Simulating IEEE 802.15.6 based Wireless Body Area Network Interference using NS2 Platform for Indian Scenario

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Abstract

A recent data suggest that currently there are more than 485 million wearable sensors or gadgets users in the world and expected to increase in the near future. The communication technologies used in these gadgets are either Wi-Fi or Blue-Tooth. These wireless technologies have inherent limitations to be used in Health Monitoring. Also, these technology gadgets are not being considered and accepted by medical practitioners for e-health monitoring. To address this issue, in 2012 IEEE 802.15.6 standard has been introduced to develop future of e- health monitoring which paves its way to Wireless Body Area Networks (WBAN) developments. India, being populated country, WBAN can be extremely useful technology to reduce burden on health care system. WBAN research has gained importance in India, where most of the research is focussed on sensor development and monitoring. The network level studies focusing on interference phenomenon are rare to find. In this paper, a focus is on developing an interference scenario in simulation environment. This interference study provided deep insight into the dynamics of co-existing WBANs where its adverse effects are observed on energy consumption, delay and throughput.

Keywords: Wearable Sensors, Wireless Body Area Network, Interference, Mobility Model, Network performance.

1. Introduction

As per the latest research in India [1], Cardiovascular Diseases (CVDs) are understood as a critical cause of deaths in the country. The report says that that CVD death and Mortality rate in India is high [1]. In 2016, 1.7 million Indians died because of Heart disease [2]. The Coronary Heart Disease (CHD) has caused continuous rise in the death rate since 2003 to till date and it's more alarming in rural population [2]. Above statistics from the latest research studies indicate a growing concern of heart related diseases in India.

Conventionally the electrocardiograph (ECG) device is used monitor hearth condition. The ECG in Intensive Care Unit (ICU) is used for monitoring the patient. In general hospitalization causes discomfort to patient and is costly. The smart watches, pulse oximeter can monitor bio-signals of the heart however, these devices have some limitations to be used in medical health monitoring systems [4]. The health monitoring is useful to reduce death rate and providing time medication. Traditionally, this is being done at hospitals by using on body wired sensors [5]. For such wired monitoring patient has to be admitted in hospital, and wear various on body sensors; limiting the movement of the patient. The wireless health monitoring provides remote sensing and enhanced mobility [5], and comfortable life for a patient as need to get hospitalized is minimized [5],[6].

This mortality rate can be reduced by using Wireless Body Area Network (WBAN) which can give early warning signs of such attacks and also help patients by real time health monitoring. Such

real time studies are rare in the Indian health sector. In the WBAN, different bio-logical sensors are placed on a human body to sense bio-signals. These sensors collect and transmit bio-medical signals to the hub or central node. This collected information at hub, then can be forwarded to a mobile or any hand held device and then to hospitals via internet technologies for medical diagnostic purposes [5]. This way WBAN can help to reduce the mortality rate and also to ensure comfort level of the patient. Because of these features, WBAN has been considered for this research. The severity of the problem discussed above can be minimized by efficient heart rate monitoring; to give early warning signs of the heart attack. This paper is a part of research work carried out to design WBAN in line with IEEE 802.15.6 standard for the heart rate monitoring in India.

The human body is mobile with various postures like sitting, standing, laying, walking and running. These postures are associated with hand and leg movements; which ultimately causes movements of the sensors mounted on hands and legs. As a result, due to these postural mobility, WBAN topology keeps on changing continuously, because of which network performs gets degraded. Thus, efforts must be put to study effect of mobility on network performance. Also, when human body moves to new location and comes in vicinity of another WBAN range co-existence of two WBAN occurs. It may be noted that, in many practical environments multiple WBANs co-exist. Such coexistence of multiple WBANs causes interference which affects adversely on throughput and energy consumption. It is also understood that co-existence of WBANs cannot be avoided as it would not be possible to keep human body stationery or confined to a typical space where less WBANs exists. Thus, efforts should be made to detect and mitigate interference, so as to keep network energy consumption and throughput at optimum levels. Thus, an objective and focus of this paper is on design and development WBAN for Indian context and to test its performance under Interference environment.

From the referred literature [1, 2, 3], it is understood that heart rate and pulse rate are the good indicators of heart disease. Accordingly, we have simulated WBAN consisting three sensors

and one hub, and tested under interference environment. Thus, performance of the designed WBAN under the influence of interference is investigated and reported in this paper. For network performance analysis, three parameters viz. delay, energy consumption and throughput are considered. The rest of the paper is arranged in the different sections. In the section 2, similar interference mitigation studies are reported. In the section 3, methodology and simulation environment used for this research is discussed followed by results in section 4, and concluding remark in section 5.

2. Literature Review

Wireless communication architecture of WBAN is found to be of three layers called as levels or tires which are Communication Level 1 called as Intra – WBAN, Communication Level-2 called as Inter-WBAN and Communication Level-3 which is called as Beyond –WBAN. Level 1 consists of mounting sensors on body for the specific purpose. The sensors collect the data and send to the hub or coordinating node. The hub transmits data to the personal server or mobile. For such kind of communication star network or multi hop network topology can be used. In Level 2, the WBAN is used to connect with various networks such as mobile phone and or internet. In this type of communication is based on two types; infrastructure based mode and Ad-hoc mode. In infrastructure based mode access points are the Wireless Local Area Network (WLAN) and different types of available networks. Ad-hoc mode communication provides the more flexibility for movement. Level 3 is termed as beyond WBAN communication [7]. It contains application specific communication. For example, if information is communicated to the hospital server, it can be considered as beyond WBAN communication as shown in above diagram. This level 3, is used for calling emergency services, calling doctors for help or informing family members in case of emergency [7]. This paper focuses on design of Intra-WBAN (level 1) for Indian scenario i.e. heart health monitoring.

