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Link Quality Based Transmission Power Control in IEEE 802.15.4 for Energy Conservation

Samrachana Nepali◆, Seokjoo Shin°

ABSTRACT

One of the major challenges in the design of wireless sensor network (WSN) is to reduce the energy consumption of sensor nodes for prolonging the network lifetime. In the sensor network, communication is the most energy consuming event. Therefore, most of the energy saving techniques conserve energy by adjusting different parameters of the trans-receiver. Among them, one of the promising methods is the transmission power control (TPC). In this paper, we investigated the effects of the link quality based TPC scheme employed to the IEEE 802.15.4 standard for energy saving. The simulation results demonstrated that the link quality based TPC scheme works effectively in conserving energy as compared to the conventional IEEE 802.15.4.

Key Words : communication, signal processing, Neutral systems, Communication Sciences, Network

Ⅰ. Introduction

Wireless Sensor Network (WSN) consists of low-powered devices capable of sensing and computing. As these small, inexpensive devices are battery powered, sensor nodes must be energy efficient[1-7]. The radio on a sensor node is usually the component that uses the most energy. The legacy MAC protocols of WSN conserve energy by introducing the concept of duty cycling where a node periodically alternates between active and inactive mode. However, there is a tradeoff between energy consumption and the latency in duty cycling MAC protocols. Radio-triggered power management is another alternative for energy conservation[8]. In radio-triggered power management, a special hardware component, a radio-triggered circuit, is connected to sensor node which wakes up the sensor node whenever it senses communication in the vicinity. The radio-triggered circuit prevents sensor nodes from duty cycling. Similarly, power control scheme is also an alternative to adjust transmit power for energy conservation. Besides saving energy, power control also improves spatial reuse of the wireless channel[9].

IEEE 802.15.4 standard uses fixed default power for transmission. Even though the commercial trans-receivers are programmable, the standard has not defined any power control mechanism. In this paper, we present the link quality based TPC algorithm which can be easily implemented into the IEEE 802.15.4 standard. The idea is to dynamically adjust the transmission power to discover and maintain a quality of the link between a pair of nodes instead of transmitting data at a full power capacity.

The rest of this paper is organized as follows. Section II provides reviews on the legacy TPC schemes applied for WSN and introduces the motivation of this study. Section III presents the proposed TPC algorithm. Similarly, experimental results are shown in Section IV and finally, we conclude our paper in Section V.

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◆ First Author : Chosun University, Department of Computer Engineering, samrachana1@gmail.com, 학생회원
° Corresponding Author : Chosun University, Department of Computer Engineering, sjshin@chosun.ac.kr, 종신회원
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Ⅱ. Related Works and Motivation

Several MAC approaches on transmission power control for WSNs are reviewed in this section. The common procedure is monitoring the current link quality by broadcasting messages to neighbors and determining the incoming acknowledgements. In some proposed schemes, a table storing network topology is required. A transmission power control in MAC protocols for wireless sensor networks is proposed in [10]. To adjust the transmission power in WSNs, two approaches are presented in the paper. The first approach employs dynamic adjustments by the exchange of information among nodes, and the second one calculates the ideal transmission power according to the signal attenuation of the link. In the first approach, the transmission power is divided into a few levels and nodes adjust its transmission power level according to the number of consecutive Acknowledgement (ACK) packets it received successfully. However, using packet reception rate (PRR) for power control may not be practical in actual applications especially when the channel is shared with other wireless technologies. In the second approach, Received Signal Strength Indicator (RSSI) readings were found to be extremely dependent on environmental conditions in WSN, thus calculation of the ideal transmission power is imprecise.

PSMAC (transmission Power control in SMAC) is SMAC based transmission power control protocol for WSNs[1,11]. PSMAC selects the minimum amount of transmitting energy required to exchange messages between any pair of neighboring nodes. The necessary power for the transmission is calculated using the RSSI of received SYNC packet. To record the required transmission power for communication for the individual neighbor, each node maintains a neighbor list. However, broadcast messages are transmitted with the maximal transmission power. In order to assign a minimum and workable transmission power to each communication link, Adaptive Transmission Power Control (ATPC) for Wireless Sensor Networks was designed based on the concept of changing a pairwise transmission power level over time[12]. Two main ideas behind its design are a neighbors table which is maintained by each node and a closed loop for transmission power control which runs between each pair of sensors. The closed loop feedback is used to obtain the minimum transmission power by gradually adjusting the power. Similarly, in [13] authors showed that transmission power levels adjusted per link give the higher network lifetime than single power level for all links. In [14], it is shown that reconfiguring transmission power levels are an effective way of saving energy in WSNs. The relation between the signal strength and the packet delivery is studied in [15] and concluded that the signal-to-noise ratio (SNR) of 15-20 dB is enough for the successful delivery of most of the data packets.

