ORIGINAL RESEARCH

Tethered Balloon Technology in Design Solutions for Rescue and Relief Team Emergency Communication Services

Saeed Hamood Alsamhi, PhD; Mohd. Samar Ansari, PhD; Ou Ma, PhD; Faris Almalki, PhD; Sachin Kumar Gupta PhD

ABSTRACT

The actions taken at the initial times of a disaster are critical. Catastrophe occurs because of terrorist acts or natural hazards which have the potential to disrupt the infrastructure of wireless communication networks. Therefore, essential emergency functions such as search, rescue, and recovery operations during a catastrophic event will be disabled. We propose tethered balloon technology to provide efficient emergency communication services and reduce casualty mortality and morbidity for disaster recovery. The tethered balloon is an actively developed research area and a simple solution to support the performance, facilities, and services of emergency medical communication. The most critical requirement for rescue and relief teams is having a higher quality of communication services which enables them to save people's lives. Using our proposed technology, it has been reported that the performance of rescue and relief teams significantly improved. OPNET Modeler 14.5 is used for a network simulated with the help of ad hoc tools (*Disaster Med Public Health Preparedness*. 2019;13:203-210)

Key Words: ad hoc, disaster, emergency communication, OPNET, rescue and relief team, tethered balloon

Natural disasters and terrorist attacks appear to be the weakness points of wire and wireless communication network technologies, for example, 2G, 3G, and 4G, through easy disablement. Natural disasters include earthquakes, floods, tornados, and so on. Examples of recent natural disasters and terrorist attacks include the 2004 tsunami in Indonesia, the 2005 earthquake in Pakistan and Wenchuan earthquake in China (2008), Hurricane Katrina in the United States (2005), the bomb blasts in the cinema halls of Delhi (2012), and the Chapala flood in Socotra Island, Yemen (2015). Disaster prediction to help prepare for and mitigate disaster impact has been discussed.[1]

During a disaster, wireless communication linkage plays a vital role in assessing a damage area, collecting data on supplies, coordinating rescue team and relief team activities, saving people's lives, and accounting for missing people. To establish an efficient and effective wireless communication network for delivering a high quality of voice and data in disaster areas, the spectrum width of wireless channels is the most highly recommended[2] and reserved channel technique.[3]

Telecommunication solutions are not capable of delivering communication services in complicated emergencies that occur over wide areas. The wireless communication technologies and networks could be either missing or unavailable owing to congestion or damage. The key factors for emergency communication network solutions are rapid deployment, immediate availability, and reliability. However, when a disaster occurs in a large area, it takes weeks or months for cellular communication providers to recover their network. Therefore, wireless communication during a disaster is limited in terms of coverage and capacity because the infrastructure is destroyed.[4]

When the infrastructure is destroyed, only space communication technologies can mitigate the impact of the disaster. Therefore, space technologies play a vital role in recovering from all types of catastrophes. They are used for collecting data needed to protect humans and reduce economic losses. In the immediate aftermath of a disaster, the satellite is one of the reliable solutions of communication.[5] Furthermore, a very small aperture terminal technology has been proposed for emergency communication in disaster areas.[6] However, delay and launching costs are the reasons for the weakness of satellite communication. Therefore, the use of an aerial platform is the best solution, taking into consideration the merits of satellite and terrestrial wireless communication systems. The categories of the aerial platform include high-altitude platforms (HAP), medium-altitude platforms, and low-altitude platforms (LAP). Mohorcic et al.[7] discussed the use of aerial platforms for disaster and emergency situations and showed that such communication significantly enhanced the performance of the rescue teams. Therefore, the aerial platforms play an essential and important role in disaster recovery when all of the communication infrastructures are destroyed. The capability of the aerial platform to deliver communication services, such as E911, to facilitate search and rescue operations is discussed.[8]

The advantages of HAP are the capability and stable coverage area, survivability,[9] mitigation of interference that occurs in wireless communication,[10] and the ability to manage the traffic.[11] HAP offers an important alternative to support emergency communications after a disaster.[12] Providing and delivering broadband communication from HAP with the cooperation of ad hoc is a novel approach, and some research has been done to show the performance. The discussion of operation and effectiveness of using ad hoc in HAP payload has been presented.[13–15] Mase[16] presented the communication needs for evacuees in shelters after a disaster incident. It is essential to develop an emergency communication service to maintain the communication channel between people in shelters, outside shelters, and in the other shelters.

