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Research Article

Priority-Based Resource Allocation and Energy Harvesting for WBAN Smart Health

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With the emergence of new viral infections and the rapid spread of chronic diseases in recent years, the demand for integrated short-range wireless technologies is becoming a major bottleneck. Implementation of advanced medical telemonitoring and telecare systems for on-body sensors needs frequent recharging or battery replacement. This paper discusses a priority-based resource allocation scheme and smart channel assignment in a wireless body area network capable of energy harvesting. We investigate our transmission scheme in regular communication, where the access point transmits energy and command while the sensor simultaneously sends the information to the access point. A priority scheduling nonpreemptive algorithm to keep the process running for all the users to achieve the maximum reliability of access by the decision-maker or hub during critical situations of users has been proposed. During an emergency or critical situation, the process does not stop until the decision-maker or the hub takes a final decision. The objective of the proposed scheme is to get all the user processes executed with minimum average waiting time and no starvation. By allocating a higher priority to emergency and on data traffic signals such as critical and high-level signals, the proposed transmission scheme avoids inconsistent collisions. The results demonstrate that the proposed scheme significantly improves the quality of the network service in terms of data transmission for higher priority users.

1. Introduction

Wireless body area networks (WBANs) have been developed as a capable solution for real-time healthcare monitoring systems. Medical applications of WBANs are more important in critical life circumstances, where real-time monitoring and high reliability of data transmission are required. In general, healthcare and medical applications in WBANs require significant goals such as quality of service (QoS), flexibility, and cost-effectiveness to be accomplished. WBAN consists of heterogeneous sensor nodes, implanted in various parts of the human body to collect physiological parameters such as critical and noncritical information and transfer them to the coordinator. Furthermore, several actuators are positioned within the proximity, on/inside the human body, to communicate through the network to a prime location.

WBAN includes a gateway that delivers via wireless communication technology back to the wired world [1–3]. Unfortunately, in highly dense areas, there is an increased chance for WBAN to meet each other, which in turn leads to high intra-WBAN interference. This intra-WBAN interference will affect the active channels simultaneously. Under these intra- and inter-WBAN interferences, the network performance is extremely affected, leading to a severe decrement in the network lifetime [4–6]. These problems are highly challenging in real-time healthcare medical applications because the interferences that cause failure in data transmission can endanger human lives. Since sensor monitoring plays an important role in saving human lives, the failure of data transmission under critical circumstances determines whether the patient survives or dies.

A few interference moderation schemes applied to colocated WBANs include resource allocation and power allocation schemes [7, 8]. These schemes use intra- and inter-WBAN interference schemes to maximize their individual utility active sensor nodes. However, as the colocated WBANs share reduced channel capacity, it is necessary to tune the sensor data reasonably to mitigate both inter- and intrainterferences to improve the QoS in high-density areas. Nevertheless, the MAC protocols when applied in WBANs have an excessive impact on ensuring reliable communication, inter intra interferences, energy efficiency, and QoS [9, 10]. The different approaches for the PHY and MAC layers suggest efficient and reliable mobile healthcare services in WBANs.

The dearth in the spectrum and the constraints in energy are the two significant challenges encountered at the time of deploying the Internet of Things (IoT) devices in sixth-generation- (6G-) enabled cognitive IoT networks. To overcome these limitations and enhance the energy efficiency and spectrum of the 6G-enabled cognitive IoT networks, the cooperative spectrum sharing and simultaneous wireless information and power transfer (SWIPT) technique is discussed in [11]. Thus, SWIPT refers to a wireless power transfer technique in which the data is concurrently transmitted through the same magnetic or electromagnetic field. A new cooperative communication system centered on a two-tier WBAN with a full-duplex and SWIPT scheme that outperforms the performance of the then-existing schemes [12]. These two novel resource allocation strategies are briefly explored in [13] to overcome the challenge of energy consumption minimization with throughput heterogeneity in a battery-assisted and battery-free wireless powered body area network (BAN).

1.1. Application of Resource Allocation Methods in WBAN. The cutting-edge technology of energy harvesting has gained the utmost importance in WBAN by introducing optimal resource allocation schemes [14, 15]. These resource allocation schemes have the potential to improve the communication performance of wireless networks by increasing throughput and network lifetime. In [16], a novel resource allocation algorithm termed the prioritized resource allocation algorithm based on the IEEE 802.15.6 active superframe interleaving strategy is proposed. This algorithm is intended to share the restricted communication channel resource between multiple WBANs. In [17, 18] for a WBAN, the authors proposed a buffer-aware resource allocation strategy that facilitates enhancing the QoS and energy efficiency. Later, the authors in [19] with the aid of a distributed resource allocation mechanism analyzed the performance optimization of the body-to-body network framework. This proposed distributed resource allocation mechanism empowers each involved WBAN user to take part and cooperatively upload one another's data. Also, an auction-based methodology was proposed for optimizing data uploading and reimbursement for all involved users.

