International Journal of Computer Information Systems and Industrial Management Applications (IJCISIM)
ISSN: 2150-7988 Vol.2 (2010), pp.020-028
http://www.mirlabs.org/ijcisim

Performance of Wireless Body Sensor based Mesh Network for Health Application

Norman A. Benjamin[1] and Suresh Sankaranarayanan[2]
[1]*Mona Institute of Applied Science*
[2] *Intelligent Networking Group, Department of computing*
University of West Indies, Kingston, Jamaica
suresh.sankaranarayanana@ uwimona.edu.jm or pessuresh @hotmail.com

Abstract

Wireless sensor network (WSN) has become a significant technology and Wireless (body) sensors can be deployed on patients to continually monitor their physiological health conditions. The wireless body sensors can then be configured to convey the patient's status directly to the assigned doctor/nurse through the personal smart phone, PDA or Palm device. In this situation, Wireless Mesh Networks (WMN) can be used to transmit vital information arising form the wireless Body sensor Network (WBSN) to the backbone network. It may be mentioned that WMN which is an extension of LAN, has far better range involving very little wiring. The integration of WBSN and WMN technologies, results in Wireless Sensor Mesh Network (WSMN) and this technique has already been proposed by one of the authors of this paper, for usage in the medical field. In this paper we present the results on the performance of such a WSMN used for patient health monitoring application, in terms of parameters like delay, MAC delay and throughput under varying number of patients and varying number of doctors in wards and also the failure performance when the mesh nodes fail based on simulation study carried out with Opnet modeller 15.0.

1. Introduction

Wireless sensor networks (WSNs) [1][2] are a significant technology attracting considerable research attention in recent years. Recently it has started attracting attention towards the health industry for monitoring the health of the patient. Typically, a WSN consists of hundreds to thousands of tiny sensor nodes that communicate over wireless channels and perform distributed sensing and collaborative data processing. In this situation, Wireless Mesh Networks (WMN) [3-8] can be used to transmit vital information arising form the wireless Body sensor Network (WBSN) to the backbone network. WMN are considered cost-effective alternatives to wireless LANs, as there is no necessity to deploy any wired infrastructure to support a mesh network. The integration of WBSN and WMN technologies, results in Wireless Sensor Mesh Network (WSMN) and this technique has already been proposed [9] by one of the authors of this paper, for usage in the medical field. The sensors being low powered and low memory devices can transmit the information to the nearest mesh nodes and these mesh nodes can use multihop routing to transmit the information to the backbone networks like the PDA or the servers for health application. In this paper we present the results of the investigation carried out by us through simulation, on the performance of such a WSMN used for patient health monitoring applications, in terms of parameters like delay, MAC delay and throughput under varying number of patients and varying number of doctors in wards and also the failure performance when the mesh nodes fail. The simulation study has been carried out with Opnet modeller 15.0. The remainder of the paper is organized as follows. Section 2 discusses the Hierarchical Agent based WSMN architecture proposed for healthcare application and taken for simulation study. Section 3 provides the results of the study carried out on the performance of this network architecture in terms of delay, MAC delay and throughput under varying number of patients, varying number of doctors and failure of mesh nodes. Section 4 is on conclusion and future work.

2. Wireless Sensor Mesh Network (WSMN)

2.1 Wireless Sensor Network

A wireless sensor network (WSN) [1][2], is a wireless network consisting of spatially distributed autonomous sensor devices to cooperatively monitor the physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants, at different locations. Although the development originally motivated by military applications such as battlefield surveillance, they are now used in many civilian application areas, including environment and habitat monitoring, healthcare applications, home automation, traffic control, etc. All sensors in WSN, normally constitute a wireless ad-hoc network and as such each sensor supports a multi-hop routing algorithm. Sensor nodes may be imagined as small micro computers, extremely basic in terms of their interfaces and their components. They usually consist of a *processing unit* with limited computational power and limited memory, *sensors* (including specific conditioning circuitry), a communication device (usually radio transceivers or alternatively optical), and a power source usually in the form of a battery. The base stations are the gate ways and they are one or more distinguished components of the WSN with much more computational, energy and communication resources. The gateway provides connectivity between sensor nodes and the end user.

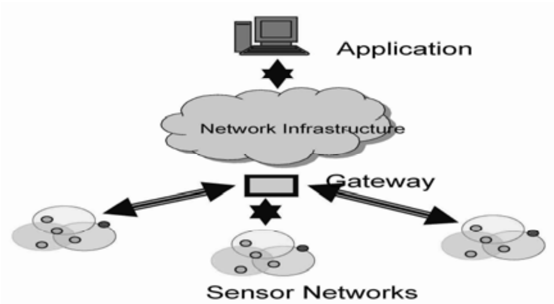

Fig.1 Wireless Sensor Network (WSN)

