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Unmanned Aerial Vehicles Operated Emergency Ad Hoc Networks

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***Abstract*—One of the vital application of Emergency Ad hoc Networks is to establish communication between those affected by emergency situation and responders providing services. In most such cases, the conventional communication infrastructure such as wired and cellular networks get damaged and therefore cannot provide communication required to exchange emergency information. Therefore, to cope with such disasters in a fast and coordinated way, the optimal provisioning of the emergency information is crucial. Unmanned Aerial Vehicles (UAV) are the paramount components for such situations. UAVs can act as mobile base stations and facilitate wireless communication to connect to nearest working telephone network access point. A large scale disaster information system can be formed by combining UAV network with existing available network regardless of some of network lines being damaged and destroyed. In this paper, we have designed a prototype of UAV assisted emergency ad hoc network (EANET). We have also evaluated and compared AODV and ZRP routing protocols by varying the number of UAV assisted EANET nodes in different transmission range cases of disaster scenarios. The experimental results illustrate that ZRP is the most appropriate protocol for emergency situations.**

***Keywords*-Emergency Ad Hoc Networks, Unmanned Aerial Vehicle, Disaster mitigation, routing**

I. Introduction

The world has seen several large–scale disasters in the recent past. Such disasters can be classified into two major groups (a) Natural disasters e.g. earthquakes, tsunamis, floods, landslides etc. (b) Anthropogenic (human caused disasters) e.g. terrorist attacks, riots, wars etc. These disasters can cause severe damage to infrastructure including communication, cause environmental degradation and lead to diseases, hunger and a large-scale loss of human lives. In such situations, existing infrastructure (wired or wireless) get impaired and emergency information would not be propagated timely and correspondingly required actions would not have been taken causing loss of lives [1]. Therefore, it is very important to endure with such disasters in a coordinated manner by timely providing emergency information. According to case studies on recent disasters in the world such as the earthquake in Nepal and Uttrakhand, tsunami in Japan, Indian ocean earthquake and tsunami [2] etc., natural disasters can have severe impacts on communication systems:

After the disaster, a detailed assessment is required for effective implementation of rescue operations by the following measures:

1) Ad hoc networks are formed by the present communication devices (mobile phones, tablets, iPads etc.) nearby so that information about the emergency cases and loss of lives is conveyed to medical and rescue teams.
2) If communication devices are not available, satellite terminals may be delivered urgently using manpower, cars or helicopters. But, this may take several days depending on the geographical terrain and the amount of damage to aerial, sea and road routes.
3) Unmanned Aerial Vehicles (UAV) are used to perform surveys of large geographical areas. These are used to assess the amount of damage to infrastructure throughout the affected area. These can be used as temporary base stations to make connection between disaster affected region and the outside world.

An Ad Hoc Network is a collection of wireless nodes that can dynamically create a network without needing any fixed infrastructure and no central administration. An EANET (Emergency Ad Hoc Network) is classified as an ad hoc network that is applicable to emergency situations typically associated with disasters. The USP of an EANET is that it makes it possible to forward *request for help* messages through nearby mobile devices until they are intercepted by emergency services.

A collection of two or more devices equipped with wireless communications and networking capability in an emergency situation can form an EANET. It is assumed that few such devices (laptops, smartphones, tablets etc.) are already available in disaster scenarios. For first responder proximity zone, we can dynamically form EANETs by provisioning new or existing devices as applicable.

EANET offers a promising solution to deal with both natural and anthropogenic disasters. In such critical scenarios, all first responders including government, public, police, fire department, civil defense, NGOs and other related agencies need to coordinate with each other in a quick and efficient manner. EANETs can be dynamically setup in different ways depending upon the type of disaster scenario.

