Performance Analysis of a Wireless Body Area Network at diverse data rates

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***ABSTRACT*: Energy efficiency is one of the prime design constraints for Wireless Body Area Network (WBAN). The current work evaluates the energy consumption of a WBAN operating at two different frequency bands (402 – 405) MHz and (2360 – 2400) MHz has been achieved. In order to do the analysis, four different supported data rates (75.9,151.8, 303.6, 455.4) Kbps and (121.4, 242.9, 485.7, 971.4) Kbps for the respective band have been considered. CMA3 model and Multilevel Quadrature Amplitude Modulation (M-QAM) scheme have been considered for computing Symbol error rate (SER), bit energy (E_b), and received power (P_r) for the considered frequency bands and supported data rates with respect to distance, a number of bits per symbol and bit rate. On comparative performance investigation, it has been depicted that at the average of considered supported data rates, average energy consumption in terms of bit energy and symbol energy at the (2360 – 2400) MHz band is lower by 55.52% and 99.45% respectively as compared to the energy consumption at the (402 – 405) MHz band. However, results indicate that the (402 – 405) MHz band appears to be more reliable than the (2360 – 2400) MHz Narrowband with SER lower by 22.59% and 0.15% of improved received power (P_r).**

***Keywords*: CM3A model; Energy Efficiency; Multilevel Quadrature Amplitude Modulation; Symbol Error Rate; Wireless Body Area Network.**

1. INTRODUCTION

The wireless Body Area Network (WBAN) is an upcoming subfield of Wireless Sensor Networks (WSN) being used for human body analysis. It comprises sensor nodes deployed in, on, and around the human body. The sensors used in WBAN are generally size limited resulting in battery constraints. This fact makes energy efficiency one of the prime design constraints for WBAN. WBAN is generally heterogeneous in nature and is capable of operating at various frequency bands. In order to support the requirements for the heterogeneous WBAN, IEEE 802.15.6 has been established as a standard model. This standard defines a Medium Access Control (MAC) layer supporting many Physical (PHY) layers, such as Human Body Communications (HBC), Ultra-wideband (UWB), and Narrowband (NB) layers [1].

Under Narrowband (NB) PHY: 402- 405 MHz, 420-450 MHz, 863-870 MHz, 902-928 MHz, 950-958 MHz, 2360-2400 MHz, and 2400-2483.5 MHz optional frequency bands are supported by the transmitting and receiving devices. Worldwide availability of license-free Industrial Scientific and Medical (ISM) band centered around 2.45 GHz makes it a suitable choice for WBAN operation. This may however result in coexistence issues with other standards such as IEEE 802.15.4 and IEEE 802.11 operational in the same band. This necessitates the need for exploring other frequency bands. One such promising band is the Medical Implant Communication System (MICS) operating in 402–405 MHz capable of providing a low range of around 2 m, low power, and high data rate [2]. The propagation characteristics of this band also make it a suitable choice for transmitting radio signals within the human body [3].

It has been shown in the literature that WBAN supports various data rates: 75.9 Kbps, 101.2 Kbps, 121.4 Kbps, 151.8 Kbps, 187.5 Kbps, 202.4 Kbps,242.9 Kbps, 303.6 Kbps, 404.8 Kbps, 455.4 Kbps, 485.7 Kbps, 607.2 Kbps, 971.4 Kbps [4].

As the sensor nodes have limited power, the energy consumption of the nodes during the continuous process of collecting and forwarding the sensed data needs to be reduced. This also tends to improve the node lifetime [5].

The literature surveyed is indicative of numerous research conducted in the past to examine the performance of WBAN by evaluating different parameters such as Signal-to-Noise Ratio (SNR), Bit Error Rate (BER), energy efficiency, and network lifetime, etc. under diverse operating scenarios. Research in the past has suggested improvement in the network lifetime by retaining high residual energy [6]. Authors [7] have presented an energy consumption model based on transmitting distance and data rate for on-body WBAN applications considering transmission energy and circuit energy as the evaluating parameters. Research work in [8] aims to optimize the network lifetime as well as to identify the best position for the sink node by evaluating SER using BPSK. Arora et al. [9] have presented a performance comparison of MICS and Terahertz band in terms of outage probability and SNR for a cooperative WBAN network.

