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A Study on Emergency Handling in WBAN

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Abstract

The emergence of Wireless Body Area Networks (WBAN) has paved the way for patient friendly health monitoring. WBAN, a wireless network of sensors is able to monitor the patient's condition collaboratively and provide a proactive health care service, relieving them from the hospital environment. Monitoring the vital signs of the patients and reporting any emergency situation without any delay is the main goal of any WBAN. The MAC protocol which takes care of access mechanisms of wireless channel plays a major role in deciding the delay and reliability constraints of data packets. In this paper we have discussed about various MAC protocols for WBAN that handles emergency and prioritized data transmission, also we have studied in detail the efficiency of two important standards IEEE 802.15.4 and IEEE 802.15.6 in handling emergency situation. The simulation studies shows that IEEE 802.15.6 (BaselineMAC) performs much better in terms of Packet delivery ratio (99%) and end-to-end delay (30ms) when compared to IEEE 802.15.4 (ZigBeeMAC), but with respect to energy consumption and delivery of normal packets IEEE 802.15.4 outperforms IEEE 802.15.6.

Keywords: WBAN, IEEE 802.15.4, IEEE 802.15.6, MAC protocols, Delay, Reliability.

Introduction

Health care service is taking another step forward through the novel technology revolution in the form of miniature devices and wireless technology. The growth of aging population with chronic diseases has made the people think of providing medical facilities that could monitor the patient continuously in their own living conditions without affecting their day to day activities(1). This has been made possible through mHealth and eHealth which together provides mobile health care services through electronic process and communication (2-3). A new type of wireless network called Wireless Body Area Network (WBAN) is able to accomplish this task of remote health monitoring..

WBAN consists of small devices called sensors in and around the human body and connected to the central hub (Network Co-ordinator) through wireless link. These sensor nodes measure certain parameters of the human body like heart rate, body temperature, electrocardiogram and send it to the hub which in turn sends it to the medical database through WAN/LAN or internet(4). This helps the medical practioners to monitor the patient condition remotely. A WBAN finds other applications like assistance for the disabled, public safety(firefighters, policemen, military environment) and being embedded in appliances such as microphone, camera, advanced human computer interface etc.,

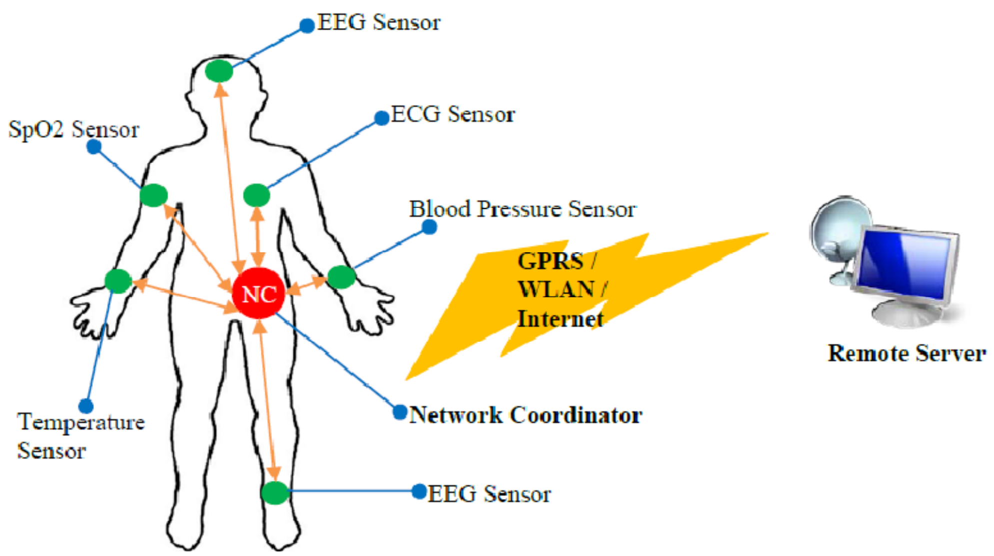

Fig.1. A Wireless Body Area Network System

The design techniques and operational requirement of WBAN is different from that of other wireless networks like Wireless Sensor network (WSN) and wireless adhoc networks. Some of its special features are (5):

- Limited energy resources due to the small form factors of the devices involved
- Low transmit power per node
- Data transmission is through a Lossy medium which is human body
- Changing network topology due to motion of human body
- Transmission of medical data that requires high reliability, low delay and more privacy and confidentiality.
- Heterogeneous nature of nodes in WBAN in terms of data rate, power consumption and QoS requirements

Emergency Handling in WBAN:

Main objective of WBAN in patient monitoring is to deliver the vital signs of the body without any delay and error as this could lead to life or death situation. If these vital signs are delivered beyond the delay and reliability limits then the very purpose of WBAN is shattered. Hence design of communication protocols should consider this as the primary goal of any WBAN. Moreover occurrence of emergency signals cannot be predicted, hence the situation need to be handled in a more dynamic way. Any sensor node in WBAN can generate emergency signal at any time, so static priorities cannot be set on the nodes based on emergency. There may be nodes in WBAN sensing heart rate, body temperature, pressure, ECG, pulse rate. As can be seen high priority would be given to node sensing the heart beat and low priority to node sensing temperature, but data from node sensing temperature becomes vital when there is alarming temperature value that can result in life critical situation(6).

In the communication protocol stack, MAC layer is responsible for medium access and this has a major influence on QoS metrics like delay, reliability, energy consumption and collisions. An efficient MAC layer protocol should ensure proper communication in WBAN with minimum delay, maximum reliability, minimum power consumption and maximum throughput. There are many MAC layer protocols in the literature that prioritizes various MAC issues, with respect to emergency handling with many new techniques being proposed. In this paper we have discussed about MAC protocols for WBAN that specially handles the priority nodes and emergency data and in detail we have studied the performance of two important standards IEEE 802.15.4 and IEEE 802.15.6 in delivering emergency packets.

Review of MAC Protocols and Standards in Emergency Handling

Sana Ullah et al has proposed a hybrid protocol which takes care of both the priority and security of the nodes. The superframe structure contains both Contention access period (CAP) and Contention Free period (CFP) with beacons being sent in every frame. Priority based data transmission takes place in CAP where the size of the contention window depends on the priority of the node as per the IEEE 802.15.6 standard. But the contention window size is doubled for each failure as against IEEE 802.15.6 where it is doubled for even number of failures. The TDMA slots in the CFP are allocated to nodes that sends request during the CAP period (7).

Jay Shree Ranjit et al has proposed a protocol that uses the inactive period of IEEE 802.15.4 standard to serve the nodes with emergency data. A fraction of the inactive period of superframe is divided into Emergency Reporting Period (ERP), Emergency Beacon (EB) and Emergency Transmission Period (ETP). Nodes reporting emergency in the ERP is allocated slots in the ETP and this information is given to the nodes by EB. The two channel access mechanisms used during ERP are Code based and Random back off based contention approach, however the number of dedicated slots in the ETP is fixed to seven (8).

McMAC divides the data traffic into four different classes based on delay and reliability constraints. The superframe is structured for the transmission of data of different traffic class with heterogeneous QoS requirements. The reliability constrained traffic is transmitted in the contention free period and the request for slots for the same is done through the CAP. The non-reliability constrained traffic is transmitted during the prioritized contention access period. The last part of the superframe is used for nodes with emergency traffic and the rest of the nodes go to sleep. Apart from this any emergency traffic that occurs during any part of the superframe is transmitted in a preemptive manner (9).

