# Multi-modal Transmission Strategies with Obstacle Avoidance for Healthcare Applications

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**Abstract.** This paper presents a novel energy-efficient MAC Protocol designed for Body Sensor networks (BSN) focusing towards pervasive healthcare applications. BSN nodes are usually attached to the human body to track vital health signs such as body temperature, activity or heart-rate. Unlike traditional wireless sensor networks, the nodes in BSN are not deployed in an adhoc manner. The network connectivity is usually centrally managed and all communications are single-hop. The BSN has to be dependable in order to ensure the availability and reliability of the data received. Hence, it is necessary to reduce energy consumption in order to prolong the operation of the network without frequent outage. It is common to duty cycle the sensor nodes to preserve the battery utilization. However, the communication between the sensing node and receiving node can be interfered by human movement that can lead to energy wastage. In this paper, A Multi-Modal Opportunistic Transmission with Energy Saving (M-MOTES) is proposed. M-MOTES uses the opportunistic transmission approach and the human kinematics to duty-cycling the node. Extensive experiments performed on real hardware show that M-MOTES can reduce the battery power consumption without affecting the packet reliability.

**Keywords:** Body Sensor Networks · Body shadowing
Multi-hop transmission · Duty cycle · Multimodal

## 1 Introduction

With the decrease in the cost and miniaturization of these electronic devices and biomedical sensors, it is possible to attach physiological sensing devices on the different body parts to form Body Sensor Networks (BSN). These devices allow non-obtrusive monitoring and capture of the vital health parameters of the human body and its environment in a decentralized manner [1]. Each device is usually consist of one or more sensors attached to or implanted in the human body with a micro-controller, a wireless radio and a power supply. These sensors can capture different physiological parameters such as body temperature, nerve


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impulses, ECG, blood pressure, and blood oxygen level. The sensory data collected can be transmitted wirelessly to the medical clinic or hospital for analysis and to monitor the patient's coordination and activity level.

However, a major hurdle for the wide adoption of BSN technology is the potential of service disruption due to radio interference [2] and battery depletion [3]. These sensor nodes usually operate under limited battery supply and in an environment where other medical devices using the same radio frequency that can interfere with the radio communication of between nodes. Communication can also be obstructed due to body part movement especially when BSNs are applied in medical health monitoring system [4]. Experimental work by Lim et al. has shown that radio interference can lead to severe packet drop and packet retransmission by the nodes [2]. As the power consumed during data transmission is higher than the combined power utilizations for both data processing and sensing, it necessary to reduce or eliminate radio communication due to packet retransmission and enable the node to sleep during non-transmission period in order to conserve energy [5]. One approach is through duty cycling. In these schemes, the device wake-ups only when necessary, otherwise it sleeps thereby saving energy. Coordinated and controlled data transmission can reduce energy consumption. Coordinate transmission can be achieved if the human activities can be predicted and the radio transmission cycle can be adapted based on the activity patterns.

In this work, we propose a Multi-Modal Opportunistic Transmission with Energy Saving (M-MOTES) Protocol that uses the opportunistic transmission approach with the ability to toggle between single-hop and multi-hop communication depending on the activities of the users. The main contributions of the paper are:

- We present the system design and implementation of the M-MOTES protocols
- We perform a comprehensive analysis of the proposed protocol.
- We evaluate the packet reliability and energy efficiency of the M-MOTES based on the current measurements.

The rest of this paper is organized as follows. The MOTES is introduced in Sect. 3. In Sect. 4, we describe the experimental setup to analysis the performance of four different transmission protocols with the nodes attached to a student attending one day lecture. The Packet Delivery Rate (PDR) and current measurements are compared and discussed in detail. Section 6 describes the future work and concludes.

## 2 Related Works

Over the last, a number of previous researches have been proposed to investigate use of wearable sensors for motion analysis, activity classification, and monitoring athletic performance [6,7]. Sensors devices such as the accelerometer and gyro-meter are usually used to assess the human kinematic and track different activities body movement. Prabh et al. [8] proposes the BANMAC based on the radio frequency signal fluctuation to schedule for packet transmission. The RF signal fluctuations are measured through the periodic exchange of probing packets in every 12 s. The authors reported that the BANMAC can reduce the packet loss rate (>30%) in comparison to the standard IEEE 802.15.4 MAC protocol. However, the exchange of periodic messages can increase the energy consumption and the computation of the FFT can be time consuming in the BSN node.

