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# An Opportunistic Transmission Protocol for Body Sensor Networks using RSSI and On-board Accelerometer

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***Abstract*—Inter-communication between nodes in Body Sensor Networks can be interrupted by body movement. Body parts can reflect and absorb radio frequencies or block the radio signal that can disrupt the radio communication. In this paper, we have proposed an opportunistic radio transmission that uses the Received Signal Strength Indicator as feedback mechanism to improve the transmission reliability. By combining the RSSI and the accelerometer reading to analyse the person's gait cycle, we determine the best time for packet transmission to improve the Packet Delivery Ratio (PDR). Our extensive experimental results obtained from 50 participants have shown that above 90% PDR has been achieved for users walking with different strides and 78% PDR when running.**

## I. INTRODUCTION

The use of Wireless Sensor Networks (WSNs) in safety critical applications has increased over the last 10 years. One of such applications of WSNs is for health monitoring in Body Sensor Networks (BSNs). BSNs have the potential to provide promising applications in medical systems to enhance quality of life, facilitate independent living, support post-operative monitoring and even to save the lives of people with the risk of sudden attacks [1]. With the decrease of the cost and miniaturization of electronic devices and biomedical sensors, it is possible to attach these devices on the different parts of the human body to capture different physiological parameters. These devices allow non-obtrusive monitoring of the physiological parameters of the human body and its environment in a decentralized manner [2]. Each node in BSN consists of one or more sensors attached to or implanted in the human body that are connected to a micro-controller, a wireless radio and a battery. These sensors can capture different physiological parameters such as the body temperature, heart rate, ECG, blood pressure, and blood oxygen level. The sensory data collected can then be transmitted wirelessly using radio transceiver of the node to a medical server for storage and analysis.

For BSNs to be accepted by the communities, the accuracy of the data captured by these applications must be dependable. Experiments have shown that human mobility and the body position can affect the wireless propagation channel and interfere with the radio that may result in data packet loss [3]. The accuracy of the sense data relies on the sensor placement. Miluzzo et al. [4] showed that the radio signal may experience severe attenuation due to human body shadowing. The radio signal strength can experience significant variations of greater than 10 dB as the radio link quality alternates between the line of sight and non-line of sight during movement [5]. Hence, it is necessary for the node not to transmit any packet during non-line of sight period. There is a need to mitigate the effect of human mobility in BSN as it affects the packet reliability and dependability of the application running on the network [6]. Once the received signal strength drops below a radio-specific threshold, the transmitted packet will fail.

The distance and relative antenna orientation between the BSN transmitter and receiver change periodically during walking and running [4]. As a result, the signal strength in BSN exhibits periodic fluctuations. In [7], an Optimistic Medium Access Control (OMAC) has been proposed to improve the transmission rate and overcome the transmission failure caused by the radio fluctuation. An accelerometer based gait analysis is used to determine the best transmission window for packet transmission. However, Lim et al. [7] assumes that the walking stride is similar and the user is walking at a constant pace. Hence, a predetermined threshold value is set to detect the best transmission period. Previous works have shown that male and female exhibit different walking patterns with different accelerometer readings. As results, the OMAC will miss or unable to detect the transmission window if the walkers have a smaller or dynamic stride.

In this paper, we propose an Opportunistic Transmission Protocol (OTP) to exploit the varying signal patterns to transmit the packets when (i) the Received Signal Strength Indicator (RSSI) is high and (ii) the accelerometer reading is showing the leg is in the forward position. We apply both the accelerometer and RSSI measurements to determine the transmission window and tune the transmission threshold according to the walking stride. This approach can improve the transmission success probability as the RSSI value changes between male and female due to the stride of the legs. The main contribution of this paper is the application of a RSSI-based feedback mechanism to adapt the accelerometer threshold according to the walking stride that can yield a higher packet delivery rate.

