Energy Efficient Priority Based Mobility Aware Heterogeneous WBAN Networks

A PROJECT REPORT

submitted by

CB.EN. P2EBS24006

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EMBEDDED SYSTEMS ENGINEERING

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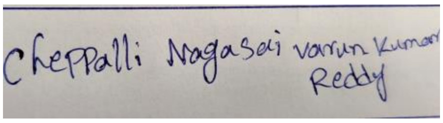

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ABSTRACT

Data aggregation in Wireless Body Area Networks (WBANs) presents a complex and multidimensional challenge, particularly due to the dynamic nature of the human body, energy constraints of sensor nodes, and the time-critical nature of medical data. In the proposed work, a scheduling strategy for allocating time slots within a Time Division Multiple Access (TDMA)-based MAC super frame is investigated. The network model considers a single-channel, resource-constrained WBAN comprising multiple sensor nodes deployed on or around the human body. Each sensor node is responsible for monitoring specific physiological parameters and transmitting the collected data to a central coordinator. Additionally, node mobility is considered, as movement patterns can affect link quality, connectivity, and scheduling efficiency. To model mobility, Random Waypoint and Linear Mobility models are used, enabling the system to evaluate scheduling performance under both random and predictable movement patterns. The system models the relationship between sensor nodes and available time slots as a bipartite graph, with the primary objective of minimizing overall energy consumption, enhancing data reliability, reducing data loss, and avoiding channel congestion. By incorporating mobility considerations, the proposed approach ensures robust performance in real-world scenarios, making it well-suited for the transmission of time-sensitive and critical health data in healthcare monitoring applications.

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
TDMA	Time Division Multiple Access
MAC	Medium Access Control
WBAN	Wireless Body Area Network
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance.
PDR	Packet Delivery Ratio
UDP	User Transmission Protocol
CCA	Channel Clear Assessment
PAN	Personal Area Network
SIMPLE	Stable Increased-throughput Multi-hop Protocol for Link Efficiency in Wireless Body Area Networks
MATTEMPT	Mobility ATTEMPT
ESTEEM	Enhanced stability and throughput for energy efficient multi hop routing based on Markov Chain Model

Chapter 1

INTRODUCTION

The convergence of Wireless Body Area Networks (WBANs), the Internet of Things (IoT), and 5G communication technologies has revolutionized healthcare in the modern era through real-time patient monitoring, early diagnosis, and continuous medical surveillance. WBANs are tiny biosensors embedded inside or worn on the human body that capture and wireless transmit physiological data such as heart rate, body temperature, glucose levels, and ECG signals to medical servers or edge nodes for analysis and decision-making. The reliability, power consumption, and communication delay in WBANs are significant to ensure patient safety as well as QoS requirements of different medical applications [1-2].

However, WBANs are faced with a number of challenges such as limited energy resources, mobility-induced link instability, heterogeneous traffic priority, and adversarial wireless channel conditions. These concerns severely affect data reliability and energy consumption, especially in healthcare setups where on-time delivery of critical physiological data with optimal accuracy is needed. Advances made in edge intelligence, blockchain security, and hybrid MAC protocols in recent times have brought hopeful answers to overcome these shortcomings. For instance, Sharma et al. [1] proposed an edge intelligent agent-based hybrid hierarchical blockchain model to facilitate constant healthcare monitoring in 5G-enabled WBAN-IoT systems. The model uses edge computing and blockchain consensus-based data transmission to provide secure, low-latency, and reliable communication of medical data while enabling distributed decision-making and privacy protection.

At the Medium Access Control (MAC) layer, effective channel access mechanisms need to be implemented to manage simultaneous transmission from a variety of body sensors with different traffic priorities. Traditional MAC protocols often suffer from collisions and power consumption during dense deployment of sensors or bursty emergency medical information. To address these issues, Alhazmi et al. [2] presented a hybrid multi-class MAC protocol for IoT-based WBANs by integrating TDMA and CSMA/CA mechanisms. Their design classifies traffic into multiple priority classes and allocates channel access dynamically based on the urgency and type of data, thus enhancing energy efficiency and reducing access delay.

For more adaptability and energy optimization, Markov-based decision models have gained much attention in research studies of WBAN communication. Liu et al. [3] introduced an energy-aware Markov Decision Processes (MDPs) MAC protocol that adjusts contention window sizes and transmission probabilities dynamically according to varying network conditions. The scheme probabilistically achieves optimal energy efficiency and delay performance using learning and adaptation techniques under changing traffic loads and link qualities. Similarly, Khan et al. [4] presented a traffic-priority-aware medical data dissemination scheme for WBANs using IoT that uses a Markov model to manage data transmission based on traffic classes in order to provide timely and trustworthy critical medical data.

Network layer routing stability and energy conservation are central concerns due to mobility of sensors and limited battery life. Khan et al. [5] presented ESTEEM (Enhanced Stability and Throughput for Energy-Efficient Multi-hop routing), a Markov chain-based protocol that enhances route stability and throughput with reduced overall energy consumption. ESTEEM models the network's stochastic nature to make best routing predictions and generates longer network lifetime and improved packet delivery rates. Complementing this, Li et al. [6] proposed a learning-based slot allocation framework in light of temperature variations and delay constraints in TDMA-MAC systems. The adaptive slot scheduling mechanism in this case maximizes delay performance and reliability in the face of dynamic physiological and environmental conditions, highlighting growing prominence of machine learning in cross-layer WBAN design.

Earlier landmark protocols like SIMPLE [7] and MATTEMPT [10] laid the groundwork for energy-efficient and reliable routing in WBANs. The SIMPLE protocol employs residual energy and link quality estimators to select forwarder nodes with even energy consumption and greater throughput. Likewise, the MATTEMPT protocol suggests a method for energy-efficient routing with lower retransmissions and higher reliability through adaptive link selection. The two protocols fall short of efficiency in managing mobility, channel variability, and traffic prioritization, which are paramount elements in the healthcare networks of today. Modern studies thereby extended these ideas with more smart and responsive systems. Wang et al. [8] reported on an energy-efficient and reliable scheduling strategy that utilizes channel periodicity to predict link states and therefore minimize retransmissions and latency.

Similarly, Alabady et al. [9] optimized priority-based dissemination algorithms to offer deterministic data delivery for emergency medical packets over varying traffic patterns.

