

DISASTER MANAGEMENT ASSISTED BY WIRELESS COMMUNICATION: USES, UNRESOLVED PROBLEMS, AND DIFFICULTIES

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ABSTRACT

Disaster management represents a critical area where effective communication is paramount for saving lives and minimizing damage. This paper explores the utilization of wireless communication technologies in disaster management, investigating their uses, unresolved problems, and associated difficulties. Wireless communication plays a crucial role in various phases of disaster management, including preparedness, response, and recovery. It enables rapid dissemination of vital information, facilitates coordination among response teams, and supports real-time monitoring of affected areas. Moreover, wireless technologies empower affected individuals to seek assistance and connect with loved ones during crises. However, despite its potential benefits, wireless communication in disaster management faces several unresolved challenges and difficulties. These include issues related to network reliability, interoperability among different communication systems, limited coverage in remote areas, and susceptibility to physical damage and cyber-attacks. Furthermore, ethical and privacy concerns regarding the collection and dissemination of sensitive information remain significant challenges. Addressing these unresolved problems and difficulties requires collaborative efforts among governments, disaster management agencies, telecommunications providers, and technology developers. Strategies such as investing in resilient infrastructure, enhancing cross-sector coordination, and leveraging emerging technologies like artificial intelligence and block chain can contribute to overcoming these challenges. This paper provides insights into the multifaceted landscape of wireless communication in disaster management, highlighting its potential benefits, ongoing challenges, and avenues for future research and development. By harnessing the power of wireless communication effectively and addressing its associated difficulties, disaster management efforts can be significantly enhanced, ultimately saving more lives and reducing the impact of disasters on communities worldwide.

Keyword: Response, Recovery, Coordination, Real-time monitoring, Interoperability, Artificial intelligence, Block chain, Disaster resilience

1. INTRODUCTION

Disaster management represents a complex and multifaceted challenge, requiring coordinated efforts across various sectors to effectively respond to and recover from emergencies. Central to this endeavour is the seamless exchange of critical information among response teams, authorities, and affected communities. In recent years, the integration of wireless communication technologies has emerged as a transformative force, offering innovative solutions to enhance communication and coordination in disaster management scenarios. The utilization of wireless communication technologies encompasses a wide spectrum of applications, each tailored to address specific needs and challenges encountered during different phases of disaster management. Satellite-based systems, for instance, provide ubiquitous coverage and enable real-time data transmission, making them invaluable tools for remote sensing, situational awareness, and emergency communication (Berioli et al., 2007a; Bouckaert et al., 2006). Meanwhile, ad-hoc mesh networks leverage the resilience and flexibility of decentralized architectures to establish communication infrastructures in dynamic and rapidly evolving disaster scenarios (Dilmaghani & Rao, 2008; Hadhrami et al., 2011). These technologies empower response teams with unprecedented capabilities, facilitating rapid decision-making, resource allocation, and the dissemination of critical information to affected populations. Real-time visual communication systems, for instance, enable remote experts to provide guidance and support to on-ground responders, enhancing situational awareness and optimizing resource utilization (Al Hadhrami et al., 2012). Similarly, novel emergency management platforms integrate data from diverse sources, such as sensors, social media feeds, and satellite imagery, to provide comprehensive insights into disaster dynamics and facilitate timely interventions (Bartoli et al., 2013).

However, alongside their potential benefits, the integration of wireless communication technologies into disaster management also brings forth a myriad of challenges and unresolved problems. Foremost among these are security concerns, encompassing issues such as data privacy, network resilience against cyberattacks, and the integrity of information exchanged across heterogeneous communication systems (Al-Janabi et al., 2017a; Dervin et al., 2009).

Interoperability remains another significant challenge, as disparate communication systems often struggle to seamlessly exchange information, leading to fragmented response efforts and coordination bottlenecks (Hadhami et al., 2011; Skinnemoen et al., 2004). Moreover, the inherent vulnerabilities of wireless networks, including susceptibility to physical damage, spectrum congestion, and power outages, pose operational risks that must be addressed to ensure the reliability and resilience of communication infrastructures during emergencies (Chen et al., 2009; Gelenbe et al., 2012). These challenges underscore the need for comprehensive and interdisciplinary approaches to disaster management, integrating technological innovations with policy frameworks, institutional coordination mechanisms, and community engagement strategies. In light of these complexities, this paper aims to provide a comprehensive exploration of disaster management assisted by wireless communication. By synthesizing insights from a diverse array of scholarly contributions and empirical studies, it seeks to elucidate the uses, unresolved problems, and difficulties encountered in harnessing wireless technologies for disaster management. Through a nuanced understanding of these challenges, stakeholders can develop targeted strategies and innovative solutions to enhance the resilience and effectiveness of disaster response efforts, ultimately contributing to the protection of lives and livelihoods in the face of adversity.

2. DISASTER MANAGEMENT STAGES IN WIRELESS COMMUNICATION

Disaster management, particularly when augmented by wireless communication technologies, encompasses several stages aimed at mitigating the impact of disasters, responding effectively to emergencies, and facilitating recovery and reconstruction efforts. These stages are essential for leveraging the capabilities of wireless communication to enhance coordination, information exchange, and resource management throughout the disaster lifecycle.

I. Mitigation: Wireless communication technologies play a crucial role in disaster mitigation by enabling early warning systems, real-time monitoring, and risk assessment. Satellite-based systems provide wide-area coverage and facilitate the collection of environmental data for hazard mapping and vulnerability analysis (Berioli et al., 2007a). Additionally, wireless sensor networks enable the continuous monitoring of environmental parameters, such as seismic activity and weather patterns, to identify potential threats and mitigate risks (Wang et al., 2006). However, unresolved challenges such as the integration of heterogeneous data sources and the accuracy of predictive models hinder the effectiveness of mitigation efforts (Gelenbe et al., 2012).

