Extending Optimistic Transmission Protocol for Other Movement Patterns

Tiong Hoo Lim
Electrical and Electronic Engineering
Institut Teknologi Brunei,
Gadong, BE3119
Brunei Darussalam
Email: lim.tiong.hoo@itb.edu.bn

Iain Bate
Department of Computer Science
University of York, York
North Yorkshire, YO10 5GH
United Kingdom
Email: iain.bate@york.ac.uk

***Abstract*—Communication between nodes in Wireless Sensor Networks (WSNs) can be interrupted by body movement. With the demand of the use of WSNs in health monitoring systems, it is necessary to investigate and provide a solution to overcome the interference caused by human body parts. The body parts such as the elbow and knee can reflect, absorb or obstruct the radio signal that can disrupt the radio communication. This can increase the energy consumption due to retransmission. In this paper, we have proposed the Enhanced Opportunistic Transmission Protocol that utilizes the kinematic reading to improve the transmission reliability. Our experimental result obtained from sixty participants has shown that the E-OTP can delivery the packet with a higher Packet Delivery Ratio using smaller number of transmissions compared to two other protocols. Our experiments have also shown that the successful transmission can be achieved as long as the node transmits its packet when leg is above the midpoint forward position.**

Keywords—Body Sensor Networks, Gait Analysis, Body Shadowing, MAC, Duty Cycle;

I. Introduction

Body sensor networks can be used to detect falls or to assist in the study of diseases that affect motor ability in health applications [1], [2]. Small, wearable sensors can be attached on specific body parts that measure limb movements, posture, and physiological conditions. These devices can yield high-resolution, quantitative data that are used to analyse the disease characteristics and develop more effective treatments. A patient can wear up to 8 sensor nodes equipped with accelerometers and gyroscopes placed at strategic locations such as the left and right ankles, knees, elbows, wrists, head and waist [3]. A base station, such as a laptop in the patients home can be used to collect data from the nodes. These data can then be sent to the clinic for analysis and to monitor the patient's coordination and activity level.

The key challenge is tuning the network's operation to achieve high data quality as well as long battery lifetimes. These sensor nodes usually operate under unpredictable radio link conditions that can be interfered with by other equipment or obstructed due to body part movement especially when applied in health monitoring [4], [5]. The node is usually small and has extremely limited energy supply. The energy supply in BSN is usually consumed in three domains namely: data collection/sensing, data processing, and data communication. The power consumed during data transmission is higher than the combined power utilizations for both data processing and sensing [6], [7]. Furthermore, communication failure is more common in BSN than traditional wireless. As a result, the energy consumption is higher due to retransmission [6]. If a potential communication failure can be predicted, a node can delay or adapt its transmission.

In order for the WSN to support real time clinical application, it is necessary to address the following challenges:

- First, it is necessary to prevent service unavailability. Extending the battery lifetime of the nodes by duty-cycling the node is the upmost priority. This requires careful management of radio communications and data processing on the sensor nodes.
- Second, the radio communication must be able to adapt its operation with respects to the variations in radio bandwidth as the patient moves around the home.
- Third, the system must yield high-quality, reliable clinical data. However, it is infeasible to keep the radio on and continuously transmit the sensor data because this would rapidly deplete the nodes batteries.

In previous work [8], an Opportunistic Transmission Protocol (OTP) has been proposed to support different walking paces and strides including running. OTP utilises the Received Signal Strength Indication (RSSI) as a feedback mechanism to adjust accelerometer threshold. Transmission only occurs when the current accelerometer reading is showing the leg movement is at the most forward position. Although the experimental result from OTP has shown significant improvement in the Packet Delivery Ratio (PDR), OTP is only tested on limited walking activities. In this paper, we perform further evaluate and analysis on the OTP to understand the issues faced when it is used for different movement patterns. This information is then used to extend the algorithm. The main contributions of the paper are:

- We provide a comprehensive analysis of three different radio transmissions: Carrier Sensing Medium Access with Collision Avoidance (CSMA/CA), Optimistics Medium Access Control (OMAC) [9] and OTP [8] at three different leg positions: forward, backward and middle for three different activities: walking, running, and climbing the stairs.