1.2. Motivation and Contributions. The identified research gaps are summarized here:

(i) A detailed study of previous research works are discussed in the introduction section; it is concluded that priority scheduling nonpreemptive algorithm with smart channel assignment (SCA) and QoS data traffic categorized for WBAN smart health have not been considered by the researchers previously

(ii) The problems associated with efficient information transfer and energy harvesting have garnered significant research attention in recent years. The WBAN performance is extremely affected under intra- and inter-WBAN interferences; these cause the failure in the data transmission and can endanger human lives

Motivated by the previously mentioned challenges of WBANs, this work proposes priority scheduling and coordinator transmission strategy to influence the network lifetime and user efficiency. As the energy level of a sensor node reduces to a lower value, the sensor node cannot progress to transmit or retransmit large-sized data packets. However, in the proposed scheme, the coordinator receives small-sized data packets in very short intervals; furthermore, the coordinator forwards the information to the decision-maker for critical rescue operations. The following points highlight the significant contributions made by this work:

(i) A priority scheduling nonpreemptive algorithm with SCA for WBAN smart health is proposed. The potential advantage of this algorithm is to keep on running the process of all users to attain maximum reliability until all the processes are executed. Also, this scheme is aimed at improving network performance by considering the reliability of the critical user to be the highest priority and the rest of the nodes to lower priority by assigning a static channel exclusively allocated for individual user

(ii) The data traffic associated with the priority scheduling nonpreemptive algorithm is categorized into four major subclasses, namely, emergency, on-demand, normal, and nonmedical data signals in order to assist the different QoS requirements. Also, this data traffic is prioritized through avoiding inconsistent collision by allocating higher priority to emergency and on data traffic signals such as critical and high-level signals. Thus, the proposed scheme reduces the channel access delay by transmitting the smaller-sized data packets to the coordinator in a short interval

(iii) The nodes can be organized and controlled by the coordinator or hub, which illustrates that priority mapping together with the installation of a constructive body node coordinator will have a great impact on the lifetime of the network and its efficiency. The results indicate that the priority scheduling nonpreemptive algorithm performs during

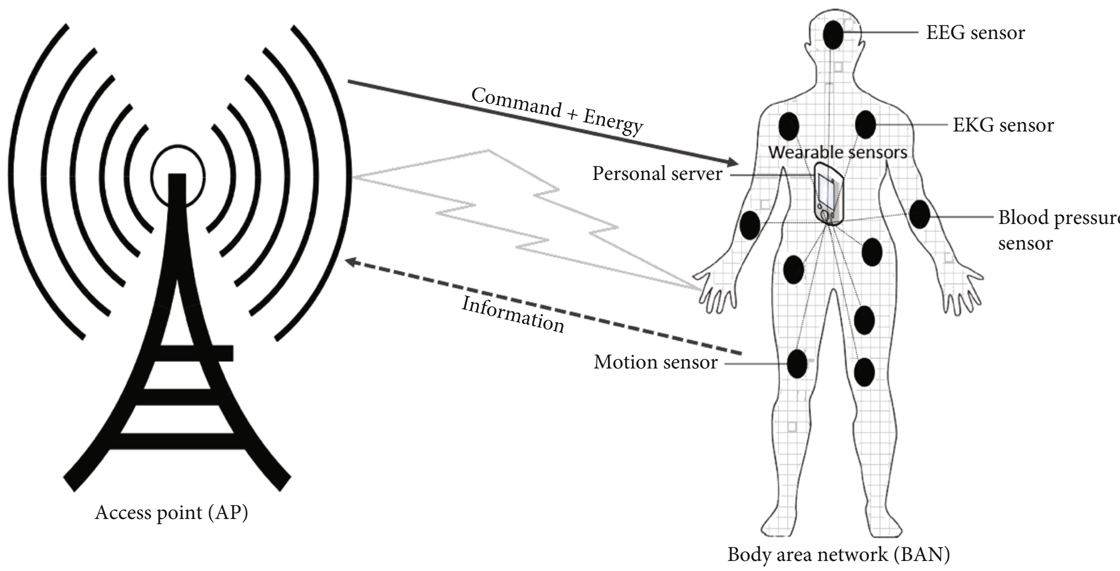

Figure 1: The communication model for energy-harvesting BAN.

emergency and on-demand signals compared to the novel priority-based channel access algorithm for contention-based MAC (NPCA-MAC) [5], low-rate wireless personal area networks (LR-WPAN) [20], and priority-based adaptive schemes [5, 20].

The rest of this paper is structured as follows: Section 2 describes the system model and general energy conception analysis. In Section 3, the regular and irregular communication schemes are explained. In Section 4, the proposed priority-based cooperation transmission scheme is briefly discussed. In Section 5, the radio energy model and path loss model utilized in the study are discussed. In Section 6, the proposed work's performance is evaluated. Sections 7 and 8 emphasize future research directions and conclusions.

2. System Model

This section discusses the communication model for energy harvesting based on BAN as shown in Figure 1. The power splitting protocol and energy harvesting in wearable sensors for regular (normal incident) and irregular communications (abnormal incident) are also described.

To monitor the physiological signal information from the human body, energy harvesting BAN along with an ultralow power consumption sensors are used. The access point (AP) transmits wireless energy to the sensors at fixed intervals and collects the information from the sensors. Based on the time division multiple access (TDMA) protocol, two main energy harvesting BAN scenarios termed the wireless energy transfer (WET) and wireless information transfer (WIT) models are considered.

