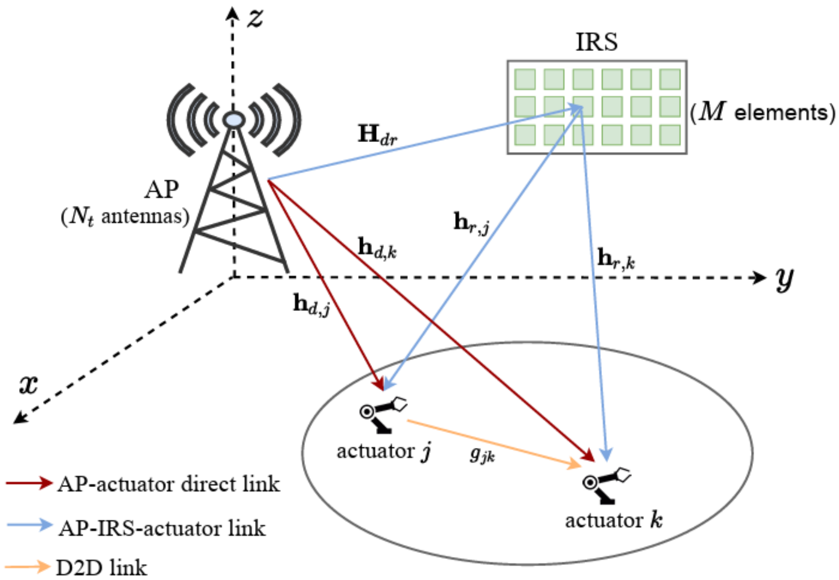

Figure 4: Communications enhanced by IRS and D2D network
Source: (Cheng et al. 2022)

(Cheng et al. 2022) investigated transmission reliability in industrial IoT settings, introducing a protocol that integrates Intelligent Reflecting Surfaces (IRS) with D2D communication, as illustrated in Figure 4. This approach, focusing on ensuring reliable communication under strict latency constraints, highlights the potential of combining IRS and D2D for robust Industrial IoT applications.

Overall, these studies collectively highlight a trend towards more efficient, reliable, and human-centered communication methods in disaster. Highlighting innovations in integrating

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advanced technologies like UAVs and IoT, these methodologies are paving the way for improved communication efficacy. Additionally, they pave the way for new avenues for research and development of D2D in disaster.

D2D Trends for Resilience Disaster Communications

Recent advancements in D2D communication have impacted disaster management strategies, offering innovative solutions for effective emergency response. Current research reveals a key focus on energy efficiency, throughput and latency optimization, interference management, secure communications, routing, and resource allocation. This demonstrates the significant role of D2D in enhancing public safety networks.

One of the primary focuses is on enhancing energy efficiency. Studies by (Ahmad et al. 2023; Elshrkasi et al. 2022; Ghosh et al. 2022; Saif et al. 2021; Seong et al. 2023) have introduced various strategies for improving energy utilization in D2D networks. These include multi-hop cognitive radio networks, clustering formation and head selection approaches, employing UAVs with energy harvesting, and the use of game theory and energy-centric nodes for routing. (Saif et al. 2021) presented an emergency communication system utilizing UAVs and energy harvesting, highlighting enhanced energy transfer efficiency and network reliability. At the same time, (Ghosh et al. 2022) explored a multi-hop cognitive radio-enabled D2D network, emphasizing the balance between collision constraints and service quality. Figure 5 displays the clustering formation approach focusing on energy efficiency proposed by (Elshrkasi et al. 2022). This study introduced the Cluster Formation and Cluster Head Selection (CFACHS) method for wireless networks in disaster scenarios, notably improving power efficiency and network capacity. Similarly, (Ahmad et al. 2023) introduced an energy-efficient UAV-assisted Energy Efficient Hierarchical Gateway Routing (EFGR) protocol for wireless sensor networks, effectively doubling network lifetime and improving coverage. These innovations aim to prolong the network lifetime, reduce power consumption, and increase network capacity, especially in disaster situations where energy sources may be extremely limited.

Meanwhile, (Seong et al. 2023) proposed the Fishbone Forwarding method to improve message delivery in IoT networks, significantly enhancing forwarding efficiency. In addition, a study by (Masood et al. 2021) explored context-aware and energy-efficient heuristic algorithms to increase the lifetime of user equipment and minimize the transmission of unnecessary discovery messages, marking a significant improvement over the traditional method that uses cellular networks.

