A survey on ad hoc networks for disaster scenarios

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***Abstract*— This survey paper is intended to provide an overview of the main ad hoc paradigms that can be applied to disaster response networks, highlighting their applicability to important tasks in disaster relief operations. In this way, we also review the main works found in the literature which employed ad hoc networks in disaster scenarios. Finally, we provide open challenges and future research directions based on what has already been proved and what is still requiring further research.**

***Keywords*— Ad-hoc networks; Disaster scenarios; MANETs; VANETs; DTNs; WSNs**

I. INTRODUCTION

Ad hoc networks have been proposed as an appealing communication technology to deal with the unexpected conditions emerged during and/or after a disaster. Communications among victims and crewmembers involved in rescue operations are crucial in order to alleviate the disaster consequences and save lives. Nowadays people mostly communicate with each other by using mobile phones, smartphones in the majority of cases, making calls or sending text messages through Internet and via applications such as Whatsapp, Facebook, and Line among others. However, cellular-based communications may not be possible after a disaster due to the damages in the telecommunication infrastructure, leaving many people isolated and unprotected. In [1] authors presented Disaster Recovery Networks (DRN) and Search and Rescue Network (SRN) as the main networks needed for disaster relief. The objective of a DRN consists of providing emergency support to victims and crewmembers taking part in the rescue operations. On the other hand, a SRN is a network formed to track individuals in an emergency operation. In [1] the authors stated the main features required DRN and SRN which are: quick response, life expectancy of the network, interoperability, tariff-free operation, network coverage, support for heterogeneous traffic types, network capacity, ease of use and cost equipment cost, outdoor and indoor operation, high precision for localization and search operation. Mobile ad hoc networks [1][2] exhibit many of the mentioned features so they are suitable for DRN and SRN and consequently for disaster response networks in general. Furthermore, in [3] the authors stated the key obstacles in effective disaster response such as communication and collaboration support, provision of real-time data to field personnel, provision of real-time data to incident command post, unified approach to data handling, visual data capture, on-site building assessment marking, access to building design documents, personal mobility support, resource allocation issues, and multiple connectivity. Ad hoc networks can be a feasible solution for those requirements related to real-time communications and collaboration between the personnel taking part in the rescue operations.

This paper continues as follows, section 2 presents the different ad hoc paradigms that can be used in disaster scenarios, describing the main features of each paradigm and their applicability for disaster scenarios. The existing works done for each ad hoc network in disaster scenarios are reviewed in section 3. Section 4 includes the open challenges and future research directions, and finally the main conclusions of this survey paper are found in section 5.

II. AD HOC COMMUNICATIONS FOR DISASTER SCENARIOS

This section is aimed to present the main features of the different ad hoc communication paradigms such as Mobile Ad hoc NETworks (MANETs), Vehicular Ad hoc NETworks (VANETs), Delay Tolerant Networks (DTNs), Wireless Sensor Networks (WSNs), Wireless Mesh Networks (WMNs), and TETRA, yet most importantly, their applicability for disaster scenarios. Table I summarizes the main features of the ad hoc communication paradigms that are described in this section. For more information about the different ad hoc networking paradigms and wireless technologies, the reader is referred to [4][5][6]. For information on disaster scenarios and computational intelligence, the reader is pointed to [7][8].

A. MANETs

In general two types of communications can be considered in classical MANETs, broadcast communications and multi-hop communications via routing protocols.

In broadcast communications, a node shares the same information simultaneously with its one-hop neighbor nodes. It may be suitable for transmitting warning messages, and alarms which are crucial forms of communications in disaster scenarios. When nodes rely on routing protocols for establishing a communication path to a destination node, nodes should maintain routing tables in order to select which is the best next hop to route the information. Regarding the applicability of routing protocols in disaster scenarios, we can think about a situation where a rescue team needs to retransmit certain information to a central unit. A multi-hop route can be established from a crewmember to the central unit. The routing protocol would be responsible for selecting the best

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nodes to retransmit the data packets from the crewmember to the central unit.

