Communication Deployability in Disaster Management: Taxonomy, Recent Developments and Future Challenges

Vipin Kumar Pandey, Suddhasil De
Department of Computer Science and Engineering
National Institute of Technology Patna, Bihar 800005, India.
Email: {vipin.pandey,suddhasil.de}@acm.org

***Abstract*—Disasters cause wide-spread damages of lives and properties as well as affect economic stability, raising the importance of efficient disaster management. Among the multiple research directions in disaster management system, significance of communication technologies has recently gained much attention in post-disaster recovery phase. Different solutions for disaster management have been proposed using available technologies in absence of communication infrastructures. However, lack of proper research direction in inexpensive, fast and easily deployable communication infrastructure for efficient disaster management system has motivated this paper. The contributions in this paper is three-fold — (1) a new taxonomy about dynamics in deployed communication network infrastructures for disaster management system in post-disaster scenarios is proposed, which paves the road for future research in this direction; (2) a comprehensive review of the recent proposals on such dynamic infrastructure for disaster management system is reported, which provides state-of-the-art in this direction; and (3) a set of open challenges for future research in dynamic infrastructures for disaster management system is also presented.**

***Keywords*-Disaster management, communication deployability, vehicular network, aerial network, unmanned aerial vehicle, ground vehicle, taxonomy, future challenges.**

I. Introduction

Disaster is a natural or man-made catastrophic phenomenon, which results in innumerable loss of lives and/or other severe disruptions [1]. In recent times, the frequencies of disasters have increased manifold, causing wide-spread devastations, including loss of lives, destruction of properties and infrastructures, as well as market disruption, affecting economic stability [2]–[4]. As per a recent report [3], more than one hundred million people have been affected globally by different disasters in the year 2015 alone. Rising occurrences of such disasters raise the importance of disaster management, particularly in post-disaster phase, and have attracted researchers' attention to use available technologies in best possible ways for carrying out mitigation, rescue and rehabilitation activities. In India, Chennai urban flood in 2015 [5], where losses of lives and property was quite high, has revealed the challenges that disaster response team faced in absence of proper communication and coordination system.

Disaster management system (DMS) is the first line of relief-response system in any disaster situation, involving careful plan and actions to reduce devastation impacts and mitigate vulnerabilities as a result of disaster [6]. DMS is the multi-dimensional managing process, involving multi-party collaboration among geographically-distributed entities, which installs relief centers, declares emergency contact numbers, deploys relief parties etc. to name a few. Several aspects of DMS have been explored in recent past. In [7], collaborative goals and activities during pre-incident, incident and post-incident phases of DMS has been elaborated. In [6], [8], management and analysis of data generated in DMS for decision support has been studied. In [9], [10], service perspective of DMS is investigated by studying the use of mobile- and web-based software applications in disaster scenarios. Effects of crowd-sourcing methods in DMS are explored in [11].

However, research on use of communication technologies, protocols and standards for improving effectiveness of DMS has gained much attention due to its primal importance. Before disaster has struck, existing and deployed communication network infrastructures, like cellular networks, wireless local area networks, wireless mesh networks, wireless sensor networks etc., can be used to detect disasters, and mitigate impact of devastations. In post-disaster scenarios, with the realistic assumption about absence of such infrastructures, temporary network infrastructures, like ad hoc networks, air-borne networks, satellite communication etc. can play vital role for DMS to facilitate disaster recovery. This paper focuses on the research direction in post-disaster environments. In [12], experimentation on mobile ad hoc network mobility models, architectures and protocols with simulated disaster setups have been explored. In [13], [14], sensor networks have been examined for situational awareness in the aftermath of disasters. In [15], [16], wireless mesh networks have been looked into for use in post-disaster scenarios. In [17], [18], probability of establishing communication networks by utilizing survived network infrastructures and extending them with additional network components, like cognitive radio technologies, have been reviewed. In [19]–[30], network structures based on different forms of ground and aerial vehicles have been researched for disaster recovery. Non-traditional approaches, like balloon/blimp-based networks, for post-disaster phases are suggested too [31]. Research has also been initiated on the use of recent computing paradigms and technologies, like cloud computing paradigm [27], [32], long-term evolution (LTE) technology [33] etc., for post-disaster management.