Collectively, these pieces of work chart a clear research course—from static, energy-centric MAC and routing protocols to dynamic, intelligent, and context-aware WBAN architectures. The meeting point of Markov modeling, machine learning, priority-aware scheduling, and edge intelligence provides a direction towards very adaptive WBAN systems which can continually ensure reliability and efficiency in dynamic body-centric environments. These systems can automatically tune energy efficiency, latency, and QoS while adapting for varying mobility, channel state, and criticality of medical data.

But there are still significant challenges in mobility-aware communication modeling, cross-layer optimization, and real-time Markov chain-based adaptation that have the ability to model the dynamicity of body sensors and stochasticity of wireless links. Solving these open research challenges will enable the development of sound, smart, and scalable WBAN frameworks that can facilitate continuous and reliable healthcare monitoring in 5G and beyond. Future research must thus focus on merging probabilistic decision models, priority-based MAC scheduling, and intelligent edge computing to support smooth, energy-efficient, and reliable transfer of medical data for future-generation smart healthcare systems. below fig1 shows the WBAN Architecture

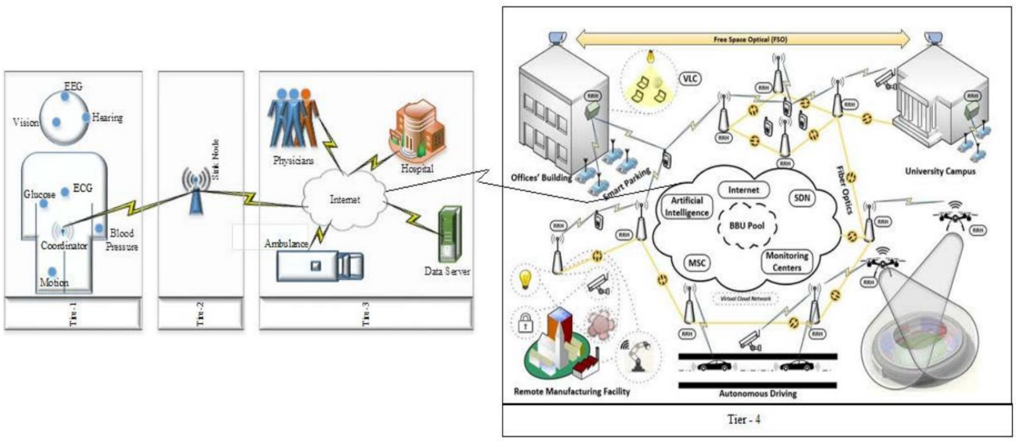


Fig.1 Multi-tier WBAN communication framework

Chapter2

LITERATURE REVIEW

New advances in Wireless Body Area Networks (WBANs) have introduced different solutions for increasing energy efficiency, data reliability, and facilitating intelligent scheduling. The Medium Access Control (MAC) layer is of main concern in WBANs due to its influence on energy consumption, delay, and packet loss. This chapter presents important contributions from prior research and highlights the existing gaps that justify the need for more adaptive and dynamic scheduling schemes.

Sharma et al. [1] proposed an edge-intelligent agent-assisted hybrid hierarchical blockchain system for continuous healthcare monitoring of 5G WBAN-IoT networks. The employment of biological Physical Unclonable Functions (PUFs) facilitated secure authentication and intelligent slot allocation for emergency data, resulting in minimized packet loss and enhanced real-time responsiveness. However, congestion and priority scheduling were not addressed by their approach, nor was it implemented in the real world, giving rise to scalability and practicability concerns.

Alhazmi et al. [2] introduced a hybrid multi-class MAC protocol for IoT-based WBAN systems. The protocol effectively handled various traffic loads with priority-based communication. Still, the protocol had only two classes of traffic and employed static scheduling, which can result in higher energy consumption. Liu et al. [3] introduced an MDP-based energy-aware MAC protocol that optimized slot assignment and back-off schemes. The radio-frequency energy harvesting-based technique showed the reduction of energy usage by up to 22% in comparison to traditional methods and could separate the critical and non-critical information. The greatest disadvantages were its immense computational complexity and the absence of security and privacy considerations. R.A.Khan et al. [4] proposed a traffic priority-aware data dissemination scheme with static thresholds to separate sensitive and normal medical data. Despite its effective ranking of the majority of health data as of utmost importance, its reliance on pre-defined thresholds renders it less accommodating to patient individualized deviations, and its scalability in large-scale WBAN deployments remains to be proven.

A.M.Khan et al. [5] proposed ESTEEM, a Markov Chain Model-based multi-hop routing protocol that optimizes the relay node selection to promote network stability and energy conservation. Although the protocol demonstrated good performance in simulations, it was never tested on actual hardware and only ran in static conditions. Li et al. [6] introduced a delay and temperature-aware slot allocation framework, named "Learning to Allocate," that operates on a TDMA-MAC topology. The framework reduced delay by 14% and canceled out temperature accumulation. But the entire evaluation was performed only on simulations without any hardware testing. Nadeem et al. [7] proposed the SIMPLE protocol, which focuses on stable and energy-efficient multi-hop communication in WBANs. It optimizes hop count and relay node choice to maximize throughput as well as network lifetime. The protocol is not adequately optimized for mobile settings and lacks mechanisms to deal with time-critical medical data and channel changes.

Wang et al. [8] proposed an adaptive scheduling algorithm that takes advantage of channel periodicity to maximize the performance of dynamic WBANs. Their method supported node mobility in an efficient manner with a decrease in packet collisions. The known channel periodic assumption limits its application in practice, especially for random mobility models, and the complexity of the algorithm is not likely to be acceptable for low-capacity WBAN nodes. Alabady et al. [9] proposed a traffic priority-aware medical data dissemination architecture with the aim of reducing end-to-end delay and maximizing energy efficiency. The protocol learns based on evolving network conditions and ensures high-priority transmission of critical data. Although it has some strengths, it is complex in terms of algorithms, depends on precise data classification, and is not validated in real-world clinical environments.

Alemdar and Ersoy [10] proposed MATTEMPT, a thermal-aware, energy-efficient multi-hop routing protocol for WBANs. MATTEMPT avoids hot spots by routing around hot nodes and can handle patient mobility. While it improves load balancing and network lifetime, it incurs increased computational overhead and potential transmission delay due to thermal-aware routing, and limited validation exists in large-scale scenarios.

Summary of Identified Gaps

The surveyed literature focuses on remarkable advances in WBAN MAC-layer optimization from the points of energy efficiency, priority to data, and mobility adaptation. Nevertheless, typical constraints are dominant in most studies, including:

1. Lack of real-world hardware verification,
2. Scalability limitation to dynamic or multi-WBAN environments,
3. Inadequate handling of mobility-aware scheduling for congestion
4. Locked-up high computational complexity for low-power sensor nodes.

