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PERFORMANCE ANALYSIS OF LT-BCH CODE FOR WIRELESS BODY AREA NETWORK

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ABSTRACT

Wireless Body Area Network (WBAN) is a technology developed for various applications, especially in the health sector. WBAN is a network of sensors, actuators and transmitters worn by humans for continuous monitoring of physiological data, which will be subsequently transmitted to a data processor for health diagnosis purposes. Data reliability is of utmost importance in WBAN as erroneously received data can result in misdiagnosis by healthcare professionals. In addition to data reliability, the implementation of a suitable channel code for WBAN must also take energy efficiency into consideration, as WBAN devices typically have limited energy. This research presents the analysis of energy consumption for the Luby Transform (LT) code with Bose-Chauduri-Hocquenghem (BCH) as the outer code, where the energy consumption is compared to SNR per bit and transmission distance. The simulation results shows that the LT-BCH code demonstrates optimal energy consumption performance for WBAN applications. The use of LT-BCH codes with high error correction capabilities, namely LT-BCH(127,64,21) and (255,71,59), is suitable for high transmission distances and poor channel conditions. Results show that code rate has minimal impacts under good channel conditions, which is signified by the converging energy consumption requirements needed for various codes in high SNR regions. The results suggest that the LT-BCH code is an energy-efficient solution for WBAN, particularly in challenging transmission environments.

Keywords: *LT Code, BCH, WBAN, Rayleigh, fading channel*

1. INTRODUCTION

Wireless Body Area Network (WBAN) is a network comprising of sensors, actuators and a transmitter worn by a person to track physiological data and transmit it wirelessly to a processing unit [1], [2]. WBAN is becoming widely researched for implementation in various fields such as healthcare, military and sport as it features continuous monitoring of vital signs and enable prompt diagnosis and preventive actions against health risks [3], [4]. Its application for healthcare is especially important due to the growing need of medical attention for people with limited mobility. Data reliability is a crucial factor in WBAN [5], [6], [7], [8]. Continuous data transmission over wireless channels which are prone to fading and noise introduces the possibility of transmission errors, which may result in erroneous data in the receiver. Errors in physiological data within WBAN applications for telehealth have the potential to cause misdiagnoses, which could be detrimental to WBAN users. Additionally, the limited power of WBAN devices needs to be addressed [9], [10], [11]. On one hand, the devices need to operate continuously to sense physiological data, process it, and transmit it to a data processor. On the other hand, the dimension and weight of wearable devices in WBAN must be constrained, which inevitably impacts the available energy of the device.

The implementation of the right channel coding scheme is very important in WBAN. Channel coding can support data reliability, by providing error detection and correction capabilities to the receiver. The channel coding scheme chosen in the WBAN must also be energy-efficient, considering the energy limitations of the WBAN devices. One of the proposed coding schemes for WBAN applications is convolutional code. The study [12] discusses the performance of concatenated code combined with a diversity technique in the form of maximal ratio combining to overcome errors in fading channels. The combination of coding and diversity techniques shows better performance of BER than conventional systems but increases the complexity of the receiver.

The use of convolutional codes in WBANs has also been studied in [13]-[14]. The proposed system model in [14] uses several coding stages for applications on UWB WBAN, namely CRC encoding, Bose-Chauduri-Hocquenghem (BCH) encoding, and Super Orthogonal Convolutional Code (SOCC) which shows good Bit Error Probability and energy efficiency performance for Ultra-Wideband (UWB) WBAN.

The use of Raptor code, which is a linear code as outer code combined with Luby Transform (LT) code, was studied in [15]. Raptor code is known to be flexible and allows data recovery at the receiver, even though there is data erasure during the transmission[16]. This is an important feature for the WBAN application, where data loss poses a high risk, especially when WBAN is applied to telehealth services. The outer code used in this study is Low Density Parity Check (LDPC). The Raptor code shows better energy efficiency compared to LT code, BCH and ARQ retransmission methods. However, LDPC encoders require large matrix generators and result in large storage and overhead computation requirements [17].

Based on [12], the use of concatenated code may be limited for WBAN applications due to its complexity. On the contrary, BCH codes is shown to be a good fit for WBAN in [13]-[14] In addition to that, the ability of Raptor code to handle data erasure as shown in [15] makes it a good fit for WBAN applications, but the outer code needs careful consideration.

To address the challenges in terms of data reliability and energy efficiency in WBAN, we propose the implementation of LT code with BCH as an outer code in WBAN system, based on previous studies. This research is based on simulations aimed at observing the coding performance of LT-BCH, focusing on the parameters of energy consumption in relation to distance and SNR. The use of LT-BCH code for WBAN system is expected to improve the BER performance, as well as keeping the energy consumption at a low level compared to standalone BCH codes. The LT-BCH codes with high error correction capabilities, namely LT-BCH(127,64,21) and LT-BCH(255,71,59) is expected to have good BER performance especially in low SNR conditions.