2.2 Zigbee Technology

Recent advances in low-power wireless communication technologies like Zigbee (IEEE 802.15.4) [3], low-power Bluetooth [4], etc. have enabled the development of small, body-wearable, wireless sensors network for patient monitoring [10]. One such architecture [5] is shown in Fig.2, wherein the body sensors are the Bio-Front End devices (BFEs) and they enable monitoring of multiple bio-parameters (such as ECG, Blood Pressure, etc.) of multiple patients at a central location. The signal Transmission Schematic is shown in Fig.3. There can be multiple BFE devices connected to a patient for monitoring multiple parameters. Normally an aggregator (AGG) device worn by the patient performs the function of receiving the wirelessly transmitted data and transmits the aggregated data to a backend PC or server. The AGG device can be a device like a Portable Digital Assistant (PDA) or a scaled down version of that, without a Liquid Crystal Display (LCD). The AGG and the BFE devices form a localized WBSN, with each BFE device having a unique device ID. The network system is normally comprised of energy constrained sensor nodes. Furthermore, communication interference between multi mode nodes in such a dynamic system is also a challenge. This limitation has led to the crucial need for energy and mobility aware protocols to produce an efficient network.

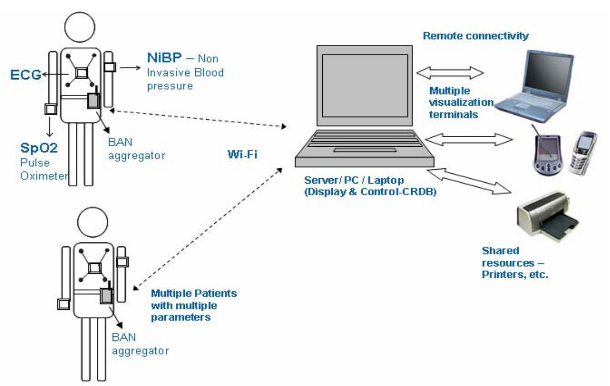

Fig.2 Body Wearable Sensors- Health Monitoring

2.3 Wireless Mesh Network

Broadband networks [6-10] are being increasingly deployed in a multi-hop wireless mesh network (WMN) [9] configuration (Fig.3). These WMNs are being used on the last mile for extending or enhancing Internet connectivity for mobile clients located on the edge of the wired network. In WMNs, nodes are comprised of mesh routers and mesh clients. Each node operates not only as a host but also as a router, forwarding packets on behalf of other nodes that may not be within direct wireless transmission range of their destinations. Commercial deployments of multi-hop wireless mesh networks (WMNs) are already in vogue. The deployed mesh networks will provide commercial Internet access to residents and local businesses [6-10]. A WMN is dynamically self-organized and self-configured, with the nodes in the network automatically establishing and maintaining mesh connectivity among themselves (creating in effect, an ad hoc network). This feature brings many advantages to WMNs such as low up-front cost, easy network maintenance, robustness, and reliable service coverage. Conventional nodes (e.g. desktops, laptops, PDA, pocket PCs, phones etc) equipped with wireless Network Interface Card (NICs) can connect directly to Wireless mesh routers. WMN is a promising wireless technology for numerous applications e.g. Broadband home networking, Community and neighbourhood networks, enterprise networking, building automation etc. Wireless Mesh Networks seamlessly integrate two network architectures – Adhoc and Wireless LAN - infrastructure based network. The wireless infrastructure access points provide the connectivity to the wired backbone. Each node in the network is both a service provider and a service consumer. Wireless Mesh Networks as show in Fig.3 are composed of three distinct network elements as below.

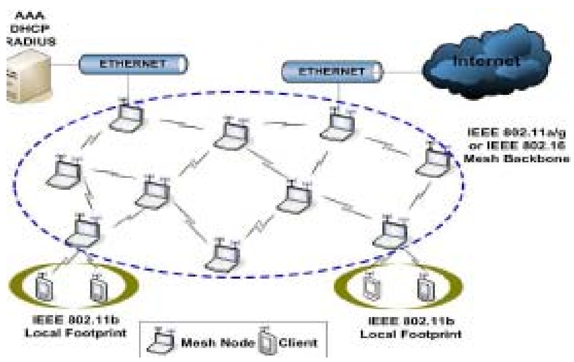

Fig.3 Wireless Mesh Network

- **Network Gateway**: One or more gateway can be deployed to allow access to different IP sub network especially wired infrastructure

- **Access Points**: The access points from wireless backbone providing connectivity in places otherwise difficult through traditional wired infrastructure. The wireless communication between the access points can use different technologies such as IEEE 802.11 a/b/g or IEEE 802.16 and different hardware (directional or omni directional antenna)
- **Mobile Nodes:** Any device embedding wireless capabilities like sensor nodes, PDAs, laptops can access the network gateway through direct or multihop communication using access point as relays

2.4 Wireless Sensor Mesh Network

We have seen that Mesh Networks which is 802.11S – an extension of Wireless LAN can cover the entire city and use multi hop routing in communication with very minimal amount cabling used at the backbone. The nodes in mesh networks can be mobile which can be a PDA, PC or laptop and even wireless sensor networks. The mobile nodes which in our case are wireless sensors can transmit the sensed information to the nearest access point i.e. mesh node which use multihop routing to transmit the information to the wired network or even to mobile devices like PDA or laptop. An integration of these two technologies is Wireless Sensor based Mesh Network [11] which is shown in Fig.4. Based on this background, a Wireless sensor based Mesh Network architecture has been proposed for health application and the same will be discussed in the next section