Zhang et al has proposed a priority guaranteed MAC protocol that adopts a frame structure with separate control channel and data channel for medical and consumer electronic traffic. This ensures that high priority medical traffic being transmitted without the intervention of bursty traffic from consumer electronics (10).

This priority based protocol classifies the data traffic into three priority class namely emergency, medical and non-medical data. In the superframe structure Contention access period is divided into three phases where the emergency data can be transmitted in all the three phases whereas medical data in the second and third and non – medical data in the third phase alone. The length of phase two and three is varied according to the number of nodes in the network. Nodes can request for GTS slots for transmission of continuous traffic in CAP (11).

The U-MAC protocol provides QoS support in WBAN through differentiated nodal access to the medium. Nodes with urgent medical information access the medium more than the nodes with non-urgent medical information. This is made possible by cutting –off the number of packet retransmission of sensor nodes with non-urgent medical information (12).

PNP-MAC a hybrid protocol uses both contention and time-division based schemes for transmitting various types of traffic in WBAN. Non-periodic data, emergency alarm and command frames are transmitted in CAP. Also requests for Dedicated Time Slots (DTS) embedded with priority are sent by nodes in CAP. The TDMA period has DTS and EDTS (emergency DTS) – time slots, during which time critical continuous and periodic data is transmitted. DTS is allocated based on priority where low priority data is preempted for high priority data if there is lack of DTS (13).

eMC-MAC protocol is a multiconstrained QoS aware MAC protocol based on traffic priority. The superframe structure is flexible with fixed Contention Access Period (CAP) for packets with delay constraints and flexible length Contention Free Period (CFP) for critical and reliability constrained packets, also mini slots in between CFP during which co-ordinator request the nodes for any emergency packets and slots for which are allocated by preemption in GTS. In eMC-MAC, emergency packets can be sent only after slots are allocated in GTS and also preemption causes some delay (14).

Kim et al have proposed a priority based channel access MAC protocol which aims at dispersing the contention complexity of packets of different priorities by dividing the CAP into sub-phases. The contention length for the packets in the sub phases is decided by their priority levels and delay threshold (15). RMAM is a MAC protocol based on IEEE 802.15.4 standard, where the reliability of the real time high priority data transmission is ensured by the allocation of GTS slots. It is made more dynamic by adjusting the Superframe Duration based on the slot requirement of nodes which is again decided by the priorities and data rates (16).Kong et al have proposed a TDMA based MAC protocol which aims at better slot utilization and decreased energy consumption through allocation of dedicated slots to the nodes and number of slots depends on the priority of the nodes (17).

Most of the protocols discussed above are based on IEEE802.15.4, in which some of them use the inactive period of the superframe for the transmission of emergency data, while some use the contention access period for prioritized channel access. In most cases priority is fixed up with the nodes and they are grouped into different classes where the medium access and data transmission is based on the priority of the class they belong and not on individual node's emergency situation.

IEEE 802.15.4 MAC PROTOCOL

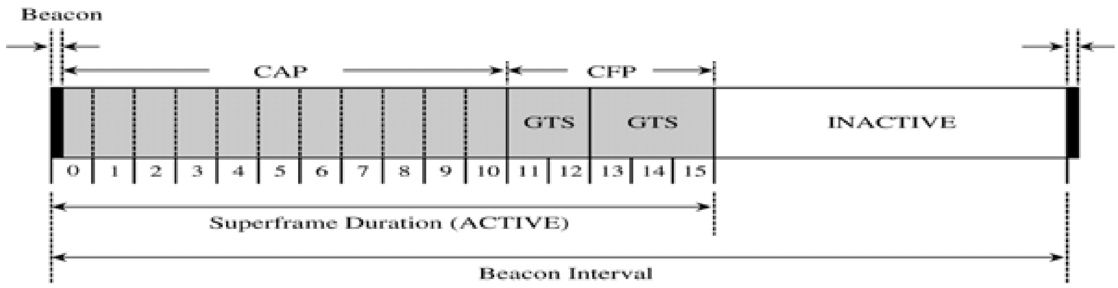

Fig.2. IEEE 802.15.4 superframe

IEEE 802.15.4 is a low-power protocol designed for low data rate applications in small area network (18). It allows two types of channel access mechanisms: beacon enabled and non-beacon enabled (beacon-free). In beacon enabled mode, coordinator starts the superframe that consists of a beacon, an active period, and an inactive period, as shown in Fig. 2. Superframe starts with a beacon signal and the nodes need to be synchronized with it. The superframe is divided into 16 slots with active and inactive period. Active period is made up of Contention Access Period (CAP) and Contention Free Period (CFP). Nodes requests for GTS in CFP which consists of 7 slots and they access the CAP with slotted CSMA/CA. In the non-beacon enabled mode, nodes access through unslotted CSMA/CA, there is no provision for GTS slots and nodes are not synchronized, hub can talk to the node only when it is polled by them. The major limitation of IEEE 802.15.4 standard is fixed length CAP period and availability of 7 maximum GTS slots. This leads to scarcity or under utilization of bandwidth and also makes it less flexible.

There is no provision for data priority in IEEE 802.15.4 standard, also GTS is based on first-in-first out, thus there are no differentiated services to handle emergency situation which is an important requirement of WBAN.

IEEE 802.15.6 MAC PROTOCOL

The IEEE 802.15.6 (19) is a standard for WBANs, drafted by the Task group 6 (TG6) to operate in and around the human body. This is a communication standard for networks with relatively low frequencies, less than one megahertz, and short-range use, low cost, reliable wireless communication and especially an ultra low power in-body and on-body nodes. The IEEE 802.15.6 standard defines a Medium Access Control (MAC) layer with three Physical Layers. The three Physical layers are: Narrowband (NB), Ultra wideband (UWB), and Human Body Communications (HBC). The type of physical layer chosen depends on the particular application. The channel is divided into structures called superframes. The superframes are bounded by beacon period of equal length. Each superframe is divided into allocation slots of equal length on the time axis where the number and the length of the allocation slot is decided by the hub. The IEEE 802.15.6 operates in three different modes, i) Beacon mode with beacon period superframe boundaries ii) Non-beacon mode with superframe boundaries and iii) Non-beacon mode without superframe boundaries.

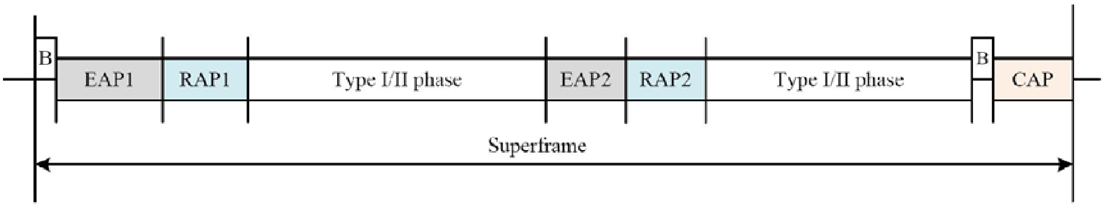

Fig.3. IEEE 802.15.6 Superframe – Beacon mode

In Beacon mode with beacon period superframe boundaries, superframe is divided into seven access phases. They are Exclusive access phase 1(EAP1), Random Access Phase1 (RAP1), Type I/II access, Exclusive access phase 2 (EAP2), Random Access Phase2 (RAP2) and CAP-Contention access Phase. EAP1 and EAP2 are exclusive access phases for transmitting data type frames of the highest user priority (i.e., containing an emergency or medical event report). During the access phases RAP1, RAP2 and CAP nodes use contended allocation for transmission of regular traffic. The CAP access phase is preceded by a beacon B2 sent by the hub.