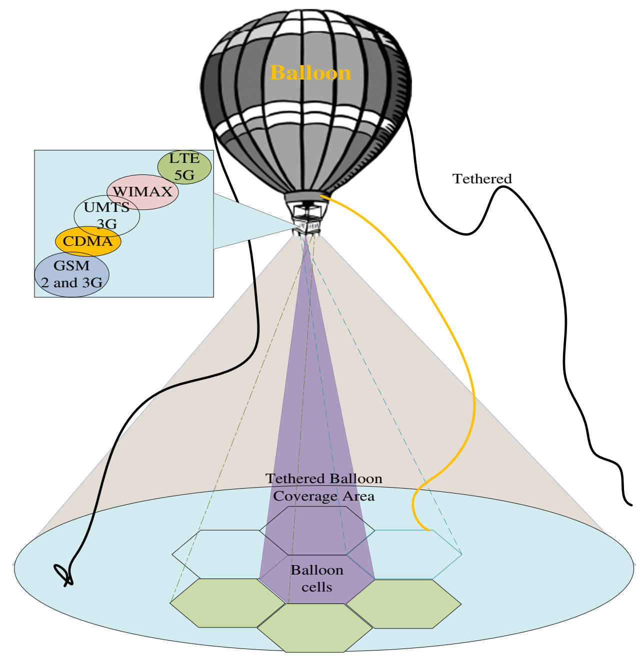
Tethered balloon technology belongs to the LAP family. It operates at an altitude of 200-440 m above the ground.[17,18] The significant advantages of tethered balloon are the cost of deployment and line of sight, low propagation delay, rapid deployment, fixed station, and especially its use in case of disasters.[10] The implementation of the tethered balloon for emergency situations is vital for natural and human-induced disasters.[19] These advantages of tethered balloon make it a more attractive concept for emergency communication through rapid deployment and for users to operate their existing mobile handsets in disaster regions. Therefore, it represents the best solution for disaster recovery, supporting the relief and rescue teams to perform their tasks effectively and efficiently. The payload of the tethered balloon includes global system for mobile communication (GSM), code division multiple access (CDMA), ad hoc, long term evolution (LTE), universal mobile telecommunication system (UMTS), and so on,[19-21] as shown in **Figure 1**.

The emergency relief and rescue teams can perform their tasks under the coverage of tethered balloon to access the Internet, video conference services, and Voice over Internet Protocol. Therefore, tethered balloon is proposed to lift a flying balloon incorporating ad hoc equipment. The aim of this work is to suggest a complete communications solution that can be deployed easily and immediately after/before a disaster, as well as more reliably.

The rest of this article is organized as follows: coverage of tethered balloon is described in the second section; the third and fourth sections describe a proposed tethered balloon for emergency communication system and implementation of the proposed technology in OPNET; results and discussions are given in the fifth section; and, finally, the conclusion is discussed in the sixth section.

FIGURE 1

Payload of Tethered Balloon



COVERAGE OF TETHERED BALLOON TECHNOLOGY

A tethered balloon is a balloon that is tethered to the ground by using ropes. The length of the tethered balloon is limited to the maximum balloon altitude. To maintain the stability of the balloon against the wind, rose ropes are used.[22] The number of ropes depends on the wind speed forecast and altitude target.

The operation of a tethered balloon is at an altitude of 200-440 m. The coverage provided by a tethered balloon is 5.5 km radius or 72 km^2 from an altitude of the balloon of 440 m.[22] Coverage can be extended by increasing the altitude of the balloon, as shown in **Figure 2**.

The tethered balloon lifts a flying platform by incorporating ad hoc equipment to provide efficient communication services. Disaster destroys all of the communication and electric supply infrastructure. For some people, availability of electricity can be a matter of life and death. Electric power is required for lighting at medical aid stations, for ventilation, and for delivering water to people in shelters. During an earthquake, the power is shut down at the first moments. During a tsunami, the water level remains high for several hours and many people are swept away several kilometers into the sea, passing an urgent need for rescue and relief over the sea. Therefore, the emergency communication system

https://doi.org/10.1017/dmp.2018.19 Published online by Cambridge University Press

FIGURE 2

Changing the Coverage of the Tethered Balloon According to the Size of the Disaster Impact Area

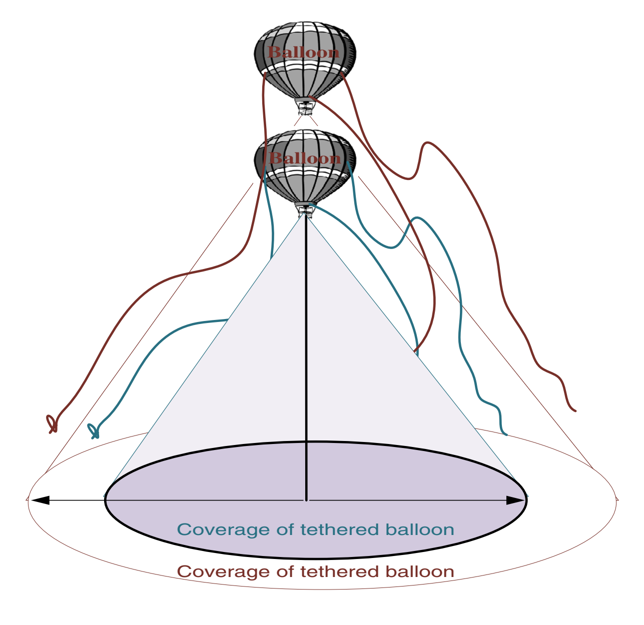
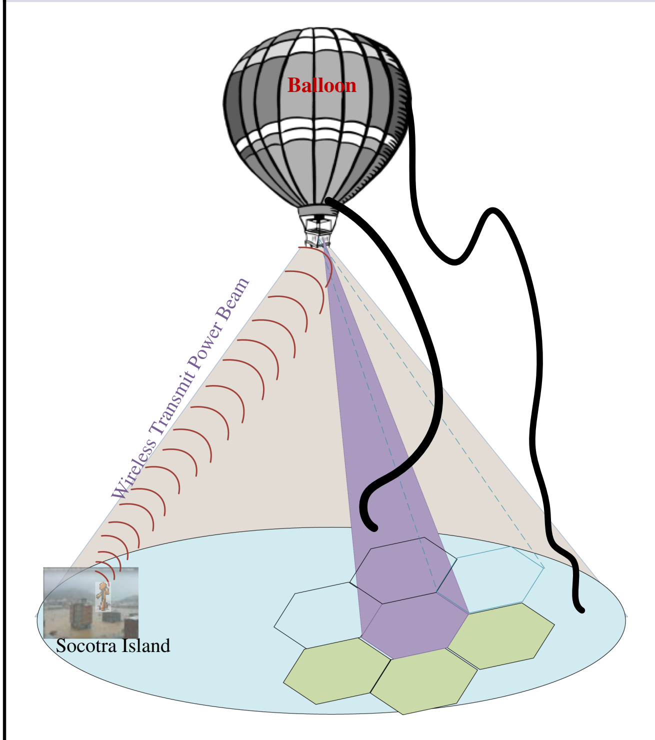