Table-1: A comparison table of wireless communication technologies in disaster management

Technology	Application	Advantages	Challenges	References Range
Wireless Mesh Networks (WMNs)	Emergency communication system, disaster recovery	Rapid deployment, self-organizing, fault tolerance	Security issues, network scalability	3, 7, 22, 52
Satellite Communications	Real-time visual communication, emergency response	Wide coverage, rapid deployment	Susceptible to weather, costly infrastructure	9, 10, 11, 12, 13, 19, 20, 21, 30, 35, 42, 43, 45, 55, 56, 60, 61
Mobile Ad-hoc Networks (MANETs)	Emergency response, routing algorithms	Flexibility, self-configuring, low cost	Security vulnerabilities, scalability issues	3, 6, 15, 36, 48, 58, 64, 66
Wireless Sensor Networks (WSNs)	Disaster recovery, intrusion detection	Low-cost deployment, energy-efficient	Limited coverage, scalability challenges	4, 46, 51, 67
Proxy Mobile IPv6 (PMIPv6)	Secure information sharing	Seamless handover, network mobility	Authentication vulnerabilities	6, 31

II. Preparedness: Wireless communication technologies enhance preparedness by facilitating the rapid dissemination of information, coordination of response efforts, and training of emergency responders. Mobile communication networks enable the distribution of emergency alerts, evacuation instructions, and preparedness guidelines to at-risk populations (Hadhami et al., 2011). Moreover, simulation and training exercises conducted over wireless networks enable responders to familiarize themselves with emergency protocols and enhance their readiness to deploy in crisis situations (Dilmaghani & Rao, 2008). However, interoperability issues between different communication systems pose a significant challenge to preparedness efforts, limiting the seamless exchange of information among stakeholders (Skinnemoen et al., 2004).

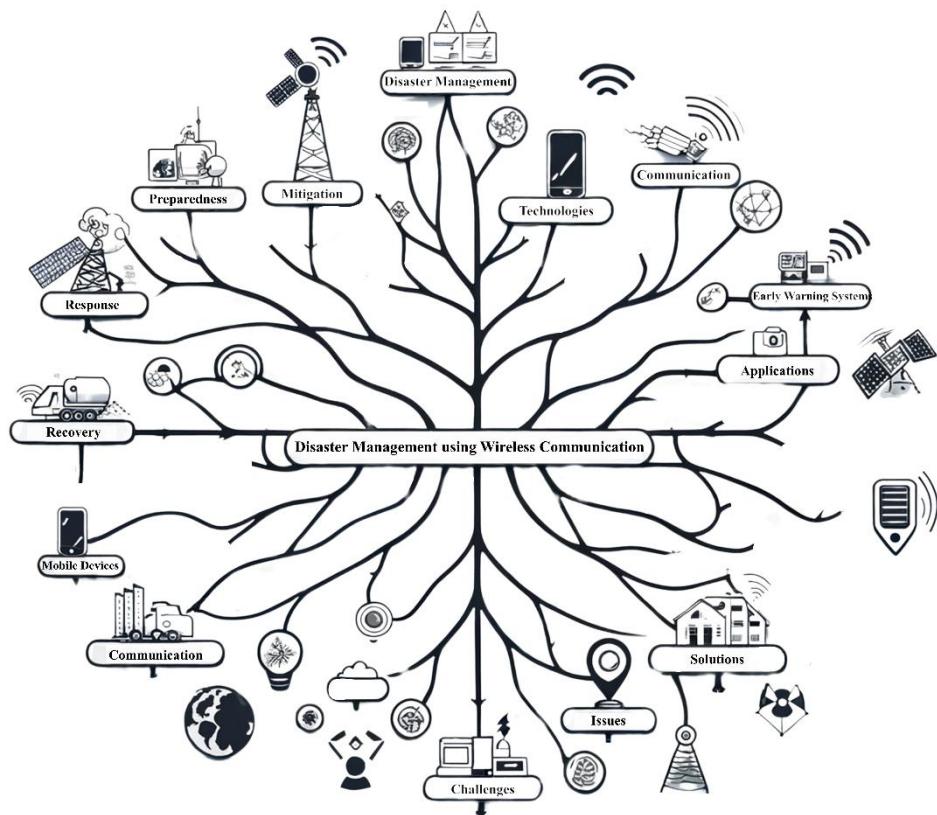


Figure 1: Illustration of Mind Map: Disaster Management Using Wireless Communication

III. Response: During the response phase, wireless communication technologies facilitate real-time communication, coordination of rescue operations, and delivery of emergency services. Wireless mesh networks enable ad-hoc communication infrastructures to be quickly deployed in disaster-affected areas, enabling responders to communicate and collaborate effectively (Bouckaert et al., 2006). Furthermore, satellite-based communication systems provide connectivity in remote or inaccessible regions, enabling the transmission of critical data and coordination of search and rescue efforts (Al Hadhrami et al., 2012). However, security concerns, such as the vulnerability of wireless networks to cyberattacks, pose significant challenges to the reliability and integrity of communication systems during response operations (Al-Janabi et al., 2017a).

IV. Recovery: Wireless communication technologies support recovery efforts by facilitating the restoration of essential services, dissemination of recovery information, and coordination of assistance programs. Mobile communication networks enable the delivery of financial aid, medical services, and other support services to affected populations (Bartoli et al., 2013). Additionally, social media platforms and crowdsourcing applications enable affected individuals to access information about available resources, community support initiatives, and government assistance programs (Peng et al., 2009). However, limited network resilience and bandwidth constraints may impede the scalability and effectiveness of recovery efforts, particularly in densely populated or resource-constrained areas (Chen et al., 2009).

V. Reconstruction: Wireless communication technologies contribute to reconstruction efforts by supporting long-term recovery planning, infrastructure rebuilding, and community resilience building. Geographic information systems (GIS) and remote sensing technologies facilitate damage assessment, land-use planning, and infrastructure prioritization for reconstruction projects (Del Re, 2011). Moreover, wireless communication networks enable the implementation of smart infrastructure solutions, such as sensor-equipped buildings and resilient communication networks, to enhance the resilience of communities against future disasters (Fantacci et al., 2010). Nonetheless, challenges such as limited funding, regulatory barriers, and technological obsolescence may impede the adoption and sustainability of wireless-enabled reconstruction initiatives (Del Re et al., 2013).