These loopholes underscore the importance of a lightweight, adaptive, and power-aware MAC-layer solution that can handle dynamic conditions, mobility, and varying traffic patterns in real-time healthcare monitoring systems.

Chapter3

SYSTEM OVERVIEW AND METHODOLOGY

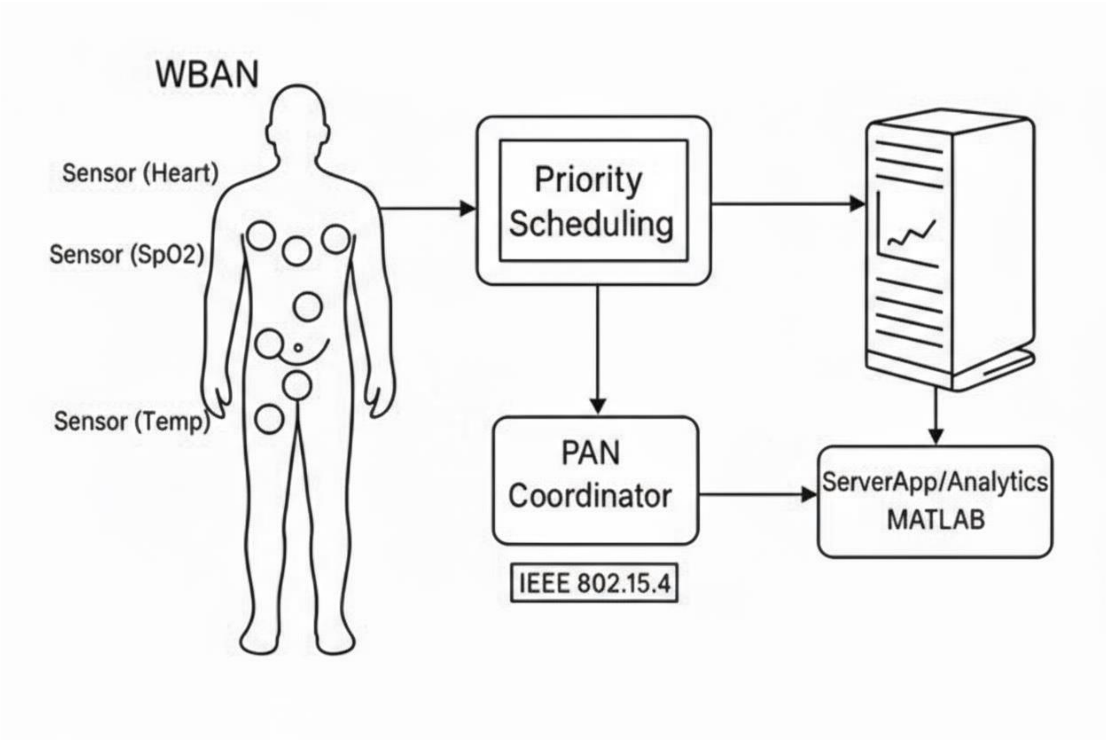
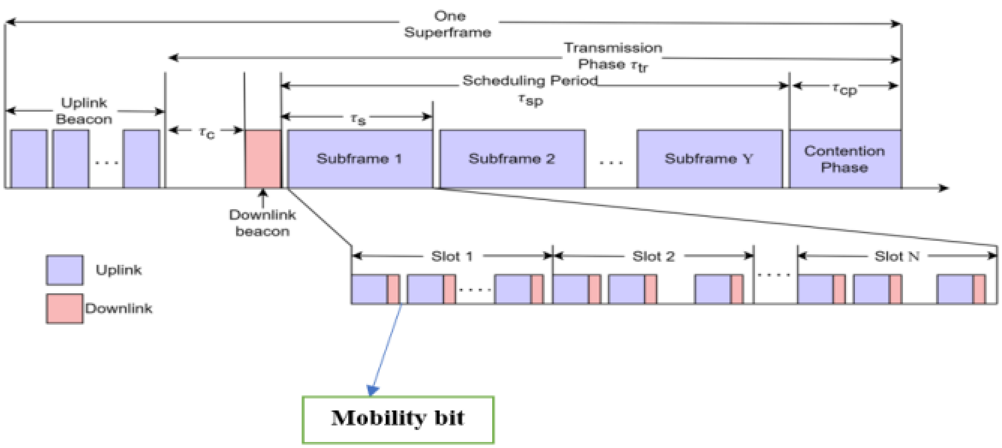


Fig. 2 System Overview

METHODOLOGY

This project introduces an Energy-Efficient Priority-Based Mobility-Aware Scheduling Mechanism for heterogeneous Wireless Body Area Networks (WBANs). The approach is based on a systematic design, implementation, and evaluation procedure to test and verify the suggested hardware under realistic WBAN situations with both static and mobile sensor nodes. The network topology of the experiment is formed by several WBANs, each including three low-rate medical sensor nodes to record physiological signals like ECG, SpO_2, body temperature, and heart rate. A Personal Area Network (PAN) Coordinator schedules TDMA, assigns slots, aggregates data from these sensors, and interacts directly with a healthcare server, which stores, processes, and displays obtained data for real-time observation. In the simulation environment, ten WBANs are deployed with three sensor nodes in each of them. Two mobility models are used to simulate the node mobility: the Random Waypoint Model for simulating random outdoor mobility and Linear Mobility Model for simulating controlled indoor patient mobility.



Mobility bit: If bit=0 no mobility Detected

If bit=1 Mobility Detected

Fig.3 TDMA Based MAC for WBAN

The system designed utilizes a TDMA-based MAC protocol that organizes communication into periodic super frames that are further divided into several phases to keep track of synchronization, scheduling, and data transmission effectively. The Beacon Phase (τb) is triggered by the PAN Coordinator to time-synchronize the network, disseminate configuration parameters, and advertise slot assignments for the next transmission period. In the Scheduling Phase (τsp), time slots are allocated dynamically based on several decision parameters such as Packet Data Rate (PDRate), Residual Energy (RE), Buffer Length (BL), and Data Sensitivity (DS). Nodes carrying high-frequency medical information, e.g., ECG signals, are given priority, with nodes having low residual energy or heavy buffer queues given higher priority in order to avoid data loss. Time-sensitive and critical measurements are always scheduled first. In the Transmission Phase (τtr), nodes send their data in allocated slots on a collision-free basis, with the duration of a slot varied based on node mobility and priority level. The Contention Period (τcp) supports non-scheduled communications, such as emergency transmissions, new node joins, or retransmissions for nodes that lost their slots because of mobility.