FIGURE 3

Delivering Power From the Tethered Balloon



must take into consideration that no support can come via ground transport. Therefore, power transmission technologies such as time-varying electromagnetic fields have to be used.[23]

Wireless transmission power is the electric power that transmits from the power source to the destination machine without discrete man-made conductors.[24] Wireless power transmission is useful in case of hazards. The machine transmitter is connected to the source of power, and then using an electromagnetic field for power transmission across an intervening space to one or more receivers, it is converted back to electric power and used.[23]

In 2011, Komerath[25] discussed the role of emergency in the overall lighter-than-air architecture of power beaming. **Figure 3** illustrates the architecture power beaming transport from the tethered balloon. A power supply at the ground is used to generate the power and then send it up to the balloon through a tethered device. Afterward, power beams from the balloon to rescue and relief teams' receiver devices over the disaster area.

PROPOSED TETHERED BALLOON FOR EMERGENCY COMMUNICATION SYSTEM

The most important idea in this scenario is the use of ad hoc technology. It allows the rescue and relief teams to move independently in the disaster area and perform their tasks efficiently. When we develop technologies without considering their impact on our environments, disasters increase daily. Natural disasters and terrorist acts have the potential to disrupt the infrastructure of wireless communication networks. Emergency communication is an important specialized field that helps save lives. During an earthquake or a tsunami, there is no way for transport via ground. Under such circumstances, the proposed tethered balloon provides and maintains operable and interoperable wireless emergency communication services during and after a disaster occurrence. As a result, the rescue and relief teams are able to perform their tasks very easily and sequentially, as shown in **Figure 4**.

The proposed technology provides a large coverage area. Therefore, the rescue and relief teams move with a very high-strength signal from the tethered balloon, enabling them to coordinate their rescue activities. High priority has been given to them to perform their tasks smoothly.

The tethered balloon enables providing emergency services effectively and efficiently during a disaster in a proper way. While the balloon reaches the desired altitude, the affected area will be captured via a digital video camera. Then, these images will be sent to the ground station for studying the area of operation and the images provide information to coordinate search and rescue teams with the first responder's arrival.

IMPLEMENTATION OF THE PROPOSED TECHNOLOGY IN OPNET

OPNET Modeler can provide different levels of modeling, relying on the requirements and the necessities of the simulation.

https://doi.org/10.1017/dmp.2018.19 Published online by Cambridge University Press