B. VANETs

The basic types of communications in VANETs are the same above mentioned in MANETs, so nodes (vehicles) can use both broadcast communications and multi-hop communications via routing protocols. However, there are significant differences in the design of broadcast and routing protocols for VANETs. First, since mobility is higher than in MANETs, a fast medium access is needed in order to establish rapid communications among nodes. Second, in VANETs scenarios are also defined static nodes namely road units which are intended to offering services to vehicles. Consequently, in VANET scenarios we can distinguish Vehicle To Infrastructure communications (V2I) and Vehicle To Vehicle communications (V2V). However, in disaster scenarios these road units are likely to be destroyed or malfunctioned so V2V should be considered as the main application of VANETs in disaster scenarios.

C. DTNs

In DTNs we cannot make the distinction between broadcast and routing protocol-based communications. In DTNs there is only one way of communication between nodes which is used in every new encounter between two nodes. In DTN communications the information is sent in units called bundles. When a node generates some information it is split in different bundles, and then, the node waits until encountering another node in order to deliver the information (bundle protocols). As a rule, DTN paradigm is suitable in cases of low density. For example, a police officer who is participating in a rescue operation and carrying certain information in order to share them with all encountered victims. Furthermore, DTN are also suitable in high mobility networks, where traditional MANETs fail due to the continuous breakages of routes between the pair source-destination nodes.

D. WSNs

WSNs are centralized networks where nodes are normally grouped in clusters. In general a node acts as the central node, head of cluster or sink node and the other nodes are collecting certain data from the environment and sending it towards the central node. As for the applicability in disaster scenarios, WSNs should play detection, warning and alerting roles. They are suitable to be deployed in areas that are likely to suffer from natural disasters. For example, suppose a WSN deployed in an area in order to sense the earth vibrations for detecting possible earthquakes or a WSN deployed in a forest to monitor and detect fires. WSNs are also envisioned to play an important role in the Future Internet and Internet of Things (IoT) which also could play a key role in disaster relief [9].

E. WMNs

Regarding WMNs, the communications are similar to that of MANET paradigm (broadcast and routing protocols). However, the applications of traditional MANET and WMNs are different, making also different the goals of the routing protocols designed for WMNs. In WMNs communications are mostly focused on extending Internet connectivity. We can imagine nodes in an urban area with Internet connectivity thanks to a WMN deployed. This is also the main application of WMNs in disaster scenarios; that is to form a backbone network to provide Internet or extend connectivity in a wireless local network, for instance, to a rescue team operating in an evacuation mission.

F. TETRA

TErrestial Trunked RAdio (TETRA) is the wireless private technology normally used by public services such as police, firefighters, ambulances, security services, etc. In its normal operation TETRA is an infrastructure-based technology which has been developed since 1990s with the cooperation of the European Commission and the ETSI members [10]. TETRA terminals can also communicate with each other in direct mode without needing infrastructure.

Although TETRA technology has been defined for emergency scenarios, providing desirable features such as security and resilience, they both lack an important aspect, which is the interoperability with other free bands wireless technologies such as WiFi and Bluetooth. It has been stated that the collaboration between victims and crewmembers is crucial in disaster response scenarios [11] so in order to establish cooperation between first responders and the victims they must be able to use a common technology. For this reason, the use of smartphones seems to be the most reasonable alternative. Most smartphones found in the market are equipped with WiFi and Bluetooth transceivers so these technologies are potential technologies for developing smartphones applications for ad hoc network paradigms in disaster scenarios.

