An Improvement Approach for Reducing Transmission Power in Wireless Sensor Networks

Md Fahad Monir, Mohamed Hadi Habaebi, Alhareth Zyoud

Abstract: Adoption of Wireless Sensor Networks (WSN) is rising dramatically and a subsequent amount of research has done on WSN power efficiency. Node power consumption reduction is an important part of study in ZigBee WSN, in order to reduce overall WSN power consumption for different applications. One approach is transmission power control for reducing WSN power consumption. In this paper, we present a Transmit Power Control mechanism (TPC), where we use Received Signal Strength Indicator (RSSI) matrix to determine the minimum required level for successful packet delivery utilizing periodically broadcast signals in WSN. We analysis the behavior of the proposed mechanism with respect to different parameter settings such as node position and antenna polarization. A testbed is used for collecting data. After that, we benchmark the result with Non-TPC mechanism. It is observed that the proposed mechanism could provide up to 60% power saving in a specific testbed setup. We also notice that the average transmitting power is inversely proportional with respect to the height of WSN nodes (from 0 meter height).

Keywords: wireless sensor networks; transmit power control mechanism; received signal strength indicator; antenna polarization; internet of things; sensor nodes; power management; ZigBee.

I. INTRODUCTION

Wireless Sensor Network (WSN) contains low powered tiny devices that communicate to each other to maintain a wireless network. Basically, it is a network with large number of wireless nodes that are equipped with the sensors and are distributed for specific applications [1]. WSN attracted a good attention in present time and wireless industry is exponentially growing over the last decade. WSNs became an emerging phenomenon both in military and civil purpose [2]. By offering real-time info from the physical world, WSNs prolonged the study of the recent cyber structures to the physical domain [3]. This attention is rising because the wireless sensor technology is being used in handling personal computers, cell phones, and other households[3]. Moreover, recent development in the WSN research brought us small and inexpensive nodes, which can obtain a lot of data about physical values, e.g. soil moisture, humidity, temperature, oxygen level, lightning condition etc.

The rapid development of wireless technology and embedded system presents numerous WSN-based productions, which are becoming very important in our daily life. Since, wireless sensors are powered by batteries, it may sometimes impossible to replace or recharge the battery when needed. Therefore, to improve the reliability and to enhance the network lifetime, it is very important to evaluate the various types of energy-saving techniques. In certain applications, reducing power consumption will be the primary focus for optimizing the power consumption, and low power energy harvesting wireless sensors. With decreasing the energy, sensor nodes become inactive and lose their efficiency gradually. Various types of power consumption reduction are used in present days and Additive Transmission Power Control (TPC) is one of them. The advantage of TPC is the capability to apply this technique in present WSN tools without developing or customize proprietary communication protocols.

In this paper, we propose a TPC mechanism whereas the transmitting power of the wireless nodes is to be adjusted based on Received Signal Strength Indicator (RSSI) matrix, coming from the base station/base node. However, the Link Quality Indicator (LQI) is used in many experiments as an effective parameter in various TPC mechanisms. There are various types of changes in the nature of the application in which the WSN is applied may cause the traffic and network parameters to vary accordingly. Such parameters are types of sensors used, antenna polarization, data rates, height and distance of the nodes, node mobility, furniture and blocking equipment etc. RSSI matrix is considered as a good indicator for adjusting transmit power, as the value of the detecting transceiver goes above the sensitivity threshold and, RSSI is recommended as a cheap and agile estimator [15]. Most of the proposed TPC mechanisms for WSN in the literature are based on simulation results [4] [5],where we came up with real test bed result. In our work, many parameters, that may affect the TPC mechanism, are evaluated and discussed such as the antenna height and antenna polarization. Data for TPC is recorded in terms of different height and distance for indoor and outdoor environment with four types of antenna polarization. Results are then compared with the Non-TPC mechanism and finally, a summary of the paper is drawn.

II. MOTIVATION

Various methods of transmitting power consumption reduction in WSN have already been proposed and

Revised Manuscript Received on May 22, 2019.

Md Fahad Monir, Department of Electrical and Computer Engineering, International Islamic University Malaysia, Gombak, Malaysia

Mohamed Hadi Habaebi, Department of Electrical and Computer Engineering, International Islamic University Malaysia, Gombak, Malaysia

Alhareth Zyoud, Department of Electrical and Computer Engineering, International Islamic University Malaysia, Gombak, Malaysia

experimented over the last decade [7].

Adaptive Transmission Power Control (ATPC) became the popular theme to do research, since ATPC mechanism can be modified and implemented in existing WSN devices without modifying the proprietary of the WSN communication protocols. In [8], authors performed the investigational calculation, which compares the TPC techniques performance with B-MAC on the standard MAC protocol of the Mica 2 platform. The B-MAC protocol is a CSMA/CA protocol without channel reservation for RTS/CTS messages. This work claims 57% less energy consumption with respect to the MAC protocol with guaranteeing the reliability of the channel. In [9]authors proposed ATPC mechanism can provide an efficient power saving (18%), while retaining the high reliability of consumption by dynamically raising the power when needed and fulfilling the minimum signal strength requirement. This work got motivated from [9], since similar approach is taken in our experiment setup. An energy-efficient clustering algorithm is presented in [4], that can reduce the energy consumption significantly and accelerate the lifetime of WSN. Moreover, a clustering algorithm simulating an optimum energy efficient routing protocol techniques by using OMNET++ is proposed by [5]. A longer network lifetime could be ensured based on the outcome of their result. However, no testbed has been implemented on this routing protocol which could be compared with the simulated result, in order to observe the efficiency in real life scenario.

