Energy Efficient Priority Based Mobility Aware Heterogeneous WBAN Networks

Subject: Dissertation I -21ES798

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Outline

Introduction

Wireless Body Area Network (WBAN) is a medical type of network that senses the human body and monitors any critical or periodic events. WBAN consists of a set of medical sensors and wearable devices that continuously collect information and send it to the coordinator (such as healthcare specialists, doctors, pharmacy, ambulance, or physicians) through a gateway.

In WBAN, energy efficiency is a major concern. Although the sensors are small and use little power, transmitting the collected data to the coordinator consumes more energy, leading to higher power usage.

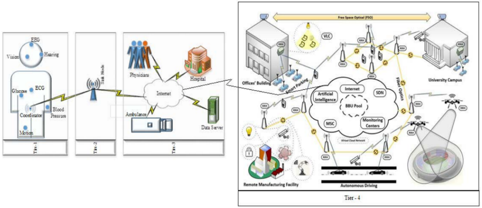

Fig.1: Wireless Body Area Network (WBAN)

Outline

Literature Review

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

- Lack of real-world hardware verification,
- Scalability limitations in dynamic or multi-WBAN environments,
- Inadequate handling of mobility-aware scheduling under congestion, and
- High computational complexity unsuitable for low-power sensor nodes.

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

Outline

Objectives

- The main objective of this project is to design and implement an energy-efficient congestion-aware priority-based scheduling mechanism for WBAN IoT networks
- A dynamic MAC scheduling algorithm is developed to improve data transfer and routing efficiency in WBAN.
- The scheduling decisions are based on:
  - Packet data rate,
  - Residual energy of nodes, and
  - Buffer length, Time-sensitive data from sensor nodes.
- This approach ensures optimal resource utilization and reduces power consumption and control over head.

Outline

System Overview of Proposed System

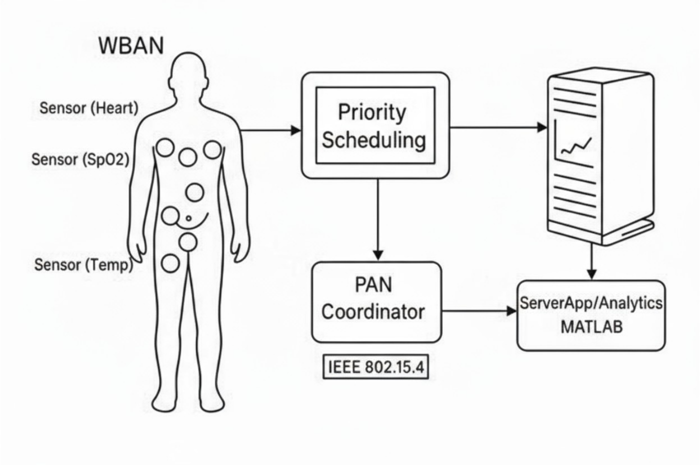

Fig.2: System Overview of Proposed System

Outline

Methodology

Step 1: Network Setup

- Each WBAN consists of multiple sensor nodes and a PAN coordinator (sink node).
- The PAN Coordinator aggregates data and transmits it to a centralized server.
- Use Mobility Models say Random Way point and linear mobility to test under indoor and outdoor WBANs network.

step 2:Define Super-frame architecture

- Each WBAN network operates in a super-frame structure consisting of multiple phases:
- **Beacon Phase** – Data will be transmitted and received in this phase
- **Scheduling Period (τ_{sp})** – Allocates Slots Based on Packet data rate, Residual energy of nodes, Buffer length, Time-sensitive data from sensor nodes.
- **Transmission Phase (τ_{tr})** – Data transmission takes place in allocated slots.
- **Contention Phase (τ_{cp})** – Optional phase for unscheduled communication.

Methodology Continued..