TABLE I. AD HOC COMMUNICATION PARADIGMS

Ad hoc paradigm	Mobility	Connectivity	Routing	Main Functionality
MANET	Low-medium Unexpected	High	Broadcast schemes Routing protocols (Network layer)	Real time communications
VANET	High Predictable and constrained by lanes	Medium-High	Broadcast schemes Routing protocol (Network layer)	Real time communications
DTN	Medium Unexpected	Medium-low	Forwarding schemes (Bundle layer)	Communications for Non delayed sensitive data
WSN	Low	High	Broadcast schemes Routing protocols (Network layer)	Detection and warning systems
WMN	Low	High	Broadcast schemes Routing protocols (network layer)	Backbone network
TETRA	Medium Tactical	Medium	Point-to-point Point-to-multipoint Repeater	Real time communications

G. The necessity of Interoperability among ad hoc communication paradigms for disaster scenarios

Communications in disasters scenarios may require interoperability among the mentioned ad hoc communication paradigms. Let us illustrate the necessity of such interoperability with the following example. Suppose a crewmember, who is in a rescue operation, will need to communicate with other crewmembers in a well connected network like a MANET. To do so, they will be establishing a communication path to another crewmember through a routing protocol or spreading out the same information to all crewmembers via a broadcast protocol, for example an emergency message indicating that they are in danger. Of course, it can be done using a specific technology like TETRA. However, later they would also require communicating with dispersed victims; let's say using a DTN in order to transmit a possible evacuation route to the victims. It is important to emphasize that this cannot be done using TETRA since no victims are expected to have a TETRA terminal. The same crewmember may also require communicating with an ambulance in order to indicate the location of trapped victims so the MANET terminal should be able to communicate with the wireless transceivers incorporated in the vehicles (VANET). With a WSN deployed in a building a crewmember could recover certain data on the building before and during the occurrence of the disaster. This information can be very important to determine tactical movements in a number of rescue operations. Consequently, the MANET terminal should be able to communicate with WSN technologies. This simple example has made clear the significance for the need of interoperable ad hoc communications in order to achieve an integral and complete communication system for disaster response situations. The interoperability of different ad hoc paradigms is also envisioned a primordial objective for the proliferation of market applications of ad hoc networks in a multi-paradigm era [6]. This interoperability must go further than just connecting different ad hoc networks; they must also communicate with other wireless technologies such as satellite communications [12] and with the infrastructure, for instance cellular phone infrastructure, in zones where it is still functioning [13].

III. REVIEW OF EXISTING WORKS ON AD HOC NETWORKS FOR DISASTER SCENARIOS

This section is focused on presenting the main works on the application of the aforementioned ad hoc communication paradigms. Table II summarizes the main research directions for the different ad hoc paradigms in disaster scenarios.

A. MANETs

The main works done on evaluating MANETs in disaster scenarios are based on the comparison of different MANET routing protocols in a disaster scenario. In [14] and [15] several popular routing protocols for MANETs (AODV, AOMDV, and DSR) were evaluated in disaster scenarios, considering different communication patterns. As for the obtained results in [14] and [15], the reactive routing protocol AODV (Ad hoc On-demand Distance Vector) is the most suitable protocol for the scenarios considered. A similar evaluation was conducted in [16] in which also several routing protocols for MANETs (AODV, DYMO, BATMAN, and OLSR) were evaluated under a simulated emergency scenario modeling an explosion in a chemical facility. According to the results shown in [16], AODV again achieved the best results. In [17] the authors also evaluated by simulation several routing protocols for MANETs (AODV, DSDV, CBRP). The main difference from the previous evaluation is that in [17] the Waypoint mobility model was used instead of disaster area mobility model [18]. According to results shown in [17] CBRP protocol outperforms its counterparts AODV and CBRP.

Regarding the evaluation of broadcast schemes in disaster scenarios, in [19] and [20] the authors used evolutionary approaches to optimize a broadcast scheme based on dissimilarity coefficients for disaster scenarios. In [19] the authors used a single objective genetic algorithm, and in [20] they presented the broadcast problem as a multi-objective optimization problem. In [21] the performance of simple broadcast was enhanced by positioning auxiliary nodes using a genetic algorithm in low connected areas of a disaster response scenario.