FIGURE 4

Proposed Technology for Rescue and Relief Teams During Emergency

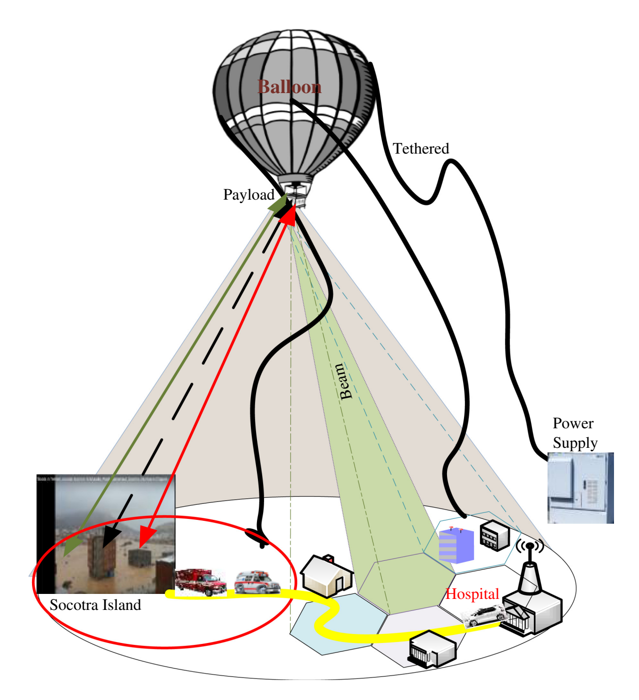
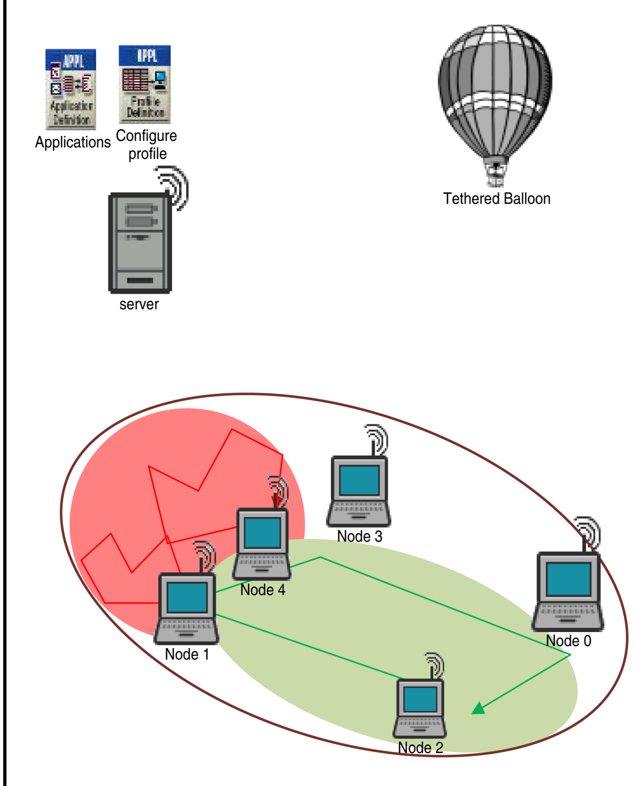


FIGURE 5

Implementation of Rescue and Relief Teams in Emergency Communication Scenario



The operator of this network model can develop several network scenarios to analyze and evaluate the performance of the network. The implementation of the particular proposed emergency network contains a balloon that carries ad hoc base station and 5 nodes, called *subscriber stations*, which are considered as rescue and relief teams.

The scenario focuses particularly on the performance of the rescue team and provides this team high quality of service (QoS) and the necessary medicine to save people's lives. The particular scenario consists of 3 teams. The first team works in the disaster area, on the bridge to transfer people from the catastrophic area to the safe area. The second team moves the evacuees from the edge of disaster to the hospital to save their lives. The third team works on monitoring, analyzing the disaster area, and giving order and guiding and directing the rescue team to perform their tasks well. Therefore, the tethered balloon is used to provide the much needed critical communication for relief, rescue, and search, as well as to control and command, as shown in **Figure 5**.

RESULTS AND DISCUSSIONS

The importance of using a tethered balloon as a space technology for emergency communication services and disaster recovery is discussed in this research. In addition, the most important is the ability of the tethered balloon to carry ad hoc, which is used to support broadband wireless services. Therefore, the communication facilities (calls and Internet) before/during and after the disaster improve significantly. **Figure 6** shows the general voice characteristics. **Figure 6** shows that jitter decreases as time increases. Negative jitter indicates that the time difference between the packets at the destination node (rescue and relief) is less than the source node. End-to-end delay for a voice packet is measured from the time it is created to the time that it is received. The minimum value of end-to-end delay is 0.1282 to 0.200 seconds.

The traffic voice received is 2194.66-47744.4 and the traffic sent is 3444.67-79543.5. The average number of bytes/second is submitted to the transport layers by all voice applications in the particular network. While time increases the packet delay, variation increases until it reaches a maximum value of 0.01722. The average number of bytes/second is forwarded to all voice applications by the transport layers in the network.

Delay of the of ad hoc in the tethered balloon is 0.003845-0.074777 seconds, as shown in **Figure 7**. It represents the end-to-end delay of the packets received by tethered balloon of all ad hoc nodes on the disaster area or on the ground. The load represents the total load (in bits/second) submitted to ad

https://doi.org/10.1017/dmp.2018.19 Published online by Cambridge University Press