In the Scheduling Phase, PAN Coordinator carries out mobility detection through RSSI-based analysis. Sensor nodes send beacon signals periodically, and the coordinator observes the Received Signal Strength Indicator (RSSI) levels to sense mobility. By dividing current RSSI (R_curr) by past averages (R_prev), the system calculates differences ΔR. If the difference crosses a threshold level, the node is deemed mobile (Mobility Bit = 1); otherwise, it is stationary (Mobility Bit = 0). Mobile nodes are assigned shorter slots and are turned on in Burst Transmission Mode so that critical information is transmitted at high speed before link breakdowns take place. Stationary nodes are allocated longer, fixed slots for uninterrupted communication. Nodes with low residual energy or high buffer occupancy are also given priority in order to offload data on time and avoid packet loss.

Dynamic Slot Allocation takes advantage of a multi-criteria priority mechanism where the following are prioritized: (1) emergency data, (2) burst mode high-mobility nodes, (3) high buffer occupancy nodes, (4) low-energy nodes, (5) data rate. In the Contention Phase, unallocated slot nodes can send access requests, which are analysed and allocated by the PAN Coordinator in the next super frame cycle. This provides QoS for high-priority healthcare data while being energy efficient in the network.

The system is simulated with four sensor nodes per WBAN. Super frame time is variable (50–100 Ms), and mobility has been modelled with both Random Waypoint and Linear Mobility schemes. The energy model is a conventional battery drain paradigm with initial capacity E_0, and the channel model adheres to IEEE 802.15.4/802.15.6 standards for low-power wireless communication.

Performance metrics are Packet Delivery Ratio (PDR), Average End-to-End Delay, Energy Consumption, Convergence Time, and Mobility Impact Analysis. PDR validates network stability, end-to-end delay measures timeliness, energy consumption measures scheduling efficiency, and convergence time validates network stabilization due to mobility or topology change. Mobility impact is evaluated by comparing PDR and delay fluctuations between Random Waypoint and Linear mobility models.

In end-to-end communication, sensor nodes send data through TDMA uplink slots to the PAN Coordinator, which collects and sends the data directly to the healthcare server via UDP protocols. The system incorporates energy-aware TDMA scheduling, mobility detection, and slot allocation based on priority for guaranteed and timely data delivery with maximum energy optimization. MATLAB simulation results confirm that the mechanism efficiently enhances reliability, minimizes delay, and saves energy in static and mobile WBAN environments.

Chapter4

Implementation

4.1Simulation model

It is discrete-event-based and simulates four WBAN sensors (Heart, SpO_2, Temperature, BP) with a PAN coordinator through IEEE 802.15.4. The coordinator talks to the server and applies mobility-aware priority scheduling through a TDMA MAC, in which the sensors report periodically a status (buffer, data rate, residual energy, time sensitivity). The coordinator broadcasts a beacon to test mobility, followed by slot allocation based on received status, and sensors broadcast in their designated slots to minimize contention and maximize energy efficiency; received data in the coordinator are routed to the server. Throughput, packet delivery ratio (PDR), residual energy, reliability, and delay are measured by the algorithm for various simulation times (100 s, 500 s, 1000 s, 1500 s). the simulation parameters mentioned in table1 are used in the implementation

Parameters	Values
Simulation time	100s
Mobile slot	0.035s
Super frame duration	0.5s
Maximum CSMA Backoffs	4
Maximum Retry limits	3
Maximum length of payload	127 bytes
macMinBE	3
macMaxBE	5
Multiplicative constant to convert time length of frame to slot length	80 bits/slot
Data Rate	250Kbps
Symbol Rate	62.5kbps
Length of ACK frame	88 bits
Operating frequency	2.45GHZ
MAC Header Size	10 bytes
PHY Header Size	6 bytes
Initial energy(E0_j)	4j
Battery voltage(vbat)	4v

Transmit current(I_TX)	8mA
Receive current(I_RX)	7mA
Idle current(I_IDLE)	0.12mA

Table.1 Simulation parameters

Energy Model:

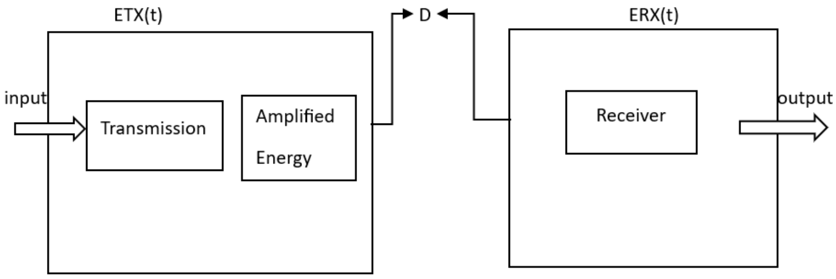


Fig.4 Energy Model

Above fig4 represents energy Model used in implementation

ETX(t) = V*Itx*t (1)

ERX(t) = V*Rtx*t (2)

The above (1), (2) are the equations used in Implementation

Where t is **time in seconds** spent in that state.

During a TDMA/CSMA slot, a sensor may **transmit packets**. Each attempt consumes:

Energy Consumed=ETX(t)+ ERX(t) (3)

Residual energy =Initial energy- Energy Consumed (4)

With the help of (3), (4) Residual Energy of each Sensor node is Calculated

Below Fig4 and Fig5 Shows how Priority scheduling happens in detail with and example

Priority Scheduling–Explanation

1. **Compute Priority Score**
   - DataScore $= \min\left(\frac{\text{initDataRate}}{50}, 1.0\right)$
   - TimeScore = 1.0 (critical), 0.5 (urgent), 0.0 (normal)
   - BufferScore $= \min\left(\frac{\text{bufferLen}}{50}, 1.0\right)$
   - EnergyFactor $= \max(0.0, 1 - \text{residualEnergy})$
   - Priority $= 0.35 \cdot \text{Data} + 0.30 \cdot \text{Time} + 0.20 \cdot \text{Buffer} + 0.15 \cdot \text{Energy}$
2. **Group by Urgency**
   - Level 2 = Critical
   - Level 1 = Urgent
   - Level 0 = Normal
3. **Sort and Schedule**
   - No Mobility: Order = Critical → Urgent → Normal
     Slot $= \frac{\text{superframeDuration}}{\text{totalSensors}}$
   - With Mobility: First slot = mobile sensor (`mobileSlotSec`) Others = Critical → Urgent → Normal
     RemainingTime = superframe transimitung Duration − mobileSlotSec
     Slot $= \frac{\text{RemainingTime}}{\text{totalSensors} - 1}$
4. **Tie-Break Rule** If equal Priority → sensor with **lower residualEnergy** first.