It may be seen from the literature review that underwhelming work has been done with respect to consideration of diverse data rates at different frequency bands considering this fact in view, in the proposed work, the performance of WBAN has been compared for (402-405) MHZ Narrowband and (2360-2400) MHz band at different supported data rates. IEEE 802.15.6 CM3A model has been used to measure path loss specifically for the human body. Based on evaluated path loss, energy consumption has been determined for the considered scenario. Further, link reliability has been measured by evaluating symbol error rate (SER) and received power. While WBAN offers tremendous benefits, it also imposes certain challenges like link reliability and energy consumption.

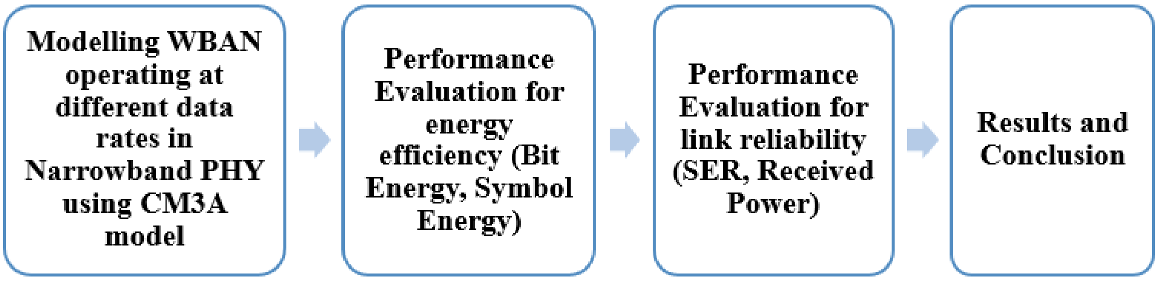

Fig.1. Flow diagram of proposed work

Proper estimation of these constraints is therefore essential for link reliability SER has been computed and for computation of energy efficiency comparative analysis of energy consumption per bit (E_b) and power received has been carried out.

Fig.1 suggests the flow of the proposed work. The rest of the work is structured as follows. Section II describes the system model. Results have been discussed in Section III and Section IV concludes the paper. In the subsequent section system model will be discussed.

2. SYSTEM MODEL

The proposed system model for WBAN is shown in Fig. 2. The sensor nodes placed on the body collect the data and forward it to the sink node which then transmits the gathered information to a server at a remote place via a gateway. The information received at the application-specific remote server may be further processed to make better diagnostic decisions. The location of the sensing nodes may be selected to measure different physiological parameters such as the arm or wrist to measure the glucose level, the head to measure the electrical activity generated by the brain, the thigh for motion analysis, and the chest for measuring electrocardiography signals [10].

The current work investigates the performance of on-body WBAN operating in Narrowband PHY at two frequency bands: (402-405) MHz and (2360-2400) MHz using the Multilevel Quadrature Amplitude Modulation (M-QAM) scheme by evaluating energy consumption, symbol error rate, and received power.

For the considered scenario, path loss between two on-body communicating nodes evaluated using the CM3A- channel model is as expressed in (1) [11].

$$PL(d)[dB] = a \times log_{10}(d) + b + N \qquad (1)$$

where d represents the distance between the transmitting and receiving nodes in millimeters (mm), (a ,b) are the constants describing coefficients of linear fitting, and N is a normally distributed variable with standard deviation σ_N.

To evaluate the energy efficiency of WBAN, energy consumption per bit (E_b) and energy consumed per symbol (E_s) are important parameters and can be computed using (2) and (3) respectively [12].

$$E_b = \left(\frac{S \times N_o \times G_t \times G_r \times \lambda^2}{(4\pi)^2 \times d^{\gamma} \times PL \times R}\right) \qquad (2)$$

