Academic Journal of Nawroz University (AJNU), Vol.13, No.1, 2024

https://doi.org/10.25007/ajnu.v13n1a1081

Energy Efficiency in Wireless Body Area Network Using Various Radios

Rezheen R. Hussein [1] and Ismail A. Ali [2]

1, 2 Dept. of Electrical and Computer Engineering, University of Duhok, Duhok, KRG – Iraq

ABSTRACT: Wireless Body Sensor Networks (WBSNs) promote continuous and low-cost health monitoring for a better healthcare system. Sensors connected to a human body are normally battery powered devices with brief life times. IEEE 802.15.6 standard is the typical choice for low power ingestion and reliable short-range communication for WBSNs. In this paper, we have evaluated the performance of IEEE 802.15.6 standard for WBSNs. Our tests examined three radios while varying their transmission power and data rates. The results show that altering these parameters affected the number of packets delivered and overall system energy consumption. The effects are demonstrated using Omnet++ simulator and its Castalia extension for WBANs.
KEYWORDS: 1- WBAN. 2- WBSN. 3- IEEE 802.15.6. 4- Castalia. 5- Energy Efficiency.

1. Introduction

Wireless Body Area Networks (WBANs) are getting lots of attention in the field of healthcare. A WBAN also referred to as Wireless Body Sensor Network (WBSN), involves bio- clinical sensor nodes that can be either wearable or implanted in the body(Cavallari, Martelli, Rosini, Buratti, & Verdone, 2014). These sensors are used to continuously monitor and collect different data such as patient's temperature, blood pressure, pulse rate etc. The sensors are equipped with radios to wirelessly transmit their data to manage and checking node residing on the body. This node then transfers its data over the Internet to an information center or a doctor room for remedy and diagnosis actions to be taken.

WBSNs for healthcare can provide mobility advantage and cost saving choices for clinical professionals and patients. A WBSN has the benefit of offering sufferers the flexibility to approach treatment which in turn provides patients with a better quality of life. Recently, WBSNs has gained great interest in health care due to their advantage of non-stop monitoring and ability to deliver fast warnings when data patterns indicating serious health problems are detected.

These appealing networks pledge to supply attractive substitutes or complements for old-style health care system due to the fact of their low cost and active monitoring of the patients. Usually, when people get sick, they choose help and a variety of healthcare services. Affected person may need non-stop live monitoring and active clinical care. That's where WBSN can work nicely for patients due to the fact of their flexibility, low-cost. WBSNs, along with their many advantages, also suffer from several issues. The most important difficulty in WBANs is energy consumption. Additionally, they have some other issues such as interference, noise, eavesdropping(N & Jhaveri, 2016).

The rest of the paper is schematized as follows: section 2 presents some related work. Section 3 is a background on IEEE 802.15.6. Section 4 explains the proposed simulation scenario. Section 5 Simulation parameters and sensor nodes on the body. Simulation results for packet delivery and energy consumptions are shown in sections 6.1 and 6.2 respectively. Finally, sections 7 conclude the work presented in this paper.

2. Related work

To study IEEE 802.15.6, many researches has been done. The authors in (El azhari, 2014) have analyzed the performance of TMAC, IEEE 802.15.6 and IEEE 802.15.4 MAC protocols questioning about throughput, consumed energy and latency using Castalia (Castalia, 2013) as a simulating tool. The author's analysis suggests IEEE 802.15.4 outperforms IEEE 802.15.6 and TMAC with temporal deviation and GTS ON. Pooja et al. (Mrs, Mohnani, & Jabeen, 2016) studied the routing problem for WBANs. They used a batch ACK for validation of packet transfer to achieve a power efficient, reliable and secure wireless body area network. A new IEEE 802.15.6 MAC superframe structure has been developed by Sultana et al. (Sultana, Huq, Razzaque, & Rahman, 2019) to handle one type of information with unique priorities, eliminating transport delays as opposed to exclusive schemes. In (Ullah & Tovar, 2015), the authors presented an accurate model to calculate the QoS parameters, i.e. throughput, lengthening and the quantity of consumed energy of the IEEE 802.15.6 CSMA/CA protocol used in beacon-supported mode. A lossy channel model is used with saturated nodes communicating over a restricted range. On the general efficiency of the un-slotted CSMA/CA activity for IEEE 802.15.4 MAC protocol, Jin et al. (Choi & Zhou, 2010) assessed the penalties of back-off parameters and various neighbourhood mechanisms (number of network strategies and dimension of statistical payload).In (Almazroa & Rikli, 2014), the authors have expected the general performance of WBAN through varying the scattering of slot and the data rates between a diversity of MAC access mechanisms used in IEEE 802.15.6 and by using Castalia simulation tool the performance of WBAN was calculated via the perceived effects of latency, power consumption and data packet breakdown. In (Goyal, Bhadauria, Patel, & Prasad, 2017), the authors proposed a TDMA-based MAC protocol for WBAN for energy efficiency and delay sensitivity to view physiological warnings such as ECG and EEG remotely. In (Rezvani & Ghorashi, 2013), the authors increase the widespread performance of the MAC protocol of WBANs using adaptive resource allocation and prioritization of website visitors based on the type of request (normal or emergency) and channel condition (presence or absence of fading).An empirical model of the IEEE 802.15.6 CSMA/CA protocol is provided by the authors in under non-saturated visitor conditions. To accomplish a higher throughput and the least interval, they calculated throughput, energy consumption, and suggested frame carrier time and enhanced area lengths.

