Energy-Efficient Hybrid Protocol With Optimization Inference Model For WBANs

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The significant advances in the Wireless Body Area Networks (WBANs) and the impact of internetwork interference caused by the combination of several WBANs, the performance accuracy of WBANs may suffer significantly. In this article, a Hybrid Energy-Efficient Multi-Channel Communication Protocol (HEEMCCP) is proposed to mitigate and avoid inter-WBAN interference. The Dynamic Interference Avoidance Algorithm (DIAMA) reduces intra-WBAN interference and consumes less energy by dynamically adjusting the Superframe (SF) distance and restricting the number of channels to two. Rescheduling or channel switching is proposed when WBAN performance falls below tolerance using the neighborhood Sensor Node (SN) list set up using Optimum Interference Mitigation Algorithm (OIMA). The simulation results show that WBAN performance parameters such as Packet Delivery Ratio (PDR), Network Bandwidth Efficiency (NBE), Lower Energy Consumption (LEC), and End-to-End Delay (EED) and Energy Residual (ER) are decreased. The system throughput improved significantly up to 60% in high-interference situations.

Keywords: WBANs, Energy Consumption, PDR, Multi-channel MAC, Inference Detection and Avoidance, End-to-End Delay

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1. Introduction

Devices implanted or attached to the human body are feasible due to recent advances in wireless communication systems and microelectronics. Wireless Body Area Network (WBAN) deployments are highly mobile and intensive, especially in testing environments or public areas where communication bandwidth can be extremely high [1]. Wireless Body Sensor Network (WBSN) is a form of wireless ad hoc network in which mobile Sensor Nodes (SNs) are wearable devices carried or worn by humans [2]. There is a lack of cohesion among those randomly distributed and accessible Body Area Networks (BAN) in WBANs, which can effectively respond to internet-work interference and dramatically impact network reliability [3]. The sensor is a small electronic device that can monitor different parameters, such as object mobility, light intensity, heating rate, and electromagnetic fields due to earthquakes. It is one of the most significant advancements of recent days. The primary cause may be the non-availability of an effective healthcare monitoring system to prevent and treat chronic diseases. So, early detection is essential for figuring out what is wrong with someone, which could save money on health care or keep moral standards high [4].

WBAN is a wireless sensor network with low-power, short-range, variable-data-rate biomedical sensors that mainly monitor bio-signals [5]. Figure 1 depicts a typical IEEE 802.15.6 WBAN-based health service system. Biomedical sensors are used to collect biomedical parameters from the human body and send signals to a personal device or a coordinator before forwarding them to a doctor or a medical hub to monitor real-time biomedical parameters [6, 7] These sensors and the coordinator form a WBAN, which plays an essential role in the sustainable development of digital health. Because the human body is mobile, the smart sensor devices associated with the various body areas are also mobile within a limited latency range, and radio transmission in WBANs is dynamic [2]. In such situations, intra and inter-WBAN interference can significantly prevent data transmission [8]. Existing Wide Area Network (WAN) and cellular technology can be used to resolve communication interference between the coordinator and the server. Interference from neighboring WBANs during wireless Sensor Node (SN) and Coordinator Node (CN) communication between the node and embedded coordinator is a primary focus when multiple WBANs are in the neighborhood.

With the help of GPS beacons [9], a neighbor table can be set up to be researched for interference mitigation and how to avoid collisions induced by an uncertain neighbor table. A hybrid model based on IEEE 802.15.6 benchmarks can be used to ensure reliable communication within and between multiple WBANs [10]. Hybrid Energy-Efficient Multi-Channel Communication Protocol (HEEMCCP) should be primarily made with context to the QoS requirement to enhance performance and reliability. While avoiding inter-WBAN interference and collisions from neighboring WBANs, the HEEMCCP improves the NT and reliability. Non-interfering SNs are required to allow the transmission of data hence, increasing Network Throughput (NT) [11, 12].

Integrating multiple sensory devices that operate at different frequencies increases the compatibility problems. Compatibility is a necessary property of implantable sensors. Excellent compatibility can prevent adverse reactions (inflammation and allergy) between the device and the human body. Flexible electronics offer compatibility with biological tissue materials, environmental adaptability, and harmless working behaviors to the human body, thereby promising a higher standard of disease monitoring and treatment [13].

Nonetheless, we emphasize co-channel interference energy efficiency for a standard WBAN in this research work. The dynamic changes and mobility of the human body affect the quality of wireless signal propagation. To address the challenges mentioned above, we designed a Dynamic

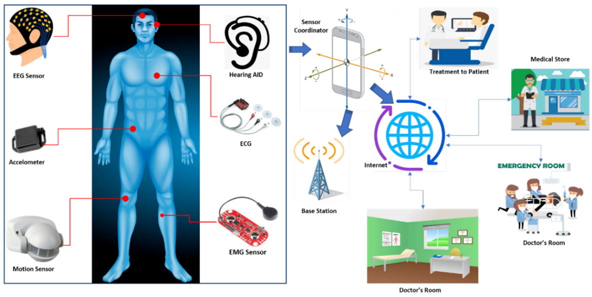

Fig. 1. Healthcare Service Model for WBANs

Interference Avoidance Algorithm (DIAA) for BANs in this research work. The method includes network interference detection, distributed neighbor discovery, and transmission rescheduling. For i-WBAN interference avoidance and mitigation, new methods are needed. In addition, to address the above-mentioned practical problems, we developed an Optimum Interference Mitigation Algorithm (OIMA) for BAN. An asynchronous approach to neighbor discovery is recommended to build a neighbor information table that can be used to arrange dynamic channel lost packets and switching. This behavior prevents data transmission upon detecting excessive interference until the interference is mitigated. As a result, we save both time and energy [14, 15].

This paper is organized as follows. Section 1 describes the basis of WBAN, how to improve energy efficiency on sensor nodes, and mitigate the inference occurrence and avoidance in healthcare processing. Section 2 explains the existing methodology through various researchers' findings and achievements. Section 3 presents the proposed HEEMCC Protocol with interference mitigation for i-WBAN communications, DIAMA and OIMA mitigate the inference on WBAN. Section 4 illustrates and discusses the performance metrics of Packet Delivery Ratio (PDR), Network Bandwidth Efficiency (NBE), Network Throughput (NT), Lower Energy Consumption (LEC), End-to-End Delay (EED), and Energy Residual (ER). Section 5 concludes this paper.