But, a proper direction of research from the perspective of communication network infrastructures for disaster management has not been provided in literature. Some existing reviews about past proposals for DMS in this regard have been presented in literature [12], [34]–[40]. But none of these reviews provide a clear view about the possibility of low-cost communication network for efficient coordination in DMS. In particular, it has been observed in these works that the inter-party communications between responders and relief parties, as well as between rescuers and distressed ones are not very effective, which have slowed down rescue operations in disaster-struck regions in the past. This paper fills the gap by providing concrete guidelines and directions in research, which are oriented towards the potency of efficient and inexpensive as well as fast and easily deployable vehicular networks for post-disaster rescue and recovery.

The contributions of this paper are three-fold. Firstly, based on an extensive study of the existing works in DMS, this paper proposes a *new taxonomy* about the dynamics in communication network infrastructures for DMS in post-disaster scenarios. The proposed taxonomy, while promoting an efficient yet inexpensive solution for coordination, plays a pivotal role in providing a road-map for future research on network infrastructures for DMS. Secondly, this paper reports a comprehensive review of the recent works in disaster management, aligning with the proposed taxonomy, to indicate research progress in communication networks for DMS. Lastly, this paper provides a set of open challenges for research in dynamic communication network infrastructures for DMS. Rest of the paper is organized as follows. Section II briefly discusses about the background required to understand the contributions of this paper. Section III presents the proposed taxonomy about communication network infrastructures for DMS, and reports about dynamics in existing DMS. Section IV elaborates the future avenues of research with illustrations, and Section V compares existing works related to this paper. Finally, Section VI concludes the paper.

II. Background

The communication technologies have evolved from archaic approaches (like telegraphic communication, telephonic communication, radio communication etc.) to wired communication. After the rapid advent of wireless communication technologies, wireless networks have improved manifold in terms of connection, setup cost, coverage and reliability. One kind of wireless networks rely on the use of existing infrastructures (like routers, access points etc.) for forwarding their traffic, whereas the wireless ad hoc networks work by involving network components in data routing without using any kind of infrastructures. A list of different forms of wireless ad hoc networks are briefly presented.

A. Wireless Mobile Ad hoc Network (MANET)

MANET [41] is the infrastructure-less network created using mobile devices (like smartphones, laptops etc.) supporting various wireless protocols, such as IEEE 802.11 a/b/g/n, 802.16 etc. MANET has provided the much needed flexibility in terms of setting-up of communication networks in nominal time with minimal resources at bay. Mobility in MANET is human-dependent, and accordingly the network topology is changed suggesting the need for dynamic routing for message exchange [42]. MANET is constrained with bottlenecks of short-lived network and infeasible for difficult terrain.

B. MANET coupled with Vehicles

On advancement of technologies, wireless devices have been equipped with more functionalities in reduced dimensions, thereby becoming conducive to be deployed on moving platforms, like vehicles. Consequently, different forms of vehicular networks have emerged.

1) Vehicular Ad hoc Network (VANET): The idea of deploying wireless devices in moving vehicles like ambulance, relief van, response fleet etc. has improved coverage and availability of VANET in any area [43]. Vehicular mobility in VANET has made it possible to reach to farthest point, where network is needed as well as feasible to be deployed using ground movement.

2) Aerial Ad hoc Network (AANET): AANET is established at the uppermost aerial layer, and is comprised of satellite networks and aviation networks. Aviation networks can be comprised of fast-moving civilian and fighter planes, which have been used for surveillance, whereas satellite networks are deployed at the outer earth orbit to support coverage of the entire globe for live TV broadcast and communication coverage in remote locations on earth.

3) Flying Ad hoc Network (FANET): FANET [42] is involved with air-based vehicular mobility equipped with networking capabilities. It comprises mainly of unmanned aerial vehicles (UAVs) with single payload having communication capabilities. These UAVs flying altitude ranges differs from aviation. FANET can provide network coverage in any topography with easier deployability; however higher cost, lower up-time and rapid dynamics in mobility of aerial vehicles pose many serious challenges for FANET.

4) Hybrid Vehicular Network: Mobile ad hoc network consolidating different forms of vehicles suitable for ground and aerial mobility has recently emerged. One such example is Ground-Flying Ad hoc Network (GFANET) [44]. Such hybrid networks have the capabilities of providing end-to-end connectivity in any topography with low setup cost.

III. Disaster Management Systems

In the background work, we have discussed about the availability of the various platform which exists as a dynamic ad hoc network for different communication scenario. In this section a Taxonomy is presented based on platforms suitable for communication deployability in Disaster Management Environment based on factors like cost, Network up-time, maneuverability and adaptiveness. The reason for proposing taxonomy is to segregate the on-going research in the dynamic ad hoc network with reference to disaster management so that the best practices can be adopted for future research.