Nevertheless, some researchers came with important contribution on WSN power saving while we have dynamic sensor movement scenarios [6]. In [10], researchers worked on wireless body area networks (WBANs) and proposed a TPC mechanism that can enhance the WSN lifetime significantly. In their experiment, the link state properties are investigated through the RSSI. Then they proposed a practical TPC mechanism, which is based on short and long-term link states estimations. This mechanism simultaneously fulfils the energy efficiency requirements as well as link reliability. The performance is evaluated based on a real-time scheme and a dynamic postural position supposition mechanism. According to this work, the lifetime of the sensor nodes get increased by 9.86%. This paper also provides a better link reliability by reducing the packet loss rate (3.02%) in wireless networks. However, RSSI is not the only estimator that is considered for transmission power control mechanism. A TPC mechanism is proposed in [11], that use Link Quality Indicator (LQI) to set the transmitting power and this work shows a very good improvement in WSN power saving. Authors present a generalized energy model for TPC protocol that can decrease the energy consumption up to 38% to 80% for connected region links and up to 66% for disconnected region links [12].

III. TPC MECHANISM

Basically, in transmission power control mechanism we set the transmitting power on transmitter (Tx) based on the received signal strength coming from receiver (Rx). It primarily consists of a base station and a mobile node as seen in Figure 1. The base station sends and receives signals to and from the mobile station. Path loss model tells us, more distance causes more path loss. Through the pass loss calculation, we set up a power level in order to ensure successful packet delivery which should perform as if nodes are running with full power support. For example, instead of transmitting packet with full power, this mechanism adjusts the minimal transmitting power at sending nodes in order to perform successful packet delivery towards the receiver. The incoming signal strength is measured by examining the RSSI value that comes from the base station. In our testbed setup, we used professional kit (WSN-PRO 02110CA) of MEMSIC, that is the IRIS Wireless Measurement System, to do the testing and the desired scenarios. It has been chosen as it is 2.4 GHz IEEE 802.15.4, tiny wireless measurement system. It is designed specifically for deeply embedded sensor networks. Data rate is set to 250 kbps which is actually the default data rate [16].

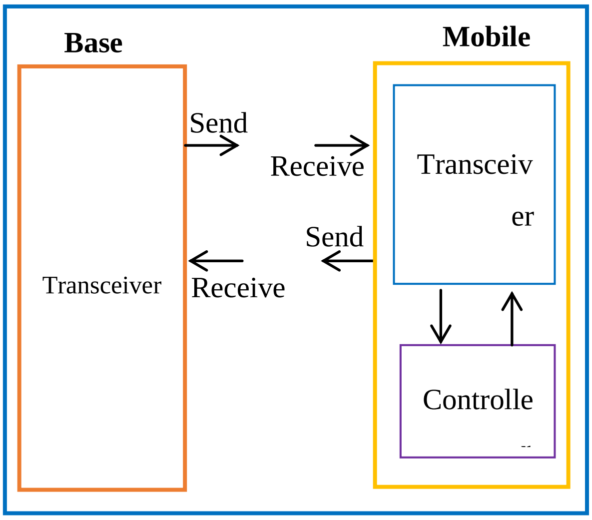

Fig. 1 Block diagram of Transmit Power Control Scheme

IV. BUILDING CONTROLLER

The basic path loss model is derived directly after obtaining the path loss index. To account the shadowing effects, the accuracy of the developed model is checked against the measurements and the error values are noted. The error is expected to follow a normal distribution curve (in decibels). Based on this distribution, the model can be modified in such a way that it can predict the path loss values. Note that, value most likely to be at least as much as in the real case scenario. The power levels that can be set on IRIS's RF230 transceiver are shown in Table. 1 [13]. In hardware, The PHY_TX_PWR register sets the transmit power and controls the FCS algorithm for transmission operation. TX_PWR is the four least significant bits in this register [13]. We estimate the distance between the Rx and Tx via calculating the path loss (based on the received RSSI matrix), i.e. Pt - Pr, then applying the inverse path loss model formula to get the distance between the Tx and Rx. The following Pseudo-code (figure 2) is proposed for our TPC mechanism, that is used for our experimental setup.

Table. 1 RF230 Transmit power levels[13]

Value of TX_PWR	Power [dBm]
0x0	+3.0
0x1	+2.6
0x2	+2.1
0x3	+1.6
0x4	+1.1
0x5	+0.5
0x6	-0.2
0x7	-1.2
0x8	-2.2
0x9	-3.2
0xA	-4.2
0xB	-5.2
0xC	-7.2
0xD	-9.2
0xE	-12.2
0xF	-17.2

- Read RSSI value from the PHY_ED_LEVEL.ED_LEVEL register

- Set distance, $d = 10^{\left(\frac{\overline{PL}-\overline{PL0}-\overline{Xa}}{10n}\right)} = 10^{\left(\frac{\overline{PL}-65.59}{21.07}\right)}$

- Calculate the expected path loss:

$PL = 59.838+21.07log_{10}(d) + 5.75$

- Set transmit power, $T_x - PL > -85dbm$

-For i = 0 to 15

- If: $T_x[i] - PL > -85\ dbm, break$:

- else: continue

- Set $PHY\_T_{x_{PWR}} = i$

- End if

- send / receive next packet

Fig. 2 Pseudo-code (TPC mechanism)

V. EXPERIMENT DESCRIPTION

In first part of our experiment setup, we have two different settings based on mote mobility; slow mobility and brisk mobility. The packet delivery ratio and power transmission levels are expected to come head to head in a trade-off and hence are used as our performance metrics. Both of the experiments are carried out in RF Digital Lab, IIUM. Testing is performed by moving the mobile sender along the grid shown in figure 3 from the point (2,1) through (2,7) then to (13,7) and back to (2,7). Note that, the base station mote was stationary at position (2,9). The aim of this experiment is to see how much energy could be saved on successful packet delivery based on different positions of motes/nodes and blocking scenarios such as furniture in RF lab. In second phase of our experiment setup, we aim at finding the effect of proposed TPC mechanism in static mode with different distances between the transceiver (Tx) and receiver (Rx). Moreover, we examine the efficiency of this mechanism with different height of the nodes with respect to the lab floor. In this case, we always calculate the node height perpendicular to the ground as shown in figure 4. Note that, experiment has been performed for indoor and outdoor scenarios, where inside the RF lab has been chosen for indoor testbed setup and Lab corridor has been chosen for outdoor testbed setup as shown in fig. 5. Apart from that, one more experiment has been performed in our campus Library. We did that in order to examine, whether the behavior of the TPC mechanism varies with different indoor environment or not. For indoor environment, the result is recorded in every one meter of distance, between Tx and Rx with Line of Sight (LOS) condition. We repeated exactly same procedure for different antenna height: 0.6, 1.1 and 1.6 meter as shown in figure 4. Note that, the transmitting power of TPC mechanism and RSSI is recorded for four types of antenna polarization: VV (Rx: Vertical, Tx: Vertical), HH, HV, VH and the measurements are taken for 1 to 15 m of range. However, for outdoor scenario, we present the behavior of TPC only for 0 m and 0.6 m of height.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