This paper is organized as follows. The second part of the paper discusses LT code, whereas the third part reviews the BCH code. The system model is given in the fourth section. The results and discussion is presented in the fifth section, while the sixth section concludes the paper.

2. LT CODE

The basic concept of LT code is fountain code. In fountain code, a block of data referred to as the source block is partitioned into several smaller blocks referred to as source symbols, with the total number of source symbols denoted by k. The sender uses a fountain encoder to generate as many encoded symbols as necessary from the source block. A receiver that accepts any subset of k encoded symbols, can use a fountain decoder to produce an exact copy of the block source identical to the original, regardless of which subset is received [18].

LT codes are efficient fountain codes. The decoding process for LT code can be expressed by a decoding graph that states the link between the source symbols and the encoded symbols that arrives at the receiver. If there are k source symbols and N encoded symbols, then each encoded symbol y_i is related to the source symbol x_{j1}, ..., x_{jl} if and only if y_i is the XOR of the source symbols x_{j1}, ..., x_{jl}.

The process of forming the LT codeword is as follows [19]

1. Source symbols are partitioned into blocks comprising k bits
2. A degree d is assigned to each codeword
3. Select d random source symbols and combine them using XOR operations to form a codeword.
4. The codeword is transmitted to the receiver, each codeword contains k or multiples of k bits of information.

The presence of redundant bits in different codewords allows the receiver to reconstruct the input symbol even in the event of a loss of the codeword in the erasure channel.

The belief propagation decoder will repeat the following steps to decode the received encoded symbols until Step 1 can't be performed, or the decoder stops in Step (4) [18].

1. Define the encoded symbol with degree 1, where i represents the index of the encoded symbol and j is the index of its unique neighbor among the source symbols. If there is no encoded symbol of degree 1, then the decoding fails.
2. Decode $x_j = y_i$
3. Let i_1, ... i_l represents the index of the encoded symbol that corresponds to the source symbol j; set $y_{is} = y_{is} + x_j$ for $s = 1, ..., l$
4. If there exist source symbols that cannot be recovered, go back to Step 1. When all the

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source symbols have been recovered, the process is complete.

Figure 1 shows an illustration of LT coding. Source symbols which comprise 8 bits are divided by k =2 resulting in 4 blocks of data. Next, XOR operations are carried out between the blocks to generate codewords. In the example illustrated in Figure 1, the XOR process is done between first and second blocks, resulting in codeword *A*. Codeword *B* is the result of XOR process between the second and the third block of source symbols. Codeword *D* is generated from the XOR process between the third and fourth block of source symbols, while codeword *C* is generated solely from the third block of source symbols. This means that codeword *C* has a degree of 1. The LT decoding process can be carried out if a codeword with the degree of 1 exist.

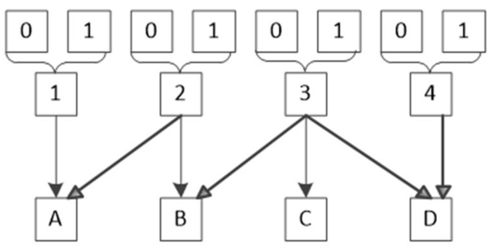

Figure 1. Illustration of LT encoding

Code degrees are the number of source symbols that are combined to form a codeword. The degree distribution is determined based on the Ideal Soliton Distribution, and the Robust Soliton Distribution [20]. Ideal Soliton Distribution (ISD) is defined as

$$\rho(i) = \begin{cases} \rho(1) = 1/k \\ \rho(i) = \frac{1}{i(i-1)} \quad i = 1,2,\dots,k \end{cases} \qquad (1)$$

A well-designed degree distribution will have a ripple of optimal size. A ripple is a set of source symbols that have not been recovered by the recipient. The ripple size must be small enough to avoid redundancy of the recovered source symbols, but it must also be large enough for all source symbols to be successfully recovered. Robust Soliton Distribution is the main degree distribution in LT code and denoted by $\mu(i)$. Let the expected ripple size for a constant $c > 0$ is [20]

$$R = c.\,ln(k/\delta)\sqrt{k} \qquad (2)$$

where δ denotes the tolerable probability of failure.

