International Journal of Engineering & Technology, 7 (4) (2018) 4003-4007

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET
doi: 10.14419/ijet. v7i4.15743
Research paper

A dual radio approach for efficient communication in mobile telemedicine environments

Adwitiya Mukhopadhyay [1] *, Rakshitha H R [2], Purnendu Goswami [3]

[1] *Department of Computer Science*
[2] *Amrita School of Arts and Sciences*
[3] *Amrita Vishwa Vidyapeetham Mysore, India*
**Corresponding author E-mail: m_adwitiya@asas.mysore.amrita.edu*

Abstract

Telemedicine technology provides patients with an effective healthcare system that complements other healthcare systems that already exist. Two different ways of implementing telemedicine systems are, (i) In a stationary environment, from a clinic in a village to a distant hospital. (ii) In a mobile environment where we connect from a moving ambulance to a remote hospital. This paper considers the latter scenario. In such a situation, the transmission of biosignals and sometimes multimedia data is required for critical patient diagnosis. We have designed a simulation scenario where Blood pressure (BP) signals are being transmitted along with streaming audio. However, we have used different radio access technologies for the purpose. BP is sent over WiFi and audio over LTE. This is done since WiFi connectivity is intermittent in a highway road network and as BP is transmitted infrequently, this serves the purpose. The LTE channel is kept free to transmit streaming audio signals. We have considered Vehicular Ad-Hoc Network (VANET) without considering any roadside infrastructure. In VANET the communication from source to destination is established using vehicle to vehicle communication. While transferring the patient from the emergency location, the ambulance makes use of the vehicular network for transmission of the relevant data. A novel attempt has been made to leverage the presence of multiple wireless technologies such as WiFi and LTE.

Keywords: *Telemedicine; VANET; LTE; Wi-Fi, AODV; NS3.*

1. Introduction

In the pharmaceutical industry, telemedicine is broadly used as an effective social medical service system. Telemedicine refers to the wireless transmission of medical information such as biological signals (BP, ECG, and SPO2), medical images (MRI, X-ray), audio and videos to a distant location for diagnosis as Patient's pre-hospital care is much required during transportation from emergency site to the medical organization in critical cases. Telemedicine provides advanced healthcare systems through electronic communications to improve patient care [1]. In emergency scenarios like disasters critical patient information is needed to be send when the patient is carried to the hospital in an ambulance. The hospital doctor gives required instructions based on the information sent. These instruction is redirected to the ambulance with the patient to provide treatment in critical conditions. This system can be used as a means to treat the patients when it's critical before the ambulance reaches destination hospital. All hybrid radio technologies will be available in next-generation communications environments. This multi-radio access technology (RAT) is the basic physical connection method for radio-based communications in telemedicine networks. Nowadays mobile phones support multiple RATs such as Bluetooth, WiFi, and 3G, 4G and Long Term Evolution (LTE) [2].

IEEE 802.11n is the improved WiFi standard proposal for the IEEE 802.11-2007, which substantially enhances organizational throughput. The new 802.11n standard has impressive performance. The main innovation of this 802.11n standard is MIMO (Multiple-Input-Multiple-Output), multiple antenna support, wider channel bandwidth. The most important advantages are greatly improved efficiency, frame aggregation, and security. It is suitable for use in the 2.4 GHz and 5 GHz bands.

LTE is an emerging wireless technology for higher data rates. LTE is a standard for rapid remote interchanges of cellular connectivity and information terminals for UMTS/HSPA and GSM/EDGE innovation. The main concept of cellular technology is multi-access, which means it transmits multiple data or voice connections on a single radio channel. The availability of bandwidth depends on the network traffic. LTE provides a variety of MIMO modes to achieve high data rates and better spectral efficiency for UEs in the uplink and downlink [3].

Patient care and prehospital care is very important during the patient's transportation from the emergency site to the medical organization in critical cases. In that case, the ambulance paramedic assistant need to transmit the patient's various vital biological signals. Fig.1 represents an ambulance moving from the countryside to a hospital in the city. There are a pair of nodes here, one is a mobile node i.e. the vehicles moving on the road and the other is fixed node, which can be primary healthcare center or hospitals.

