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An Overview of Transmission Power Control Techniques in Wireless Body Area Sensor

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Abstract
The recent researches in Wireless Body Area Networks (WBAN) are focused on making the communication of their sensors more reliable, energy efficient, secure, and to better utilize system resources. Investigators have used different methods and protocols to manage the sensors energy and their communication. Transmission power control (TPC) is one of the popular techniques that are used to regulate sensor transmission power dynamically proportional to the destination distance, link quality, and so on. Because using of fixed transmission power in sensors lead to waste energy in good state of link and low reliability in bad state of link, by TPC technique, we can control these criteria and others. In this paper, we present a discussion of TPC technique and provide some of the recent researches that used this technique in the presented protocols.

Keywords: WBAN, Energy, TPC, Transmission Power.

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1. Introduction

In recent years, more attempts have been made to design Medical Information and Communication Technology (MICT) with high performance; that these cases are natural due to population growth and development of the human societies led to increase the number of needy people to such systems in one hand and increasing use of the portable devices such as mobile phones, tablets and Personal Digital Assistant (PDA) on the other hand [1].

MICT includes a network with high security and reliability for the collection and transfer of information related to the body's vital signs that consists of sensors which set into different parts of body and act to its obligations under the wireless communication platform. It should be noted that WBAN, is a special type of WSN that the applied sensors are heterogeneous, and their number is limited. Given that distances of sensors in WBAN is less and in most cases, it is 1 to 1.5 meters, therefore, it is necessary that certain ways must be considered in the routing of packets in the network.

Link in WBAN is always influenced by factors such as mobility of different organs, body posture, Interference, noise, and different environmental ones and also link state is determined by fading, path loss and shadowing in the WBANs [2, 3]. Therefore, considering of link state in routing protocols of sent packets in such networks is very important and so directly effect on successfully receiving of sent packet from transmitter to sink.

Energy consumption of sensors happens in both receiving and sending modes that energy consumption in receiving mode is the same for all sensors. But the energy consumption in sending mode depends on the sending type in sensors. Delay in sending of data packets in Single-Hop method is much lower than Multi-Hop method that this is due to interference forwarder between the transmitter and sink to send data packets to the destination that may lead to congestion in the network, too [4].

The collected data in sensors usually contain critical information that must be delivered in destination on time and without error. In other words, WBANs should guarantee low latency and high reliability. Each sensor in WBAN have several levels of transmission power that selecting higher levels lead to consuming more energy and selecting lower levels lead to consuming low energy. Using of fixed transmission power in sensors lead to waste energy in good state of link and low reliability in bad state of link. Therefore, it’s desirable to adopt sensors transmission power proportional to the destination distance, link quality, and such factors to have an expected performance in network.

One of the used techniques to reduce the sensors' energy consumption in sending of data packets modes is transmission power control (TPC) that different levels of sensor transmission power can be used proportional to mentioned factors. Many transmission power control protocols have been employed in WSNs. Most of them concentrated on maintaining the lowest transmission power level compatible with the acceptable link quality. Thus, they could achieve energy efficiency, high link reliability, and reduced interference. However, conventional transmission power control protocols are inappropriate for WBANs because they assume that the network is static. Therefore, transmission power control has become an emerging issue in WBANs. Several researchers have proposed transmission power control protocols for WBANs.

The recently presented articles in this context can be classified into four categories [5]:

- network-level solution
- node-level solution
- neighbor-level solution
- packet-level solution

Table 1. Radio properties of CC2420 sensor.

Row	Parameter	CC2420
1	DC Current (RX)	17.4 mA
2	DC Current (TX)	19.7 mA
3	Minimum Supply Voltage	2.1 V
4	$E_{rx-elec}$	172.8 nJ/bit
5	$E_{tx-elec}$	96.9 nJ/bit
6	E_{amp}	2.71 nJ/bit
7	Wavelength (λ)	0.15 m
8	Frequency (f)	2.4 GHz

The network-level solution uses a single fixed transmission power for all of the network sensors, whereas the node-level solution uses a different transmission power for each sensor. In the neighbor-level solution, each sensor uses different transmission powers for different neighbors. These solutions are appropriate for a constant link status, but are inappropriate for a variable link status. The packet-level solution changes the transmission power of each sensor in response to feedback information from packets. Thus, this solution is suitable for the variable link status. Because of different characteristics of WSN and WBAN there are several conventional transmission power control protocols for WBANs.

The paper is organized as follows. In the second section we introduce and discuss some articles that presented transmission power control protocols. In the third section we compare investigated methods. Finally, some conclusions are given in the fourth section.