The distance and relative antenna orientation between the BSN transmitter and receiver can change periodically during walking and running [9]. As a result, the signal strength in BSN exhibits periodic fluctuations due to obstruction, reducing the probability of a packet being transmitted successfully. To overcome this issue, an Optimistic Medium Access Control (OMAC) has been proposed in [10] to detect the maximum forward foot position and to overcome the transmission failure caused by body parts obstruction during walking. OMAC assumes that the walking stride and paces are similar for all the test participants and a predetermined accelerometer threshold is applied to detect the best transmission period. However, previous work by Barclay et al. [11] has shown that male and female exhibit different walking patterns with different accelerometer readings. As results, the OMAC may miss or unable to detect the transmission window if the walkers have a smaller or dynamic stride.

To support different operating environments, multi-modal approaches are usually applied. Kandukuri et al. [12] investigate novel channel access schemes for packetized wireless networks, which can dynamically switch between specific transmissions modes in order to match the channel state and success delivery rate. They proposed the multimodal dynamic multiple access (MDMA) schemes based on the observed state of the channel and the transmitter queue where each user can autonomously select the best transmission mode and power level to transmit at. In [13], A Multimodal Routing Protocol (MRP) is implemented and evaluated in WSNs to tolerate between different failures. The results have shown the MRP can tolerate failures with different durations. An application-aware event-oriented MAC protocol (App-MAC) to support prioritization, fairness, and reduce energy consumption is proposed in [14]. App-MAC leverages the advantages of contention- and reservation-based medium access control (MAC) protocols to coordinate channel access and propose channel contention and reservation algorithms to adaptively allocate the time slots according to application requirements and current events status.

## 3 The Multi-modal Opportunistic Transmission with Energy Saving (M-MOTES)

To address the multi-scenario environments, we present the Multi-Modal Opportunistic Transmission with Energy Saving (M-MOTES) that uses the built-in accelerator and the Received Signal Strength Indication (RSSI) measurements to switch between the single-hop and multihop transmission protocol depending on the user activities, and adjust the duty cycle of the transmission protocol accordingly to avoid packet collision.

### 3.1 M-MOTES Hardware Architecture

The M-MOTES architecture consists of three main components namely: the collector, the sensing nodes and a base node. The collector is used to gather the information send by the sensing nodes. The sensing node is used to capture the sensor reading and store the data temporary in the memory buffer until a sufficient number of readings is collected. Once the minimum threshold is met, the node can begin to determine the operating mode and the best time for transmission. The base node is used to collect the data from the collector. The base node can be in the form of mobile phone or laptop.

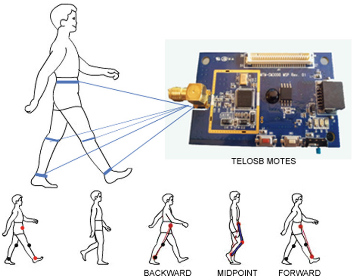


**Fig. 1.** The placement of the sensing nodes and the collector.

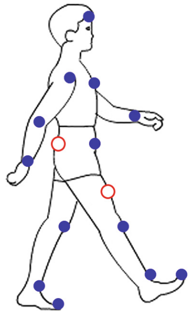

**Fig. 2.** Suitable node placement to ensure packet delivery

In M-MOTES architecture, it is critical to ensure the sensing node are attached at the right locations to ensure maximum radio signal. Maximum RSSI occurs when there is a direct LoS between the nodes. The node's placements are usually restricted to the subject's body parts and the most common locations are the waist, wrist, thigh, ankle and head [6,7]. We have conducted a preliminary experiment to determine the best location to attach the sensing node in order to achieve maximum packet delivery. Figure 2 shows the good, bad or placement with no significant benefit when communicating with a node placed in the waist. In this work, we will attach the node on the knee, ankle and waist as shown in Fig. 1.

### 3.2 Algorithm Design

The M-MOTES consists of three modules:

**Opportunistic Transmission:** It is common to duty cycle the node to reduce the energy consumption. In M-MOTES, each sensing node is designed to operate in two cycles namely: sleep and awake modes. During sleep mode, the energy consumption is the lowest as each sensing node only reads and processes the sensor data and stores them in its buffer with its radio interface is switch off.

The sensing node will continue to be in the sleep mode until the node is ready for transmission. The node will turn its radio on when these two conditions are satisfied:

– When the transmitting queue or buffer is 50% utilization and
– When the GKA is showing the foot is in the forward position.