Fig. 3 Node mobility test

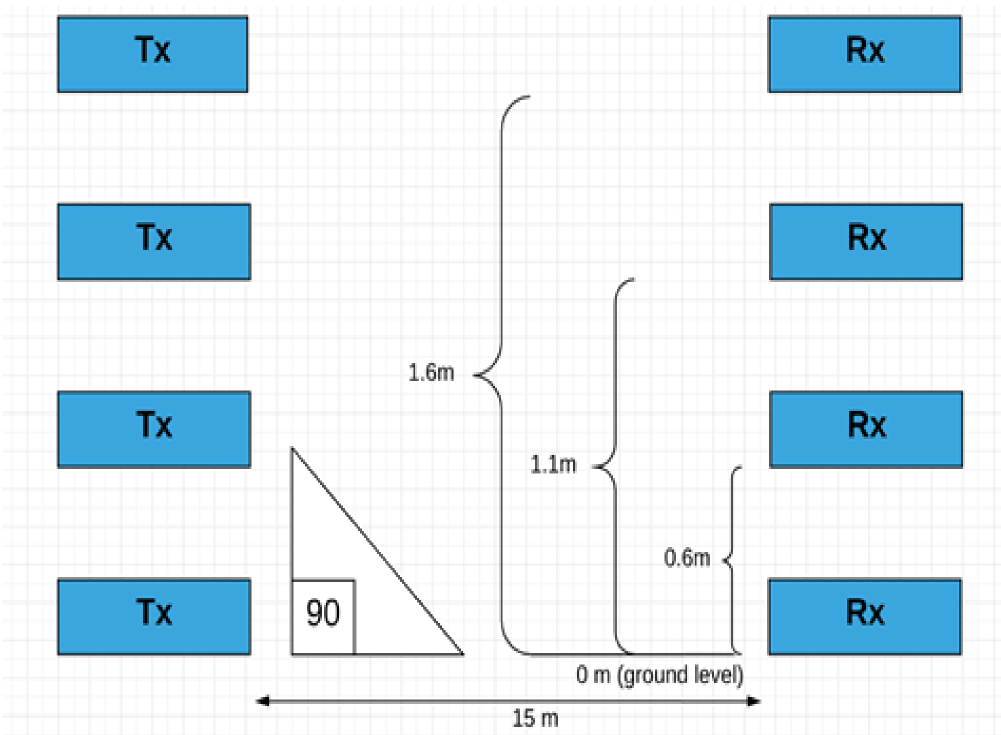

Fig. 4 Node placement at different height

Fig. 5 Testbed for testing our TPC mechanism with respect to different height and position

VI. RESULT AND EVALUATION

Table. 2 presents the result of the TPC mechanism performance with a range of 10 meter link and 1 meter of interval. Nodes send packets and after receiving 100 packets, the mote is moved one meter further. It can be seen, packet delivery ratio (PDR) decreases with increasing the distance between Tx and Rx. This is normal. Because with full power, we may also observe similar pattern of packet loss [13]. Table. 3 shows average PDR for TPC vs Non-TPC. The data is achieved with a setting the desired received energy at the base station to be -80 dBm, this is of course projected by approximating the distance between Tx and Rx first and then setting transmit power accordingly.

Figure 5 illustrates a comparison between TPC and Non-TPC with the parameter RSSI and packet numbers. It can be deduced from the graph that unnecessary power is wasted, when transmitting in default full power mode as the received power levels far exceed the sensitivity threshold of the transceiver in use – i.e. -91 dBm for Iris motes. When transmission power is controlled, the RSSI values are close to the -80 dBm mark throughout as it can be observed from the following figure. Figure 6 illustrates a comparison between TPC and Non-TPC with parameter RSSI and packet numbers. It can be deduced from the graph that unnecessary power is wasted, when transmitting in default full power mode as the received power levels far exceed the sensitivity threshold of the transceiver in use – i.e. -91 dBm for Iris motes. Figure 6, 7, 8, 9 and 10 present the result of the second phase of our experiment scenario(s). Figures give the testbed result for indoor and outdoor environment. Result between TPC and Non-TPC is compared in order to find how much power consumption reduction could be possible in a real testbed scenario. Power consumption is measured in dBm with respect to the distance between the Tx and Rx (1-15m), and height (0m, 0.6m, 1.1m, and 1.6m). Note that, the data is collected for four types of antenna polarizations of the Tx and Rx.

Table. 2 Performance Analysis of TPC at 1 Meter Distance Intervals With A Stationary Node

Distance (m)	PDR %	Average RSSI at base (dBm)
1	100	-81.43
2	99.01	-81.89
3	100	-84.07
4	98.04	-82.97
5	98.04	-82.38
6	82.64	-86.88
7	93.34	-85.58
8	90.91	-85.36

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

9	71.94	-89.05
10	90.09	-85.71

Table. 3 PDR for TPC vs non-TPC

Transmission and mobility		Average Packet Delivery Ratio (%)
Controlled Power transmission	Brisk walking	92.5
	Slow walking	96.2
Full Power transmission	Brisk walking	98.9
	Slow walking	99.2

Figure 7 displays the power consumption of Tx for successful packet delivery for four types of antenna polarization. For simplicity, we represent the Rx and Tx polarization as VV, HH, HV and VH respectively. For example, VH represents Rx(Vertical)-Tx(Horizontal). As we see from the figure 6, transmission power increases exponentially with increasing the distance between Tx and Rx. For example, the transmitted power is -17.2 dBm or 0.01905 mW for VV at the distance of one meter which increases to -12.2, -9.2, -7.2, -5.2, -2.2, -1.2, 1.6, 2.1, 2.6, and 3 dBm with the distance of 2, 3, 4, 5, 6, 7, 8, 9, 10 and 15 meter respectively. For Antenna polarization, VH consumes the least power, where VV appears with comparatively more power consumption.

