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LTE-NBP with holistic UWB-WBAN approach for the energy efficient biomedical application

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Abstract
Increased use of ultra-wideband (UWB) in biomedical applications based on wireless body area networks (WBAN) opens a variety of options in the field of biomedical research. WBAN may aid in the continuous health monitoring of patients while they go about their everyday lives. Many studies and researchers were conducted several experimentations in the same field for the performance improvement. This study covered the hybridization of UWB technology, as well as on-body, off-body, and human-body ultra-wideband communication (HB-UWB). In this paper, the parameters considered are throughput, energy consumption, energy efficiency, energy used, network survival and delay. An improved model for design and assessment of power-saving UWB-WBAN was developed in this paper. A novel protocol model was introduced in this paper, namely low-power traffic-aware emergency based narrowband protocol (LTE-NBP) to overcome the major drawbacks of emergency, critical data transmission, reliability and the power issues in UWB-WBAN. It's the emergency-based low-power traffic-aware narrowband protocol. It is based on the dual-band physical layer technology. The suggested protocol considered an aware traffic model and an emergency medium access control (MAC) protocol. The proposed model's performance was evaluated and compared with the related algorithms on different performance parameters. The improved model is found to be efficient in throughput, energy efficiency, energy consumption, and delay.

Keywords UWB · WBAN · HB-UWB · UWB-WBAN · Throughput · Energy consumption and network delay

1 Introduction

For enhancing mobility in traditional medical services, wireless technology has been used in the current age [8]. It has been more expletive if ultra-wideband technology (UWB) along with

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the UWB wireless body area network (WBAN) enlisted with the traditional medical system [8, 25]. It may be advantageous to continually monitor patient health status while imposing no constraints on the patient's lifestyle [24]. In contemporary trends, a variety of methodologies are accessible to assist WBAN applications [11]. Biofeedback, remote monitoring, provides assisted living by adapting to their specific requirements, for example. WBAN technologies comprise Bluetooth, Zigbee, IEEE802.15.4, IEEE 802.11, and IEEE 802.15.3. Wearable medical devices, intrusion detection, emergency, authentication, fitness, performance, and well monitoring applications are all possible implementations [30]. Researchers are paying a lot of attention to WBAN-based healthcare devices. UWB techniques are frequently deployed as a communication interface for BANs. IEEE 802.15.6 is the frequency band standard for on-body communication. The computation of path loss is a critical concern in WBAN [15, 16]. Swastika slot-ultra-wideband (SS-UWB) patch was recently implemented and is being tested in on-body applications. The SS-UWB antenna model's dimensions are (27 mm) × (27 mm) × (1.6 mm). In free space, efficiency ranges between 81.3% 90.67%. S11, radiation pattern, antenna efficiency, and gain are calculated using the simulation findings [6, 20, 21]. IEEE 802.15.6 is a wireless short-range communication system, whereas IEEE 802.15.3a is a personal area network (PAN) network for wide-area applications. Short-range radio wave technologies are used in most human-body ultra-wideband communication (HB-UWB) networks. The research focuses on the features of transfer functions as well as transmission loss. [43].

The major factors considered for the energy efficient biomedical application are the monitoring, energy efficient replacement, imaging, data communication, bandwidth, transmission rate etc. [9, 13, 14, 36, 38, 40]. The main motivation of this study is to present the effectiveness of low-power traffic-aware emergency based narrowband protocol (LTE-NBP) model to showcase the applicability in the biomedical applications. The main contributions of this paper are in the direction of transfer rate, throughput, energy consumption and end to end delay. It may be useful in the high-end biomedical applications and imaging with the high data speed communication. It also covers power consumptions and mobility in the same for the energy efficient use of biomedical application. So, in this paper power transmission, distance and handovers between the sensor nodes were considered for the improvement of the transmission signals efficiency. In case of model development, the model with low cost and low power implementation with good immunity to interference signals were considered. Then reliable low power two-way communication was considered along with the emergency and critical data transmission and the reliability in the technologies of WBAN for the biomedical application.