- We show that the PDR for both forward and middle leg positions are similar. If we transmit the packet when the leg is moving forward past the midpoint, the PDR is not significantly different when it is in the forward position. We enhanced the OTP to determine when the leg position is optimum for transmission, i.e. when the leg above the midpoint position, and then transmit the packet. The enhanced algorithm is referred to as Enhanced Opportunistic Transmission Protocol (E-OTP).
- We present an experiment to analyze how different activities such as walking, running and climbing the stairs can affect the transmission using a mixture of teenage male and female samples. The evaluation clearly shows the revised algorithm provides improved PDR for the new activities, no worse PDR for the original activities, and it provides improved energy efficiency.

The rest of this paper is organized as follows. In section II, we highlight some of the related works that have motivated this research work. The E-OTP is introduced in III. In V, we describe the experimental setup to analysis the performance of four different transmission protocols when the users are performing three different activities: walking, running and climbing the stairs and compare the PDR when transmissions are made when the leg is in the forward, midpoint and backward position. We compared the results of CSMA/CA, OMAC, OTP, E-OTP and provide a detailed analysis of the results. Section VI describes the future work and concludes.

II. 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 [10], [11]. 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. [12] 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. 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 [13]. As a result, the signal strength in BSN exhibits periodic fluctuations, reducing the probability of a packet being transmitted successfully. To overcome this issue, an Optimistic Medium Access Control (OMAC) has been proposed in [9] to detect the maximum forward leg 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. [14] 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.

It is necessary to detect the best time for packet transmission. Vahdatpour et al. [15] 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 [8], Lim et al. uses both the accelerometer and RSSI measurements to locate the best leg position for packet transmission. OTP identifies the forward leg position as the non-obstructive position where the maximum RSSI can be observed and the probability of successful packet delivery is high. With the receiving node attached to the waist and the transmitting node attached to the ankle, an increased in the number of packet delivered is observed. However, OTP is only tested when the users are walking and running. Other common activities need to be supported by OTP if it is to be used in a real world application.

III. The Enhanced Opportunistic Transmission Protocol (E-OTP)

In this section, we present the E-OTP, an improved version of the previous OTP algorithm that uses the built-in accelerator reading to determine the best leg position to communication and adjust the duty cycle of the node is designed.

The E-OTP Architecture consists of three main components namely: the aggregation node, the sensing node and a base station node. The E-OTP uses the same number of nodes and attachment position as proposed in OTP where the aggregation node is attached to the waist, the sensing nodes are attached to the ankle and the base station node is connected to a laptop through the USB interface as shown in figure 1.

Fig. 1. The placement of the transmitter (Leg) and the receiver (waist).

A. Algorithm Design

To reduce the energy consumption in the node, each sensing node is designed to operate in three cycles namely: idle, listening and transmitting mode as shown in figure 2.

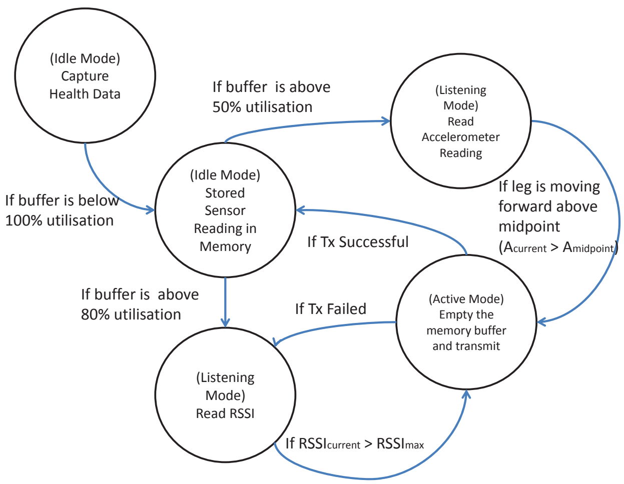

Fig. 2. The flow diagram to detect the transmission interval in E-OTP

When the node in an idle mode, the energy consumption is the lowest as it only reads and processes the sensor data and stores them in its buffer. The sensing node will continue to be in the idle mode and read the sensor data until its memory buffer is half full (50% utilisation). The node will switch to listening mode and prepare for transmission. The node will transmit all the packets in its buffer when one of these conditions occurs:

$$Tx(t) = \begin{cases} Tx_{Power} = minimum & \text{if } A_{current} \geq A_{midpoint} \\ Tx_{Power} = maximum, & \text{if buffer} \geq 80\% \end{cases}$$

When the buffer is 80% full, the node will attempt to transmit immediately using the maximum Tx_{Power} required when the leg is backward. If the transmission fails, the node will continue to increase the Tx_{Power} until all the packets have been successfully transmitted. Once all the packets in the buffer have been transmitted, the node will return to idle mode. The three operation modes in the earlier OTP is not available and the node will always in the listening mode and will transmit when the leg position in the forward position.

IV. Detecting the Mid-point position using the accelerometer reading

In order to determine the value of $A_{midpoint}$, it is necessary to detect the leg movement and identify the accelerometer reading when the leg has moved past the midpoint position as it is moving forward. People from different age group and genders may walk at different paces. It is necessary to have a large samples in determining the midpoint position ($A_{midpoint}$) to ensure that we have covered all the possible walking position.

Sixty participants consisting of both male and female between ages of 17-30 year old have been assigned to walk freely at their own speeds for 1 minute in a large room. Two nodes have been attached to the participants where one node is placed on the waist while the other is placed either on the left or right ankle. We randomly divide the participants into two groups: left foot and right foot, and attached the sensor nodes accordingly. To trigger a reading of the accelerometer, another node is configured to send a signal to the two nodes attached to the participants when the leg is at the three positions: forward, midpoint and backward. The participant will hold the node on his or her hand and observe his or her leg movement. The participant will press the button on the node to initiate the signal when the leg is at the forward, midpoint and backward. Upon the receiving signal, the receiver will read the accelerometer and store the value in its memory.

The corresponding RSSI values from the signal packet received are also collected when the leg is at the different positions. These RSSI value will be used to verify the accelerometer reading as there is correlations between the accelerometer and RSSI values [8]. The RSSI can be affected by the leg position. The RSSI will be at the highest when the leg is at the most forward position and the lowest when it is at the most backward position as shown in Fig 3.

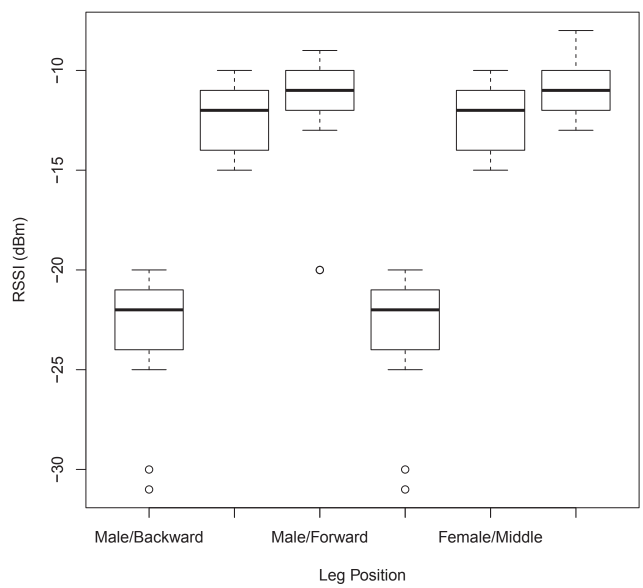

Fig. 3. The RSSI reading from the signal packet received measured by the nodes for the 60 participants (30 female and 30 male) at three different legs position (Backward, Midpoint, Forward

From figure 3, the RSSI increases significantly when the leg position is at the midpoint and is continue to increase gradually as the leg reach the maximum forward position. The range of RSSI values collected also varies from -15 to -10 as indicated by the two tails. One of the contributing factors of the variations is due to the different height of the participants and time when the participants press the button on the node as the leg position is in the middle. The RSSI differences between the male and female forward and midpoint leg position are also not significant with *p-value* $>$ *0.05* when the distributions are tested using the Rank-Sum test.