2. Related works

Because of the WBAN's high sensitivity and reliability in telemedicine, a dramatic change in a decision variable could cause significant harm, if not death, to a patient with a chronic disease. Patient autonomy is increased by utilizing wireless medical technology, as the presence of a wired device no longer constrains the patient. A WBAN co-channel interference mitigation and coexistence algorithm should ensure that co-located WBANs function effectively and that their communication channels are carried out without significant performance degradation, either freely or cooperatively. Beacon shifting, channel hopping, and interleaving techniques are just a few of the WBAN coexistence protocols proposed in the literature and the IEEE 802.15.6 standard. The standard was primarily created to support efficient i-WBAN and beyond-WBAN communications, but not i-WBAN communication. When the SNs get the beacon signal, they learn how to send data packets to the CN. Cooperative coexistence modes are located between WBANs, where coordinators/on-body sensors of distinct WBANs can communicate with each other [16]. It is required to support the design of efficient WBAN system applications for life and personal security applications. To increase available NBE and NT, multi-channel MAC frameworks have been used in wireless networks, including WBANs. For i-WBAN transmission, the MAC protocol for multiple channels is used, and the CN selects inactive channels before broadcasting the list to the SNs via the beacon signal.

A WBAN application's resource requirements must be considered when developing an interference mitigation strategy. Researchers have developed an energy-aware topology design for WBANs that considers the topology challenge and thus reduces total energy consumption and network infrastructure costs while significantly reducing the number of intermediate nodes. However, this model did not consider topology constraints and routing processes that could introduce increased energy modules. On the other hand, some solutions use multiple MAC mechanisms and link adaptation to avoid or mitigate co-channel interference [17–19].

Energy Aware WSN Design (EAWD) framework achieved energy optimization in WSN nodes at different levels, such as the hardware design, the operating system choice, the data acquisition technique, and the networking technology [20]. The Blockchain-Integrated Software-Defined Network framework model for the Industrial Internet of Things achieves efficient energy utilization and cluster-head selection provides the best energy consumption, end-to-end latency, and overall throughput [21]. Power control is a critical technology for interference suppression in multiple-access wireless networks. On the other hand, WBANs are distributed and independent, so centralized power control techniques are unsuitable. The researcher put forth several methods, including a WBAN interference measurement method, a noncooperative game theory approach, and a learning algorithm without regret. They are all developed to determine the best channel and signal strength. Because these methods require many permutations to determine the channel and energy to get the best value, they could result in an imbalance in the system if the values have to be frequently changed and set [3].

3. Proposed methodology

3.1. Problem Formulation

In a network formation with $'n'$ WBANs, there are " $P \times Q$ " transmissions that are orthogonal in a Super Frame (SF) that has "Time" time slots. Time $= P \times Q$ is the maximum range of time - slots required. The total number of received data packets is Rec_{ij} at the coordinator as Cor_i. The total NT is computed as Eq. (1).

$$NT = \frac{\sum_{i=1}^{P} \text{Rec}_i}{\text{Execution Time}} + \frac{\sum_{i=1}^{Q} \text{Rec}_i}{\text{Execution Time}} \tag{1}$$

The NT can be improved by increasing the number of nodes transmitting simultaneously. As a result, the problem's objective is to either expand the number of nodes that can transmit in the same time slot or achieve the maximum standard time slots between many WBANs. $P \times Q$ represents the number of data transmissions in n WBANs, whereas |Time| symbolizes the set of time slots in a fixed SF. We set up the scheduling multi-objective optimization problem to find out how many WBANs can be sent to a single time slot, as shown in Eq. (2): the SNs in the SF send up to transmissions in " n " WBANs to their coordinators during the ith time-slot, and the scheduling decision can be symbolized by a vector $Xi = [Xi, j, k, Xl, h, k, \ldots, Xm, n, k]$, where $Xi, j, k = 1$ if the j th sensor in $Reci$ is updated for the i th time-slot, and $Xi_i, j, k = 0$ otherwise.

If two WBANs do not communicate over the same interference link (Interference Edge (IE)) in the Interference Graph (IG), they can consider sharing the same time slot [22, 23]. Regarding payload size and Network Traffic Priority (NTP), different nodes require significantly more time for transmission. Given the NTP level of each SN, we can infer that the WBAN with the top priority can enter the channel until it completes transmission [4].

$$\text{Max} = \sum_{i=1;j=1;k=1}^{P,Q,T} X_{i,j,k} \left[\text{ Time }_k \right] \tag{2}$$

The proposed scheduling algorithm in this methodology focuses on the highest number of sensors that can transmit in each time slot. Based on this description of NT, the following changes have been made to the goal in Eq. (3):

$$\text{Max} = \sum_{i=1;j=1;k=1}^{P,Q,T} \frac{X_{i,j,k} \left[\text{Rec} \left(P_{i,j} \right) \right]}{\text{Time}_k} \tag{3}$$

$$X_{i,j,k} + X_{i,j,k} \leq 1 \mid jIEG_i, h \in IEG_l, I \in L_i \tag{4}$$

$$1 < X_{i,j,k} + \sum_{h=IEG}^{l} X_{i,j,k} \leq \text{ Time} \tag{5}$$

$$\sum_{i=1}^{P} \sum_{j=1}^{Q} X_{i,j,k} \leq N \tag{6}$$

$$X_{i,j,k} = [0,1] \tag{7}$$

$$\text{Time}_{\ k} = \text{ Max}_{\ i=1}, \text{ Time}_{\ i,j,k}, X_{i,j,k}$$
$$\mid \text{Time}_{i,j,k} = \frac{\text{Rec}\left(X_{i,j}\right)}{\text{Send}\left(Y_{i,i}\right)} X_{i_{j,j,k}} \tag{8}$$

Hypotheses of NTP-based planning and control are included in Eq. (4). Due to the routing method's slotted frame in the time-frequency domain, multiple data transmissions from numerous WBANs can be distributed to a single time slot. The time slot for the non-interfered WBANs is indicated in Eq. (5). Eq. (6) shows that only one SN membership to an ISG of two neighbors can transmit at the x^{th} time slot if more than two WBANs interfere [24]. To mitigate i-WBAN interference, only one SN of a WBAN can ISG transmit data at a time using Eq. (7)'s criterion. Fig. 8 states that the total transmission time of all SNs in the k^{th} time slot is equal to the length of the i^{th} time slot. If $X_{i,j}, k = 1$, the i^{th} WBAN's SN is dynamic; otherwise, it is static.