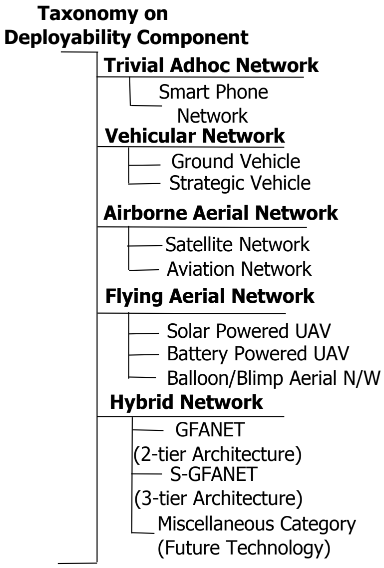

Fig. 1. Proposed Taxonomy in Dynamic ad hoc network (on Deployability)

A. Proposed Taxonomy

The proposed taxonomy is presented in Figure 1, which is vertically arranged on the dynamics of deployability component in any ad hoc network. The arrangement order followed in the taxonomy i.e. Trivial Ad hoc Network, VANET, AANET, FANET and Hybrid (e.g. GFANET), is according to their order of evolvement.

Comparison among the different categories and subcategories of the taxonomy is presented in Table I, which is based on ad hoc paradigm, dynamics, cost, up-time and maneuverability aspects. Usage column corresponds to the references of this paper that have used different deployment strategies. The last three deployment categories shown in the table are of hybrid type, which can perform better with respect to the attributes taken for comparison in the table; however, shortcoming in efficiency in dynamic routing among such categories is still prevalent, which needs to be improved before using them in realistic scenarios.

Hybrid category consideration is done irrespective of non-trial in realistic scenarios for the completion of Taxonomy, so that much needed focus towards Hybrid category is ensured in disaster scenarios. For e.g., if the affected area become flooded or rescue operation is to be carried out in some island, a floating bed for placing base of Transiever system integrated with ground and aerial vehicles can be an alternative hybrid category in the taxonomy.

B. Dynamics in Existing Disaster Management

Some significant research on the section/subsection of proposed taxonomy has been carried out in the recent past which helps us in better understanding of the work in real time environment. In [7], [12], Collaborative approach to use mobile phones by disaster stranded people to create an ad hoc network for faster transfer of critical information is proposed. Simulation and testing is carried out to see the effectiveness of the overall approach. In [20], [27], [29], Vehicular mobile ad hoc network is tested in disaster affected area. Ground vehicles are used as an intermediate mobile stations that provide data exchange services between smart phone users and central server, carrying out distributed data analysis at the location using vehicular setup and storing information at cloud. In [19], small-scaled battery powered UAV system equipped with high quality cameras is tested for collecting field information of disaster affected area and transferring the information to ground stations for analyzing the situation. Their research has shown strong potential to use the system in forest fire, landslide and flooded area; however the up-time of the system is quiet low. In [24], [26] UAVs are tested in tactical environment to achieve best result in terms of coverage, up-time and data exchange. In [19], [31], Multi GV-UAV 2-tier Vehicular Network is proposed, which is a hybrid network. In recent times the research has shifted towards hybrid combination network to deploy in the affected area. The best added advantage is that the local vehicles available at the site can also be used for erecting an efficient dynamic ad hoc network which is boon for resource scarce country.

On analyzing the recent works, It appears that the coming future in the disaster management will be of Hybrid setup. Technological advancement in terms of better drones/UAV, Solar-powered UAVs can make it possible at the low cost. There are other sub-classifications of taxonomy such as Satellite Network, Aviation Networks, WSN and others, which are not used and applied much in disaster scenario because of their expensiveness and dynamic routing needs but in future there is possibility that they will be used in disaster management as research advancement is going to happen in those areas.

IV. Future Challenges

Even though research is going on in disaster management for quite some time, still providing the best available services for faster relief and rehabilitation of normal life in post-disaster scenarios has remained challenging. These challenges have opened scope for further research in this direction.