FIGURE 6

Voice Network Characteristics

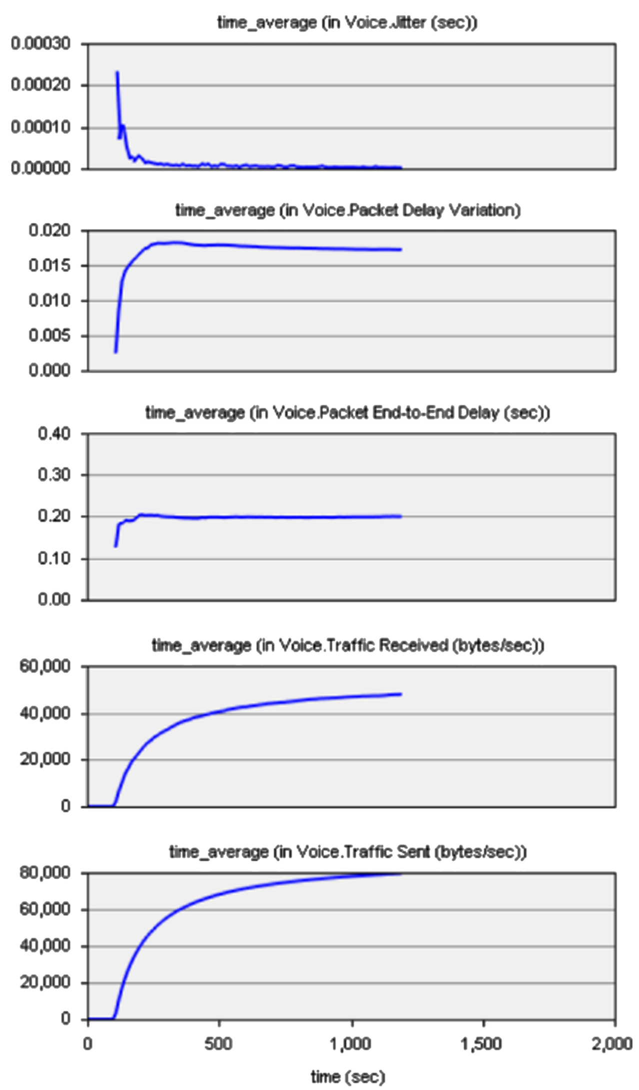
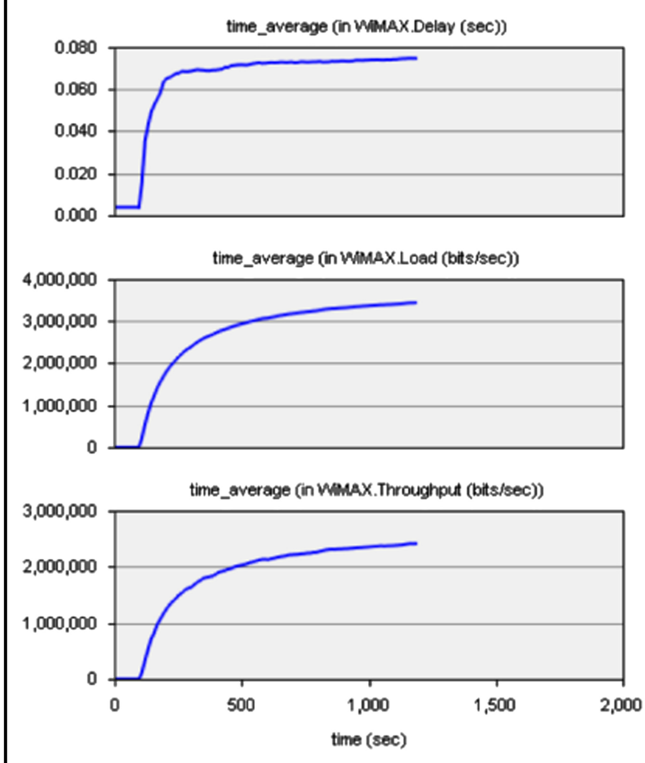


FIGURE 7

Network Characteristics



hoc layers in all ad hoc nodes of the network. The load is 34.6667-3442285.893, as shown in Figure 7. Throughput represents the total data traffic (in bits/second) forwarded from ad hoc layers to higher layers in all ad hoc nodes of the network. Throughput is increased from 208 to 2420475.653 bits/second, as shown in **Figure 7**.

The mobile-based station is represented by node 0 to node 5. Node 1 and node 4 represent the rescue teams. Therefore, the traffic received at node 1 and node 4 is given a higher priority than others, as shown in **Figure 8**.

Basically, the throughput increases with the increase in packet size through all of the nodes. Therefore, the difference between each number of nodes also increases during the increase of packet size at different times, as shown in **Figure 9**.

Throughput decreases when the number of wireless nodes increases. Throughput is the total data traffic in bits/second that is successfully received, and then it is forwarded to the ad hoc MAC in the tethered balloon.

The delay will be affected by an increase in the number of wireless nodes and decreases with the increase of packet size through all of the different number of nodes. The delay was constant at 0.003845 seconds, with time varying from 0 to 84 seconds, as shown in **Figure 10**. For node 3, a delay of setup increases between 84 and 156 seconds, and then it decreases between 0.013754 and 0.010809, when time changes between 168 and 1188 seconds. The server decreases from 108 to 1188 when the delay decreases from 0.004504 to 0.002006.