The motivation behind this paper is that in BSN, the

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communication in between the node attached on the body part is dynamic as the body is moving all the time and the walking stride varies. By locating the non-obstructive body position for transmission and adapting the transmission power in the MAC can improve the rate of transmission without increasing the energy consumption. The body movement pattern can be determined using accelerometer-based gait kinematics especially when someone is walking at a constant pace [8]. Rather than designing a new communication protocol, we implement the OTP on top of existing MAC protocol in Tiny OS and performed a comparison of OTP against OMAC and RSSI based MAC protocol in TinyOS, and extensively evaluate the results using the data taken from a set of experiments involving 50 different subjects. Although our solution is only tested on IEEE 802.15.4 communication technology, we believe that the opportunistic transmission approach and the experimental results can also be applied to other 2.4-GHz wireless communications that have the ability to measure RSSI and perform duty cycling.

Section II discusses the related work. In Section III, we present the design of the proposed OTP and provide a study on the typical on-body signal strength fluctuations between male and female. The results from the study will also provide us the initial RSSI threshold to be used in OTP. Our measurements, conducted in the 2.4-GHz band with a set of three IEEE 802.15.4 transceivers attached to the body parts confirm that walking can introduce significant signal strength variations for RF communication. The magnitude of the RF signal strength fluctuation depends on the leg and waist position. In Section IV, we performed a comparison of the proposed protocol against OMAC and BANMAC. The results are evaluated and discussed in Section V before we conclude the paper in Section VI.

## II. RELATED WORK

RSSI can be used to assess the human kinematic and track the body movement for the classification of gait patterns. Blumrosen and Luttwak [9] use criteria and analytical methods, kinematic motion feature extraction, and a Kalman filter model for the aggregation of RSSI and inertial sensor. Prabh et al. [10] 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 12s. In order to compute the signal frequency, Fast Fourier Transform is applied to the filtered signal strength time series. The future peak is further determined by adding the multiples of the period to the initial peak time. 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.

Vahdatpour et al. [11] presents a technique based on built-in accelerometer measurement to recognize the position of sensors on the human body. They applied a combination of supervised and unsupervised time series analysis methods to estimate the location of the device attached on the user's body based on the motion data captured from the accelerometer. The proposed solution has achieved 89% accuracy in estimating the location of the devices. In [7], an optimistic medium access control transmission is proposed to determine the best time for packet transmission. By predicting the accelerometer reading from the BSN node, Lim et al. [7] identifies the forward leg position as the non-obstructive position for reliable communication between two nodes. With the receiving node attached to the waist and the transmitting node attached to the ankle, an increased in the number of packets delivered is observed. However, the test sample used to evaluate the protocol is small and does not reflect the wider users in health monitoring where the walking stride varies between users. A study based on gait analysis has shown that human gait between male and female is different [12]. Female walks in a slower pace with a shorter step and more pelvic movements while the males move their shoulders more often.

## III. OPPORTUNISTIC TRANSMISSION PROTOCOL

In order to ensure that data are delivered reliably, it is necessary to determine the best time for transmission when the user is performing a specific activity. Previous studies have shown that it is possible to use the accelerator measurement to determine the body position and capture movement pattern [3], [8], [13]. Accelerometers are available in most BSN devices as they have a low energy consumption and yield excellent performances [8], [13]. The objective of this paper is to develop an OTP that can reduce the transmission failures caused by the movement of the human body by predicting the best time for transmission using the accelerometer reading and radio signal quality.

For OTP to function, we need at least two sensors: one aggregator and one tracker with accelerometer sensor reading. To evaluate the performance of OTP of both left and right legs, we proposed three sensor nodes to be placed in three locations: on the waist, left ankle and right ankle as shown in Figure 1. It is a standard and common setup to place the sensor nodes at the location specified in health monitoring application to evaluate the localisation of the body position or to collect physiological information such as pulse [3]. We can also place the sensor nodes on the wrist to determine the swing of the arm. For these experiments, we only focus on the left and right legs positions. The accelerometer readings are collected from the on-board accelerometer sensor on the TelosB sensor mote [14]. The RSSI values for the three different leg positions (backward, midpoint and forward) are also analyzed. These different values will be used to evaluate the design of the OTP.