(1) Geo-tagging of the critical service centers which are functional after disaster in affected areas: It can be done manually or by using pre-recorded information available of the affected geographical areas. The technological approach improves the trustworthiness of the process and at the same time lessen the bandwidth consumption. Figure 2 depicts a process to achieve geo-tagging in sync with any communication setup deployed in the affected area. The stranded survivors using the network can geo-tag the functional critical service centers in the locality (like, point **A**, which is a hospital in the figure) on receiving such requests. The geo-tagged information will be delivered to central server for preservation in hosted databases to provide the important inputs regarding affected regions to rescue teams. The requesting message method in the manual approach will be flooding in nature while the same can be selective-flood in the technological approach based on available information of the location.

TABLE I
COMPARISON AMONG DIFFERENT DEPLOYABLE COMPONENT IN DYNAMIC AD HOC NETWORK

Deployable Category	Ad hoc paradigm	Dynamics	Cost	Up-time	Maneuverability	Status	Properties	Usage
Ground Vehicular Network	VANET	High	Low	High	Confined	Simulated, tested; deployed in disaster-struck areas	Not for difficult terrain; less network coverage	[20], [27], [29]
Balloon/Blimp Aerial Network	AANET	Low	Low	High	Restrictive	Research proposal; not deployed yet	Adaptive to topography; difficulty in windy climate, ground support, reusability etc.	[31]
Battery-powered mini-UAV Network	FANET	High	High	Low	Improved	Simulated, tested; deployed in disaster-struck areas	Adaptive to topography	[19], [24], [26]
Solar-powered UAV Network	FANET	High	Low	High	Improved	No research to deploy in disaster-struck areas	Adaptive to topography; high initial cost; difficult in scarce or inconsistent sunshine	No existing proposals
Multi GV-UAV 2-tier Vehicular Network	GFANET	High	Moderate	High	Adequate	Research proposal; not deployed yet	Adaptive to topography	[44]
Ground-Aerial-Satellite 3-tier Network	Next-Gen Ad hoc Network	High	High	High	Adequate	No research to deploy in disaster-struck areas	Adaptive to topography	No existing proposals
Hybrid Multi-tier Network	Next-Gen Ad hoc Network	High	Varying	High	Adequate	No research to deploy in disaster-struck areas	Adaptive to topography	No existing proposals

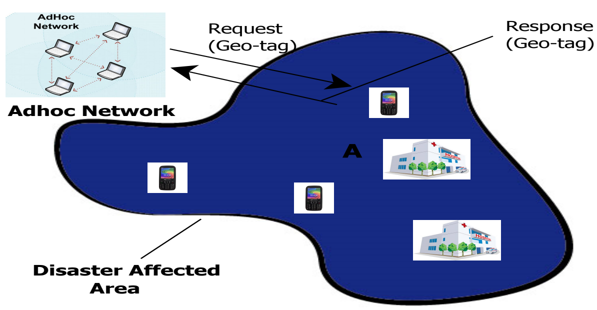

Fig. 2. Geo-tagging Process

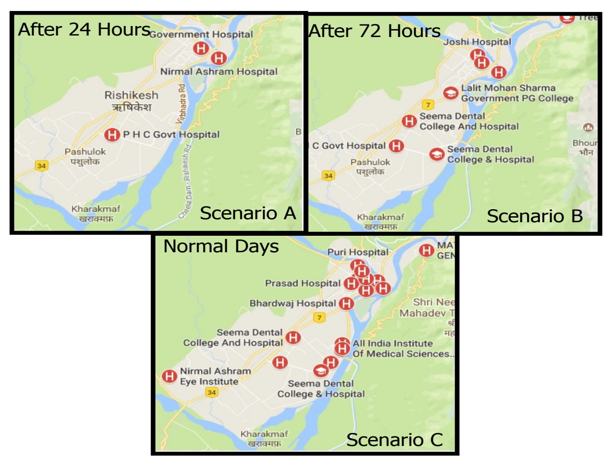

Fig. 3. Static Map Positioning in flash flood to mark Hospitals in Rishikesh, Uttarakhand, India in Post-disaster scenario (Image:©Google maps.)

(2) Utilizing available information for static map positioning system, where semi-dynamism can be achieved through regular updates: The method meets the static nature of the relief camps and emergency services with the lower bandwidth ad hoc network. The system can help in providing the location of functional emergency services to the stranded people without accessing data services. Regular updates will be there when a service become functional in the area through broadcasted message for applications installed in user handsets. For example, in Figure 3, scenario A depicts the status of hospitals/medical centers running in a disaster-affected area in the first 24 hours, while scenario B is showing the medical centers running after 72 hours. Scenario C is the overall availability of such medical centers in the region after the rescue operations is over. So overall in 3-4 small updates critical information can be made available in first 72 hours of disaster.