3. IEEE 802.15.6 Standard

IEEE 802.15.6 (Society, 29 Feb. 2012) is a new standard used to support short range, low-energy devices that can be positioned on or implanted within the human body for assortment of functions such as medical, consumer electronics, pleasure, etc. A network generated by means of IEEE 802.15.6 accommodating devices is seen as a WBAN. The aim of IEEE 802.15.6 was to establish new layers of physical (PHY) and medium access control (MAC) for WBSN (Kwak, Ullah, & Ullah, 2010).The standard describes a single MAC layer to support three physical PHY layers.
The PHY layer takes care of modulation and error correction functions create a stable hyperlink between WBAN transmitter and receiver units. The MAC layer governs the access of a several WBAN devices to the channel.

3.1 IEEE 802.15.6 Physical Layer

The IEEE 802.15.6 standard supports three physical (PHY) layers, i.e. NarrowBand (NB), Ultra Wideband (UWB) and Human Body Communication (HBC)(Liu, Mkongwa, & Zhang, 2021). The resolution of each layer is based on the application requests. NB is responsible for radio transceiver activation and deactivation, direct channel evaluation, and all transmission or reception of facts. UWB runs in two bands of frequency, low and excessive bands; these are split into channels(Čuljak, Lučev Vasić, Mihaldinec, & Džapo, 2020). The entire protocol for WBSN(Kwak et al., 2010) is protected by HBC.

3.2 IEEE 802.15.6 MAC Layer

The IEEE 802.15.6 MAC specifications define three special operating modes: superframe beacon mode, superframe non-beacon mode and non-beacon mode without superframe. The first mode is the most commonly used in scientific applications(Benmansour, Ahmed, & Moussaoui, 2016).This mode makes the network extra stable and extra energy efficient in terms of electrical power. Figure 1 shows superframe of beacon enabled mode. Using two beacons, the superframe used in this mode is surrounded. We find a beacon positioned with the assistance of two successive cycles at the beginning of each and every superframe. Each superframe is divided into several sub-periods: Exclusive Access Phase (EAP1, EAP2), Random Access Phase (RAP1, RAP2), Type I/II and Controlled Access Phase (CAP). In superframe beacon mode of operation, RAP1 period is mandatory, the coordinator can inactivate any of other phases by setting their associated period length to zero.

In EAP, RAP, and CAP phases, nodes use either CSMA/CA or a slotted Aloha access method to gain access to the channel. EAP periods are used to send high priority traffic when critical data patterns are detected. The RAP and CAP intervals are reserved for steady traffic. The Type I/II phases are used for uplink allocation pauses, downlink allocation pauses, bilink allocation intervals, and delay bilink allocation intervals. In Type I/II phases, polling is used for resource allocation.

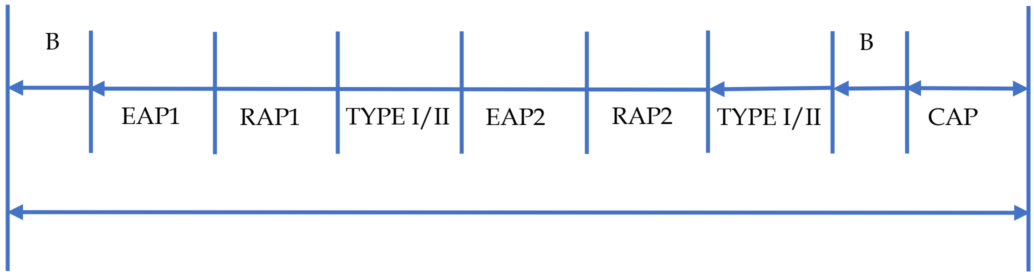

Figure 1. Beaconed with super frame mode in IEEE 802.15.6.

4. Proposed Architecture

In the proposed scenario, five static sensor nodes are attached to the body. These sensor nodes are for measuring temperature, blood pressure, ECG and EEG as shown in Fig. 2. Simulation parameters are given in Table 1. The variety and number of nodes is limited to five due to the fact sufferers would not be comfortable when many sensors are attached to their bodies. Network is designed in a mode that all the sensor nodes transfer their data to the sink node which can relay the traffic to a server located at hospital. Node zero is considered as the sink node and the rest of the nodes are normal nodes. The sensor nodes utilized IEEE 802.15.6 and three different radios.

The first radio is CC1000 (Instruments, 2004) with highest transmit power of +10 dBm and four frequency bands at 315, 433, 868 and 916 MHz. The second radio used in our tests is CC2420 radio (Instruments, 2006) that works at 2.4Ghz frequency band. The last radio was the BANRadio, BAN has been extensively premeditated at frequency extending from 400 MHz to 60 GHz and beyond(Luca P., 29 Apr 2014).

The MAC used for BAN in the proposed architecture is baseline BAN(Lu, Khan, & Iqbal, 2013), which is a BAN-designed IEEE 802.15.6 MAC. In order to analyse the critical signals at the hospital, the records from the sink node should be sent to the coordinator node, which serves as a portal to the internet, so that urgent steps for prescription or analysis could be taken.

