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# Energy Optimization of ZigBee based WBAN for Patient Monitoring

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**Abstract**

This paper proposes an energy efficient wireless telemonitoring scenario of cardiac patients through ZigBee, based on variable duty cycle being rendered to sensors. In an intra hospital telemedicine scenario, Electrocardiogram (ECG ) signals of patients are acquired through ECG sensor nodes having transmission capability and these ECG signals are received by Personal Digital Assistant (PDA) kept at nursing station through ZigBee network. ECG signals are further transmitted to Doctor's PDA. If the duty cycle is varied as per the load or number of active sensors, total energy consumed in idle mode can be avoided and total energy consumed by sensors is reduced hence increasing total network lifetime. This paper, comparatively analyzes the energy efficiency of ZigBee sensors with different percentage of duty cycle on the basis of energy consumption parameter under variable load conditions. The matrices used in performance evaluation are energy consumption in transmit mode, energy consumption in received mode and energy consumption in idle mode using Qualnet 5.0.2 simulator.


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*Keywords:* WBAN; ZigBee; ECG; Bellmanford; Qualnet 5.0.2

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## 1. Introduction

Advancements in Telemedicine network have its use in Information and Communication Technology platform for the delivery of healthcare services. It has enormous potential for increasing the access to medical services by increasing its reach [1]. In-time detection of medical emergencies based on real time monitored patient's physiological data and hence need for a real time monitoring platform serves this purpose well. Here the challenge lies in meeting the very strict and peculiar requirements of sending sensitive healthcare data in terms of transmission parameters and latency over a wireless network mostly due to its sensitivity and utmost importance as it is related to human life. For in house or intra hospital tele-monitoring of patients, Wireless Sensors Nodes (WSNs) is an emerging technology due to advancements made in wireless communication [2]. Based on the availability and performance of two small range communication technologies Bluetooth/IEEE 802.15.1 [3] and ZigBee/802.15.4 [4] considered for networking of two end devices , ZigBee has turned out to be a big advantage due to its low cost, low power and a big alternative for Bluetooth because of later's small range network and connectivity issues. Since, real time patient monitoring is a critical issue in telemedicine and to perform it successfully, adapting to controlled power consumption of the battery powered ECG sensors attached to patient's body is equally important task. One of the methods to improve the energy efficiency in a ZigBee network is varying the duty cycle in accordance with packet load in beacon enabled mode operation. This paper investigated the energy optimization in the beacon enabled mode of IEEE 802.15.4 in which adaptable duty cycle operation is achieved by setting two system parameters, macBeaconOrder (BO) and macSuperframe order (SO).The paper is organized as follows : section 2 gives brief literature overview of ZigBee and power saving methods under the head related work. An introduction to ZigBee (IEEE 802.15.4 standard) has been provided in section 3. Proposed intra hospital cardiac patient monitoring scenario has been discussed in section 4 along with simulation parameters and set up. Section 5 lists results and discussion from the current simulation study. Current work has been concluded in section 6.

## 2. Related work

For energy saving work efforts in ZigBee, Ran Peng et. al [5] proposed a mixed routing strategy of AODV and tree routing for energy efficient routing in ZigBee network. A mixed power control strategy is proposed to improve the ZigBee routing; the simulation results show that this power control strategy greatly balances the node energy and network lifetime. Rinki Sharma et.al [6] analyzed the ZigBee network for remote patient monitoring based on varying node density data traffic size. Results suggest the need to choose appropriate node density, data transmission rate, amount of data to transmit and duration of communication, to achieve required performance in terms of PDR, throughput, latency and energy consumption for the patient monitoring system. .Yuanlong Liu et. al., [7] have shown, through simulations, that multiple Wireless Personal Area Networks (WPAN's) improve the efficiency of remote patient monitoring. Use of multiple WPAN's ensures lesser delays and better overall throughput but at the expense of increased cost and need to check for overlapping frequencies due to more number of sensors attached with each WPAN working in same environment. Search for an energy efficient routing protocol has been carried out here in this work keeping in mind different transmission power values of transmitters which would actually effect the overall network lifetime and performance of overall proposed monitoring network. Shashwat Pathak et.al[8] analyzed energy efficiency in a tele-cardiology ZigBee network by use of efficient routing protocols AODV,DYMO and LANMAR for a energy efficient network and by varying different transmission powers for moving as well as stationary doctor conditions. Tarique Rashid et.al [9] proposed a comparative study on performance of routing protocols in the direction of efficient tele-cardiac patient monitoring in real time using different protocols in proposed telemedicine scenario.