### A. Anaylsis of RSSI and Leg Movements

In this section, an experiment to investigate how different walking patterns can affect the RSSI value is performed.

To design the OTP, it is necessary to analyze how the wireless radio signal strength changes with different leg positions and to determine the minimum RSSI value required to deliver a packet for different leg positions. This can be achieved by computing the number of packets received by a node attached on the waist of the person walking naturally with its respective RSSI values. It is also necessary to determine the minimum power signal required to transmit the packet from a node attached to the ankle. The results from experiments will determine the minimum power setting (RSSI) and the acceleration threshold ($a_{threshold}$) for OTP.

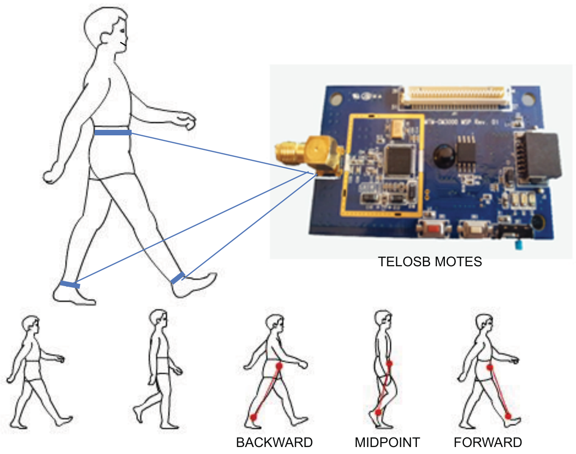

Fig. 1. A TelosB (top-right) with Accelerometer sensors is placed on 3 different regions on the body: The waist, left ankle and right ankles to analyse the different RSSI value

To identify the leg position that generates the most and the least attenuation, 25 male and 25 female are selected to participate in the experiment. The participants are asked to walk at their normal pace for 30 seconds with a TelosB node attached to both left and right ankles. These two nodes act as a transmitter while the receiver is attached to the waist. The transmitting nodes will transmit packets every 100ms in order for the receiving nodes to capture different RSSI values using 8 transmission power levels ($Tx_{pw}$): -25dBm, -15dBm, -10dBm, -7dBm, -5dBm, -3dBm, -1dBm, and 0dBm. The receiver will record the RSSI of received packets while the transmitter will record the accelerometer reading based on three different leg positions: (1) backward; (2) mid-swing; (3) forward are recorded.

The results from the experiment are presented in Figure 2. From the box-and-whiskers plot, the following observations can be made:

- The forward leg position has the higher RSSI value as it is closer to the receiving node.
- The RSSI values vary between male and female and the RSSI distribution for the male is larger than the female as indicated by the longer whiskers in the figure 2.

From the experiment, we can deduce that the walking stride for male is different from female. The stride for male is more dynamic as the variation between 1st and 3rd quartile is large for male. The results from the experiments can also allow us to determine the minimum RSSI and accelerometer values when the leg is at different positions. These values will be used for the design of OTP in the next section.

### *B. The Design of OTP*

In this section, we present the design of OTP as shown in Figure 3. In previous work, we have used the accelerometer measurement to determine the best time for transmission [7]. However, the previous approach assumes that the walking stride is periodic and the walking pattern is at a constant pace with similar strides. As male and female may exhibit different walking patterns, we utilise the RSSI to determine the current radio quality and adapt the parameter used in OMAC accordingly.