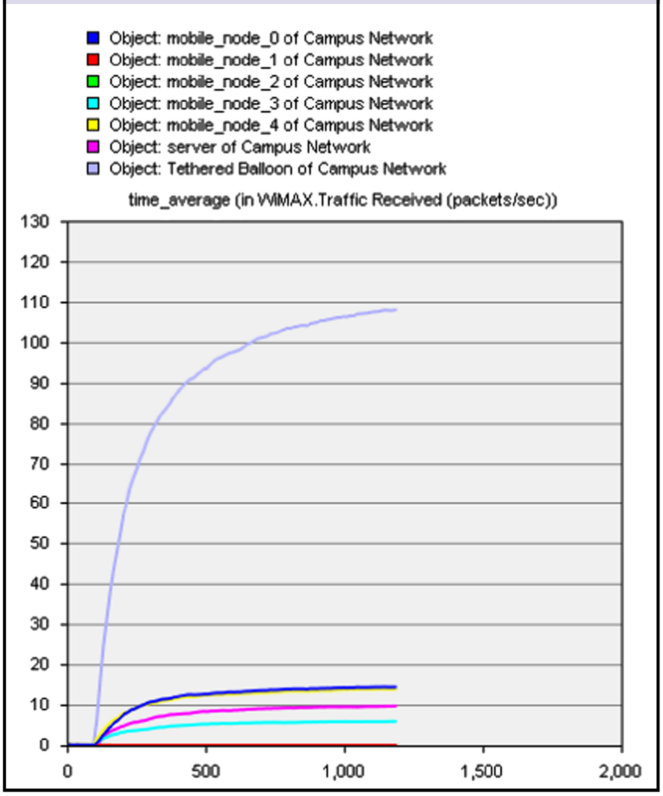
The server characteristics are shown in **Figure 11**. Traffic sent and received, as well as load, increases with an increase in time. Traffic received in the server is more than the traffic sent because all mobile users send traffic. However, the delay is still minimum.

Signal-to-noise ratio (SNR) is measured in decibels. Downlink SNR value represents the packet transmissions through the ad hoc. For rescue and relief nodes, the SNR is measured for all packets arriving from the tethered balloon. Uplink represents the packet transmissions through the ad hoc.

https://doi.org/10.1017/dmp.2018.19 Published online by Cambridge University Press

FIGURE 8

Scenario Traffic Received



For rescue and relief nodes, the SNR is measured at the particular tethered balloon for all packets arriving from rescue and relief (**Figure 12**).

The call admission control is implemented in the tethered balloon, as well as the total capacity of uplink and downlink and the number of admitted calls and rejected calls. In this particular scenario, the number of admitted calls is 30 calls and the number of rejected calls is 0. This means that the QoS from the tethered balloon is significantly effective and efficient.

FIGURE 9

Scenario Throughput

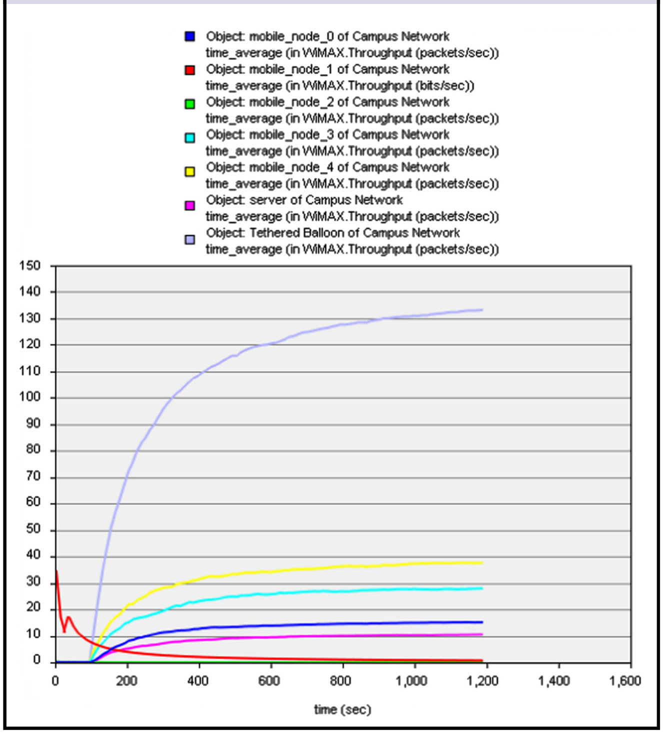
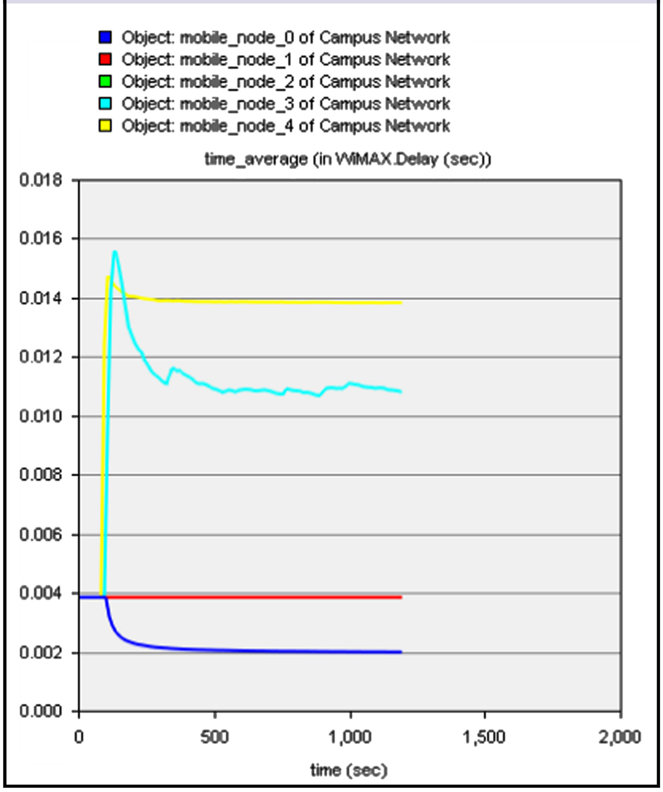