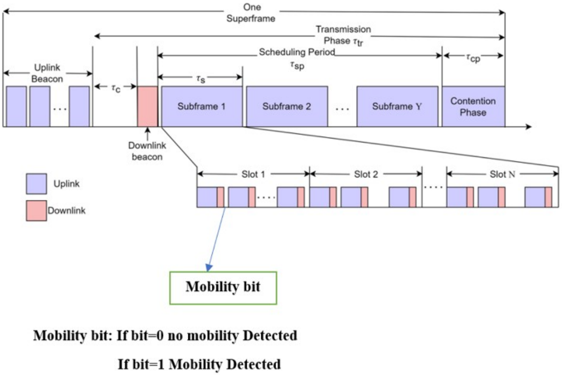

Fig.3: TDMA-based MAC for WBAN

Methodology Continued..

Step 3: Scheduling Phase

- WBAN does:
  - Monitors RSSI data/beacon frames from each sensor
  - RSSI variation is analyzed by comparing current signal strength with historical (old) signal values to infer body motion. .
  - PAN coordinator allocates slots based on:
    - **RSSI (mobility indicator)**
    - **Data rate requirement**
    - **Buffer occupancy**
    - **Remaining energy**
  - **If mobility is detected (via RSSI variation):**
    - PAN coordinator triggers **burst transmission** mode.
    - Ensures critical data is sent before connection loss.

Methodology Continued..

Step 4: Dynamic Slot Allocation & Contention Handling

- **Dynamic Slot Allocation Based on Mobility**:
  - Prioritize **non-mobile nodes** (`mobility bit = 0`) for consistent slot allocation.
  - Assign **shorter or adaptive slots** for **mobile nodes** (`mobility bit = 1`).
- **Contention Phase Handling**:
  - Allow new nodes to request access during this phase.
  - Enable nodes with missed slots due to mobility to rejoin communication.
- **Energy and Buffer Awareness**:
  - MAC scheduler integrates **remaining energy**.
  - Considers **buffer occupancy** (queue length at MAC layer).
  - Gives higher priority to nodes with **low energy** or **high buffer load**.

Methodology continued..

Step 5: Simulation Configuration

- Simulation Parameters used in Implementation is mentioned below in Table 1

Step 6: Performance Metrics

- Track the following during simulation:
  - Packet Delivery Ratio (PDR)
  - Average End-to-End Delay
  - Residual Energy
  - Mobility Models – Random Waypoint (RWP), linear mobility

Methodology Continued..

Step 7: Performance Evaluation

- MATLAB(open source)
- Mobility Models

Step 8: PAN Coordinator to Server Communication

- PAN Coordinators send their collected/aggregated data to a Server which is recevied from Multipile sensor nods.
- Used IEEE 802.15.4 for Communication.

Outline

Implementation(Simulation Model)

```
Algorithm 1: CoordinatorApp Scheduling Algorithm

socket.bind(localPort)
socketBound ← true
for each sensor ∈ sensors do
    if (|sensor.rssi - sensor.prevRssi| ≥ rssiThreshold) then
        mobileDetected ← true
    end if
end for
if (mobileDetected) then
    sendBeaconBurst()
end if
mobileIdx ← findMobileSensor()
if (mobileIdx ≠ -1) then
    order[0] ← mobileSensor, durations[0] ← mobileSlotSec
    remaining ← superframeDuration - mobileSlotSec
else
    sortByPriorityScore()
    slotDuration ← superframeDuration / sensors.size()
end if
sendScheduleToSensors()
```

Fig.4: Algorithm for Coordinator App

implementation Continued..

```
Algorithm 2: Priority Calculation Algorithm

drScore ← min(initDataRate / 50.0, 1.0)
if (timeSensitive ≥ 2) then timeScore ← 1.0
else if (timeSensitive = 1) then timeScore ← 0.5
else timeScore ← 0.0
bufScore ← min(bufferLen / 50.0, 1.0)
energyFactor ← max(0.0, 1.0 - residualEnergy)
priorityScore ← 0.35×drScore + 0.30×timeScore +
                0.20×bufScore + 0.15×energyFactor
return priorityScore
```

Fig.5: Algorithm for Priority Calculation

```
Algorithm 3: Sensor Data Management Algorithm

socket.bind(localPort), socketBound ← true
scheduleAfter(exponential(1.0/initDataRate), genTimer)
case GEN_TIMER:
    bufferLen++, residualEnergy -= uniform(0.00005, 0.0002)
case SLOT_START:
    maxPackets ← floor(slotDur × initDataRate)
    toSend ← min(bufferLen, maxPackets)
    for i ← 0 to toSend do
        sendDataPacket(), bufferLen--
        residualEnergy -= uniform(0.001, 0.003)
    end for
```

Fig.6: Sensor Data Management

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.