Although there have been various works discussing the TPC mechanism, no previous work has discussed the possibility of using TPC in IEEE 802.15.4 standard. In this paper, we will show how IEEE 802.15.4 standard can be enhanced by implementing TPC mechanism.

In a typical WSN, sensor nodes are randomly deployed in the interested region. Thus, the distance between any two nodes is variable. In some cases, the nodes may be very close to each other, whereas in other cases, the distance between the nodes may be farther. In this kind of scenario, using the same transmission power by all sensor nodes might not be an effective solution. The nodes which are close to each other can communicate easily by using lower transmission power. Using full transmission power, even though the reliable communication can be done with lesser power, is just the waste of energy.

The IEEE 802.15.4 standard for Low-Rate Wireless Personal Area Network (LR-WPANs) is becoming a de-facto standard for WSN applications due to its low energy consumption, low cost, and small size. The CC2420 is a single-chip 2.4 GHz IEEE 802.15.4 compliant RF module and is used in most of the commercial sensor motes[16]. In CC2420, the transmission power is programmable; therefore, we can change the transmission power of the sensor node according to our requirement. Table 1 shows

Table 1. CC2420 transmission power level

Power level	Output power (dBm)	Current (mA)
31	0	17.4
27	-1	16.5
23	-3	15.2
19	-5	13.9
15	-7	12.5
11	-10	11.2
7	-15	9.9
3	-25	8.5

the different transmission power level of CC2420. However, the benefit of this programmable power level is exploited by IEEE 802.15.4 standard. Thus, we proposed to dynamically adjust the transmission power according to the link quality measurement in order to conserve energy.

Ⅲ. Proposed Link Quality based TPC Scheme for IEEE 802.15.4

The aim of the proposed algorithm is to lower transmission power to a level which maintains acceptable packet success rate.

In order to reduce the energy consumption, the proposed method adjusts the transmission power corresponding to the distance between a sender and a receiver. Link Quality Indication (LQI) value is used to estimate the distance between sensor nodes, which is feedback in the ACK frame. In IEEE 802.15.4, every MAC frame contains LQI value, which ranges from 0 to 255. The LQI measurement is a characterization of the strength and/or quality of a received packet. However, the calculation of the LQI is not specified in the IEEE 802.15.4 standard. Thus, the receiver Energy Detection (ED), Signal-to-Noise ratio (SNR), or the combination of these methods can be used in commercial IEEE 802.15.4 modules to calculate the LQI[16].

In order to observe the change in LQI with respect to distance, we conducted a simple experiment as described below. The simulation was performed in NS-2[17]. Two nodes, Node 1 and Node 2, were placed next to each other. Node 2 transmitted data to Node 1 at 2 kbps. Node 1 was fixed and Node 2 was slowly moved away from Node 1 at the speed of 0.5m/s. Transmission range was set to 15m. The LQI value of data received at Node 1 is shown in Figure 1. In NS-2, the LQI is calculated based on the received signal strength and the signal to noise ratio. A packet is only received if its LQI is equal or greater than 128. Thus, LQI obtained ranged from 128 to 255 because the packets whose LQI is below 128 were dropped. Also, the LQI value of 255 was observed when the distance between two nodes is less than 12m, and the gradual decrease in the LQI was observed once the distance between nodes exceeded 12m. In [18] and [19], authors also obtained similar LQI result. Also from the NS-2 experiment, we observed that the LQI value between 140 and 170 is sufficient for the reliable communication between nodes. Thus, based on the NS-2 experiment, we proposed the following algorithm for estimating distance and adjusting the transmission power.