It is assumed that S_n number of sensors and T_{tn} number of time slots are denoted as $S = \{S_1, S_2, S_3, \cdots, S_n\}$ and $T = \{T_{t1}, T_{t2}, T_{t3}, \cdots, T_{tn}\}$, respectively. Table 1 defines the symbols and notations used in the various equations.

Table 1: Symbols and notations.

Symbols	Definition
$y_{[s_n]}$	Signal received by the sensor from AP
P_T	Transmitter power of AP
n_{sn}	Noise added at the sensor
$\mathbf{x_t}$	Energy and information transmitted from AP to sensor
h_d	Downlink channel gain between AP and sensor
E	The average energy access period
D_k^i	The delay of the k^{th} packet
N_i	The total number of priority nodes
N_T	The total number of transmitter nodes
α	The channel bandwidth for the sensor
P_{Ts}	The received signal power at the AP
L_{CAP}	The length of the connection access period
η	The energy converting efficiency $(0 < \eta < 1)$
ρ	The required energy conversion for one-bit data
$\mathrm{g_u}$	Uplink channel gain from sensor to AP
n_a	Noise added at the AP
τ	The amplify-and-forward coefficient at the sensor
x_{ts}	Information transmitted from sensor to AP
$P_{s,ab}$	Transmitter power of the sensor from node
T	Total transmission time

$$\sum_{i=0}^{n} T_{ti} = T. \quad (1)$$

2.1. Wireless Energy Transfer. WET has become a vital technology to power sensor devices. WET delivers an indispensable technology and attractive solutions to supply uninterrupted and steady energy for sensor devices. WET transmits the energy to the desired receivers, with the help of radio signals.

$$E^i_{\text{WET}} = \psi P_{et} h_{et} T_{tn}, \tag{2}$$

where ψ represents the power ratio, P_{et} represents the AP transmit power, h_{et} is the downlink channel gain from the AP to the sensor, and T_{tn} represents the total number of time slots.

2.2. Wireless Information Transfer. Consistent WIT is a significant factor for WBANs. It is substantial to accomplish a trade-off among WET and WIT. A portion of the radio frequency signal is used for wireless energy harvesting and another portion is applied to wireless information processing at each sensor device.

$$R_i = \alpha \log_2 \left(1 + \frac{P_{it} h_{it}}{\sigma^2} \right), \tag{3}$$

where σ^2 is the variance of complex white Gaussian noise and α is the channel bandwidth for the sensor. P_{it} represents the transmitted power and h_{it} is the downlink channel gain from the AP to the sensor.

2.3. General Energy Consumption Analysis. The energy utilized by the circuit of the sensor S_i is denoted as E^i_c. The energy consumed by signals processed by the sensor is denoted as $E^i_{\text{proc}} = \gamma_i \omega_i$, where γ_i is the energy required to process one bit of data. The amount of energy consumed is associated with the size of data ω_i. Energy utilized for information transfer by the sensor is denoted as $E^i_{\text{Trans}} = P_{it} \omega_i / R_i$. So, E^i_{Trans} is written as follows:

$$E^i_{\text{Trans}} = P_{it} T_{ti} = \left(2^{\omega_i/\alpha T_{ti} - 1}\right) \frac{\sigma^2 T_{ti}}{h_{it}}. \tag{4}$$

The overall energy consumption by the sensor E_i^{Total} is denoted by

$$E^i_{\text{Total}} = E^i_c + E^i_{\text{proc}} + E^i_{\text{Trans}} \tag{5}$$

$$= E^c_i + \gamma_i \omega_i + \left(2^{\omega_i/\alpha T_{ti} - 1}\right) \frac{\sigma^2 T_{ti}}{h_{it}}, \tag{6}$$

where T_{ti} is the time slot duration.

3. Communication in WBAN

This section describes two different circumstances in sensor communication, namely, regular communication and irregular communication.

3.1. Regular Communication. In regular communication, the AP simultaneously transmits both energy and the command to the sensor. The sensor forwards the information to the AP without delay.

The signal received by the sensor can be expressed as

$$y_{[s_n]} = \sqrt{(P_T)} h_d x_t + n_{sn}. \tag{7}$$

The average energy harvested at the sensor is given by

$$E = \eta \rho E\left[|y_{sn}|^2\right] \left(\frac{T_{ti}}{2}\right) \approx \eta \rho P_a |h|^2 \left(\frac{T}{2}\right). \tag{8}$$

The signal received at the AP is expressed as

$$y_{[ap]} = \sqrt{(P_{Ts})} g_u x_{ts} + n_a. \tag{9}$$

The average energy harvested to transmit information at the sensor is given by

$$E_s = E\left[|y_a|^2\right] \left(\frac{T}{2}\right). \tag{10}$$

The energy harvesting inequality constraint is streamlined into an equality constraint by considering $E_s = E$.

3.2. Irregular Communication. In irregular communication, the sensor initially transmits a command to the AP for energy requirement. The AP in turn sends wireless energy to the sensor and passes on the sensor send information to AP by leveraging energy.