However, the aggregation node will always keep its radio in the awake mode to ensure that it will not miss any packet transmitted by the sensing nodes. The CSMA/CA is enabled in all the nodes with a maximum of 3 retransmissions.

**Multimodal Function:** To support multi-modal approach, M-MOTES uses its node's outgoing transmitting buffer size to toggle between single-hop or multihop communication. The single-hop is initially applied as the node can use its accelerometer and radio signal to determine when there is a direct LoS based on the packet outgoing buffer. Otherwise, M-MOTES switches to a multihop when no direct LoS is available. To toggle between the transmission modes, the sensing node will switch to a specific mode and transmit all the packets in its buffer based on the following conditions:

$$Tx(mode) = \begin{cases} Tx(OTP_{Singlehop}) & \text{If Buffers} \geq 50\% \\ Tx(OTP_{Multihop}) & \text{If Buffers} \geq 75\% \\ Tx(Max_{Singlehop}) & \text{If Buffers} \geq 90\% \\ Tx(Sleep) & \text{Otherwise} \end{cases}$$

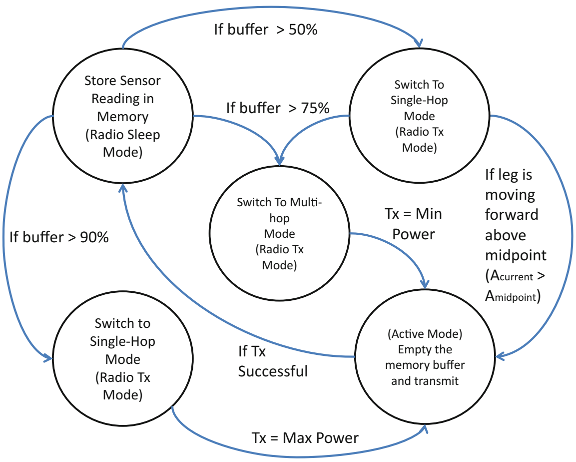


**Fig. 3.** The state chart representing the different operating modes of M-MOTES

In a typical medical application, the data is usually sensed frequently (every 10 ms) [15]. As the variations in the data collected are minimum, it is not necessary to send every data immediately. Instead, each sensing node will store the data in its buffer and switch to single-hop mode when the data buffer is 50%. By delaying and reducing transmission frequency, it will conserve its battery and switch off its radio. If no direct LoS is available and the buffer reaches 75%, the node will switch to multihop mode. However, it is necessary to install a routing protocol in the node to operating in multi-hop. A static route table is configured in the forwarding node as the physical node position is not moved or changes. Finally, if it is still not possible to send the packet in either modes, the node will increase its transmission power to the maximum and transmit the packets to the aggregation node for up to three retransmission before dropping the packets. The flow diagram for the M-MOTES is shown in Fig. 3.

**Gait Kinematic Analysis:** To allow transmission in a single-hop mode with minimum transmission power, it is necessary to determine when there is a direct LoS between the foot and the waist. This can be achieved by analyzing the build-in accelerometer and RSSI of the radio. When the foot is at the most forward position, the RSSI value is usually higher and the x-y reading from the accelerometer gives a sine wave. Using these values, the node can detect and transmit its packets in the buffer when the foot is in the most forward position. The transmission period can be determined by each node attached on the foot. As the node will only transmit when the foot is moving forward, packet collision can be avoided as the transmission cycle will alternate between both feet.

## 4 Evaluation of the M-MOTES

To evaluate the performance of the M-MOTES, we conduct a comprehensive analysis on the performance of M-MOTES against OTP, E-OTP and CSMA/CA on multihop using TelosB motes.

### 4.1 Experiment Setup

A group of 40 students are selected in mixed gender to perform the experiment over 20 days. Each student is requested to wear the TelosB motes on his or her feet with the aggregation node attached to the waist and four sensing nodes on the knees and ankles. A base station is used to collect the data for the experiments. The sending nodes are configured to transmit at the same power for all the four different transmission protocols and to collect the daily temperature. Each of the temperature data collected is time-stamped and is used to evaluate the reliability of the protocol to provide continuous data.

To ensure that proposed protocol can support different activities, each participant is requested to perform the following tasks: walking, running, climb up the stairs, and doing normal daily activities from 8:00 to 16:30.