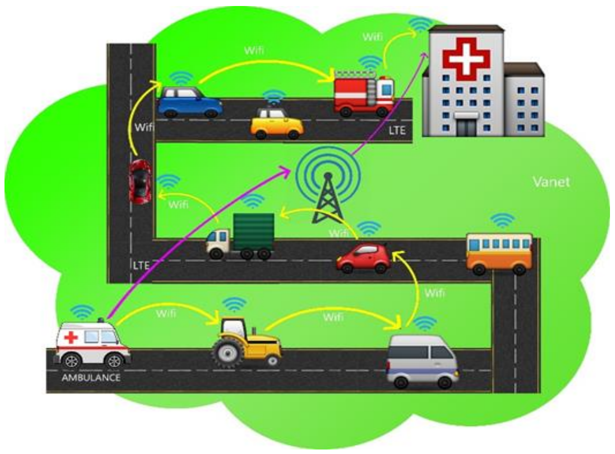

Fig. 1: General Architecture of Telemedicine Systems.

2. Related works

In recent years, the health field has been rapidly integrating technology into remote monitoring, diagnosis, and patient treatment. The literature survey described below shows a variety of wireless network standards that help patients perform prehospital care.

Khalifehsoltani et al. [4] mentioned that due to the development of network technology, the Quality of Service (QoS), and human lifestyle has changed. In other words, e-health is a newly discovered and well-organized way to provide society with medical and health services to improve the relationships among experts, patients, and users of all medical systems. Broadly speaking, this paper also discusses the application of modern information technology and e-commerce in various aspects, including the advantages and problems of healthcare systems. Therefore, in this article, it presents challenges and opportunities to improve the state of e-health in these countries. It will assist decision makers in developing better strategies for these issues. Afterward, we can study existing plans based on the experiments obtained in this study and develop appropriate telemedicine strategies for developing countries.

Ullah et al. [5] introduced an unwavering quality leading to tolerance by using a source to destination reporting framework that is used to transfer e-recovery (electronic therapy) systems is considered unverifiable. In this study, we focused on the characteristics of a series of medical resources. It highly emphasizes QoS and QoE tolerance for these parts of the system. Review and propose QoS parameter determination and related prerequisites, clinically valuable boundaries in the electronic health literature, and qualitative representation of non-mergers.

In [6] as the author describes the previous protocol used in telemedicine framework, namely the VehiHealth routing protocol finds the location of every node in the network for communication, and traffic information helps to transfer data from source to destination. Then the data will redirect by managing the neighbor's intersections and then forward the data with the smallest intersection value. This process makes it easy to send data to a target. However, mobility can cause problems with this protocol. Therefore, this routing technique cannot be used in busy traffic areas.

In [7] the author deployed a system which consist of a truck having different telecommunications equipment and spiral computed tomography (CT) machine and through audio/video conferencing with the medical center, this unit can help run medical diagnoses. Through the use these systems, pharmaceutical services are provided to rural areas.

Vergados et al. [8] use DiffServ to increase the height of packet loss in crisis medical services. Information is partitioned according to variety of classifications and requirements. The creators showed excessive demand for information, and the information was unfortunate and delayed much less than the loss of lower demand information. They think that this arrangement is amazing under the extremely demanding movement conditions and is particularly suitable for telemedicine situations. In [9], a DiffServ-based system was additionally proposed, in which the creator proposed a multicast engineering to accomplish QoS destinations in LTE Vehicular Ad-Hoc Network (VANET) systems. The author focuses on the work of multimedia traffic.

In [10] the author have mentioned that VANET depends on the adjacent vehicles which collects the data packets from the origin of the node that sends the data. So when the nodes are decreased then there will be a link interruption. The author have mention about another technology which helps avoiding traffic in emergency scenario is UWSN and combine it with the proposed energy-saving mechanism.

In [11] the author introduced a new network management software combining both WLAN and MANET that can be used where traditional communication system is not available like at the time of disasters. Therefore the system provide an alternative communication mechanism where in which the main data communication is lost.