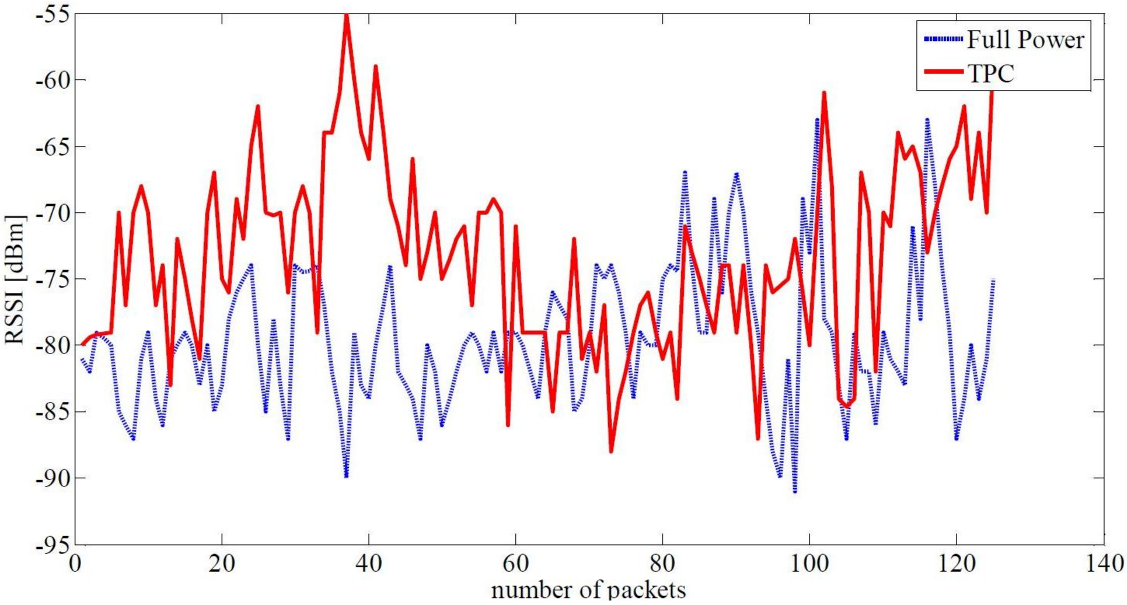

Fig. 6 Received signal strength at base station in slow mobility scenario.

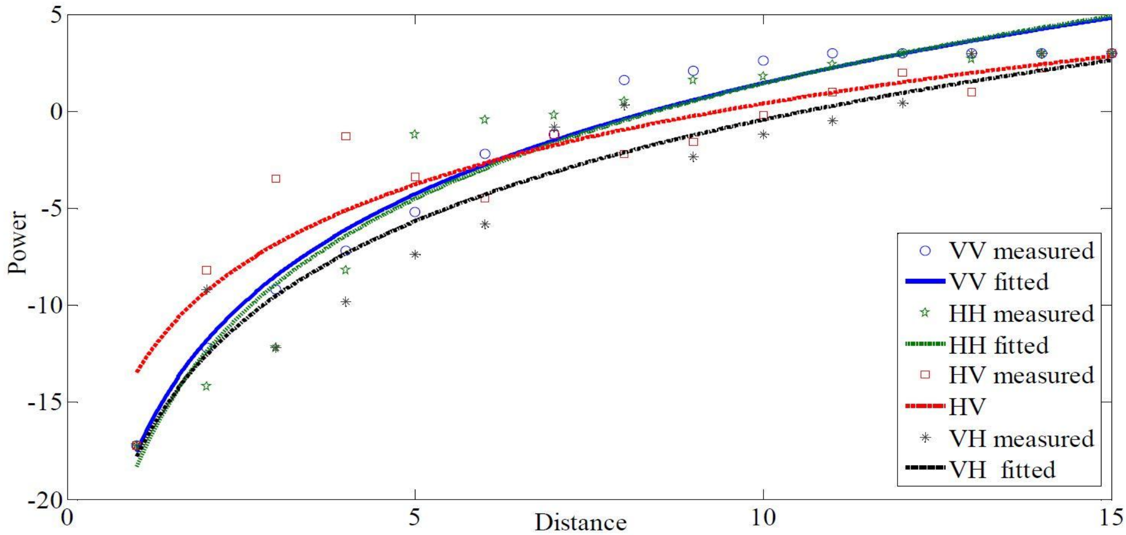

Fig. 7 Transmitting Power of TPC Mechanism for 1 to 15 meters of range at 0 meter height(measured and fitted data)

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

Overall, the figure shows that approximately 1.97 mW power consumption reduction would be possible based on this testing environment. The validity of our plotted graph could be compared with the work of [9], where authors achieved similar pattern through simulation. In figure 8 and 9, we draw the power consumption in transmitting node by using our TPC mechanism. These graphs are made to show the variation between TPC power consumption at different parameter setup. For example, figure 8 (a) shows power consumption of TPC at 0 meter height (ground) with four different types of polarization. In figure 9, we make a comparison with respect to different height and same polarization. We can notice that, power consumption decreases while we increase the node height. Almost similar pattern has been noted for each graph (exponentially upward) which authenticates the simulated data in [9].