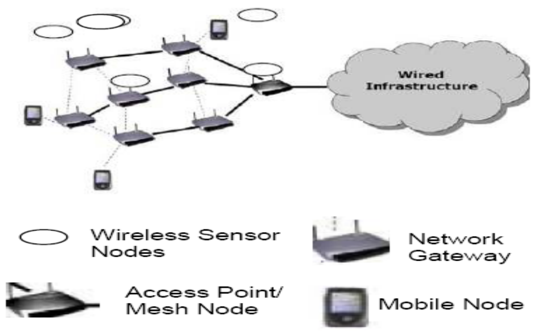

Fig.4 Wireless Sensor Mesh Network

3. Intelligent agent based hierarchical WSMN Architecture

In the architecture [12][13] so proposed as shown in Fig.5, we conceive the mesh nodes to be placed in each of the hospital building i.e. Pediatrics, Obstetrics, Gynecology, etc. Each of these building would have a lot of wards with many in-patients. In such a scenario, the sensed information from each of these wards with many in-patients to be transmitted to the hospital administrative building may be overloading the mesh node in the building in view of the fact that the doctor who would be responding to the call from the department also has got to go through the mesh node of the building to intimate the nurse over there for necessary action. Apart from this overloading, in the architecture proposed, these mesh nodes has got static agent to interpret the sensed information. So failure of a mesh node in one building would result in total collapse of the patient health monitoring system. So taking these aspects into consideration, we have come up with a decentralization scheme in the architecture by employing agents at ward level only as shown in the figure.5. The purpose of the agent at ward mesh node is to interpret the sensed information from sensors and intimate to the doctor's PDA through a Mobile agent and the building mesh node enables the wireless communication with the agent at the appropriate ward and convey the information sent from the Doctor's PDA, similar to a nurse in one department would convey the information to nurse in another department. Based on these aspects so proposed, we have investigated through simulation, the performance of this architecture using the Opnet modeler. The results of this simulation study would be discussed in the next sections. The details on agent development are beyond the scope of this paper and have been published elsewhere [14].

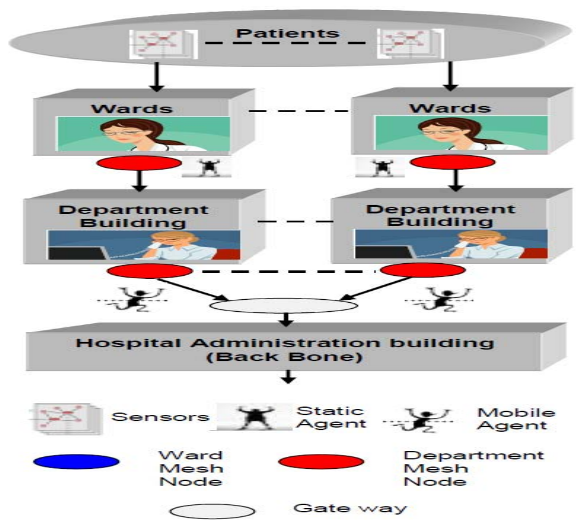

Fig.5 Hierarchical Agent based Architecture

4. Performance study using OPNET simulation

The architecture was simulated [15][16] using Opnet modeler 15.0., for studying its performance. Here, for simulation, we considered a hospital with three departments, each department consisting of three wards. For performance study, in each ward we varied the number of patients as 5, 10, 15, 20, and 25. Totally the network can thus have a maximum of 225 patients in the hospital. Each of the patients would have body sensors (S1 to S5) with a cluster head (CH) as shown in Fig. 6

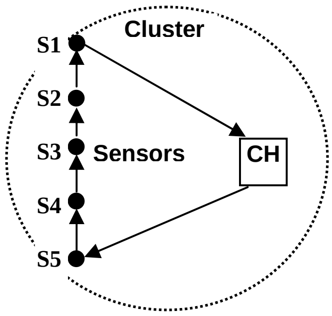

Fig.6 Sensors, Cluster Head

Fig.7 shows a screen shot of the simulation scenario with 25 patients per each ward. In our simulation, we have organized the sensors for patients with 5 PAN End Nodes which are the sensors and one PAN coordinator which is the cluster head (similar to the one shown in Fig.2). This is shown in greenish blue colored octagonal in Fig.3. The Pan End nodes and Pan Coordinator is 802.15.4 zigbee model. In each ward and department we have simulated the wireless LAN router which is 802.11a/b with a data rate of 11Mbps. These 802.11 nodes communicate through the wireless medium to the Main mesh node which is wireless LAN cum wired router. The main mesh node of hospital is also 802.11a/b and is connected to Ethernet switch through a 100 BaseT connectivity which is then connected to three Ethernet servers that run heavy database application of the hospital. Also we got nine PDAs - 802.11 workstations which are the simulated doctors.