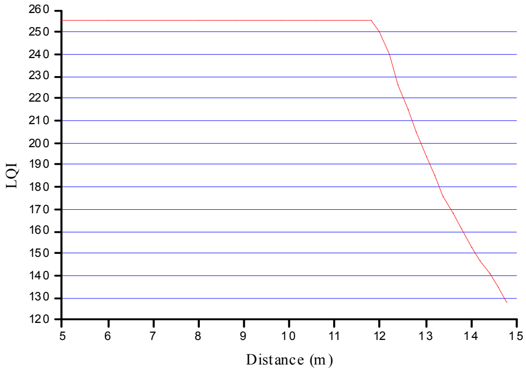

Fig. 1. Change in LQI with distance

At the beginning of the network, nodes use the default transmission power, which is the highest power level (level 31 in Table 1). As the nodes communicate, they estimate the distance (or link quality) between them and adjust the transmission power accordingly. During data transmission, the receiving node calculates the LQI value of the received packet. However, for adjusting the transmission power, the sender should know about the LQI at the receiver. Thus, as a feedback, the LQI of the received data packet is piggybacked and sent to the sender in the ACK packet. From the

ACK, the sender knows about LQI of its sent packet at receiver, adjusts its transmission power such that the LQI at the receiver is in the range between LQI_{low} and LQI_{high}. For filtering the noise in LQI, the running average of LQI is calculated, i.e., the LQI is normalized by averaging the multiple LQI received from the receiver. The normalized LQI, denoted by LQI_{avg}, is used for adjusting the transmission power. Figure 2 shows the flowchart for adjusting the transmission power. All the nodes maintain a table called transmission power table, which records the required transmission power for each neighbor. However, in the case a node needs to broadcast, the maximum power level is used.

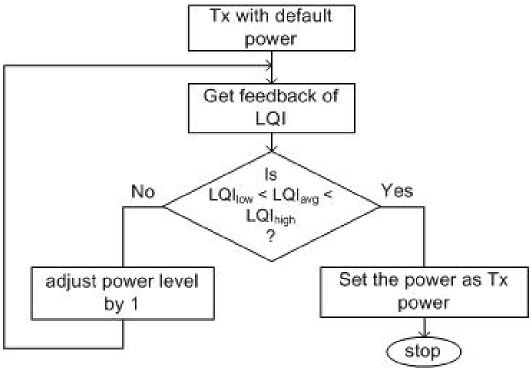

Fig. 2. Flowchart for link quality based TPC algorithm.

Ⅳ. Experimental Results

For the performance evaluation, we implemented the proposed link quality based TPC method on IEEE 802.15.4 and SMAC protocols in the NS-2 simulator. Note that the IEEE 802.15.4 and SMAC is readily available in the NS-2 simulator. A Simulation study has been performed for the proposed TPC and compared it with the original protocols. For the simulation, nodes are deployed in a 100×100m field with the given topology shown in Figure 3. Similarly, the parameters used for the simulation are shown in Table 2. The parameters of Table 2 are taken from CC2420 datasheet[15]. In the case of IEEE 802.15.4, BO=SO=3 was used. Similarly, in SMAC, duty cycling was not used so as to be comparable with BO=SO (no inactive

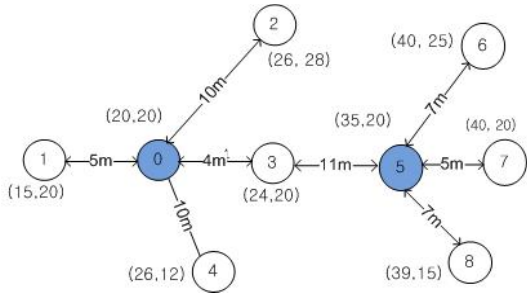

Fig. 3. Topology used in the simulation.

Table 2. Network Parameters.

Parameter	Value
Power Supply	3 V
Sleep Power	30 uw
Idle Power	2.76 mw
Data traffic	CBR
Radio rate	250 Kbps
Routing protocol	DumpAgent / AODV
Data rate	Variable
Transmission range	15 m
Packet size	Variable
LQIlow	140
LQIhigh	170

period) of IEEE 802.15.4. In Figure 3, node 1, node 2, node 3, and node 4 transmits data to the node 0. Similarly, node 6, node 7, and node 8 transmit data to the node 5. The distance between sender and receiver is variable. Table 3 shows the transmission power and range of different power levels used in the simulation. Therefore, using Table 3, the transmission powers of source node were set.

Table 3. Transmission power and range.

Power level	Tx. power (mw)	Tx. Range (m)
31	52.2	15
27	49.5	13
23	45.6	11
19	41.7	9
15	37.7	7
11	33.6	5
7	29.7	3
3	25.5	1

Different experiments were performed to test the performance of the proposed TPC algorithm.