Type I/II access phases are used for uplink, downlink and bilink allocation intervals in which any scheduled, unscheduled and improvised transfer happens. Scheduled access by the node takes place in the reserved slots and unscheduled and improvised access starts after receiving pool or post frame from the hub. In the Type I/II access phases, only any one of the access types either Type I or Type II happens but both are not mixed in a superframe. In Type I access phase, allocation is in terms of time units whereas in Type II access phase allocation is in terms of number of frames. In the Non – beacon mode with superframe boundaries, the entire superframe duration is covered either by a type I or a type II access phase but not by both phases. In Non – beacon mode without superframe boundaries, the coordinator provides only unscheduled Type II polled allocations.

IEEE 802.15.6 standard has provision for handling emergency situation in WBAN. During the contention access phase the minimum and maximum size of the contention window is based on the priority of the node, highest priority has the smallest contention window and lowest priority has the largest window size in case of CSMA/CA as shown in table-1. Also of the seven access phases, two of the access phases EAP1 and EAP2 – the exclusive access phases are meant for transmission of high priority data alone. As the size of the various access phases can be decided by the hub, the superframe can be made to have only exclusive access phases.

Table-1 Contention Window Size Based on Priority

Priority class	CW_{min}	CW_{max}
0	16	64
1	16	32
2	8	32
3	8	16
4	4	16
5	4	8
6	2	8
7	1	4

Results and Discussions
Simulation Study
Simulations are carried out in Castalia Simulator (20). This Simulator is based on OMNET++ platform, meant mainly for the study of Wireless Sensor Networks (WSN) and Body Area Networks (BAN). In general it can be used for any low power embedded devices (21).The simulated WBAN consists of a hub or Central Co-ordinator connected to the sensor nodes through wireless link in star topology. The nodes in WBAN send normal packets and emergency packets at different rates to the hub. The network is simulated for the MAC protocol standards ZigbeeMAC (IEEE 802.15.4) and BaselineMAC (IEEE 802.15.6).

Performance Evaluation
The simulation study is carried out for WBAN in star topology with a central hub connected to sensor nodes through wireless link. These sensor nodes generate two types of packets namely emergency packets and normal packets at different rates. The emergency packets are generated randomly. In both ZigBeeMAC and BaselineMAC, only contention access using CSMA/CA is used, GTS(Guaranteed Time Slots) or

Scheduled Access is not used. Simulations for increasing number of nodes (5, 10, 15) are recorded. The result file is analysed for various parameters.

Table-2 Comparative study of ZigBeeMAC and BaselineMAC

Protocol	**PDR-Epackets**			**PDR-Normal packets**			**Energy Consumption**		
	No. of Nodes			No. of Nodes			No. of Nodes		
	5	10	15	5	10	15	5	10	15
ZigBeeMAC	89%	75%	69%	93%	71%	53%	0.06028	0.05269	0.04968
BaselineMAC	100%	100%	99%	37%	39%	41%	0.15776	0.15775	0.15779

As the emergency packets need to be delivered with minimum delay and maximum reliability the end-to-end packet delivery ratio (PDR) and delay are studied. The results are summarized in the table – 2.The following inferences are drawn from the Simulation study:

- PDR for emergency packets is higher in the case of BaselineMAC when compared to ZigBeeMAC. With the increasing number of nodes (5, 10, 15) PDR for BaselineMAC is almost the same (nearly 100%) whereas for ZigBeeMAC PDR value deteriorates (from 89% to 69%) hence BaselineMAC shows a better performance than ZigBeeMAC.(fig-5)
- The graphs in fig-4 shows the comparative study of end-to-end delay for emergency packets. We can infer that even as the number of nodes is increased, almost 90% of the emergency packets are delivered within 30 ms which is very minimal delay when BaselineMAC protocol is used. With ZigBeeMAC as underlying protocol more than 50% of the packets are delivered with maximum delay of more than 200ms which is very much beyond the delay limits of emergency packets.
- PDR for the normal packets are studied for increasing number of nodes. ZigBeeMAC is able to deliver the packets better than the BaselineMAC. As the number of nodes is increased the PDR for ZigBeeMAC decreases but it is still much higher than the BaselineMAC (fig-6).
- Delay for normal packets is again very less with BaselineMAC when compared to ZigBeeMAC. The BaselineMAC for all the three runs (5, 10, 15 nodes) had more than 90% of the packets delivered within 60ms whereas ZiigBeeMAC shows a very high delay for more than 60% of the normal packets(fig – 7).
- The energy consumption of the nodes, which is a very important factor for WBAN is studied for both the protocols and it is found that ZigBeeMAC performed much better than BaselineMAC. In both the case the energy consumption for hub is almost the same whereas for other nodes it is four times low with ZigBeeMAC when compared to BaselineMAC as shown in fig-8.

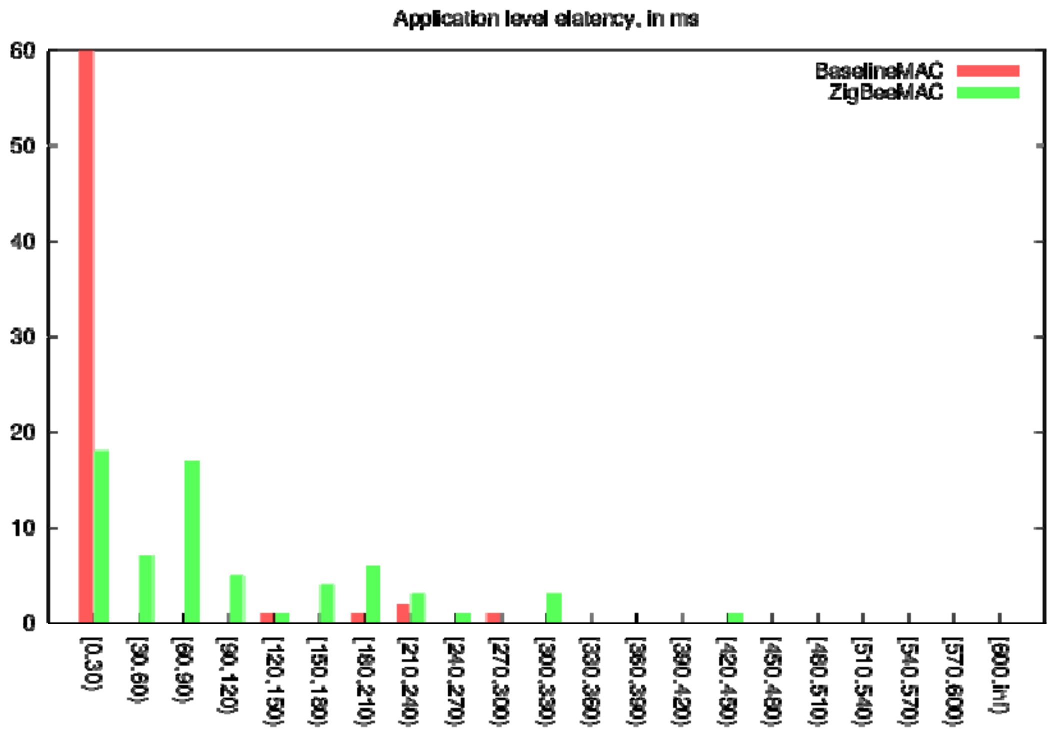
Application level elatency, in ms
BaselineMAC
ZigBeeMAC
60
50
40
30
20
10
0
[0,30)
[30,60)
[60,90)
[90,120)
[120,150)
[150,180)
[180,210)
[210,240)
[240,270)
[270,300)
[300,330)
[330,360)
[360,390)
[390,420)
[420,450)
[450,480)
[480,510)
[510,540)
[540,570)
[570,600)
[600,inf)