The signal received at the sensor terminal is given by

$$y_{[a1]} = \sqrt{(P)_{s,ab}} g x_{sc} + n_a. \tag{11}$$

The average energy harvested at the sensor is given by

$$E_{(sc)} = \eta \rho E\left[|y_{a1}|^2\right] \frac{(1-\tau)T}{2} \tag{12}$$

$$= \left(P_{(s,ab)} |g|^2 + \sigma^2_n\right). \tag{13}$$

The signal received at the AP is expressed as

$$y_{[s,ab]} = \sqrt{(P_a)} h x_a + n_s, \tag{14}$$

where P_a and P_s denote the sensors transmit power of the AP and energy harvested at the sensor at the receiver side under normal conditions $P_s << P_s$ and n_a and n_s represent sensor noise by a zero-mean complex Gaussian random variable.

The average energy harvested required to transmit information at the sensor

$$E_{s,ab} = \eta E\left[\left|y_{s,ab}\right|^2\right] (\tau T) \approx \eta P_a |h|^2 (\tau T), \tag{15}$$

where τT represents signal transmitted during of sensor phase of duration. The energy harvesting inequality constraint is streamlined into an equality constraint such as $\mu_s (E_{sc} + E_{si}) \le E_{s,ab}$. The total length of the subphases is calculated as follows:

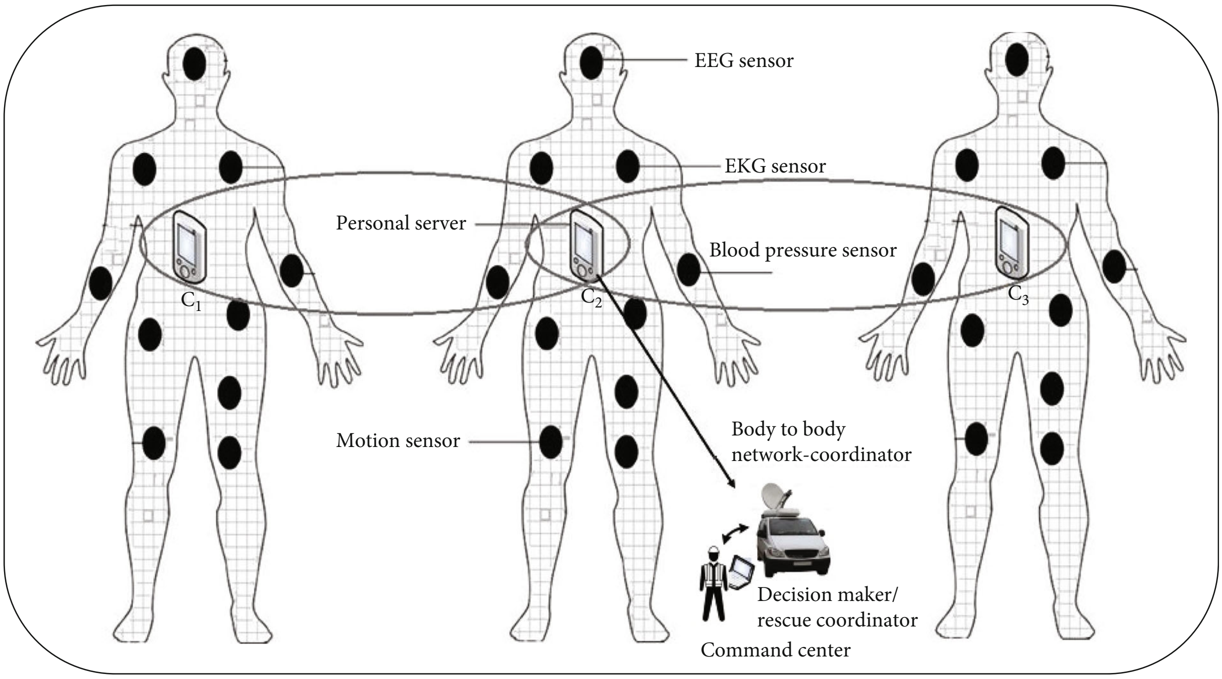

Figure 2: Body-to-body network communication with the coordinator model for critical-rescue operation.

Bits: Bit order

4	3	1	8	8	8
b0–b3	b4–b6	b7	b0–b7	b0–b7	b0–b7
Frame subtype	User priority	Reserved	Minimum allocation length request	Normal allocation length request	Maximum allocation length request
Allocation ID					

Figure 3: Framework for unscheduled allocation and request format.

$$\ell_i = \sum_{k=0}^{(i-1)} + L_{(\mathrm{CAP})} * \left(\frac{N_i}{N_T}\right). \quad (16)$$

The average transmission delay of data packets is calculated by the following equation:

$$D_k^i = \alpha * D_{k-1}^i + (1-\alpha) d_k^i, \quad (17)$$

where D_k^i is the average transmission delay or waiting time for the k^{th} packet in the traffic category and α is the average medical service delay of 125 ms. Equation (17) above computes the average delay transmission on the basis of the delay requirements.

Delay is a crucial QoS parameter for data forwarding to the concerned WBAN environment. In general, the data transmission failure and retransmission increase the average delay. The proposed analytical model calculates the average transmission delay to determine the arrival rate of incoming packets during an emergency or critical situation for the higher priority users. The average delay is reduced drastically for the higher priority users. In contrast, the average delay grows in a steady manner as the number of packets increases for the nonpriority users.