In the first experiment, message inter arrival period is varied from 1 to 4 seconds. Packet size was fixed to 50 bytes. The simulation was carried for 500 seconds. Figure 4 and Figure 5 show the average Packet Delivery Ratio (PDR) and average energy consumption of network obtained from the simulation. It is observed that at the message interval of 1-second, PDR of the conventional IEEE 802.15.4 is higher than the proposed TPC. The reason for this is that, whenever there is a collision, at the same power level, the receiver was successful in decoding the data packet from the node which is near to it, which is generally referred to as the capture effect. However, in the case of applying TPC, since power was adjusted based on the distance, in the case of collision, all transmitted data packets were dropped as a receiver is unable to decode any data packet. Conversely, PDR for IEEE 802.15.4 is almost same in both protocols for higher message intervals. Furthermore, PDR in SMAC is almost same for all message intervals, which can be explained by the fact that SMAC is not employing duty cycling, hence significantly reducing overheads associated with network synchronization giving more bandwidth for data communication. As expected, in Figure 5, proposed TPC is able to save energy in the network. As the message inter-arrival period increases, the traffic load in the network decreases. Therefore, the energy consumption decreased as the message inter-arrival period increased. Furthermore, since SMAC does not go into power saving mode, the energy conservation in SMAC is significantly high in compared with the IEEE 802.15.4.

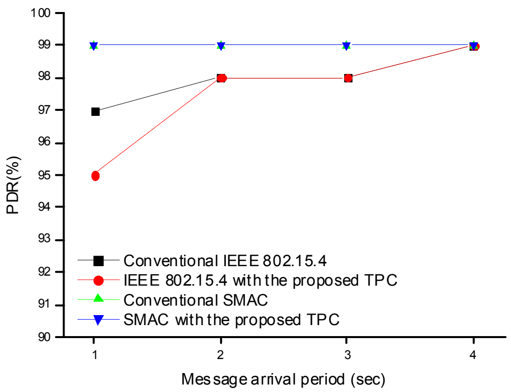

Fig. 4. Average packet delivery ratio.

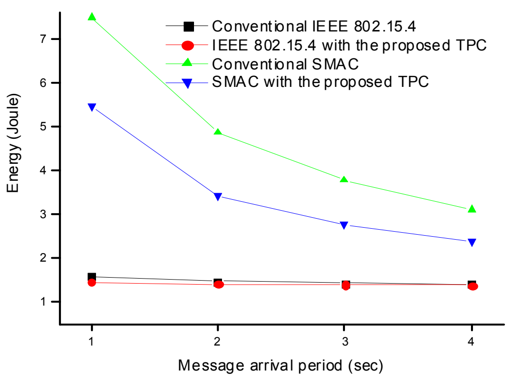

Fig. 5. Average energy consumption.

In the econd experiment, the message inter arrival period is fixed to 1 second while packet size was varied from 50 to 100 bytes. The simulation was carried for 500 seconds. Figure 6 and Figure 7 show the average PDR and average energy consumption of network obtained from Experiment 2, respectively. It was observed that PDR of the conventional IEEE 802.15.4 was higher than the one with the proposed TPC whereas the PDR for SMAC is same for all cases. The reason for this is same as with the first experiment. It was also observed that as the packet size was increased, the PDR decreased because as the packet size increases, more power is consumed. Therefore, as expected, in Figure 7, the energy consumption increased with the increase in

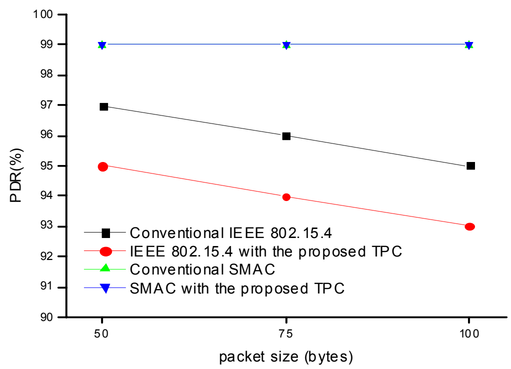

Fig. 6. Average packet delivery ratio.

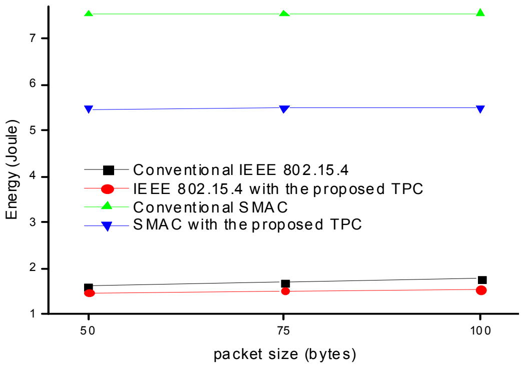

Fig. 7. Average energy consumption.