Fig-4(a)

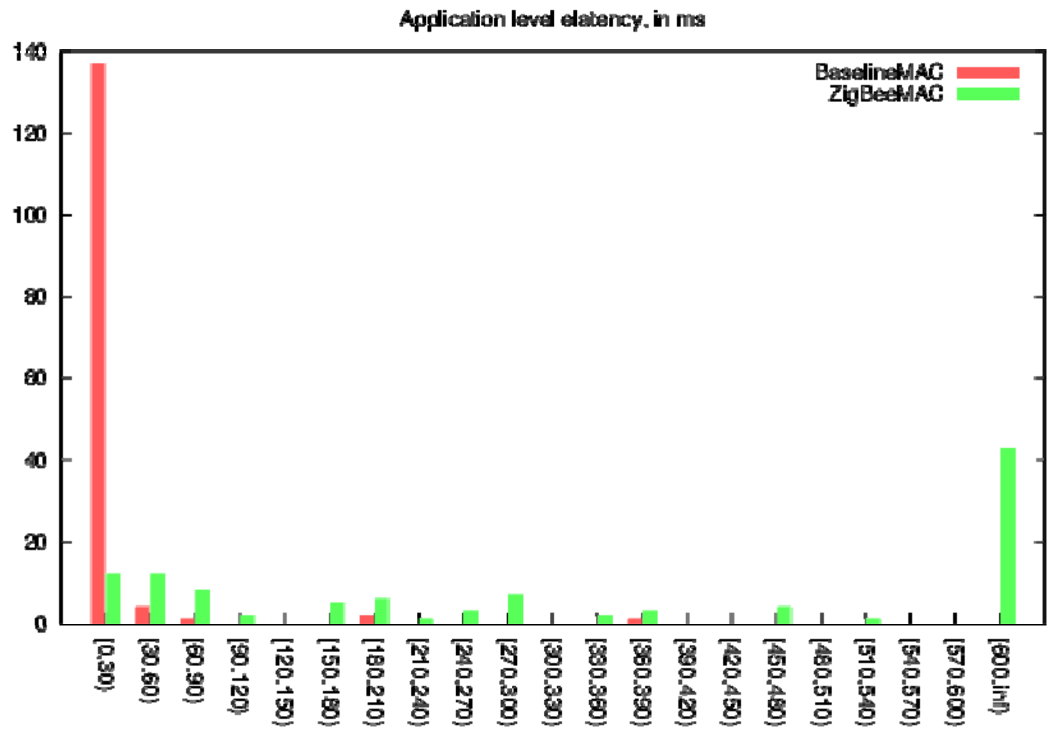
Application level elatency, in ms
BaselineMAC
ZigBeeMAC
140
120
100
80
60
40
20
0
[0,30)
[30,60)
[60,90)
[90,120)
[120,150)
[150,180)
[180,210)
[210,240)
[240,270)
[270,300)
[300,330)
[330,360)
[360,390)
[390,420)
[420,450)
[450,480)
[480,510)
[510,540)
[540,570)
[570,600)
[600,inf)

Fig-4(b)

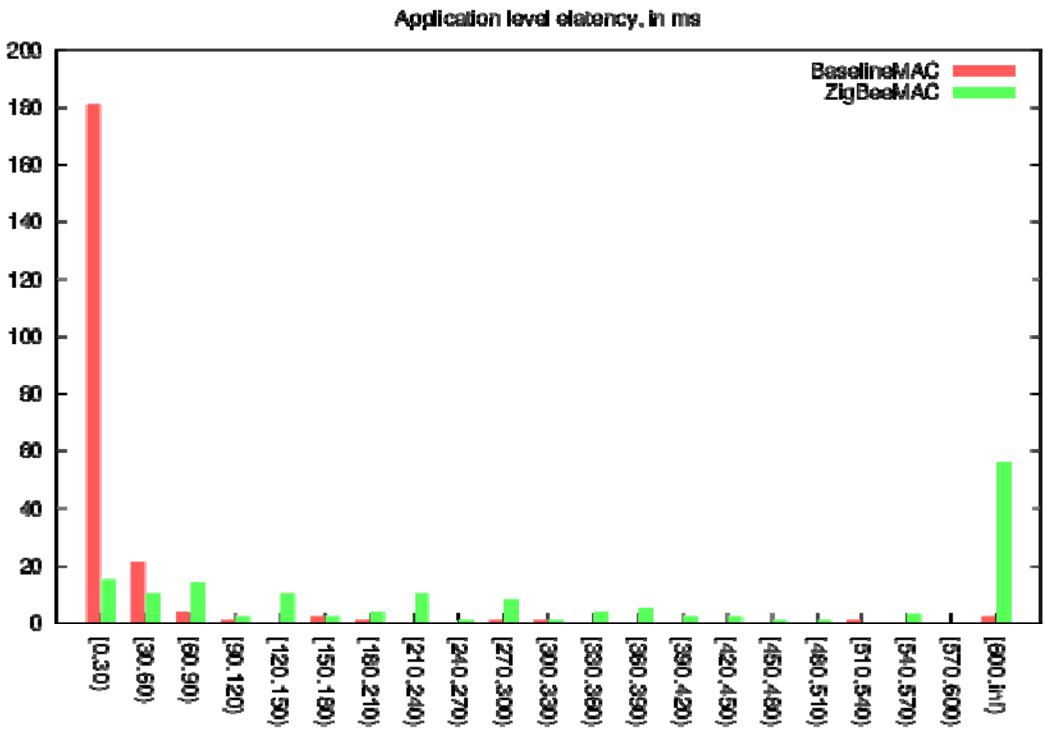

Fig-4(c)