In [12] the author proposed IPv6 vehicle platform mechanism which integrates eHealth devices that permits data communication between these devices and remote servers, i.e., data like personal health records (PHRs). This allows remote monitoring of the patient's vital signs by the doctor from a hospital located in distant location.

Manishankar et al. [13] the basic QoS parameters in WiFi, LTE and WiMAX technologies are studied. The research concludes that the knowledge on QoS parameters are limited in the minds of people. In [14] the author proposed an actual-time multi-function medical telemedicine framework that runs on Bluetooth, GSM, and GPRS. The system generates ECG data which is transmitted through the above-mentioned channels. The proposed system have been tested by considering downtime interval, packet loss rate, downtime frequency, packet error rate and throughput.

In [15] the author proposed a method to localize the position of a node itself and its neighboring nodes by calculating the distance of all the neighboring nodes and it shares the distance with the neighboring node which forms as a cluster. Using this cluster with the help of 3 nodes it is possible to find the 4^{th} node position. This helps in tolerating noise and more accurate position can be produced.

In [16] author described about the main factors that are required in transmission of data in emergency scenarios like adaptive resource allocation with priority and multiple service type. The author proposed a network which is designed for eHealth services and can handle normal and emergency situations, including admission control and bandwidth allocation as per IEEE 802.16 standard. The speed of ambulance and WiFi nodes through which the data is transferred differ significantly which leads the recalculation of routing quickly in order to provide efficient data transmission. Recalculation of packet routing, in turn, creates a considerable workload for each nodes. There are many attacks such a DOS which can lead the system to crash. To solve this problem, we can consider the security features and described above [17].

In [18] the telemedicine systems, maintaining QoS (quality of service) is of prime importance. Receiving very good quality of audio signals and other biological signals of timely manner in a telemedicine network is crucial. In any VANET, the time for establishing a connection between nodes is very short because the nodes are constantly moving. Therefore, establishing a network that can quickly establish new routes and have high connection time is a challenging task [19].

In [20] author describes the network must be smart enough to use all available bandwidth. Some imperative QoS parameters used to evaluate the corresponding system are information rate, packet delay, and packet loss. The information rate is the amount of bits that will be transmitted through the network system. In general, packet delay can be seen as a mix of management, queuing, transmission and propagation delays.

In [21] the author did a survey on different sensor network solutions in smart city. The survey is done by considering many emergency message passing scenarios like ambulance sharing and cab sharing using real-time traffic data service to navigate efficiently. The author has simulated the service on ns2 using MANET routing protocols to study the effectiveness.

In [22] the author proposed a system that emphasizes the propagation of emergency messages through multiple hops. The system was tested in sparse networks, freeway scenarios, and cluster-based networks. In [23] author have did a survey on different mechanisms like traffic scheduling, radio resource management and admission control based on IEEE 802.16 and WiMAX. Author have proposed an algorithm which combines admission control and bandwidth allocation for IEEE 802.16 for wireless telemedicine services. The proposed algorithm utilizes radio resources more efficiently.

In [24] the author uses tree-based and mesh-based routing protocols to provide a successful delivery which makes use of Lempel-Ziv-Oberhumer method for collision control in MANET. The author introduced a conduction control mechanism when sending messages, which improved the efficiency of the message transmission rate.

3. Methodology

In our telemedicine framework which is a blend of LTE and WiFi, a patient is being transferred in an ambulance to a distant hospital. Medical information like vital signals will be transferred continuously to the doctor in hospital from ambulance until the ambulance reaches the hospital. The patient facts we consider being transmitted is Blood Pressure (BP), which is a very important vital for any human. This is sent using WiFi. Apart from BP, audio signals are transmitted utilizing LTE. The reason for using WiFi for BP signals is that the frequency of sending these signals is less and WiFi connectivity when the ambulance moves, may be intermittent. For the transmission of audio signals, we use LTE since we may be sending streaming audio and LTE provides a better connectivity.