2.1 Mobility Modelling

As discussed earlier, WBAN is a network of sensors mounted on the human body that sense the bio-signals and transmit them wirelessly. It can be easily understood that in actual practice it is not

possible for human being to remain static at one location. Thus, human beings are active and busy in day to day activities. Humans are busy with their daily activities such as sitting, walking, running and lying down, etc. So, as an activity changes, in response to the activity, position of the node mounted on human body also changes. This is called as WBAN mobility. As the whole network is moving, a distance between the source node and hub or destination node of the network keeps on changing. Various authors have presented many types of mobility models in the literature. A descriptive survey of mobility models is presented in [8]. Mobility models can be categorized into two main categories; Singular node mobility and group node mobility [9].

In single node mobility, there is no relation between movements of all other nodes of the network, so individual node movement is separate. Single node mobility has different models. Random Walk Mobility Model (RWMM) defines single node mobility for which direction and velocity are randomly selected from a pre-defined range of movements. The simulation area defines the total moving area of nodes [10]. Random Waypoint Mobility Model (RWPM) is a revised version of RWMM. It also has a defined range in a given area but when the node changes its direction, intermission time is introduced [11]. Random Direction Mobility Model (RDMM) works upon the distribution of all nodes in the specified simulation area in such a way that the gathering of all nodes in the centre is avoided [12]. Random Gauss Markov Mobility (RGMM) defines the single node mobility by using a Markovian and Gaussian model. Node speed and direction are calculated by using Markovian property. Gaussian distribution is used for calculation of the mean value of mobility parameters of a node such as the direction of node movement and its speed [13].

In a group node mobility, instead of focussing on individual nodes, the focus is on a group of nodes. There are many models for a group mobility. It is assumed that all nodes are having similar relative movement with each other for example all sensors in a group may take the same direction and speed. Small World In Motion (SWIM) presents a group mobility model in which probable geographical locations were considered such as home, market or areas where a person can visit more often [14].

Reference Point group Mobility model (RPGM) is a group mobility model that defines an area of mobility and its direction was represented with respect to fixed reference usually called a Logical centre (LC). In this type of mobility, for all nodes of a group LC is to be defined. The direction of the sensor group is defined by a vector called the Group Motion vector (GM). Every node has an initial position defined with respect to the reference point (RP) and the motion of an individual sensor is defined by the Random Motion vector (RM) [15]. The Mobility model for WBANs (MoBAN) describes an accurate pattern of movements for a single node as well as for the whole group. It has a module to select body posture of individual nodes and global movement control module for the motion of whole WBAN [16]. This paper uses SWIM in which market scenario of 100 x 100 m area is considered in simulation. Such assumption is done to replicate a real life market situation in India. More details about simulation are discussed in later stages of the paper.

2.2 Interference studies

When communication ranges of two neighbouring WBANs overlap on each other it is called as interference. WBAN interference can be categorized into three types [17]

2.2.1 Intra-WBAN

When interference occurs amongst single WBAN sensor nodes; then it is said to be having intra-WBAN interference.

2.2.2 Inter-WBAN Coexistence and Interference

When there are several number of WBANs are set up in the 2.4 GHz band then it is said to have inter WBAN coexistence and interference.

2.2.3 Inter-Domain Coexistence or cross Interference

When other wireless networks such as Wi-Fi, Zigbee or Bluetooth devices work at same location of the WBAN and at the alike frequency at the matching time and place within the 2.4 GHz band of the WBAN, then it is said to be inter domain coexistence and interference. Another terminology used in literature as Homogeneous and Heterogeneous coexistence. In homogeneous coexistence WBAN of same technology are interfering with each other whereas in heterogeneous interference WBAN of different

technologies are interfering with each other. Coexistence is also grouped as static or semi-dynamic or dynamic or no interference.

This paper is a case of homogeneous, dynamic, Inter-WBAN coexistence. IEEE 802.15.6 standard is considered for designing each WBAN, thus there is only one technology used in communication. This represents homogeneous interference. The networks are considered with SWIM mobility randomly moving in a given area, representing dynamic nature of WBANs whose directions and topology keeps changing. In this paper, 50 co-existing WBANs are considered, where each WBAN has three sensor and hub. Thus, it represents inter-WBAN interference of homogeneous, randomly moving (dynamic) WBANs.

2.3 Effects of Interference

The interference phenomenon cannot be avoided, thus it is necessary to minimise its ill effects. In dynamic co-existence; when nodes are mobile, intra-WBAN and inter-WBAN interference severely impair transmission. Thus, in mobile WBANs, signal integrity becomes unstable which may degrade the network performance [17]. Another study mentioned that an augment in the amount of WBANs and their communication data rate will cause elevated performance deprivation i.e. low packet delivery ratio and packet rate in WBANs [18]. In [19], the co-channel interference effect was analyzed by varying the boundary network distance for maintaining the reasonable SINR (signal to interference plus noise ratio). It has been found that if the network space decreases below 7 to 12.5 m then the SINR cannot be maintained of the border line nodes [19].