2 Literature review

In this section related work has been discussed with the analysis of methods and results to focus mainly on the challenges and advantages. In 2016, Teawchim and Promwong [41] presented the characteristics of the HB-UWB transmission model for WBAN. They have classified their channels model with body mass index (BMI). They have used root raise cosine passband waveform. It has been used as the UWB transmitted waveform. Their result is helpful in the human body evaluation channel. In 2018, Sanguanpuak et al. [34] discussed body area network (BAN). They have suggested UWB technology for the BAN system. It has been suggested because of impulse radio and low power. They have studied the HB-UWB channel. They have reported the distortion analysis due to the antenna and human body of HB-

UWB. In 2018, Promsrisawat and Promwong [29] discussed short-range communication systems in wireless communication technologies. They have presented waveform distortion due to the human body in transfer function for WBAN. Their technique found to be useful in accurate design and evaluation. In 2018, Chai sang and Prom wong [7] discussed short-range communication networks around the human body. Their model has been designed for the testing and measurement of the human body in an indoor environment. In 2019, Sanguanpuak et al. [35] discussed the combination of UWB and wireless human body applications. They have also discussed parameter, path loss and power delay profiles. In 2020, Ashyap et al. [4] reviewed the wearable/flexible antennas. It has been reviewed the electromagnetic band-gap structure with single and dual-band designs. In 2020, Umar et al. [42] discussed the development of WBAN. They have proposed a mutual authentication and data encryption scheme. It is based on signal propagation characteristics. They have also conducted security and performance analyses. In 2020, Sambandam et al. [33] discussed off-body communication. The main advantage of their approach is the directional radiation pattern. It has been obtained from the developed antenna. It also ensures low backward radiation for WBAN applications. In 2020, Ling et al. [22] studied point-to-point WBAN with the Backscatter Communication and Harvest-Then-Transmit mode. They have formulated a throughput maximization problem. It has been done by optimizing the time allocation, reflection coefficient and transmission power of the sensor. In 2020, Alani et al. [1] suggested the wide usability of UWB. It has been discussed in terms of WBAN. The main purpose is to explore it in the medical applications. They discussed several aspects including advantages and disadvantages. In 2020, Munivel et al. [23] discussed about health care devices. Their study main aim is to improve the selection algorithm for the dynamic channel. Their proposed method has proficient in time as comparison to the traditional methods. In 2021, Parameswari and Chitra [27] introduced a UWB antenna using Jeans. It is flexible, planar and in small size. The bandwidth proposed is 12 GHz. It is suitable for the WBAN operation as it can be operated from 2.8 to 10.9 GHz. In 2021, Alhawari et al. [2] presented a UWB antenna based on metamaterial. It was used for the breast imaging and WBAN applications. The wearable antenna is required to be a planar and low-profile structure using flexible materials. Their results found to be prominent for both of the applications. Sowndeswari and Kavitha [39] discussed about energy-efficient clustering. Artificial bee colony optimization has been used for the wireless sensor network (WSN). It is found to be prominent with different performance measures. Cherifi et al. [10] discussed regarding WBAN. It is found to be useful in jamming attacks. Different WBAN techniques along with the node selection approaches have been discussed for achieving efficient energy [17, 32, 37, 40]. In 2022, Ashraf et al. [3] discussed regarding the sensor in WBAN. They suggested that the sensor can be helpful as the coordinator node. They have proposed energy efficient dynamic channel allocation algorithm. Their approach is found to be efficient in throughput, packet delivery ratio and energy consumption minimization. In 2022, Karunanithy and Velusamy [18] discussed WBAN in terms of health monitoring. But the data volume is the bigger challenge in the processing of the data. They proposed edge shared approach with ant colony optimization algorithm to decrease the latency. It is prominent and effective in quality-of-service parameters. In 2022, Du et al. [12] discussed WBAN in terms of UWB. They have varied the bending radius, working bandwidth and other parameters to improve the test performance. In 2022, Bhatti et al. [5] discussed the biosensors in terms of WBAN. They have used deep learning approaches. It can be helpful in health information and medical informatics. They have applied deep learning-based approach for the COVID-19 detection. It is helpful in real = time monitoring system.

The above literature suggested that the combination of UWB-WBAN approach may be efficient for different biomedical and healthcare application. But there is the need of improvement in the communication system through transfer rate, throughput, energy consumption and end to end delay. It is also indicated that the system level improvement may be helpful in the high-end biomedical applications and imaging.