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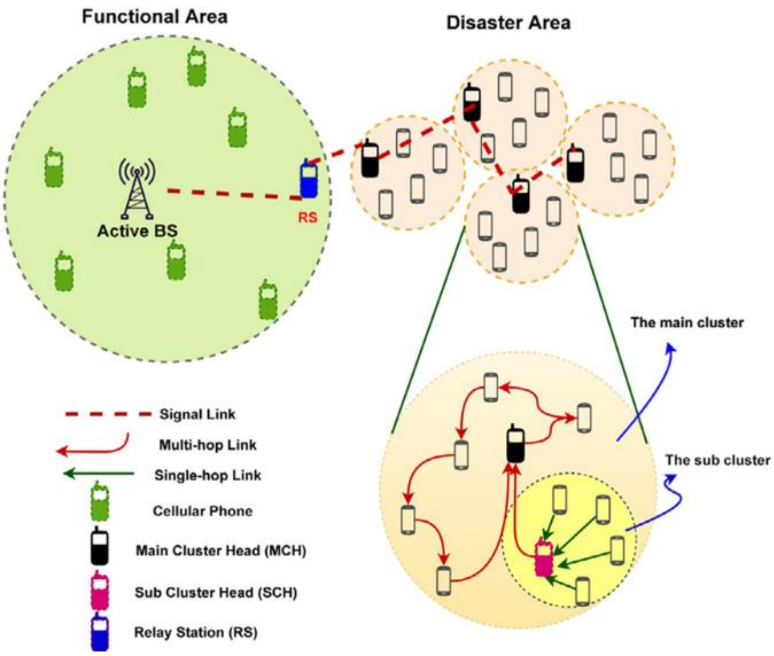

Figure 5: Energy Efficient Clustering Approach
Source: (Elshrkasi et al. 2022)

Interference management is a significant concern in D2D communications, particularly when using shared spectrum resources. Hence, research by (Murry, Kumar, and Tuithung 2021) proposed a hybrid Adaptive Neuro-Fuzzy Inference Network-based Genetic Algorithm (D2D ANFIS-GA) for optimizing CH selection and routing. This method exhibits improved energy utilization, battery lifetime, and delivery probability in disaster scenarios.

Secure communications are crucial, especially in sensitive scenarios like disasters. Therefore, (Tata and Kadoch 2022) and (Miao et al. 2023) have developed protocols and algorithms to enhance the security of D2D communications. These include the Generalized Secure Network Coding-based Data Splitting algorithm and a D2D group communication protocol for 5G wireless IoT, which integrates advanced cryptographic and network coding techniques. These protocols ensure the integrity and confidentiality of data transmissions, an essential aspect of public safety networks.

Routing and resource allocation are crucial for optimizing network performance, especially in the context of disaster, where resources are limited and need to be utilized efficiently. (Ding et al. 2022; Hussein et al. 2021; Raja et al. 2022) have explored these aspects extensively. The introduction of the OptCH_L-LDAR protocol and various algorithms for vehicular networks within the 5G framework have been instrumental in ensuring reliable Vehicle-to-Vehicle (V2V) link connectivity, maximizing Vehicle-to-Infrastructure (V2I) random capacity, and enhancing overall network utilization. These studies demonstrated significant improvements in network bandwidth efficiency and the ability to handle high-density V2V and V2I communications. Table 4 lists the clustering parameters in (Hussein et al. 2021) that are considered to optimize the network performance using clustering approaches.

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Table 4: Clustering Parameter Consideration

Parameter	Definitions
M	Total number of Cellular Users (CUs)
K	Total number of D2D Users (Dus)
$Clus_m$	Cluster of CU_m
Rem	All remaining DUs that have not been assigned to a cluster yet
Rem_{old}	Old remaining DUs from the previous loop
C_i	Possible cluster in iteration *i*
E	Remaining DUs in the current cluster
D	Selected DUs pair
L	Total number of DUs valid for clustering
d	Number of DUs in current C_i
d_{max}	Maximum cluster length
x	Cumulative sum of DUs clustered
DL	Specified maximum depth length in Depth First Search Tree (DFST)
$\max\_ff$	Maximum value of fitness function output
$best\_DU\_id$	The index number of DU that leads to the maximum value of fitness function output

Source: (Hussein et al. 2021)

In conclusion, integrating D2D communications into disaster management presents a promising prospect, including energy efficiency, interference, secure communications, and resource allocation. Research in this field is rapidly evolving, with a strong focus on developing innovative solutions adaptable to the dynamic and often unpredictable nature of disaster scenarios. Moreover, the advancements in this area not only contribute to the field of emergency communications but also pave the way for more resilient and efficient communication systems.

The Future Direction of D2D in Disaster

The research direction of D2D communication in 2023 has seen significant advancements, particularly in the context of disaster. Recent studies have focused on clustering to enhance energy efficiency, optimizing resource allocation, improving proximity services, and leveraging UAVs as alternative communication means.