In conclusion, disaster management stages, when assisted by wireless communication, represent a comprehensive approach to enhancing resilience and reducing vulnerability to disasters. While wireless communication technologies offer significant potential to improve disaster management outcomes, unresolved problems such as security vulnerabilities, interoperability issues, and resource constraints underscore the need for continued research, innovation, and collaboration to address these challenges effectively.

1.2 Wireless Communication-Based Disaster Management Applications:

Wireless communication technologies offer versatile applications in disaster management across various stages of mitigation, preparedness, response, recovery, and reconstruction. Leveraging these technologies can significantly enhance the effectiveness and efficiency of disaster management efforts. Some key applications of wireless communication in disaster management:

I. Early Warning Systems: Wireless communication enables the rapid dissemination of early warnings to at-risk populations in disaster-prone areas. SMS alerts, mobile applications, and broadcast messages can deliver timely notifications about impending hazards such as floods, earthquakes, tsunamis, or severe weather events (Al Hadhrami et al., 2012).

II. Remote Monitoring and Sensing: Wireless sensor networks (WSNs) facilitate remote monitoring of environmental parameters such as temperature, humidity, air quality, and seismic activity. These sensors provide real-time data to support decision-making and hazard assessment by emergency responders and authorities (Chen et al., 2009).

III. Coordination and Communication: During disaster response operations, wireless communication networks enable seamless coordination and communication among emergency responders, government agencies, and humanitarian organizations. Mobile phones, two-way radios, satellite phones, and broadband internet connections facilitate information exchange, resource allocation, and situational awareness in the field (Bai et al., 2010).

IV. Search and Rescue Operations: Wireless communication technologies support search and rescue operations by enabling location tracking, communication with survivors, and coordination of rescue teams. Global navigation satellite systems (GNSS), such as GPS, and satellite communication systems provide precise location information and communication links in remote or inaccessible areas (Fantacci et al., 2010).

V. Medical Assistance and Telemedicine: Wireless communication facilitates the delivery of medical assistance and telemedicine services to disaster-affected populations. Mobile health (mHealth) applications, remote diagnostics, and teleconsultations enable healthcare providers to assess and treat patients, even in resource-constrained or remote environments (Bartoli et al., 2013).

VI. Damage Assessment and Mapping: Wireless communication technologies support post-disaster damage assessment and mapping efforts. Unmanned aerial vehicles (UAVs) equipped with cameras and sensors can capture high-resolution imagery and data for assessing infrastructure damage, identifying hazards, and prioritizing recovery efforts (Del Re et al., 2013).

VII. Community Engagement and Information Sharing: Social media platforms, community-based networks, and crowdsourcing applications empower disaster-affected communities to share information, report incidents, and access support services. These platforms facilitate peer-to-peer communication, community organizing, and the dissemination of recovery information and resources (Peng et al., 2009).

VIII. Recovery and Reconstruction Planning: Wireless communication technologies support long-term recovery and reconstruction planning by enabling data collection, analysis, and stakeholder engagement. Geographic information systems (GIS), remote sensing, and participatory mapping tools facilitate spatial planning, infrastructure design, and community engagement in rebuilding efforts (Berioli et al., 2011b).

Table-2: A case studies table for recent disasters involving wireless communication technologies

DISASTER	LOCATION	DATE	WIRELESS TECHNOLOGY USED	APPLICATION	OUTCOME	REFERENCES
HURRICANE HARVEY	Houston, Texas	August 2017	Wireless Mesh Networks	Emergency communication system, disaster recovery	Facilitated coordination among rescue teams	1
CALIFORNIA WILDFIRES	California, USA	2019-2020	Satellite Communications	Real-time visual communication, emergency response	Enabled aerial surveillance and coordination	2,3
HURRICANE MARIA	Puerto Rico	September 2017	Mobile Ad-hoc Networks	Emergency response,	Provided connectivity in areas with	4

				routing algorithms	damaged infrastructure	
EARTHQUAKE IN NEPAL	Nepal	April 2015	Wireless Sensor Networks	Disaster recovery, intrusion detection	Used for monitoring structural integrity of buildings	5
TSUNAMI IN JAPAN	Japan	March 2011	Proxy Mobile IPv6	Secure information sharing	Supported mobile communication during evacuation	6

In summary, wireless communication-based applications play a vital role across all phases of disaster management, from early warning and preparedness to response, recovery, and reconstruction. By harnessing the capabilities of wireless technologies, stakeholders can improve disaster resilience, enhance situational awareness, and facilitate more effective and coordinated responses to disasters.

Open Issues in Wireless Communication:

The significant progress made in leveraging wireless communication for disaster management, several unresolved issues persist, hindering the full realization of its potential. Some of the open issues in wireless communication for disaster management:

I. Network Resilience and Robustness: Wireless communication networks are susceptible to disruptions caused by power outages, physical damage to infrastructure, and network congestion during disasters. Ensuring the resilience and robustness of wireless networks to withstand such disruptions remains a challenge (Gorbil & Gelenbe, 2013).

II. Interoperability and Standardization: Interoperability among diverse wireless communication systems used by different agencies and organizations is crucial for seamless coordination and information sharing during disaster response. However, achieving interoperability and standardization across heterogeneous networks poses technical and organizational challenges (Portmann & Pirzada, 2008).

III. Scalability and Capacity: During large-scale disasters, the demand for wireless communication services surges, leading to congestion and degraded network performance. Scalability and capacity issues arise concerning the ability of wireless networks to handle increased traffic and support a growing number of users simultaneously (Sterbenz et al., 2010).