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·Data + 0.30·Time + 0.20·Buffer + 0.15·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.

implementation(Analytical model)

The analytical model is developed using a Markov chain with defined states for CCA1, CCA2, successful transmission, and failure. Nodes access the channel through a CSMA/CA mechanism based on assigned priority levels (Critical, Urgent, and Normal) and mobility detection using ΔRSSI thresholds. The channel behavior is represented by a Gilbert–Elliott two-state model depicting good and bad channel conditions. Transition and success probabilities are computed to evaluate transmission performance. Finally, key performance metrics such as throughput, packet delivery ratio (PDR), delay, and residual energy are analyzed to assess overall system efficiency. below fig 7 shows the markov chainmodel implementation

Markov Chain Model

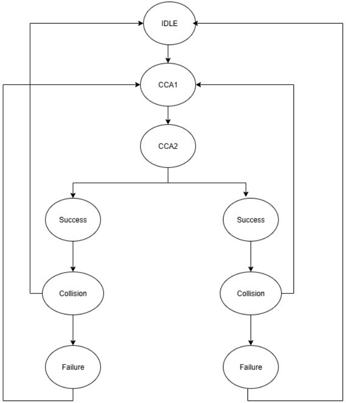

Fig7: Markov Model for implementation

Metrices

$$\text{Throughput (bps)} = \frac{\sum(P_{\text{succ},i} \times L_{\text{pkt}})}{T_{\text{sim}}} - (1)$$

$$\text{PDR} = \frac{P_{\text{recv}}}{P_{\text{sent}}} - (2)$$

$$E_{\text{res}} = \frac{1}{N_s} \sum(E_{\text{init}} - E_{\text{cons},i}) - (3)$$

$$\text{Delay} = \frac{1}{P_{\text{succ}}} \sum(T_{\text{recv},i} - T_{\text{send},i}) - (4)$$

these formulas are used for calcuating PDR,Throughput,Delay,Residual energy

Outline

Simulation Parameters

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

Table 1: Simulation parameters used for the WBAN network evaluation.

Results and Analysis

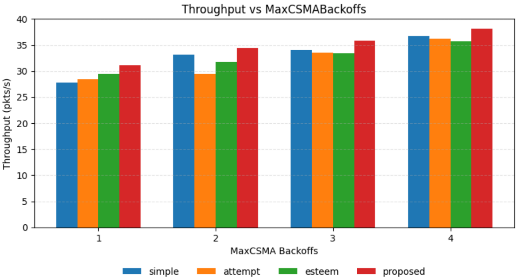

Fig.8: MaxCSMA Backoffs vs Throughput

Fig.8 shows throughput increasing with higher MaxCSMA backoff values for all protocols. The proposed scheme achieves 8 percent the highest throughput at every level, indicating superior contention handling and efficient channel utilization.

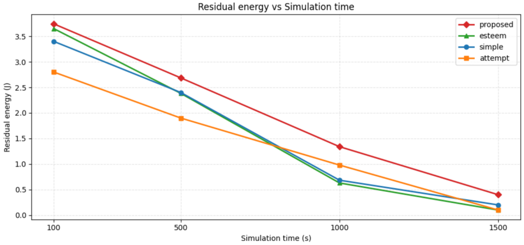

Fig.9: Residual Energy vs Simulation Time

Fig.9 shows that the proposed superframe scheduling outperforms ESTEEM, M-ATTEMPT, and SIMPLE. Using mobility- and priority-aware TDMA slots enables efficient transmission, resulting in higher residual energy, fewer retries, and reduced control overhead.

Results and Analysis

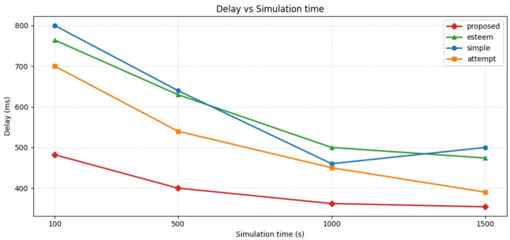

Fig. 10: Delay vs Simulation Time

Fig. 10 shows that the proposed system has a smaller delay(-15 percent)than SIMPLE, M-ATTEMPT, and ESTEEM. This is due to deterministic TDMA slots allocated based on mobility and priority scheduling, while others rely on single-hop or multi-hop transmissions, causing higher delays.