Table 1: Varieties of Data Transfer

Transfer	Network
Transference of BP data from the ambulance to the hospital	IEEE 802.11n
Transference of Audio data from the ambulance to the hospital	LTE

The simulations are done using SUMO [25] and NS3 [26]. The speed of the ambulance and the vehicle is constant from beginning to the end. Multiple simulations are performed using different node densities such as 75, 95, 115 and 150 with packet size of 250 and 500 bytes. At first 75 nodes where used for the simulation where the 1st node is considered as the hospital and the 75th node is considered an ambulance. We have considered all nodes with a constant speed of 30km/hr. Our topology is built by enabling the WiFi 802.11n standard and LTE in user nodes which are standard mobile devices for fast remote communications. In WiFi, we utilize the Ad-hoc On-demand Distance Vector (AODV) routing protocol [27] to send the packets from source to destination and eNB or eNodeB is a base station and UE or user equipment nodes is used to specify LTE network. All the mobile phones are controlled using eNB or UE node representing as a base station. The communication between the end user is done using mobile device which is equipped with UE. It needs a packet gateway node (PGW) to communicate.

3.1. Architecture design

Our system design focuses on telemedicine scenario which consists three primary parts: the ambulance, the VANET, and the hospital. In our scenario, the ambulance is equipped with all the hardware's expected to evaluate the biological signal along with audio. In order to obtain reliable communication, we need to maintain required QoS standards. Table 2 shows QoS matrix required for data transmission. QoS parameters evaluated for the scenario are throughput, packet loss ratio (PLR), and packet delay. Table 3 shows a complete description of the parameters used for the simulation.

Table 2: QoS Matrix

Type of data	Default Data Rate Required	Maximum Delay	PLR in %
BP	2 kbps- 5 kbps	1 s	0
Audio	4 kbps- 25 kbps	150- 400 ms	3

For transmission of BP, it is required to consider a data rate of at least 2 kbps, tolerating a maximum latency of 1 second [28] and for audio data transmission, needs a default data rate of at least 4 kbps with minimum latency of 150 milliseconds and maximum latency of 400 milliseconds [19]. To maintain this requirements, 500 bytes of audio data and 250 bytes of BP need to be sent every second. So in our scenario, we send 10 packets each of 25-bytes for BP as well as 50-bytes packets for audio per second.

The packet size and inter-packet interval values are taken into account and calculated as follows.

$$\text{Bps} = \frac{1000*\text{kbps}}{8} \quad [19] \tag{1}$$

Where,
Bps = number of bytes transferred per second
kbps = number of kilobits transferred per second

Using the above equation, we change over kbps to Bps for finding the best time interval. We use the below formula to calculate the interval time.

$$\text{inter packet interval} = \frac{1}{\text{N}} \tag{2}$$

Where,
N= total number of packets per second

Taking into account the parameters of these conditions, the formulas for packet delivery ratio (PDR), packet loss ratio (PLR), packet delay, and throughput are,

The PDR is calculated using the following formula:

$$\text{PDR} = \frac{\text{rx}*100}{\text{tx}} \tag{3}$$

Where,
rx= total packets received.
tx= total packets transmitted.

The PLR is measured using the following formula:

$$\text{PLR} = \frac{\text{lp}*100}{\text{tx}} \tag{4}$$

Where,
lp= total packet loss.
tx= total number of packets transmitted.

Delay rate used for the simulations is measured using the formula:

$$\text{Mean delay} = \frac{\text{ds}}{\text{rx}} * 1000 \tag{5}$$

Where,
ds= the sum of all delays for the number of packets received.
rx= total packets received.

In the below equation, tb is the transmitted bytes and tt is total time taken to transmit.

$$\text{Throughput} = \frac{(\text{tb}*8)/1000}{\text{tt}} \quad [19] \tag{6}$$

Table 3: Simulation Parameters and Values

Parameter	Values
Simulator	NS3 (v3.26)
Simulation Time	880s
Routing Protocol	AODV
Routing Standard	802.11n
Node Densities	75, 95, 115 & 150
Packet Size	250 bytes (blood pressure) 500 bytes (audio)
Type Of Traffic	Constant bit rate (CBR)
Road length	5 km

4. Results and analysis

Based on the study we have plotted performance of the proposed system by considering throughput, PLR, and delay. The study was done by using ns3.