IV. Security and Privacy: Wireless communication systems in disaster scenarios are vulnerable to various security threats, including eavesdropping, data interception, and network breaches. Ensuring the security and privacy of communication channels, sensitive data, and infrastructure remains a pressing concern (Casoni & Paganelli, 2011).

V. Energy Efficiency: Many wireless communication devices used in disaster management, such as mobile phones and sensor nodes, operate on limited battery power. Enhancing the energy efficiency of these devices and optimizing energy consumption to prolong operational lifetimes are essential for sustained communication capabilities in prolonged disaster situations (Karakostas & Markou, 2008).

VI. Coverage and Connectivity: Remote or geographically isolated areas may lack adequate wireless coverage and connectivity, posing challenges for communication and coordination efforts in disaster response. Extending coverage and ensuring connectivity in underserved regions remain critical issues (Shibata et al., 2008).

VII. Data Management and Analytics: Wireless communication generates vast amounts of data during disaster events, including sensor data, imagery, and communication logs. Effectively managing, processing, and analyzing this data to derive actionable insights and support decision-making present significant technical and computational challenges (Madni et al., 2018).

VIII. Human Factors and Behavioral Considerations: Human factors, such as user behavior, trust in technology, and information-seeking patterns, influence the adoption and effectiveness of wireless communication systems in disaster scenarios. Understanding and addressing human-centric factors are essential for designing user-friendly and culturally appropriate communication solutions (Loukas et al., 2013b).

These open issues require collaborative efforts from researchers, practitioners, policymakers, and technology developers. Tackling these challenges, the resilience, effectiveness, and impact of wireless communication in disaster management can be significantly enhanced.

Table-3: Key Challenges and Proposed Solutions

Challenge	Proposed Solutions	References
Limited Bandwidth and Power Consumption	- Implement efficient compression algorithms to reduce data size without compromising quality. - Optimize power management strategies to extend device battery life.	9, 21, 22, 34, 53
Security and Privacy Concerns	- Employ encryption techniques to secure data transmission and storage. - Implement access control mechanisms to restrict unauthorized access to sensitive information. - Integrate authentication protocols to verify the identity of users and devices.	1, 14, 26, 41, 53
Interoperability Issues Between Different Wireless Networks	- Develop standardized communication protocols and interfaces to facilitate interoperability between heterogeneous wireless technologies. - Implement gateway devices or middleware solutions to bridge communication gaps between disparate networks.	10, 35, 53, 55, 66
Signal Interference and Degradation in Satellite Communication	- Deploy advanced antenna technologies and signal processing algorithms to mitigate signal interference and enhance communication reliability. - Utilize adaptive modulation and coding techniques to optimize satellite link performance under varying environmental conditions.	19, 21, 23, 44, 53
Scalability and Reliability of Emergency Communication Systems	- Design distributed and redundant communication architectures to ensure scalability and fault tolerance in emergency scenarios. - Implement dynamic resource allocation algorithms to prioritize critical communication traffic and adapt to changing network conditions.	1, 4, 11, 23, 30
Deployment Logistics and Infrastructure Damage	- Develop lightweight and portable communication equipment for rapid deployment in disaster-affected areas. - Pre-position emergency communication kits and infrastructure components in strategic locations to facilitate quick deployment and setup.	11, 34, 41, 61, 64
Localization Accuracy and Coverage Limitations	- Integrate multiple positioning technologies (e.g., GPS, Wi-Fi, cellular) to improve localization accuracy and reliability in diverse environments. - Enhance network coverage through the deployment of additional access points or relay nodes in areas with poor signal reception.	3, 13, 38, 60, 66
Routing Efficiency in Dynamic Network Environments	- Implement adaptive routing protocols that dynamically adjust to network topology changes and node mobility. - Utilize multi-path routing strategies to improve resilience and reliability in the face of link failures or congestion.	3, 16, 50, 60, 66

3. RESEARCH CHALLENGES

In this section, some of the major design challenges and considerations of Wireless communication-based disaster management are discussed. Some of the research challenges are as follows:

I. Dynamic Network Management: Wireless communication networks in disaster scenarios must dynamically adapt to changing conditions such as network topology changes, resource availability, and user mobility. Research is needed to develop efficient network management algorithms that can optimize performance and resource utilization in dynamic environments (Kafaie et al., 2018).

II. Reliable Communication Protocols: Designing communication protocols that ensure reliable message delivery in the presence of intermittent connectivity, network partitions, and high packet loss rates is essential. Research is required to develop robust communication protocols that can tolerate disruptions and provide timely delivery of critical information (Perkins & Royer, 1999).

III. Spectrum Allocation and Utilization: Efficient spectrum allocation and utilization are crucial for maximizing the capacity and performance of wireless communication systems in disaster scenarios. Research is needed to explore dynamic spectrum access techniques, cognitive radio networks, and spectrum sharing policies to address spectrum scarcity and interference issues (Skinnemoen et al., 2004).

IV. Data Fusion and Decision Support: Integrating heterogeneous data sources from sensors, social media, and other sources requires advanced data fusion techniques. Research is needed to develop data fusion algorithms and decision support systems that can integrate, analyze, and visualize diverse data streams to support situational awareness and decision-making by emergency responders (Ellison et al., 1997).

V. Privacy and Security: Protecting the privacy and security of sensitive data transmitted over wireless communication networks is paramount. Research is required to develop encryption, authentication, and access control mechanisms that can safeguard data privacy and mitigate the risk of cyberattacks, data breaches, and unauthorized access (Michalas et al., 2012).

VI. Energy-Efficient Networking: Wireless communication devices often operate on limited battery power, making energy efficiency a critical concern. Research is needed to develop energy-efficient networking protocols, power management techniques, and energy harvesting solutions to extend the operational lifetime of devices and ensure continuous communication capabilities (Wodczak, 2012a).

VII. User-Centric Design and Human Factors: Understanding the needs, capabilities, and limitations of end-users is essential for designing effective wireless communication systems for disaster management. Research is needed to incorporate user-centric design principles, usability testing, and human factors considerations into the development of communication technologies to enhance user acceptance and adoption (Loukas et al., 2013a).