The accelerometer measurement also exhibits the same characteristics where the accelerometer reading increases as the leg moves forward as shown in figure 4. The accelerometer reading is at its maximum (A=2800) when the leg is at the most forward position.

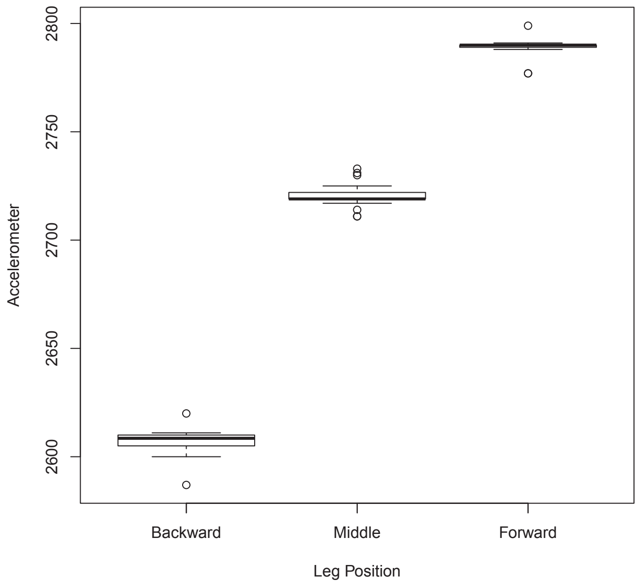

Fig. 4. The accelerometer measurement captured by 60 participants (30 female and 30 male) for three different legs position (Backward, Midpoint, Forward

A. Summary

From the both graphs, we conclude that the $A_{midpoint}$ is equal to **2730** and the packet can be transmitted as soon as the leg is above this position as similar RSSI value can be observed when the leg is at the maximum forward position. To show that we can successfully transmit the packet when the leg cross over the midpoint forward direction and the results obtained will be similar when it is transmitted at the maximum forward position, we hypothesize that:

H_o: The difference in the PDR when the packet is transmitted above the midpoint forward position and the maximum forward position is not significant.

V. Evaluation of the Enhance OTP

In this section, we conduct a comprehensive analysis on the performance of E-OTP against OTP, OMAC and CSMA/CA in term of the number of packets successfully delivered to the aggregation node from the nodes attached to the ankles.

A. Experimental Setup

Similar hardware setup to Section III has been used where a base station and an aggregation node have been used to collect the data. However, two TelosB nodes will be attached to the participants to collect the left and right foot information [16]. The sending nodes are also configured to transmit at the same power initially for all the four different transmission protocols. Sixty participants are selected to perform the following tasks:

- Task 1: Walk along the running track at his or her normal pace.
- Task 2: Run along the running track.

TABLE I. Node system setting

Parameters	Values
Medium Access Protocol	CSMA/CA
TelosB Node Tx Power	1
Radio Channel	16
Max sensing reading can be stored in memory	1000 packets
Default sensing intervals	10ms
Default Tx intervals	100ms
Min Tx Power Setting	1
Max Tx Power Setting	5
Experiments time	300 seconds

- Task 3: Climb up the stairs one steps at a time .

In order to configure the node for the experiment, the parameters used to configured each of the nodes are shown in table I

To evaluate the reliability of the packet transmission, the PDR metric has been computed using the formula below:

$$PDR = \frac{Number\ of\ Packet\ Received}{Number\ of\ Packets\ Sent} \quad (1)$$

B. Results

Figure 5, 6 and 7 show the Boxplot representation of the PDR for 4 different transmission protocols when the participants are walking, running and climbing the stair. We will analyse the results for each of the activities.