## 3. Overview of IEEE 802.15.4

It is an emerging standard for low rate wireless body area network (WBAN). It is designed to provide low data rate, low power consumption and low cost of wireless networking. It provides low cost connectivity for the ZigBee based sensor nodes which needs long battery life or low power consumption operation. The IEEE 802.15.4 standard mainly defines the physical (PHY) and medium access control (MAC) layers characteristic for wireless body are network (WBAN). In IEEE 802.15.4 the physical layer provides an interface between the MAC layer and the physical radio channel [10, 11].

### *3.1. Physical layer (PHY)*

The PHY provides two services: the PHY data service and the PHY management service interfacing to the physical layer management entity (PLME) service access point (SAP) (known as the PLME-SAP). The PHY data service enables the transmission and reception of PHY protocol data units (PPDUs) across the physical radio channel. The features of the PHY are activation and deactivation of the radio transceiver, ED, LQI, channel selection, clear channel assessment (CCA), and transmitting as well as receiving packets across the physical medium. The radio operates at one or more of the following unlicensed bands: — 868–868.6 MHz (e.g., Europe) — 902–928 MHz (e.g., North America) — 2400–2483.5 MHz (worldwide) [11].

### *3.2. MAC layer (MAC)*

The MAC sublayer provides two services: the MAC data service and the MAC management service interfacing to the MAC sublayer management entity (MLME) service access point (SAP) (known as MLME-SAP). The MAC data service enables the transmission and reception of MAC protocol data units (MPDUs) across the PHY data service. The features of the MAC sublayer are beacon management, channel access, GTS management, frame validation, acknowledged frame delivery, association, and disassociation [11].
The IEEE 802.15.4 MAC layer mechanism is based on CSMA/CA protocol. IEEE 802.15.4 supports two modes of operation, beacon enabled and non beacon-enabled mode operation. For beacon enabled mode it uses slotted CSMA/CA and unslotted CSMA/CA is used for beaconless mode. In beacon enabled mode, a PAN coordinator periodically generates beacon frame that provide synchronization, and slots to RFDs for data transmission.A coordinator can allocate at most seven GTS to network devices. Superframe provides a duty cycle operation by setting two system parameter, macbeaconorder (BO) and macsuperframeorder(SO), such that low power operation is achieved for deployed network . The superframe active period also called as superframe duration (SD)[12]. The superframe duration (SD) and beacon interval (BI) for given BO and SO are defined as follows.
BI= aBaseSuperFrameDuration×2BO
SD= aBaseSuperFrameDuration ×2SO
For beacon enabled operation SO and BO should satisfy the relationship 0≤SO≤BO≤14, and for non beacon mode BO=SO=15. Low power operation for network is achieved by choosing low duty cycle. Thus, duty cycle is :
Duty cycle= $(2)^{SO\text{-}BO} \times 100\%$
Therefore, each device will be active for (2) SO-BO portion of time, and sleep for 1-(2) SO-BO portion of time. A large duty cycle result in higher power consumption as devices remains in active state for longer periods [13].