2. Transmission Power Control in WBAN

CC2420 are one of the sensors which usually use for WBANs. It has its own characteristics in terms of hardware and power consumption which it can be seen in Table 1. Also Figure 1 depicts an instance of CC2420 sensor.

Figure 1. CC2420 sensor.

Sensor transmission power is measured by dBm unit which is usually proportional to the distance of transmitter and receiver that Table 2 shows different levels of CC2420 sensor transmission power with the sensor energy consumption at all levels of output power.

Table 2. CC2420 Transmission power levels.

Output power	DC Current Consumption
0 dBm	17.4 mA
-1 dBm	16.5 mA
-3 dBm	15.2 mA
-5 dBm	13.9 mA
-7 dBm	12.5 mA
-10 dBm	11.2 mA
-15 dBm	9.9 mA
-25 dBm	8.5 mA

Transmission power control (TPC) is related to dynamically adjust the transmission power of sensors in different types of wireless sensor networks. Transmission Power Control techniques improve the performance of the network in several aspects as [6]:

- First, Power control improves the reliability of a link. Upon detecting that link reliability is below a certain threshold, the MAC protocol increases the transmission power, improving the probability of successful data transmissions.
- Second, only nodes which really must share the same space will contend to access the medium, decreasing the amount of collisions in the network. This enhances network utilization, lowers latency times and reduces the probability of hidden and exposed terminals.
- Finally, by using a higher transmission power, the physical layer can use modulation and coding schemes with a higher bit/baud ratio, increasing the bandwidth in the presence of heavy workloads, or decreasing it to maximize energy savings.

In this paper, we review and compare 6 current techniques for transmission power control.

2.1. Link State Estimation Technique

Seung Ku Kim and Doo-Seop Eom [6] have used TPC technique for sending sensors' packets in WBAN and have done it through estimation of link state. Given that link state is determined by fading, path loss, and shadowing in the WBANs they have classified link state into three categories: stationary, body posture change, and dynamic body motion according to experimental scenarios and then they have described the distinct features of each link-state category using empirical experiments. For this purpose, they have benefited RSSI value.

Proposed protocol in this paper as LSE-TPC offers short-term and long-term estimation for link state that both of them done simultaneously. When the link state fluctuates frequently, the transmission power control protocol reflects its transition pattern rather than the momentary link state. To satisfy these requirements, they propose an LSE-TPC protocol that simultaneously estimates the link state in short and long terms.

In the short-term link-state estimation, the transceiver estimates the link state from several RSSI samples, which enables the transceiver to adapt quickly the transmission power. On the other hand, the long-term link-state estimation adjusts the target RSSI threshold range according to the degree of variation in the RSSI samples, which can enhance the link reliability in the variable link state. They argue that conventional transmission power control protocols use a fixed-target RSSI threshold range, which is enough to guarantee high reliability, but high reliability cannot be guaranteed if the link state varies frequently and abruptly, because the RSSI oscillation scale is larger than the target RSSI threshold range.

In this paper they performed an empirical experiment by adjusting the distance and the transmission power to determine the relation between the RSSI value and the PRR. In fact, proposed protocol tries to keep RSSI value between target RSSI threshold range so that leads to tradeoff between link reliability and energy efficiency. The main propose of this article is to reduce energy consumption in network sensors so that link reliability be increased. Presented protocol adapts the transmission power level on the basis of the two link-state estimation methods, resulting in lower transmission power levels and corresponding RSSIs than those observed in the other protocols. Moreover, the packet loss is lesser.

The authors argue that their presented practical approach for transmission power control and the performance of the proposed protocol was verified through empirical experiments. Therefore, they conclude that the LSE-TPC protocol can be practically deployed for WBANs.

2.2. RSSI/LQI Based Technique

Seungku Kim and colleagues in a paper [7], have considered practical transmission power control technique for optimizing the energy consumption and so they studied the parameters impact RSSI and LQI on packet reception ratio in sink through empirical experiments. The authors have used both the mentioned parameters for packet routing algorithms and sensors transmission power control in their formulas. In the paper, there are three primary contributions:

- The first contribution is a presentation of the effect of interference on a WBAN’s link based on real experimental results. The results showed that the conventional transmission power control protocols are inappropriate for a WBAN in a case where interference is present.
- As the second contribution, they propose an RSSI/LQI-based transmission power control as RL-TPC protocol. It distinguishes between the signal attenuation and interference using the RSSI and LQI. In a case where no interference exists in the link, it controls the transmission power to maintain the RSSI within the dynamically defined range. Otherwise, it changes the current channel to avoid interference.
- The last contribution is an evaluation of the performance of this RL-TPC protocol implemented on a real sensor node. They argue that the RL-TPC protocol is more energy efficient and reliable than the conventional RSSI-based transmission power control protocol.