In simulation based research for co-channel interference mitigation, it has been found that in co-channel interference it is difficult to maintain signal quality [20]. In similar studies, it has been found that the number of lost beacons increase when the number of coexisting WBANs changes. In other words, data loss is elevated in the existence of interference leading to beacon confrontation and data collision [21]. The BER performance of the UWB-based WBANs is found to be depending on the power signal of the interfering networks such as IEEE 802.15.4a (piconets) or IEEE 802.15.4f (RFID) systems [22]. In cross interference learning the simulation results

show that Wi-Fi negatively impact WBANs from the 6th to 9th channels. The packet loss rate of WBANs is elevated when Wi-Fi or Zigbee device is around a transmission range [23]. From above literature, it is clear that the interference of any form causes data collision, beacon loss and affects on signal quality. Furthermore, it can also be elaborated that such loss results in reliability and increases power consumption of the network. Overall it can be concluded that the interference causes network performance degradation. In this paper, interference is considered as an event occurring due to randomly moving WBANs. Thus, objective of this paper is to investigate effect of interference for the WBAN designed to cater Indian problem. It is assumed that in future Indian Healthcare system will adapt IEEE 802.15.6 standard to design WBAN and many such WBANs will co-exist in a given confined area as market, hospitals etc. Thus the current research contributes into investigations of network performance of homogeneous (IEEE 802.15.6 Based) interference studies with randomly moving WBANs.

3. Methodology

To fulfill the research objective, the first step was to Design WBAN architecture which can be practically used by the people or patients. Design of WBAN includes choice of bio-signals, sensor specifications, their topology, and WBAN requirements as per IEEE 802.15.6 standard. The heart rate, pulse rate and human body temperature are three bio-signals selected for the patient's health monitoring. These sensors are conceptualized and simulated in the NS2 by specifying their data rate and energy conditions of the trans-receivers as per the IEEE 802.15.6 standard. These sensors are arranged in a single hop star topology with a hub at the centre to create WBAN for the research. The node-1 is a heart rate sensor mounted close to heart, node-2; a pulse rate sensor is mounted near to left hand wrist and node -3 is a temperature sensor mounted under the arm. Accordingly, WBAN was designed and tested successfully in NS2 (simulated environment). After first successful trials, 50 WBANs with same characteristics were created and given different mobility patterns. Some were assigned static mode and others were allowed to move randomly with walking speed of 1.5 m/s. Thus, interference environment is created with 50 WBANs which are

allowed to co-exist in the area of 100m X 100m area. This is tested successfully in the NS2. This process is called as Mobility and Interference Modelling. To check the performance of WBAN under the influence of interference three network parameters viz. throughput, delay and energy consumption are selected. Three simulations are designed and tested in this research. The multiple iterations are carried out to tabulate the results of simulation. The first three trials were conducted for 50 WBANs and parameters such as energy consumption, throughput and delay were tabulated. Later, the number of WBANs was gradually increased from 50 to 300 in the steps of 50 keeping area constant. Thus, intensity of interference was increased and network parameters were tabulated. This experiment helped to understand design of interference model and also to understand the effect of intensity of interference on the network parameters.

3.1 WBAN Simulation Design

The first step in simulation studies was to replicate ET-WBAN in simulation environment. Accordingly, the WBAN network is designed in NS2 (simulated environment) as shown in fig 1. A central node represents Hub and heart sensor is represented by the node 0. Similarly, other two sensor nodes, 1 and node 2 represents pulse rate and temperature sensors. All nodes are connected with wireless links in star topology. These three sensors nodes will be communicating with a single hub as shown in fig 1. Accordingly, a program of four nodes is written.

Network design in NS2 contains a Frontend and Backend structure. The frontend is used to design a WBAN. A frontend is used to design wireless body area network. To create functional network, the simulation time and routing protocol is assigned. We assigned 50 second simulation time and MAC 802.15.6 protocol. IEEE 802.15.6 MAC contains two input files such as cbr (Constant Bit Ratio) which is used to describe connection pattern of nodes. The second input file is scen (Scenario file) which is used to hold location information of all nodes. The code is developed in main.tcl file which is used to call two input files. Thus, two output files are generated; res.nam and out.tr. In output files, res.nam file is used for visualization and out.tr is used to record all information of nodes i.e. data

transmitted per second from source to destination node. This out.tr file is used to get results. These results are analyzed to find performance of WBAN using three parameters such as energy, throughput and delay under various protocols. These results are obtained by applying awk script to out.tr file.
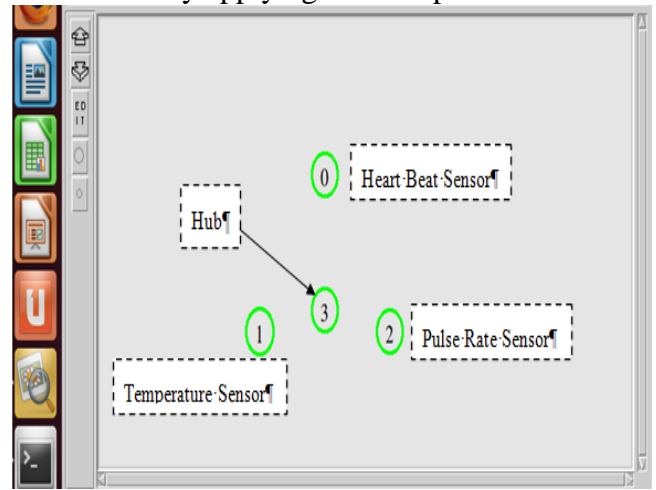

Fig.1. Placement of the sensor node and hub on the body and Network in NS2

Following Fig 2 show the output results received by applying awk script to the out.tr file.