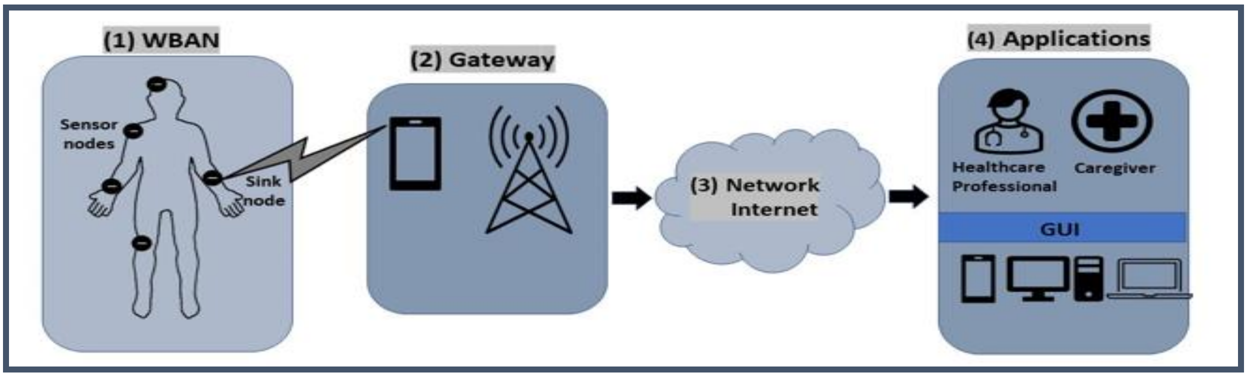

Fig.2. WBAN model

Table 1 Simulation parameters [4] [13] [14] [15]

Parameters		**Value**
R (402-405) MHz band	Data Rate	75.9, 151.8, 303.6, 455.4 (Kbps)
R (2360-2400) MHz band		121.4, 242.9, 485.7, 971.4 (Kbps)
d	distance between the transmitting and receiving nodes	10, 15, 20, 25 (mm)
S	Signal-to-Noise Ratio	10 dB
N_o	Noise Power	-204 dB
a (402-405) MHz band	Constants describing coefficients of linear fitting	3
a (2360-2400) MHz band		6.6
b (402-405) MHz band		34.6
b (2360-2400) MHz band		36.1
N (402-405) MHz band	Normally distributed variable with standard deviation σ_N	4.63
N (2360-2400) MHz band		3.8
G_t, G_r	Transmitting and receiving antenna gains	4.6 dBi
Υ	Path loss exponent	3.5
m	Number of bits per symbol	4, 5, 6, 7
B	Bandwidth	200 KHz, 300 KHz
M	Modulation Level	16, 32, 64, 128

$$\frac{E_s}{N_o} = \frac{E_b}{N_o}(dB) + 10 \times log10(m) \qquad (3)$$

Here, S denotes the threshold SNR considered as 10 dB, G_t and G_r represent the respective gains for transmitting and receiving antenna, λ signifies wavelength, Υ is the path loss exponent and R represents the data rate. The performance of WBAN has been analyzed considering four different data rates supported by each of the operating bands. N_0 represents the noise power and m represents is the transmitted bits per symbol.

Other parameters that can be used to measure WBAN performance are symbol error rate (SER) and received power (P_r). These parameters are used to measure the reliability of the link. SER is defined as the probability of receiving an erroneous symbol and is dependent upon type of modulation and modulation size, and Es/No is the SNR received per symbol. The SER, for M-QAM, can be evaluated using (4) [8] where M is the modulation level.

$$SER_{M-QAM} = 4 \times \left(\frac{\sqrt{M}-1}{\sqrt{M}}\right) \times Q\left(\sqrt{\frac{3 \times E_s}{N_o \times (M-1)}}\right) - 4 \times \left(\frac{\sqrt{M}-1}{\sqrt{M}}\right)^2 \times Q^2\left(\sqrt{\frac{3 \times E_s}{N_o \times (M-1)}}\right) \qquad (4)$$

Power received at the destination node can be evaluated using (5) [12] as,

$$P_r = N_o \times B \times \left(log_2 \times \left(\frac{R}{B}\right) - 1\right) \qquad (5)$$

Where B is the channel bandwidth.

The various parameters used for the modelling and simulation purpose are as summarized in Table 1.

These metrics have been used to evaluate the link quality parameters such as SER, P_r in detail. In the next section simulation results and discussion pertaining to that have been discussed.

3. SIMULATION RESULTS

This section presents the numerical results obtained to critically compare the performance of on-body WBAN operating in Narrowband PHY at (402-405) MHz and (2360-2400) MHz band. Considering the CM3A channel model, simulations have been carried out on MATLAB 2020b to evaluate energy consumption, symbol error rate and received power.