Let

$$\tau(i) = \begin{cases} R/ik & i = 1,\dots,k/R-1 \\ Rln(R/\delta)/k & i = \frac{k}{R} \\ 0 & i = k/R+1,\dots,k \end{cases} \qquad (3)$$

Subsequently, $\mu(i)$ can be calculated using

$$\mu(i) = \frac{(\rho(i)+\tau(i))}{\sum_{i-1}^{k} \rho(i)+\tau(i)} \qquad i = 1,\dots,k \qquad (4)$$

3. BCH CODE

The BCH code is formed by a polynomial generator $g(X)$ which can be stated as

$$g(x) = p(x)p_3(x)p_5(x)\dots p_{2t-1}(x) \qquad (5)$$

where $p(x)$ is a primitive polynomial and all polynomials in (5) must be divisible by $p(x)$, namely

$$p_3(x^3) = p_5(x^5)\dots p_{2t-1}(x^{2t-1}) = 0 \pmod{p(x)} \qquad (6)$$

For a BCH code which is generated based on a field element α, the error polynomial can be stated as [21]

$$e(x) = e_{n-1}x^{n-1} + e_{n-2}x^{n-2} + \dots + e_1(x) + e_0 \qquad (7)$$

where at most t coefficients are non-zero. If v errors occur with $0 \le v \le t$, and these errors occurs at locations i_1, i_2, …, i_v , the error polynomials can be written as

$$e(x) = e_{i_1}x^{i_1} + e_{i_2}x^{i_2} + \dots + e_{i_v}x^{i_v} \qquad (8)$$

where e_{ik} is the magnitude of the k^{th} error. The syndrome of the BCH code can be calculated from:

$$\begin{aligned} S_1 &= v(\alpha) = c(\alpha) + e(\alpha) = e(\alpha) \\ &= e_{i_1}x^{i_1} + e_{i_2}x^{i_2} + \dots + e_{i_v}x^{i_v} \end{aligned} \qquad (9)$$

If the error magnitudes are defined as $Y_k = e_{ik}$ for k = 1, 2, …v and the error locations are stated as $X_k = \alpha^{ik}$ for k = 1, 2, …v where i_k is the location of the k^{th} error

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and X_k is the field element related with the particular location, the syndrome can be stated as [21]

$$S_1 = Y_1X_1 + Y_2X_2 + \cdots + Y_vX_v \qquad (10)$$

A matrix which consists of all the syndromes of the received polynomials can be used to determine the error locations. A BCH code is commonly stated as BCH(n,k,e) where n denotes the number of bits in the codeword, k is the number of bits in the information sequence, and e is the number of erroneous bits that can be corrected by the code.

4. SYSTEM MODEL

This research uses a simulation-based experimental design to analyze the performance of the LT-BCH coding scheme in WBAN. The model is similar to simulation frameworks introduced in previous research on coding schemes to analyze BER and energy consumption on wireless communication channels, as real-world prototyping is constrained by access to actual communication networks. By carrying out simulations, the tradeoffs between error correction and energy consumption can be observed and tested. The system model used in this research is given in Figure 2. The information bit sequence is processed by the BCH encoder before subsequently encoded into LT codewords. In the first simulation, the coding schemes used are standalone BCH(31,21,5) and LT code with BCH(31,21,5) as an outer code. In the subsequent simulations, the LT codes are equipped with BCH(31,21,5), (63,36,11) and (127,64,21) as outer codes. BCH(127,64,21) has the lowest code rate compared to the other two BCH codes, and therefore provides the strongest protection against bit errors.

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The parameters used in the simulations are given in Table 1.

Table 1: Simulation Parameters

Modulation	BPSK
Channel	Rayleigh fading
Modulation	BPSK
Soliton Distribution	Robust Soliton
SNR range	0 – 20 dB
Number of iteration	10,000

5. RESULTS AND DISCUSSION

Figure 3 shows the performance of standalone BCH(31,21,5) and LT code with BCH(31,21,5) in terms of energy consumption per bit versus transmission distance, in a Rayleigh fading channel. It is shown that the energy consumption increases as the transmission distance increases, owing to the increase of signal attenuation as the communication distance increases. The energy consumption increases exponentially in accordance with the increase of the communication distance, due to rapid signal deterioration in Rayleigh fading channel. From the simulation result, it is shown that LT code equipped with BCH code has slightly higher energy consumption throughout all distances compared to standalone BCH code, especially when the distance reaches 400 meters and beyond. BCH as a block code uses constant length codeword and therefore consumes less energy, compared to LT code which has high complexity and redundancy. However, LT code is still a suitable choice for WBAN applications, where error correction capability and adaptability is of utmost importance.