3.2. System Model

For each link provided by a router, an interference model clearly states which links can potentially interfere with each other. Interference between two communication links $i = (Si, Di)$ and $j = \left(S_{j,j}, D_j\right)$ has been studied in the literature, and the standard theory is that, if one of the communication links (S_i or D_i) is within the interference range of the other $\left(S_j \text{ or } D_j\right)$, then the two links are interfering. S_i or D_i are the transmitter and receiver interfaces of the two links. In sensor networks, it is a crucial nonlinear interference key feature; in Body-to-Body Network (BBN), this is even more limited due to the random processes and rapidly changing Radio Frequency (RF) attributes of nodes and environments. Radio channels with high interference ratios cannot be routed by any routing protocol in a high-interference environment. Thus, the design of BBN networks involves channels being communicated following the interference configurations [24, 25].

A. Node Interference Range (NIR): In this range, totally irrelevant channels can significantly impact nodes in the form of packets and potentially trigger PDR. For simplicity's sake, in physical networks, ranges are not necessarily assumed to be symmetric [26]. The NIR was determined using Signal to Interference Ratio (SIR), with the authors assuming a transmission state with a transmitter-receiver range of " l " meters and an interfering node " r " meters away from the receiver initiating a transmission at the same time. Received signals are assumed to succeed if the SIR level is above a predefined threshold.

B. Conflict Graph (CG): A CG can be used to represent the set of communication link pairs that interfere with each other in a given interference model, which assumes mutual and cross-interference. When modeling interfering wireless links between different technological developments, we use an extended CG. This is how $CG\left(V_{cg}(\text{ Time }), E_{cg}(\text{ Time }\right))$ is defined for an extended conflict: In the network, $Vcg(\text{ Time }) = Lw(\text{ Time })\text{Lz}, Vcg(\text{ Time })$ is a set of vertices that represent the communication links between Wi-Fi and ZigBee [27].

C. $\mathbf{E}_{cg}$ (Time) : Edges represent the interference between links. The extended CG of the three BANscenarios $(E_1, E_2)\, E_{cg}$ (Time) is a conflict edge between two vertices that use the same radio technology, i.e., $(E_1, E_2)\, L_w$ (Time) or $(E_1, E_2)\, L_z$, and they are interfering with each other. Dashed lines are used to show conflicts between vertices with multiple radio technologies. Our objective is to minimize network interference on the whole. Let's take a look at this hypothetical situation as an illustration. There are different interference ranges between neighboring BANs for individual BBNs. If only three channels from the 2.4 GHz band are available, BAN1, BAN2, and BAN3 can be directed to Wi-Fi orthogonal channels (1, 5, and 12), respectively [28]. There would be no interference in this case. Let's assume that only two Wi-Fi orthogonal channels (1, 5, 3) overlap with channel 1. As a result, channels (1, 5, 3) would be assigned to BAN1, BAN2, and BAN3. Because the interference ranges of BAN1 and BAN3 are disjointed, they can use overlapping channels with little fear of interfering.

Many more BANs/overlapped interference ranges are involved in real-world things and multiple wireless communications. As a result, a comprehensive framework for wireless resource sharing based on interference configurations should be investigated. A BBN level for Wi-Fi bandwidth utilization and a WBAN level for ZigBee spectrum access in such heterogeneous networks is required. Mobile nodes can exchange control packets using a cellular signaling protocol to minimize shared and cross-technology interference or maximize SIR at Wi-Fi and ZigBee radio access technologies. A comprehensive description of the protocol for information exchange is provided. Fig. 2 shows the WBAN Conflict Graph Test case.

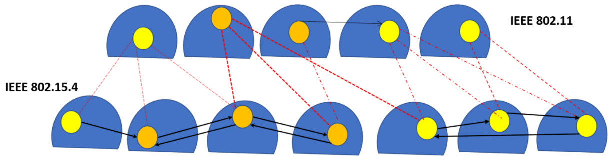

Fig. 2. WBAN Conflict Graph Test case

3.3. Proposed Hybrid Energy-Efficient Multi-Channel Communication Protocol

Fig. 3 demonstrates our HEEMCCP with interference mitigation for inter-WBAN communications. Intra and inter-WBAN communication and channel selection are all modules in interference mitigation.

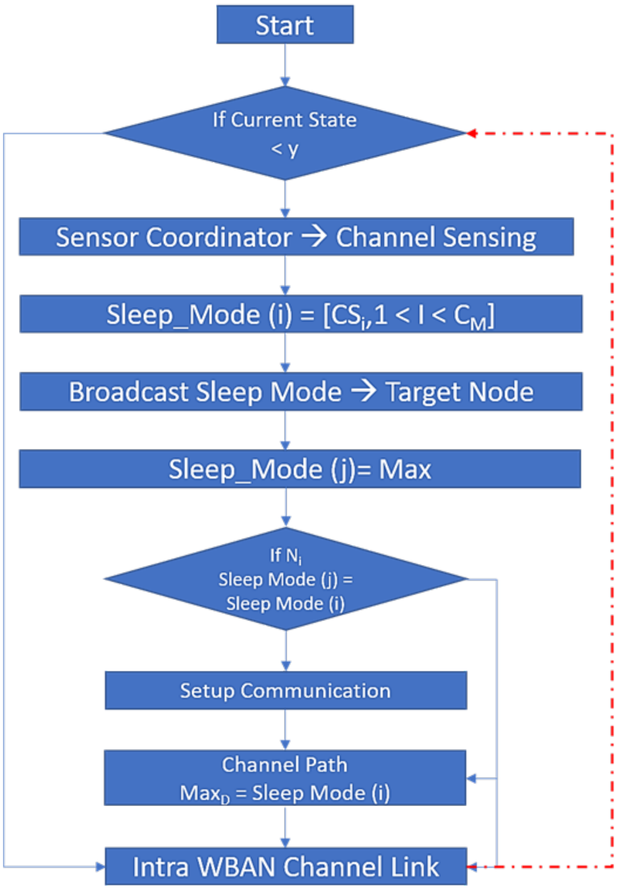

Fig. 3. Framework of WBAN interference detection using HEEMCCP Multiple

WBANs are assisted by the interference mitigation algorithm that researchers created. The CN will use the SINR value to list the interfering SNs. The CN then detects an idle channel using the active node energy level detection. Using the design, the CN sends a list of idle channels to its 1-hop neighbors. The range of possible channels from the 1-hop neighbors is stored in the received message. It's possible that a neighbor N_j with the same idle channel set as Ni could use our proposed algorithm's message exchange to find a suitable data channel set. It is called No Available Channale i_{ij} = Idle Channel (i) ∩ Idle Channel (j) for two WBANs (j). Using an Algorithm, a WBAN can initiate i-WBAN communication once it has identified a set of data channels free of interference.