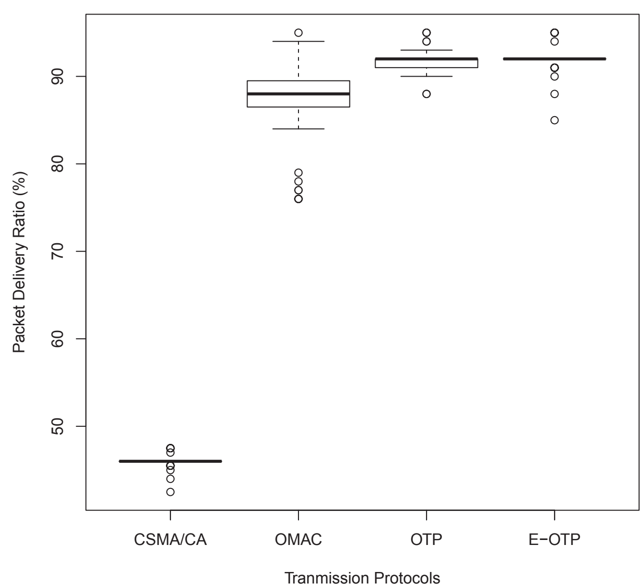

Fig. 5. shows the PDR distributions when the participants are walking. The results have shown that the PDR for E-OTP is no different than OTP and OMAC as the statistical test has shown a *p-value* = 0.5.

1) Walking: From figure 5, the PDR for CSMA/CA is the lowest as the sensing node will attempt to transmit the packets every 100 ms using the default transmission interval. The count for the number of transmissions made for CSMA/CA is also higher as the node attempts to retransmit the packets upon a failed transmission. The transmission of the packet using OMAC is less unreliable than OTP and EOTP as the distribution of the PDR for OMAC is wider with a median at 88% compared to OTP and E-OTP with both having a median at around 91%. However, there is no differences in the performance of OTP and E-OTP as the median and spread of the distributions shown in Figure 5 are similar.

To verify the claim and to test the hypothesis H_o, we apply the statistical significant test (Ranksum test) and scientifically significant test (A-test) to the distributions [17]. Using the same statistical test framework from Lim et al. [17], the *P-value* from Ranksum test must be less than 0.05 and the *A-test* must compute an *A-Value* < 0.29 or > 0.71 in order to show the differences in OTP and E-OTP are scientifically significance. The results from the tests have shown the difference between OTP and E-OTP is not significant as the tests have returned a *P-Value* of 0.52637 and *A-Value* of 0.46694 as shown in column 8 and 9 of table II. We have also conducted the Kolmogorov-Smirnov test (KS-test) where the *p-value*=0.99760 is computed in column 10 of table II. According to the null hypothesis of KS-test, the samples are drawn from the same distribution and the null hypothesis can be rejected if *p-value* $<= 0.05$ at 95% confidence level [17]. Hence, we can accept the Null hypothesis that the PDR distributions of OTP and E-OTP are drawn from the same distribution. From the results of the statistical test, we can accept the H_o that there is no difference in the PDR when the leg is in the forward or above the midpoint forward direction for transmission.

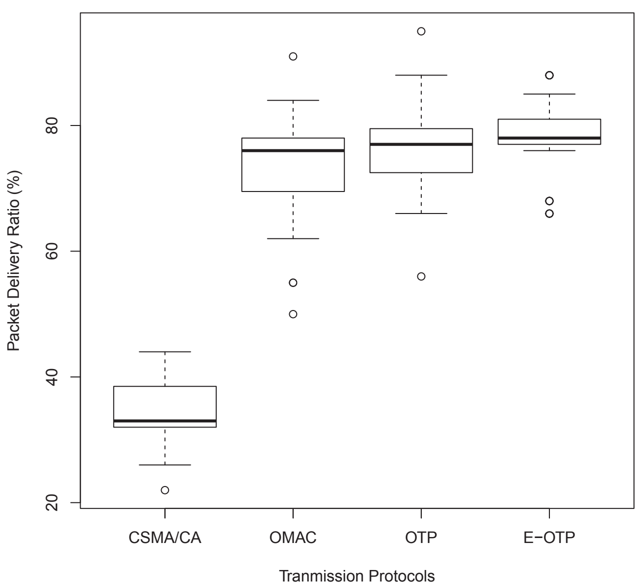

Fig. 6. shows the PDR distributions when the participants are running. The results have shown that the PDR for E-OTP is slight better than OTP and OMAC and the distributions are smaller.