5. Simulation Parameters and Sensor Nodes on the Body

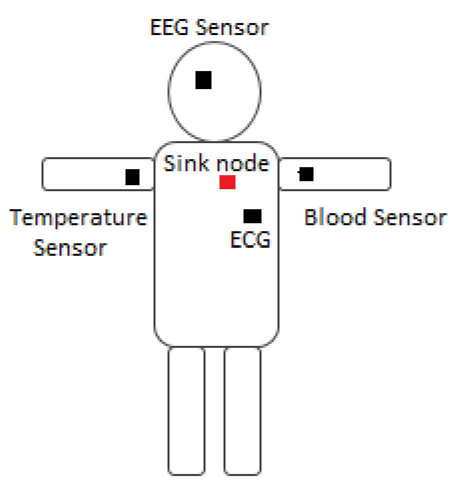

Figure 2. Static sensor nodes on the body.

Table.1. Simulation parameters

Parameter	Value
Simulation Time	51 seconds
Number of Nodes	5 (1 Sink and 4 Sensors)
Sensor Node Application Name	Throughput Test
TX Power	CC1000: 10dBm, -20dBm CC2420: 0dBm, -25dBm BAN Radio: -10dBm, -25dBm
Application Packets Rate	5 PPs
Application Data Rate	(80, 120, 250, 1024) kbps
Mobility	No Mobility

6. Simulation Result

Three radios were used, namely: CC1000, CC2420 and BAN radio. The performances of these radios were assessed while varying some parameters such as transmission power and physical data rate.

The first tests were conducted using the CC1000 radio with data rates of 80, 120, 250 and 1024 kbps with a maximum and minimum transmission power of 10dBm and -20dBm respectively.

The second set of tests were conducted using the CC2420 radio with same data rates and a maximum/minimum transmission power of 0dBm/-25dBm.

The last set of tests were done using BAN radio and same data rates but with a maximum/minimum transmission power of -10dBm/-25dBm.

The changes in data rates and transmission power were essential to assess the number of packets received by the sink node as well as the overall energy consumption per node.

6.1 Packets Received by the Sink Node

Figures 3 and 4 are the results of first set of tests using CC1000 radio at 80, 120, 250 and 1024kbps transmission rate. In these graphs, the x-axis represents the time (from 20ms up to infinity) for a data packet to travel from one destination to the other. The y-axis represents the total number of packets received by the sink node from all sensor nodes. Transmission power was at maximum of 10dBm in Fig. 3 and minimum of -20dBm in Fig.4. As it is clear from these figures, the whole number of received packets is very low at both maximum and minimum transmission powers. However, the overall number of packets received at minimum power (-20dBm) are 739 packets less than those received at maximum transmission power (10dBm) are 927 packets.