Figure 4 shows the performance of LT codes with BCH (31,21,5), (63,36,11) and (127,64,21) as outer codes in terms of energy consumption per bit when the SNR ranges from 0 to 20 dB, in a Rayleigh fading channel. The energy consumption per bit for all three codes decreases as the SNR increases, as better signal quality which is signified by a high SNR will require fewer retransmission and subsequently necessitates lower energy consumption per transmitted bit. It is shown that for low SNR (0-6 dB), the energy consumption per bit is significantly higher compared to that in

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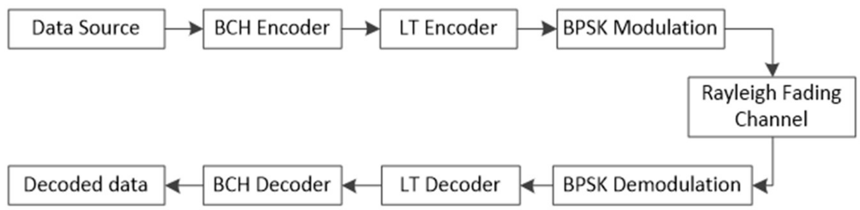

Figure 2. System model

high SNR, indicating that highly erroneous bit transmission in the low SNR region requires high energy consumption to mitigate errors. In the high SNR region (10 – 20 dB), it is shown that the energy consumption for all three codes converges, suggesting that the code rates do not significantly affect the energy consumption at certain SNR threshold. It is also shown that the LT code equipped with BCH (63,36,11) and (127,64,21) have slightly lower energy consumption compared to BCH(31,21,5). As LT with BCH(63,36,11) and (127,64,21) provides better error protection compared to LT with BCH (31,21,5), the low energy consumption makes them suitable for WBAN applications.

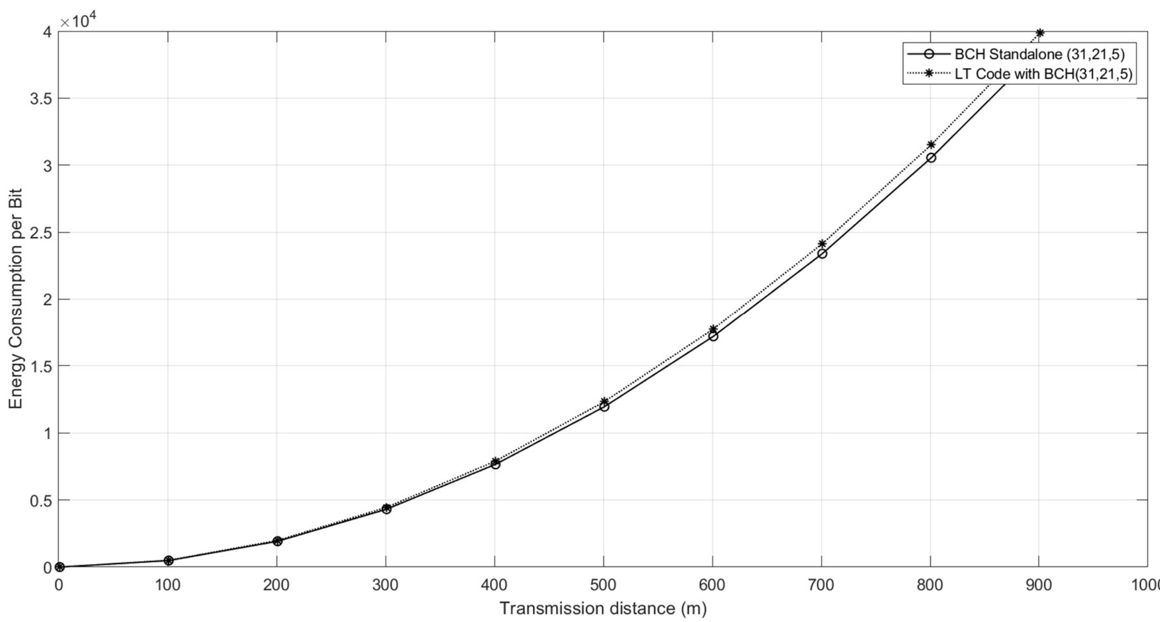

Figure 3. Energy consumption per bit vs transmission distance of standalone BCH (31,21,5) and LT Code with BCH (31,21,5) in a Rayleigh fading channel