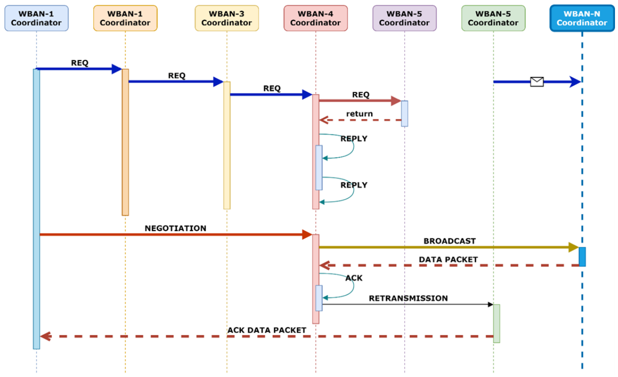

Fig. 4. Inter WBAN Communication Process

Algorithm 1: Hybrid Energy-Efficient Multi-Channel Communication Protocol

Input: Neighbourhood Node (NB). NBj (Sleep State_Channel(j). NBi, Mobilitly_Meta_Datai=0) available channels
Output: Each WBAN Mobilitly_Meta_Datai has its own set of communication channels

Step 1. Compute the total number of available channels for NBj and NBi.
Step 2. Sleep State_Channel (i) = Total_AvailabIe_Channel (j) Sleep State_Channel
Step 3. Find Higher Priority Index Value (HPIV) for each WBAN
Step 4. The number of communication channels for WBANi in Total_Available_Channel with a HPIV
Step 5. If HPIV > ∞ Channeli
Step 6. P = MAX [(HPIV / 2), ∞ Channeli]
Step 7. Else
Step 8. P = MIN [(HPIV / 2, ∞ Channelj]
Step 9. End IF
Step 10. The following are the total channels for the other WBAN
Step 11. Q = [Total_Available_Channel - P]
Step 12. The i-WBAN channel is set at a WBAN
Step 13. For Count = [1: P]
Step 14. Increment 1
Step 15. Mobilitly_Meta_Datai = [Mobilitly_Meta Datai + Total_Available_Channeli (Count)]
Step 16. End For
Step 17. Mobilitly_Meta_Datai, j=[Total_Available_Channel-Mobilitly_Meta_Datai]
Step 18. End IF

3.4. Proposed Dynamic Interference Avoidance Algorithm (DIAMA) and Description

There is a possibility that Multiple devices on the body may interfere with each other. WBANs, which consist of several miniaturized body sensor units (BSUs) together with a single body central unit (BCU) [27], larger decimeters (tab and pad) sized smart devices still play an essential role in terms of acting as a data hub. To mitigate the interference of multiple devices on the human body, a Dynamic Interference Avoidance Algorithm (DIAMA) is proposed. As in Figure 5, a new SF model is a setup of two parts: a CAP part and a Time-division multiple access situations (TDMA) subset to enable our proposed DIAMA. CAP-I and CAP-II are sub-parts of the Contention Access Period (CAP) [27].

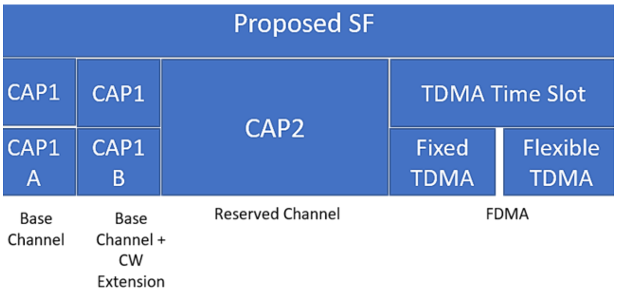

Fig. 5. Proposed SF model

Algorithm 2: Dynamic Interference Avoidance Algorithm (DIAMA)

Step 1. Find *i-WBAN* Node Interference List (NIL)
Step 2. For P = 1 to N Do
Step 3. For Q = 1 to N Do
Step 4. Find *i*-WBAN as a Root
Step 5. If *i*-WBANroot < 2root
Step 6. Update i-WBANNIL = NIL of WBANi
Step 7. Else
Step 8. i-WBANroot =
Step 9. End IF
Step 10. End For
Step 11. End For
Step 12. Circular Retransmission
Step 13. For P = 1 to N Do
Step 14. For Q = 1 to N Do
Step 15. Select NIL from x, y, i, j, k, l from iWBANs (CNi or SNj)
Step 16. End for
Step 17. End For
Step 18. Find iWBAN to NIL
Step 19. For P = 1 to N do
Step 20. For Q = 1 to N do
Step 21. If WBANP, Q < WBANthreshold
Step 22. Update SNP, Q to NIL Sensors
Step 23. Else
Step 24. Update SNp, q to non.NIL sensors
Step 25. End If
Step 26. End For
Step 27. End For
Step 28. Broadcast Data Packet
Step 29. For P = 1 to N Do
Step 30. Broadcast NIL of Current Nodei
Step 31. End For
Step 32. Set Time Frame Slot
Step 33. Execute DIAA Parameters
Step 34. Identify Inference Nodes