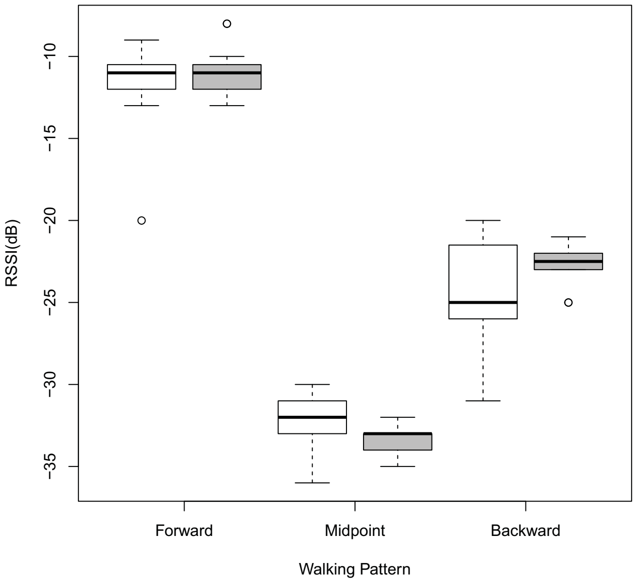

Fig. 2. RSSI Variation for three different leg positions taken from 25 males and 25 females.

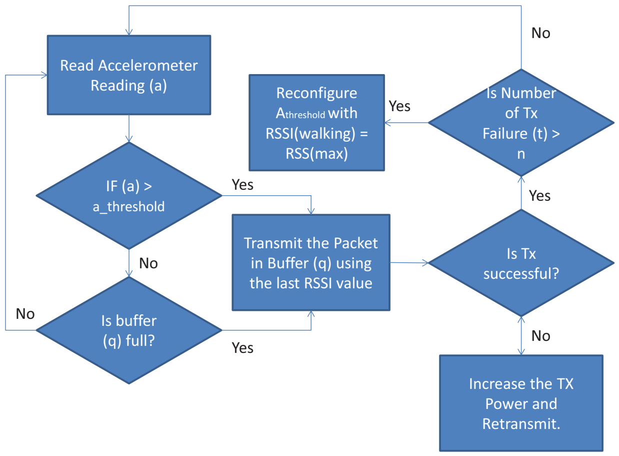

Fig. 3. The flowchart for the OTP

Gait analysis is performed using the on-board accelerator reading from the sensor node [15]. When the system starts, a watchdog timer is introduced and initialized to monitor the ($a_{threshold}$). ($a_{threshold}$) is set according the average accelerometer reading computed in Section III-A. Each node attached on the ankle will collect the sensory readings every 50ms and store them in the node outgoing buffer. A counter (C) is used to keep track on the number of reading collected to ensure that the outgoing buffer does not overflow. C is set to 1000 to avoid memory buffer overflow as the memory can only stored up to 5000 sensor readings due to limited size. The sensing data will not be deleted from the buffer until they have been successfully delivered. When C $<$ 1000 and the leg is not in the best position for transmission ($a_{current} < a_{threshold}$), the radio transceiver is switched off to reduce the battery consumption during idle period.

In order to ensure that there are sufficient number of readings avaliable for transmission, a minimum C value is set (20 readings) to minimize low data transmission. An analysis has shown that it takes 1 sec for human to finish a gait cycle and during a gait cycle, the sensor can capture 20 readings [7]. Hence, in OTP The radio transceiver will only be turned on and all the packets will be transmitted when one of the following conditions occur:

1) the $a_{current} > a_{threshold}$ and $C > 20$.
2) $C > 1000$

If $C > 1000$, the transmission power will be set to $Tx_{power} = 3$ equivalent to the minimum RSSI when the leg is at the backward position to ensure successful transmission at all positions. When the timer reaches the maximum period (currently set as 60s) and the first condition (1) did not occur within the set period, OTP will invalidate the $a_{threshold}$ and reconfigure the $a_{threshold}$ as the stride period may have changed.

## IV. EXPERIMENTAL SETUP

In our experiments, we have randomly selected 25 male and 25 female to test the OTP. On each participant, one WSN node (CM3000) is placed on the waist as the aggregation node and a xy-axis accelerometer (MTS-3000) is attached on their left and right ankle. These nodes act as transmitters that sense and send the acceleration measurement in the x- and y-direction. It should be noted that only x-axial (backward, midpoint and forward) acceleration reading is captured and used as the main movement of the ankle is on the x-axis. This setup is usually used in sport medicine for foot related problem. The radio node used in this experiment is Telosb mote module with CC2420 Radio Frequency (RF) transceiver using the configuration shown in Table I [16]. The TelosB nodes allow the OTP to collect the RSSI value and configure the transmission power used by the transceiver and the $a_{threshold}$ during runtime.