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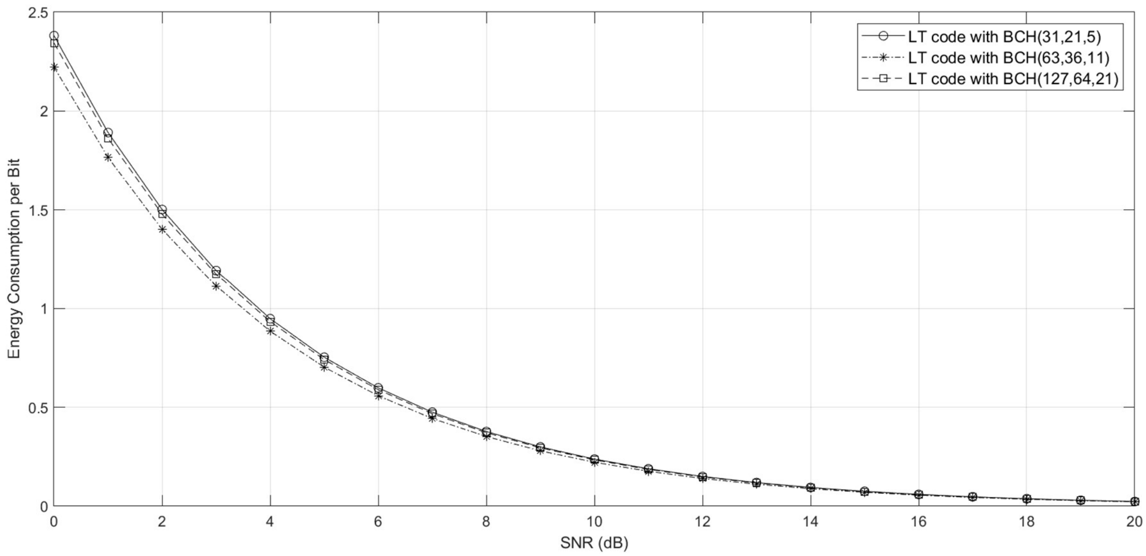

Figure 4. Energy consumption vs SNR (dB) of LT with BCH Codes in a Rayleigh fading channel

Figure 5 shows the performance of LT codes with BCH (31,21,5), (63,36,11) and (127,64,21) as outer codes in terms of energy consumption and transmission distance. It is shown that the energy consumption for all three codes will increase in accordance with the transmission distance, as an increase in transmission distance will also increase signal attenuation. This will negatively affect the error rate and require an increase of energy to transmit data reliably. An outer code of BCH (31,21,5) requires the lowest energy consumption for all distances, as the number of redundancy bits are low. BCH(63,36,11) offers higher error protection and requires more energy compared to BCH(31,21,5). BCH(127,64,21) has the lowest code rate and therefore provides the highest error protection compared to the other two codes and requires the highest energy consumption.

The difference in energy consumption for the three simulated codes becomes more significant as the transmission distances increases, namely from 60 to 100 meters. It is shown that the tradeoff between error correction capability and energy becomes more apparent in long distances.

Given the importance of data security in the WBAN application, further simulations were conducted for LT codes with BCH which have higher error correction capabilities, namely BCH(255,71,59), (255,87,53) and (255,91,51). Figure 6 shows the performance of energy consumption per bit for LT code with BCH(255,71,59), (255,87,53) and (255,91,51) against SNR (dB). From the simulation results, it is shown that LT BCH which has the highest error correction ability, namely BCH(255,71,59) will have higher energy consumption than the other two codes that have lower error correction capabilities. The difference in energy consumption between the LT code and BCH(255,71,59), (255,87,53) and (255,91,51) is more apparent in the low SNR region (0 - 8 dB), indicating that poor channel conditions required high retransmission. This in turns increases the energy consumption of the code with a high error correction rate and high redundancy. However, in the region of high SNR, the energy consumption for all three codes tends to converge. The convergence is more pronounced in LT-BCH BCH(255,71,59) and (255,87,53). This shows that the use of code with moderate error correction capability, namely LT-BCH(255,87,53), is suitable for poor channel conditions. The simulation results depicted in Figure 7 show the performance of the energy consumption of LT-BCH(255,71,59), (255,87,53) and (255,91,51) against the transmission distance. As expected, the energy consumption increases in accordance with the distance. The highest energy consumption is required by the code with the highest error correction capability, which is LT-BCH(255,71,59). This shows that the LT-BCH(255,71,59) scheme is suitable for WBAN applications at long distances and poor fading conditions, although it requires higher energy consumption. For good channel conditions, the use of LT-BCH (255,87,53) and (255,91,51) are more suitable because they have better energy efficiency compared to LT-BCH (255,71,59).