B. VANETs

The main work done on vehicular ad hoc networks for disaster scenarios was focused on two respects. First, a protocol improvement in the emergency messages dissemination among vehicles is produced by proposing new broadcasting and routing protocols for emergency scenarios. Second, a creation of an attached schema specifically designed for attending disaster situations in the actual VANET infrastructure is produced.

Information exchange via broadcast messages in VANETs for safety applications is summarized in [22]. Broadcast communications for emergency scenarios was studied in [23], [24]. Furthermore, there are a few works specifically centered in pre and post disaster situations. In [25] RescueME system is incorporated in the existing communication infrastructures to provide the method and entities to store users' location.

C. DTNs

The work done on DTNs is diverse, ranging from evaluating existing protocols to proposing new routing protocols and even new systems to improve the network performance in disaster areas.

In [26] the authors evaluated the performance of different opportunistic network's forwarding protocols (Epidemic, PRoPHET, MaxProp, and TTR) in disaster scenarios. The results showed that MaxProp protocol has the best delivery ratio, while the TTR protocol has the best overhead and cost results. It was concluded that there is no such thing as the absolute best protocol, but it depends on the scenario and the property needed to be utilized. In [27] the performance of (Direct delivery, First contact, Epidemic, Spray and wait, Binary spray and wait and PROPHET) forwarding protocols was evaluated in terms of the fairness in delivering the message between the nodes. It was concluded that according to the simulations none of the tested protocols were able to satisfy the fairness criteria.

Regarding proposing new forwarding schemes for DTNs in disaster scenarios, in [28] two energy efficient opportunistic routing protocols (PropTTR and PropNTTR) were proposed.

In [29] the authors proposed a DTN forwarding protocol that assigns priorities to the messages before handling each message according to that priority. Appreciating and assigning several levels of priority in disaster scenarios is of significance importance. In this way, nodes will retransmit incoming messages according to a given priority. As for the energy efficiency proposed in PropTTR and PropNTTR, it is crucial to extend the lifetime of an opportunistic network. Note that the possibility of recharging electronic devices after a disaster can be limited.

D. *WSNs*

The main work done on wireless sensor networks in disaster scenarios was concentrated on two aspects. Firstly, in disaster predicting and alert systems i.e., how can a WSN be used to detect, warn and alert about a possible disaster. Secondly, by assisting in the post disaster search and rescue missions by deploying nodes in the disaster area as the WSN node mobility is low.

A disaster alert system that uses WSN and Analytic Network Process (ANP) to predict any possible landslides disasters is proposed in [30]. In [31] the authors proposed a flashflood alerting system based on a WSN in a rural area. Regarding the work done for post disaster scenarios, in [32] the authors proposed a multi-agent system based WSN approach for crisis management. In [33] the authors evaluated using autonomous mobile robots to deploy a WSN in a disaster area.

E. *WMNs*

The main application of WMNs for disaster response networks is as backbone network to extend Internet connectivity or to extend local connectivity in a WLAN so the WMNs can be seen as the mechanism to rapidly form an ad hoc infrastructure.

In [34] the authors presented SKYMESH a mesh network based on WiFi access points to provide rapid access to a WLAN network in a disaster area. The authors proposed using helium-filled balloons floating in the air with WiFi transceivers as the nodes to form the mesh network. A similar approach is presented in [35] where the authors proposed a WMN for providing multimedia services in a disaster area.

TABLE II. TABLE STYLES

Ad hoc paradigm	Research directions
MANETs	Evaluation of routing protocols and broadcast schemes in disaster scenarios. New routing protocols for disaster scenarios. Real experimentation.
DTNs	Evaluation of forwarding schemes in disaster scenarios. New systems for the use of DTNs in disaster scenarios. Real experimentation.
VANETs	Secure broadcast schemes for emergency scenarios. Post disaster systems.
WSNs	Prediction and warning systems. Systems for improving post disaster search and rescue operations. Crowd sensing.
WMNs	Extending Internet connectivity in isolated zones.