FIGURE 10

Different Delay for Different Nodes



CONCLUSION

The aerial platform is considered as the essential key for developing an emergency communication system because of its reliability and ease of deployment. A tethered balloon represents the best solution for emergency communication because it is a stable station and it provides a large coverage area. The proposed emergency communication is implemented by using the OPNET model. This study deeply describes the tethered balloon technology for emergency communication and saving people's lives. The results show that the rescue and relief teams performed their tasks in an orderly manner because they were provided with a high-priority service. The QoS parameters are significantly enhanced effectively and efficiently by using the proposed technology.

https://doi.org/10.1017/dmp.2018.19 Published online by Cambridge University Press

FIGURE 11

Server Characteristics and Parameters

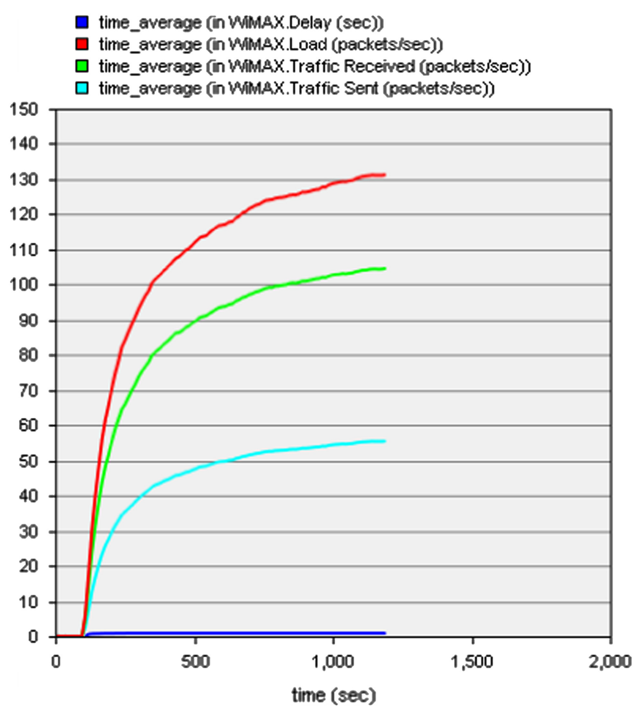
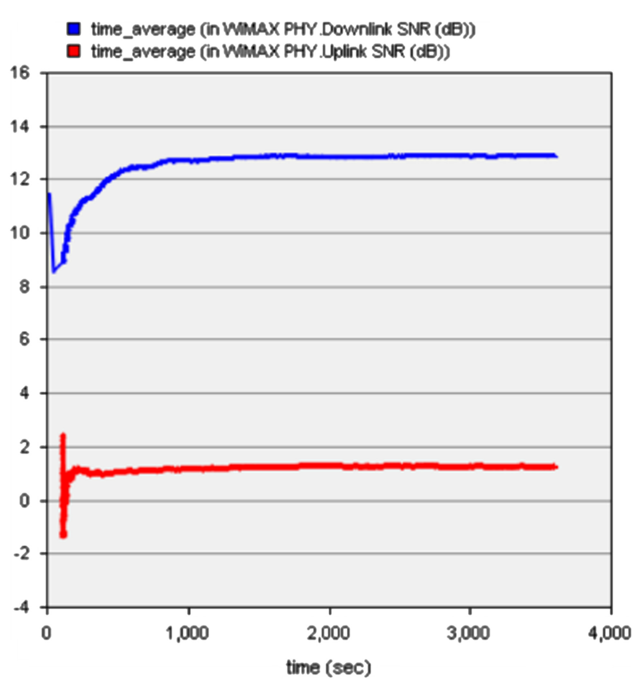


FIGURE 12

Uplink and Downlink Signal-to-Noise Ratio



About the Authors

Aerospace School, Tsinghua University, China; AMU, India and IBB University, Yemen (Dr Alsamhi), Electronics Engineering, Aligarh Muslim University, Aligarh, India (Dr Ansari), College of Engineering and Applied Science, University of Cincinnati, Cincinnati, Ohio, USA (Dr Ma), Electronics Engineering, Taif University, Taif, Kingdom of Saudi Arabia (Dr Almalki), and Electronics and Communication Engineering, Shri Mata Vaishno Devi University, India (Dr Gupta).

Correspondence and reprint requests to Saeed Hamood Alsamhi, Aerospace School and Engineering, Tsinghua University, China and IBB University, Yemen (e-mail: salsamhi@tsinghua.edu.cn).