3 Methods

To overcome the major drawbacks of emergency, critical data transmission, reliability and the power issues in UWB-WBAN, a novel protocol model have been introduced in this paper, namely low-power traffic-aware emergency based narrowband protocol (LTE-NBP).

The LTE-NBP UWB protocol model has been designed considering low coupling in case of human body. It is basically a mono-cone cooperative design. It is efficient in body communications. For the height reduction a semi sphere is used. It enhances the impedance bandwidth of -15 dB. The height is approximately 6.2 mm and the ground plane is 30 mm × 30 mm with the area under coverage is 1000 × 1000 m. It covers the range of 1.5 to >15 GHz.

The simulation parameter and values are shown in Table 1. IEEE 802.15.4 standard was considered. Two ray propagation model with omni-directional antenna were considered. File transfer protocol with transmission control protocol agent were considered for the experimentation.

This protocol was explained and discussed based on the below model.

- Traffic Aware Model,
- Emergency medium access control (MAC) protocol based on a dual-band physical layer technology
  - Emergency MAC protocol
  - Narrowband path

3.1 Traffic-aware model

The traffic model of this algorithm has two main areas. They are channel sensing and channel bonding. The parameters used in Algorithm 1 are usable list, free channels recognition and threshold values. Initially, the recognized channels are used to match node requirements. Then, allocation of signals to noise ratio (SNR) values to every channel from the channels list was

Table 1 Simulation parameter and values

Parameters	Values
Time for the Simulation	100 ms
Area under coverage	1000 × 1000 m
Number of Nodes	10–400
Routing Protocol	AODV
Power range	100–1000 J
Range for Idle Power	0–1 J (Default: 0.1 J)
Type of Queue	Drop-Tail

performed. The gateway device works using these algorithms, and it is accountable for channel allocation. Channel allocation provides some conditions to the usable channel list. The rate of data must be higher than the channel capacity. If this condition satisfies, then the process of channel bonding will be initiated. If the rate of data is not higher than the channel capacity leads to the process single channel for communication.

Algorithm 1 Channel Sensing Algorithm

Step 1 – Input C_{List}
Step 2 – Output U_{List}
Step 3 – while initially $U_{List}= 0$
Step 4 – Variable threshold limits are initiated
Step 5 – If [SNR of $C_{UL}>$ ($Threshold_{MAX} \times R_{energy}$)]
$U_{List}= C_L$ Ù C_{UL}
Step 6 – end If
Step 7 - If [SNR of $C_{UL}<$ ($Threshold_{MAX} \times R_{energy}$)]]
$U_{List}= C_{List} + 1$
Step 8 – end if
Step 9 – end while

Where,

- C_{List} – Channel List
- U_{List}- Usable List
- C_{UL} – Channel from Usable List
- R_{energy} – Residual Energy

Algorithm 2 Channel Bonding Algorithm

Step 1 – Input $Node_{count}$ and U_{List}
Step 2 – Output D_{out} (at initial condition outputs are zero)
Step 3 – If $Node_{count}>C_{count}$ (when $U_{List}\neq 0$)
Step 4 – $Bonded_{rate} = C_{count} – A_{List}$ (Where $A_{List}= C_{count} - U_{List}$)
Step 5 – end if
Step 6 – If $Node_{count}<C_{count}$ (when $U_{List}\neq 0$)
Step 7 - $Bonded_{rate} = C_{count} - Node_{count}$
Step 8 – end if
Where,

- $Node_{count}$ – Sink node traffic
- C_{count} – Channel rate
- A_{List} - Avaliable Channel List

3.2 Emergency MAC protocol

For the case of emergencies MAC protocol approach, the following steps were employed.

Step 1: The nodes begin by determining the optimal intermediate node from the given location. This is made feasible either through the periodic transmission of hello messages. In this model, a hello message is exchanged every 30 seconds. The hello memory is then sent across nodes, allowing them to locate the next neighbour and put the information in the neighbours list.

Step 2: Next, the node begins to sense its important parameters and communicates the packet to its destination using the carrier-sense multiple access (CSMA) protocols. With the two conditions, the procedure is repeated. In the absence of the emergencies packet transfer case, there should be no increment in traffic congestion.

Step 3: Finally, a communication channel based on high priority regions is established. Suppose a node is detected as being in a high priority region. In that case, its neighbours retain the data and switch to time-division multiple access (TDMA), assigning the current slot to the node in the high priority station.