## 5 Results and Discussions

To compare the performance between the four different protocols, a box-and-whiskers plot showing the median and upper and lower quartiles of the PDR is presented in Figs. 4, 5, 6 and 7 for each of the activities conducted. We also performed and showed the statistical test results to measure the statistical and scientifically significance of the results using the Conceptual Statistical Test Framework (CSTF) proposed by [16]. Two tests have been applied namely the Rank-Sum and A-Tests. The results from the tests are shown in Table 1. For energy efficient, we computed the current utilization in milli-amp in Table 2.

### 5.1 Activities: Walking

From Fig. 4, more data packets were received by the aggregation node in a multi-hop network than single-hop network. The maximum PDR for the multihop CSMA/CA and M-MOTES is above 98% compared to single-hop OTP and E-OTP where both is 95%. The M-MOTES has a higher median compared to M-CSMA due to the ability to delay the transmission after the buffer is above 50% utilized. In term of different between the multihop CSMA/CA and M-MOTES, the values computed from the statistical tests have shown that the higher median observed in M-MOTES is not significant and there are differences between M-CSMA and M-MOTES. However, the current consumption for M-MOTES is significantly less than the other three protocols as shown in the Table 2. Hence, it is more energy efficient when it is applied when the users are walking.

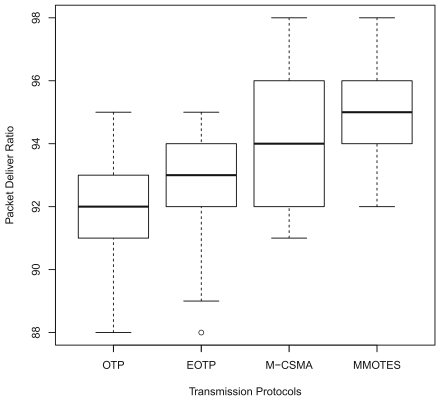


**Fig. 4.** PDR distributions for walking.

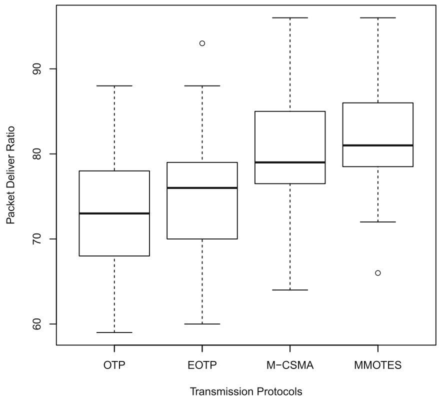


**Fig. 5.** PDR distributions for running

### 5.2 Activities: Running

The Boxplot in Fig. 5 shows the performance of multi-hop networks is higher than single-hop networks as the PDR is significantly higher. The median for running is 82% compared to 95% while walking in M-MOTES. This is due the foot movement in running is more chaotic and faster than walking causing the radio frequency unstable. A higher PDR is also observed in M-MOTES than M-CSMA. However, the statistical tests shows the performance improvement is not significant as the p-test and a-test show values of 0.0743 and 0.6023. To achieve a significance difference, the values have to be $\leq 0.05$ for p-test and the a-test should give a value of $<0.29$ or $>0.71$. A larger distribution of PDR is also observed for all protocols when running. We believe the larger range of PDR observed is caused by the speed of the foot movement is moving too fast and the aggregation may not be able to receive the packets.

### 5.3 Activities: Climbing the Stairs

We have tested the transmission protocol to support a more challenging and dynamic movement of climbing the stair. The results presented in Fig. 6 has shown that the M-MOTES can deliver more packet than OTP and EOTP. This is because when the two communicating nodes are always within the line of sight. When compare against M-CSMA/CA, the median for M-MOTES is slight higher than M-CSMA/CA. The statistical tests have shown that the PDR differences between M-CSMA and M-MOTES is statistical significance but not scientifically significance.