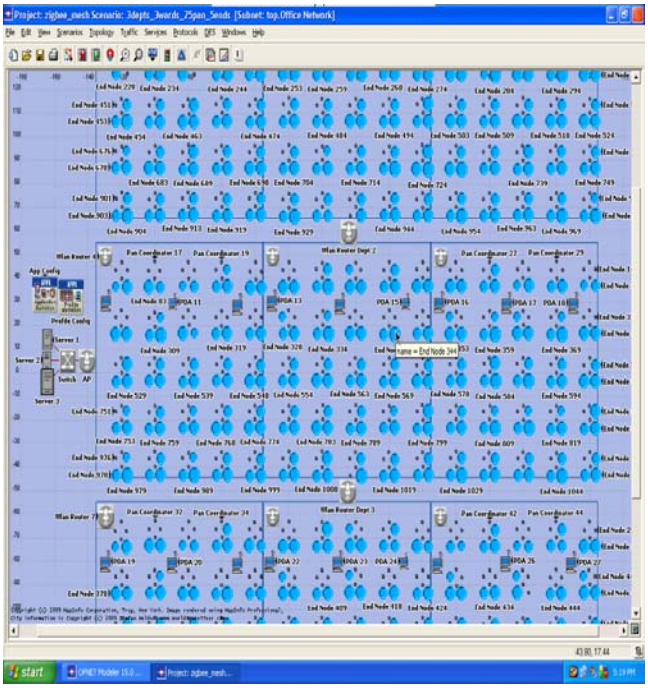

Fig.7 Opnet Simulation Scenario

4.1 Delay, Mac delay and throughput

As mentioned earlier, we have operated the simulated network with 5, 10, 15, 20, 25 patients and studied the performance of the network [15] in terms of delay, MAC delay and throughput and the results are shown in Figs. 8 to 10. The simulations were run for 30 minute duration in each of the following cases.

From Fig.8 it can be seen that delay in the network for the varying number of patients 5, 10, 15, 20 and 25 in the ward seems to be very marginal. It is seen from the graph that value of the delays were 0.0054, 0.0056, 0.0056, 0.0054 and 0.0054 expressed in seconds, respectively for varying number of patients as 5, 10,15, 20 and 25, shown respectively in blue, red, green, light blue and yellow lines. But this increase in the delay with increasing number of patients seems to be very marginal. The reason could be that the sensors do not transmit data traffic pertaining to the patient health information continuously. Only when required, the pan coordinator queries the sensors for the health information and the data gets transmitted.

From Fig.9, it can be seen that the MAC delay in the network for varying number of patients 5, 10, 15, 20, 25 also seems to be very marginal. It can be seen from the graph that the values of MAC delay are 0.0041, 0.0041, 0.0041, 0.0040 and 0.0040 respectively expressed in seconds, shown as before in blue, red, green, light blue and yellow lines. The reason again could again be due to not all sensors transmit the health data continuously and so there is not much of competition in accessing the channel medium during transmitting data over the network to the doctor's PDA.

From Fig.10, it can be seen that the throughput of the network for varying the number of patients again as 5, 10, 15, 20 and 25 in the ward, seems to be very marginal. It is seen from the graph that values of throughputs are 400000, 420000, 400000, 400000, 390000 respectively, expressed in bits/seconds, shown in blue, red, green, light blue and yellow lines. We can see that the throughput is anyway dependent on the delay and MAC delay of the network. This means that the amount of data transmitted in the network seems to have a very marginal difference with varying number of patients.

Till now we have seen the performance of the network when the number of patients is varied from say as 5, 10, 15, 20 and 25 per ward in a department. However, in this simulation, we have kept the number of PDAs of doctors to be 3 per department totaling 9 for the entire network. Now we increased the number of PDA's to 18 and studied the network performance for 25 patients per ward, in the entire hospital network, in terms of delay, Mac delay, and throughput. The simulations were again run for 30 minute duration in each of the following cases. The results are shown in Figs. 11 to 13

In Fig.11 we see that the delay in the network slightly increases as the number of doctor's PDA's is doubled from

9 to 18 even though the number of patients per ward is kept as 25. It is seen from the graph that value of delay is 0.0060 seconds when number of PDAs doubled compared to 0.0055 seconds for previous scenario shown in red and blue lines respectively. Even here the sensors would transmit patient data only when required. Doctor’s PDA would transmit the data regarding patients to the database and also receive the information about the patient from a ward. Also there would be communication between the doctors though their mobile phones too. These do exist in the previous scenario too but the number of PDAs remained as 9. But when the number of PDA’s in hospital, is doubled from 9 to 18, we see that the network is getting loaded and consequently the delay in the network also increasing more than in the previous scenario, shown respectively in red and blue lines.

In Fig.12 we see that MAC delay in the network slightly increasing as the number of doctor’s PDAs is doubled from 9 to 18, even though the number of patients per ward is kept as 25. It is seen from the graph that value of MAC delay is 0.0044 seconds when number of PDAs doubled compared to that of 0.0040 seconds for previous scenario, shown in red and blue lines respectively. Even here the sensors would transmit only when required and so there would not be much competition in accessing the channel medium. But as the number of doctor’s PDA gets doubled, network gets loaded too and there seems to be more competition towards accessing the channel medium for transmitting the data to the database or communicating with other doctors. This shows the variation in MAC delay as shown respectively in red and blue lines

Finally Fig.13 shows the throughput of the network when number of PDA’s gets doubled from 9 to 18. In this case, throughput refers to the amount of data transmitted over the network. It is seen from the graph that the value of throughput is 800000 bits/seconds when number of PDAs doubled compared to 400000 bits/seconds for previous scenario, shown in red and blue lines respectively. These simulations here were also run for 30 minute duration. This when compared to the previous scenario has also been doubled when the number of PDA’s was doubled shown respectively in red and blue lines.