F. *Integration of different ad hoc paradigms*

In section II, we have stated the significance of combining different ad hoc paradigms in a complete solution for disaster response networks. To the best of our knowledge, there is no work which includes all the ad hoc paradigms reviewed in a paper. Yet there are some promising works on combining several ad hoc paradigms. It is especially relevant the case of combining MANETs and DTNs. The main issue to address is when nodes should switch between MANET to DTN paradigm. It is obvious that the density of nodes must be the main clue for making such change. In high density scenarios nodes should behave as in MANETs and in sparse situations nodes should switch to DTN behavior.

In [36] the authors presented DistressNet, a system that helps with the search and rescue operation after a disaster. DistressNet is a complete complex system that adopts DTNs as well as WSNs and MANETs.

A real prototype of a communication system for ad hoc communications in disaster scenarios combining both MANET and DTN paradigms is presented in [37]. It is based on an application for smartphones which switches between both modes of performance. The authors validated their prototype with two field experiments. The first experiment was focused on message relay in urban area, while the second was focused on the interconnection with Unmanned Aircraft Systems (UAS). Note that in this sense ad hoc network for communications among unmanned vehicles is a promising vision [38]. In addition, robots and drones are also envisioned as significant elements to improve mobility in disaster response networks [39]. Consequently, ad hoc communications among robots and drones is a significant field that requires further research.

In [12] the authors combine MANETs and WMNs with satellite communications. The crewmembers of a rescue team communicate each other in a MANET, and the coverage range within the crewmember can communicate is enlarged using a WMN with WiMax technology. In addition, the different rescue teams operating in different areas far away each other and performing different tasks communicate via satellite. Experimental results are presented in [12] to validate the proposed communication architecture.

In [40] the authors presented CodeBlue, a suite of protocols and services for many types of devices such as wireless sensors, location beacons, handheld computers, laptops, among others. The authors focused on the issue of interconnecting constrained devices in terms of power consumption and resources in disaster scenarios. Among the services offered by CodeBlue for disaster response networks are, integration of medical sensors, routing and prioritization, and 3D location.

Although the aforementioned works clearly demonstrate that the interoperability among different ad hoc communications is possible, further research is needed in order to propose integral solutions. For instance, solutions integrating MANETs and VANETs have not been proposed so far.

IV. OPEN CHALLENGES

This section presents a detailed list of open challenges and future work on the application and evaluation of ad hoc network paradigms in disaster scenarios. A common future work in all ad hoc paradigms is the necessity of more real experimentation since most of the work done remain in the simulation phase. Another common challenge is to achieve secure mechanisms for exchanging information.

A. *MANETs*

- Although a large amount of literature can be found about broadcast schemes in MANETs and good comparison among different schemes have been also proposed, it has not been still proposed an evaluation of different broadcast schemes in disaster scenarios.
- In real experimentation cases surveyed in this paper OLSR routing protocol has been the one selected to be implemented [36][37] to establish real time ad hoc communication in disaster scenarios. However, OLSR is a proactive routing protocol which has problems of scalability in networks with a high number of nodes. We think that other reactive routing protocols like AODV would perform better in disaster scenarios according to the results obtained in [14][15].

B. *VANETs*

- Broadcasting for emergency scenarios is an active research topic in VANETs. However, there is no comparison among all the proposed schemes in the literature.

C. *DTNs*

- Although new DTN forwarding protocols are constantly being proposed, it has not been presented a protocol that utilizes required protocol properties in disaster scenarios such as fairness in delivering the message and to be energy efficient. Consequently, more research on forwarding schemes for disaster scenarios is required.
- Many of the proposed schemes depend on manual user interaction which can be inefficient; for future work more automated independent systems must be researched.