Step 4: Furthermore, if two nodes in the existing slot represent the highest-priority location, they will be allocated to transmit information one after the other. Finally, CSMA mode will be implemented.

The frame includes all of the node identifying details, which are sent together with the packets to increase the speed of data flow from one node to the next. The buffer level of the node furthest from the sink is extremely low, prompting the node to migrate closer to the end nodes to raise the buffer level. The network's threshold model was used to calculate the total memory availability (Eqs. 1 and 2).

$$Q_T = [(\lambda - \alpha)\ 10]\ \alpha < \lambda \tag{1}$$

$$Q_T = [(\alpha)\ 10]\ \alpha = \lambda \tag{2}$$

Where α = Current node and λ = total number of nodes.

Except for the last node, Eq. 1 includes data on the nodes in the networks that lead to the sink. The node that had been left out of Eq. 1 is determined by Eq. 2. As a result, the dynamic buffer level supports the reductions in energy utilization.

3.3 UWB with narrowband physical layer

Impulse radio-based transmission model UWB has to be chosen as a physical layer technology. The core concept is based on the carrier-based model, namely narrow band. UWB systems directly receive the matched data from the pulses, and that is termed direct modulation.

4 Results

The main parameters used in this work are throughput, energy consumption, energy efficiency and delay. The results discussed with limited nodes to show the functionality and for the comparison variable nodes were considered. The simulation has been performed on the NS-2 environment. The performance of the proposed protocol is analyzed with different parameters including supporting planes and legs. It is first optimized to produce the desired UWB frequency. The following ranges have been inferred and considered for the simulation based on the return loss depiction.

Frequency: 4GHz to 15GHz.

Optimum dimension: 3 mm to 5 mm.

Ground dimension: 25 mm to 30 mm.

Height: 5 mm to 7 mm.

4.1 Throughput

The network's throughput is defined as the number of information processes by all nodes according to the total number of nodes. Figure 1 shows the throughput of the network. The x-axis represents the number of nodes, and the y-axis represents the average throughput of the network. Our proposed LTE-NBP method produces the maximum throughput of 3.85 Kbps with 12 nodes.

4.2 Energy consumption in terms of node

Consumed energy is defined as the energy which is used during the process of functioning and transmission. It is calculated concerning the number of nodes. The energy usage is shown in Fig. 2 as a function of the number of nodes. The x-axis depicts the number of nodes, while the y-axis depicts the network's energy usage. LTE-NBP technique uses 1230 J.

4.3 Energy consumption in terms of data rate

Figure 3 shows the energy consumption concerning data rate. The x-axis represents the date rate, and the y-axis represents the energy consumption of the network. LTE-NBP method produces the energy consumption of 1350 J.

4.4 Energy consumption concerning time (ms)

Figure 4 shows the energy consumption concerning time. The x-axis represents time, and the y-axis represents the energy consumption of the network. LTE-NBP method produces reduced energy consumption of 1250 J.