In such scenarios when all other services are unavailable, an EANET helps assess the situation in terms of the extent of damage caused by allowing people to share photos, videos

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and location information to first responders. This information is then propagated to rescue command centers for analysis and subsequent recovery actions. An EANET can overcome the limitations of traditional Ad hoc networks and it is designed to deal with the following challenges:-

1) Network topology may be unpredictable and/or network may be disconnected due to random movement of nodes.
2) Wireless network range is limited and it is also affected by environmental conditions. This may lead to network bottlenecks because of dynamicity in network topology and link capacities.
3) Mobile devices have limited power and processing capability, these can be serious limitations in a disaster situation where predictability is crucial.

Apart from addressing all the problems mentioned above, an EANET must ensure quick delivery of emergency messages as well as an accurate assessment of the situation at ground.

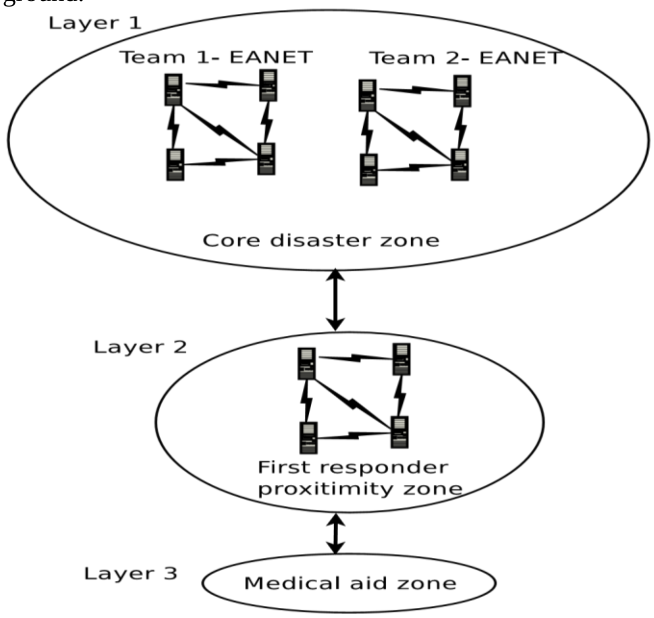

Figure 1. The deployment of EANET at emergency site. The network topology is partitioned in several EANET subnets. These subnets may be connected via UAVs.

Rescue operations in post disaster situations can be managed in three zones as shown in Figure 1:-

1) Core disaster zone i.e. Incident location

2) First responder proximity zone 3)

Medical aid zone.

These zones can be increased/decreased based upon the type or severity of disaster. User motion trajectory is semideterministic, i.e derived by instructions from superiors, but can be subject to deviations of speed, direction, and pause time within a zone.

An EANET offers an efficient and reliable mechanism to coordinate communication between and within these zones using Unmanned Aerial Vehicles (UAVs). UAVs are used to provide backbone infrastructure in situations where predefined infrastructure has been damaged i.e. within these isolated zones. UAVs are also used to establish communication within a zone by acting as a mobile access point. In EANETs, a message travels along the network hopping between nodes until it reaches the destination [5]. UAVs can enter or leave the disaster effected area at any time [10], thereby providing communication to the outside world.

For successful deployment/enaction of EANETS in events of disaster, routing mechanism has to be aware of the surroundings. Specific aspects of the disaster affected region such as connectivity (e.g. hilly terrains), node density, energy efficiency of nodes, availability of other networks and connectivity with these need to be looked into. From an EANET perspective, other parameters such as optimal use of bandwidth, mobility patterns, and cross-compatibility with other networks are also of primary importance and need to be investigated.

Mobility patterns play a crucial role in evaluation of EANETs performance. No existing mobility model is suitable that can simulate movement of users in a heterogeneous disaster environment. It is intended to design a group based mobility model that can incorporate the heterogeneous environment parameters such as obstacles, node density, movement of nodes and routing etc. In a real disaster scenario, the salvage operation is always performed by several teams or groups. In a group mobility model, the entire group follows the same movement pattern initiated/commanded by group leader.