D. *WSNs*

- More automated WSN node deployment systems need to be researched as it is sometimes difficult to deploy the nodes manually in a disaster area either during or even after the occurrence of a disaster. In this research direction, the possibility of using UAS, robots, and drones could facilitate the deployment in sensors.
- Since the continuous evolution of the sensor market, new sophisticated solutions based on WSN will be possible in the near future. Special attention must be taken on mobile phone and crowd sensing which will be possible thanks to the incorporation of new sensor technologies in the new generation of smartphones.

E. *Integration of different ad hoc paradigms*

- Although there are existing works that prove the feasibility of the combination of different ad hoc networks in a unique system, more work is needed to find an integral and complete solution. The interoperability between MANETs and DTNs has been already demonstrated successfully in several works [36][37]. However, little effort has been done to demonstrate the interoperability between other technologies such as WSNs and MANETs or DTNs. The main issue for this interoperability is due to the fact that these ad hoc paradigms normally use different wireless technologies. It could be solved by incorporating bridge platforms in WSNs, for instance, to communicate WSNs using Zigbee and MANET or DTN using WiFi and/or Bluetooth.

V. CONCLUSIONS

The applicability of ad hoc networks in disaster scenarios is still in an initial phase. Most works done on this idea are only based on simulations rather than real experimentation. The works based on real experimentation presented in this survey reveal that the application of ad hoc networks in disaster scenarios is feasible and may help to save many lives and reduce the number of casualties. We have surveyed in this paper the main fields of application of the different ad hoc paradigms found in the literature and we have also reviewed the main contributions made by researchers in the last decade. However, it is clear that more research is needed, especially more work is required to achieve greater levels of interoperability between different ad hoc paradigms, which is a primordial requirement to obtain an integral and complete ad hoc system for disaster response.

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REFERENCES

[1] R. G. Lakshmi Narayanan and O. C. Ibe. “A joint network for disaster recovery and search and rescue operations”. Computer Networks, Vol. 56, pp. 3347-3373. 2012.

[2] D. G. Reina, S. L. Toral, F. Barrero, N. Bessis, and E. Asimakopoulou. “The role of ad hoc networks in the internet of things”. In Internet of Things and Inter-cooperative Computational Technologies for Collective Intelligence, Ed. By N. Bessis, Springer, pp. 89-113. 2013.

[3] F. Peña-Mora and Z. Aziz and A. Chen and A. Plans and Foltz. “Building assessment during disaster response and recovery”. Proceedings of the Institution of Civil Engineers, Vol. 161, pp. 183-195. 2008.

[4] M. Conti and S. Giordano. “Multihop Ad Hoc Networking: The Theory”. IEEE Communications Magazine, Vol. 45, pp. 76-86. 2007.

[5] M. Conti and S. Giordano. “Multihop Ad Hoc Networking: The Reality”. IEEE Communications Magazine, Vol. 45, pp. 88-95. 2007.

[6] M. Conti and S. Giordano. “Mobile Ad Hoc Networking: Milestones, Challenges, and New Research Directions”. IEEE Communications Magazine, Vol. 52, pp. 85-96. 2014.

[7] E. Asimakopoulou, N. Bessis, R. Varaganti anf P. Norrington “A Personalised Forest Fire Evacuation Data Grid Push Service – The FFED-GPS Approach”, in Asimakopoulou E and Bessis N (eds)

Advanced ICTs for Disaster Management and Threat Detection: Collaborative and Distributed Frameworks, pp: 279-295. 2010.

[8] N. Bessis, E. Asimakopoulou, T. French, P. Norrington and F. Xhafa. “The Big Picture, from Grids and Clouds to Crowds: A Data Collective Computational Intelligence Case Proposal for Managing Disasters, Fifth International Conference on P2P, Parallel, Grid, Cloud and Internet Computing (3PGCIC, 2010), pp: 351-356. 2010.