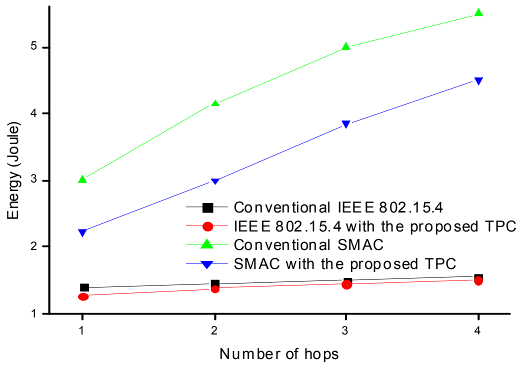

Fig. 8. Average energy consumption.

packet size in both IEEE 802.15.4 and SMAC. Note that the proposed TPC is able to save the significant amount of energy in the network as compared to the conventional protocols.

In the third experiment, we fixed the message inter arrival period and the packet size to 5 seconds and 100 bytes, respectively. The simulation was carried for 500 seconds. The results obtained are shown in Table 4. The results show that PDR is same for all the protocols. However, energy consumption is much lesser in the case of the proposed TPC.

In the final experiment, 50 nodes were randomly deployed in the 100x100m area. Multiple source and sink nodes were randomly chosen for data exchange. We fixed the message inter arrival period and the packet size to 1 second and 100 bytes, respectively. The simulation was carried for 500 seconds. The average energy consumed based on the hop distance between source and sink nodes was calculated and shown in Figure 8. Note that hop distance of 1 means that source and sink can directly communicate with each other and hop distance of 2 means an intermediate node relays data between a

Table 4. Comparison results.

Protocols	PDR (%)	Energy (joule)
Conventional IEEE 802.15.4	98	1.45
IEEE 802.15.4 with the proposed TPC	98	1.4
Conventional IEEE SMAC	99	2.85
SMAC with the proposed TPC	99	2.12

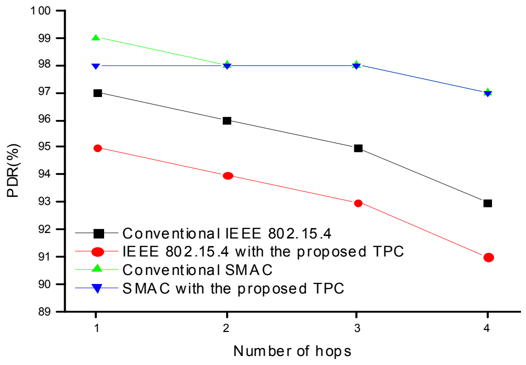

Fig. 9. Average packet delivery ratio.

source and a sink. As can be seen from the figure, as required hop between a source and a sink increases, energy consumption also increases. However, the energy saving by the proposed TPC protocols was considerably high in compared with original protocols. The PDR obtained from the experiment is shown in Figure 9. Because of the capture effect as explain above, the PDR of proposed protocol is slightly less than original IEEE 802.15.4.

From the above experiments, it is patently clear that the proposed protocol can significantly decrease the power consumption of IEEE 802.15.4 network and consequently increase the life time of a network. The results demonstrate that in the case of low traffic, the performance of the proposed TPC is better than that of the conventional IEEE 802.15.4; the proposed protocol delivered the same PDR, but with significantly less power consumption.

V. Conclusion

In this paper, we presented a TPC scheme that can be easily implemented in IEEE 802.15.4 protocols. In the proposed TPC mechanism, LQI value is used to estimate the distance between two nodes. And based on the estimated distance, the transmission power is adjusted without degrading the link quality. The experimental results demonstrated that the proposed protocol can significantly decrease the power consumption of IEEE 802.15.4 network without degrading PDR.

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네팔리 삼라차나 (Samrachana Nepali)

2009년 8월 : 포카라대학교 컴퓨터공학과 졸업 (네팔)

2015년 3월~현재 : 조선대학교 컴퓨터공학과 석사과정

<관심분야> 인체영역통신, 헬스케어 모니터링 시스템

신 석 주 (Seokjoo Shin)

1999년 2월 : GIST 정보통신공학과 석사

2002년 8월 : GIST 정보통신공학과 박사

2003년 9월~현재 : 조선대학교 컴퓨터공학과 교수

<관심분야> 이동통신시스템, WSN, 네트워크보안