This paper focuses only on the routing perspective of UAV assisted EANET. We present comparative analysis of AODV and ZRP routing protocols. The organization of the paper is as follows. Section II presents overview of UAV enabled EANET. Related work of ad hoc networks in disaster scenarios are discussed in Section III. Experimental setup and results are presented in Section IV. Finally, concluding remarks with future work are covered in Section V.

II. UAV BASED EANET

Generally, UAVs are used in military technology systems but recently have found a use case in civilian life as well [8], e.g., in emergency situations such as earthquakes, tsunami, floods etc. where existing infrastructure is destroyed. UAVs can be used for taking videos or photos, for remote sensing, or even for package delivery in such situations. UAVs are controlled without the aid of on-board human operator. Here, the signals are received and processed by an onboard micro-controller which then forwards this signal to motors electronic speed controllers. For an autonomous flight, signals are received by sensors attached to the UAV and then processed by micro-controller before forwarding the signals to motors electronic speed controllers.

UAVs are used to perform tasks that are considered too harmful to be performed by human [9].

The basic parts that every UAV must have to achieve flight are the micro-controller, the electronic speed controllers (ESCs) and the motors. Other equipments such as sensors, antennas and GPS can also be included to incorporate more functionality. The micro-controller is the brain of the machine. It processes inputs and sends the appropriate signals as outputs to maintain and control flight.

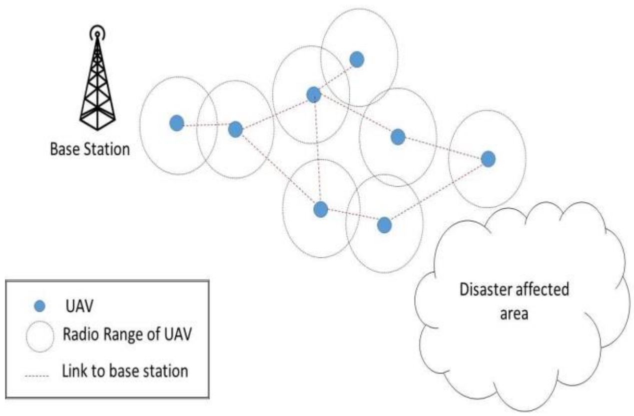

Figure 2. An Ad Hoc Network of UAVs and base station (forming a communication link between disaster affected area and base station through series of UAVs.)

In emergency situations, where existing infrastructure (base stations, access points) has collapsed and it is not possible to communicate with outside world, this problem can be solved by employing mobile base stations in the form of UAVs. It has become much easier to accomplish since those affected by emergency situations are able to call emergency services without needing to find a fixed land-line. A problem still exists when the access points (cell towers or base stations) become damaged or destroyed during the emergency situations, causing communication to become impossible. When this happens, mobile phones become unable to send or receive calls, effectively isolating them from communicating with emergency responders. One solution to this problem is to employ the use of a mobile base station. But the problem is that mobile stations are maneuvered by driving trucks to affected area. These mobile base stations are limited to move on road only and slow because of damaged road infrastructure also. It is paramount to find some other way so that communication can be restored instantly in order to save and protect large number of people.

A certain number of UAVs can be deployed in these areas as shown in Figure 2. These UAVs act as mobile base stations and provide coverage for a certain area. These UAVs are able to communicate with each other (either through single or multi-hop communication) and to the nearest working base station or mobile access point. This UAV assisted EANET provide the communication in affected area by forwarding the received information to the nearest available infrastructure. This network will continue to function until some stable infrastructure can be put in place to reinforce communication to the affected area.

III. RELATED WORK

UAV based EANETs are not only intended to provide assistance in battlefield such as tracking, sensing and detecting target areas, but can also be used for civilian applications to observe places that are hard to access such as in disaster situations. Performance of EANETs depend on: (a) connection between UAVs and (b) connection between UAV and base stations since reliable connectivity is very important to forward time-critical information either through single-hop or multi-hop communication.