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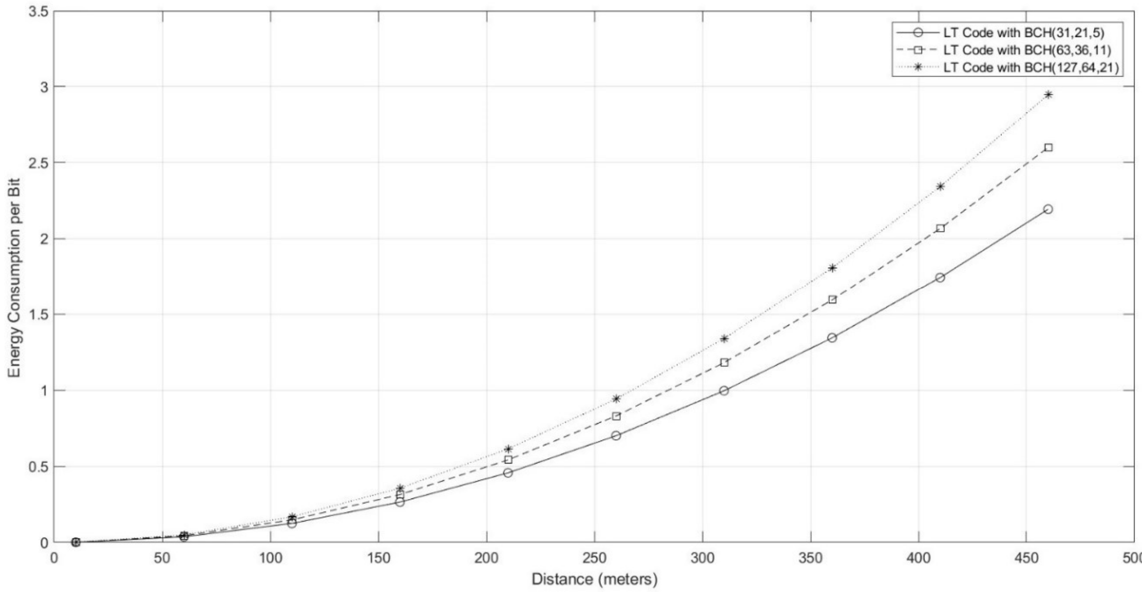

Figure 5. Energy Consumption vs transmission distance of LT with BCH Codes in a Rayleigh fading channel

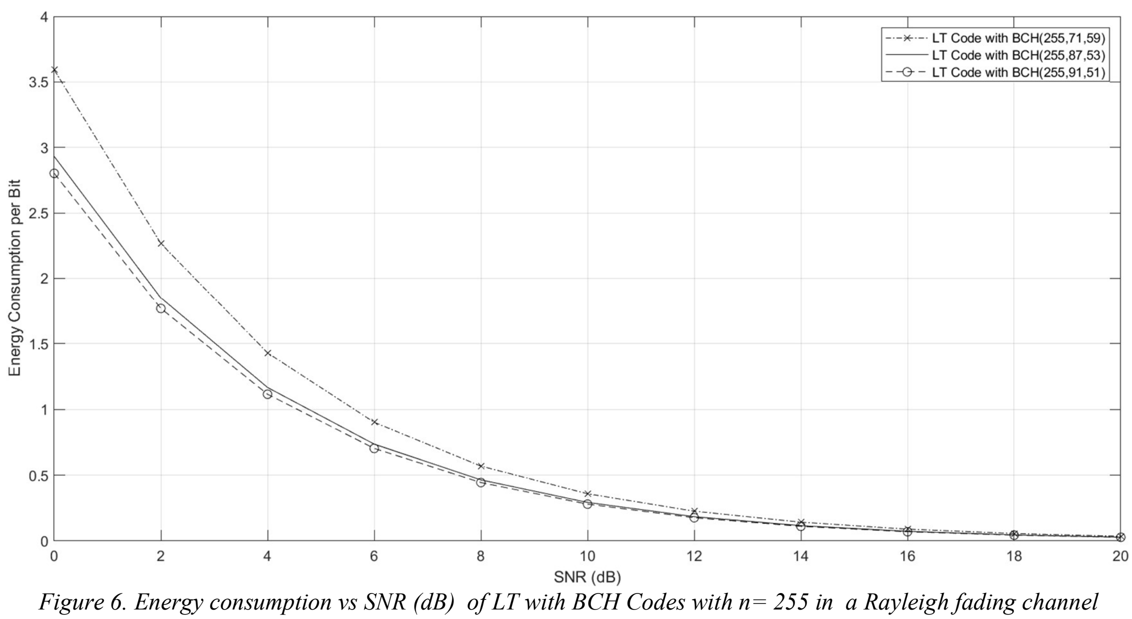

Figure 6. Energy consumption vs SNR (dB) of LT with BCH Codes with n= 255 in a Rayleigh fading channel