(3) Segregating stranded people into vulnerable and safe group by user profiling: Such segregation is an important research aspect which can help in planning the rescue operations in such a way that the one who needs emergency attention can be aided first. Profiling of the victims/survivors can be done through different hand-held devices connected to ad hoc network, which can be matched with social security number or similar identification system to get relevant information such as finding a physician among victims can be asset in such situations,another e.g. of getting medical history of people can be useful to anticipate resources needed during rescue.

(4)Towards fully automated system: Maneuverability of UAV-based aerial networks is better in comparison to ground vehicular network or balloon/blimp-based aerial network. However, cost and power bottleneck of UAV-based network can be overcome by deploying multiple mini-UAVs with lesser payloads in distributed form, which in turn can reduce the costs of aerial network and increase its up-time.mini-UAV with single payload based aerial network has it own limitations in achieving adaptive automated ad hoc network capable of distress routing, as well as ensuring availability of payloads at all locations without compromising cost and up-time. A routing algorithm with added information of the payload details of the UAV, grouping of UAVs with all the payload set and reactive mechanism to handle the request of payloads by swapping the position with the requesting UAV can be a key research dimension to devise fully-autonomous system.

5) Hybrid multi-tier ad hoc network: Heterogeneity in ground and aerial vehicles shows the path for the future research scope. Other combinations of network components such as including satellite networks, floating devices equipped with base transceiver system and others can be researched for its utilization in disaster management. Another area which will be open for research in such networks can be Routing mechanism and synchronization between different systems and system components.

V. Related Works

Disaster and disaster management have been the focus of inter-disciplinary research domain for long time. Several surveys and reviews on multi-faceted aspects of disaster management exist in literature. Findings on disasters in the past decades have been reviewed by [45], [46]. Disaster management from operations research and management perspectives have been studied by [47]–[50].

There exists in literature few related reviews exploring vehicular networks for disaster management. In [34], the past proposals about image acquisition and sensing in disaster-affected areas using isolated aerial vehicles have been studied, which is primarily aiming for post-disaster evaluation as well as infrastructure reconstruction. In [37], the use of geographic information systems (GIS) for disaster response has been reviewed, focussing in personal profile of GIS. In [38], stress has been given on geo-spatial information, and the past proposals to gather such information using different isolated ground and aerial vehicles and their utilization in disaster response have been examined. In particular, use of such devices for land mapping, disaster mapping, rescue operation tracking, resource transporting etc. This paper focuses on the communication usage of networks of ground and/or aerials vehicles for disaster responders and victims, unlike the focus of [34], [37], [38].

In [35], [36], routing techniques for different forms of ad hoc networks (like, MANET, VANET, DTN, WSN, WMN, TETRA, RFID etc.) and open challenges in such networks have been reviewed. In [39], [40], usage of WSN and UAVs for 3-phase cycle of disaster, viz. pre-, in- and post-disaster phases, have been explored, by identifying tasks for each phase and involvement of UAVs in each such task has reviewed.

This paper differs from [35], [36], [39], [40] in that (i) primary focus of this paper is on different forms of vehicular networks, whereas no review of aerial networks is present in [35], [36] and no review of ground vehicular networks is present in [39], [40], (ii) a new taxonomy for vehicular network deployability is proposed here, whereas no taxonomy is proposed in [35], [36], [39], [40], and (iii) future challenges on improving coordination in disaster management is indicated in this paper, unlike listing generic issues in ad hoc networks, as is done in [35], [36], and no such reporting in [39], [40].

VI. Conclusion

This paper has focused on the importance of efficient Disaster Management System(DMS) in post-disaster phase, where existing communication infrastructures are non-functioning. In this paper, a new taxonomy about dynamics in communication network infrastructures of available technologies for DMS in post-disaster scenarios has been proposed with the purpose of leading future research. In light of the proposed taxonomy, existing DMSs on dynamic communication infrastructures have been analyzed to provide state-of-the-art research in this direction. Further, this paper has presented several open challenges for future research in DMS, which will not only pave the path for growth of efficient DMS overlying inexpensive as well as fast and easily deployable communication infrastructure, but will also provide a guideline for research in other extreme environments.

Acknowledgement

This work is supported by the Science and Engineering Research Board, a statutory body of the Department of Science and Technology (DST), Government of India, under grants number ECR/2016/002040. Suddhasil De is the corresponding author. The authors would also like to thanks the anonymous reviewers for their valuable comments.