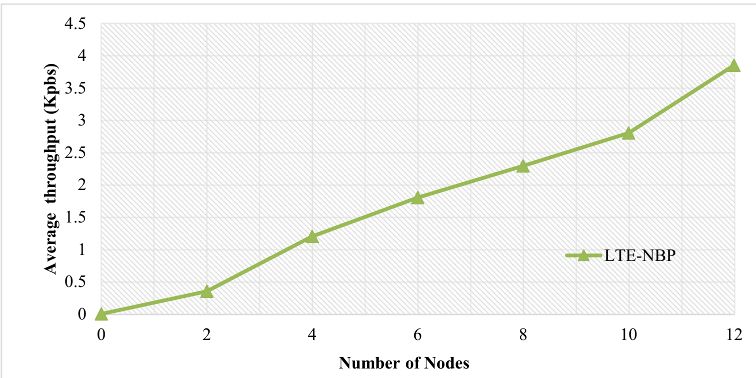

Fig. 1 Throughput of the network with limited nodes

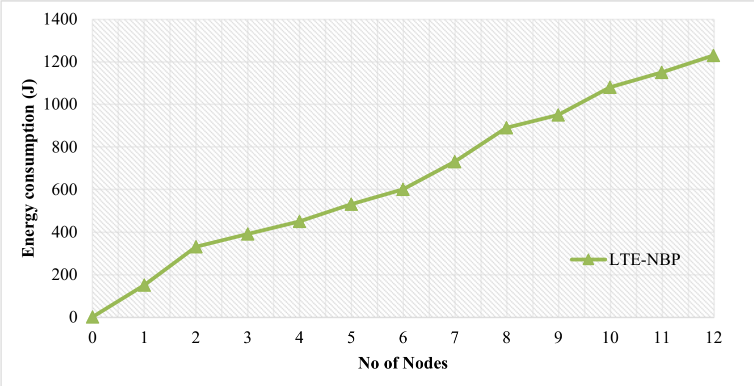

Fig. 2 Energy consumption concerning the number of nodes

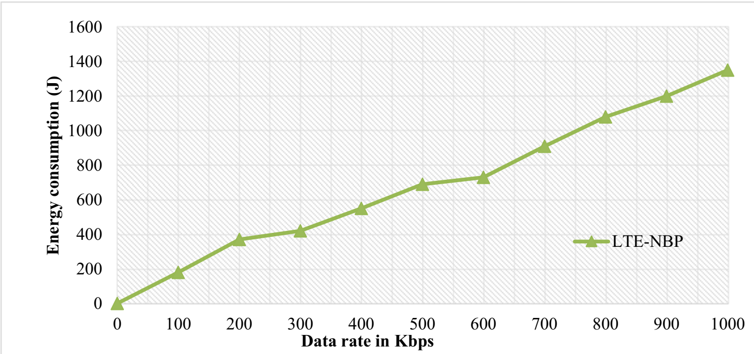

Fig. 3 Energy consumption concerning data rate

4.5 End to end delay calculation concerning the number of nodes

The end-to-end latency is shown in Fig. 5 as a function of the number of nodes. The overall network latency is determined as a function of the number of nodes. The x-axis in this graph

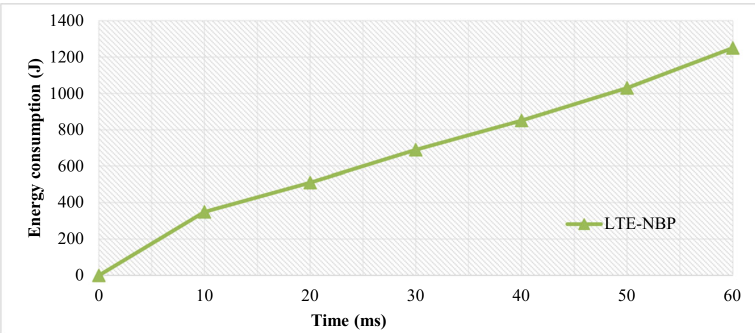

Fig. 4 Energy consumption concerning the time

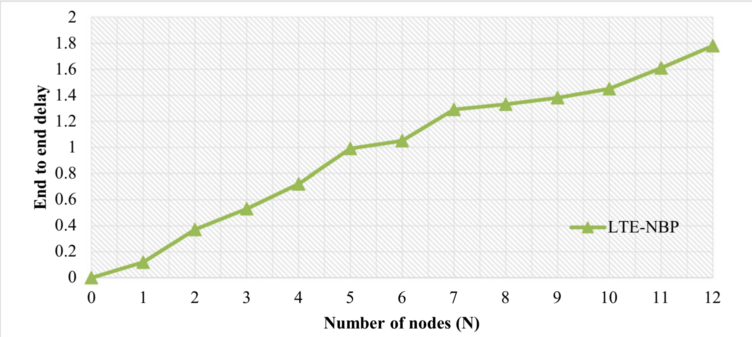

Fig. 5 End to end delay concerning the number of nodes

shows the number of nodes, while the y-axis represents the network's end-to-end latency. LTE-NBP approach has an end-to-end latency of 1.780 (ms).

Figure 6 shows the energy consumption in case of variable nodes. Figure 7 shows the average energy consumption in different epochs. Figure 8 shows the time delay in case of variable nodes. Figure 9 shows the energy used in case of variable nodes. Figure 10 shows the average network survival time in different epochs. The comparative clearly depicts the effectiveness of our approach.