4.2 *Mesh node failure*

Having seen how the network performs with varying number of patients and doctors, we now study the reliability of the network under device failures [16]. These scenarios were run for 5 minute duration. For this study we consider the following two scenarios:

- Sceanrio-1: Failing of the mesh node of all the wards in the departments
- Scenario-2: Failing of the mesh node of all the departments.

In both scenarios, when mesh node fails we find that the load on the network also drops as 600000, 300000 and 0 bits/second with each mesh node of ward /department failing shown as red, blue and green lines in Fig. 14. This is due to the fact that the amount of data being transmitted reduces as the sensors in the ward needs to see the nearest mesh node to transmit and also the mesh node needs to be congestion free to transmit the data.

Now coming to the throughput when the mesh node getting failed, we find that throughput i.e. number of data packets being sent reduces to 600000, 300000 and 0 bits/second shown in red, blue and green lines for three mesh nodes of ward/department being failed shown in Fig.15. The reason being, as mesh node of a ward/department getting failed, the sensors in that ward would try to find the next nearest mesh node to transmit the data and also as there are other sensors trying to transmit the data through those mesh nodes, the throughout actually drops. These are shown in Fig.15. The corresponding values of delay drops as 0.0058, 0.0042 and 0.008 seconds for mesh nodes of ward/department failing are respectively shown in red, blue and green lines as shown in Fig. 16. The MAC delay also drops as 0.0049, 0.0040 and 0.002 seconds for mesh nodes of ward/department failing as shown in red, blue and green lines in Fig.17. The delay and MAC delay drops because not all sensor data would be transmitted by the next/nearest mesh node when the mesh node in ward/department fails, as it depends on congestion in the network too as shown in Figs. 16 and 17. The conclusion we therefore draw here is, that failure of mesh node in a ward/department leads to less amount of data being transmitted meaning certain patient information cannot be transmitted in time as mesh node in that ward or department has failed and data transmission has got to look for the next nearest mesh node to transmit, which also got to be congestion free to transmit