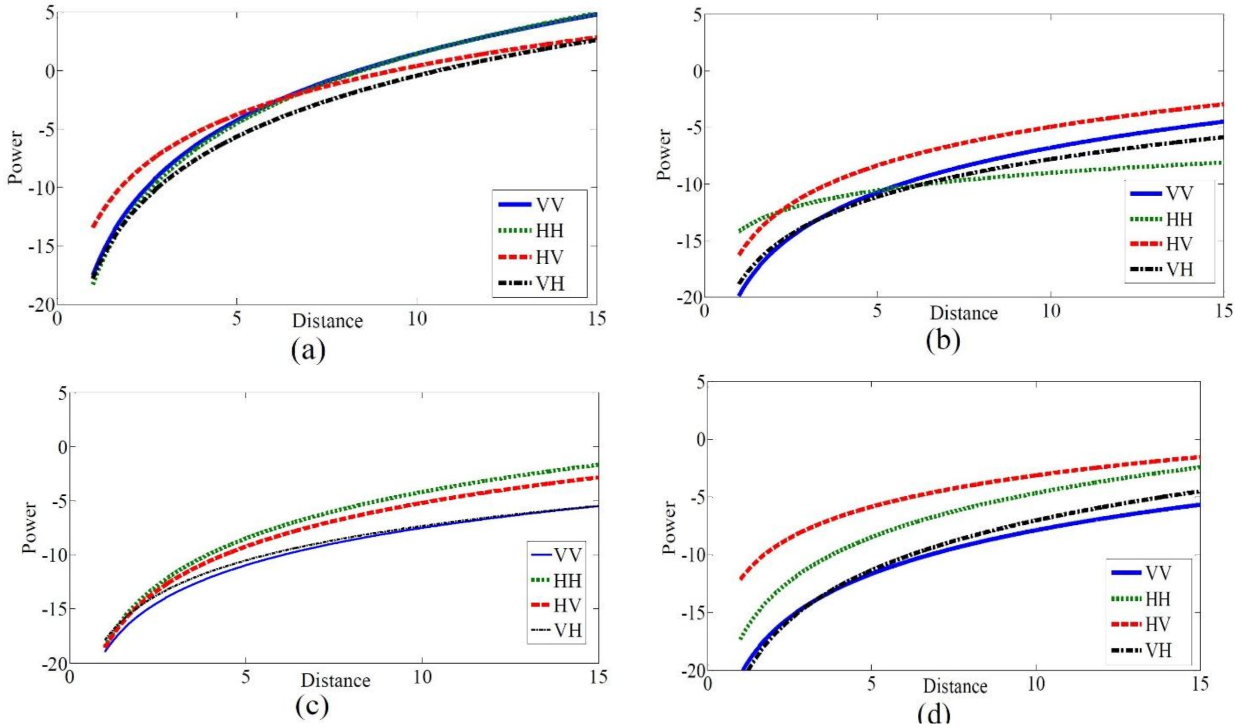

Fig. 8 Transmitting power as a function of distance for different antenna polarizations at (a) 0 m height; (b) 0.6 m height; (c) 1.1 m height; (d) 1.6 m height (measured and fitted data)

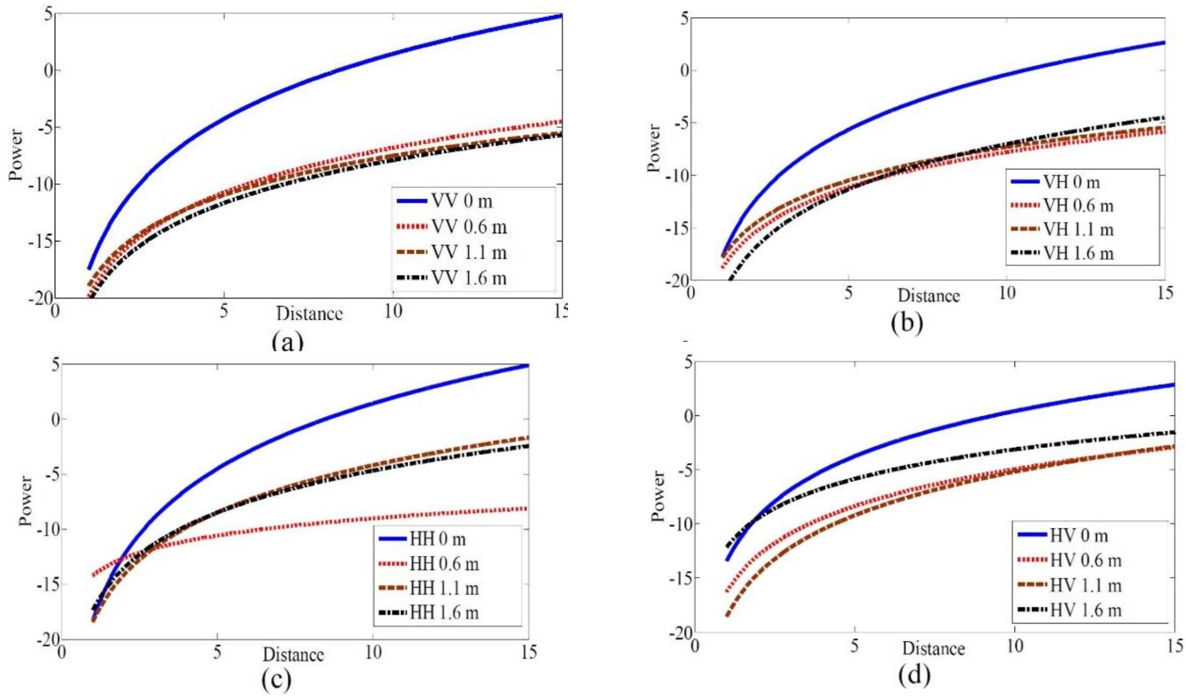

Fig. 9 Transmitting power at different heights and same polarization for indoor scenarios: (a) VV; (b) VH; (c) HH; (d) HV (measured and fitted data)

Table. 4 presents numerical values of power consumption with different polarizations and height for a better understanding as we have plotted the line graphs for fitted values.