Critical and mobile sensors transmit first, while buffer and energy are balanced for optimal WBAN performance.

Fig.5 Priority Schedling Explantion

Priority Scheduling – With Example

1. **Priority Score Calculation**
   - DataScore $= \min\left(\frac{\text{initDataRate}}{50}, 1.0\right)$
   - TimeScore = 1.0 (critical) / 0.5 (urgent) / 0.0 (normal)
   - BufferScore $= \min\left(\frac{\text{bufferLen}}{50}, 1.0\right)$
   - EnergyFactor $= \max(0.0,\ 1 - \text{residualEnergy})$
   - **Priority** $= 0.35 \cdot \text{Data} + 0.30 \cdot \text{Time} + 0.20 \cdot \text{Buffer} + 0.15 \cdot \text{Energy}$
2. **Sensor Example**

Sensor	Data	Time	Buf	Energy	Priority
Heart	20	2	15	0.6	0.645
SpO2	15	2	12	0.7	0.592
BP	10	1	8	0.8	0.355
Temp	5	0	3	0.9	0.097

3. **Grouping & Ordering**
   - Critical: Heart (0.645), SpO2 (0.592)
   - Urgent: BP (0.355)
   - Normal: Temp (0.097)
4. **Scheduling (No Mobility)**
   - Super frame transmision time = 0.1s, Slots = 4
   - Each slot = 0.025s
   - **Order: Heart → SpO2 → BP → Temp**
5. **Scheduling (With Mobility)**
   - Heart mobile → 1st slot = 0.035s
   - Remaining = 0.065/3 0.0217s
   - **Order: Heart → SpO2 → BP → Temp**

Critical and mobile sensors transmit first, balancing data rate, urgency, buffer, and energy.

Fig.6 Prioirty Scheduling Example

Algorithm 1: Energy-Efficient CSMA/TDMA Operation in WBAN

```
Input: S = {s1, s2, …, sn}, E0, SF
Output: Th, PDR, RE, Rb, Dly

for i = 1 → n do
    pos[i], buf[i], E[i] ← init(), 0, E0
end for
EQ ← {e_bind(coord), e_bind(server)}
t ← 0
while t < T_sim do
    (ei, si) ← pop(EQ)
    switch ei:
        case e1:
            sched(coord_beacon)
        case e2:
            RSSI[i] ← upd_RSSI(si)
            Mflag[i] ← |RSSI_new − RSSI_old| ≥ RSSI_th
            E[i] ← E[i] − ΔE_idle
            sched(coord_sched)
        case e3:
            PS[i] = 0.35·D[i] + 0.30·T[i] + 0.20·B[i] + 0.15·E[i]
            if Mflag[i] = 1 → slot[i] ← burst_slot
            else slot[i] ← norm_slot
            sched(sensor_slot[i])
        case e4:
            while (Q ≠ ∅) ∧ (t_slot > 0) do
                BO ← rand(0, CW)
                if CCA1 ∧ CCA2 = idle then
                    TX()
                    if ACK = 1 → suc_pkt++
                    else retry++
                else defer++
            end while
    end switch
end while
Th  = Σ(pkt_suc × L_pkt) / T_sim
PDR = pkt_suc / pkt_sent
Rb  = Th / Th_max
Dly = Σ(T_end − T_start) / pkt_suc
RE  = mean(E[i]), ∀i ∈ S
```

Fig.7 Scheduling algorithm

Variable meanings (symbol form):

- S – sensor node set
- E_0 – initial energy
- SF – superframe duration
- T_sim – total simulation time
- EQ – event queue
- RSSI_th – RSSI threshold
- PS[i] – priority score of node *i*
- Mflag[i] – mobility flag
- BO – backoff time
- CCA_1, CCA_2 – clear channel assessments
- Th – throughput
- PDR – packet delivery ratio
- RE – residual energy
- e1-cordinator binding
- e2-Cordinator beacon
- e3-Cordinator Schedule
- e4-Sensor Slot

Algorithm 2: RSSI-Based Mobility Detection

```
Input: Current RSSI (Rnew), Previous RSSI (Rold)
Output: Mobility flag (Mflag)

Compute ΔRSSI = |Rnew − Rold|
if (ΔRSSI ≥ RSSI_threshold) then
      Mflag ← 1    // Mobile node detected
else
      Mflag ← 0    // Stationary node
end if
return Mflag
```

Fig.8 Mobility detection algorithm

Priority Score Calculation and Scheduling:

Data Rate, Time Sensitivity, Buffer Length, and Residual Energy of each sensor as inputs and the slot order and allocation duration as outputs for TDMA scheduling. first computes four standalone scores for every sensor.

Data Score= min (initial data rate/50,1.0) (5)

Time Score is allocated based on the level of urgency of data= 1(critical),0.5 (urgent), and 0 (normal) (6)

Buffer Score=min (buffer Len/50,1.0) (7)

Energy Score=max (0.0,1-Residual Energy) (8)

Then, a Priority Value (P) is calculated for each sensor using weighted parameters:

P = a1 Data Score + a2 Time Score + a2 Buffer Score + a4 Energy Score (9)

By substituting these values of a1=0.35, a2=0.30, a3=0.20, a4=0.15 in (9) and with substitute the scores of Data Score, Buffer Score, Energy Score, Time Score

From (5), (6), (7), (8) Priority Value is Calculated in detail explanation is shown in fig4,5 and Algorithm explanation from fig 6,7

All the sensors are then ranked in decreasing order of priority

If a node is found to be mobile, it is allotted the first slot (burst slot) so that transmission becomes assured, and the balance time available in the super frame is distributed among other nodes.

If there are no mobile nodes, slots are distributed equally according to priority class critical nodes are assigned first, followed by urgent and then normal ones.

From the above priority score Calculation and Scheduling us the implementation of How priority score calculated and Scheduling Happens and how the mobility detected with the help of All these algorithms Implemented simulation model from these Algorithms.

The simulation Collects and averages the values of Throughput, PDR, Residual energy and Delay from each sensor node.