Fig.2. Output of NS2 file

In the output, three files will be stored in the same folder where our main.tcl file is stored. We will get output files of energy, throughput and delay. Test run was carried out to check network configuration. Designed network works successfully and desired output is obtained as shown in fig 3. It means that all nodes, hub and wireless links are working properly. Fig 3 shows output of NS2 program, which shows the network of three nodes and one hub was created which follows IEEE 802.15.6 MAC and routing protocol AODV.

Fig.3. Throughput, energy and delay Output of NS2 file

3.2 Interference Modelling for Designed ET-WBAN

The interference environment is created in the first set by designing 50 WBANs coexisting at a single place having area of 100 x 100 meters. Following fig 4 shows 50 WBANs in simulation window. Each WBAN in this figure (the interference environment) is having three nodes and hub; similar to the model discussed in the fig 1.
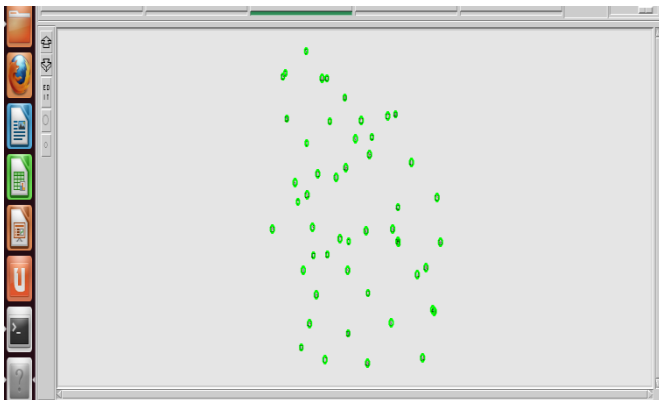

Fig.4. Fifty WBANs in a simulation window

To simulate real time crowded environment, we kept on adding 50 WBANs in each trial up to 300 WBANs. The fig 5 shows simulation window with added WBANs. It can be seen that adding more number of WBANs keeping same area will create dense cluster of WBANS. In 300 WBANs this dense cluster can be seen easily. For each of WBAN, the random mobility is provided to simulate unpredicted Random behavior of WBANs. It may be noted that every WBAN has a different mobility pattern. For example, some WBANs are static where which simulated to the person standing at a particular place and some are moving with 1.5 m/s speed to replicate walking.
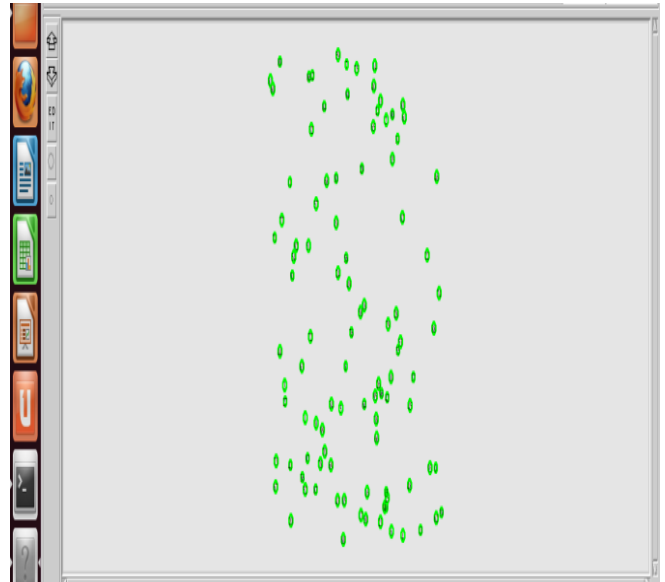

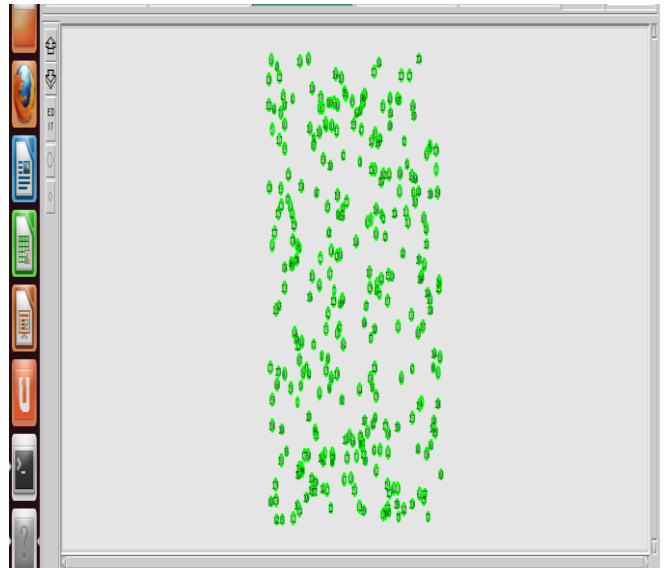**Fig.5a. 100 WBAN in the area of 100 x 100 area**