VIII. Cross-Disciplinary Collaboration: Disaster management involves multiple stakeholders from diverse disciplines, including engineering, social sciences, public policy, and emergency management. Research is needed to foster interdisciplinary collaboration and knowledge exchange to address the complex challenges of disaster management effectively (Rose et al., 2005).

Table-4: Summary of Literature Review

Reference	Uses of Wireless Communication	Unresolved Problems	Difficulties
Adam et al. (2008)	Secure information sharing and analysis for effective emergency management.	-	-
Al Hadhrami et al. (2012)	Real-time visual communication to aid disaster recovery in a multi-segment hybrid wireless networking system.	Limited bandwidth and power consumption present challenges in transmitting high-quality real-time visual data.	Resource constraints and network congestion can hinder the efficient delivery of critical visual information, especially in large-scale disaster scenarios.
Al-Janabi et al. (2017a)	Survey of main challenges (security and privacy) in wireless body area networks for healthcare applications.	Security and privacy concerns, including unauthorized access to sensitive health data and potential breaches of confidentiality.	-
Bai et al. (2010)	Development of an emergency communication system using heterogeneous wireless networking technologies.	Interoperability issues between different wireless networks and devices, which can hinder seamless communication during emergencies.	Integration complexity when combining various wireless technologies, as well as reliability concerns in maintaining continuous communication channels.
Berioli et al. (2007b)	Integration of satellite and terrestrial technologies for	Interference from environmental factors and signal degradation during transmission over long	Cost implications associated with deploying and maintaining hybrid satellite-terrestrial communication

	emergency communications, focusing on the Wisecom project.	distances, particularly in remote or disaster-affected areas.	infrastructure, as well as challenges in coordinating communication protocols and standards between different systems.
Calarco et al. (2010)	Development of a satellite-based system for managing crisis scenarios, with a focus on the E-Sponder perspective.	Scalability issues in handling large volumes of emergency data and ensuring reliable communication links under high network load conditions.	Latency introduced by satellite communication delays and signal attenuation due to atmospheric conditions, which can impact the responsiveness and effectiveness of the crisis management system.
Chen et al. (2009)	Exploration of wireless mesh network applications in earthquake response, particularly for facilitating communication among rescue teams and affected communities.	Challenges related to maintaining network connectivity in dynamic and unpredictable environments, as well as ensuring timely and reliable data transmission.	Deployment logistics for setting up wireless mesh infrastructure in disaster-affected areas, as well as potential damage to existing infrastructure hindering network operations.
Del Re (2011)	Design and implementation of an integrated satellite-terrestrial navigation/communication/GMES system for emergency scenarios.	Security vulnerabilities in satellite-based communication systems, including the risk of unauthorized access to sensitive navigation and communication data.	Bandwidth limitations and spectrum management challenges when allocating resources for emergency communication services, as well as interoperability issues between different navigation and communication protocols.
Del Re et al. (2013)	Development of satellite-assisted localization and communication systems for emergency services, focusing on the Salice project.	Localization accuracy challenges in satellite-based positioning systems, particularly in urban environments with tall buildings and obstructed line-of-sight conditions.	Cost-effectiveness considerations when deploying satellite-based emergency communication infrastructure, as well as user adoption barriers related to unfamiliarity with satellite technology and services.
Iapichino et al. (2008b)	Implementation of mobile ad-hoc satellite and wireless mesh networking solutions for public safety and crisis management applications.	Routing efficiency challenges in dynamic network environments, where frequent topology changes and node mobility can disrupt communication paths.	Node mobility constraints and topology changes affecting the stability and reliability of ad-hoc communication links, as well as scalability issues when expanding network coverage to support larger disaster scenarios.
Portmann et al. (2008)	Deployment of wireless mesh networks for public safety and crisis management purposes, focusing on ensuring reliable communication in emergency situations.	Coverage limitations in wireless mesh networks, particularly in large-scale disaster areas with sparse population density or geographical obstacles.	Signal interference from environmental factors and neighboring wireless networks, as well as power consumption concerns in maintaining continuous network operations during prolonged emergencies.

4. CONCLUSION AND FUTURE DIRECTION

In conclusion, the integration of wireless communication technology into disaster management systems presents a compelling avenue for bolstering response efforts across the globe. Despite its potential, this integration encounters multifaceted challenges that demand concerted attention and innovative solutions. Moving forward, research and development efforts should prioritize several key areas. Firstly, the incorporation of emerging technologies such as artificial intelligence, machine learning, and edge computing can revolutionize disaster response by enabling real-time data analytics, predictive modeling, and autonomous decision-

making. These advancements have the potential to significantly enhance situational awareness and coordination among response teams. Secondly, community engagement and empowerment should be central to future endeavors. By involving local communities in the design, deployment, and maintenance of communication infrastructure, resilience can be greatly improved. Initiatives such as participatory approaches and citizen science projects can foster trust, collaboration, and effective communication during crises.

Moreover, resilient infrastructure design is essential for ensuring continuity of communication services in the face of natural disasters, cyber-attacks, or other disruptions. This necessitates exploring robust network architectures, self-healing mechanisms, and redundant communication pathways. In parallel, the development of policy and regulatory frameworks is crucial to address legal, ethical, and privacy concerns while facilitating innovation and deployment. Collaboration with policymakers, regulators, and industry stakeholders is imperative to navigate these complex issues. Investing in capacity building and training initiatives is another critical aspect. By enhancing the technical expertise and preparedness of emergency responders, telecommunication professionals, and community volunteers, the effectiveness of wireless communication systems in disaster response can be maximized.