4. Proposed Priority-Based Coordinator Transmission

Priority-based communication divides the superframe into two access phases, namely, connection-access period (CAP) and the contention-free period (CFP). The four substages of the CAP period based on the traffic priorities are emergency traffic with the highest priority, on-demand traffic with minimum priority, normal traffic with the lowest priority, and nonmedical traffic with normal priority. Figure 2 shows body-to-body network communication with the coordinator for critical-rescue operations, and Figure 3 shows the framework for unscheduled allocation and the request format for user priority scheduling. The step-by-step process of the proposed scheme is highlighted in Figure 4 through a flowchart. As emergency signals play a vital role in the medical application that concern with the life of the patient, it is necessary to prioritize data traffic services for different medical applications. Table 2 elaborates BAN priority

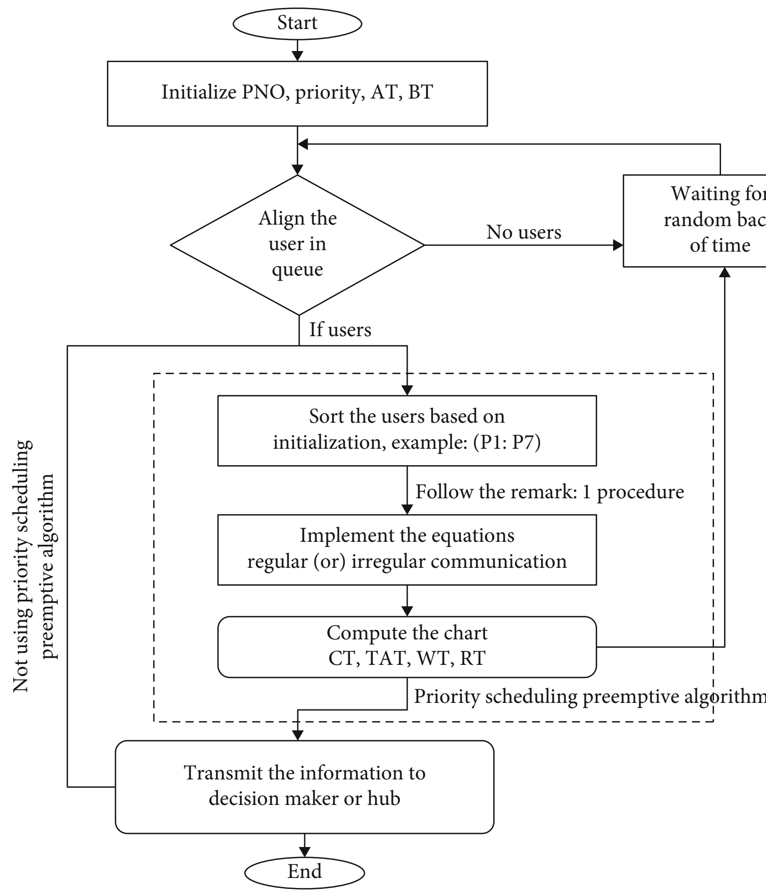

FIGURE 4: Step-by-step process flowchart.

TABLE 2: WBAN priority of service.

BAN priority	WBAN medical services
3	Highest priority medical services
2	General priority medical services
1	Mixed medical and nonmedical services
0	Nonmedical services

TABLE 3: Different levels of data traffic.

Data traffic	Priority	Signal classifications	Impact
Emergency	Highest	Emergency alarm	Critical
On-demand	Minimum	Continuous medical	High
Normal	Lowest	Discontinuous medical	Minimum
Nonmedical	Normal	Audio/video/data	Low

services for different medical applications. The different types of data traffic, priority levels, signal classifications, and their impact are listed in Table 3.

Definition (priority scheduling nonpreemptive algorithm). The proposed model employs a priority scheduling nonpreemptive algorithm. The uniqueness of the algorithm is that during an emergency or critical situation, the process does not stop until the decision-maker or the hub takes the final decision.

Remark. Priority scheduling nonpreemptive algorithm is one of the most prominent scheduling algorithms used to classify users. The priority is the number of users associated throughout each process. During the rescue situation, the process with the highest priority is allocated first in the queue, since a larger burst time lowers the priority (smallest integer = highest priority). However, if two users have the exact arrival time, then the priorities are compared and the highest process is given first priority. Similarly, if two users have the same priority, then the process numbers are compared and the lower process number is given the first priority. This process is repeated while all the users' priorities get executed during the emergency or critical situation and continues until the decision-maker or the hub takes the final decision. Thus, the proposed scheme keeps the hub always busy and continually analyzes the user's situation.

The data traffic is classified into four categories, namely, emergency, on-demand, normal, and nonmedical applications as given in Table 3. It is essential to identify the factors that play a decisive role in grading the nonpriority scheduling preemptive algorithm. The ideal conditions for a proposed priority scheduling nonpreemptive algorithm are when the following norms encounter their corresponding standard conditions with regard to maximum throughput, minimum turnaround time, minimum response time, and minimum waiting time. The proposed scheme continually analyzes the user's situation. The user is classified based on the factors such as throughput (TP), throughput time (TP-T), waiting time (WT), start time (ST), arrival time (AT), start time (ST), burst time (BT), response time (RT), and completion time (CT) or exit time (ET).