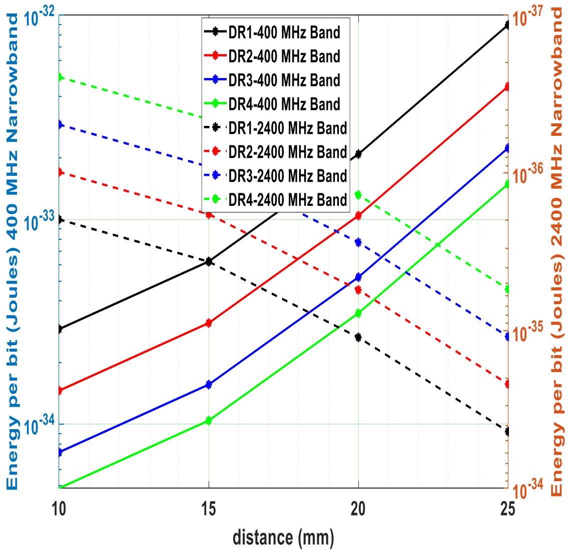

Fig.3. Effect of increasing distance on bit energy

Fig.3 depicts the effect of distance on bit energy for different data rates and Fig.4 represents the energy consumed per symbol corresponding to an increase in number of bits per symbol considering M-QAM. It can be noticed that energy consumption of a node increases with increase in distance and the modulation level. However, energy consumption is lower at (2360-2400) MHz Narrowband compared to energy consumed at (402-405) MHz Narrowband. The average energy consumed per bit at (2360-2400) MHz band is lower by 55.52% as compared to the bit energy consumed at (402-405) MHz band. While the average energy consumed per symbol at (2360-2400) MHz band is lower by almost 99.45% compared to the average symbol energy at (402-405) MHz band.

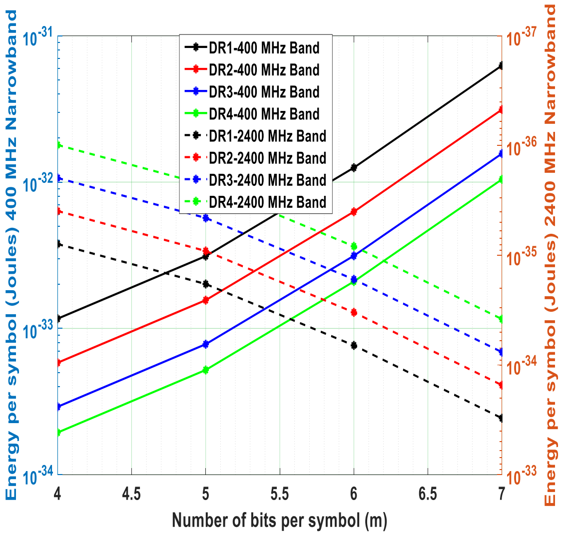

Fig.4. Effect of increasing m on symbol energy

Link reliability can also be evaluated in terms of symbol error rate and received power. The effect of increasing modulation level on SER for M-QAM can be seen from Fig.5. As observed from the plot, SER increases as the number of bits transmitted per symbol is increased from 4 to 7 but is lower for (402-405) MHz Narrowband as compared to SER obtained at (2360-2400) MHz Narrowband by 22.59%.

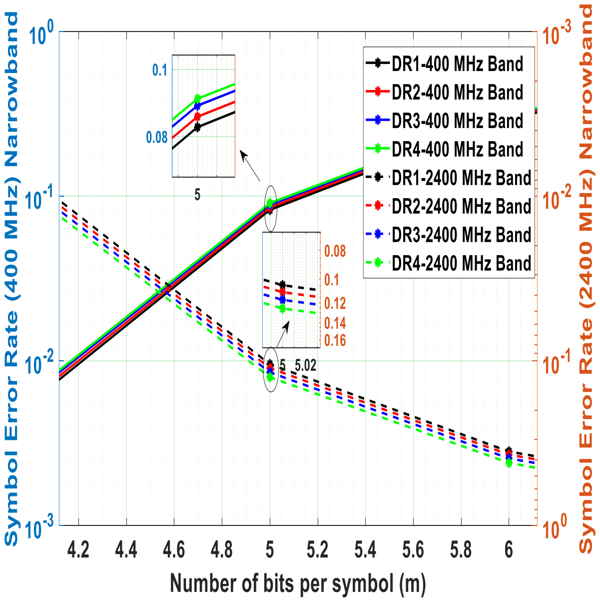

Fig.5. Effect of increasing m on SER

Next, the link reliability has been evaluated in terms of received power as shown by double axis graph in Fig.6 and Fig.7 for (402-405) MHz Narrowband and (2360-2400) MHz Narrowband respectively. Higher the received power, better is the link reliability. It can be observed that received power decreases with increase in data rate and for same bandwidth consideration, received power at (402-405) MHz Narrowband is lower by 0.15% than at (2360-2400) MHz Narrowband.