Fig – 4 Latency for Epackets a.) 5 nodes b.) 10 nodes c.) 15 nodes

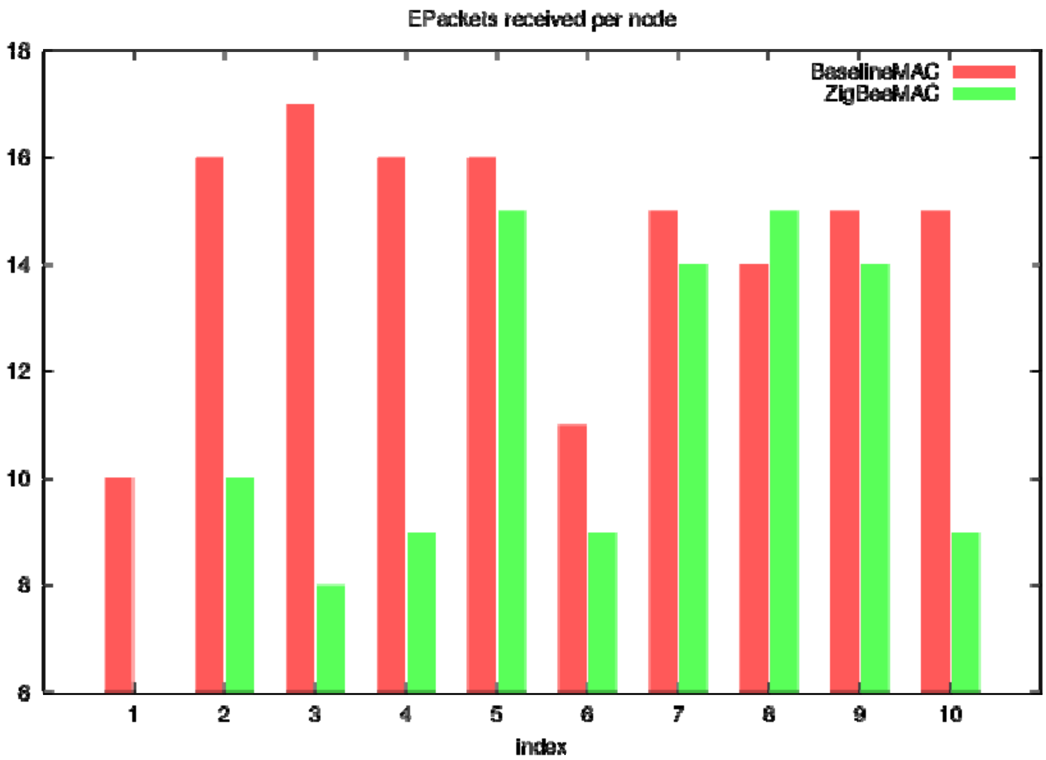

Fig-5(a)

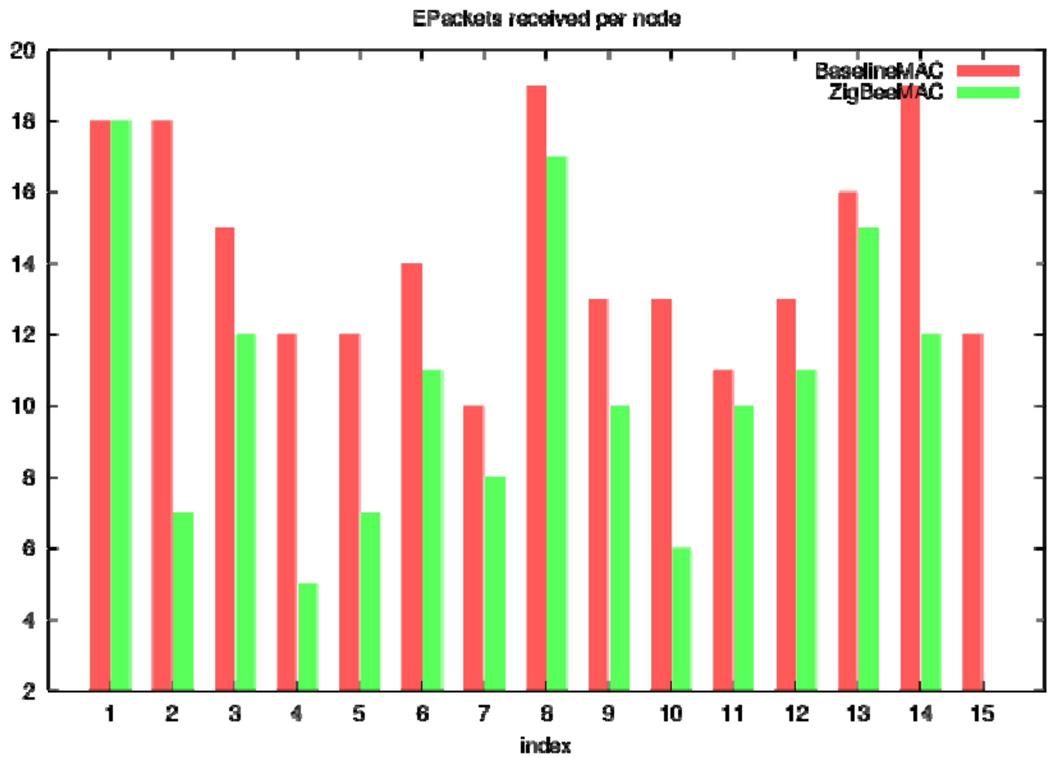

Fig-5(b)

Fig – 5 Epackets received per node a.) 10 nodes b.) 15 nodes

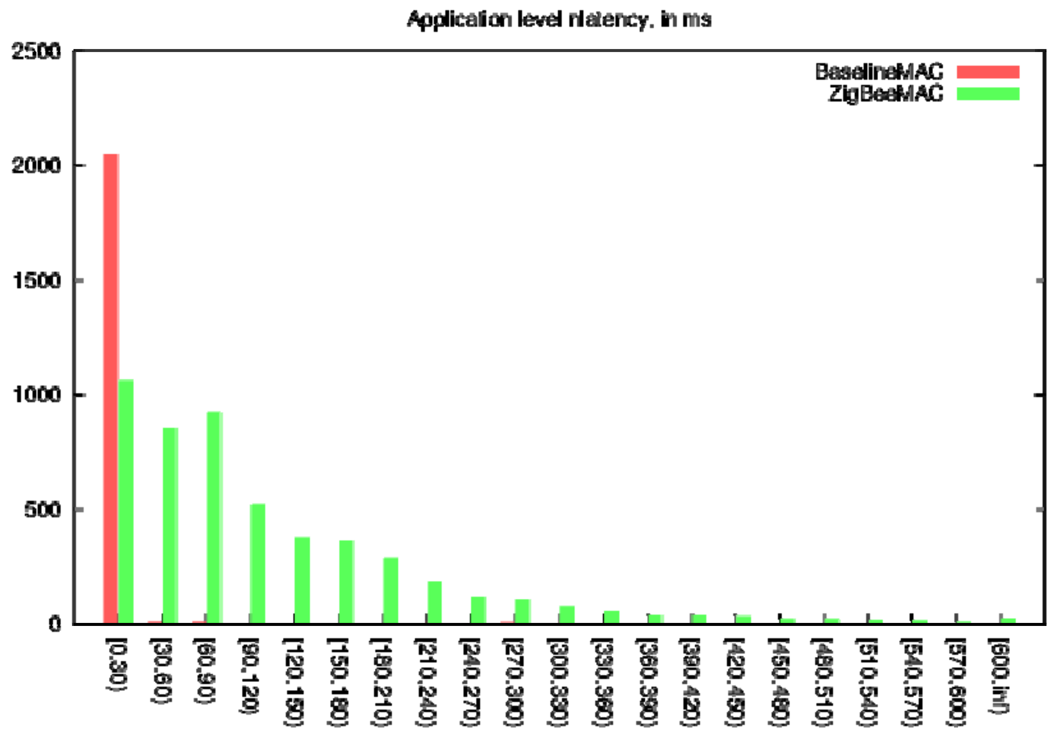

Fig-6(a)