1) Throughput: The observation analysis indicates that speed of vehicles remains constant with the increases in the number of mobile node densities. As node density 'n' increases, there will be more nodes within the range of the source node which will lead in reducing the number of hops. When node density is varied as 75, 95, 115 and 150 the throughput gets decreased eventually from 0.854 kbps to 0.338 kbps depending upon the position of the vehicles. For LTE, it shows stable performance regardless of node density.

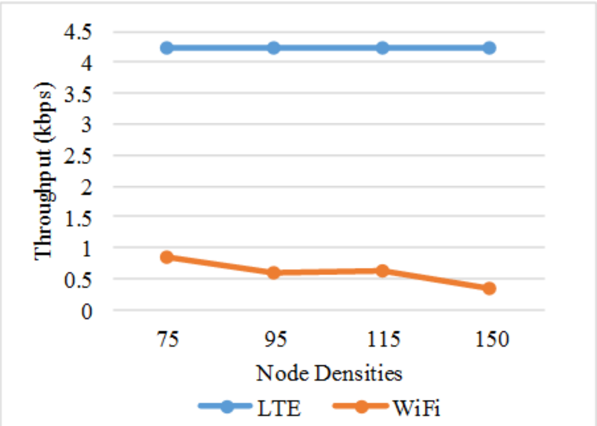

Fig. 2: Node Densities vs. Throughput.

2) PLR: PLR depends on network traffic, node densities, bandwidth, etc. As per the result obtained in WiFi when node density increases the PLR also increases. From the Fig. 3 we can see that for lesser node density, PLR is also less. The reason for this can be that with the decrease in number of nodes the routing messages traversing the network also decrease. This leads to lesser packets being dropped. The performance worsens as the number of nodes in the network increase.

In LTE scenario, the PLR is shown to be 0.11% for all node density because the range of eNB is 45km and in our scenario, the total distance to send the audio data is much lesser than the maximum range. So there is only one eNB being used in all node densities and number of hops is also minimal.

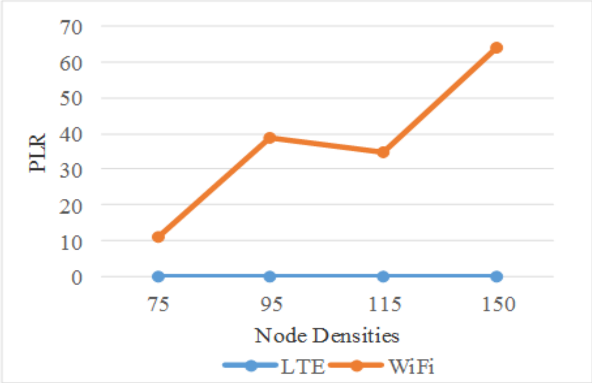

Fig 3: Node Densities vs. PLR.

3) Delay: Here also we can observe that the performance degrades with an increase in node density. However, the delay observed is very much within acceptable limits required for maintenance of QoS as mentioned in Table 2.

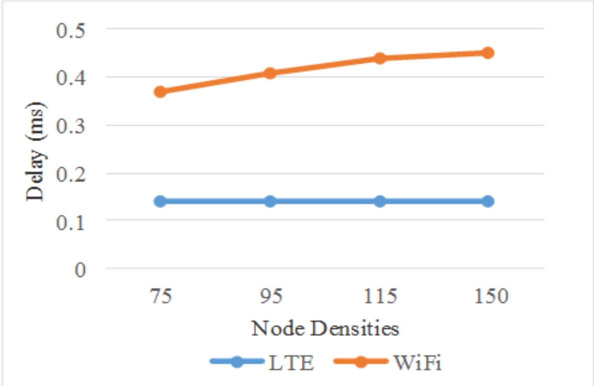

Fig. 4: Node Densities vs. Delay.

5. Conclusion

We carried out simulation-based experiments to evaluate a multi-RAT environment for transmission of human vitals and streaming audio data in telemedicine scenarios. Experimentations over a road length of 5 km and varying node densities show that the various QoS parameters such as PLR, delay, and throughput show a deterioration in performance with an increase in the node density.

Acknowledgment

First and foremost, we are deeply grateful to her most admired Mata Amritanandamayi Devi our beloved chancellor for her motivation and guidance in incredible and unbelievable ways. Thank you, heartily, to everyone at Amrita Vishwa Vidyapeetham Mysuru campus for providing the necessary environment, infrastructure, and motivation for conducting this work.