Fig 5b. 300 WBAN in the area of 100 x 100 area

Following fig 6 shows simulation trial snapshots. To understand mobility of the WBANs, we need to observe WBAN number 14 and 33 (highlighted in the red box). In each ms of the simulation, these WBANs will move closer to each other. We can observe and compare the position after 15.92 ms, and after 47.44 ms. It is seen that WBAN 14 and 33 are moved closer to each other. In the similar way, each WBAN is moving randomly. When the WBANs move in a specified area and come close to each other, it is called as Dynamic Coexistence. In such dynamic coexistence scenarios, WBAN communication ranges overlap on each other; this phenomenon is called as Interference. Thus, interference is the effect seen due to mobility of the WBANs.
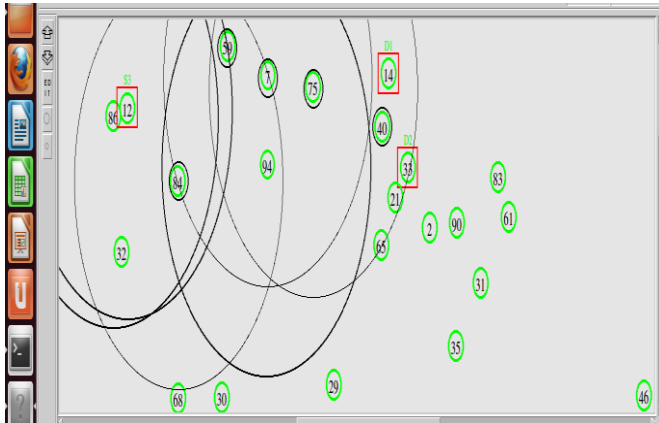
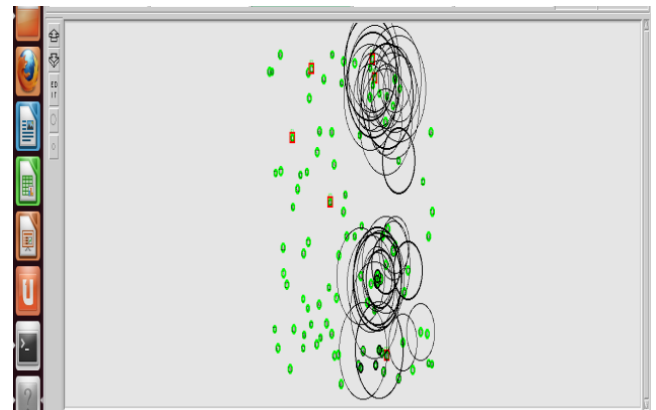**Fig. 6a Movement of 50 WBANs in the Random Mobility Model At 15.92**

Fig. 7a. Interference scene in for 100 WBANs after 40 ms

Following fig 8 shows interference scene for 150 and 300 WBANs. It is observed that as number of WBANs increases, intensity of interference further increased. We can see more dense overlapping ranges, as WBANs increased from 150 to 300. It can be understood that due to the overlapping ranges, network performance can degrade; which is investigated in this research.
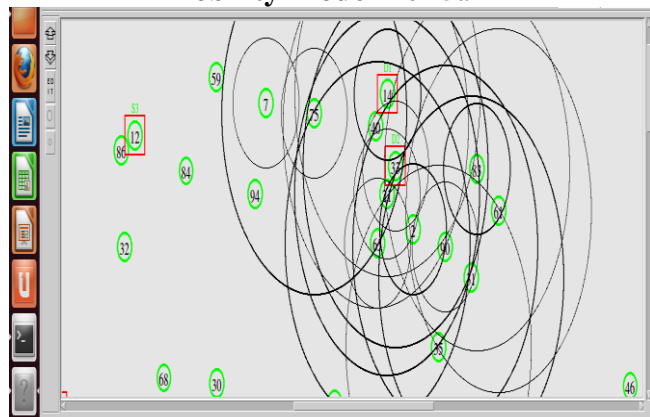

Fig.6b. Movement of 50 WBANs in the Random Mobility Model At 47.44

In the fig 7, interference scene in simulation window for different WBAN numbers in different timeframes is shown. In the first figure there are 50 WBANs and in the second figure there are 100 WBANs. It is observed that as number of WBANs increases, intensity of interference increases. We can see more dense overlapping ranges, as WBANs increased from 50 to 100.
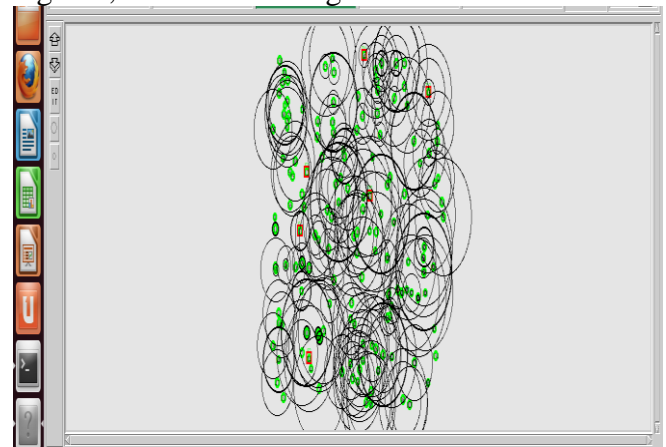