Throughput is the number of users' processes that completes their execution per time unit. Throughput time is defined as the time required to execute a specific process such as emergency or critical user processes. Turnaround time is the total time taken to complete the overall process. Arrival time is the initial time to enter the process into a ready state for execution. Burst time is the overall time occupied by the process for its execution. Start time is the initial time to enter the process of the information. Waiting time points to the total time waited by a process in the queue. Response time is the amount of time it takes from when the request is submitted by other users until the emergency or critical user response is completed.

Completion time or exit time is the finish time at which the process accomplished its execution. Table 4 illustrates the proposed user scheduling table, wherein users are scheduled from high to low based on the priority with the lowest priority user being assigned as a coordinator. Figure 5 shows the analysis chart for the proposed scheme.

The time required to complete the entire process was calculated by summing the turnaround time and the start time. Turnaround time is the time required to complete a particular event, which is calculated as the difference between the complete time and the arrival time. The average waiting time was calculated as the difference between the turnaround time and the burst time. These calculations are presented in (18) to (20). The average waiting time was found to be 6.57143 while the average turnaround time was 10.1429 as calculated from Table 4. The standard IEEE 802.15.4 superframe structure for the transmission sequence is shown in Figure 6. The proposed priority scheduling preemptive scheme is summarized in Algorithm 1.

$$(\mathrm{CT}) = (\mathrm{BT}) + (\mathrm{ST}), \tag{18}$$

$$(\mathrm{TAT}) = (\mathrm{CT}) - (\mathrm{AT}), \tag{19}$$

$$(\mathrm{WT}) = (\mathrm{TAT}) - (\mathrm{BT}). \tag{20}$$

5. Energy Efficient Model

This section presents the transmission time, radio energy model, and path loss model approaches for the proposed scheme. In general, the user sensor nodes keep track of the information status of the individual adjacent neighboring nodes. The node information is frequently updated in a small interval and based on this information data traffic and inconsistent collisions are avoided. This efficient routing approach uses the basic model of radio energy consumption for the WBAN protocol.

Table 4: User scheduling table.

User	Priority	AT	BT	ST	CT	TAT	WT
P_1	2 (low)	1	4	1	5	4	0
P_2	2	2	2	5	7	5	3
P_3	6	3	3	7	10	7	4
P_4	10	4	5	10	15	11	6
P_5	8	5	1	15	16	11	10
P_6	12 (high)	6	4	16	20	14	10
P_7	9	7	6	20	26	19	13

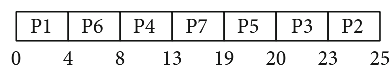

Figure 5: Analysis chart for the proposed scheme.

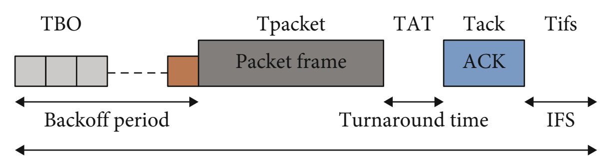

Figure 6: IEEE 802.15.4 superframe structure for transmission sequence.

5.1. Transmission Time. The data frame transmission protocol sequence is shown in Figure 6. TBO is the channel access backoff time, T_{packet} is the data packet transmission time, TAT is the transceiver's turnaround time, Tack is the frame transmission time, and Tifs is the time for an interframe space. Tavg represents the average transmission delay which is the total time required to transmit data packets in a minimal interval from the sensor node to the coordinator. It can be evaluated in [20] as follows:

$$\mathrm{Tavg} = \mathrm{TBO} + T_{\text{packet}} + \mathrm{TAT} + \mathrm{Tack} + \mathrm{Tifs}. \tag{21}$$

For the maximum number of backoff periods denoted by K, it is understood that the successful channel access by the node is denoted by

$$P_s = \sum_{b-1}^{K} P_a (1 - P_a)^{b-1}, \tag{22}$$

where the probability of accessing the idle or static channel by the node is denoted by P_a and the probability of calculating the network device transmitting time is denoted by q. The equation connecting the parameters P_a and q are given by

$$P_a = (1 - q)^{b-1} \tag{23}$$

Step : **1**. **Initialize**: Priority, AT, BT, $T = \{T_{t1}, T_{t2}, T_{t3}, \cdots, T_{tn}\}$; to analyze the user situation to decision Maker. $\triangleright \longrightarrow$ Phase I
Step : **2** while(ready ≤≥ null)
∗If(larger bust time of all users > coordinator user bust time)
Each time slot-priority of process: $\sum_{i=0}^{n} T_{ti} = T$,
Else $\triangleright \longrightarrow$ Phase II
Step : **3** Sort the users based on the initialization: example;
P1:P7
For $i = 1$: N do,
Implementing equations: 18-20
Compute average WT, TAT, and CT
Calculate the user chart based on: Remark 2
Repeat: until N user. $\triangleright \longrightarrow$ Phase III
End if
End while.
Go to step 1: if a new user arrives ready in queue.