In case of energy consumption, it is clearly depicted from Figs. 6 and 7 that the energy consumption found to be prominent in case of LTE-NBP. So, it may be helpful in the efficient and robust transmission of data and signal both in case of biomedical applications. It is due to the narrowband protocol as it is efficient in increasing the density of the transmission power. Hence enhance the coverage capabilities and reduces the consumption.

In case of time delay, it is clearly depicted from Fig. 8 that the transmission delay is less in comparison to the traditional approaches. It is due to the low latency and low duty cycle in case

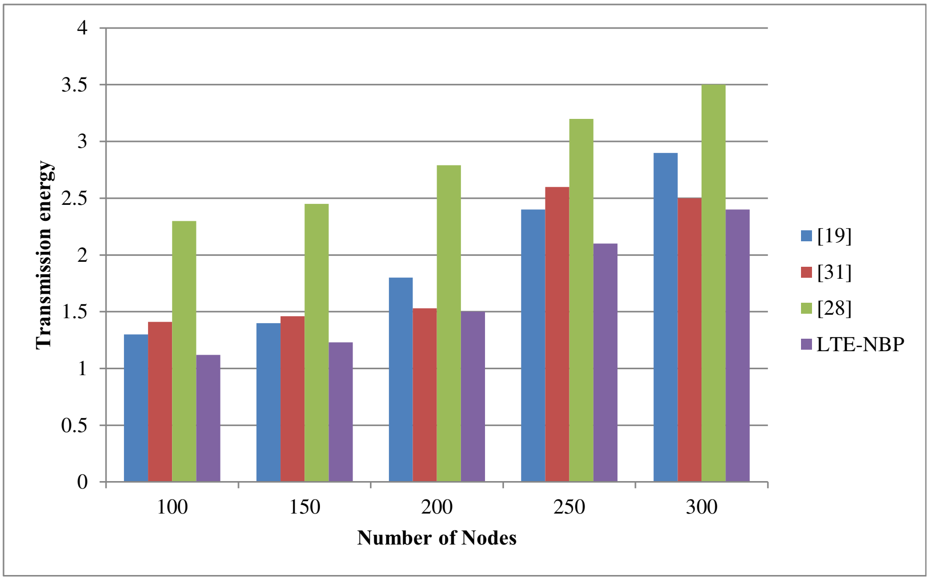

Fig. 6 Energy consumption in case of variable nodes

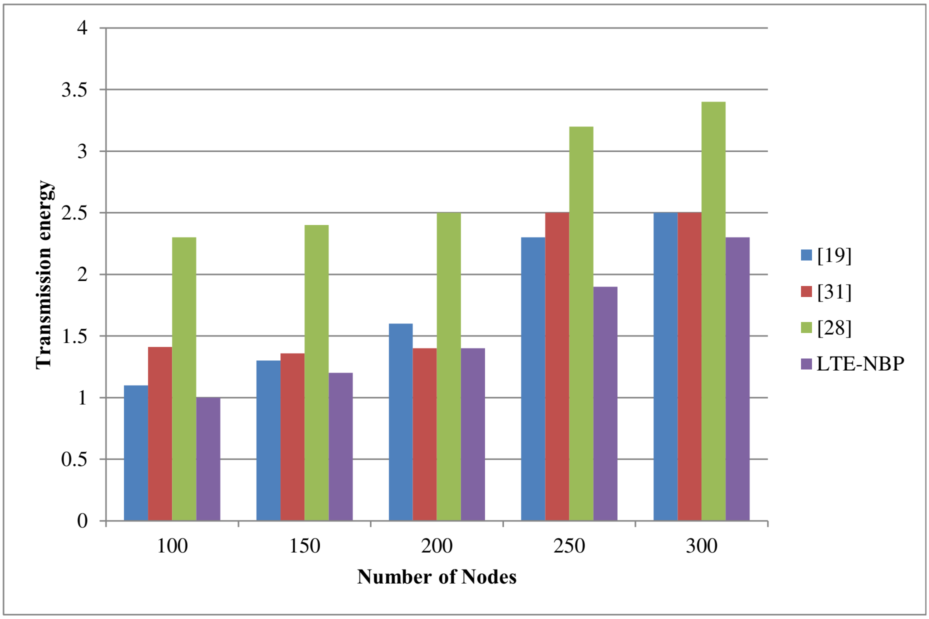

Fig. 7 Average energy consumption in case of variable nodes

of low-power traffic-aware model. It also beneficial in reducing the power consumption. Figure 9 also depicted the same. The survival time in different epochs also shows prominent results with different cycles.