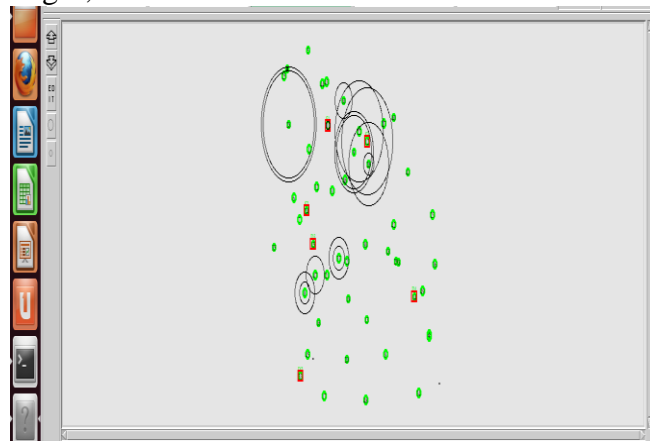**Fig.8a. Interference scene for 150 WBANs after 10.10 ms**

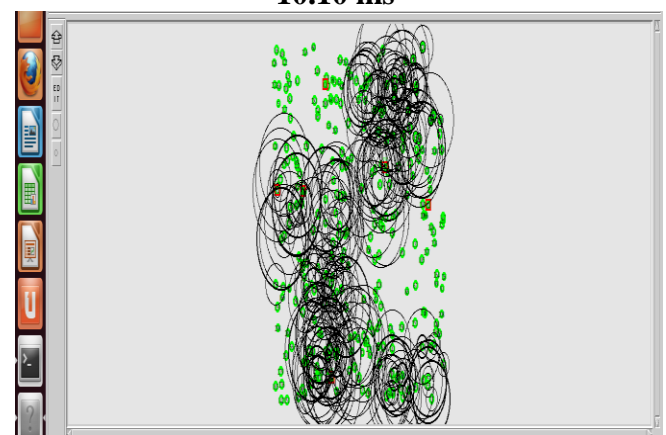**Fig. 7a. Interference scene for 50 WBANs after 20 ms**

Fig. 8b. Interference scene for 300 WBANs 10.05 ms

Thus, the coexistence and mobility of multiple WBANs in the given area resulted in the interference. It is verified that the interference simulation is created successfully. The next step in the research is to evaluate the effect of interference on the performance of the network. To investigate the interference effect, three performance parameters were used viz. throughput, energy consumption and delay. The detailed network performance study is discussed in the coming section.

3.3 Investigation on effect of Interference on network performance

Following Table 1 shows all simulation parameters. To enable design as per IEEE 802.15.6, we applied MAC 802.15.6 protocol. The simulation environment consists of 100 m x100 m area. As discussed in the previous section, initially 50 WBANs with random mobility scenario were created. Initial energy, transmitter and receiver energy values were maintained as mentioned in the Table 1. We conducted the simulation trial for 50 seconds and then analyzed the results by applying the awk script to the output file of the program. We fixed the same data rate for all sensors. To check the network configuration a test run was carried out. The designed network worked successfully and the desired output is obtained which confirmed that all nodes, hub and wireless links are working properly. Simulations are carried out for three parameters viz. throughput, delay, and power consumption. AODV protocol is applied and testing is done without application of any interference mitigation technique.

Table.1. Network Simulation Parameters

Network Area	100 x 100
Type of Network	WBAN
Number of WBAN	50-300
Number of Sensors in Each WBAN	3
Velocity	1.5 m/s
MAC	802.15.6
Simulation Time	50 second

Initial Energy	0.5 J
Transmitter energy consumption	16.7 nJ
Receiver energy consumption	36.1 nJ
Protocol	AODV

4. Results

For performance analysis, we have studied throughput, delay and energy consumption. Following table 2 provides network performance analysis for AODV protocol under interference environment. In coming section, each parameter is discussed in detail.

Table 2. Network performance analysis for AODV protocol with interference

Number of WBANs	Throughput	Delay	Energy Consumption
50	322.1	0.047	0.0105
100	229.45	0.049	0.0111
150	182.92	0.087	0.0111
200	154.26	0.125	0.0120
250	104.44	0.164	0.0135
300	50.72	0.383	0.0153

4.1 Effect of increasing number of WBANs on throghput

Following fig 9 shows throughput analysis and Table 2 shows throughput analysis comparative for AODV with interference. From fig. 9, it is observed that with increase in number of WBANs, the throughput goes on reducing. This slope is uniform. When WBANs are increased from 50 to 300, throughput is decreased from 322 to 50 (refer table 2); which is 6.350 times. Due to coexistence of these many numbers of WBANs in particular area, 6.350 times decrease in throughput is observed for the network. Thus, we can conclude that co-existence of multiple WBANs decreases throughput.