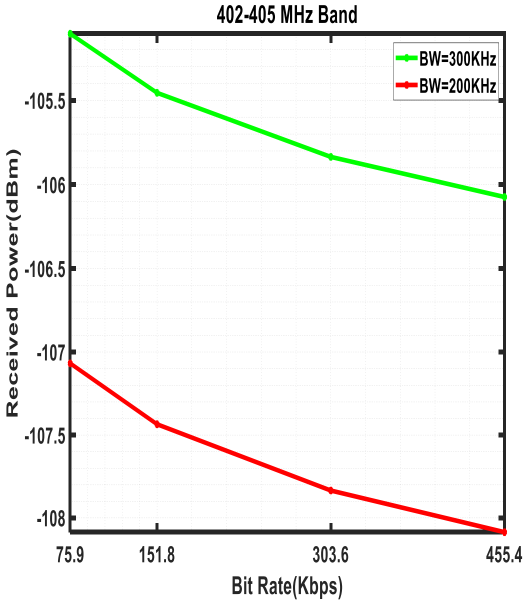

Fig.6. Effect of increasing data rates on received power for (402-405) MHz band

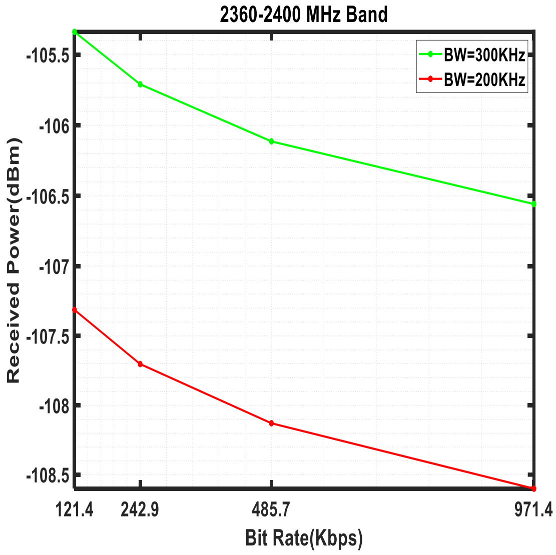

Fig.7. Effect of increasing data rates on received power for (2360-2400) MHz band

Fig.8 highlights the percentage difference by which energy consumed and SER is less at (2360-2400) MHz Narrowband and percentage difference by which received power is lower at (402-405) MHz band. The next section concludes the current work.

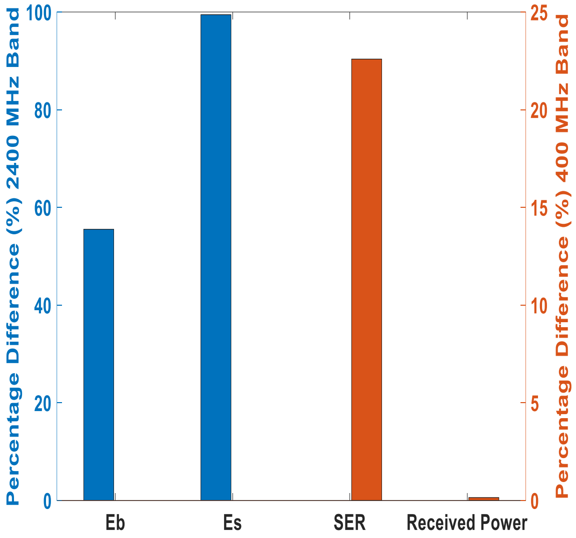

Fig.8 Percentage difference for different metrics

4. CONCLUSION

With reliability and energy- efficiency as the prime challenges in WBAN, the current work aims to examine and compare the energy efficiency and link reliability of WBAN at (402-405) MHZ Narrowband and (2360-2400) MHz band for different supported data rates. For the considered scenario, results obtained reveal that the (2360-2400) MHz band appears to be more energy energy-efficient as compared to the (402-405) band with average energy bit energy and symbol energy lower by 55.52% and 99.45% respectively. However, the (402-405) band appears more reliable with SER and received power lower by 22.59% and 0.15% respectively as compared to SER and received power at (2360-2400) MHz Narrowband. It can also be seen that received power decreases with increase in data rates. Hence a trade-off is required while considering the data rates. In future, the obtained results may be utilized for analyzing the energy efficiency and link reliability of a WBAN operating at other suitable frequency bands as well as for different modulation schemes.