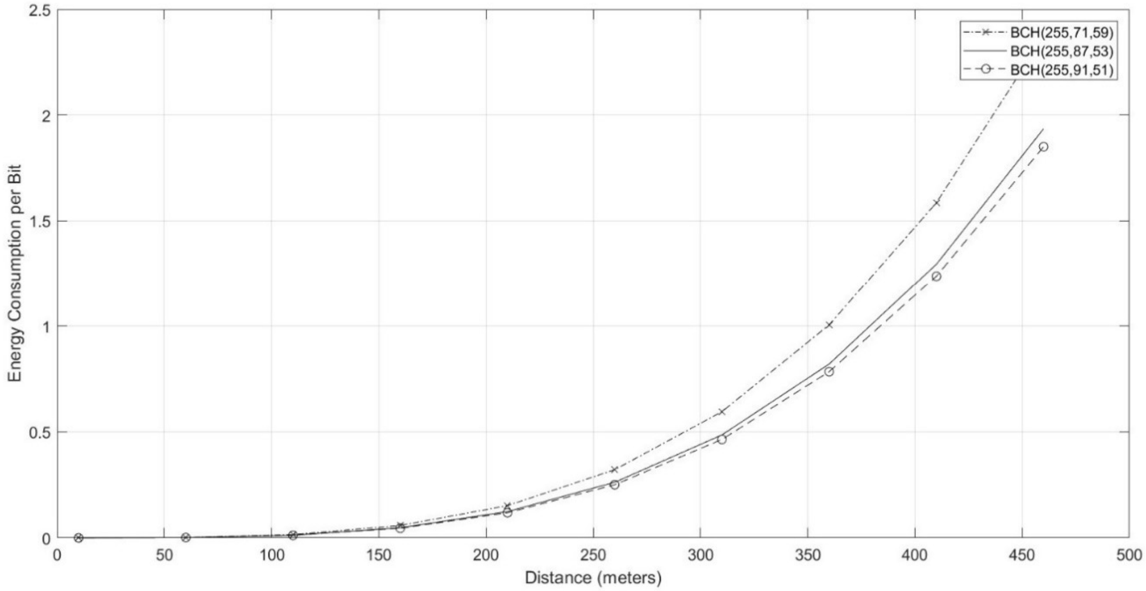

Figure 7. Energy consumption vs distance of LT with BCH Codes with n= 255 in a Rayleigh fading channel

6. CONCLUSION

A simulation-based experiment has been done to achieve both reliable data transmission and energy efficiency in WBAN, particularly in telehealth, where errors introduced during the transmission might pose detrimental misdiagnoses. The simulations have been done to analyze the energy consumption of LT-BCH codes for BCH (31,21,5), (63,36,11) (127,64,21), (255,71,59), (255,87,53) and (255,91,51) in Rayleigh fading channels for WBAN applications. A simulation to compare the energy consumption between standalone BCH code with LT-BCH code has also been done and the result shows that the energy consumption is comparable between the two schemes. This indicates that the use of Raptor-BCH code is suitable for WBAN as it offers stronger error correction capability compared to standalone BCH code. However, the results also show that there is a tradeoff between error correction capability and energy consumption of LT-BCH codes. The codes with strong error correction capability requires high energy consumption, making them suitable for applications for long distances of poor channel condition. This indicates room of improvement in optimizing the redundancy and complexity of the LT codes used.

Further research is needed to yield practical hardware implementation of the LT-BCH scheme in real WBAN devices and to analyze its performance in terms of data reliability and energy efficiency in practical channels.

7. ACKNOWLEDGMENT

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REFERENCES:

[1] L. Sari and A. Aditya, “Raptor Code for Energy-Efficient Wireless Body Area Network Data Transmission,” *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 13, no. 1, p. 277, Mar. 2015, doi: 10.12928/telkomnika.v13i1.924.

[2] K. Zhang, P. Jack Soh, and S. Yan, “Meta-wearable antennas-a review of metamaterial based antennas in wireless body area networks,” *Materials*, vol. 14, no. 1, 2021, doi: 10.3390/ma14010149.

[3] Q. Liu, K. G. Mkongwa, and C. Zhang, “Performance issues in wireless body area networks for the healthcare application: a survey and future prospects,” 2021. doi: 10.1007/s42452-020-04058-2.

[4] A. S. M. Alqadami, K. S. Bialkowski, A. T. Mobashsher, and A. M. Abbosh, “Wearable Electromagnetic Head Imaging System Using Flexible Wideband Antenna Array Based on Polymer Technology for Brain Stroke Diagnosis,” *IEEE Trans Biomed Circuits Syst*,

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vol. 13, no. 1, 2019, doi: 10.1109/TBCAS.2018.2878057.

[5] W. H. W. Hassan, D. M. Ali, J. M. Sultan, and M. Kassim, "A review of wireless body area networks," Jan. 01, 2024, *Institute of Advanced Engineering and Science*. doi: 10.11591/ijeecs.v33.i1.pp167-178.