[9] G. Deak, K. Curran, J. Condell, E. Asimakopoulou, and Nik Bessis. “IoTs (Internet of Things) and DfPL (Device-free Passive Localisation) in a disaster management scenario”. Simulation Modelling Practice and Theory, Vol. 35, pp. 6-96. 2013.

[10] H. A. Ketterling. “Introduction to Digital Professional Mobile Radio”. Artech House. 2004.

[11] D. A. McEntire. “Disaster Response and Recovery”. Wiley. 2007.

[12] W. Lu and W. K. G. Seah and E. W. C. Peh, and Y. Ge. “Communications Support for Disaster Recovery Operations using Hybrid Mobile Ad-Hoc Networks”. 32nd IEEE Conference on Local Computer Networks, pp. 763-770. 2007.

[13] F. Chiti and R. Fantacci and L. Maccari and D. Marabissi, and D. Tarchi. “A broadband wireless communications systems for emergency management”. IEEE Wireless Communications, Vol. 15, pp. 8-15. 2008.

[14] D. G. Reina, S. L. Toral, F. Barrero, N. Bessis, and E. Asimakopoulou. Evaluation of Ad Hoc Networks in Disaster Scenarios. Third International Conference on Intelligent Networking and Collaborative Systems (INCoS, 2011), pp. 759-764. 2011.

[15] D. G. Reina, S. L. Toral, F. Barrero, N. Bessis, and E. Asimakopoulou. “Modelling and assessing ad hoc networks in disaster scenarios”. Journal of Intelligent Ambient and Humanized Computing. D.O.I. 10.1007/s12652-012-0113-3.

[16] C. Raffelsberger and H. Hellwagner. “Evaluation of MANET Routing Protocols in a Realistic Emergency Response Scenario”. 10th International Workshop on Intelligent Solutions in Embedded Systems, pp. 88-92. 2012.

[17] L. E. Quispe and L. M. Galan. “Behavior of Ad Hoc routing protocols, analyzed for emergency and rescue scenarios, on a real urban area”. Expert Systems with Applications, Vol. 41, pp. 2565-2573. 2014.

[18] N. Aschenbruck, E. Gerhards-Padilla, P. Martini. "Modeling mobility in disaster area scenarios". Performance Evaluation, pp.773-790. 2009.

[19] D. G. Reina, S.L. Toral, J. M. Leon-Coca, F. Barrero, N. Bessis, E. Asimakopoulou. “An Evolutionary Computational Approach for Optimizing Broadcasting in Disaster Response Scenarios”. Seventh International Conference on Innovative Mobile and Internet Services in Ubiquitous Computing (IMIS 2013), pp. 94-100, 2013.

[20] D. G. Reina, J. M. Leon-Coca, S. L. Toral, E. Asimakopoulou, F. Barrero, P. Norrington, and N. Bessis. “Multi-objective performance optimization of a probabilistic similarity/dissimilarity-based broadcasting scheme for mobile ad hoc networks in disaster response scenarios”. Soft Computing. DOI 10.1007/s00500-013-1207-3.

[21] D. G. Reina, S. L. Toral, N. Bessis, F. Barrero, and E Asimakopoulou. “An evolutionary computation approach for optimizing connectivity in disaster response scenarios”. Applied Soft Computing, Vol. 13, pp. 833-845. 2013.

[22] R. Chen, J. Wen-Long, and A. Regan. "Broadcasting safety information in vehicular networks: issues and approaches," IEEE Network, Vol.24, pp. 20-25. 2010.

[23] A. Murali, K. Bhanupriya, S. B. Smitha, G. N. Kumar. "Performance evaluation of IEEE 802.11p for vehicular traffic congestion control". 11th International Conference on ITS Telecommunications (ITST), pp. 732-737. 2011.

[24] M. Chuang and M. C. Chen. "DEEP: Density-Aware Emergency Message Extension Protocol for VANETs" IEEE Transaction on Wireless Communications, Vol. 12, pp. 4983-4993. 2013.