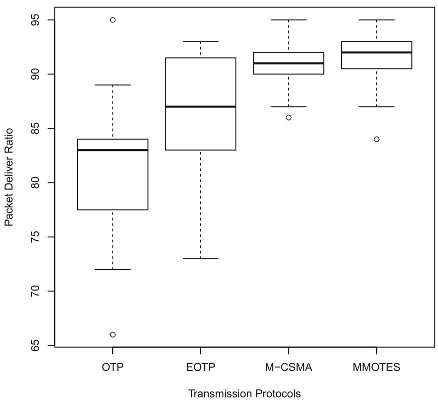


**Fig. 6.** PDR for climbing stairs

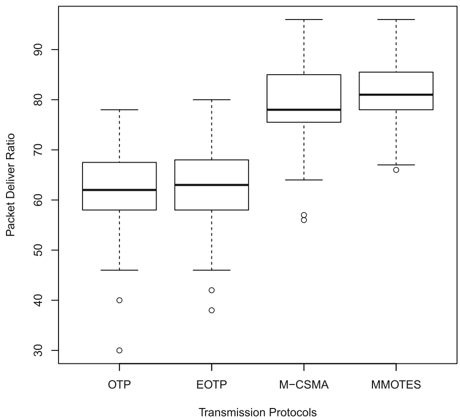


**Fig. 7.** PDR for normal daily routine

### 5.4 Activities: Normal Student Activities

For the last set of results, we evaluated the performance of the protocol based on students performing their normal daily activities from the time they come to the university to the time they left the campus. This set of experiments attempt to evaluate the a comprehensive of set of daily activities taken by the students that includes tea break, lunch break outside campus, driving a car, walking, climbing the stairs, and sitting down attending lectures. The result of these experiments also show the ability of the nodes to provide the information without restricting the participant's activities.

**Table 1.** Statistically (P-test) and scientifically (A-test) significant tests on the differences between the transmission protocols

| Activities | Walk | | Run | | Stair | | All day | |
|---|---|---|---|---|---|---|---|---|
| Protocols | p-test | a-test | p-test | a-test | p-test | a-test | p-test | a-test |
| OTP:EOTP | **0.0012** | **0.3185** | 0.1578 | 0.4189 | **1.14E−06** | **0.2254** | **0.3759** | **0.4491** |
| OTP:MMOTES | **3.57E−12** | **0.1065** | **6.15E−07** | **0.2141** | **9.11E−17** | **0.0290** | **3.09E−14** | **0.0640** |
| OTP:M-CSMA | **1.63E−07** | **0.2049** | **4.95E−10** | **0.1432** | **5.48E−17** | **0.0251** | **1.40E−16** | **0.0256** |
| EOTP:MMOTES | **3.74E−08** | **0.1884** | **0.0002** | **0.2860** | **0.0003** | **0.2977** | **8.05E−14** | **0.0711** |
| EOTP:M-CSMA | **0.0019** | **0.3239** | **1.37E−07** | **0.1980** | **1.21E−06** | **0.2261** | **5.36E−16** | **0.0348** |
| EOTP:MMOTES | **3.74E−08** | **0.1884** | **0.0002** | **0.2860** | **0.0003** | **0.2977** | **8.05E−14** | **0.0711** |
| M-CSMA:MMOTES | 0.0837 | 0.4018 | 0.0743 | 0.6023 | **0.0094** | 0.6450 | **0.0406** | 0.6175 |

### 5.5 Energy Consumption in Term of Current Reading

In term of energy consumption, the average current consumed by the nodes is lower in M-MOTES than the other three protocols. Although both CSMA/CA and M-MOTES use multihop communication, M-MOTES only utilized half the amount of the current in the battery for most of the activities as tabulated in Table 2. This is because the packets are collected and queued until it the buffer is half full. The packets are only transmitted when the foot is in the forward position. Hence, the number of transmissions made in each foot is reduced and the number of packet collisions resulting in a lower energy consumption in M-MOTES.

**Table 2.** Average current consumption for nodes for 8 h

| Activities | OTP | EOTP | M-CSMA | MOTES |
|---|---|---|---|---|
| Walking | 0.711 mA | 0.680 mA | 0.821 mA | 0.347 mA |
| Running | 1.126 mA | 0.741 mA | 0.845 mA | 0.571 mA |
| Climbing stairs | 0.994 mA | 0.710 mA | 0.882 mA | 0.477 mA |
| Attending classes | 3.131 mA | 2.540 mA | 1.721 mA | 0.965 mA |

## 6 Conclusion

In this paper, we have shown that by the transmitting the packets in the multi-hop network, it is much more energy efficient than using single hop network as a higher transmission power is required to reach the aggregation node. More packets can also be delivered in the multi-hop environment as there is less obstruction created by body movement. By buffering of packets before transmission in M-MOTES, the transmission frequency is reduced. Although the packet transmission duration increases as the number of transmitted packet increase, energy consumption within the nodes reduces. Hence, the proposed M-MOTES is more reliable and energy efficient than traditional CSMA/CA networks. However, as the forward foot position relies on the movement and speed of users, it maybe necessary to adjust the transmission duration to ensure the node stop transmitting when the nodes is moving backward and adjust the minimum buffer size to prevent overflow.

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