Yanmaz [6] has discussed trade off between connectivity and area covered by UAV in emergency situations. Alshbatat *et al.* [7] have measured the impact of directional antennas on throughput and end-to-end delay in UAV communication network. Han *et al.* [8], presented the network connectivity restriction in ad hoc networks. UAV-assisted broadband network for emergency and public safety communications is presented in [11][12]. Layout of UAV networks is presented in these papers.

In [3], authors have analyzed the performance of MANET routing protocols (DSDV, AODV and CBRP) by selecting a real urban area of the city of Loja, in Ecuador, for the emergency and rescue scenario. A new method that realistically represents the movements in a disaster affected area is presented by [4]. The model analyses the plotted issues of civil protection. This analysis considers parameters such as heterogeneous area-based movement, obstacles, and dynamicity of nodes in order to influence network performance in public safety communication networks. In [5][13], behaviour of MANETs routing protocols under realistic disaster scenarios have been analyzed.

It is important to design a practical mobility model for disaster scenario. In delay tolerant Peer-to-Peer wireless network, Post disaster situation analysis and resource management is presented in [14][15]. In [16], authors have presented the comparative analysis of routing protocol using RPGM mobility model in Qualnet simulator.

IV. EXPERIMENTAL SETUP AND SIMULATION RESULTS

In this paper, we have analyzed the impact of UAV density and speed on packet delivery ratio and number of dropped packets in UAV assisted EANETs. These parameters are evaluated on well defined routing protocols such as AODV [18] and ZRP [19]. All the experiments are performed in NS2 simulator [17] as it allows the simulations of complex networks. It also facilitates different mobility models such as random way point and Reference Point Group Mobility Model (RPGM). The simulation model includes varied number of mobile nodes starting from 20 to 200 moving in an area of $3000_m \times 3000_m$. We have used two ray ground propagation model. At transport layer, User Datagram Protocol (UDP) is used. List of parameters for our framework are presented in Table I.

Table I

SIMULATION PARAMETERS

Parameter	Description
Packet Size	512 bytes
Data Traffic	constant bit rate (CBR)
Packet Rate	3 packets/sec
Simulation Area	3000m $\times$3000m
No. of nodes	20,50,150,200
Transmission Range	250m, 500m
Simulation time	6000sec
Antenna Type	Omni Directional
Propagation Model	Two ray ground
Average Speed	1m/s–15 m/s

Following parameters are considered to measure the performance of proposed scheme:

- **Packet Delivery Fraction (PDF)**: It is the ratio of the number of generated packets at source end and the number of packets received by the destinations end at application layer.
- **End to End Delay**: It is the time required to transmit a packet from source and destination in a network. This delay is measured in milliseconds.

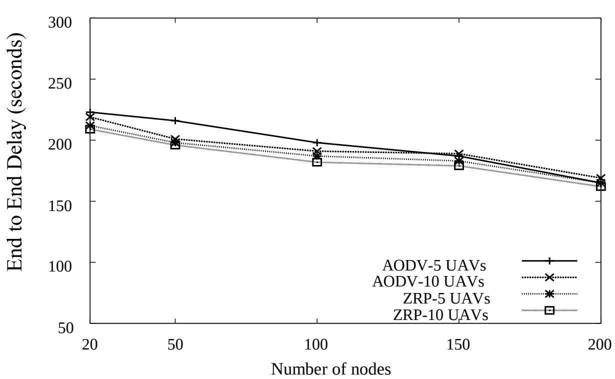

Figure 3. Impact of varied number of EANET nodes on end to end delay

Figure 3 shows effect of varied number of nodes on end to end delay. We have considered two cases:-(a) with 5 UAVs and (b) 10 UAVs. AODV and ZRP routing protocol is considered for evaluation. AODV protocol is observed with more end-to-end delay as compared to ZRP because of its hierarchical behaviour. We also analysed that as the number of UAVs increase, less delay is observed in both the protocols.