TABLE I. INITIAL TINYOS CONFIGURATIONS FOR OTP

| **Parameters** | **Values** |
|---|---|
| *Tx interval:* | 250ms |
| *Tx Channel:* | 26 |
| *MAC*: | 802.15.4 (CSMA/CA) |
| *RSSI Setting:* | 1 |

### A. Experimental Setting

50 mixed participants are asked to perform two tasks: (i) walking at a normal pace with different strides and (ii) brisk running. The experiments are conducted in a large hall with the participants wearing a flat sport shoes without receiving any special instruction.

To evaluate the effectiveness of the OTP, each node attached to the ankle is configured to transmit data packets every $1/4$ second, each packet consists of 20 Bytes of information to the receiver. In order to increase the probability of transmission, the number of retransmission is configured to 3 and the CCA backoffs to 0, which reduces the transmission time to 2.56ms [17]. If the transmission fails, the packet will be retransmitted until it is delivered successfully. The OTP is compared against OMAC proposed by [7], BANMAC [10] and the default CSMA/CA using the minimum transmission power ($Tx_{power}$=1) when the leg is at the forward position.

### B. Evaluation Metrics

In order to compare the performance between the different transmission protocols, the same Packet Delivery Ratio (PDR) used in [7] is computed to measure the network reliability. The PDR represents the percentage of the number successful packet received to the total number of packet transmitted. The results are further validated using the experimental validation approach proposed in [18] where box-and-whiskers plot and statistical tests (Rank-Sum and *A*-statistic) are applied to evaluate the significance of the results observed. Each experiment is repeated 30 times and the average PDR is computed.

## V. RESULTS AND ANALYSIS

Figure 4 and 5 show the box-and-whiskers plot for PDR between the three transmission protocols: OMAC, BANMAC and OTP using the results collected from two sets of activities: walking and running. The PDR for normal transmission using CSMA/CA protocol is also provided for performance comparison.

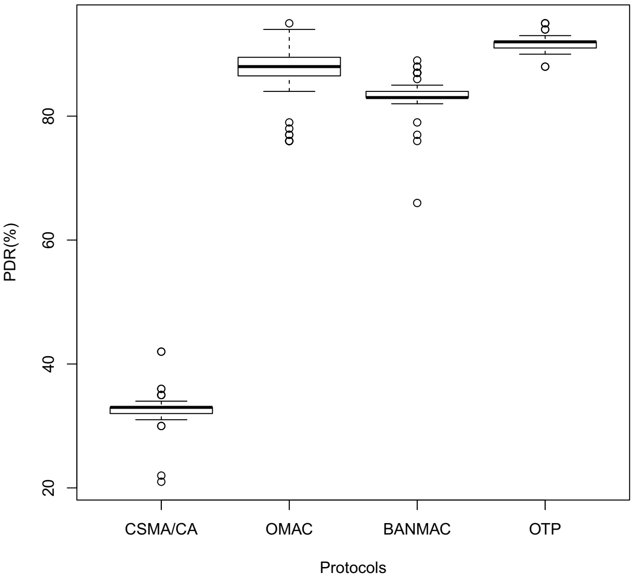

Fig. 4. A higher PDR is observed in OTP when the participants walk normally.

In Figure 4, the PDR for OTP is greater than 90% when the users are walking at a constant pace with different strides. The

PDR is slightly higher than OMAC and BANMAC as the OTP will reconfigure the accelerometer threshold accordingly when the accelerator transmission missed the transmission deadline due to different stride periods. As the result, the distribution of the PDR for OTP is smaller than OMAC as shown by the distance between the lower and upper end of the whiskers. The statistical tests have also shown that the different between OTP and OMAC is both statistical and scientifically significant with $p$-value$= 4.921e - 09$ and $A$-value$= 0.169$ as shown in Table II. $A$-Values of $< 0.29$ and $> 0.71$ are required as they indicate large effect size.