TDMA, on the other hand, mainly comprises fixed and ad hoc sub-parts. CAP-I also includes CAP-I, A and CAP-I, B sections, which deal with Test Case-I and Test Case-II, respectively. All of the sources' transmissions on the Base Channel (BC) (Test Case-I and Test Case-II) must finish just before the end of CAP-I to be fully explained. On the other hand, all sources transmitting on the reserved channel (Test Case-II) must begin shortly after the end of CAP-I and finish just before the end of CAP-II's second period. However, all sources' transmissions to the relays have been completed in CAP-I and CAP-II. The TDMA segment begins when relays start transmitting their delayed messages to Delaymsg using their TDMA-allocated time slots. Time slots for a specific relay set are allocated in advance in the frame's "fixed" portion. To account for the unforeseen relay, the following data packet frame is used due to network interference; Delay y_{msg} assumes how many flexible time slots can be available in the next frame. Each source $SET_i \in S$ whose $\alpha_1 SET_i \geq \alpha_{Threshold}$ (i.e., no interference) uses the BC to communicate directly to the relays (Test Case-I). The source $SET_i \in IS$ otherwise extends the CW to avoid the current state interference. Following that, any source that has already performed its CW extension retries sensing the BC. If it proves successful ($\alpha SET_i \geq \alpha_{\text{Threshold}}$), it transmits its message over the BC to relays (Test Case-II). If not, source $SET_i \in IS$ reencounters interference and switches to the allotted communication channel (Test Case-III), initiating a new contention (α_3). As a reminder, here is a list of all the test cases already discussed.

- Test Case I: $SET_i = S \& \alpha_1 SET_i \geq \alpha_{\text{Threshold}}$, SET_i uses BC
- Test Case II: $SET_i = IS \& \alpha_2 SET_i \geq \alpha_{Threshold}$, SET_i uses BC with CW extension phase
- Test Case III: $SET_i = IS \& \alpha_3 SET_i < \alpha_{\text{Threshold}}$, SET_i uses reserved channel

3.5. Optimum Interference Mitigation Algorithm (OIMA)

Fig. 6 shows the interference mitigation algorithm [29, 30] based on the best time to retransmit, which goes through the following steps:

A. Setup Phase : For example, congestion is more likely than a bad channel to be responsible when a WBANi senses significant performance degradation, when the CN detects a marginal decrease in NT or PDR, whereas the received beacon signal frequency does not drop. Start setting up the interference mitigation, and when the active phase is over, the CN goes into the listening phase.

B. Neighbor Node Discovery : An SF length is used by the CN to decode the beacon packets of its neighbors and gather their data. The algorithm then creates a neighbor table and discovers the neighbors.

C. Packet Retransmission: The CN runs the retransmission to determine the possible retransmission data transfer time $T_{\text{temp.}}$. Thus, interference with other WBAN transmissions is minimized while at the same time maintaining uninterrupted service. During the retransmission phase, the current channel's retransmission data transfer time T_{temp} can't be obtained if the current channel is fully utilized. To begin, it first looks for broadcasting with available time slots. The CN of $WBAN_i$ broadcasts the idle channel to all WBANs, both the CN and $WBAN_{\text{i}}$ execute the retransmission based on the sleep mode channel.

D. Data Transfer: SNs in WBAN_{i} receive information about the new scheduling algorithm from the beacon, and

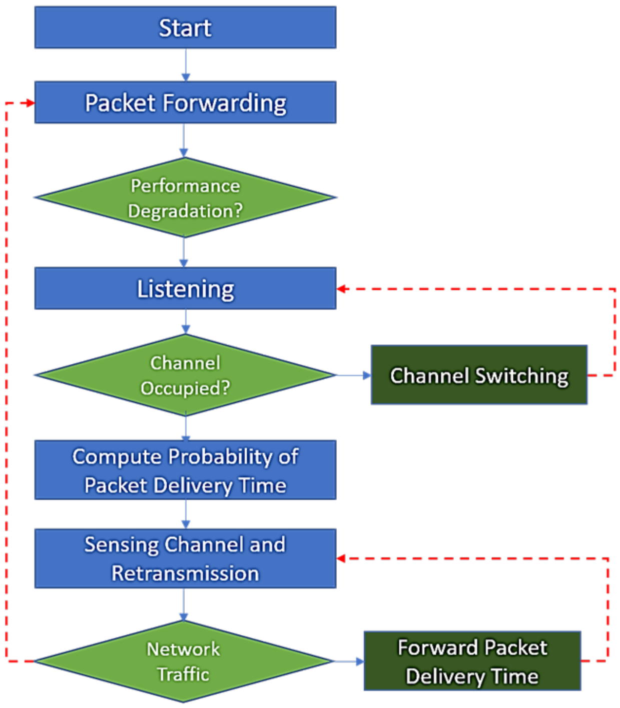

Fig. 6. Flowchart of Optimum Interference Mitigation

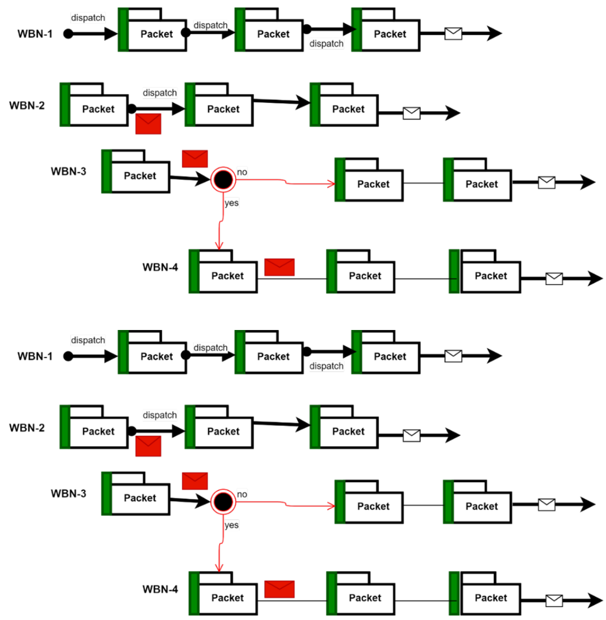

Fig. 7. WBAN Internetwork Interference Mitigation Model

they begin transmitting data in their allocated time frame until the next scheduled iteration [31]. To avoid collisions caused by an incomplete neighbor list, $\mathrm{WBAN_i}$ transmits at the retransmission time (T_{temp}) using carrier sensing and then retransmits.