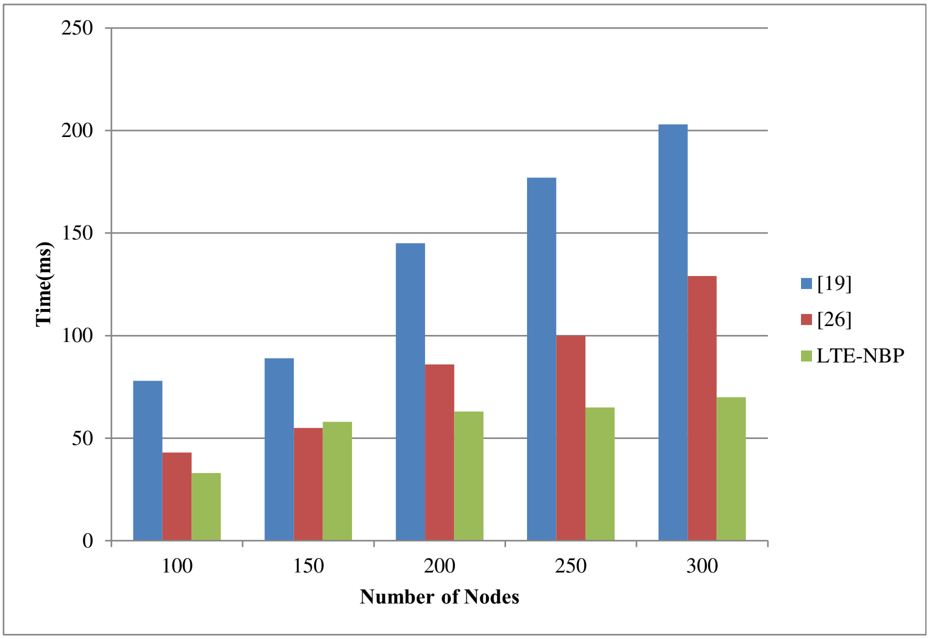

Fig. 8 Time delay in case of variable nodes

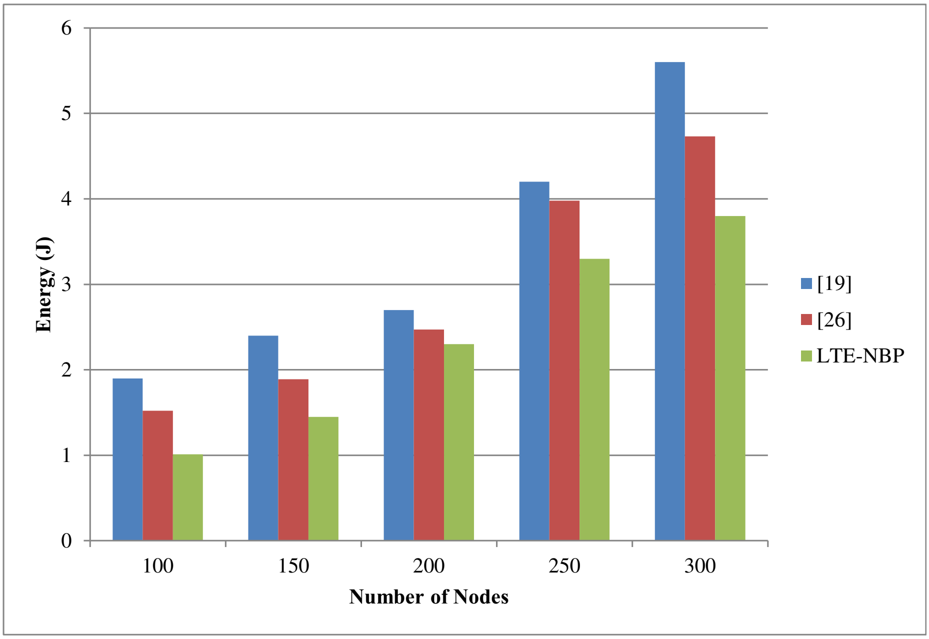

Fig. 9 Energy used in case of variable nodes

The proposed LTE-NBP is perform well in throughput of the network in terms of data and signal processing. Similarly in case of the consumed energy during the process of functioning and transmission. So, through the proposed approach the efficiency of the transmitted signals