WBAN Performance Metrics:

1. Throughput:

Throughput indicates the Cumulative amount of correctly transmitted data over the network during the simulation time. It indicates how Properly the channel is used for data transmission. from (10) Throughput is Calculated.

$$\text{Throughput (bps)} = (\Sigma\ (P\_succ,i \times L\_pkt))\ /\ T\_sim \qquad (10)$$

Where P_succ,i is the Number of successfully received packets from node *I* and L_pktis the total size Packet size (in bits), T_sim = Total simulation time and N_s = Total number of sensor nodes

2. Packet Delivery Ratio (PDR)

PDR measures the reliability of the network by Computing the ratio of the number of Correctly delivered packets to the total number of packets transmitted. From (11) we get the value of PDR.

$$PDR = P\_recv\ /\ P\_sent \qquad (11)$$

Where is P_recv is Total number of packets received on Successfully data Transmission, P_sent is Total number of packets transmitted by all sensors.

3. Residual Energy:

Residual energy represents the average left over energy in all sensor nodes at the end of the simulation. It shows the energy efficiency of the Implementation. From (12) we get the residual energy left in sensor node.

$$E\_res = (1\ /\ N\_s) \times \Sigma\ (E\_init - E\_cons,\ i) \qquad (12)$$

Where is E_init indicates Initial energy of each node and E_cons, i indicates Energy consumed by node *i* during operation, N_s is the total Number of nodes present in WBAN

4. Delay

Delay is the average time Consumed for a data packet to travel from the source sensor node to the sink. It Calculates the timeliness of data delivery in WBAN communication. From (13) we will get the delay

$$Delay = (1 / P\_succ) \times \Sigma (T\_recv,i - T\_send,i) \quad (13)$$

Where T_recv,i is the reception time of the *i*th packet, and T_send, is Transmission time of the *i*th packet, and P_succ is Total number of successfully delivered packets From (10), (11), (12), (13) calculated the values of PDR, Throughput, Delay and Residual energy plotted Graphs to Compare the proposed Implementation with SIMPLE, ATTEMPT, ESTEEM Protocols

4.2 Analytical model:

The analytical model is simulated with the help of Markov chain model.

Same Simulation Parameters are used which in Purposed system and transmission States are created for Markov chain corresponding to Clear Channel Assessments (CCA1, CCA2), Successful Transmission (SU), and Failure (FL). Transition probabilities and probability of successful transmission are calculated. Nodes contend access to the channel during multiple mini slots that compose each super frame, competing based on assigned priority levels (Critical, Urgent, or Normal) and mobility status (ΔRSSI $\geq$ threshold). The data transmission procedure conforms to a CSMA/CA procedure with double CCA and up to three retransmission attempts, providing precise identification of successful or unsuccessful transmissions. The channel statistics are simulated with a Gilbert–Elliott two-state model for depiction of good and bad channel states with transition probabilities (pGB, pBG). Lastly, after simulation, important performance parameters like Throughput, Packet Delivery Ratio (PDR), Delay, and Residual Energy are calculated and compared to analyse the overall performance of the system proposed. Below fig4.5 shows the WBAN State Transition flow

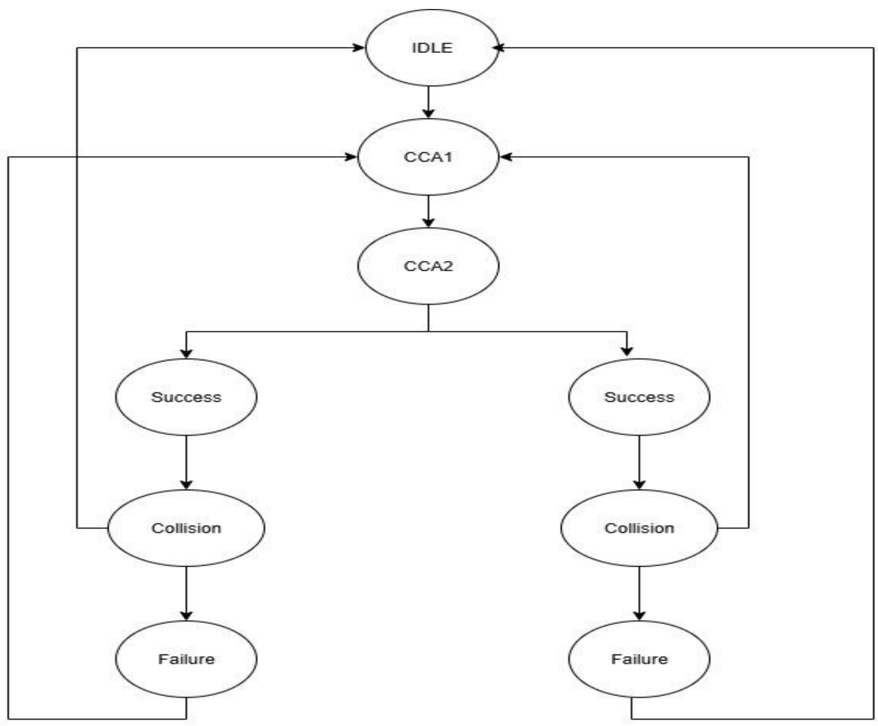


Fig.9 WBAN Markov Chain Model

Chapter5

Result and Analysis

In this work we use MATLAB [11] as a Simulation tool used IEEE 802.15.4 radio medium For Communication. Simulations are Performed for a WBAN that follows Star Topology of IEEE 802.15.4 Standard and communicates using 2.4GHZ ISM band. From the Simulation Accordingly Calculated the throughput, PDR, Residual Energy and Delay The parameters used in simulation are Tabulated in table 4.1.

Compared simulation model with SIMPLE [7], ESTEEM [10] and MATTEMPT [5] and the simulation is done with different simulation time like 100s, 500s,1000s ,1500s to plot Graphs.