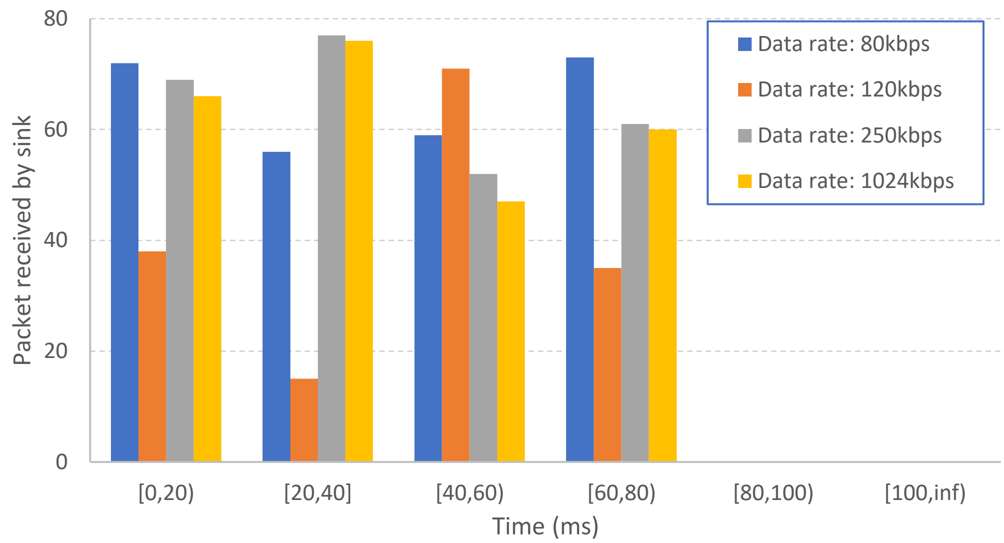

Figure 3. Packets received with CC1000 radio and 10dBm Tx power

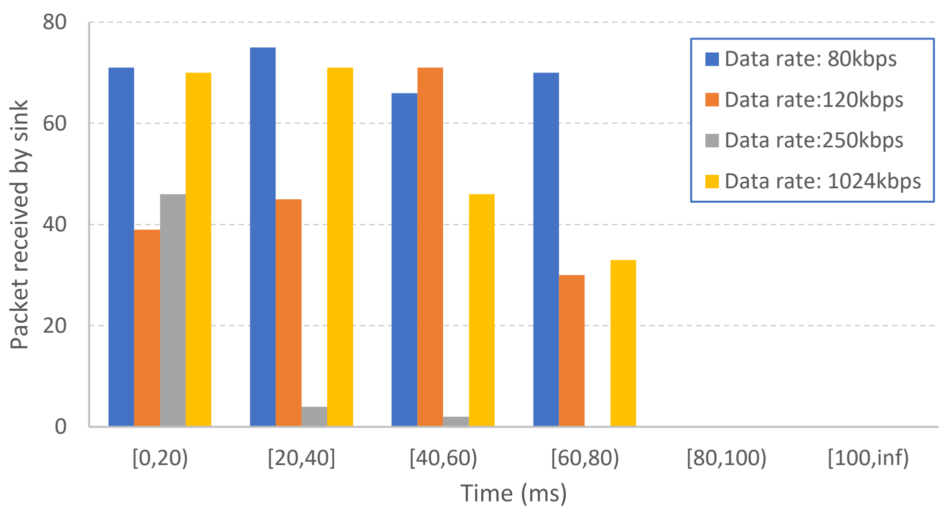

Figure 4. Packets received using CC1000 radio and -20 dBm Tx power

Results shown in Fig. 5 and Fig. 6 are for using CC2420 radio. At 20ms, there is a significant increase in the number of packets received by the sink node 581 to 985 packets when transmission power is increased from -25dBm (Fig. 5) to 0dBm (Fig. 6) respectively.

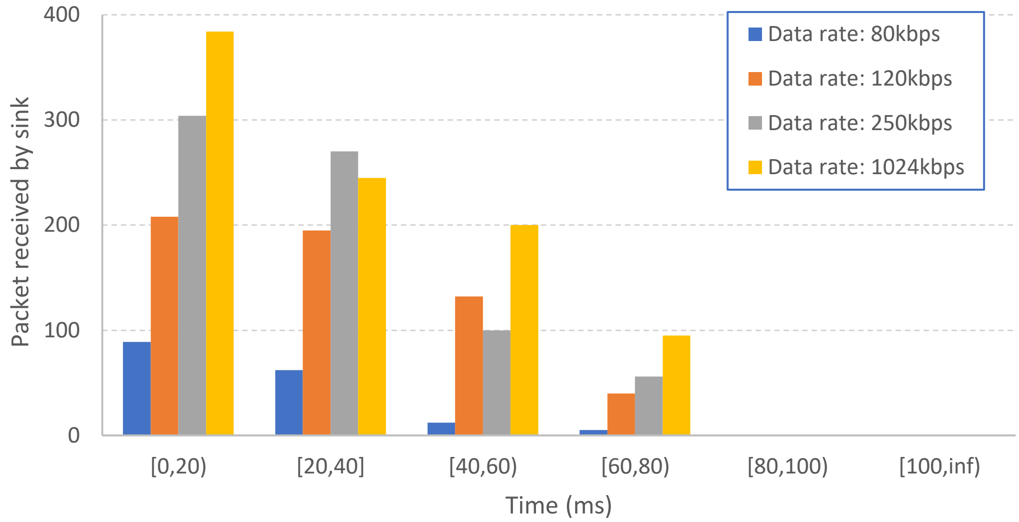

Figure 5. Packets received with CC2420 radio at -25 dBm TX power.

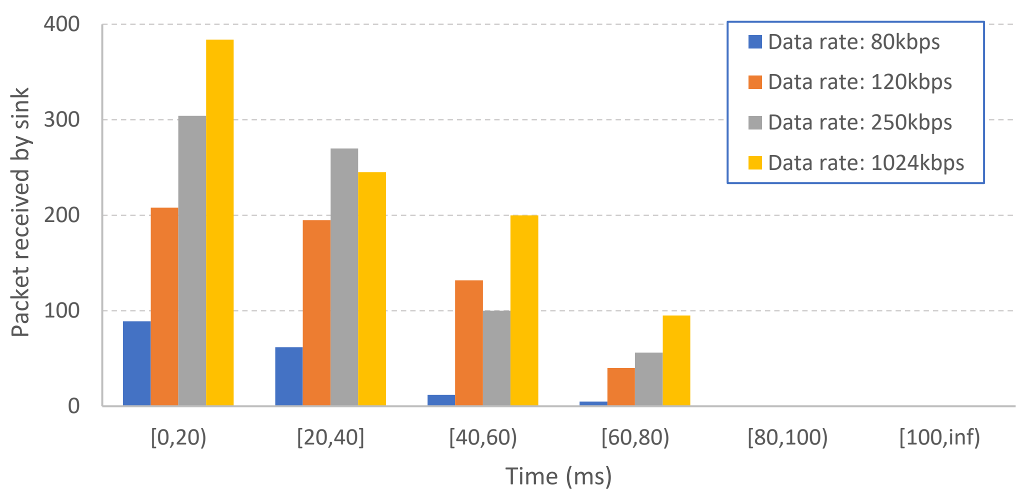

Figure 6. *Packets received with CC2420 radio and 0dBm TX power.*

Figures 7 and 8 show the packets received by the sink node when using BAN radio at different data rates. Again, the average number of packets received by the sink node increases from 5520 to 7466 packets, when the power is increased from -25dBm (Fig. 7) to -10dBm (Fig. 8). Figure 8 also shows that the number of packets received by sink node is almost constant and independent of time when the transmission power is high enough.