Algorithm 1: Priority scheduling preemptive algorithm.

$$= (1 - P_s)K + \sum_{b-1}^{K} bP_a(1 - P_a)^{(b-1)}. \quad (24)$$

The total packet transmission time T_{packet} is calculated as follows:

$$T_{\text{packet}} = \frac{\left(L_{\text{Phy}} + L_{\text{MacH}} + L_{\text{Payload}} + L_{\text{MacF}}\right)}{R_{\text{Tdata}}}, \quad (25)$$

where L_{Phy} is the length of the physical layer in bytes, L_{MacH} is the MAC header length represented in bytes, L_{Payload} is the length of the total received data packets in bytes, L_{MacF} is the length of the MAC footer in bytes, and R_{Tdata} is the data transmission rate.

5.2. Radio Energy Model. The radio energy model uses the efficient routing approach [21]. The energy consumed by the user sensor nodes to transmit and receive the k number of bits over the distance d is expressed as

$$E_{\text{Tx}}(k, d, n) = E_{\text{Tx(elect)}}k + E_{\text{amp}}(n)kd, \quad (26)$$

$$E_{\text{Rx}}(k) = E_{Rx(\text{elect})}k, \quad (27)$$

where E_{Tx} and E_{Rx} are the energy utilization for transmitting and receiving data packets, respectively. E_{amp} represents the energy utilized for the amplification of signals and n represents the signal coefficient utilized to represent the path loss. $E_{\text{Tx(elect)}}$ and $E_{\text{Rx(elect)}}$ indicate the transmission and reception energy consumption, respectively, for radio operation purposes with minimum delay.

5.3. Path Loss Model. The proposed model deals with the attenuation of radio signal propagation between the transmission and the reception power. The attenuation of signals and the variation in path loss are affected due to the line-of-sight and nonline-of-sight effects in radio transmission. In addition, the wireless signal propagation of WBANs experiences shadowing and fading effects on the human body. A Friss formula-based path loss model is utilized in our proposed scheme [22]. Further, the utilization of a path loss model with high complexity results in higher energy consumption. Hence, in the present scheme, simple path-loss models are considered, where the path-loss PL(d) is defined as

$$\text{PL}_{\lambda,x}(\text{d}) = \text{PL}_0 + 10(n) \log_{(10)} \frac{d_{i,j}}{d_0} + X_\sigma, \quad (28)$$

where the path loss (PL) in decibels (dB) is measured as the distance d between the transmitting and receiving nodes. The path loss at the reference distance d_0 is considered as 10 cm and the signal coefficient n in free space is considered as 2. X represents a random variable with a Gaussian distribution, and σ represents the standard deviation that can be derived from the equation (28). The first term of equation (28) is expressed as

$$\text{PL}_0 = 10 \log_{(10)} \frac{(4\pi d_0)^2}{c\lambda^2}, \quad (29)$$

where c denotes the speed of light and λ represents the signal wavelength.

6. Numerical Results

In this section, the performance of the proposed priority scheduling nonpreemptive algorithm is evaluated with priority-based adaptive algorithm, NPCA-MAC, and LR-WPAN schemes. It has been assumed that numerous biomedical sensors are inserted on/inside the human body. The coordinator is the master node, which forwards the information to the decision-maker for critical-rescue operations. The physical, MAC, and network layer protocols are defined according to the IEEE 802.15.4 standard. The channel rate is 250 kbps, the frequency bandwidth is 2.4 GHz, the beacon interval is 245.76 ms, and the transmission time is 192 μs. The ideal network power is 712 mW, whereas the transmission and reception powers are 36.5 mW and 41.4 mW, respectively. The sensor nodes are deployed randomly within an area of 4 m radius around the coordinator to monitor and transmit the data packets randomly during the contention access period.

Figure 7 shows the average execution time of the users. The x-axis represents the normal and the proposed execution processes based on the user priority while the y-axis represents priority scheduling based on the analysis chart in Figure 5. The proposed scheme assigns minimum priority users as a coordinator and remaining users based on the proposed priority scheduling scheme. The normal and the proposed execution order of the users are shown in Figure 7. This result is predictable, since the proposed transmission scheme reduces the network delay by assigning fixed dedicated channels for the individual users.

Figure 8 shows a comparison of the average transmission time during a critical situation for the proposed priority scheduling preemptive algorithm with that of the priority-based adaptive algorithm, NPCA-MAC, and LR-WPAN schemes. Since the emergency alarm signals and continuous medical signal nodes transmit small-sized data packets in a very small interval, the proposed transmission scheme allocates a higher priority to transmit emergency and on data traffic signals such as critical and high level signals,thereby causing longer channel access delay to the priority users to be neglected. The proposed scheme provides significant improvement by considering the coordinator and priority strategy that influences the network lifetime and efficiency eminently.

The evaluation of the performance of the proposed preemptive-scheduling scheme with SCA and SCA with sequential model-based algorithm configuration (SMAC) WBAN schemes is illustrated in Figure 9. The best feature of the proposed schemes' performance is that critical node sensors are given higher priority in transmitting smaller data packets to the coordinator in a short period of time. Since the size of the data packets is significantly small for high priority medical users, critical node sensors consume significantly less energy to transmit the sensor node status. There is only a marginal degradation in the performance, when the sensor nodes transmit medium- and low-level signals such as lowest and normal priority signals. In Figure 9, the average energy consumed by the proposed algorithm is low for the less number of coexisting WBANs (high-priority users). This is due to critical or emergency users taking only minimal average waiting time and transmitting small packets in a concise time interval. Whereas, for the nonpriority users, as the number of coexisting WBANs increases, the average energy consumption by the proposed algorithm also increases slightly higher than the existing SCA with a SMAC due to the large burst time.