Fig.8 Wireless LAN Delay

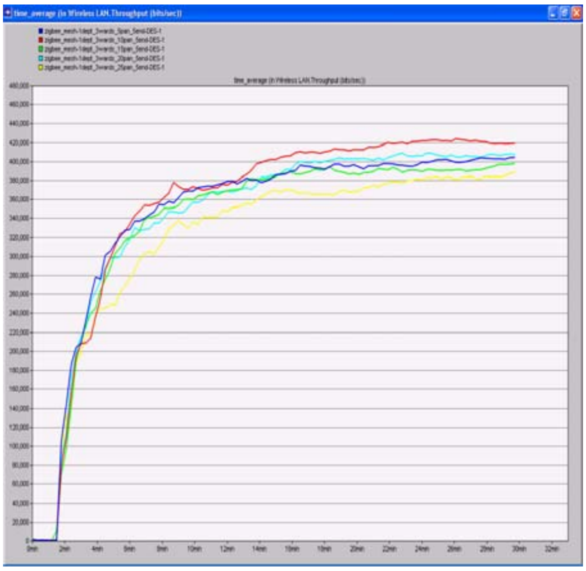

Fig.9 Wireless LAN MAC Delay

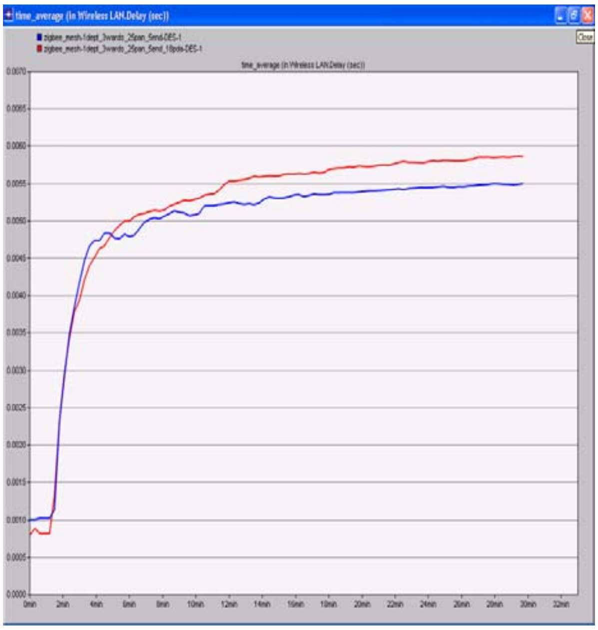

Fig. 11 Wireless LAN Delay - PDAs Doubled

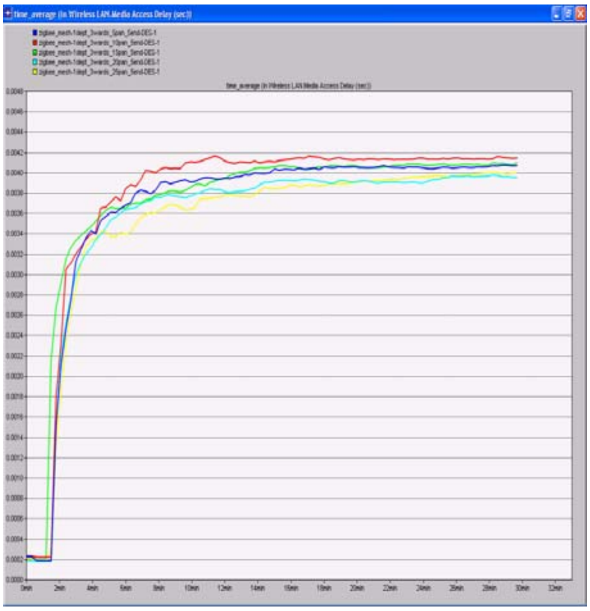

Fig.10 Wireless LAN Throughput

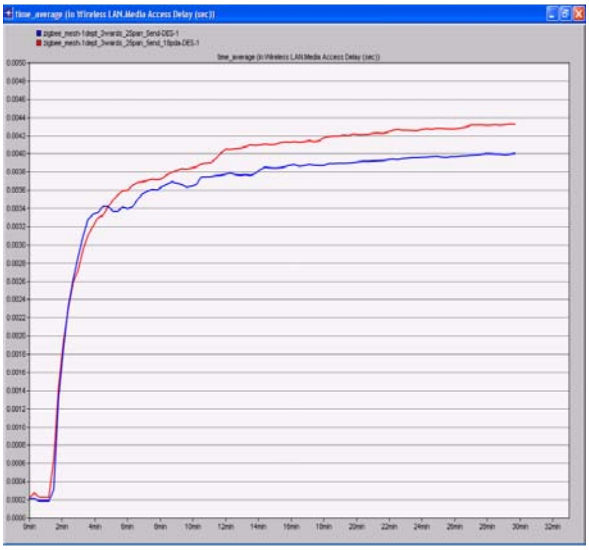

Fig.12 Wireless LAN MAC Delay – PDAs Doubled

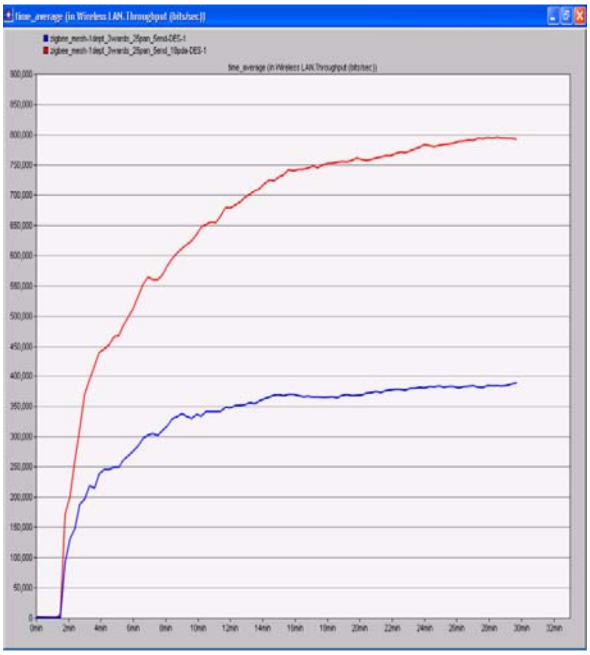

Fig.13 Wireless LAN Throughput- PDAs Doubled

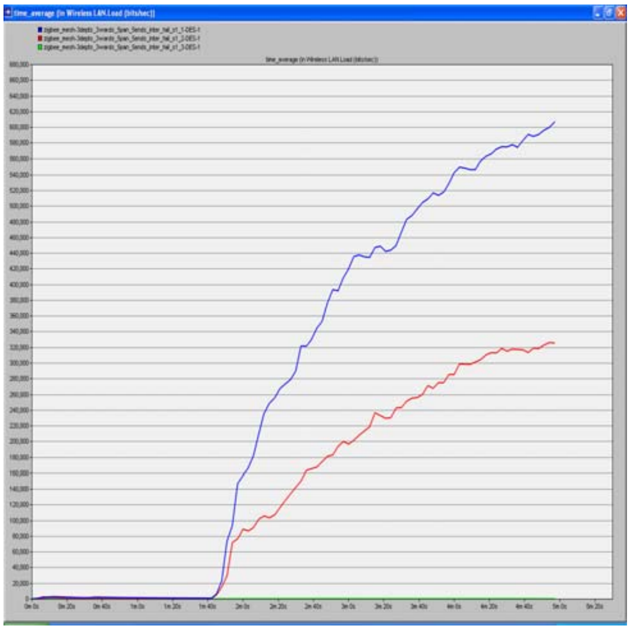

Fig. 15 Wireless LAN Throughput- Failure

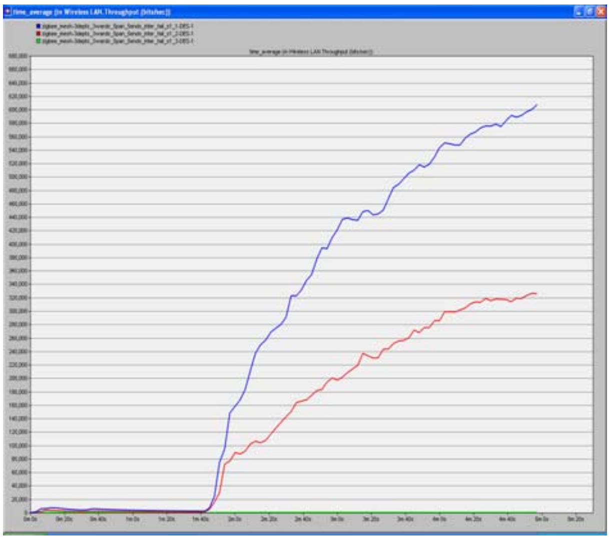

Fig. 14 Wireless LAN Load- Failure

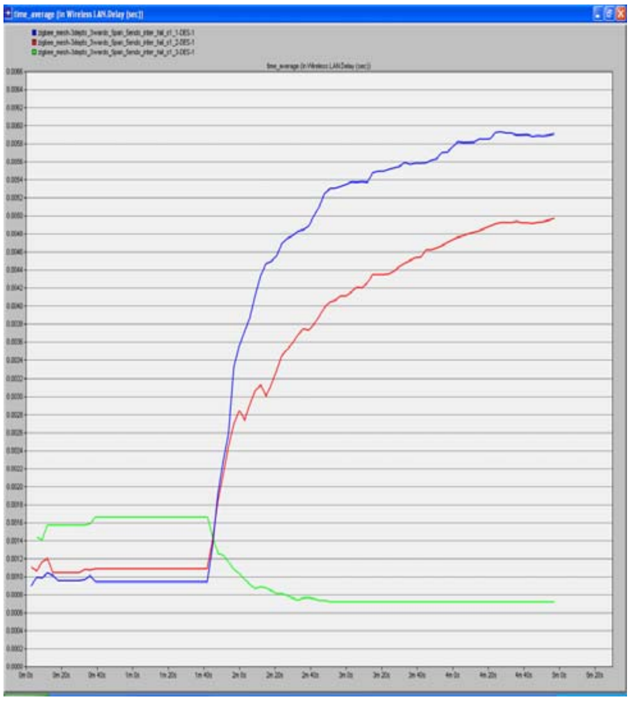

Fig. 16 Wireless LAN Delay - Failure

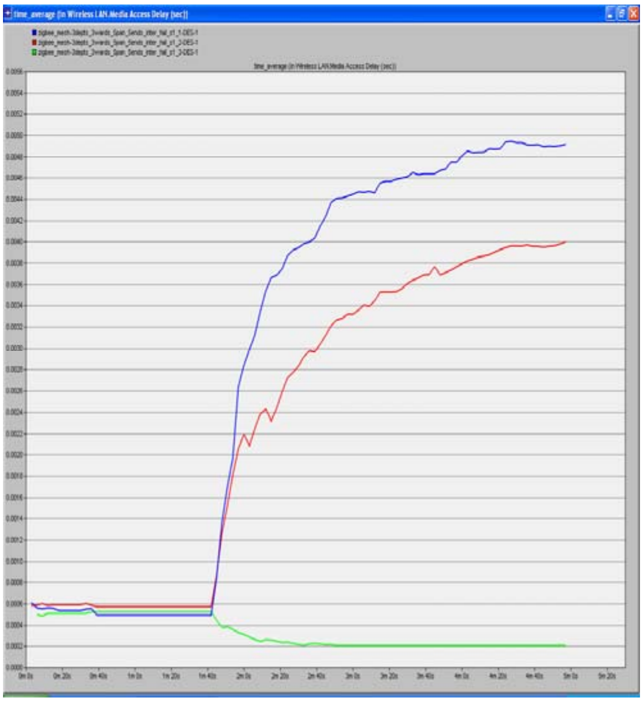

Fig. 17 Wireless LAN Delay - Failure

5. Conclusion

In this paper, we have presented the results of the performance studies of Agent based hierarchical architecture employing Wireless sensor based Mesh Network for health application based on simulation using Opnet modeler 15.0 For this study we conceived a hospital network with three wards and three department. The general observation from the simulation is that the performance of the network shows a marginal difference in delay, MAC delay and throughput while the number of in-patients is getting increased from 5, 10, 15, 20 and 25 per ward. It has also been observed that the same network shows a great variation in delay, MAC delay and throughput, when the number of PDA's in the hospital is doubled from 9 to 18. So we conclude that increasing number of in-patients may not pose that severe problem in the delay performance. It was also seen as how the network performs under failure .In future we also proposed to study the network under channel interference using FHSS and DSSS mode of communication.