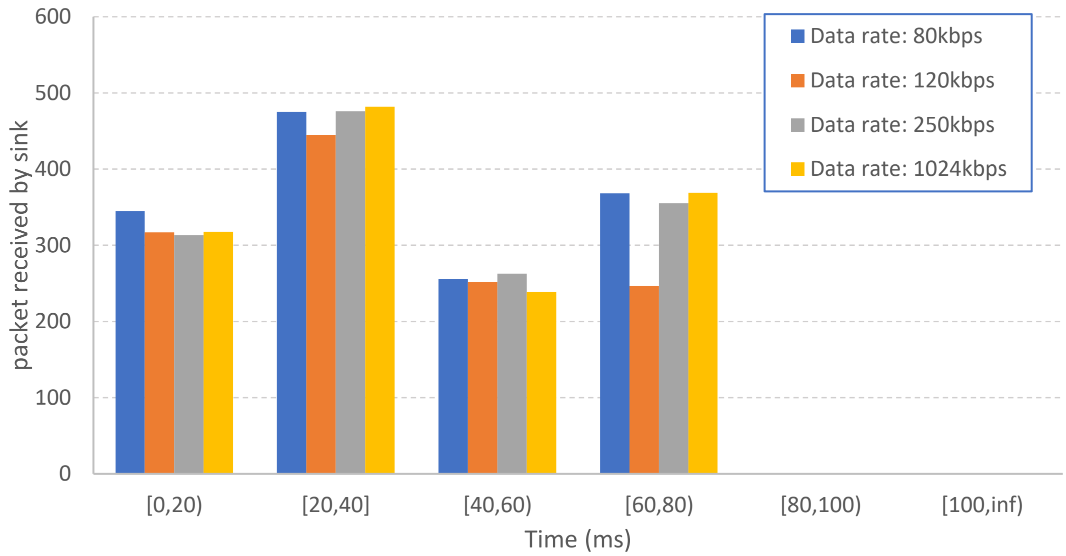

Figure 7. Packets received using BAN radio and - 25dBm TX power.

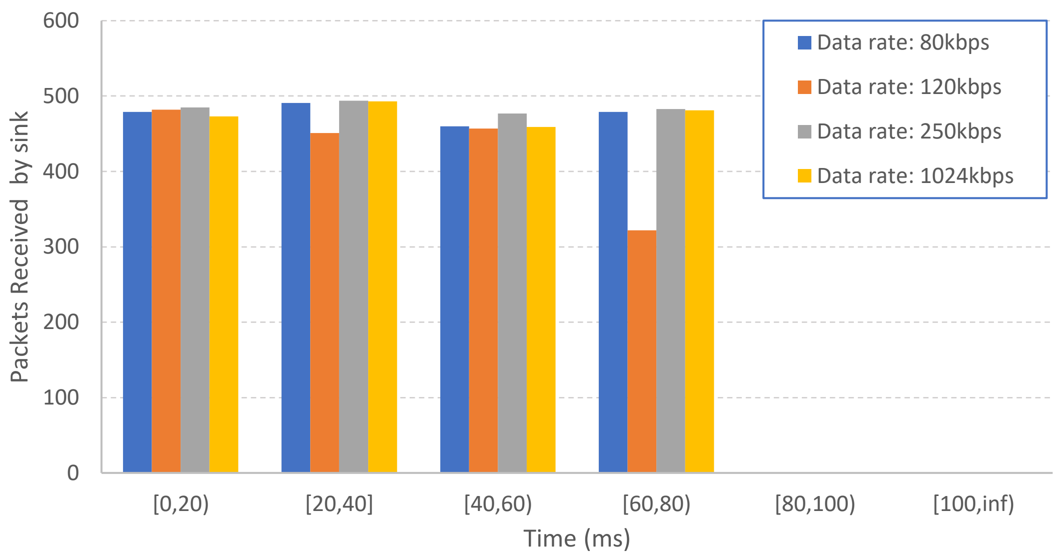

Figure 8. *Packets* received *using BAN radio and -10dBm TX power.*

Figure 9 shows the highest number of packets received by sink node for different radios and different transmission powers. As the results clearly show that BAN radio can deliver significantly higher number of packets even when using transmission powers less than the other two radios.

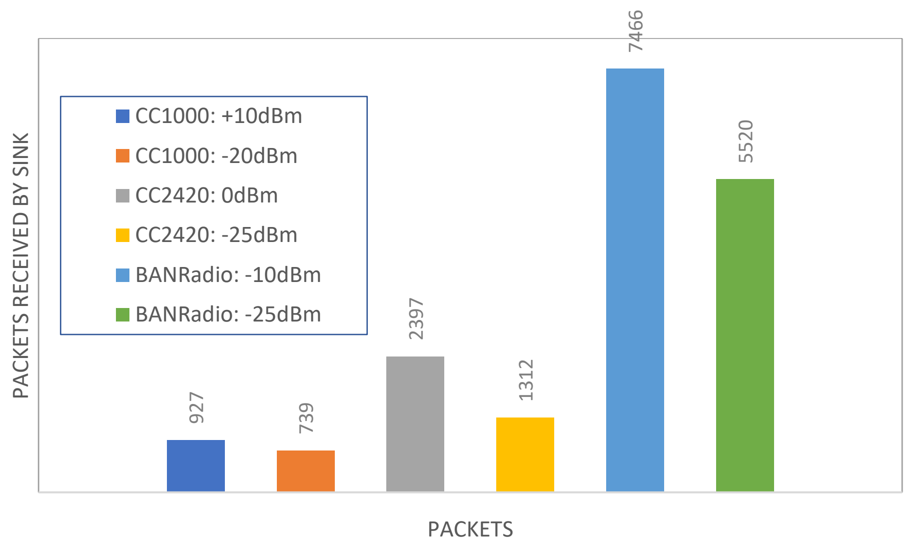

Figure 9. Packets received using different radios and different transmission powers.