References

[1] A Pal, V. W. Mbarika, F. Cobb-Payton, P. Datta, and S. McCoy, "Telemedicine diffusion in a developing country: the case of India (March 2004)," *IEEE Trans Inf Technol Biomed*, vol. 9, no. 1, pp. 59–65, 2005. https://doi.org/10.1109/TITB.2004.842410.

[2] M. Porjazoski and B. Popovski, "Radio access technology selection algorithm for heterogeneous wireless networks based on service type, user mobility and network load," *2011 10th Int. Conf. Telecommun. Mod. Satell. Cable Broadcast. Serv.*, vol. 2, pp. 475–478, 2011.

[3] I. Shayea, M. Ismail, and R. Nordin, "Advanced handover techniques in LTE-Advanced system," in *2012 International Conference on Computer and Communication Engineering, ICCCE*

2012, 2012, pp. 74–79. https://doi.org/10.1109/ICCCE.2012.6271155.

[4] S. N. Khalifehsoltani and M. R. Gerami, "E-health Challenges, Opportunities and Experiences of Developing Countries," in *2010 International Conference on e-Education, e-Business, e-Management and e-Learning*, 2010, pp. 264–268.

[5] M. Ullah, M. Fiedler, and K. Wac, "On the ambiguity of Quality of Service and Quality of Experience requirements for eHealth services," in *2012 6th International Symposium on Medical Information and Communication Technology (ISMICT)*, 2012, pp. 1–4.

[6] W. Liu, Y. Yang, and M. Zhu, "Research on inter hospital and ambulance data transmission using LT-coding over VANET," in *2013 ICME International Conference on Complex Medical Engineering, CME 2013*, 2013, pp. 119–123. https://doi.org/10.1109/ICCME.2013.6548223.

[7] M. Takizawa, S. Sone, K. Hanamura, and K. Asakura, "Telemedicine system using computed tomography van of high-speed telecommunication vehicle," *IEEE Trans. Inf. Technol. Biomed.*, vol. 5, no. 1, pp. 2–9, 2001. https://doi.org/10.1109/4233.908348.

[8] D. D. Vergados, D. J. Vergados, C. Douligeris, and S. L. Tombros, "QOS-aware tdma for end-to-end traffic scheduling in ad hoc networks," *IEEE Wirel. Commun.*, vol. 13, no. 5, pp. 68–74, 2006. https://doi.org/10.1109/WC-M.2006.250361.

[9] R. Sivaraj, A. K. Gopalakrishna, M. G. Chandra, and P. Balamuralidhar, "QoS-enabled group communication in integrated VANET-LTE heterogeneous wireless networks," in *International Conference on Wireless and Mobile Computing, Networking and Communications*, 2011, pp. 17–24.

[10] K. A. U. Menon, A. Gungi, and B. Hariharan, "Efficient Wireless Power Transfer Using Underground Relay Coils," *2014 Int. Conf. Comput. Commun. Netw. Technol. (Icccnt*, 2014.

[11] J. C. Kim *et al.*, "Implementation and performance evaluation of mobile ad hoc network for Emergency Telemedicine System in disaster areas.," *Conf. Proc. IEEE Eng. Med. Biol. Soc.*, vol. 2009, pp. 1663–1666, 2009.

[12] S. Imadali *et al.*, "eHealth service support in future IPv6 vehicular networks," *Futur. Internet*, vol. 5, no. 3, pp. 317–335, 2013. https://doi.org/10.3390/fi5030317.

[13] S. Manishankar, C. R. Srinithi, and D. Joseph, "Comprehensive study of wireless networks qos parameters and comparing their performance based on real time scenario," in *Innovations in Information, Embedded and Communication Systems (ICIIECS), 2017 International Conference on*, 2017, pp. 1–6.

[14] M. Tounsi and B. Qureshi, "A Bluetooth-enabled mobile intelligent remote healthcare monitoring system: analysis and design issues," *Int. J. Healthc. Technol. Manag.*, vol. 9, no. 5/6, p. 473, 2008. https://doi.org/10.1504/IJHTM.2008.020199.