2) Running: The Boxplot in figure 6 also exhibit the similar PDR patterns observed in walking. However, all the protocols have shown a wider range of PDR values with CSMA/CA having lowest value and OMAC, OTP and E-OTP having the highest PDR. We believe the larger range of PDR observed is caused by the speed of the leg movement is too fast and the node may have only transmitted the packet as the leg is moving toward the back position. With E-OTP, the distribution is smaller and the PDR is higher and better than OTP and OMAC as the node can start transmission before the leg is at the maximum forward position.

In order to validate that the better PDR observed in E-OTP significant, we need to perform the same three statistical tests on the distribution. From the test results, all three statistical tests have shown that the performance of E-OTP is better than OMAC with a higher PDR and the differences in PDR are statistically and scientifically signifcance (*P-Value* = 0.00051 and *A-Value* = 0.30085) as shown in column 5 and 6 of table II. However, the statistical test results (in Italic) between E-OTP and OTP have shown the PDR is not scientifically significant and both distributions do not come from the same distribution. The significant *P-Value* of 0.039 (< 0.05) is only observed due to the large sample sizes used for the Rank-sum test and the results from A-test have shown that the differences are not significant. The KS-test also shows that the distributions are the same where the *p-value* = 0.1863 ($>> 0.05$). Hence, we can accept the the H_o that there is no difference in the PDR when the leg is in the forward or above the midpoint forward direction for transmission.

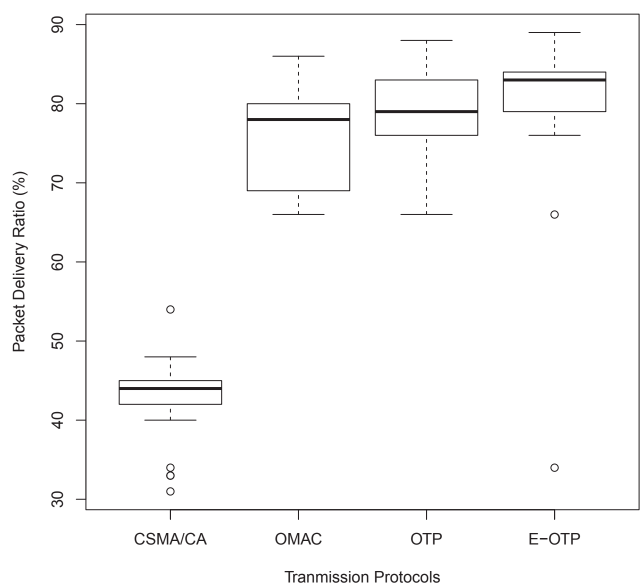

Fig. 7. shows the PDR distributions when the participants are climbing the stairs. The results have shown that the PDR for E-OTP is better than OTP and OMAC as E-OTP attempts to transmit when the legs are in the midpoint.

3) Climbing the stairs: We have tested the transmission protocol to support a more challenging and common activity of climbing the stair. The results presented in figure 7 has shown that the E-OTP can deliver more packet than OTP and OMAC. This is because when the leg is in midpoint, the ankle and the waist are within the communication line-of-sight as the participants climb up the steps at walking pace. The results also show that the maximum PDR achieved by OTP is slightly lower than E-OTP and the OTP distribution is slightly smaller than E-OTP.

When we compare the PDR distribution of the OTP and E-OTP, the statistical tests has computed a *P-Value* of 0.00307 and *A-Value* of 0.33 and the KS *p-value* = 2.2e-16. Hence, the PDRs achieved by E-OTP are statistically different and the E-OTP can delivery more packets than OTP and OMAC.