6.2 Energy Consumption

Energy usage is of primary importance for WBANs and should be minimized to increase the system lifetime. The following figures show the consumed energy for different nodes using different radios. In these figures, the x-axis denotes the node number and y-axis represents the energy consumption in joules.

Figure 10 is the energy graph for CC1000 radio with a transmission power of 10dBm and Figure 11 is for -20dBm transmission power. Obviously, and as can be seen from these two figures, energy consumption is lower nearly about 1.114J at -20dBm transmission power for all nodes and at different data rates when compared to energy usage about 1.41 J when using 10dBm transmission power.

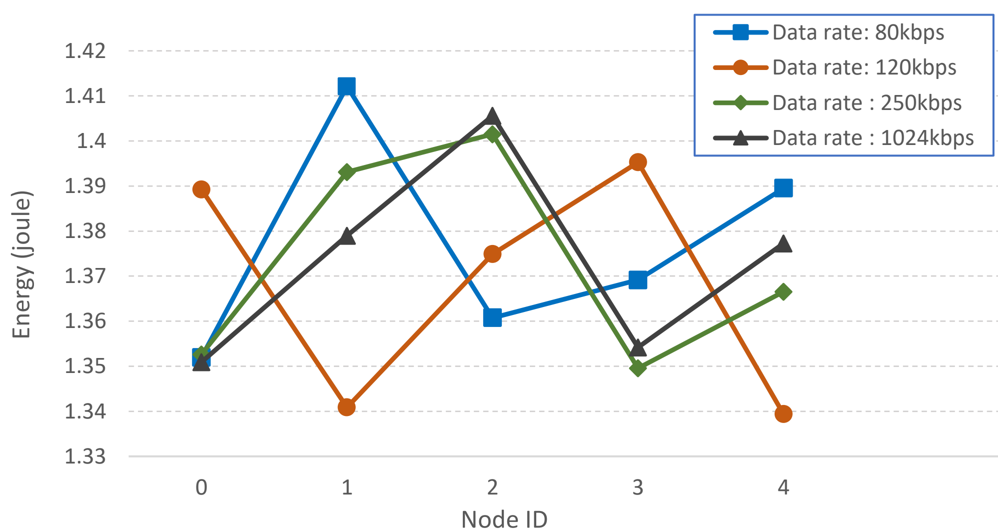

Figure 10. Energy consumption with CC1000 radio and 10dBm TX power.

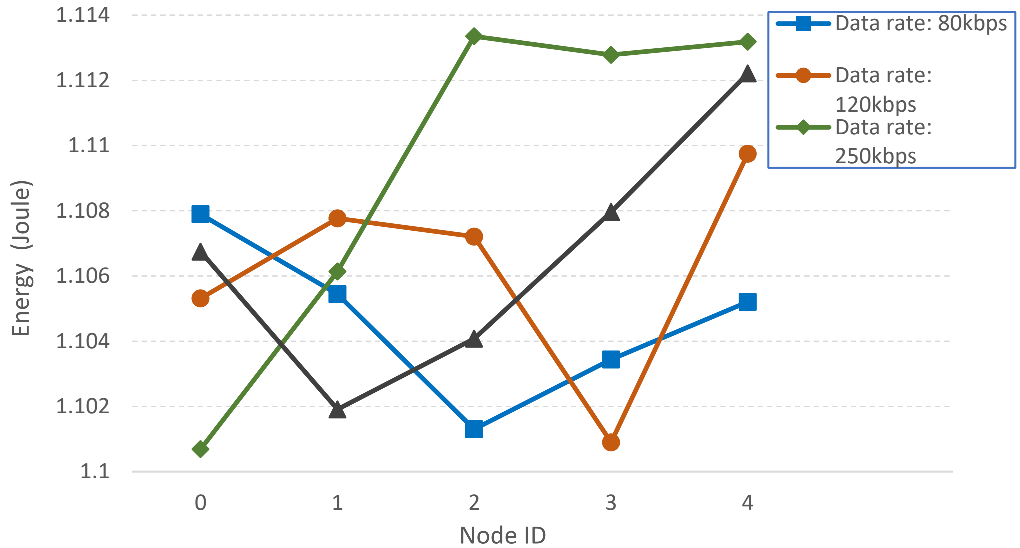

Figure 11. Energy Consumption with CC1000 radio and -20dBm TX power.

Figures 12 and 13 show the energy graphs for CC2420 radio at 0dBm and -25dBm transmission powers about 3.159J and 3.148J respectively and at different data rates. This radio uses a large amount of energy when compared with CC1000 and BAN radios. The CC2420 radio's highest power consumption is about 3.159 joules.