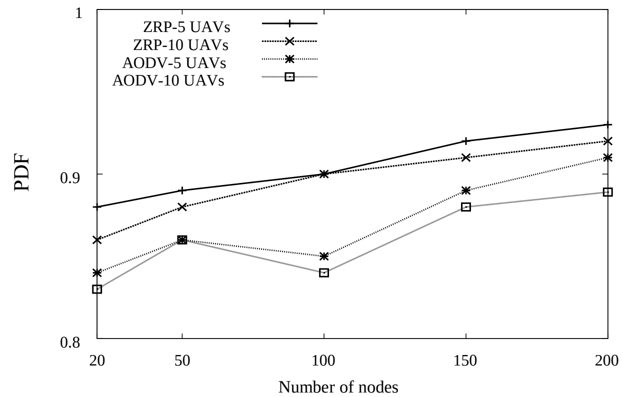

Figure 4. Impact of varied number of EANET nodes on PDF

PDF is also evaluated with varied number of nodes in figure 4. Here, also ZRP routing protocol behaves better than AODV. As the number of UAVs increase, PDF also increase in both the protocols i.e. ZRP and AODV.

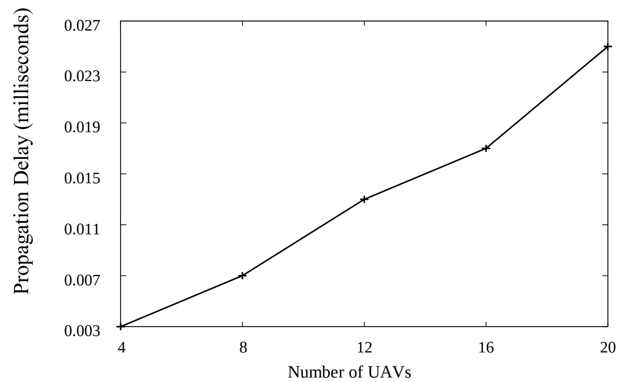

Figure 5. Propagation delay vs. number of UAVs in ZRP routing protocol

Figure 5 considers the effect of varied number of UAVs on propagation delay in ZRP routing protocol. As the number of UAVs increase in the network, propagation delay increases exponentially. This is because each new UAV adds a point of its failure in an EANET.

Figure 6 shows the relationship between network transmission range and the number of UAVs in the network. It shows a linear graph. It can be inferred that possible transmission range of network increases as the number of UAVs increases.

In this paper, we have shown the impact of varied number of EANET nodes on PDF and end-to-end delay. We also

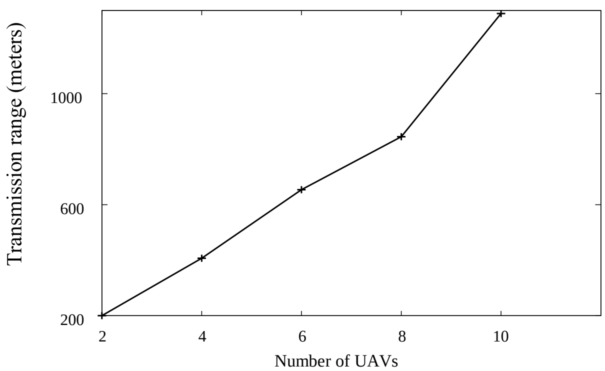

Figure 6. Transmission range vs. number of UAVs in ZRP routing protocol

illustrated that as more number of UAVs are deployed in disaster scenarios, larger area can be covered, thereby more human lives can be saved and loss can be minimized.

V. CONCLUSION

This paper discusses the layout of UAV assisted EANET for disaster scenario. Conventional routing protocols cannot fulfill requirements of a EANET, therefore, It is paramount to use UAV in these scenarios. UAV assisted EANET can be deployed much quicker than traditional ad hoc networks. UAVs are used to rapidly restore communication to areas where the base stations are unusable and provide a stable communication platform for emergency responders. Extensive research work related to existing routing protocols is presented in literature, but there is also space for discovering these routing algorithms in disaster scenarios. In this paper, we have evaluated and compared AODV and ZRP routing protocols by varying the number of UAV assisted EANET nodes in different transmission range cases of disaster scenarios. The experimental results illustrate that ZRP is the most appropriate protocol for emergency situations. PDF is more in ZRP as compared to AODV.