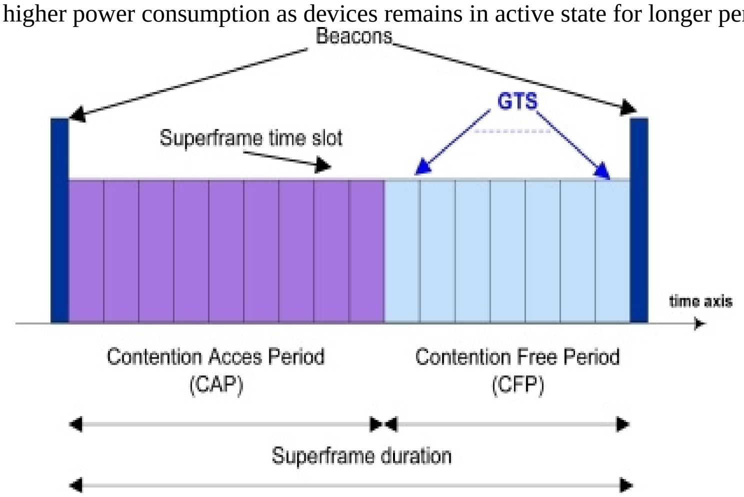

Fig. 1. Superframe structure of IEEE 802.15.4

### 3.3. Network Devices And Topology

IEEE 802.15.4 consists of two types of devices which can be FFDs (full function devices) and RFDs (reduced function devices). The FFD can operate in three modes such as a PAN coordinator, a simple coordinator or a device. An FFD can communicate to RFDs or other FFDs but RFD can communicate only to FFD. The RFDs only act as end devices which sense the event and send sensed information to coordinator or PAN coordinator. An IEEE 802.15.4 supported three type of network topology: the star topology, mesh topology and tree topology. In star topology, devices are interconnected in form of star in which central node is PAN coordinator and other RFDs, FFDs directly communicate to PAN. In mesh topology, devices communicate with other devices placed in its radio range.

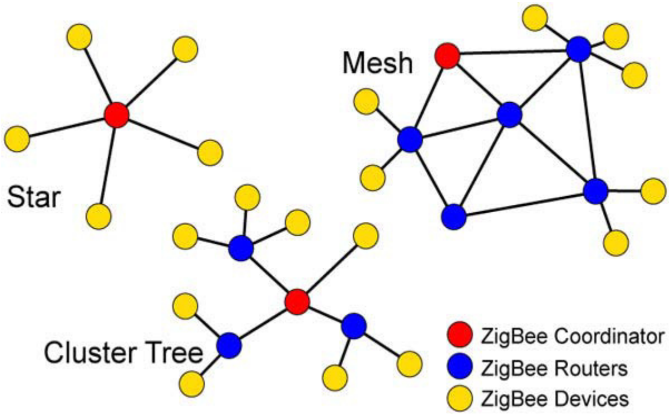


Fig. 2. Network topology supported by IEEE 802.15.4

## 4. Intra hospital patient monitoring scenario and its simulation setup

This paper proposes a tele-cardiac patient monitoring in which ECG of cardiac patients is being monitored in an intra hospital scenario consisting of 4 wards. Each ward consists of 10 patients each. Their ECG signal is assumed to be measured by ECG sensors placed on their body which are battery operated. Each sensor sends data to a main nurse's Personal Digital Assistant (PDA). Further it is being sent to Doctor's PDA for monitoring in case of emergency. Connection in between sensors and nurse PDA is ZigBee for the sake of fast connection and high scalability of this short range communication standard. Doctor's PDA is connected to nurse's PDA by ZigBee connection. Here assumption is being made 3 point measurement of ECG signal with typical sampling rate requirement of 500 samples per second with a assumed bit resolution of 10 bits which amounts to a data rate of 15kbps. As per the QoS requirements, average end to end delay should be less than 350 ms for the efficient transmission of ECG signal from the patient node to the doctors PDA. Now in a typical 200m*200m hospital scenario the ECG sensors are connected to the FFD device called the nurse's PDA which takes the data from the RFD device or ECG sensors which are planted on patients. The sink node or the PDA are connected to a central node which receives all the data from the nurse PDA is doctor's PDA. The parameters being monitored in this proposed scenario is Super frame duty cycle which is being varied with change in macSuperframeorder(SO) and macBeaconOrder (BO). Here a search for optimum duty cycle is being carried out by varying load by inducing varied packet rates. To route the packet from source to destination Bellman Ford routing protocol is selected. The configured simulation parameters are given in table 1. With the help of simulation results, energy consumption in transmit mode, energy consumption in receive mode, and energy consumption in Idle mode are analyzed. Simulation is carried out by Qualnet 5.0.2 [14]. The performance metrics are Throughput, Average End To End Delay, Residual Battery Capacity, and Energy consumption.