To observe the interference effect on the RSSI, they performed a simple experiment using CC2420 sensor that supports two different transmit test modes. They measured the RSSI at the receiver under six scenarios. Each scenario is considered for 1 min. From the experimental results, they could classify the link into three states. When the channel is free from interference, the RSSI is still a useful value for identifying the signal attenuation of the link. If the RSSI is smaller than determined threshold, this indicates that the link suffers from signal attenuation, regardless of the LQI. The presence of interference can be distinguished using the LQI. The link is regarded as having no signal attenuation in a case where the RSSI is greater than or equal to determined threshold. However, because the interference degrading the link quality cannot be identified by the RSSI, they examine the LQI, which does not vary by the interference, to identify whether or not interference exists. They regard the link as suffering from interference if the LQI is smaller than the LQI threshold. Otherwise, they consider the link state to be good.

In the RL-TPC protocol, they consider the link state before the transmission power control. To determine the link state, they used the average RSSI and LQI values instead of the latest received values because of their variance. They argue that the LQI always has high variance, while the variance of the RSSI is influenced by the mobility. For performance evaluation they divided their experimental environment into two scenarios: a link without interference and one with interference. In each scenario, they performed the experiment for static, semi dynamic and dynamic cases, which caused different levels of signal attenuation. These were based on the classification method in IEEE 802.15.6.

2.3. Accelerometer-Assisted Technique

Presented protocol by Weilin Zang and et.al in an article [8], uses a method of improving WBAN energy efficiency that takes advantage of body movement, rather than regarding body movement as a nuisance. This study was motivated by two important observations. First, some human activities (e.g. walking and running) can result in varying and periodic link quality. Transmitting at the point when link quality is ideal not only reduces the transmission power but also guarantees reliability. Second, a WBAN node usually consists of several sensors that collect different signals simultaneously. Therefore, a few kinds of sensor data (e.g. motion signal, biological signals, location information) are available at the node. This provides the possibility of improving energy efficiency through data fusion from separate information sources.

In this paper, they introduce an adaptive transmission power control system for WBAN that uses human activity recognition. This system first runs a physical activity recognition algorithm to recognize whether the body is static or moving.

When the body is static, a conventional power control protocol, such as RSSI/LQI-based transmission power control (RL-TPC), is adopted and when the body is moving, they propose an accelerometer-assisted transmission power control (AA-TPC) scheme to arrange the transmission. The accelerometer is common in WBAN equipment– almost all smart watches or smart bracelets that are currently on the market are equipped with this technology. It is used in many applications, including fall detection, abnormal movement detection, step counting, energy expenditure estimation and human activity detection.

They suppose the accelerometer have been already used in such applications. Therefore, the acceleration information can help to obtain the periodic link quality information without additional costs. For AA-TPC, they first conduct experiments, with the assistance of the accelerometer, to show the channel periodicity and its correlation with body movement. Based on this correlation, they then analyze the local acceleration signal to propose an algorithm to locate the time point with the best link quality in each period to transmit packets. The specific transmission power is then determined by the feedback information from the receiver.

Finally, they evaluate the energy efficiency of AA-TPC based on a CC2420. This paper’s main contribution to the WBAN field is that the proposed scheme takes advantage of the periodic fluctuation of link quality through integration of acceleration data with RSSI values and therefore drives a stable on-body link in a fast dynamic channel scenario for TPC. To their knowledge, their scheme is the first use of data fusion of multi-sensor information for TPC in WBAN.

2.4. Energy-Efficient Adaptive Technique

Ali Hassan Sodhro and colleagues in a paper [9] proposed an energy-efficient transmission protocol with adaptive power control (APC) algorithm for adapting temporal variations in on-body wireless channel during body posture of walking. The channel is characterized with real-time data sets of two experimental scenarios, “right wrist to right hip” and “chest to right hip” in WBAN. In this algorithm transmission power is adjusted to adapt to the channel deviations then parameters are selected and optimized to enhance the performance of WBAN.

They select optimize and theoretically analyze the parameters in an appropriate manner for performance enhancement in WBAN. The proposed algorithm is run by the base station as well as the transmitter sensor nodes. For further simplification, it has been assumed that there is only an uplink data transmission.Their work basis is like most of researches, by using RSSI value and the proposed algorithm uses eight main parameters: latest or current RSSI sample, lowest RSSI sample or sample received after latest, RSSI average, RSSI target, averaging weight of good channel, averaging weight of bad channel, and global value of fixed lower threshold.