Fig. 7 depicts the presence of WBAN-1, WBAN-2, and WBAN-3 in a geographical area. These WBANs transmit data over the same channel, *Chx*. Initially, only WBAN-1 was transmitting data, while WBAN-2 and WBAN-3 will later relocate adjacent to WBAN-1. WBAN-1, WBAN-2, and WBAN-3 are rescheduled to fixed time slots following a listening period to avoid conflicts. The transmission of WBAN-1 is, therefore, identical. Assume that WBAN-2 needs to transmit; it first analyzes its neighbor's beacon to determine WBAN1's channel (Chx) availability. WBAN-2 then initiate transmission from Time1 after the rescheduling method approximates the time Timetmp = Timel . Likewise, after WBAN-3 arrives, it is challenging to decode the beacons of WBAN-1, WBAN-2, and WBAN-3. We have already identified *Chx* channel availability through our beacons during the listening phase of WBAN-3. As can be seen, WBAN-3 is also being listened to. It has been unable to transmit channel status information via the beacon.

Therefore, the beacons attained by WBAN4 represent only the data packet position of WBAN-1 and WBAN-2 and the scheduled time of WBAN-1 and WBAN-2 on the channel (Ch_x) .T_3 represents the end of WBAN-1 scheduling, while Time $_2$ represents the end of WBAN3 listening. During the listening phase of WBAN-3, WBAN-3 is unaware of the existence of WBAN-2. WBAN-3 has to wait for (Time3-Time2) seconds because it knows from WBAN1's beacon that WBAN-1 controls the channel (Chx) and can only end at Time3. In the intervening period, WBAN-3 receives the beacons to determine the channel (Ch_x) information, which is similar to that derived by WBAN-3. The transmission begins at Time $_3$ if WBAN-2 occupies the frequency band (Ch_x) before WBAN-3. It is possible to wait for WBAN-3 to finish transmission before WBAN-3 can attempt to transmit data through the channel at Time3. It is evident that (Time4-Time3) is the time interval where WBAN-4 and WBAN-3 collide. To start formal transmission at Time 3 , WBAN-3 must wait for extra mobility due to the absence of neighbor node information from other nodes.

4. Simulations and results

In order to evaluate the performance of the proposed algorithm, we have performed simulation of the proposed scheme in NS-2 simulator with a one hop star topology. WBANs are randomly deployed over a $100 \times 100\ \mathrm{m}^2$ simulation area. Each WBAN contains CN and SN. Each WBAN consists of 1CN and 10 bio-medical SNs distributed randomly within a 2 m radius around the CN. The physical layer limits were set according to IEEE 802.15.4's requirements [32]. The SNs are given priority numbers ranging from 1 to 30 in the Random Way Mobility Model (RWMM). To simulate case studies, WBANs are static nodes for 30

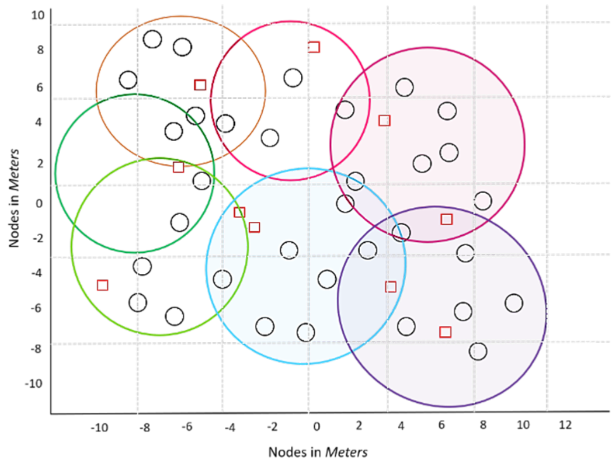

Fig. 8. Network Simulation Topology Test Case

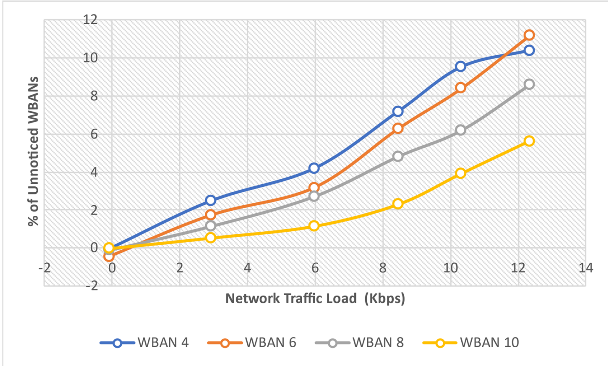

Fig. 9. Unnoticed WBANs PDR to Neighbourhood Nodes

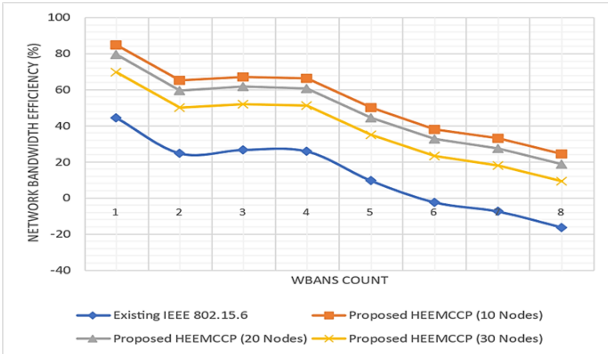

Fig. 10. NBE for Proposed HEEMCCP vs IEEE 802.15.6

seconds and dynamic nodes for 5 seconds.

WBANs move at a random speed ranging from 1.5 ms to 2.5 ms during node mobility. Each WBAN's transmission distance is calculated to be 2 meters. The path loss ' λ ' is 2.4 when using the vertebral body path loss model, and the practical learning ' σ ' is $6dB$. Because typical medical electroencephalography and electrocardiography applications have a transmission rate of 6kbps, and body temperature, cardiovascular, and oscillation frequency sensors typically have a PDR of 2kbps, researchers set the SF length $\sigma = 0 : 1$ s and the PDR to 300kbps. The traffic load per WBAN increases from 5kbps to 25kbps to utilize all of these cumulative sensors. To keep things simple, all WBANs have the same network traffic. We also simulate the scenarios of 10 nodes and 20 nodes later (Fig. 8). We use the RWMM for movement. As the number of WBAN neighbors grows and the network traffic increases, interference is expected to rise.