Lastly, fostering international collaboration, knowledge sharing, and technology transfer is essential to address global challenges in disaster management comprehensively. Leveraging lessons learned, best practices, and innovative solutions from diverse regions and contexts can accelerate progress and enhance the resilience of communities worldwide. In essence, while significant strides have been made in leveraging wireless communication for disaster management, there is still considerable work ahead. By addressing the identified challenges and embracing emerging opportunities, we can harness the full potential of wireless communication to save lives, protect livelihoods, and build more resilient communities in the face of disasters.

5. REFERENCES

- [1] Adam, N.R., Atluri, V., Chun, S., Ellenberger, J., Shafiq, B., Vaidya, J., Xiong, H., 2008. Secure information sharing and analysis for effective emergency management. In: Proceedings of the 2008 International Conference on Digital Government Research. Digital Government Society of North America, pp. 407–408.
- [2] Al Hadhrami, T., Wang, Q., Grecos, C., 2012. Real-time visual communication to aid disaster recovery in a multi-segment hybrid wireless networking system. In: SPIE Photonics Europe, International Society for Optics and Photonics 84370R.
- [3] Al Hadhrami, T., Wang, Q., Grecos, C., 2013. Power-and node-type-aware routing algorithm for emergency-response wireless mesh networks. In: Vehicular Technology Conference (VTC Spring), 2013 IEEE 77th. IEEE, pp. 1–5.
- [4] Al-Janabi, S., Al-Shourbaji, I., Shojafar, M., Shamshirband, S., 2017a. Survey of main challenges (security and privacy) in wireless body area networks for healthcare applications. Egyptian Inf. J. 18, 113–122.
- [5] Al-Janabi, S., 2017b. Pragmatic miner to risk analysis for intrusion detection (pmra-id). In: International Conference on Soft Computing in Data Science. Springer, pp. 263–277.
- [6] Ali, S.H., 2013. Novel approach for generating the key of stream cipher system using random forest data mining algorithm. In: 2013 Sixth International Conference on Developments in ESystems Engineering, pp. 259–269.
- [7] Bai, Y., Du, W., Ma, Z., Shen, C., Zhou, Y., Chen, B., 2010. Emergency communication system by heterogeneous wireless networking. In: Wireless Communications, Networking and Information Security (WCNIS), 2010 IEEE International Conference on. IEEE, pp. 488–492.
- [8] Bartoli, G., Fantacci, R., Gei, F., Marabissi, D., Miccillo, L., 2013. A novel emergency management platform for smart public safety. Int. J. Commun. Syst. 28, 928–943.
- [9] Berioli, M., Courville, N., Werner, M., 2007a. Integrating satellite and terrestrial technologies for emergency communications: the wisecom project. In: QShine 2007 Workshop: Satellite/Terrestrial Interworking, ACM, p. 2.
- [10] Berioli, M., Courville, N., Werner, M., 2007b. Emergency communications over satellite: the wisecom approach. In: Mobile and Wireless Communications Summit, 2007. 16th IST. IEEE, pp. 1–5.

[11] Berioli, M., Chaves, J.M., Courville, N., Bouthry, P., Fondere, J.-L., Skinnemoen, H., Tork, H., Werner, M., Weinlich, M., 2011a. Wisecom: a rapidly deployable satellite backhauling system for emergency situations. In: International Journal of Satellite Communications and Networking, vol. 29. Wiley Online Library, pp. 419–440.

[12] Berioli, M., Molinaro, A., Morosi, S., Scalise, S., 2011b. Aerospace communications for emergency applications. In: Proceedings of the IEEE, vol. 99, pp. 1922–1938.

[13] Calarco, G., Casoni, M., Paganelli, A., Vassiliadis, D., Wódczak, M., 2010. A satellite based system for managing crisis scenarios: the e-sponder perspective. In: Advanced Satellite Multimedia Systems Conference (Asma) and the 11th Signal Processing for Space Communications Workshop (spsc), 2010 5th. IEEE, pp. 278–285.

[14] Casoni, M., Paganelli, A., 2011. Security issues in emergency networks. In: Wireless Communications and Mobile Computing Conference (IWCMC), 2011 7th International. IEEE, pp. 2145–2150. Channa, M.I., Ahmed, K.M., 2010. Emergency response communications and associated security challenges. Int. J. Netw. Secur. Appl. 2, 179.

[15] Chen, Z., Chen, L., Liu, Y., Piao, Y., 2009. Application research of wireless mesh network on earthquake. In: Industrial and Information Systems, 2009. IIS'09. International Conference on. IEEE, pp. 19–22.

[16] Crondstedt, M., 2002. Prevention, preparedness, response, recovery an outdated concept? Aust. J. Emerg. Manag. 17, 10–13.

[17] Degwekar, S., DePree, J., Beck, H., Thomas, C.S., Su, S.Y., 2007. Event-triggered data and knowledge sharing among collaborating government organizations. In: Proceedings of the 8th Annual International Conference on Digital Government Research: Bridging Disciplines & Domains. Digital Government Society of North America, pp. 102–111.

[18] Del Re, E., 2011. Integrated satellite-terrestrial nav/com/gmes system for emergency scenarios. In: Wireless Communication, Vehicular Technology, Information Theory and Aerospace & Electronics Systems Technology (Wireless VITAE), 2011 2nd International Conference on. IEEE, pp. 1–5.

[19] Del Re, E., 2012. Satellite communications for emergency. In: Satellite Telecommunications (ESTEL), 2012 IEEE First AESS European Conference on. IEEE, pp. 1–5.

[20] Del Re, E., Jayousi, S., Morosi, S., Ronga, L., De Sanctis, M., Cianca, E., Ruggieri, M., Falletti, E., Iera, A., Araniti, G., et al., 2013. Salice project: satellite-assisted localization and communication systems for emergency services. In: Aerospace and Electronic Systems Magazine, IEEE, vol. 28. IEEE, pp. 4–15.

[21] Dervin, M., Buret, I., Loisel, C., 2008. Very wide band satellite transmissions for emergency situations. In: Advanced Satellite Mobile Systems, 2008. ASMS 2008. 4th, IEEE, pp. 328–332.