Table. 4 RSSI and transmitting power for indoor environment in various height (VH)

Distance	RSSI (0m) VH	Power (0m)	RSSI (0.6m) VH	Power (0.6m)	RSSI (1.1m) VH	Power (1.1m)	RSSI (1.6m) VH	Power
1	-83	-17.2	-79	-17.2	-81.58	-17.2	-78.92	-17.2
2	-81	-9.2	-82	-17.2	-77.4	-17.2	-75.61	-17.2
3	-79	-12.2	-79	-12.1	-79.29	-12.2	-78.67	-17.2
4	-82.25	-9.8	-81	-11	-80.8	-12.2	-78.68	-17.2
5	-80.5	-7.4	-82	-12.2	-83.52	-12.2	-81.58	-8.6
6	-81.33	-5.8	-81.27	-8	-81.86	-7.2	-82	-17.2
7	-85.7	-0.8	-84	-5.2	-81.6	-7	-81.22	-12.2
8	-85.17	0.3	-82.2	-7.2	-82.23	-7.2	-82	-7.2
9	-83.7	-2.33	-79	-5.1	-83.1	-6.2	-83.33	-6.4
10	-84	-1.2	-83	-5.2	-81.9	-7.2	-86.22	0
11	-85.3	-0.5	-82	-6.2	-83.5	-7.2	-82.45	-4.3
12	-86	-0.4	-83	-7.2	-82	-8.4	-81.88	-7.2
13	-87	-3	-82	-7.2	-82.37	-6.1	-84	-6.7
14	-86	-3	-81.5	-5.2	-82.86	-6.6	-84.76	-1.2
15	-86	-3	-82	-4	-82.32	-6.4	-85	-7.2

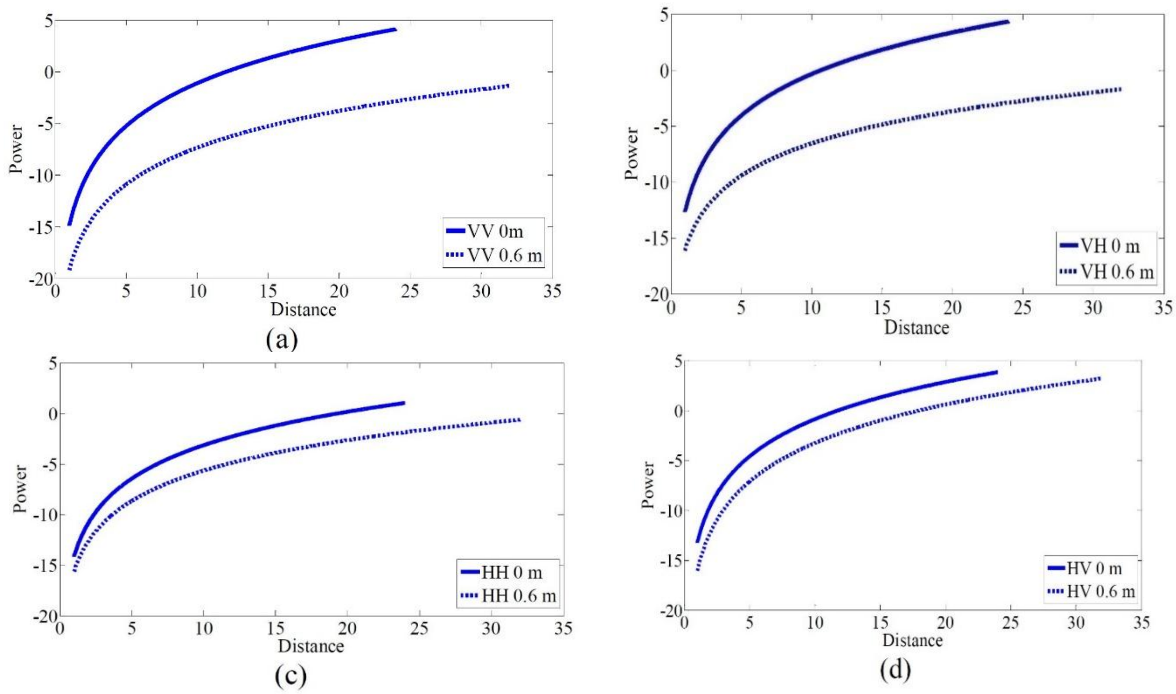

Fig. 10 Same antenna polarization, different heights for outdoor scenarios (a) VV; (b) VH; (c) HH; (d) HV (measured and fitted data)

Figure 10 shows nodes power consumption for an outdoor environment. The comparison was made only between 0 m and 0.6 m as shown in Figure 8. Unlike indoor environment, outdoor experiment approximately gives the similar result. As can be seen, power consumption goes lower when we increase the antenna height. In figure 11, we present a comparison of TPC behavior between indoor and outdoor environment. Note that, almost similar pattern is observed for power consumption of the behavior of TPC mechanism for indoor and outdoor scenarios with a height 0 m and 0.6 m where we took different antenna polarization in consideration as well. This figure is plotted in order to observe whether nodes behavior change with different environment. However, almost similar pattern is noticed for power consumption for indoor and outdoor environment.