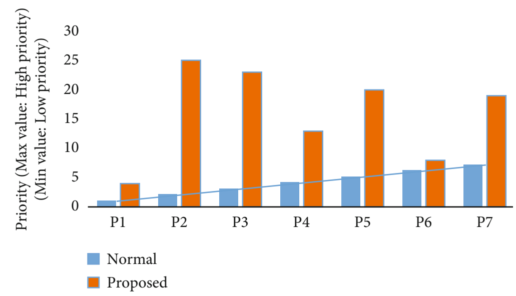

Figure 7: Average execution time for the users.

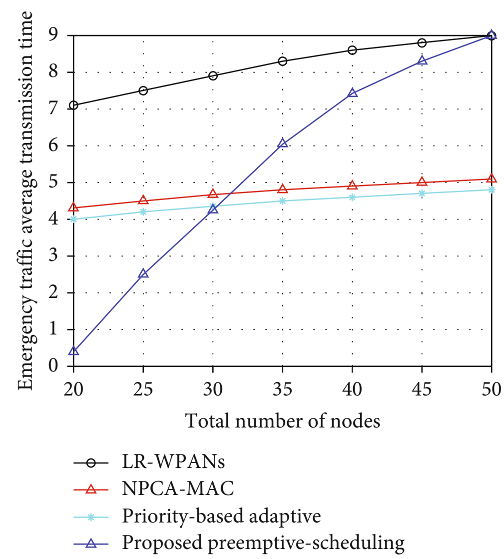

Figure 8: Average transmission time during a critical situation.

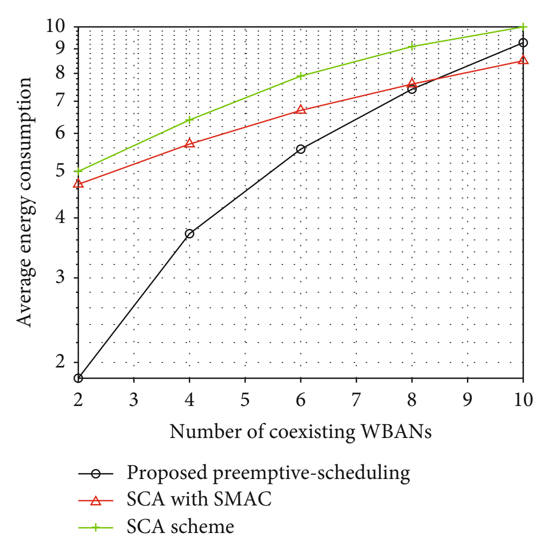

Figure 9: Average energy consumption during a critical situation.

7. Discussion and Future Directions

In the past few years, WBANs have established an innovative approach for remote healthcare monitoring. WBAN is a precise technology requiring frequent recharging or battery replacement. Data manipulation is vital and critical; it must be trustworthy. This work mainly studies the priority-based resource allocation scheme and classifies WBAN medical services into four major categories, namely, highest priority, general priority, mixed medical and nonmedical priority, and nonmedical services. Through classifying the resource allocation based on priority, frequent battery recharging is minimized. During the emergency or critical rescue situation, the highest priority user information is processed with minimum service delay without compromising the QoS.

The proposed scheme preserves the hub, keeping it constantly busy as much as possible all the time. The user's situation is analyzed through considering the factors, namely, start time, waiting time, throughput, throughput time, arrival time, burst time, response time, and completion time or exit time. In addition, the proposed method prioritizes the sensor nodes and classifies data traffic into emergency- (highest priority-), on-demand- (minimum priority-), normal (lowest priority-), and nonmedical- (normal-) based applications. When compared to the existing algorithms, the priority scheduling nonpreemptive algorithm provides significant improvement in energy consumption for the highest priority (emergency) users. The future directions of WBAN are dealing with smart WBAN healthcare, trust management, trust negotiation, data security, uninterrupted lifetime, and intelligent decision-making (enhance the predictions from prior information) processes.

8. Conclusion

This paper has addressed the investigation of a priority scheduling nonpreemptive algorithm for WBANs in order to mitigate the transmission delay and data collision. During critical-rescue operations, a hike in the number of control packets was visible in the network. This hike in the control packet number in turn leads to increased energy consumption and prolonged waiting time at the individual WBAN. The proposed algorithm allows the coordinators to select the channels by allocating higher priority to critical and high-level data signals and the rest of the nodes to lower priority by allocating a dedicated static channel for individual users. The proposed scheme reduces the channel access delay through transmitting small-sized data packets in a short interval to the coordinator by which substantial inconsistent collisions between neighboring WBANs are prevented significantly. The simulation results show that the proposed priority scheduling nonpreemptive algorithm delivers considerable improvements in terms of energy consumption, transmission time, and collision ratio as compared to the LR-WPAN, NPCA-MAC, and priority-based adaptive schemes. An uninterrupted lifetime with an increasing number of WBANs to improve the overall energy efficiency performance will be investigated in the future.

Data Availability

Data available on request. We did not use any third-party data for this work.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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