References

[1] John A. Stankovic, "Research Challenges for Wireless sensor Networks", Available from www.cs.virginia.edu/sigbed/archives/stankovic.pdf, 2005

[2] Mohammad I and Imad M, "Handbook of Sensor Networks: Compact Wireless and Wired Sensing systems", CRC Press, 2006

[3] Farahani, S., "ZigBee Wireless Networks and Transceivers"., Oxford , UK, Elsevier, 2008.

[4] Bluetooth, Available from http://en.wikipedia.org/wiki/Bluetooth

[5] Amit B and Nagaraju K, "A self managing frame work for health monitoring", Intel Technology Journal-Autonomic computing, Vol.10(4), Nov, 2006

[6] Akyildiz I.F., and Wang X, "A survey on Wireless Mesh Networks", IEEE Communication Magazine, 2005, Vol.43 (9), 23-30.

[7] Ilyas, M., and Mahgoub, I., "Handbook of Sensor Networks: Compact Wireless and Wired Sensing Systems., Florida, CRC Press, 2006.

[8] Misra, S et al ., "Guide to Wireless Mesh Networks"., London, Springer, 2009.

[9] Waharte S., and Boutaba R, "Tree based Wireless Mesh Network Architecture: Topology Analysis", Available from: http://bcr2.uwaterloo.ca/~rboutaba/Papers/Conferences/ MeshNets-05.pdf, 2005.

[10] Toh C.K., "Adhoc Mobile wireless Networks: Protocols and Systems", UK, Prentice Hall, 2002.

[11] Suresh S., "Performance of 802.11b Mesh Network under channel interference for Wireless Internet", International Journal of business Data communication Networking, vol.3 (4), pp.47-59, 2007.

[12] Suresh S., "Policy based Agent Architecture for Sensor based Mesh Networks - Health Care Monitoring"- Proceedings of the International Conference on High Performance Computing, Networking and Communication Systems (HPCNCS-08), Florida, USA, July 7-10 2008. Pp.75-81, ISBN: 978-1-60651-004-9.

[13] Suresh S and S Ganesan, "A layered architecture for agent based wireless sensor based mesh networks – applications in health sector", Intl. Journal of Embedded Systems and Computer Engineering , Serial Publications,Vol.1(1), pp.51-61, 2009

[14] K Miller and S Suresh, "Role of Intelligent Agents and Wireless Body Sensor Mesh Networks in Patient Monitoring",. Proceedings of the 5th IEEE International conference in Networked Computing, Seoul, Korea, 25-27, August 2009.pp 369-375. ISBN: 978-0-7695-3769-6/09

[15] N. Benjamin and S Suresh, "Performance of Hierarchical Agent based Wireless Sensor based Mesh Network for Health Care"-Proceedings of the 8th IEEE International conference on Computer Information Systems and Industrial Management, Coimbatore, Chennai, 9-11, December 2009. Pp.1653-1656. ISBN: 978-1-4244-5612-3

[16] N. Benjamin and S Suresh, “Failure Performance Study of Hierarchical agent based Patient Health Monitoring in Wireless Body Sensor Mesh Networks”, Proceedings of 2009 IEEE International Conference on Advances in Computing, Control and Telecommunication Technologies, Trivandrum, India, 28-29, December 2009.pp 85-87. ISBN: 978-0-7695-3917-7.

Author Biography

Norman A. Benjamin received the Bachelor’s degree in Computer Science from the University of West Indies, Mona (2006). He is presently pursuing Master’s degree in computer Science since 2007. He has extensive skills in Java, PHP, XML, MySQL, OPNET Modeler, Linux and Windows Operating System. He got three papers published in IEEE proceedings and International journal towards his Master’s Dissertation which he has submitted. His research interests are mainly in Wireless Sensor Networks, Wireless Mesh Networks.

Suresh Sankaranarayanan received his Ph.D degree (2006) in Electrical Engineering with specialization in Networking from the University of South Australia. Later he has worked as a Postdoctoral Research Fellow and then as a Lecturer in the University of Technology, Sydney and at the University of Sydney, respectively. He is the recipient of University of South Australia President Scholarship, towards pursuing the PhD degree programme and has also bagged the IEEE travel award in 2005.Presently he is working as a Lecturer in the Department of Computing and leads the Intelligent Networking Research Group, in the University of West Indies, Kingston, Jamaica, since 2008. He has supervised thirteen research students leading to M.Sc, ME and M.S degrees. He has got to his credit, as on date, 32 research papers published in the Proceedings of major IEEE international conferences, as Book Chapters and in Journals. He is also a Reviewer and Technical Committee member for a number of IEEE Conferences and Journals. He has also given Keynote talks in IEEE conferences too. In additions he has conducted many tutorials, workshops and also given Guest Lectures in Networking and Agent Applications in various Universities, Colleges and Research Institutes. Presently he manages a collaborative research programme with Oakland University, Rochester, USA. He also received a research grant from University of WestIndies towards Wireless Sensor Network project towards patient Health Monitoring. His current research interests are mainly towards ‘Intelligent Agents and their applications in Wireless Sensor based Mesh networks’ used in the Health and Engineering sectors; Applications in mobile commerce.