In this paper, a network as a simple and cost-effective health monitoring technology has attracted extensive attention in inter-disciplinary areas. The variable data rates from 10 kbps to 10 Mbps are used depending on the nature of the targeted application. The proposed network contains a base station (BS) and numerous on-body sensor nodes that accumulate vital-sign signals such as body temperature, blood pressure, electrocardiogram (ECG) and electroencephalogram (EEG) etc. from the human body. The accumulated data are sent to electronics health (eHealth) centers and medical hospitals via the base station.

In the proposed network, base station receives one data packet from transmitter sensor node then measures RSSI of each data packet. If RSSI of the packet is out of the RSSI target than base station responds to respective data packet after the short inter-frame space period. An acknowledgment (ACK) is communicated to increase or decrease the transmission power on request. The ACK data packet with TPC controls the transmission power of successfully transmitted data packets. They assume that feedback information is perfect, i.e. ACK packets are never lost. The transmission power is then adapted for each transmitter sensor node after getting a TPC command from base station. This process will continue up to the complete transmission of current data packets or new TPC commands are received from base station.

For performance evaluation, they were considered performance metrics such as packet loss ratio (PLR) that is defined as the ratio of total number of lost data packets to the total number of transmitted data packets (it is measured in percentage), total energy consumption that is the sum of the product of transmission power level of a node and time t, (it can be minimized with APC strategy, when transmitter sensor node transmits or base station receives packets in active state), and standard deviation are presented for the proposed algorithm. The main advantages of the proposed algorithm are to save more energy with acceptable packet loss ratio (PLR) and very low complexity in implementation of desired tradeoff between energy savings and link reliability.

2.5. PID Based Technique

In the paper [10], Tingting Guan and et.al present a closed-loop transmission power algorithm to adjust transmission power level dynamically in WBANs for energy saving and high link reliability. In their presented power assignment mechanism, the power controller is designed with the help of the concept of proportional-integral-derivative (PID) control, which is one of the most extensively used control theoretic approaches in the industry. The PID controller is by far the most common control algorithm. Most feedback loops are controlled by this algorithm or minor variations of it. Figure 2 illustrates the general structure of a PID-based control system including a PID controller and a process which is to be controlled.

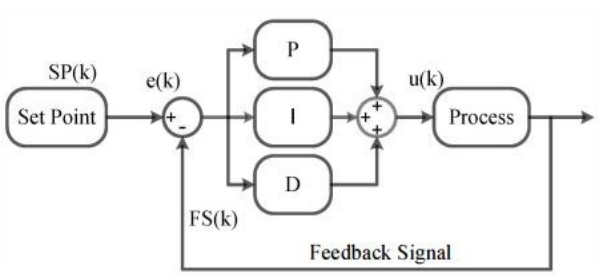

Figure 2: General structure of a PID control system

For implementing dynamic transmission power assignments, they modified mentioned structure of PID controller. As an adaptive power control scheme, it increases transmission power level in the deteriorating channel conditions, and decreases transmission power level when the channel conditions improve.

According to the variation of the on-body channel conditions, this PID-based controller is used to calculate the amount of adjustment of transmission power. In order to eliminate the oscillation caused by frequent control actions, the further modification has been examined by introducing a dead-zone into the control system. Owing to its simple structure, the presented PID-based power controller is light-weight, and thus has a low computational cost.

In this paper, three different power control schemes are evaluated and compared in terms of energy consumption, power and RSSI. To evaluate the performance of proposed transmission power control assignment mechanism by using PID-based controller, they apply this adaptive scheme to a large WBANs radio channel-gain dataset in the simulation, where real-time channel measurements is performed by transmitting test signals emanating from a VSA at 2360 MHz with transmission power level of 0 dBm. During the experiment, different body movements were defined, i.e., walking and running, with multiple small body-mounted transceivers (T_x / R_x) locating on different places of the body. We choose four links of the T_x / R_x measurements in the simulation, including two kinds of body actions (i.e., walking and running) with two sets of T_x / R_x positions defined as the following. Perfect feedback information is assumed in their simulation; in other words, acknowledgment packets are never lost.