[22] Dervin, M., Buret, I., Loisel, C., 2009. Easy-to-deploy emergency communication system based on a transparent telecommunication satellite. In: Advances in Satellite and Space Communications, 2009. SPACOMM 2009. First International Conference on. IEEE, pp. 168–173. Dilmaghani, R.B., Rao, R.R., 2008. A wireless mesh infrastructure deployment with application for emergency scenarios. In: ISCRAM 2008, p. 484.

[23] Durresi, A., Durresi, M., Paruchuri, V., Barolli, L., 2009. Trust management in emergency networks. In: Advanced Information Networking and Applications, 2009. AINA'09. International Conference on. IEEE, pp. 167–174.

[24] Ellison, R.J., Fisher, D.A., Linger, R.C., Lipson, H.F., Longstaff, T., 1997. Survivable Network Systems: an Emerging Discipline. Tech. Rep. CMU/SEI-97-TR-013. Carnegie Mellon University.

[25] Fantacci, R., Marabissi, D., Tarchi, D., 2010. A novel communication infrastructure for emergency management: the in.sy.eme. Vision. Wireless Commun. Mobile Comput. 10 (12), 1672–1681.

[26] Gelenbe, E., Gorbill, G., Wu, F.-J., 2012. Emergency cyber-physical-human systems. In: Computer Communications and Networks (ICCCN), 2012 21st International Conference on. IEEE, pp. 1–7.

[27] Giddens, A., 1984. The Constitution of Society: Introduction of the Theory of Structuration. Univ of California Press.

[28] Gorbill, G., Gelenbe, E., 2012. Resilience and security of opportunistic communications for emergency evacuation. In: Proceedings of the 7th ACM Workshop on Performance Monitoring and Measurement of Heterogeneous Wireless and Wired Networks. ACM, pp. 115–124.

[29] Gorbill, G., Gelenbe, E., 2013. Disruption tolerant communications for large scale emergency evacuation. In: Pervasive Computing and Communications Workshops (PERCOM Workshops), 2013 IEEE International Conference on. IEEE, pp. 540–546.

[30] Goss, K.C., 2001. Guide for All-hazard Emergency Operations Planning, Federal Emergency Management Agency (FEMA).

[31] Gundavelli, S., Leung, K., Devarapalli, V., Chowdhury, K., Patil, B., August 2008. Proxy Mobile Ipv6, RFC 5213, RFC Editor.

[32] Hartikainen, H., Harnesk, D., 2009. A review of secure emergency communications: technical and organisational aspects. In: 32nd Information Systems Research Seminar in Scandinavia, IRIS 32.

[33] Iapichino, G., Bonnet, C., 2009. Combination of Ad Hoc Mobility with Ipv6 Mobility Mechanisms Report. Tech. rep. Eurecom.

[34] Iapichino, G., Bonnet, C., del Rio Herrero, O., Baudoin, C., Buret, I., 2008a. Advanced hybrid satellite and terrestrial system architecture for emergency mobile communications. In: 26th AIAA International Communications Satellite Systems Conference (ICSSC 2008), pp. 10–12.

[35] Iapichino, G., Bonnet, C., del Rio Herrero, O., Baudoin, C., Buret, I., 2008b. A mobile ad-hoc satellite and wireless mesh networking approach for public safety communications. In: Signal Processing for Space Communications, 2008. SPSC 2008. 10th International Workshop on. IEEE, pp. 1–6.

[36] Karakostas, G., Markou, E., 2008. Emergency connectivity in ad-hoc networks with selfish nodes. In: LATIN 2008: Theoretical Informatics. Springer, pp. 350–361.

[37] Kose, S., Koytak, E., Hascicek, Y.S., 2012. An overview on the use of satellite communications for disaster management and emergency response. In: International Journal of Emergency Management, vol. 8. Inderscience, pp. 350–382.

[38] Li, Y., 2011. A Survey on Communication Networks in Emergency Warning Systems. Master's thesis. Department of Computer Science & Engineering – Washington University, St. Louis.

[39] Loukas, G., Gan, D., Vuong, T., 2013b. A review of cyber threats and defence approaches in emergency management. In: Future Internet, vol. 5. Multidisciplinary Digital Publishing Institute, pp. 205–236.

[40] Madni, A.M., Sievers, M., Madni, C.C., 2018. Adaptive cyber-physical-human systems: exploiting cognitive modeling and machine learning in the control loop. In: INCOSE International Symposium, vol. 28, pp. 1067–1077.

[41] Michalas, A., Bakopoulos, M., Komninos, N., Prasad, N.R., 2012. Secure & trusted communication in emergency situations. In: Sarnoff Symposium (SARNOFF), 2012 35th IEEE. IEEE, pp. 1–5.

[42] Miranda, F., Keuls, F.V., Romanofsky, R., Subramanyam, G., 1998. Tunable microwave components for ku- and k-band satellite communications. In: Integrated Ferroelectrics, vol. 22. Taylor & Francis, pp. 269–278.

[43] Morello, A., Mignone, V., 2006. Dvb-s2: the second generation standard for satellite broad-band services. In: Proceedings of the IEEE, vol. 94. IEEE, pp. 210–227.

[44] Moskowitz, R., Nikande, P., Jokela, P., Henderson, T., April 2008. Host Identity Protocol, RFC 5201, RFC Editor.

[45] Moy, j., October 1989. The Open Shortest Path First (Ospf) Specification. Tech. rep., Technical Report RFC-1131. RI Network Information Center.

[46] Naeem, T., Loo, K.-K., 2009. Common security issues and challenges in wireless sensor networks and IEEE 802.11 wireless mesh networks. Int. J. Digit. Content Technol. Appl. 3 (1), 89–90.

[47] Oberg, J.C., Whitt, A.G., Mills, R.M., 2011. Disasters will happen—are you ready? In: Communications Magazine, IEEE, vol. 49. IEEE, pp. 36–42.