TABLE II. STATISTICALLY (P-TEST) AND SCIENTIFICALLY (A-TEST) SIGNIFICANT TESTS ON THE DIFFERENCES BETWEEN THE TRANSMISSION PROTOCOLS USING THE RESULTS COLLECTED THE HARDWARE EXPERIMENTS

Activities	Walking up the stairs			Running			Walking		
Protocols	*P-Value*	*A-Value*	*p-value*	*P-Value*	*A-Value*	*p-Value*	*P-Value*	*A-Value*	*p-Value*
CSMA/CA,OMAC	**2.70E-18**	**0**	**2.20E-16**	2.29E-18	0	2.29E-18	2.84E-18	0	2.29E-18
CSMA/CA, E-OTP	**1.10E-13**	**0.07420**	**2.20E-16**	7.81E-19	0	7.81E-19	2.79E-18	0	7.81E-19
CSMA/CA, OTP	**1.81E-18**	**0**	**2.20E-16**	1.21E-18	0	1.21E-18	2.85E-18	0	1.21E-18
OTP,OMAC	0.12343	0.4117647	0.1863	0.14505	0.41638	0.87200	4.92E-09	0.16974	1.84E-11
E-OTP,OMAC	**3.21e-06**	**0.2337562**	**9.52e-06**	0.00051	0.30085	0.01321	2.52E-09	0.16628	4.40E-12
E-OTP,OTP	**0.00307**	**0.33**	**2.2e-16**	*0.03950*	*0.38197*	*0.18630*	*0.52637*	*0.46694*	*0.99760*

4) Energy Utlisation: To compare the energy utilised for transmission, the mean and median of the total number of transmissions includes retransmission of the failed packets are computed and presented in table III.

TABLE III. TOTAL NUMBER OF TRANSMISSIONS INITITIATED BY THE NODES DURING THE EXPERIMENT

Protocols	CSMA-CA		OMAC		OTP		E-OTP	
Activities	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Stairs	6401	6360	1162	1176	1099	1102	661	638
Running	7036	7020	595	563	470	454	190	181
Walking	7042	7020	581	582	459	454	187	181

From table III, E-OTP has generated the least traffic on the networks as it has the lowest mean for all the activities. The number of transmissions in E-OTP is nearly half of OTP and OMAC as the packets are buffered prior to transmission until it is 80% full in E-OTP. For OMAC and OTP, it will begin transmission as soon as it detects the leg is at the most forward position. Hence, more transmission are observed. As for CSMA-CA, the packets are sent periodically every 10s. As the results, the total number of packet transmissions is the highest. As the transmission power is set to the minimum (Tx=1) for OMAC, OTP and E-OTP during normal operation, E-OTP can be considered to be more energy efficient as the total number of transmissions in E-OTP is significantly lower than OTP and OMAC. Although the protocols may switch to the maximum transmission power when the transmission buffer reaches its specific threshold (OMAC and OTP = 50% and E-OTP = 80%), the number of times that E-OTP switches its transmission power should be less than OMAC and OTP as the E-OTP will only switch its transmission power when the buffer is more than 80% occupied. Hence, we claim that E-OTP have the least power consumptions compared to all the other protocols.

VI. CONCLUSION

In this paper, we have shown that by the transmitting the packets after the legs has crossed the midpoint forward position can increase the PDR. The E-OTP has been developed where it will start transmitting its packet when the leg is in the midpoint forward position and stop transmitting when the leg crossed back the midpoint position. This approach increases the time window avaliable for transmission, allowing more packets to be stored in the memory buffer, Hence, it reduces the energy required for transmisssion. The results show that E-OTP is no worse for the previously examined activities of walking and running, however it then provides significant improvements for the new activities considered, i.e. walking up the stairs. This is because the knee is always blocking the transmission between the ankle and waist. We believe the E-OTP can also support other activities which will be evaluated as future work.