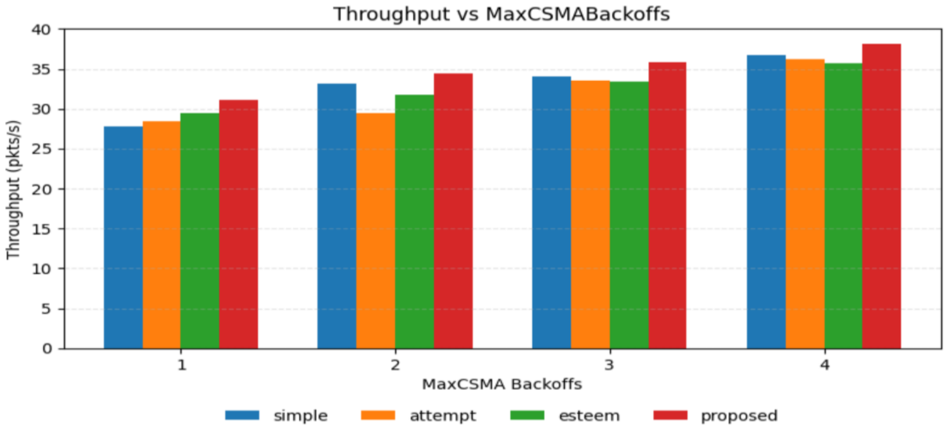


Fig.10 MaxCSMA Backoffs vs Throughput

From fig 10 Illustrates throughput efficiency of the four protocols SIMPLE, ATTEMPT, ESTEEM, and the Purposed scheme is compared in terms of varying MaxCSMA backoff values. throughput improves in a gradual manner as the number of MaxCSMA backoffs increases from 1 to 4 for all the protocols, showing better channel utilization with increased backoff limits. Out of the protocols, the Purposed scheme has the highest throughput at every backoff level, displaying superior contention handling and effective channel utilization. The performance disparity between the protocols decreases as the backoff value increases, showing that more backoff chances allow for reduced channel contention.

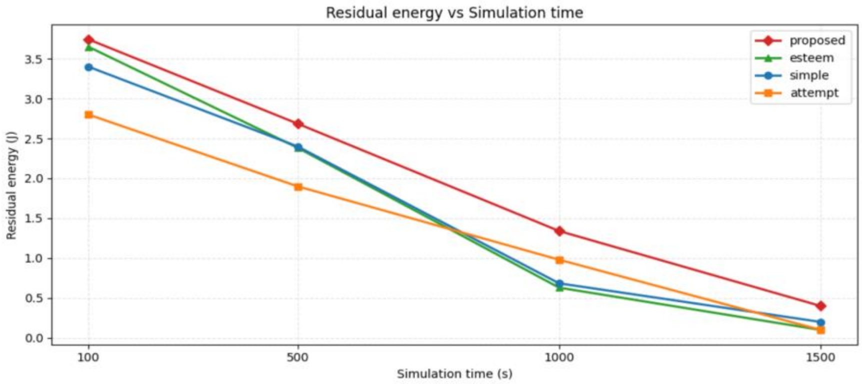


Fig.11 Reisdual energy vs Simulation time

From fig 11 Illustrates Purposed super frame scheduling is better than protocols such as ESTEEM, M-ATTEMPT, and SIMPLE. Although ESTEEM and SIMPLE improve multi-hop routing to stability and throughput, respectively, they are still disadvantaged by uncontrolled collisions, wakeups, and queue aging because of the absence of deterministic slot allocation. M-ATTEMPT minimizes collisions using thermal-aware rerouting but is still dependent on contention and additional control packets, resulting in energy wastage. On the contrast, the purposed system leverages mobility- and priority-aware TDMA slots so that nodes transmit once and sleep longer, depleting queues effectively, reducing retries, and keeping radios off most of the time, which results in consistently higher residual energy and lower control overhead.

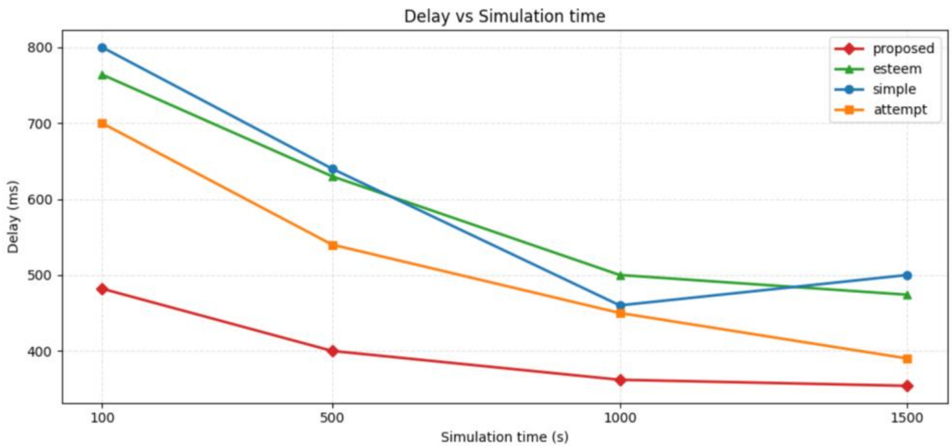


Fig.12 Delay vs Simulation time

From fig12 illustrates that there is small delay for purposed system compared to SIMPLE,MATTEMPT,ESTEEM because of Determinstic TDMA slots which is alloacted based on Mobility and Priority schudeling for data transmission where as other implementations depends upon hoping like single hop and multihop for data transmission which leads to increase in delay.

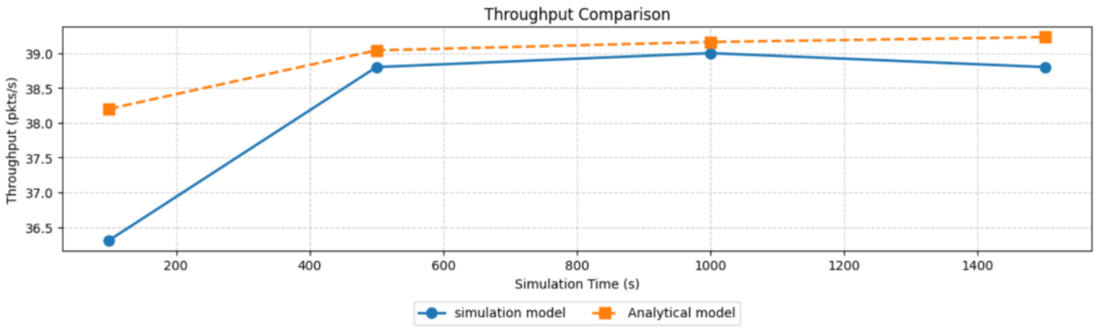


Fig.13 Throughput Comparison

From fig13 larger throughput of the purposed scheme is confirmed by the analytical Markov model that correctly calculates transmission and collision probabilities. Limited in-slot CSMA-assisted mobility-and priority-aware TDMAscheduling reduces collisions and backoffs. RSSI-enhanced mobility detection and priority scoring eliminate queue build-ups and retransmissions. Analytical curves are slightly higher but smoother under idealized CCA1/CCA2 success assumptions. The close analytical–simulation match certifies the correctness and high efficiency of the proposed design.