REFERENCES

[1] B. S. Manoj, A. H. Baker (2007) Communication challenges in emergency response *Communications of the ACM*, pp.51–53.

[2] CRS Report for Congress, Indian Ocean Earthquake and Tsunami: Humanitarian Assistance and Relief Operations, 2005 *http://www.fas.org/sgp/crs/row/RL327 15.pdf*

[3] L. E. Quispe, L. M. Galan.(2014) Review: Behavior of Ad Hoc Routing Protocols, Analyzed for Emergency and Rescue Scenarios, on a Real Urban Area *Journal of Expert Systems with Applications*, **41(5)**, pp. 2565–2573

[4] A. Nils, G. P. Elmar, M. Peter (2009) Modeling mobility in disaster area scenarios *Journal of Performance Evaluation, Elsevier Science Publishers B. V.* **66(12)**, pp. 773-790.

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

[6] E. Yanmaz (2012) Connectivity versus area coverage in unmanned aerial vehicle networks *IEEE International Conference on Communications (ICC 2012)*, pp. 719–723.

[7] A. I. Alshbatat and L. Dong (2011) Performance analysis of mobile ad hoc unmanned aerial vehicle communication networks with directional antennas *International Journal of Aerospace Engineering*, **2010**.

[8] Z. Han, A. L. Swindlehurst, K. R. Liu (2006) Smart deployment/movement of unmanned air vehicle to improve connectivity in MANET *IEEEWCNC* pp. 252257.

[9] A. C. Watts, V. G. Ambrosia, E. A. Hinkley (2012) Unmanned aircraft systems in remote sensing and scientific research: Classification and considerations of use *Remote Sensing* **4(6)**, pp. 1671–1692.

[10] R. Austin (2011) Unmanned aircraft systems: UAVs design, development and deployment *John Wiley Sons*, **54**.

[11] A. Merwaday, I. Guvenc (2015) Uav assisted heterogeneous networks for public safety communications *IEEE Wireless Communications and Networking Conference Workshops (WCNCW)*, pp. 329–334.

[12] R. Grodi, and D. B. Rawat, Uav-assisted broadband network for emergency and public safety communications, in 2015 IEEE Global Conference on Signal and Information Processing (GlobalSIP), 2015.

[13] C. Mbarushimana, A. Shahrabi (2007) Comparative study of reactive and proactive routing protocols performance in mobile ad hoc networks *21st International Conference on Advanced Information Networking and Applications Workshops*, **2**, pp. 679–684.

[14] S. Saha, S. Nandi, P. S. Paul, V. K. Shah, A. Roy, S. K. Das (2015) Designing Delay Constrained Hybrid Ad Hoc Network Infrastructure for post-disaster Communication *Journal of Ad Hoc Networks (Elsevier)*, **25(B)**, pp. 406–429.

[15] D. D. Deb, S. Bandyopadhyay (2014) Post-disaster resource management using peer-to-peer opportunistic networks] *International Conference on Advances in Computing and Information Technology (ACIT 2014)*, pp.20–24.

[16] A. Srivastava, D. Kumar, S. C. Gupta (2014) Mobile Ad-Hoc Network Performance in a Disaster Management Scenario *Afr J. of Comp ICTs*, **7(1)**, pp.1–10.

[17] NS *The Network Simulator NS-2 http://www.isi.edu/nsnam/ns/*

[18] C. E. Perkins, E. M. Royer (1999) Ad-hoc on-demand distance vector routing *Proceedings WMCSA99´ Second IEEE workshop on Mobile Computing Systems and Applications* pp.90–100.

[19] Z. J. Haas, M. R. Pearlman, P. Samar (2002) The Zone Routing Protocol (ZRP) for ad hoc Networks *Draft ietf-manet-zone-zrp-04.txt*