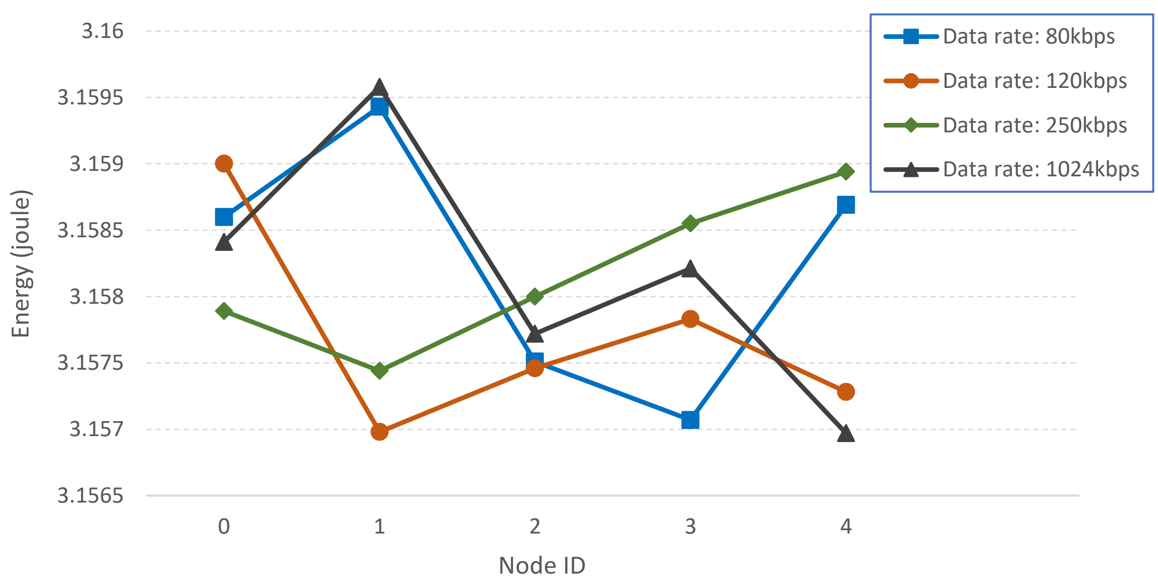

Figure 12. Energy consumption with CC2420 radio and 0dBm TX power.

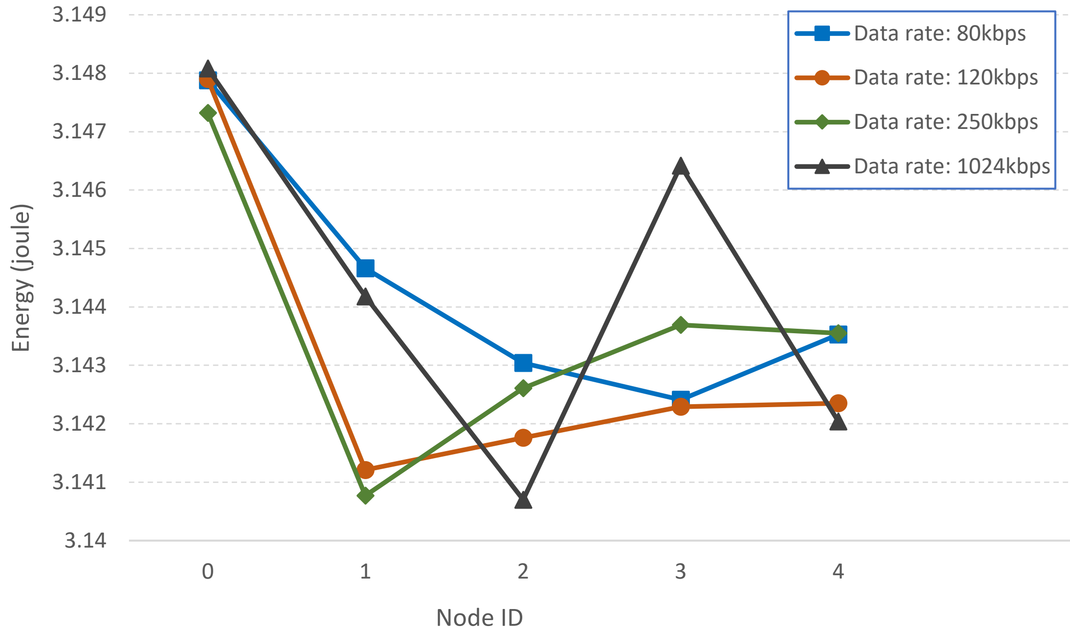

Figure 13. Energy consumption with CC2420 radio and -25dBm TX power

The power graphs of BAN radio at -10dBm and -25dBm transmission power are shown in Fig.14 and Fig.15 respectively. As can be seen, energy consumption remains constant at about 0.158J independent of transmission power and data rates. Relative to the other two radios, the energy consumption of BAN radio is the lowest. Our simulation results indicate the BAN radio is better for lower energy consumption applications than CC2420 and CC1000 radios.

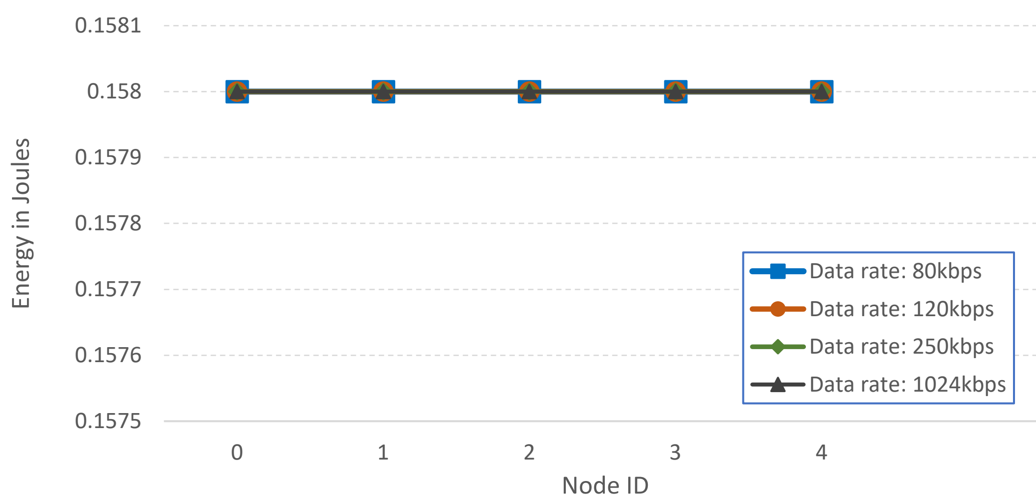

Figure 14. Energy Consumption with BAN radio and-10dBm TX Power.