[15] D. Moore, J. Leonard, D. Rus, and S. Teller, "Robust distributed network localization with noisy range measurements," in Proceedings of the 2nd international conference on Embedded networked sensor systems - SenSys '04, 2004, p. 50.

[16] M. A. Algaet, Z. A. B. M. Noh, A. S. Shibghatullah, A. A. Milad, and A. Mustapha, "Provisioning quality of service of wireless telemedicine for E-health services: A review," *Wireless Personal Communications*, vol. 78, no. 1. pp. 375–406, 2014. https://doi.org/10.1007/s11277-014-1758-3.

[17] [17]A. N. Indrajith, S. Manishankar, and B. R. Monika, "Alpha scheduler approach to enhance security and high performance in cluster environment," *J. Theor. Appl. Inf. Technol.*, vol. 87, no. 1, pp. 138–145, 2016.

[18] B. Huntgeburth, M. Maruschke, and S. Schumann, "Open-source based prototype for quality of service (QoS) monitoring and quality of experience (QoE) estimation in telecommunication environments," in *International Conference on Next Generation Mobile Applications, Services, and Technologies*, 2011, pp. 161–168.

[19] A. Mukhopadhyay, S. Raghunath, and M. Kruti, "Feasibility and performance evaluation of VANET techniques to enhance real-time emergency healthcare services," *2016 Int. Conf. Adv. Comput. Commun. Informatics, ICACCI 2016*, pp. 2597–2603, 2016.

[20] S. Saravanan, P. Harikrishna, and J. Vaideeswaran, "Big data exchange between Ambulance bus to hospital network through internet in Telemedicine using computer communication network and 3G Mobile antenna," in *2015 International Conference on Computer Communication and Informatics, ICCCI 2015*, 2015. https://doi.org/10.1109/ICCCI.2015.7218072.

[21] E. Jacob and P. Sivraj, "Performance analysis of MANET routing protocols in smart city message passing," in *2016 International Conference on Advances in Computing, Communications and Informatics, ICACCI 2016*, 2016, pp. 1255–1260. https://doi.org/10.1109/ICACCI.2016.7732218.

[22] G. Narayanan, "Comparison of the delay performance for various vehicular communication network scenarios," in *International Conference on Communication and Signal Processing, ICCSP 2014 - Proceedings*, 2014, pp. 711–715.

[23] D. Niyato, E. Hossain, and J. Diamond, "IEEE 802.16/WiMAX-based broadband wireless access and its application for telemedicine/E-health services," *IEEE Wirel. Commun.*, vol. 14, no. 1, pp. 72–83, 2007. https://doi.org/10.1109/MWC.2007.314553.

[24] [24]S. Akshay and P. Apoorva, "Bandwidth optimized multicast routing algorithm based on hybrid mesh and tree structure with collision control in MANET using lempel-ziv-oberhumer method," in *Communication and Signal Processing (ICCSP), 2017 International Conference on*, 2017, pp. 495–500.

[25] D. Chandy *et al.*, "Evaluation of QoS in data mobile network for vital signs transmission," in *2016 IEEE Healthcare Innovation Point-of-Care Technologies Conference, HI-POCT 2016*, 2016, pp. 146–149.

[26] M. Behrisch, L. Bieker, J. Erdmann, and D. Krajzewicz, "SUMO - Simulation of Urban MObility - an Overview," *Proc. 3rd Int. Conf. Adv. Syst. Simul.*, no. c, pp. 63–68, 2011.

[27] C. Perkins, E. Belding-Royer, and S. Das, "Resquest For Comments: 3561 Ad hoc On-Demand Distance Vector (AODV) Routing," *Internet Eng. Task Force - Netw. Work. Gr.*, p. 13, 2003.

[28] M. C. Batistatos, G. V. Tsoulos, and G. E. Athanasiadou, "Mobile telemedicine for moving vehicle scenarios: Wireless technology options and challenges," *J. Netw. Comput. Appl.*, vol. 35, no. 3, pp. 1140–1150, 2012. https://doi.org/10.1016/j.jnca.2012.01.003.