REFERENCES

1. Alsamhi SH, Samar Ansari M, Rajput NS. Disaster coverage predication for the emerging tethered balloon technology: capability for preparedness, detection, mitigation, and response. *Disaster Med Public Health Prep*. Published online August 9, 2017. https://doi.org/10.1017/dmp.2017.54.
2. Komnakos D, Vouyioukas D, Maglogiannis I, Constantinou P. Performance evaluation of an enhanced uplink 3.5 G system for mobile healthcare applications. *Int J Telemed Appl*. 2008. http://dx.doi.org/10.1155/2008/417870
3. Alsamhi S, Rajput N. An efficient channel reservation technique for improved QoS for mobile communication deployment using high altitude platform. *Wireless Personal Commun*. 2016;91: 1095-1108.
4. Lee YM, Ku Bl, Ahn DS. "A satellite core network system for emergency management and disaster recovery." In *2010 International Conference on Information and Communication Technology Convergence (ICTC)*. IEEE, 2010:549-552.
5. Satellite communications an essential tool for emergency management and disaster recovery. Disaster Resource Guide. http://www.disaster-resource.com/index.php?option=com_content&view=article&id=215%3Asatellite-communications-an-essential-tool-for-emergency-management-and-disaster-recovery&Itemid=13. Accessed August 18, 2017.
6. Simmons SC, Murphy TA, Blanarovich A, Workman FT, Rosenthal DA, Carbone M. Telehealth technologies and applications for terrorism response: a report of the 2002 coastal North Carolina domestic preparedness training exercise. *J Am Med Inform Assoc*. 2003; 10:166-176.
7. Mohorcic M, Grace D, Kandus G, Tozer T. Broadband communications from aerial platform networks. *IST Mobile Summit*, Lyon, 2004.
8. Mohammed A, Arnon S, Grace D, Mondin M, Miura R. Advanced communication techniques and applications for high-altitude platforms. *EURASIP J Wireless Commun Networking*. 2008. https://doi.org/10.1155/2008/934837.
9. Alsamhi SH, Rajput NS. An intelligent hand-off algorithm to enhance quality of service in high altitude platforms using neural network. *Wireless Personal Commun*. 2015;82:2059-2073.
10. Alsamhi SH, Rajput NS. Methodology for mitigation of interferences from high altitude platform ground station to terrestrial stations. *Int J Sci Eng Res*. 2012;3:1-7.
11. Alsamhi SH, Rajput NS. Implementation of call admission control technique in HAP for enhanced QoS in wireless network deployment. *Telecommun Sys*. 2015;63:1-11.
12. Deaton JD. High altitude platforms for disaster recovery: capabilities, strategies, and techniques for emergency telecommunications. *EURASIP J Wireless Commun Networking*. 2008;2008:1-8.
13. Ahmed BT, Ramon MC. "WiMAX in high altitude platforms (HAPs) communications over large cities." In *6th International Multi-Conference on Systems, Signals and Devices, 2009*. IEEE, 2009:1-4.
14. Likitthanasate P, Grace D, Mitchell PD. Coexistence performance of high altitude platform and terrestrial systems sharing a common downlink WiMAX frequency band. *Electronics Lett*. 2005;41:858-860.

https://doi.org/10.1017/dmp.2018.19 Published online by Cambridge University Press

15. Alsamhi SH, Rajput NS. Neural network in a joint HAPS and terrestrial fixed broadband system. *Int J Technol Exploration Learn*. 2014;3:344-348.
16. Mase K. How to deliver your message from/to a disaster area. *IEEE Commun Mag*. 2011;49:52-57.
17. Khaleefa S, Alsamhi S, Rajput N. "Tethered balloon technology for telecommunication, coverage and path loss." In *2014 IEEE Students' Conference on Electrical, Electronics and Computer Science (SCEECS)*. IEEE, 2014:1-4.
18. Alsamhi SH, Rajput NS. An intelligent HAP for broadband wireless communications: developments, QoS and applications. *Int J Electron Electrical Eng*. 2015;3:134-143.
19. Qiantori A, Sutiono AB, Hariyanto H, Suwa H, Ohta T. An emergency medical communications system by low altitude platform at the early stages of a natural disaster in Indonesia. *J Med Syst*. 2012;36:41-52.
20. Kassa SR, Barman K, Kosale D. "A most promising HAPs technology for next generation wireless communication systems." In *Proceedings of the 4th National Conference*. New Delhi: INDIACom, 2010:1-6.
21. Bilaye P, Gawande VN, Desai UB, et al. "Low cost wireless Internet access for rural areas using tethered aerostats. In *2008 IEEE Region 10 and the Third International Conference on Industrial and Information Systems. ICIIS*. IEEE, 2008:1-5.
22. Hariyanto H, Santoso H, Widiawan AK. "Emergency broadband access network using low altitude platform." In *2009 International Conference on Instrumentation, Communications, Information Technology, and Biomedical Engineering (ICICI-BME)*. IEEE, 2009:1-6.
23. Shinohara N. *Wireless Power Transfer via Radiowaves*. Hoboken, NJ: John Wiley & Sons; 2014.
24. Bush SF. *Smart Grid: Communication-Enabled Intelligence for the Electric Power Grid*. West Sussexpo1985Q, United Kingdom: John Wiley & Sons; 2014.
25. Komerath N. "An imaging, communications and beamed power architecture for first responders." In *Proceedings of the 1st International Conference on Wireless Technologies for Humanitarian Relief*. Amritapuri, Kollam, Kerala, India: ACM, 2011:421-428.