[6] H. Taleb, A. Nasser, G. Andrieux, N. Charara, and E. Motta Cruz, "Wireless technologies, medical applications and future challenges in WBAN: a survey," *Wireless Networks*, vol. 27, no. 8, pp. 5271–5295, Nov. 2021, doi: 10.1007/s11276-021-02780-2.

[7] P. Thippun, Y. Sasiwat, D. Buranapanichkit, A. Booranawong, N. Jindapetch, and H. Saito, "Implementation and experimental evaluation of dynamic capabilities in wireless body area networks: different setting parameters and environments," *Journal of Engineering and Applied Science*, vol. 70, no. 1, Dec. 2023, doi: 10.1186/s44147-022-00171-8.

[8] F. Ullah, M. Z. Khan, G. Mehmood, M. S. Qureshi, and M. Fayaz, "Energy Efficiency and Reliability Considerations in Wireless Body Area Networks: A Survey," 2022, *Hindawi Limited*. doi: 10.1155/2022/1090131.

[9] G. Mehmood, M. Z. Khan, S. Abbas, M. Faisal, and H. U. Rahman, "An Energy-Efficient and Cooperative Fault-Tolerant Communication Approach for Wireless Body Area Network," *IEEE Access*, vol. 8, pp. 69134–69147, 2020, doi: 10.1109/ACCESS.2020.2986268.

[10] O. Ahmed, F. Ren, A. Hawbani, and Y. Al-Sharabi, "Energy Optimized Congestion Control-Based Temperature Aware Routing Algorithm for Software Defined Wireless Body Area Networks," *IEEE Access*, vol. 8, pp. 41085–41099, 2020, doi: 10.1109/ACCESS.2020.2976819.

[11] A. Sammoud, M. A. Chalouf, O. Hamdi, N. Montavont, and A. Bouallegue, "A new biometrics-based key establishment protocol in WBAN: energy efficiency and security robustness analysis," *Comput Secur*, vol. 96, Sep. 2020, doi: 10.1016/j.cose.2020.101838.

[12] B. Sansoda and S. Choomchuay, "Performance evaluation of concatenated coding with diversity reception for body area network," in *2015 International Symposium on Intelligent Signal Processing and Communication Systems, ISPACS 2015*, Institute of Electrical and Electronics Engineers Inc., Mar. 2016, pp. 479–482. doi: 10.1109/ISPACS.2015.7432819.

[13] K. Takabayashi, H. Tanaka, and K. Sakakibara, "Evaluation of Wireless Body Area Network Utilizing Super Orthogonal Convolutional Code," in *Proceedings - 2019 International Symposium on Intelligent Signal Processing and Communication Systems, ISPACS 2019*, Institute of Electrical and Electronics Engineers Inc., Dec. 2019. doi: 10.1109/ISPACS48206.2019.8986385.

[14] K. Takabayashi, H. Tanaka, and K. Sakakibara, "Toward Dependable Internet of Medical Things: IEEE 802.15.6 Ultra-Wideband Physical Layer Utilizing Superorthogonal Convolutional Code," *Sensors*, vol. 22, no. 6, 2022, doi: 10.3390/s22062172.

[15] P. Kaythry, R. Kishore, and V. Praveena, "Energy Efficient Raptor Codes for Error Control in Wireless Body Area Networks," *Wirel Pers Commun*, vol. 103, no. 2, pp. 1133–1151, Nov. 2018, doi: 10.1007/s11277-018-5271-y.

[16] A. Shokrollahi, "Raptor codes," *IEEE Trans Inf Theory*, vol. 52, no. 6, 2006, doi: 10.1109/TIT.2006.874390.

[17] R. Wang, W. Chen, and C. Han, "Low-complexity encoder implementation for LDPC codes in CCSDS standard," *IEICE Electronics Express*, vol. 18, no. 9, 2021, doi: 10.1587/ELEX.18.20210128.

[18] A. Shokrollahi and M. Luby, "Raptor codes," in *Foundations and Trends in Communications and Information Theory*, vol. 6, no. 3–4, 2009, pp. 213–322. doi: 10.1561/0100000060.

[19] O. Etesami and A. Shokrollahi, "Raptor codes on binary memoryless symmetric channels," *IEEE Trans Inf Theory*, vol. 52, no. 5, 2006, doi: 10.1109/TIT.2006.872855.

[20] N. Chakani, S. M. Mirrezaei, and G. A. Hodtani, "Performance and time improvement of LT code-based cloud storage," *EURASIP J Wirel Commun Netw*, vol. 2022, no. 1, Dec. 2022, doi: 10.1186/s13638-022-02136-0.

[21] R. Bose, *Information Theory Coding And Cryptography*, 3rd ed. Tata McGraw-Hill, 2004.