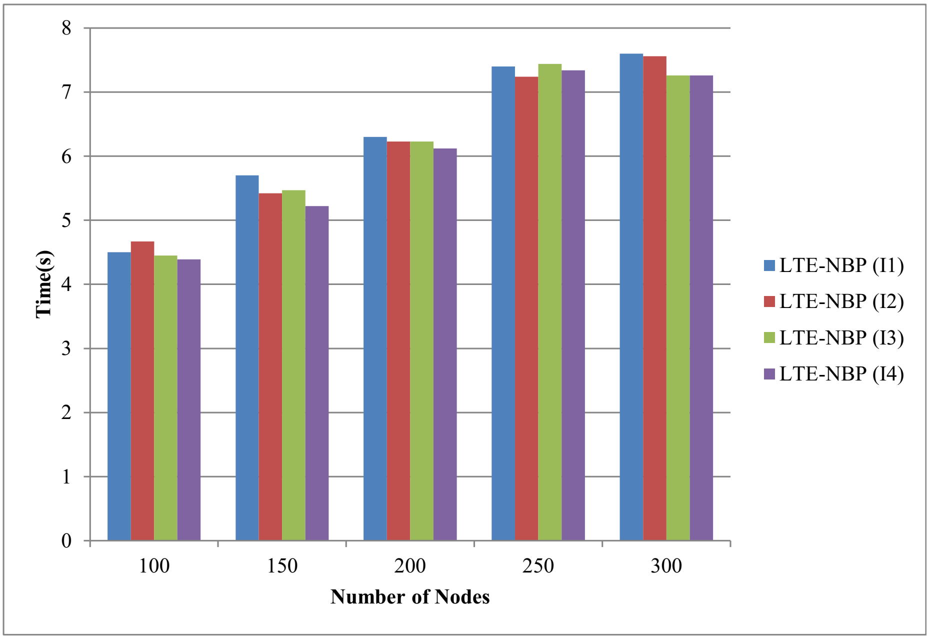

Fig. 10 Average network survival time in different epochs

may be improved. The main working areas considered are controlling the power transmission, detecting the distance and handovers between the sensor nodes. Here user develops the model with low cost and low power implementation with good immunity to interference signals has been considered. Then reliable low power two-way communication was been considered along with the emergency and critical data transmission and the reliability in the technologies of WBAN. So, it may be useful in biomedical applications as these terms are helpful in human body evaluation process more robust, effective and seamlessly.

5 Discussion

The result impact are as follows through the LTE-NBP approach.

1. LTE-NBP approach is found to be efficient and robust in case of data transmission and signal both. It is capable in enhancing the coverage capabilities and reduces the energy consumption. So, it may be helpful in health and biomedical applications.
2. Due to the low latency and low duty cycle in case of low-power traffic-aware model, it is beneficial in power consumption reduction.
3. The main working areas considered are controlling the power transmission, detecting the distance and handovers between the sensor nodes. So, it may be useful in biomedical applications as these terms are helpful in human body evaluation process more robust, effective and seamlessly.
4. It is also efficient in terms of throughput maximization problem in terms of time allocation and the transmission power of the sensor.
5. The proposed protocol is based on a dual-band physical layer technology with efficient network survival and reduced packet delay.

The main limitation of this study is the live implications of this approach with biomedical applications. In future this approach can be replicated with the real time biomedical applications for the parameter approvals and validations as the study provides a direction towards the ease in biomedical applications.

6 Conclusions

In this paper, UWB-WBAN has been discussed for the biomedical applications. A novel LTE-NBP protocol model was introduced in this paper to overcome the major drawbacks of emergency, critical data transmission, reliability and power issues in UWB-WBAN. The parameters considered for the experimentation are throughput, energy consumption, energy efficiency, energy used, network survival and delay. The main working areas considered were power transmission control, detecting the distance and handovers between the nodes. The proposed model was designed with low cost and power with good immunity to interference signals. Then reliable low power two-way communication was considered along with the emergency and critical data transmission with the reliability in the technologies of WBAN. The result indicates that our approach has better performance than traditional methods based on the parameter used.

Declarations

Conflict of interest The authors have no conflicts of interest to declare.

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