2.6. Context-Specific Temporal Correlation Technique

Sukhumarn Archasantisuk and colleagues in a paper [11] proposed the transmission power control using the context-specific temporal correlation model. Given that the WBAN channel characteristics highly depend on the human activity, sometimes the last known channel gain information becomes outdated rapidly. Therefore, the context-specific temporal correlation model can be used to determine whether the long-term average channel gain or the last known channel gain is more accurate for determining the future condition of the WBAN channel.

In the Proposed protocol, because the long-normal distribution provides good fit for majority of links, the context-specific WBAN channel is modeled using the log-normal distribution. Instead of using the relay node, the transmit power was adjusted according to the estimated channel condition. The provided temporal correlation model was used to estimate the channel condition utilizing information of the last known channel gain.

Estimating the condition of the WBAN channel using the temporal correlation model requires two data: the last known channel gain and time passed since the last transmission. The channel gain is obtained by comparing the received power and the transmit power. Some modifications were made for the received signal strength information to be available at the sender. When any sensor node has data to transmit, it executes the power control algorithm and set the Tx output power accordingly. When the receiver receives the data, it measures the received signal strength. After that, the receiver will create an acknowledgement packet, attach the received signal strength and send it to the sender. When the sender receives the acknowledgement packet, it will extract the received signal strength, compute the channel gain and store the last channel gain value for executing the transmission power control algorithm of the next transmission.

For performance evaluation, they were considered two metrics, which are the percentage of each packet reception status and energy consumption. For packet reception they considered four types of the packet reception status: MAC buffer overflow, fail since acknowledgement is not received, transmission success in 1st try, and retransmission success (2nd try). A packet error rate was measured by the summation of the buffer overflow and the failed transmission, while a packet reception rate is the percentage of the total successful transmission. Energy consumption measured the energy consumed by the sensors in each radio activity. Table 2 provides the summary of main properties of investigated protocols.

4. Conclusion

In this paper, we reviewed and compared 6 current techniques for transmission power control, and showed that how act each technique to manage energy consumption in sender sensors and to increase reliability which is same the increasing of packet reception rate in sink, to regulate transmission power of sender sensors.

The first technique adjusts the transmission power level on the basis of the two link-state estimation methods, resulting in lower transmission power.

In the second technique, the authors classify the link into three states and in each state they regulate the transmission power of sensors based on RSSI and LQI values which indicate quality of the link.

The third technique regulates transmission power of sensors by using the accelerometers. The acceleration information helps them to obtain the periodic link quality information without additional costs.

In the fourth investigated article, the authors present an adaptive power control (APC) algorithm for adapting temporal variations in on-body wireless channel during body posture of walking. The channel is characterized with real-time data sets of two experimental scenarios in WBAN. In this algorithm transmission power is adjusted to adapt to the channel deviations then parameters are selected and optimized to enhance the performance of WBAN.

The fifth technique works based on a closed-loop transmission power algorithm to adjust transmission power level dynamically by using the power controller that is designed with the help of the concept of proportional-integral-derivative (PID) control.

In the sixth article, the transmission power control using the context-specific temporal correlation model has been presented. the context-specific temporal correlation model is used to determine whether the long-term average channel gain or the last known channel gain is more accurate for determining the future condition of the WBAN channel.

Table 2. Popular transmission power control protocols and their properties

Protocol	Main Idea	Advantage	Disadvantage
S. Kim et.al [7]	Transmission power control by short-term and long-term estimation for link state.	-Estimating the link state in short and long terms, simultaneously. -Is based on empirical experiments.	**-Less attention to network stability.**
S. Kim, and D. Eom [8]	Transmission power control by using of RSSI and LQI values.	-Relying two values, rather than a value that leads to high reliability. -Is based on empirical experiments.	**-Less attention to network stability.**
W. Zang et.al [9]	They provide an accelerometer-assisted transmission power control	Takes advantage of body movement, rather than regarding body movement as a nuisance.	**-N**etwork cost **wasn't considered.**
A. H. Sodhro et.al [10]	Managing of Transmission power control with a central base station.	Simple and cost-effective health monitoring technology.	**Base station is a bottleneck.**
T. Guan et.al [11]	Transmission power control by proportional-integral-derivative (PID) controller.	By introducing a dead-zone into the control system Examines modification that leads to high reliability.	**-Less attention to path-loss.** **-N**etwork cost **wasn't considered.**
S. Archasantisuk et.al [12]	Transmission power control by estimating the condition of the channel using the temporal correlation model	-The model is used to determine more accurate for determining the future condition. -Considers the energy consumption in transmitting mode, receiving mode, sleep mode, and state transition.	**-Less attention to path-loss.** **-Haven't good comparison with conventional protocols**

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