Consequently, there will be more beacon loss. Fig. 9 demonstrates that even in the worst case (10-WBAN data aggregation and 25 kbps collision each), our proposed HEEMCCP can ensure that the neighborhood table captures more than 92.19% of the WBAN information for the neighbor's node. As a result, when it comes to retransmission, the neighbor node list table is a helpful tool that provides sufficient information to ensure reliable packet transmission.

4.1. Network Bandwidth Efficiency (NBE)

There are 10, 20, 30, and 40 success rates for NEB in the WBAN and SNs from the tests shown below. The performance trend of NBE (WBAN) is between 1 WBAN and 30 WBAN. According to the results, the percentage of NBE is inversely related to the number of WBAN. It indicates that the WBAN's performance is diminished in scenarios with more WBANs. All simulations have zero NBE at the outset, and performance varies with increasing WBAN numbers. Fig. 10, depicting the performance of a single WBAN, demonstrates an exponential increase in NBE over time. Consequently, the single WBAN has impressive performance, which continues to improve gradually because the WBAN is not presumed to have achieved its optimal state within the simulation's time. The proposed HEEMCCP model significantly improves NBE under switching node mobility possibilities of patient activities. Depending on the number of SNs in each WBAN scenario, the improved efficiency ranges from 35.75% to 64.25%.

4.2. Network Throughput (NT)

The HEEMCCP-based improved IEEE 802.15.6 protocol model for WBAN interference detection and mitigation model for the NT for 10 nodes, 20 nodes, and 30 nodes multi-channel WBAN scenarios is shown in the result obtained. WBAN- NT is compared with 10-30 WBANs over some time in this simulation. It is demonstrated by the results trend in Fig. 11 , which depicts the NT vs. existing IEEE 802.15.6-time trend. WBAN-NT performance decreases as the number of WBANs increases, resulting

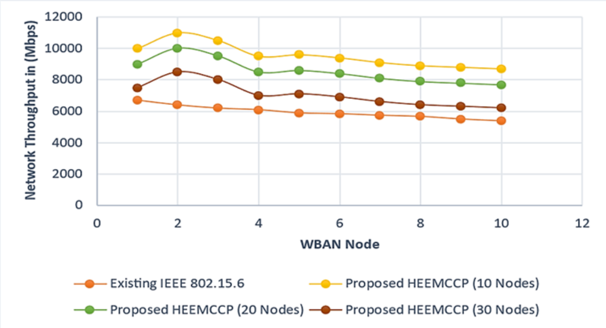

Fig. 11. NT for Proposed HEEMCCP vs IEEE 802.15.6

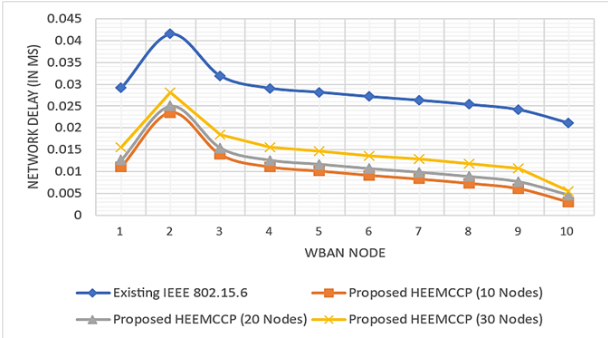

Fig. 12. NEED for Proposed HEEMCCP vs IEEE 802.15.6

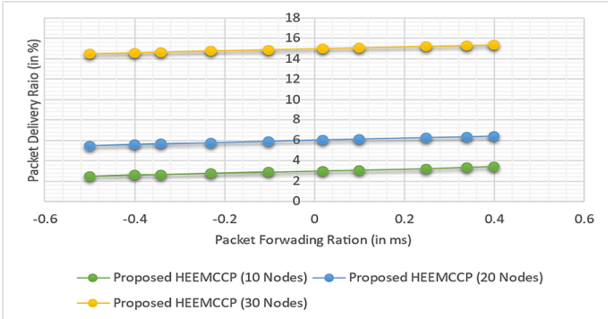

Fig. 13. Packet Delivery Ratio on WBAN

in increased interference levels, affecting WBAN performance. The results indicate that the 1-WBAN-NT becomes the finest potential NT at around 100 kbps. Even though 75 kbps is below the optimum levels for 1WBAN for 9WBAN, the increasing rate of NT is constant after resources are exhausted. This is an expected performance since the expected NT marginally decreases as the number of WBAN increases. This behavior is also observed in 10WBAN, 20WBAN, and 30WBAN. We know from this evaluation that NT increases as a patient's dynamic nature increases. Node mobility scenarios benefit significantly from the proposed HEEMCCP model, as evidenced by the graphs at the top layers.

4.3. Network End-to-End Delay (NEED)

Due to the nature of the WBAN's practical application, NEED is an essential factor in the success of the WBAN. The performance of NEED is demonstrated in these experimental simulation results. In all multi-WBAN scenarios, the new HEEMCCP interference detection and mitigation process performed better than the original and current interference mitigation models. Compared to the existing IEEE 802.15.6 standard, the HEEMCCP interference detection and mitigation model for multi-WBAN scenarios decreases. Figure 12 illustrates the performance relationship between NEED and the number of WBANs. As can be seen, the increase in WBAN is directly proportional to the increase in NEED, as can be seen from the single WBAN's NEED of 33.09 ms, the 39.78 ms NEED to be depicted by WBAN 10; the 47.13 ms NEED to be shown by WBAN 20; the 52.58 ms NEED to be proven by WBAN 30. It proposed that an increase in WBAN in a given environment reduces WBAN's performance in terms of EED.

The proposed HEEMCCP model's improvement and contribution to emerging technologies can be evident as shown in this example. The primary cause of the NEED is congestion in the transmission medium due to multiple SNs attempting concurrent access to the channel. In comparison with single WBAN, the performance of multi-WBAN degrades quickly. The delay levels are much lower because of the lower interference levels and have increased with the number of WBANs. As the interference accumulates over time, the EED gradually increases. Because of this, retransmissions occur, resulting in greater demand.