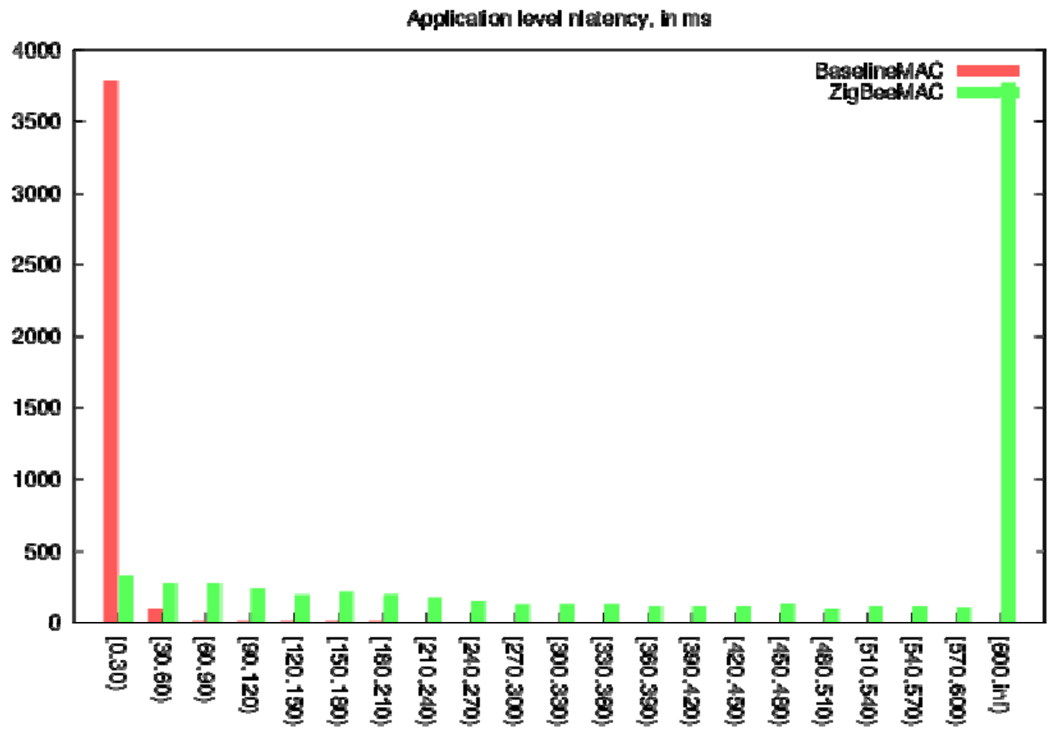

Fig-6(b)

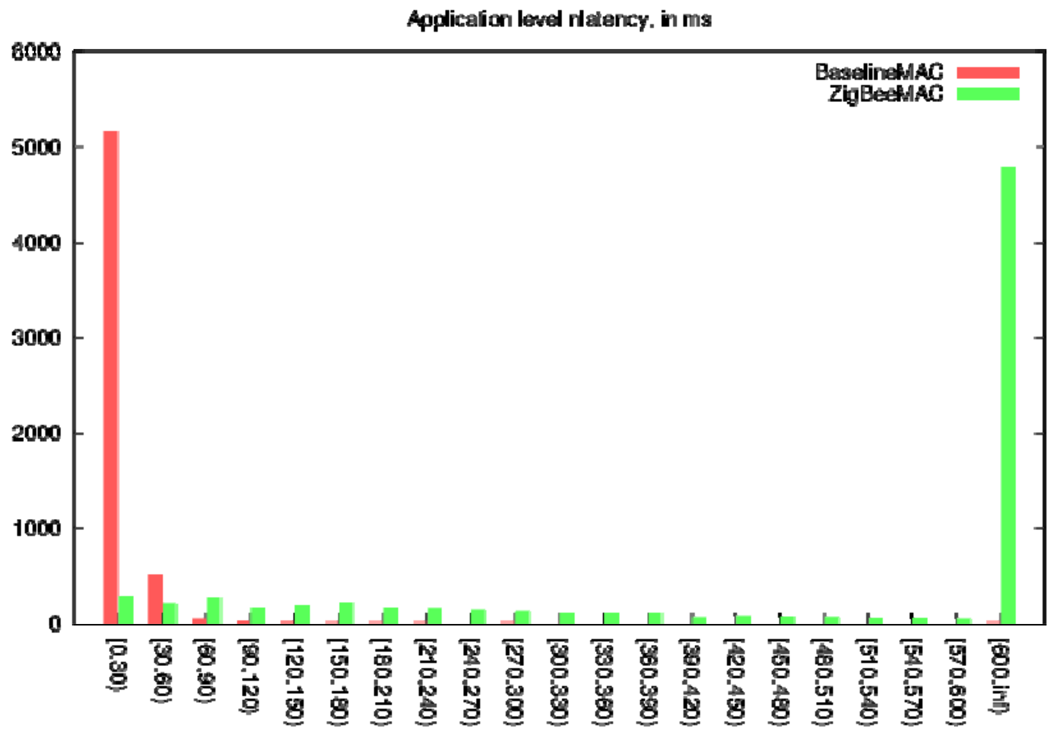

Fig-6(c)

Fig – 6 Latency for Normal packets a.) 5 nodes b.) 10 nodes c.) 15 nodes

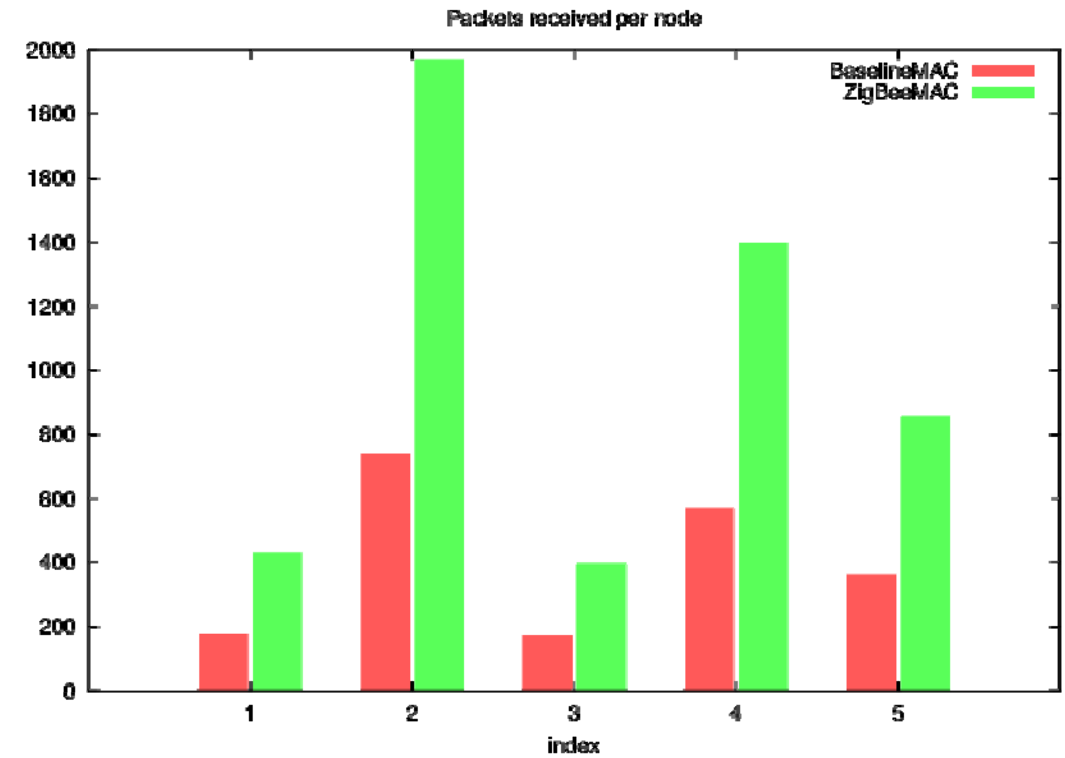
Packets received per node
BaselineMAC
ZigBeeMAC
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1
2
3
4
5
index

Fig-7(a)