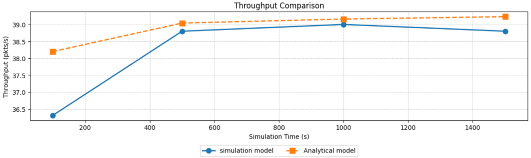

Fig. 11: Throughput vs Simulation Time

Fig.11 confirms the higher throughput of the proposed scheme through the analytical Markov model.Mobility-and priority-aware TDMA with limited in-slot CSMA reduces collisions and backoffs.The close match between analytical and simulated results validates the model's accuracy and efficiency.

Results and Analysis

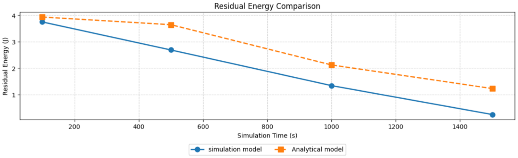

Fig.12: Residual Energy vs Simulation Time

Fig12 shows Analytical residual energy remains higher as it ignores backoffs and retries, while simulation energy drops faster due to mobility bursts and retransmission overheads. The close match validates the analytical model for realistic WBAN energy behavior.

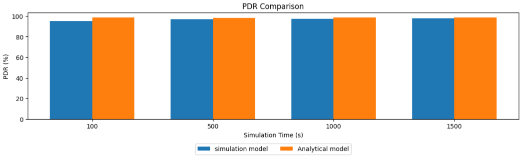

Fig.13: PDR vs Simulation Time

Fig.13 ShowsThe analytical model predicts high PDR, closely matching simulations. Slightly higher analytical values are due to averaged loss estimates. The correlation confirms accurate modeling of priority- and mobility-aware transmission behavior.

Results and Analysis

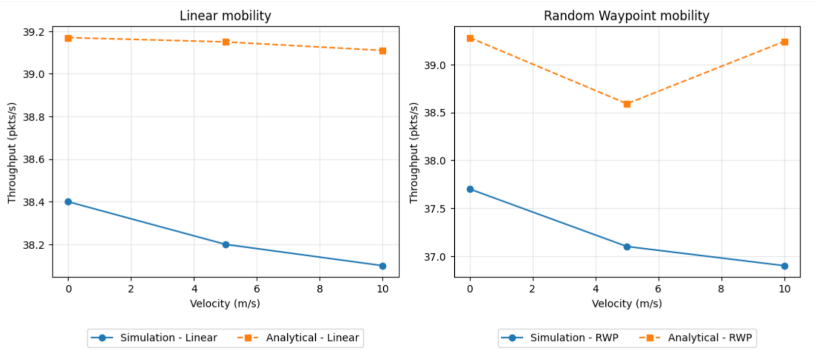

Fig.14: Velocity vs Throughput

Fig.14 shows the analytical model gives higher throughput, serving as an upper bound. Throughput decreases at higher velocities due to mobility and resynchronizations. The close match confirms the accuracy of mobility-aware scheduling.

Outline

Time Frame

SI.NO	Month	Task
1.	June	Literature Survey and Methodology
2.	July	Simulating Model
3.	August	Simulating Model
4.	September	Plotting Graph's and Comparing Results
5.	October	Report Writing

Fig15:TimeFrame

Outline

Conclusion

The proposed WBAN MAC scheme is a mobility- and urgency-aware TDMA MAC with bounded in-slot CSMA. It significantly improves reliability, energy efficiency, and throughput compared to contention-based and routing-only approaches. Analytical modeling and event-driven simulations confirm high accuracy and strong correlation with predicted trends. The scheme maintains higher residual energy and packet delivery ratio by reducing idle listening, redundant backoffs, and retransmissions. Future extensions include machine learning-based parameter tuning and cross-layer interaction to enhance adaptability and overall performance in dynamic WBAN environments.

Outline

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