[25] J. 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, Vol.29, pp. 659-669. 2011.

[26] A. M. Campillo, J. Crowcroft, E. Yoneki, R. Marti. "Evaluating opportunistic networks in disaster scenarios". Journal of Network and computer applications, 870-880. 2013.

[27] A. Takahashi, H. Nishiyama, N. Kato. "Fairness Issue in Message Delivery in Delay- and Disruption-Tolerant Networks for Disaster Areas". International Conference on Computing, Networking and Communications, Wireless Networks Symposium, pp. 890-894. 2013.

[28] A. M. Campillo, R. Marti. "Energy-efficient forwarding mechanism for wireless opportunistic networks in emergency scenarios". Computer Communications, pp.1715–1724. 2012.

[29] Inwhee J., Sang-Bo K.. "A Message Priority Routing Protocol for Delay Tolerant Networks (DTN) in Disaster Areas". Future Generation Information technology, pp. 727-737. 2010.

[30] M. Castillo-Effen, D. H. Quintela, R. Jordan, W. Westhoff, W. Moreno. "Wireless Sensor Networks for Flash-Flood Alerting". Fifth IEEE International Caracas Conference on Devices, Circuits and Systems, pp.142-146. 2004.

[31] M. Bahrepour, N. Meratnia, M. Poel, Z. Taghikhaki, P. J.M. Havinga. "Distributed Event Detection in Wireless Sensor Networks for Disaster Management". International Conference on Intelligent Networking and Collaborative Systems, pp. 507-512. 2010.

[32] A. Sardouk, M. Mansouri, L. Merghem-Boulahia, D. Gaiti , R. Rahim-Amoud. "Crisis management using MAS-based wireless sensor networks". Computer Networks, Vo. 57, pp.29-45. 2013.

[33] G. Tuna, V. C. Gungor, K. Gulez. "An autonomous wireless sensor network deployment system using mobile robots for human existence detection in case of disasters". Ad Hoc Networks, Vol. 13, pp.54-68. 2013.

[34] H. Suzuki, Y. Kaneko, K. Mase, S. Yamazaki, and H. Makino. “An ad hoc network in the sky, SKYMESH, for large-scale disaster recovery”. Proceedings of Vehicular Technology Conference, pp. 1-5. 2006.

[35] K. Kanchana, A. Tunpan, M. A. Awal. D. K. Das, T. Wongsaardsakul, and Y. Tsuchimoto. “A Multimedia Communication System for Collaborative Emergency Respond Operation in Disaster-affected Areas”. Internet Education and Research Lab, Asian Institute of Technology, Thailand, Technical report. 2007.

[36] H. Chenji , W. Zhang , R. Stoleru, C. Arnett. "DistressNet: A disaster response system providing constant availability cloud-like services". Ad Hoc Networks, pp.2440–2460. 2013.

[37] H. Nishiyama, M. Ito, and N. Kato. “Relay-by-Smartphone: Realizing Multihop Device to Device Communications”. IEEE Communications Magazine, Vol. 52, pp. 56-65.

[38] İ. Bekmezci and O. K. Sahingoza, and Ş. Temelb. “Flying Ad-Hoc Networks (FANETs): A survey”. Ad Hoc Networks, Vol. 11, pp. 1254-1270. 2013.

[39] G. Tuna, V. G. Gungor, and K. Gulez. “An autonomous wireless sensor network deployment system using mobile robots for human existence detection in case of disasters”. Ad Hoc Networks, Vol. 13, pp. 54-68. 2014.

[40] K. Lorincz, D. Malan, T. Fulford-Jone, A. Nawoj, A. Clavel, V. Shnayder, G. Mainland, S. Moulton, and M. Welsh. “Sensor Networks for Emergency Response: Challenges and Opportunities”. IEEE Pervasive Computing, Vol. 4, pp. 16- 23. 2004.