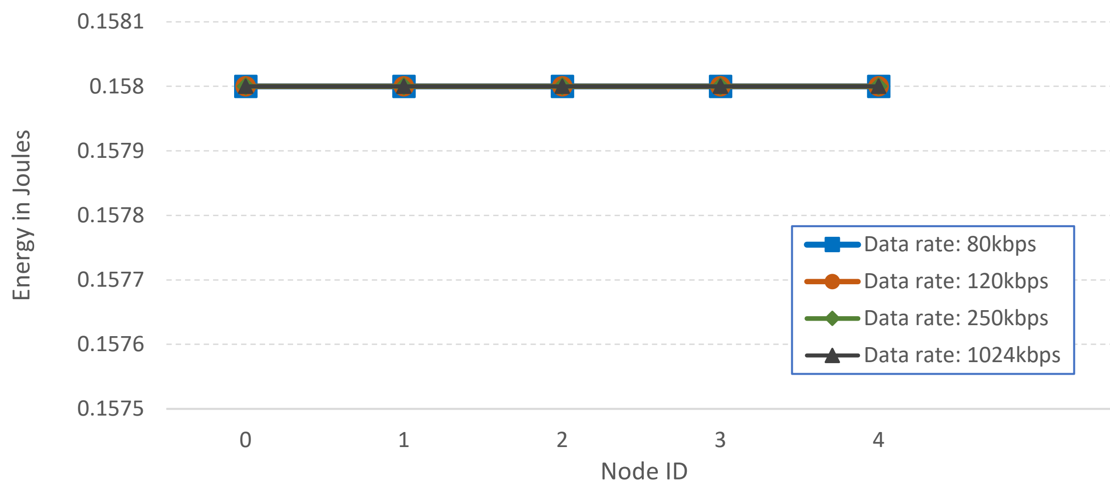

Figure 15. Energy consumption with BAN radio and-25dBm TX power.

Figure16 compares the overall energy consumption of all the radios tested in this work. The BAN radio uses the least energy 3.1J in comparison to CC1000 and CC2420 radios. CC2420 consumes the high amount of energy as clarified in the figure below.

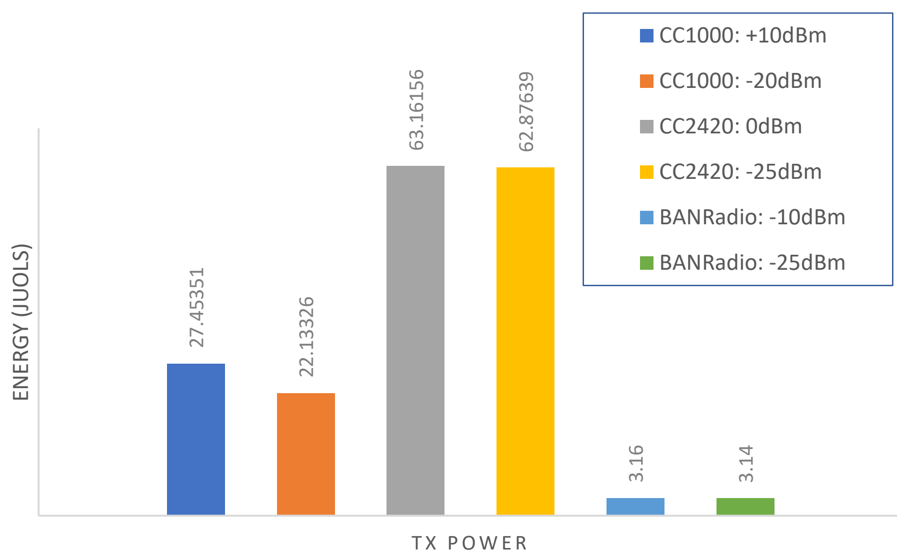

Figure 16. Energy consumption of different radios.

7. Conclusion

The impact of using WBSNs in medical care systems is increasing massively as a result of their ease of use, reliability, reduced cost and freedom. In this paper, the performance of some common IEEE 802.15.6 MAC parameters is analysed for three radios at different data rates and transmission powers. The performance is evaluated using Castalia to simulate a WBSN consisting of five fixed sensor nodes. Number of acquired packets and energy consumption per node were used as performance metrics. The impact of increasing and decreasing the data rates and using maximum and minimum transmission power on the received packets and energy consumption is also studied. In our tests, BAN radio with a minimum/maximum transmission power of -25dBm/-10dBm achieved the lowest overall energy consumption 3.1J as compared to the other two radios (CC1000 and CC2420). Additionally, BAN radio achieved the highest rate of packet 5520 to 7466 packets. Where CC2420 with -25dBm and 0dBm transmission powers consumed the highest amount of energy 62.8J to 63.1J and received 1312 to 2397 number of packets. However, the CC1000 with a transmission power of -20dBm and 10dBm consumed less energy around 22.1 J to 27.4J as compared to CC2420 but received lowest number of packets 739 to 927 packets.

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