4.4. Packet Delivery Ratio (PDR)

Fig. 13 compares the proposed inference detection and mitigation algorithm's PDR to the conventional AIM's PDR. The PDR at each WBAN is the ratio of successfully received packets at the CN to the total number of packets generated by the sensors of the WBANi. IEEE 802.15.6 PDR decreases in dense deployment and high traffic rate scenarios. The proposed HEEMCCP, on the other hand, consistently achieves a higher PDR than IEEE 802.15.6. In HEEMCCP, an SF's first available time slot is assigned to only the SN with the highest priority or most significant packet size. Long waiting times may result in the inevitable loss of some packets generated by SNs. Furthermore, the 2-hop neighbors can share the same time slot, increasing NT.

This research measures the spatial reuse factor as the number of SNs that share the same time slot. The proposed HEEMCCP achieves greater spatial reuse than IEEE 802.15.6. If the algorithm increases the number of SNs

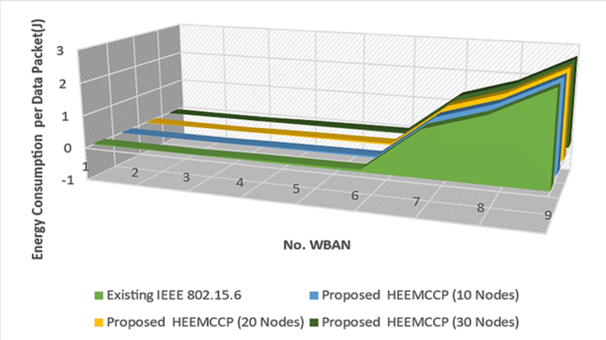

Fig. 14. Energy Consumption by Individual Data Packets

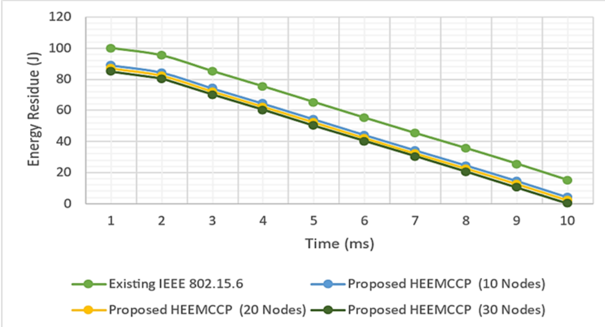

Fig. 15. WBAN-ER vs. proposed DIAA

transmitting simultaneously to their coordinator within the same time slot without interfering with their neighbors, the network have a high level of spatial reuse. The spatial reuse factor for both algorithms is determined by the number of WBANs used. The schedule of an SF shared among WBANs in the proposed HEEMCCP allows nodes in Non-Interfered Sensor Lists (NISG) of non-interfered WBANs to be transmitted time-slot of Interfered Sensor Lists (ISG) simultaneously. As a result, neighboring 2-hop WBANs can reuse the time slot, increasing the spatial reuse factor.

4.5. Energy Consumption (EC)

The total EC for receiving and transmitting increases as the number of WBANs increases, as shown in Fig. 14. Control, data, negotiation, and channel switching packet energy consumption are all accounted for. As a result, we don't consider how much power is consumed by listening nodes inactively. The EC of proposed HEEMCCP and traditional Multi-Channel-MAC tasks is depicted. In both cases, HEEMCCP consumes less energy than traditional Multi-Channel-MAC. Although the proposed HEEMCCP reduces energy consumption more than traditional Multi-Channel-MAC, the EC for transferring data of significantly greater nodes is closer to zero in both case scenarios.

The proposed HEEMCCP requires less energy to change channels than traditional IEEE 802.15.6, as only nodes with high-priority traffic can alter the working channel. In TDMA, the transmitting nodes do not alter the working channel, thus saving EC. For example, nodes with highly variable traffic priorities will share the channel using CSMA/CA, but they can switch channels to avoid collisions when required. Regardless, it may result in increased EC in 802.15.6. In addition, the EC per packet is calculated based on the proportion of the total EC attributable to PDR that was successfully received. The average EC per packet of Proposed HEEMCCP is less than 802.15.6, as shown in Fig. 14.

4.6. WBAN Energy Residue (ER)

It is to determine whether the proposed DIAA outperforms other schemes in terms of extending the energy lifetime of the WBAN. In WBANs, the most stringent factor (energy) is linearly related to ER. The WBAN-ER at time t is defined as the sum of the remaining energies in the batteries of each WBAN sensor. Fig. 15 compares and displays the ER versus time for three different schemes. As is evident from this graph, the ER of the DIAA outperforms and is always more significant than the ER of the IEEE 802.15.6 methods. The ER of DIAA falls slightly, while the ER of the other methods falls dramatically. It increases the WBAN's energy lifetime. The proposed DIAA, on the other hand, minimizes packet collisions and retransmissions because all interfering nodes proactively use the CW-enhanced version method and, most likely, the broadcast control scheme. In the PC scheme, a power control system changes the power level at sources and relays on the fly. It lowers the EC of the WBAN as a whole.

Using a flexible TDMA, the DIAA reduces the EC of the entire WBAN. In contrast, the absence of IEEE 802.15.6 power control increases EC at sources and relays, significantly lowering WBAN energy life. Other approaches do not implement as the proposed DIAA does.

5. Conclusion and future work

WBAN is an emerging technology that will revolutionize healthcare applications in the years to come. Since these protocols have proven to be effective at saving sensor energy and routing crucial data, they have gained widespread acceptance. WBAN also receives the benefit from IEEE 802.15.4, which is an energy-efficient model. Mutual influences of contention access period (CAP) and contention-free period (CFP), the unslotted mode performs better than the slotted one regarding throughput and latency. The proposed HEEMCCP model significantly outperforms the existing IEEE 802.15.6-based WBAN advanced technologies in the reference areas of the network, PDR, EED, NBE, NT, and ER, as demonstrated by the effects of various mobility models. WBAN technology can benefit significantly from an IEEE 802.15.6-compliant HEEMCCP framework incorporating CSMA/CA with a user priority index value and a dynamic scheduling algorithm for interference detection avoidance and mitigation. The CSMA/CA phase allows higher-priority nodes to send data packets, while the TDMA phase permits regular data intervals to be sent. In the case of high interference, the NT versus node priorities demonstrate comparable improvements. However, in the case of high interference, the system throughput shows a significant improvement of up to 60.19%. As future work, we plan to examine whether multi-channel MAC techniques in multi-WBAN scenarios are energy-efficient without requiring negotiations and to examine human movement in an environment with several WBANs by utilizing the dynamic topology.

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