In the area of energy efficiency and resource allocation, (Ghosh, Roy, and Kundu 2023) investigated the integration of Non-Orthogonal Multiple Access (NOMA) in 5G networks, specifically utilizing UAVs to support communications in out-of-coverage areas. This study combines D2D communications and Simultaneous Wireless Information and Power Transfer (SWIPT) technologies in a two-hop system, as illustrated in Figure 6. The equipment labeled (d) is the D2D, and (u) is the SWIPT. The first hop assesses outage probabilities between NOMA and Orthogonal Multiple Access (OMA) schemes, while the second hop aims to optimize energy efficiency through strategic power allocation. This dual approach demonstrates efficacy in both analytical and simulated environments.

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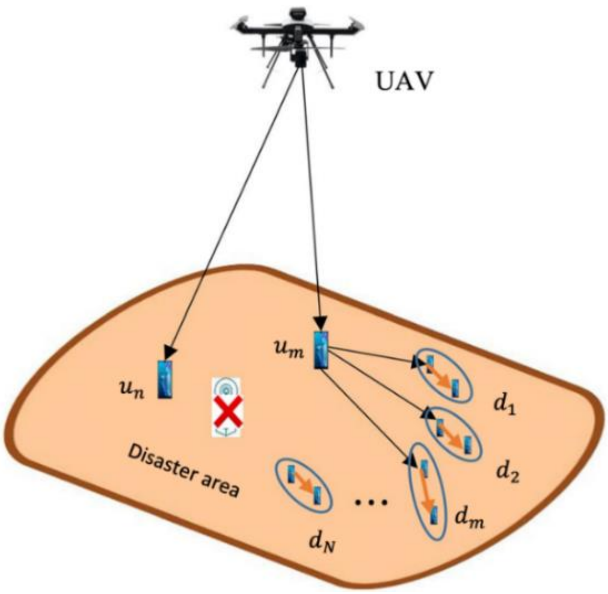

Figure 6: UAV-Assisted Downlink Multi-Hop NOMA-based D2D Network
Source: (Ghosh et al. 2023)

On the other hand, (Mai and Li 2023) focused on D2D communication within Long Term Evolution-Vehicle (LTE-V) networks. This study introduced the Semi Persistent Gain Aware Resource Allocation (SP-GARA) algorithm, targeting efficient radio resource allocation. Moreover, this algorithm addresses the interference challenges in LTE-V mode-3 standards, where cellular and V2V links share the same spectrum. The SP-GARA algorithm optimizes resource allocation based on cycle size to enhance the total sum rate, demonstrating effectiveness in improving communication efficiency and driving safety under various cycles and speeds.

Significant advancements have been made in Proximity Service (ProSe) and Wi-Fi Direct. (Chukhno et al. 2023) analyzed the evolution of New Radio (NR) sidelink compared to LTE-A sidelink, focusing on D2D-based ProSe in public safety and factory automation scenarios. This study highlights the need for mission-critical and ultra-reliable low-latency communications, conducting a preliminary analysis of NR sidelink's strengths and weaknesses. The paper also discusses future directions for NR sidelink development, emphasizing the need for standardization. In addition, (Sultan, Flayyih, and Ali 2023) proposed a mechanism to build an infrastructure-less ad hoc network for Android smartphones using Wi-Fi Direct technology. This network aims to overcome challenges posed by unreliable Internet connectivity in various scenarios, enhancing the Wi-Fi direct protocol to support reliable communication via Transmission Control Protocol (TCP).

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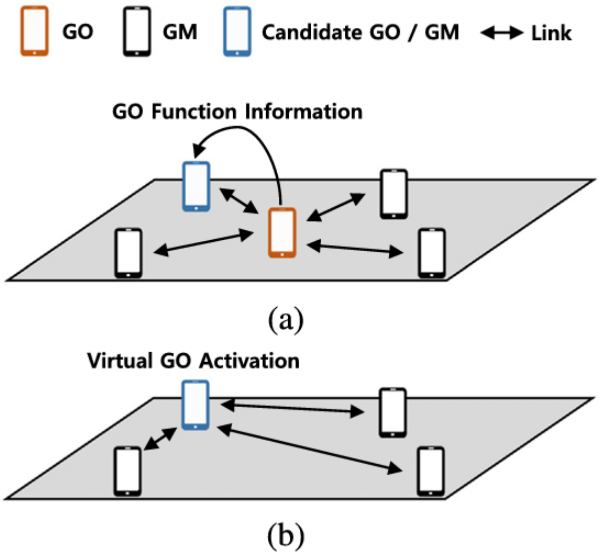