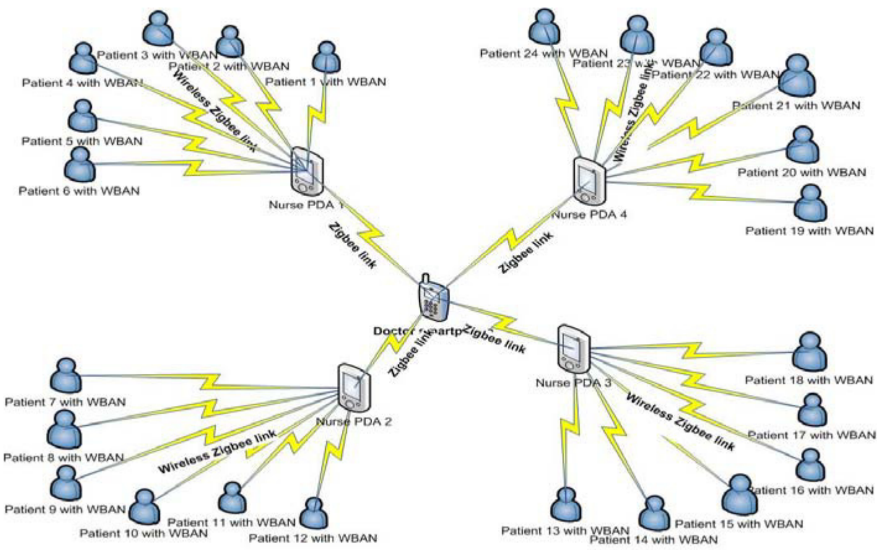


Fig. 3. Intra hospital tele-cardiac monitoring simulation scenario

Table 1. Simulation parameters

| Simulation Parameter | Corresponding values |
|---|---|
| Channel frequency | 2.4 GHz |
| Simulation time | 300s |
| Radio Type | IEEE 802.15.4 |
| Packet reception model | PHY 802.15.4 |
| Data rate | 15 kbps |
| Average end to end delay | < 350ms |
| MAC protocol | IEEE 802.15.4 |
| CCA mode | Carrier-sense |
| Antenna type | Omni directional |
| Routing Protocol | Bellman ford |
| Network Protocol | IPv4 |
| Beacon order | 5,4,3 |
| Super frame order | 3(fixed) |
| Application | CBR |
| Packet rate (packet per second) | 10,20,30 |
| Energy Model | MICAZ |

## 5. Results and discussion

*5.1 Throughput:* For the transmission of ECG signals the data rate should be more than 15kbps. By using this data rate variable amount of packets are sent. Fig. 4 shows that at higher duty cycle throughput decreases. It shows that at 50% duty cycle model is performing well with increased number of sent packets. As we increase total number of packets QoS is maintained at lower duty cycle value.