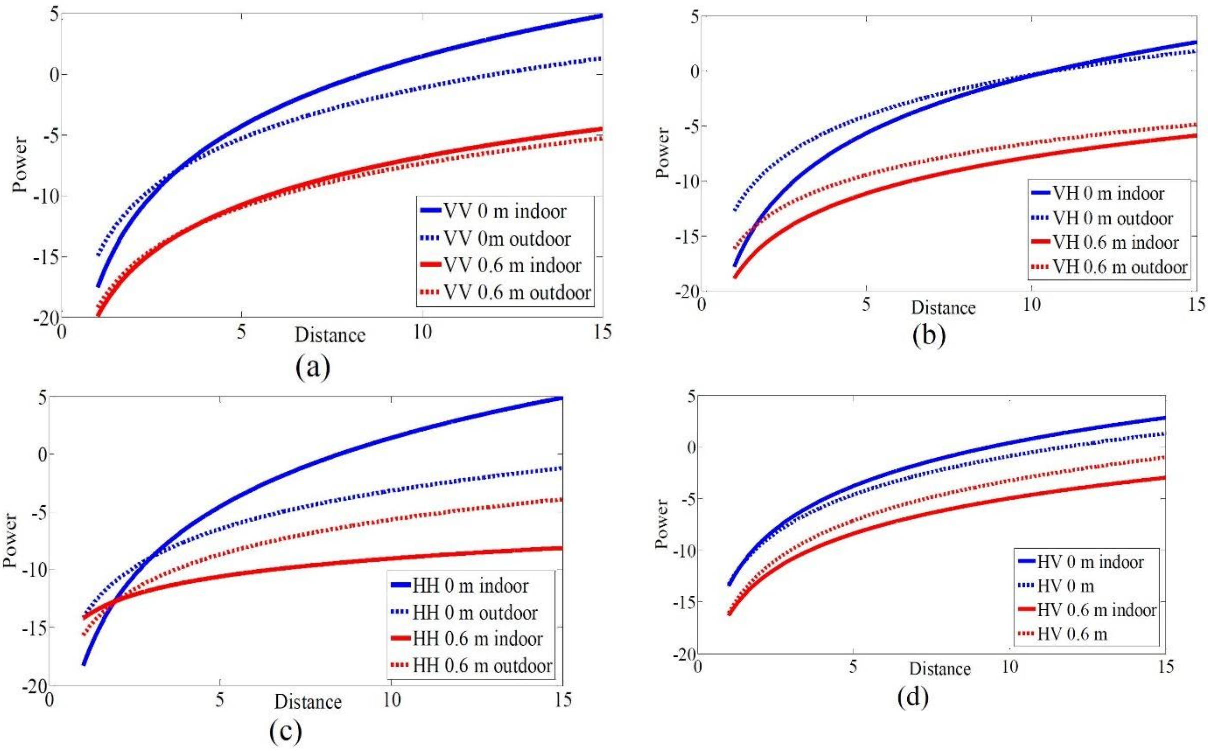

Fig. 11 Transmitting power at different heights and same polarization for indoor and outdoor testing(measured and fitted data)

In figure 12, we present a comparison between TPC and Non-TPC mechanism, where VV polarization and zero meter antenna height were taken in consideration. Figure 12 shows, applying TPC could reduce the overall transmitting power significantly compared with non-TPC. However, it can be noticed that TPC mechanism works up to 10 meter distance between the Tx and Rx in our testbed. We also present a table with all recorded data in order to show how effective this TPC mechanism would be, compared with full transmitting power scenario.

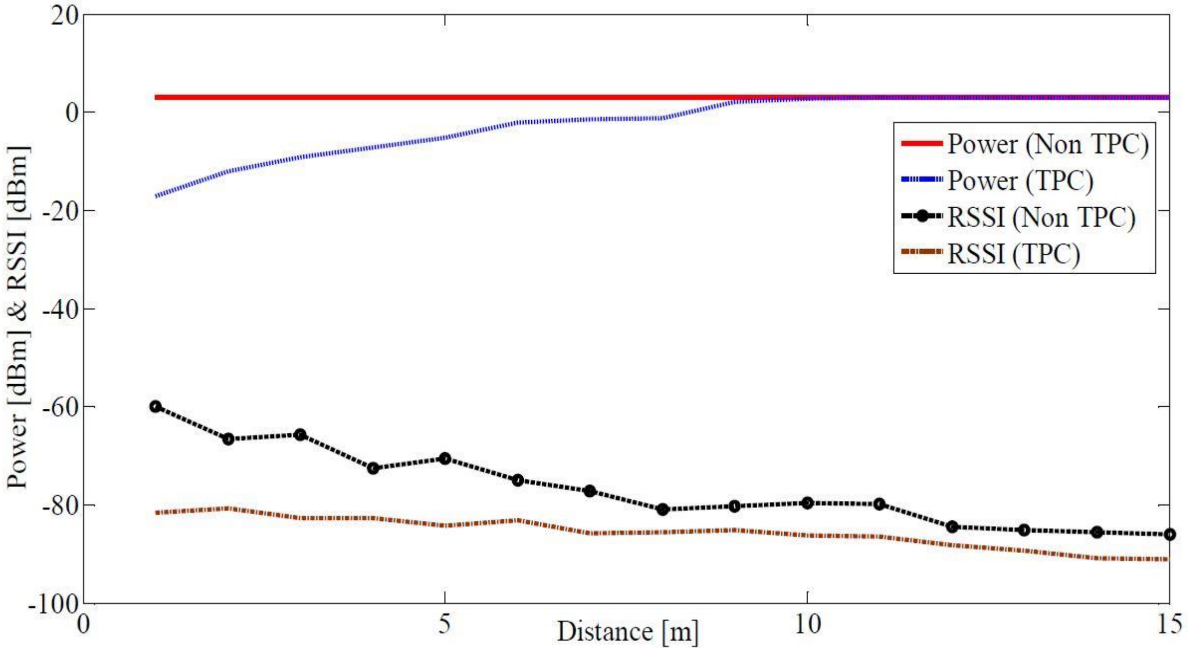

Fig. 12 TPC vs Non-TPC (indoor environment)

Table. 5 Comparison table between TPC and non-TPC

Distance (m)	Transmitting Power with TPC (dBm)	Transmitting Power with Non-TPC (dBm)	Difference (dB)	RSSI (dBm) with TPC	RSSI (dBm) with Non-TPC
1	-17.2	3	20.2	-81.65	-60.00
2	-12.2	3	15.2	-80.68	-66.63
3	-9.2	3	12.2	-82.78	-65.72
4	-7.2	3	10.2	-82.71	-72.48
5	-5.2	3	8.2	-84.21	-70.53
6	-2.2	3	5.2	-83.12	-75.05
7	-1.6	3	4.6	-85.78	-77.18
8	-1.2	3	4.2	-85.46	-80.84
9	2.1	3	0.9	-85.22	-80.18
10	2.6	3	0.4	-86.22	-79.64
11	3	3	0	-86.52	-79.91
12	3	3	0	-88.13	-84.37
13	3	3	0	-89.21	-85.21
14	3	3	0	-90.94	-85.45
15	3	3	0	-91.00	-86