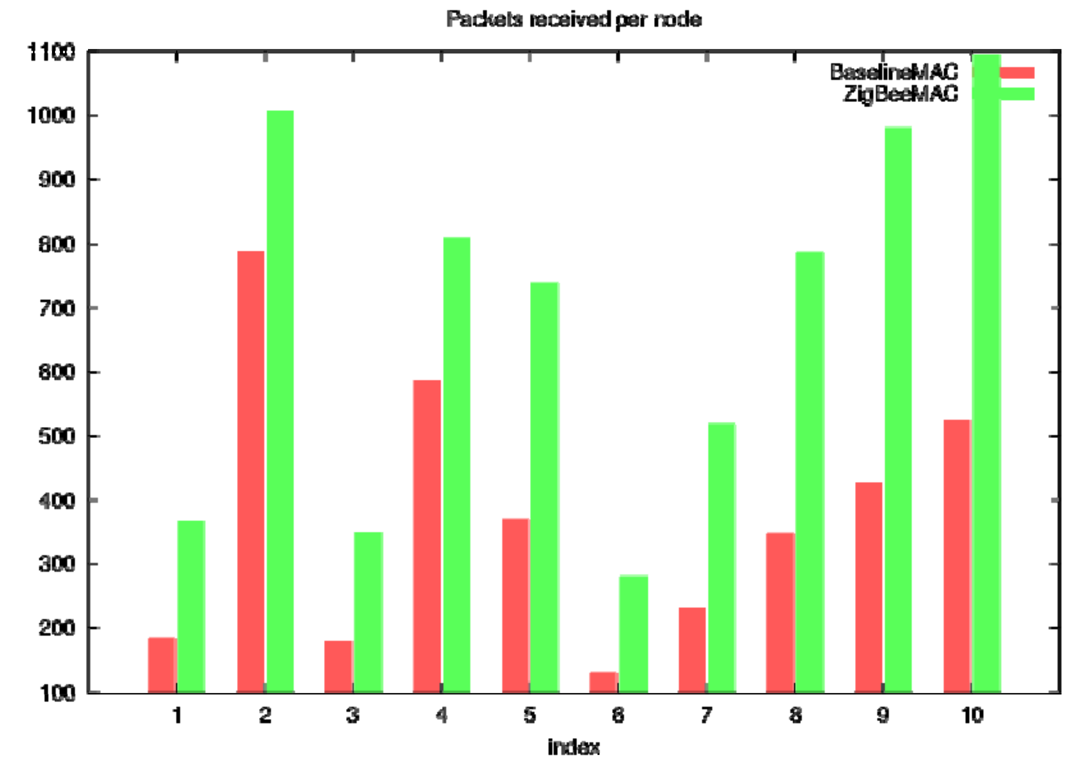
Packets received per node
BaselineMAC
ZigBeeMAC
1100
1000
900
800
700
600
500
400
300
200
100
1
2
3
4
5
6
7
8
9
10
index

Fig-7(b)

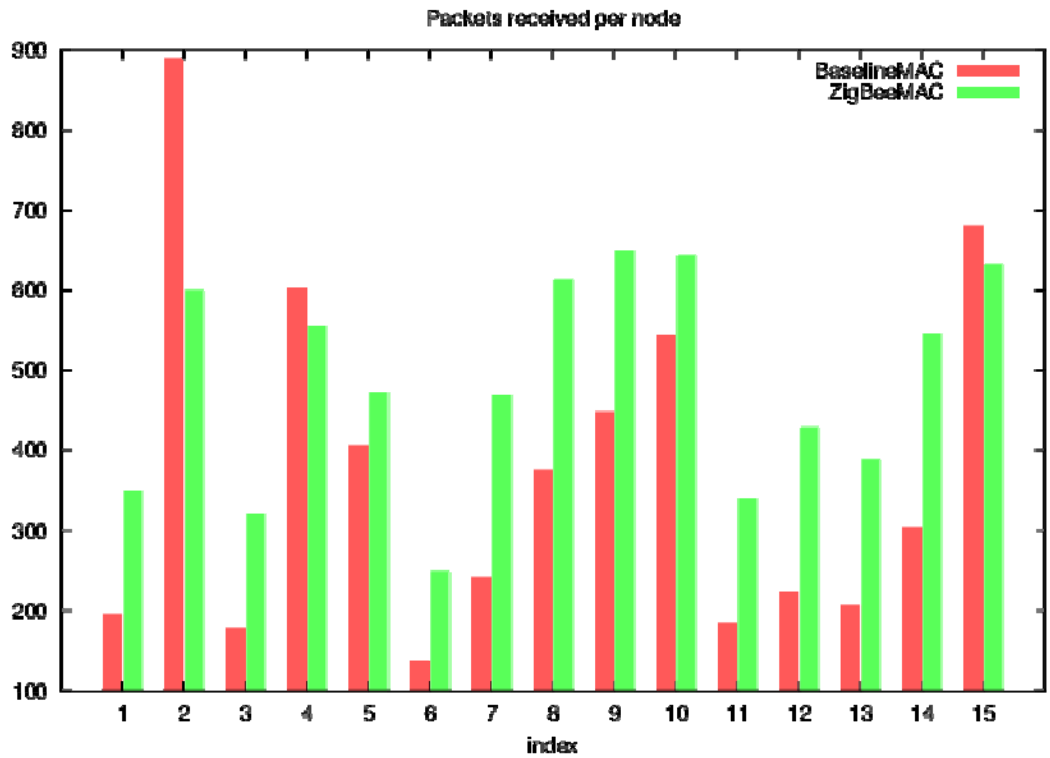

Fig-7(c)

Fig – 7 Normal packets received per node a.) 5 nodes b.) 10 nodes c.) 15 nodes

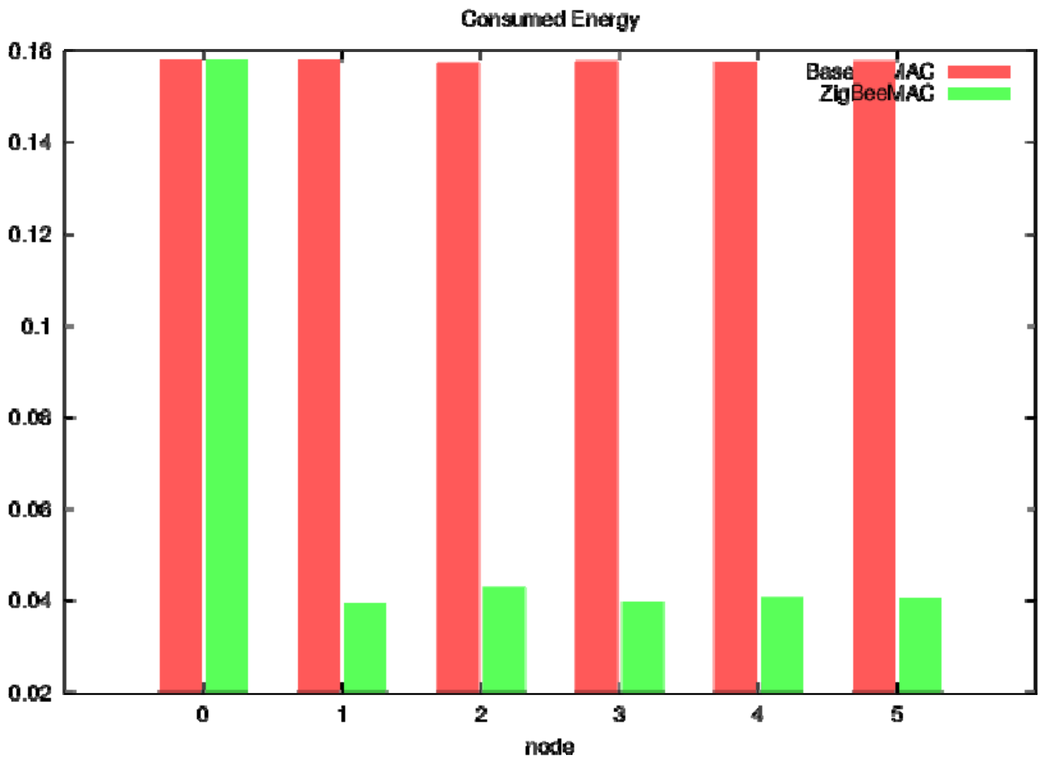

Fig-8(a)