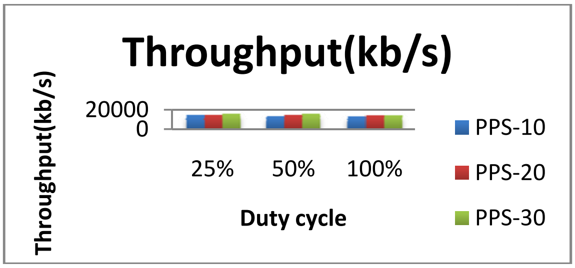

Fig. 4. Throughput

*Average End to End delay:* Fig. 5 shows that average end to end delay in ECG transmission increases with increase in duty cycle.ECG signal requires an average delay of less than 350ms

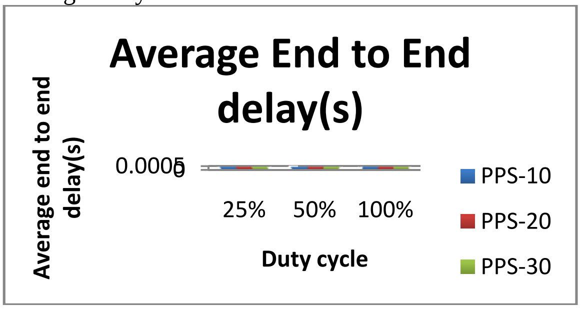

Fig. 5. Average end to end delay

*Energy consumed in Transmit mode:* Fig. 6 shows that in transmit mode, when the duty cycle increases with increase in number of packets the energy consumed in transmit mode increases.

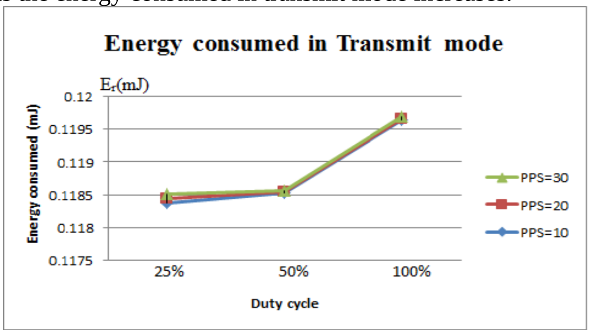

Fig. 6. Energy consumption in transmit mode

*Energy consumed in received mode:* It was observed that energy consumed in receive mode is less for selected duty cycles at higher number of packets being sent.

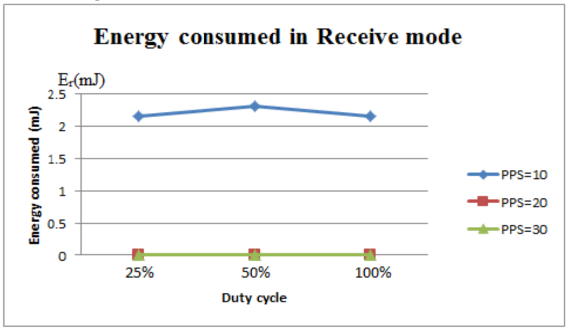

Fig. 7. Energy consumed in received mode

*Energy consumed in idle mode:* Fig. 8 shows that in energy consumed in idle mode increases with both duty cycle increments as well as increased number of packets.

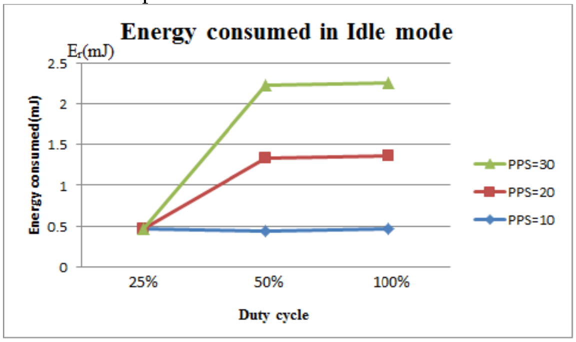


Fig. 8. Energy consumed in idle mode

## 6. Conclusion

In the cross layer approach (PHY/MAC), WSNs and energy model have been analyzed under different percentage of duty cycle with IEEE 802.15.4 standard. Different energy consumption parameters were calculated and it can be inferred that under different packet load, QoS parameter performance was found to be better with higher duty cycle and it degraded with lower duty cycle. In the perspective of energy consumption, lower duty cycle performance is better as compared to higher duty cycle and it can further enhance the overall lifetime of the network.

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