4.2 Delay Analysis

Following fig. 10 shows delay analysis and Table 2 shows delay analysis for AODV with

interference. From fig. 9b, it is observed that with increase in number of WBANs, the delay goes on increasing. When WBANs are increased from 50 to 300, delay is increased from 0.047 to 0.383 (refer table 2); which is 8.15 times. Due to coexistence of these many numbers of WBANs in particular area, 8.15 times increase in delay is observed for the network. The delay is drastically increased when the numbers of WBAN are increased from 250 to 300. Thus, we can conclude that co-existence of multiple WBANs increases delay.
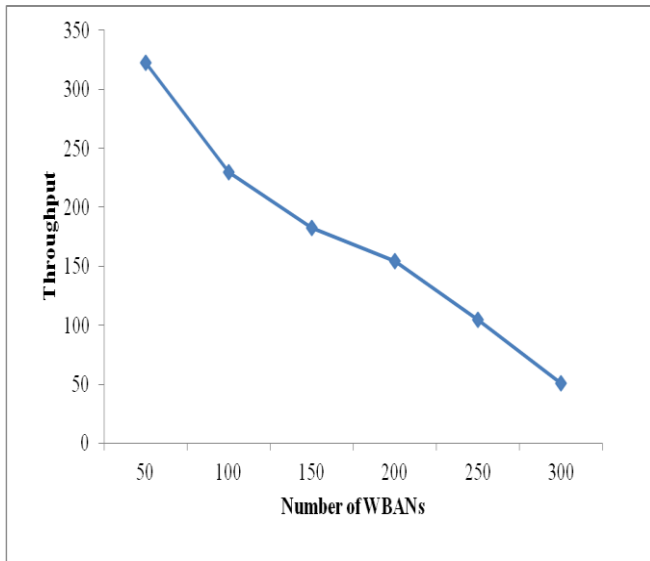

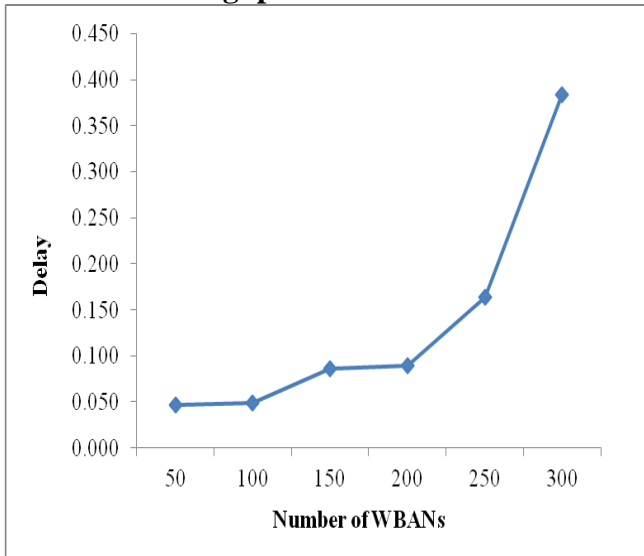**Fig.9. Effect of increasing number of WBANs on throughput with Interference**

Fig.10. Effect of increasing number of WBANs on Delay with Interference

4.3 Energy consumption Analysis

Following fig. 11 shows energy consumption analysis and Table 2 shows energy consumption analysis for AODV protocol with interference.
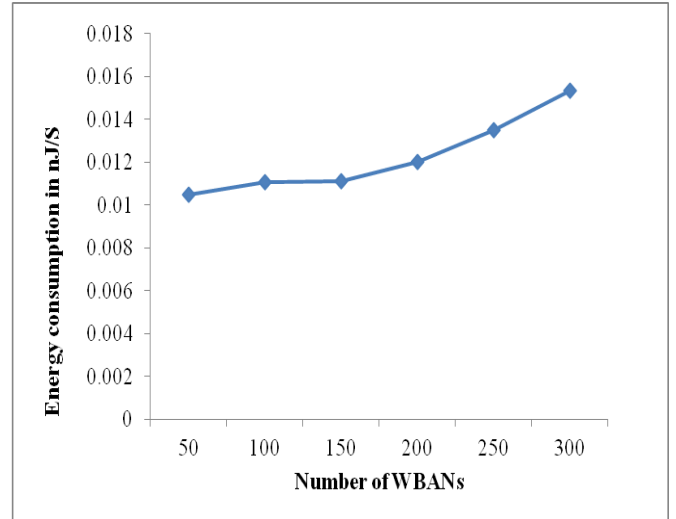

Fig.11. Effect of increasing number of WBANs on energy consumption with Interference

From fig. 11, it is observed that with increase in number of WBANs, the energy consumption goes on increasing. When WBANs are increased from 50 to 300, energy consumption is increased from 0.0105 to 0.0153 (refer table 2); which is 1.46 times. Due to coexistence of these many numbers of WBANs in particular area, 1.46 times increase in energy consumption is observed for the network. Thus, we can conclude that co-existence of multiple WBANs increase energy consumption.

Conclusions

In this paper, coexistence of WBAN is discussed with special focus on interference modeling. We observed dense clusters of WBANs in a specified area and observed random mobility pattern of the WBANs. From co-existence and mobility, studies we observed that there is interference i.e. overlapping of communication ranges. This phenomenon is further investigated to see the performance of network. The simulation environment is created and performance was monitored using throughput, energy consumption and delay analysis. After multiple simulation trials, collected data is analyzed to understand effect of interference. It is concluded that interference caused decrease in throughput, and increase in delay and energy consumption. Thus, there is a need to mitigate interference by developing

suitable Interference Mitigation technique to improve performance of ET-WBANs.

References

[1]. Prabhakaran, D., Jeemon, P., & Roy, A. Cardiovascular diseases in India: current epidemiology and future directions (Circulation, 133(16) , 2016), pp. 1605-1620.