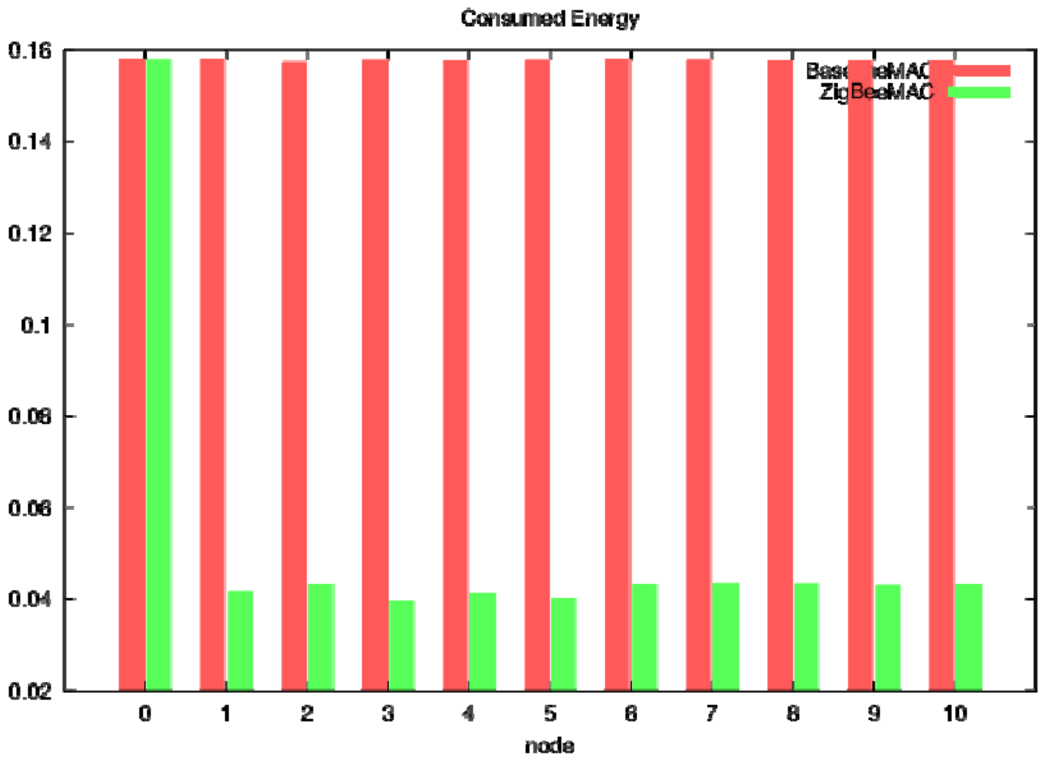

Fig-8(b)

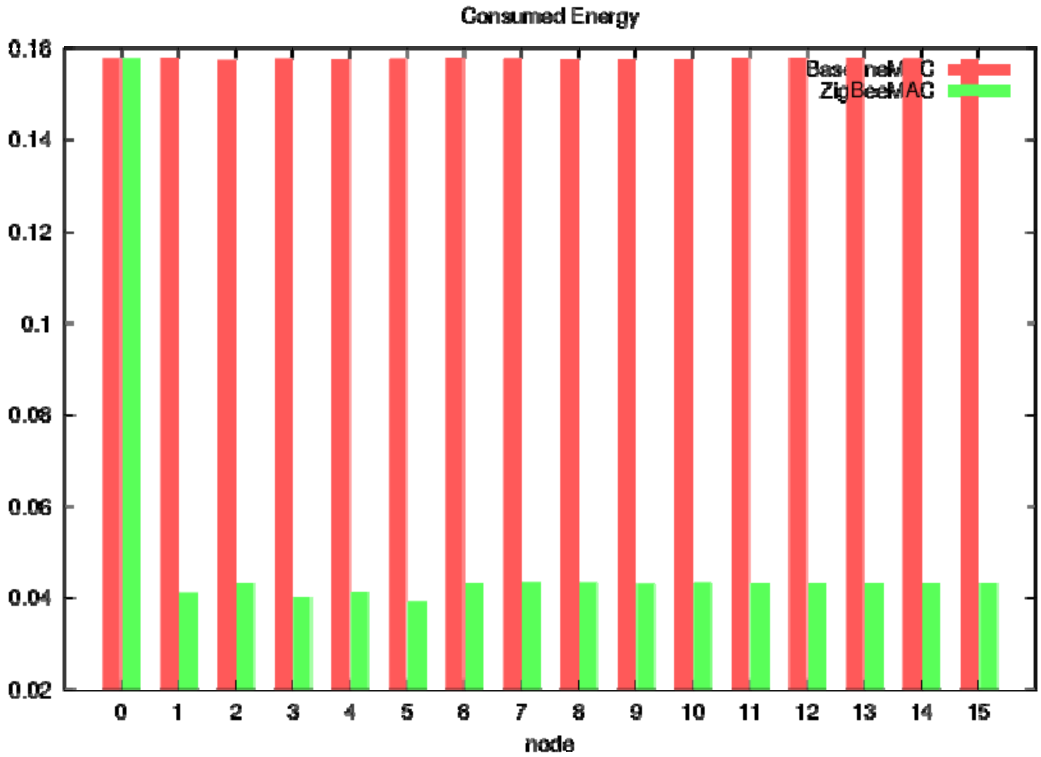

Fig-8(c)

Fig – 8 Energy onsumption per node a.) 5 nodes b.) 10 nodes c.) 15 nodes

Conclusion:

The ability of WBAN in handling emergency situation is mainly decided by the efficiency of MAC protocol which need to minimize delay, maximize reliability and minimize power consumption in the transmission of emergency packets. In this paper we have reviewed many MAC protocols that deal with channel access mechanisms for prioritized and emergency data, also in detail we have done a simulation study on emergency handling using two IEEE standards namely IEEE 802.15.4(ZigBeeMAC) and IEEE 802.15.6 (BaselineMAC). A comparative study shows that BaselineMAC performs better with a PDR of 99% and delay of around 30ms for 90% of the emergency packets, whereas ZigBeeMAC gives a PDR of 78% and delay of more than 300ms for the emergency packets. ZigBeeMAC was able to deliver the normal packets with a PDR of 72% as compared to 39% for BaselineMAC, but with respect to delay requirements again BaselineMAC was successful in the early transmission of normal packets. ZigBeeMAC is able to conserve the energy of the nodes by four times than BaselineMAC. A overall picture shows that BaselineMAC handles the emergency situation better in accordance to the delay and reliability requirements, but was lacking in the area of energy consumption and in the delivery of normal packets. Future work can improve upon BaselineMAC to handle the normal packets and energy conservation of nodes which will make it a more efficient MAC protocol in providing a more successful WBAN.

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