VII. CONCLUSION AND FUTURE WORK

This paper presents an empirical experimentation for developing and testing the proposed TPC mechanism. First, measurement is taken for calculating required parameters for developing an indoor path loss model, which can be linked with the distance between Tx-Rx. After that, we evaluated the proposed scheme in two scenarios: brisk walking and slow walking. In second phase of our experiment, we performed different testing scenarios for indoor/outdoor environment with different antenna polarization and node positions. The reason of conducting these experiments is to examine the performance of proposed mechanism based on different environmental setup and to identify which setup could provide the optimal power saving. The results were elaborated clearly, which proves the advantages of using the TPC mechanism compared with the Non-TPC. As we examined the behavior of TPC mechanism based on different scenarios, our optimal power saving varies while we change the parameter value such as height and distance. We could roughly reach up to 50% power consumption reduction for a specific testbed setup. However, the present work gives some shortcomings. For instance, though the power gets reduced with this mechanism, transmitting power fluctuates with increasing the antenna height. This might be the result of noise interference in our surrounding. As can be seen, more noise causes more fluctuation in RSSI that results oscillation in TPC power adjustment. We also noticed that more distance between the Rx and Tx causes less packet delivery ratio. However, this is quite normal as according to the IEEE802.15 standardization, ZigBee devices transmit and receive data at 2.4 GHz ISM band and there will be always a small portion of packet loss in data transmission. Therefore, it cannot be avoidable in our experimental devices, i.e. IRIS's RF230 [13].

Nonetheless, our future work includes designing and implementing a steady TPC mechanism, which would ensure a smooth power adjustment regardless of noise in the air. Moreover, multiple-input and multiple-output (MIMO) Technology could be used in future sensor nodes that can provide more reliability in data transmission.

ACKNOWLEDGEMENT

This work was conducted at the IOT and Wireless Communication Protocols Lab, and is partially funded by International Islamic University Malaysia (IIUM) Publication RIGS grant no. P-RIGS18-003-0003.

REFERENCE

1. Elshrkawey, M., et al. (2017) 'An enhancement approach for reducing the energy consumption in wireless sensor networks', Journal of King Saud University—Computer and Information Sciences, 30(2), pp. 259–267.
2. Wenliang Wu, Naixue Xiong, Chunxue Wu,"Improved clustering algorithm based on energy consumption in wireless sensor Networks,"IET Network Journal 2017.
3. Hamouda, Y., Msallam, M. Variable sampling interval for energy-efficient heterogeneous precision agriculture usingWireless Sensor Networks. Journal of King Saud University – Computer and Information Sciences (2018), https://doi.org/10.1016/j.jksuci.2018.04.010
4. Min, X., Wei-Ren, S., Chang-Jiang, J., and Ying, Z. (2010) 'Energy efficient clustering algorithm for maximizing lifetime of wireless sensor networks', AEU-International Journal of Electronics and Communications, 64 (4), pp. 289-298.
5. G. Yi, D. Yu, N. Kim, "Adjusting control packet transmission intervals in low power sensor systems", *Int. J. Distrib. Sensor Netw.*, vol. 10, no. 8, pp. 139682, Aug. 2014.
6. Zhang, J., Wu, C. D., Zhang, Y. Z., and Ji, P. (2011) 'Energy-efficient adaptive dynamic sensor scheduling for target monitoring in wireless sensor networks', ETRI journal, 33(6), pp. 857-863.
7. S. Lin, J. Zhang, G. Zhou, L. Gu, T. He and J. A. Stankovic, "ATPC: Adaptive Transmission Power Control for Wireless Sensor Networks" Proc. of the 4th ACM Conference on Embedded Networked SensorvSystems (SenSys'06), Nov., 2006
8. Correia, L. H., Macedo, D.F., dos Santos, A. L., Loureiro, A. A., and Nogueria, J. M. S. (2007) 'Transmission power control techniques for wireless sensor networks', Computer Networks, 51 (17), pp. 4765-4779.

9. Horvat, G., Sostaric, D., and Zagar, D. (2012, July) 'Power consumption and RF propagation analysis on ZigBee XBee modules for ATPC', In 35th International Conference on Telecommunications and Signal Processing (TSP), pp. 222-226.
10. Kim, S., and Eom, D. S. (2014) 'Link-State-Estimation-Based Transmission Power Control in Wireless Body Area Networks', IEEE Journal of Biomedical and Health Informatics, 18(4), pp. 1294-1302.
11. Tantubay, N., and Sharma S. (2011) 'Transmission Power Control Management for Radio PHY802.15.4 based on LQI for Wireless Sensor Network', International Journal of Computer Applications, Volume 25– No.7, pp. 43-49.
12. Hughes, J, B., Lazaridis, P., Glover, I., and Ball, A. (2017) 'Opportunities for Transmission Power Control Protocols in Wireless Sensor Networks', in Proc. 23rd International Conference on Automation & Computing, University of Huddersfield, Huddersfield, UK, 2017.
13. ATMEL AT86RF230. (2009) Low Power 2.4 GHz Transceiver for ZigBee, IEEE 802.15. 4, 6LoWPAN, RF4CE and ISM Applications, ATMEL Corporation, San Jose, CA, available online. "http://www.atmel.com/images/doc5131.pdf (Accessed 01 June 2018)
14. Mangir, T., Sarakbi, L., & Younan, H. (2011) 'Detecting Malicious Activitiesin ZigBee Networks using Cognitive Radio', International Journal of Distributed and Parallel Systems(IJDPS). Vol.2, No.6, pp. 51-62.
15. Philip, L., (2006), TinyOSProgramming Manual, at http://www.tinyos.net.
16. MEMSIC, IRIS. (2010) Wireless Measurement System-Datasheet. Available online. http://www.memsic.com/userfiles/files/datasheets/wsn/iris_datasheet.pdf (Accessed 22 May 2018)