[2]. http://www.indiaspend.com/wp-content/uploads/storify_620.png

[3]. Gupta, R., Mohan, I., & Narula, J. Trends in coronary heart disease epidemiology in India. (Annals of global health, 2016).82(2), pp. 307-315.

[4]. Hao, Y., & Foster, R. (2008). Wireless body sensor networks for health-monitoring applications. Physiological measurement, 29(11), R27.

[5]. Osseiran, A., Braun, V., Hidekazu, T., Marsch, P., Schotten, H., Tullberg, H., ... & Schellman, M. (2013, June). The foundation of the mobile and wireless communications system for 2020 and beyond: Challenges, enablers and technology solutions. In Vehicular Technology Conference (VTC Spring), 2013 IEEE 77th (pp. 1-5). IEEE.

[6]. Cheng, S. H.l, & Huang, C. Y. (2013). Coloring-based inter-WBAN scheduling for mobile wireless body area networks. IEEE Transactions on parallel and distributed systems, 24(2), 250-259.

[7]. Arefin, Md Taslim, Mohammad Hanif Ali, and AKM Fazlul Haque. "Wireless Body Area Network: An Overview and Various Applications." Journal of Computer and Communications 5.07 (2017): 53

[8]. Nabi, Majid, Marc Geilen, and Twan Basten. "MoBAN: A configurable mobility model for wireless body area networks." Proceedings of the 4th International ICST Conference on Simulation Tools and Techniques. ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), 2011.

[9]. M. Zonoozi and P. Dassanayake. User mobility modeling and characterization of mobility patterns. IEEE Journal on Selected Areas in Communications, 15(7):1239–1252, 1977

[10]. E. Hyyti¨a and J. Virtamo. Random waypoint mobility model in cellular networks Wireless Networks, 13(2):177–188, 2007.

[11]. E. Royer, P. Melliar-Smith, and L. Moser. An analysis of the optimum node density for ad hoc mobile networks. In Proc. IEEE Int'l Conf. On Communications (ICC), pages 857–861. IEEE, 2001.

[12]. B. Liang and Z. Haas. Predictive distance-based mobility management for PCS networks. In Proc. 8th annual joint Conf. of the IEEE Computer and Communications Societies (INFOCOM), pages 1377–1384. IEEE, 1999.

[13]. A. Mei and J. Stefa. SWIM: A simple model to generate small mobile worlds. In Proc. 28th IEEE Conference on Computer Communications (INFOCOM), pages 855–863. IEEE, 2009.

[14]. X. Hong, M. Gerla, G. Pei, and C. Chiang. A group mobility model for ad hoc wireless networks. In Proc. 2nd ACM Int'l Conf. on Modeling, analysis, and Simulation of Wireless and Mobile Systems (MSWiM), pages 53–60. ACM, 1999.

[15]. Majid Nabi, Marc Geilen, Twan Basten " MoBAN: A Configurable Mobility Model for Wireless Body Area Networks ". ICST SIMUTools 2011 March 21–25, Barcelona, Spain. 2011

[16]. Cavallari, R.; Martelli, F.; Rosini, R.; Buratti, C.; Verdone, R. A Survey on Wireless Body Area Networks: Technologies and Design Challenges. IEEE Commun. Surv. Tutor. 2014, 16, 1635–1657.

[17]. De Silva, B.; Natarajan, A.; Motani, M. Inter-User Interference in Body Sensor Networks: Preliminary Investigation and an Infrastructure-based Solution. In Proceeding of the Sixth International Workshop on Wearable and Implantable Body Sensor Networks, Berkeley, CA, USA, 3–5 June 2009; pp. 35–40.

[18]. Xuan, W.; Lin, C. Interference Analysis of Co-existing Wireless Body Area Networks. In Proceeding of the Global Telecommunications Conference (GLOBECOM 2011), Houston, TX, USA, 5–9 December 2011; pp. 1–5.

[19]. Zhang, A.; Smith, D.B.; Miniutti, D.; Hanlen, L.W.; Rodda, D.; Gilbert, B. Performance of Piconet Co-Existence Schemes in Wireless Body Area Networks. In Proceeding of the Wireless Communications and Networking

Conference (WCNC), Sydney, Australia, 18–21 April 2010, 2010; pp. 1–6.

[20].Deylami, M.; Jovanov, E. Performance Analysis of Coexisting IEEE 802.15.4-Based Health Monitoring WBANs. In Proceeding of IEEE Conference on Engineering in Medicine and Biology Society (EMBC), San Diego, CA, USA, 28 August–1 September 2012; pp. 2464–2467.

[21].Hernandez, M.; Miura, R. Coexistence of IEEE Std 802.15.6TM-2012 UWB-PHY with Other UWB Systems. In Proceeding of the IEEE International Conference on Ultra-Wideband (ICUWB), Syracuse, NY, USA, 17–20 September 2012; pp. 46–50.

[22].Martelli, F.; Verdone, R. Coexistence Issues for Wireless Body Area Networks at 2.45 GHz. In Proceeding of the 18th European Wireless Conference on European Wireless, Poznan, Poland, 18–20 April 2012; pp. 1–6.

[23].Jin, Z.; Han, Y.; Cho, J.; Lee, B. A Prediction Algorithm for Coexistence Problem in Multiple-WBAN Environment. Int. J. Distrib. Sens. Netw. 2015, 2015, 1–8.