Figure 7: (a) Wi-Fi Direct before GO disappears (b) Wi-Fi Direct after GO disappears
Source: (Joo, Ko, and Kyung 2023)

(Joo et al. 2023) introduced the Autonomous Wi-Fi Direct Connectivity Maintenance Scheme (AWS) to maintain connectivity in Wi-Fi Direct group communications in Android-based smartphones. Figure 7 illustrates that CH is represented as Group Owner (GO), and next in line for CH is represented as Candidate GO (CGO). This approach maintains connectivity in the group communications by pre-selecting CGO to replace GO when it loses connection with the group. Therefore, this ensures seamless connectivity and significantly reduces group disruption time.

The use of UAVs as substitute BS in disaster zones has been a research focus point in enhancing communication networks. Figure 8 research by (Shen et al. 2023) presents an approach to UAV network deployment, integrating D2D communications where users within the UAV's range serve as hotspots, thus extending service to those outside the UAV's direct reach. This study focuses on optimizing various aspects such as UAV positioning, bandwidth allocation, data rates, and routing paths to maximize user utility.

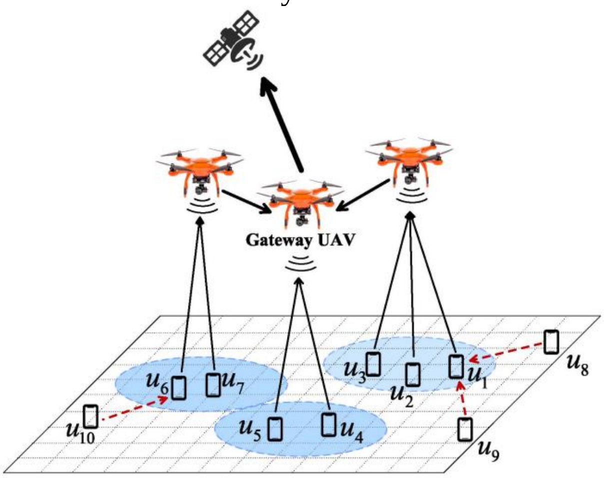

Figure 8: UAV Network with D2D Communication
Source: (Shen et al. 2023)

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The current research in D2D communications for disaster management emphasizes enhancing network resilience and efficiency. Key focuses include improving energy efficiency, optimizing resource allocation, and developing robust communication protocols, particularly in high-demand scenarios like vehicular networks. Advanced technologies such as NOMA, SWIPT, and the SP-GARA algorithm are employed to optimize network resources and minimize energy consumption.

The exploration of ProSe and Wi-Fi Direct highlights the need for self-sufficient communication systems in situations where conventional networks fail. Additionally, the use of UAVs as alternative BSs is an emerging solution to extend network coverage in disaster-affected areas. These collective efforts in D2D communications aim to build more resilient and efficient networks for effective disaster management and emergency response.

Conclusion

In conclusion, existing disaster communication systems, like the GIRN that uses Trunked Radio Network, have served vital roles in disaster management. However, they often suffer from limitations, particularly when the infrastructure is damaged. D2D communication emerges as an innovative alternative, capable of operating independently of damaged infrastructures and facilitating direct device communications.

The resilience of D2D in disaster situations is highlighted by its ability to maintain connectivity even when cellular networks break down. This feature is critical in disaster response, where communication is crucial for coordinating rescue and relief efforts. Notably, D2D's characteristics, such as energy efficiency, low latency, and support for other technologies such as drones and IoT, push forward for rapid deployment and development. This significantly enhances emergency communication's effectiveness and efficiency.

Current trends in D2D technology focus on enhancing resilience in disaster communications. Nevertheless, D2D's implementation in disaster management is not without challenges. Key areas of improvement possibilities include energy efficiency, secure communication channels, and effective interference management, all crucial for reliable disaster response. These areas are not only essential for the robustness and resilience of D2D in emergencies but also for the need to prolong the network timeline for rescue operations communications.

Looking towards the future, continuous research and development in D2D technology are vital. Advancements in areas like integration with the IoT, UAVs, and advanced energy efficiency and security algorithms are expected to play a significant role in enhancing D2D communications. Moreover, exploring innovative solutions for interference management and resource allocation will further bolster the efficacy of D2D in disaster situations.

Lastly, while D2D communication presents a promising future for disaster management, addressing challenges such as energy consumption, reliability, and security remains a primary focus of research and development. Moreover, the evolution of D2D technology will significantly contribute to more resilient, efficient, and adaptable communications to the unpredictable nature of disasters.

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