References

[1] Enrico Louis Quarantelli, editor. *What is a Disaster? Perspectives on the question*. Routledge, 2005.

[2] Disaster Statistics. URL= "https://www.unisdr.org/we/inform/disaster-statistics" [last accessed: 31-Jul-17].

[3] International Federation of Red Cross and Red Crescent Societies (IFRC). World Disasters Report 2016. URL= "http://media.ifrc.org/ifrc/publications/world-disasters-report-2016/" [last accessed: 31-Jul-17].

[4] National Disaster Management Authority (NDMA), India. Disaster Data & Statistics. URL= "http://www.ndma.gov.in/en/disaster-data-statistics.html" [last accessed: 31-Jul-17].

[5] Interdisciplinary Centre for Water Research (ICWaR), IISc, India. Chennai Floods 2015. URL= "http://www.icwar.iisc.ernet.in/chennai-floods-2015/" [last accessed: 31-Jul-17].

[6] Tao Li, Ning Xie, C. Zeng, Wubai Zhou, Li Zheng, Y. Jiang, Yimin Yang, Hsin-Yu Ha, Wei Xue, Yue Huang, Shu-Ching Chen, J. Navlakha, and S. S. Iyengar. Data-driven techniques in disaster information management. *ACM Computing Surveys*, 50(1):1:1–1:45, 2017.

[7] Rui Chen, Raj Sharman, H. Raghav Rao, and Shambhu J. Upadhyaya. Coordination in Emergency Response Management. *Communications of the ACM*, 51(5):66–73, 2008.

[8] Vagelis Hristidis, Shu-Ching Chen, Tao Li, Steven Luis, and Yi Deng. Survey of Data Management and Analysis in Disaster Situations. *Journal of Systems and Software*, 83(10):1701–1714, 2010.

[9] Ananya Banerjee, Jayanta Basak, Siuli Roy, and Somprakash Bandyopadhyay. Towards a Collaborative Disaster Management Service Framework Using Mobile and Web Applications: A Survey and Future Scope. *Intl. Jrnl. of Information Systems for Crisis Response and Management*, 8(1):65–84, 2016.

[10] Mathias Leidig and Richard Teeuw. Free Software: A Review, in the Context of Disaster Management. *Intl. Journal of Applied Earth Observation and Geoinformation*, 42:49–56, 2015.

[11] Marta Poblet, E. García-Cuesta, and P. Casanovas. Crowdsourcing Tools for Disaster Management: A Review of Platforms and Methods. In P. Casanovas, Ugo Pagallo, Monica Palmirani, and Giovanni Sartor, editors, *AI Approaches to the Complexity of Legal Systems - LNCS 8929*, pages 261–274. Springer-Verlag, Berlin, Germany, 2014.

[12] Erika Rosas, Nicolás Hidalgo, Veronica Gil-Costa, Carolina Bonacic, Mauricio Marin, Hermes Senger, Luciana Arantes, Cesar Marcondes, and Olivier Marin. Survey on Simulation for Mobile Ad-Hoc Communication for Disaster Scenarios. *Journal of Computer Science and Technology*, 31(2):326–349, 2016.

[13] Nikos Pogkas, George E Karastergios, Christos P Antonopoulos, Stavros Koubias, and George Papadopoulos. Architecture Design and Implementation of an Ad-Hoc Network for Disaster Relief Operations. *IEEE Transactions on Industrial Informatics*, 3(1):63–72, 2007.

[14] S. M. George, Wei Zhou, H. Chenji, M. Won, Yong Oh Lee, A. Pazarloglou, R. Stoleru, and P. Barooah. DistressNet: A Wireless Ad Hoc and Sensor Network Architecture for Situation Management in Disaster Response. *IEEE Communications Magazine*, 48(3):128–136, 2010.

[15] A. Fragkiadakis, I. Askoxylakis, E. Tragos, and C. Verikoukis. Ubiquitous Robust Communications for Emergency Response using Multi-operator Heterogeneous Networks. *EURASIP Journal on Wireless Communications and Networking*, 2011(1):13, 2011.

[16] R Murugeswari and S Radhakrishnan. Reliable Data Delivery for Emergency and Disaster Recovery in Wireless Mesh Network. In *Proc. Intl. Conf. on Information Communication and Embedded Systems (ICICES'14)*, pages 1–6, Piscataway, NJ, USA, 2014. IEEE.