Conflict of interest: No conflict of interest has been found among any of the authors.

Ethical approval: The current work presented does not involve any study performed on any of the living creature.

REFERENCES

[1] S. Ullah, M. Mohaisen, and M. A. Alnuem, “A Review of IEEE 802.15.6 MAC, PHY, and Security Specifications ,” http://dx.doi.org/10.1155/2013/950704, vol. 2013 (2013), doi: 10.1155/2013/950704.

[2] P. K. D. Pramanik, A. Nayyar, and G. Pareek, “WBAN: Driving e-healthcare Beyond Telemedicine to Remote Health Monitoring: Architecture and Protocols,” Telemedicine Technologies: Big Data, Deep Learning, Robotics, Mobile and Remote Applications for Global Healthcare, pp. 89–119 (2019), doi: 10.1016/B978-0-12-816948-3.00007-6.

[3] N. Arora, S. H. Gupta, and B. Kumar, “Performance analysis of Terahertz communication link for cooperative Wireless Body Area Network,” Optik (Stuttg), vol. 242, p. 167376 (2021), doi: 10.1016/j.ijleo.2021.167376.

[4] R. Cavallari, F. Martelli, R. Rosini, C. Buratti, and R. Verdone, “A survey on wireless body area networks: Technologies and design challenges,” IEEE Communications Surveys and Tutorials, vol. 16, no. 3, pp. 1635–1657 (2014), doi: 10.1109/SURV.20 14.012214.00007.

[5] S. Talha, R. Ahmad, A. K. Kiani, and M. M. Alam, “Network Coding for Energy Efficient Transmission in Wireless Body Area Networks,” Procedia Computer Science, vol. 113, pp. 435–440 (2017), doi: 10.1016/J.PROCS.2017.08.285.

[6] S. R. Chavva and R. S. Sangam, “An energy-efficient multi-hop routing protocol for health monitoring in wireless body area networks,” Network Modeling Analysis in Health Informatics and Bioinformatics 2019 8:1, vol. 8, no. 1, pp. 1–10 (2019), doi: 10.1007/S13721-019-0201-9.

[7] C. Yi, L. Wang, and Y. Li, “Energy Efficient Transmission Approach for WBAN Based on Threshold Distance,” IEEE Sensors Journal, vol. 15, no. 9, pp. 5133–5141 (2015), doi: 10.1109/JSEN.2015.2435814.

[8] A. Razavi and M. Jahed, “Node positioning and lifetime optimization for wireless body area networks,” IEEE Sensors Journal, vol. 17, no. 14, pp. 4647–4660 (2017), doi: 10.1109/JSEN.2017.2710350.

[9] N. Arora, S. H. Gupta, and B. Kumar, “Analyzing and Optimizing Cooperative Communication for in Vivo WBAN,” Wireless Personal Communications 2021 122:1, vol. 122, no. 1, pp. 429–450 (2021), doi: 10.1007/S11277-021-08906-1.

[10] C. Chatzaki et al., “The Smart-Insole Dataset: Gait Analysis Using Wearable Sensors with a Focus on Elderly and Parkinson’s Patients,” Sensors 2021, Vol. 21, Page 2821, vol. 21, no. 8, p. 2821 (2021), doi: 10.3390/S21082821.

[11] K. Yazdandoost, "Channel model for body area network (BAN)." IEEE 802.15-08-0780-05- 0006 (2009).

[12] JG Proakis and M. Salehi M, Digital communications, vol. 5.(McGraw Hill Education, New York:2014).

[13] Ł. Januszkiewicz, P. di Barba, and S. Hausman, “Multi-Objective Optimization of a Wireless Body Area Network for Varying Body Positions,” Sensors 2018, Vol. 18, Page 3406, vol. 18, no. 10, p. 3406 (2018), doi: 10.3390/S18103406.

[14] M. Kaushik, S. H. Gupta, and V. Balyan, “An approach to optimize performance of CM3A cooperative WBAN operating in UWB,” Sustainable Computing: Informatics and Systems, vol. 30, p. 100523 (2021), doi: 10.1016/j.suscom.2021.100523.

[15] K. S. Kwak, S. Ullah, and N. Ullah, “An overview of IEEE 802.15.6 standard,” 2010 3rd International Symposium on Applied Sciences in Biomedical and Communication Technologies, ISABEL 2010 (2010), doi:10.1109/ISABEL.2010.5702867.