[48] Papageorgiou, C., Birkos, K., Dagiuklas, T., Kotsopoulos, S., 2009. Dynamic trust establishment in emergency ad hoc networks. In: Proceedings of the 2009 International Conference on Wireless Communications and Mobile Computing: Connecting the World Wirelessly, IWCMC '09, ACM, New York, NY, USA, pp. 26–30.

[49] Patel, A., Al-Janabi, S., AlShourbaji, I., Pedersen, J., 2015. A novel methodology towards a trusted environment in mashup web applications. Comput. Secur. 49, 107–122. Peng, W., Yan, C., Liu, X., Deng, L., 2009. Emergency command system for geologic disasters prevention. In: Information Assurance and Security, 2009. IAS'09. Fifth International Conference on, vol. 2. IEEE, pp. 410–413.

[50] Perkins, C.E., Royer, E.M., 1999. Ad-hoc on-demand distance vector routing. In: Mobile Computing Systems and Applications, 1999. Proceedings. WMCSA'99. Second IEEE Workshop on. IEEE, pp. 90–100.

[51] Pirzada, A.A., Portmann, M., Indulska, J., 2006. Evaluation of multi-radio extensions to aodv for wireless mesh networks. In: Proceedings of the 4th ACM International Workshop on Mobility Management and Wireless Access. ACM, pp. 45–51.

[52] Portmann, M., Pirzada, A.A., 2008. Wireless mesh networks for public safety and crisis management applications. In: Internet Computing, IEEE, vol. 12. IEEE, pp. 18–25.

[53] Redwan, H., Kim, K.-H., 2008. Survey of security requirements, attacks and network integration in wireless mesh networks. In: New Technologies, Mobility and Security, 2008. NTMS'08. IEEE, pp. 1–5.

[54] Rose, J., Jones, M., Truex, D., 2005. Socio-theoretic accounts of is: the problem of agency. *Scand. J. Inf. Syst.* 17.

[55] Roy-Chowdhury, A., Baras, J.S., Hadjitheodosiou, M., Papademetriou, S., 2005. Security issues in hybrid networks with a satellite component. In: *Wireless Communications*, IEEE, vol. 12. IEEE, pp. 50–61.

[56] S.-S. Working Group, et al., 2008. Overview of Present Satellite Emergency Communication Resources. Tech. rep., Technical Report ETSI TR 102 641.

[57] Sakellari, G., Loukas, G., Dec. 2013. A survey of mathematical models, simulation approaches and testbeds used for research in cloud computing. *Simulat. Model. Pract. Theor.* 39, 92–103.

[58] Shibata, Y., Sato, Y., Ogasawara, N., Chiba, G., 2008. Ballooned wireless mesh network for emergency information system. In: *22nd International Conference on Advanced Information Networking and Applications, AINA 2008, Workshops Proceedings*, GinoWan, Okinawa, Japan, March 25-28, 2008. IEEE Computer Society, pp. 1118–1122.

[59] Siddiqui, M.S., Hong, C.S., 2007. Security issues in wireless mesh networks. In: *Multimedia and Ubiquitous Engineering, 2007. MUE'07. International Conference on*. IEEE, pp. 717–722.

[60] Skinnemoen, H., Leirvik, R., Hetland, J., Fanebust, H., Paxal, V., 2004. Interactive ip-network via satellite dvb-rcs. In: *Selected Areas in Communications, IEEE Journal on*, vol. 22. IEEE, pp. 508–517.

[61] Skinnemoen, H., Hansen, S.K., Jahn, A., Berioli, M., 2007. Satellite based infrastructure for emergency communications. In: *Proceedings of the 25th AIAA International Communications Satellite Systems Conference & Exhibit*, pp. 10–13.

[62] Sterbenz, J.P., Krishnan, R., Hain, R.R., Jackson, A.W., Levin, D., Ramanathan, R., Zao, J., 2002. Survivable mobile wireless networks: issues, challenges, and research directions. In: *Proceedings of the 1st ACM Workshop on Wireless Security*. ACM, pp. 31–40.

[63] Sterbenz, J.P., Hutchison, D., Çetinkaya, E.K., Jabbar, A., Rohrer, J.P., Schöller, M., Smith, P., 2010. Resilience and survivability in communication networks: strategies, principles, and survey of disciplines. In: *Computer Networks*, vol. 54. Elsevier, pp. 1245–1265.

[64] Thomasson, L., Verelst, G., Deprey, S., Bouthy, P., Berioli, M., Courville, N., 2008. Hybrid satellite-terrestrial based solutions for rapid deployment of wireless telecommunication networks in emergency situations. In: *15th Annual Conference of the International Emergency Management Society (TIEMS)*, pp. 7–19.

[65] Tøndel, I., Jaatun, M., Nyre, A., 2009. Security requirements for manets used in emergency and rescue operations. In: *Security and Communication Networks (IWSCN), 2009 Proceedings of the 1st International Workshop on*. IEEE, pp. 1–7.

[66] Viswanath, K., Obraczka, K., Tsudik, G., 2006. Exploring mesh and tree-based multicast. Routing protocols for manets. In: *Mobile Computing, IEEE Transactions on*, vol. 5. IEEE, pp. 28–42.

[67] Wang, Y., Attebury, G., Ramamurthy, B., 2006. A survey of security issues in wireless sensor networks. In: *Communications Surveys Tutorials*, vol. 8. IEEE, pp. 2–23.

[68] Wodczak, M., 2012a. Autonomic cooperative communications for emergency networks. In: *Globecom Workshops (GC Wkshps), 2012 IEEE*. IEEE, pp. 809–813.

[69] Wodczak, M., 2012b. Cooperative emergency communications. In: *Next Generation Mobile Applications, Services and Technologies (NGMAST), 2012 6th International Conference on*. IEEE, pp. 87–92.

[70] Wu, B., Chen, J., Wu, J., Cardei, M., 2007. A survey of attacks and countermeasures in mobile ad hoc networks. In: *Wireless Network Security*. Springer, pp. 103–135.