[17] Quang Tran Minh, Kien Nguyen, C. Borcea, and S. Yamada. On-the-fly Establishment of Multihop Wireless Access Networks for Disaster Recovery. *IEEE Communications Magazine*, 52(10):60–66, 2014.

[18] Saim Ghafoor, Paul D Sutton, Cormac J Sreenan, and Kenneth N Brown. Cognitive Radio for Disaster Response Networks: Survey, Potential, and Challenges. *IEEE Wireless Communications*, 21(5):70–80, 2014.

[19] Markus Quaritsch, Karin Kruggl, Daniel Wischounig-Strucl, Subhabrata Bhattacharya, Mubarak Shah, and Bernhard Rinner. Networked UAVs as Aerial Sensor Network for Disaster Management Applications. *e & i Elektrotechnik und Informationstechnik*, 127(3):56–63, 2010.

[20] Jinyuan Sun, X. Zhu, C. Zhang, and Y. Fang. RescueMe: Location-Based Secure and Dependable VANETs for Disaster Rescue. *IEEE Journal on Selected Areas in Communications*, 29(3):659–669, 2011.

[21] Iván Maza, Fernando Caballero, Jesús Capitán, J. R. Martínez-De-Dios, and Aníbal Ollero. Experimental Results in Multi-UAV Coordination for Disaster Management and Civil Security Applications. *Journal of Intelligent and Robotic Systems*, 61(1-4):563–585, 2011.

[22] Gurkan Tuna, T. Mumcu, and K. Gulez. Design Strategies of Unmanned Aerial Vehicle-aided Communication for Disaster Recovery. In *Proc. 9th Intl. Conf. on High Capacity Optical Networks and Enabling Technologies*, pages 115–119, Piscataway, NJ, USA, 2012. IEEE.

[23] Gurkan Tuna, Bilel Nefzi, and Gianpaolo Conte. Unmanned aerial vehicle-aided communications system for disaster recovery. *Journal of Network and Computer Applications*, 41:27–36, 2014.

[24] Jesús Sánchez-García, José Manuel García-Campos, S L Toral, D G Reina, and Federico Barrero. An Intelligent Strategy for Tactical Movements of UAVs in Disaster Scenarios. *International Journal of Distributed Sensor Networks*, 2016:18:1–18:20, 2016.

[25] Robin R Murphy. Emergency Informatics: Using Computing to Improve Disaster Management. *Computer*, 49(5), 2016.

[26] Nilanjan Dey, Amartya Mukherjee, Noreen Kausar, Amira S. Ashour, Redha Taiar, and Aboul Ella Hassanien. A Disaster Management Specific Mobility Model for Flying Ad-hoc Network. *International Journal of Rough Sets and Data Analysis*, 3(3):72–103, 2016.

[27] Ram S. Raw, Loveleen, Arvind Kumar, Arushi Kadam, and N. Singh. Analysis of Message Propagation for Intelligent Disaster Management Through Vehicular Cloud Network. In *Proc. 2nd Intl. Conf. on Information and Communication Technology for Competitive Strategies*, pages 46:1–46:5, NY, USA, 2016. ACM.

[28] Seoungjun Lee, D. Har, and D. Kum. Drone-Assisted Disaster Management: Finding Victims via Infrared Camera and Lidar Sensor Fusion. In *Proc. 3rd Asia-Pacific World Congress on Computer Science and Engineering*, pages 84–89, Piscataway, NJ, USA, 2016. IEEE.

[29] Peng Li, T. Miyazaki, Kun Wang, Song Guo, and W. Zhuang. Vehicle-assist Resilient Information and Network System for Disaster Management. *IEEE Transactions on Emerging Topics in Computing*, 2017. In Press.

[30] Milan Erdelj, Enrico Natalizio, Kaushik R. Chowdhury, and Ian F. Akyildiz. Help from the Sky: Leveraging UAVs for Disaster Management. *IEEE Pervasive Computing*, 16(1):24–32, 2017.

[31] TCOE-IITM-JICA. DISANET: Disaster Management Network. URL= "http://tcoe.iitm.ac.in/media/disanet.pdf?" [last accessed: 31-Jul-17].

[32] Kamran Ali, Huan X Nguyen, Quoc-Tuan Vien, and P. Shah. Disaster Management Communication Networks: Challenges and Architecture Design. In *Proc. Intl. Conf. on Pervasive Computing and Communication Workshops*, pages 537–542, NJ, USA, 2015. IEEE.