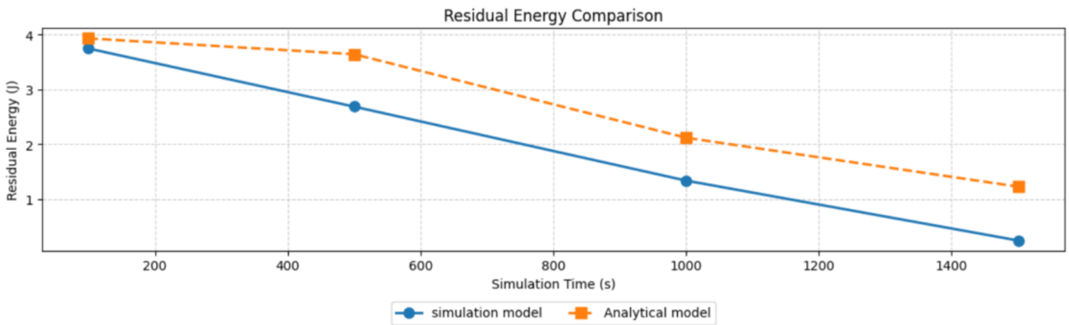


Fig.14 Residual energy Comparison

From fig14 illustrates the analytical residual-energy curve stays higher since it considers average sensing and transmission expenses but not random backoffs, fades, and retries. Simulation results decrease at a faster rate due to mobility-induced bursts and ACK/listen overheads within TDMA slots. Periodic low-SINR retransmissions also add to energy loss in the simulation. The analytical model is therefore an ideal upper limit, while simulation realizes actual variations. This coincidence validates the analytical model's accuracy in modelling realistic WBAN energy behaviour.

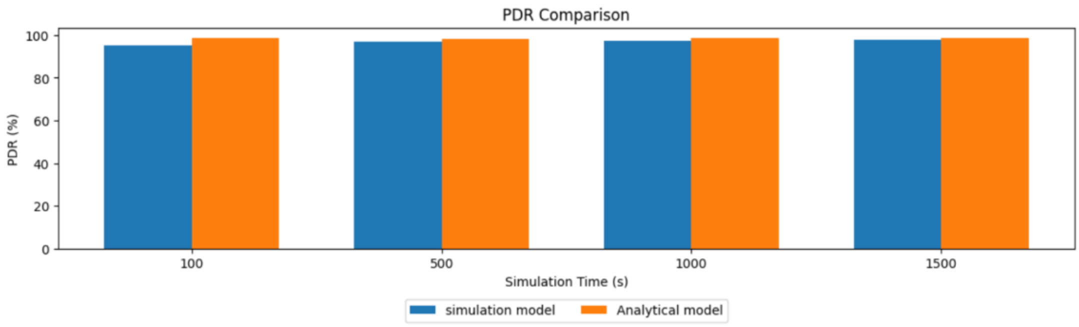


Fig.15 PDR Comparison

From the fig15 the analytical model estimates consistently high PDR, creating a realistic cap consistent with simulation output. Slightly elevated analytical values result from averaging loss estimation, whereas simulations involve random backoffs. The close correlation confirms that the model correctly models the protocol's delivery behaviour. Priority-and mobility-aware scheduling achieves timely, reliable transmissions under both models.

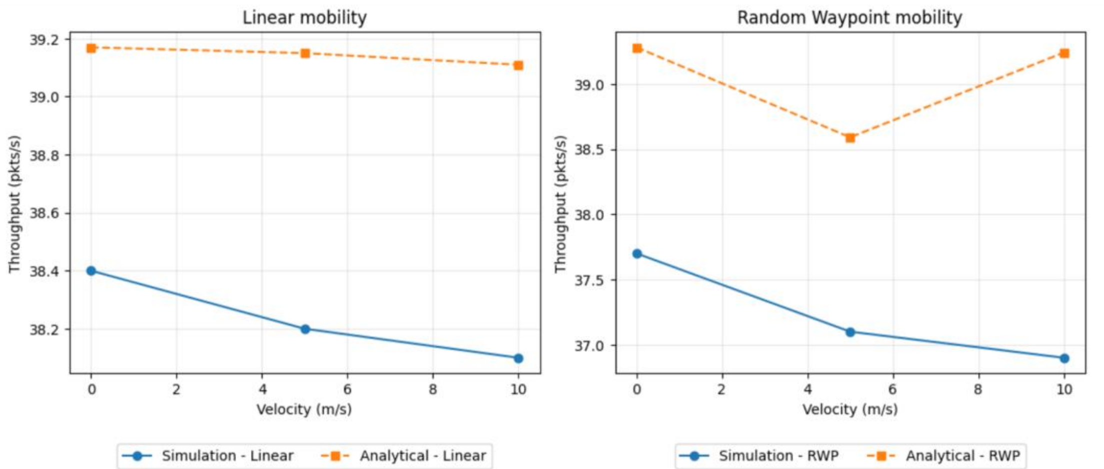


Fig.16 Throughput vs Velocity

From fig16 illustrates the model estimates greater throughput than simulation, creating an upper bound through averaging collision and CCA success rates. The models both demonstrate throughput reduction at higher velocity, more so under Random Waypoint because of irregular movement and resynchronizations. The analytical curve is smoother because it excludes random fades and backoff jitter. Simulation drops are real mobility-imposed losses, confirming the model's predictive accuracy. Therefore, the tight analytical–simulation correspondence verifies the accuracy and effectiveness of the suggested mobility-aware scheduling.

Chapter6

CONCLUSION

This purposed system suggested a mobility- and urgency-aware TDMA MAC with bounded in-slot CSMA tailored for WBANs. The scheduling scheme improves greatly in terms of reliability, energy efficiency, and throughput compared to contention-based and routing-only approaches. Analytical modeling provided an upper bound on performance, and event-driven simulations using realistic RSSI-based mobility and energy dynamics closely tracked the predicted trends, confirming the model's Accuracy. The suggested scheme always maintained greater residual energy and attained high PDR by mitigating idle listening, redundant backoffs, and retransmissions. Mobility analysis ensured stable performance under linear and random movements, resisting channel and movement fluctuation robustness. In general, the high correlation between analysis and simulation confirms the design accuracy and advocates mobility-aware TDMA with reduced contention as a robust and effective MAC platform for future WBAN improvements.

In future we can extend Machine learning–based parameter tuning can be explored to dynamically adjust super frame duration, backoff limits, and mobility thresholds in response to varying channel and traffic conditions Cross-layer interaction with routing and transport layers can improve end-to-end reliability, latency, and overall energy efficiency in dynamic WBAN environments.

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