REFERENCES

[1] Q. Li, J. Stankovic, M. Hanson, A. Barth, J. Lach, and G. Zhou, "Accurate, fast fall detection using gyroscopes and accelerometer-derived posture information," in *Proceedings of the 6th International Workshop on Wearable and Implantable Body Sensor Networks*. IEEE, 2009, pp. 138–143.

[2] J. Ko, C. Lu, M. Srivastava, J. Stankovic, A. Terzis, and M. Welsh, "Wireless sensor networks for healthcare," *Proceedings of the IEEE*, vol. 98, no. 11, pp. 1947–1960, 2010.

[3] J. Wendt and M. Potkonjak, "Medical diagnostic-based sensor selection," in *IEEE Sensors*, 2011, pp. 1507–1510.

[4] T. H. Lim, I. Bate, and J. Timmis, "A self-adaptive fault-tolerant systems for a dependable wireless sensor networks," *Design Automation for Embedded Systems*, pp. 1–28, 2014.

[5] P. Phunchongharn, E. Hossain, D. Niyato, and S. Camorlinga, "A cognitive radio system for e-health applications in a hospital environment," *IEEE Wireless Communications*, vol. 17, no. 1, pp. 20–28, 2010.

[6] T. H. Lim, I. Bate, and J. Timmis, "Multi-modal routing to tolerate failures," in *Proceedings of the International Conference on Intelligent Sensors, Sensor Networks and Information Processing*, 2011, pp. 211–216.

[7] *CC2420 2.4 GHz IEEE 802.15. 4/ZigBee-ready RF Transceiver Data Sheet (rev. 1.3)*, Chipcon, A. S., 2011, rev. 3.

[8] T. H. Lim, I. Bate, and J. Timmis, "An opportunistic transmission protocol for body sensor networks using rssi and on-board accelerometer," in *Proceedings of the 10th International Conference on Intelligent Sensors, Sensor Networks and Information Processing*, 2015, pp. 1–6.

[9] T. H. Lim, T. Weng, and I. Bate, "Optimistic medium access control using gait anaysis in body sensor networks," in *Proceedings of the 5th International Conference on Wireless Mobile Communication and Healthcare*, Nov 2014, pp. 1–4.

[10] A. Bourke, J. O' Brien, and G. Lyons, "Evaluation of a threshold-based tri-axial accelerometer fall detection algorithm," *Gait & posture*, vol. 26, no. 2, pp. 194–199, 2007.

[11] M. Kangas, A. Konttila, P. Lindgren, I. Winblad, and T. Jamsa, "Comparison of low-complexity fall detection algorithms for body attached accelerometers," *Gait & posture*, vol. 28, no. 2, pp. 285–291, 2008.

[12] K. Prabh, F. Royo, S. Tennina, and T. Olivares, "BANMAC: an opportunistic MAC protocol for reliable communications in body area networks," in *Proceedings of the 8th International Conference on Distributed Computing in Sensor Systems*, 2012, pp. 166–175.

[13] E. Miluzzo, X. Zheng, K. Fodor, and A. Campbell, "Radio characterization of 802.15.4 and its impact on the design of mobile sensor networks," in *Wireless Sensor Networks*, 2008, pp. 171–188.

[14] C. Barclay, J. Cutting, and L. Kozlowski, "Temporal and spatial factors in gait perception that influence gender recognition," *Perception & Psychophysics*, vol. 23, no. 2, pp. 145–152, 1978.

[15] A. Vahdatpour, i. N. Amin, W. Xu, and M. Sarrafzadeh, "Accelerometer-based on-body sensor localization for health and medical monitoring applications," *Pervasive and mobile computing*, vol. 7, pp. 746–760, 2011.

[16] MEMSIC. (2011) TelosB mote. [Online]. Available: http://www.memsic.com/products/wireless-sensor-networks.html

[17] T. H. Lim, I. Bate, and J. Timmis, "Validation of performance data using experimental verification process in wireless sensor network," in *Proceedings of the 17th Conference on Emerging Technologies Factory Automation*, 2012, pp. 1–8.