[33] Umme Zakia, Muntasir Wahid Turza, Enamul Karim, T. Moumita, and T. Khan. A Navigation System for Rescue Operation during Disaster Management using LTE Advanced Network and WPAN. In *Proc. 7th Ann. Information Technology, Electronics and Mobile Communication Conference*, pages 1–6, NJ, USA, 2016. IEEE.

[34] Stuart M Adams and Carol J Friedland. A Survey of UAV Usage for Imagery Collection in Disaster Research and Management. In *Proc. 9th Intl. Workshop on Remote Sensing for Disaster Response*, 2011.

[35] D. G. Reina, J M. León Coca, M. Askalani, S. L. Toral, F. Barrero, E. Asimakopoulou, S. Sotiriadis, and N. Bessis. A Survey on Ad Hoc Networks for Disaster Scenarios. In *Proc. Intl. Conf. on Intelligent Networking and Collaborative Systems (INCOS'14)*, pages 433–438, Washington, DC, USA, 2014. IEEE-CS.

[36] D. G. Reina, M. Askalani, S. L. Toral, F. Barrero, E. Asimakopoulou, and N. Bessis. A Survey on Multihop Ad Hoc Networks for Disaster Response Scenarios. *International Journal of Distributed Sensor Networks*, 2015:3:3–3:3, 2015.

[37] Brian Tomaszewski, Michael Judex, Joerg Szarzynski, Christine Radestock, and Lars Wirkus. Geographic Information Systems for Disaster Response: A Review. *Journal of Homeland Security and Emergency Management*, 12(3):571–602, 2015.

[38] Christopher Gomez and Heather Purdie. UAV-based Photogrammetry and Geocomputing for Hazards and Disaster Risk Monitoring - A Review. *Geoenvironmental Disasters*, 3(1):23, 2016.

[39] Milan Erdelj and E. Natalizio. UAV-assisted Disaster Management: Applications and Open Issues. In *Proc. Intl. Conf. on Computing, Networking and Communications*, pages 1–5, NJ, USA, 2016. IEEE.

[40] Milan Erdelj, Michał Król, and Enrico Natalizio. Wireless Sensor Networks and Multi-UAV Systems for Natural Disaster Management. *Computer Networks*, 124:72–86, 2017.

[41] MK Jeya Kumar and RS Rajesh. A survey of manet routing protocols in mobility models. *Int. Journal of Soft Computing*, 4(3):136–141, 2009.

[42] Ozgur Koray Sahingoz. Networking models in flying ad-hoc networks (fanets): Concepts and challenges. *Journal of Intelligent & Robotic Systems*, 74(1-2):513, 2014.

[43] Saif Al-Sultan, Moath M Al-Doori, Ali H Al-Bayatti, and Hussien Zedan. A comprehensive survey on vehicular ad hoc network. *Journal of network and computer applications*, 37:380–392, 2014.

[44] Vishal Sharma and Rajesh Kumar. G-fanet: an ambient network formation between ground and flying ad hoc networks. *Telecommunication Systems*, 65(1):31–54, 2017.

[45] David E Alexander. A Survey of the Field of Natural Hazards and Disaster Studies. In *Geographical Information Systems in Assessing Natural Hazards*, pages 1–19. Springer-Verlag, Berlin, Germany, 1995.

[46] Emanuele Lettieri, Cristina Masella, and Giovanni Radaelli. Disaster Management: Findings from a Systematic Review. *Disaster Prevention and Management*, 18(2):117–136, 2009.

[47] Nezih Altay and Walter G Green. OR/MS Research in Disaster Operations Management. *European Journal of Operational Research*, 175(1):475–493, 2006.

[48] Yiping Jiang, Yufei Yuan, Kai Huang, and Lindu Zhao. Logistics for Large-Scale Disaster Response: Achievements and Challenges. In *Proc. 45th Hawaii Intl. Conf. on System Sciences (HICSS'12)*, pages 1277–1285, Washington, DC, USA, 2012. IEEE-CS.

[49] Gina Galindo and Rajan Batta. Review of Recent Developments in OR/MS Research in Disaster Operations Management. *European Journal of Operational Research*, 230(2):201–211, 2013.

[50] Maria Camila Hoyos, Ridley S Morales, and Raha Akhavan-Tabatabaei. OR models with Stochastic Components in Disaster Operations Management: A Literature Survey. *Computers & Industrial Engineering*, 82:183–197, 2015.