TABLE II. *p* AND *A* VALUES FOR PDR BETWEEN THE PROTOCOLS (BOLD HIGHLIGHTS SIGNIFICANCE VALUE)

| Protocol | *p*-value | *A*-value | *p*-value | *A*-value |
|---|---|---|---|---|
| Normal&OTP | **1.212e-18** | **0** | **1.212e-18** | **0** |
| OMAC&OTP | **4.921e-09** | **0.169** | 0.145 | 0.416 |
| BANMAC&OTP | **1.235e-18** | **0.001** | **0.008** | **0.260** |

As for CSMA/CA, the PDR is significantly less than OMAC, BANMAC and OTP. This is because the node will just retransmit the packet periodically, including when the radio link is obstructed and weak.

When the same group of participants are asked to run instead of walking at a normal pace, the PDR for OTP is marginally higher than OMAC and BANMAC in Figure 5 with the 1st quartile of OTP is above 90%. However, the statistical tests have shown that the difference between the PDR for OMAC and OTP is not statistically significant with $p$-value=0.145 and $A$-value=0.416. The PDR for OTP is higher than BANMAC but is not statistically different from OMAC.

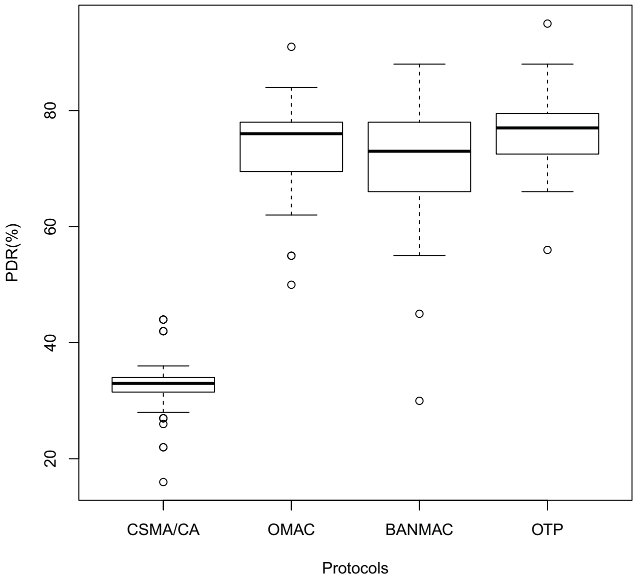

Fig. 5. When the user is running, the PDR in OTP is not significantly different to OMAC

In terms of the energy consumption in Table III, we measure the lifespan of the node based on the operating time of the node before the battery ran out. The results have shown that both the OTP and OMAC have a longer battery lifespan compare to CSMA/CA and BANMAC. CSMA/CA can operate up to 8 hours while the mote running OTP and OMAC can operate for 14 hours. As for BANMAC, it can operate for 10 hours due to the exchange of RSSI value. From the results of above experiments, it can be concluded the sensor node is more reliable and energy efficient using OTP.

TABLE III. THE NODE AVERAGE OPERATIONAL LIFESPAN IN TERMS OF HOURS

| Protocol | CSMACA | OTP | OMAC | BANMAC |
|---|---|---|---|---|
| Time (Hours) | 8 | 14 | 14 | 10 |

## VI. CONCLUSION

By combining the RSSI measurement and gait analysis to determine position and the transmission trajectory, we develop and implement the OTP that adjusts the transmission power and cycle according to the body position using the accelerometer and rssi measurements. We have evaluated the performance of our proposed solution extensively. Our experiments have demonstrated that a significant improvement in the number of successful packets delivered has been achieved without any additional energy consumption when the users are walking. However, the PDR for OTP during running is not significant different from OMAC but the performance is better than default CSMA/CA protocol. We suspect this can be caused by the parameters (such as watchdog timer) used in OTP is configured. Further works are required to optimize the parameter in order to improve the PDR during running.

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