Comparisons of Transmission Power Control Algorithms in Wireless Body Sensor Systems

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Abstract

In wireless body sensor systems (WB-SNSs), all sensor nodes need energy-efficient techniques due to battery limitations. The transmission power control (TPC) algorithm is a representative technique to reduce energy consumption in WB-SNSs. But the sophisticated control of transmission power is very difficult because of many factors such as sensor placements and human motions. So, we must consider these factors for efficient TPC algorithms. However, previous researches in TPC algorithms have concentrated on just one or two factors in the static environment so that the effectiveness of the proposed algorithms is very limited. Therefore, in this paper, we compare previous TPC algorithms with diverse environments. We analyze the received signal strength indication (RSSI) pattern and energy consumption of representative TPC algorithms in view of the interaction of sensor placements and human motions.

Keywords: *body sensor networks, power control, closed loop system, wireless sensor network, wearable sensors*

1. Introduction

In the future development of technologies, many applications of wireless body sensor systems (WB-SNSs) will be used to help people in such areas as patient recovery and human monitoring in the real environment [1–3, 16–18]. In this environment, all sensor nodes are dynamically deployed in, on, or around a human body. So, they mostly operate with limited batteries. However, when the sensors are deployed out of the reach of humans, it is difficult to change the batteries. For this reason, we need very-low-power wireless technologies that extend the lifetime of sensor nodes. There are two representative technologies for extending the battery lifetime: medium-access control (MAC)-based sleep scheduling [4–6, 19] and transmission power control (TPC) [7–10]. Between them, we focus on TPC techniques in this paper [20].

In Wireless Sensor Networks (WSNs), TPC techniques have been widely researched as an important technology. The ultimate goal of TPC techniques is to extend the lifetime of sensor nodes using an optimal transmission power level (TPL), which ensures a balance between energy consumption and packet loss on links. However, in WB-SNSs, there are diverse factors to achieve the requirement of TPC algorithms, such as sensor placement and human motions. These factors are closely related to each other. So, we must consider these factors simultaneously for efficient TPC algorithms. However, previous researches only considered limited factors without giving careful consideration. Therefore, to analyze the relationship of various factors and prove the

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effectiveness of previously proposed TPC algorithms, we compare representative TPC algorithms with diverse factors in WB-SNSs. In this paper, we conduct real WB-SNS experiments with diverse environments and analyze the results. Then, we summarize the needs for feasible TPC algorithm in WB-SNSs [20].

2. Related Work

According to the previous studies, there are three representative TPC algorithms: linear, binary, and dynamic. The linear search algorithm [14] is the simplest search algorithm for finding a particular TPL value. This algorithm finds a desirable TPL by linearly incrementing or decrementing the current transmission power based on the RSSI values. The desirable TPL is a particular point on which the current RSSI value falls within the target RSSI margin. The binary search algorithm [15] finds a desirable TPL by exponentially increasing or decreasing the current transmission power. That is, if the current RSSI value is lower than the target RSSI margin, the next TPL is chosen to be the midpoint level between the current and the maximum possible TPL. Similarly, if it is above the target RSSI margin, the next TP level is chosen as the midpoint level between the current and minimum possible TPL. The dynamic search algorithm [13] uses the equation of a straight line for assigning the best possible TPL. This algorithm needs up to two RSSI values to make the equation. After making a new straight line equation, this algorithm finds the desirable TPL using the created equation. [20]

Most of the previous researches are based on these three TPC algorithms. However, not all of them considered the diverse link characteristics such as sensor placements and human motions in WB-SNSs [11-12]. Therefore, we need to compare the representative TPC algorithms considering these requirements. Quwaider’s research [13] is most similar to our works. His research compared the representative TPC algorithms according to body postures in a static environment. However, he does not consider human motions such as standing, walking, and running in the dynamic environment. So, we must consider both the static and the dynamic environments for appropriate TPC algorithms. Therefore, in this paper, we build a WB-SNS with commonly used motes and compare representative TPC algorithms through experiments in WB-SNS’s environment. Then, we highlight the proper TPC algorithms at each situation for energy-efficient management. In conclusion, we summarize future needs for feasible TPC algorithms in WB-SNSs.

3. Transmission Power Control

3.1. System Architecture

A large majority of sensors in WB-SNSs periodically collect various data about human vital signs such as pulse, body temperature, breathing rate, and blood pressure. Therefore, such sensors need to operate a real-time system for energy management. As shown in Figure 1, the closed loop mechanism can realize this requirement by continually communicating between the nodes of transmitters and receivers as follows. The transmitter node sends a data packet to the receiver node. Next, the receiver node measures the RSSI values of the received data packet. Then, if the measured RSSI is out of the target RSSI margin, it searches for a new TPL using a particular TPC algorithm. After, the receiver node sends a control packet including this TPL to the transmitter node. Through these steps, sensor nodes can control transmission power [20].

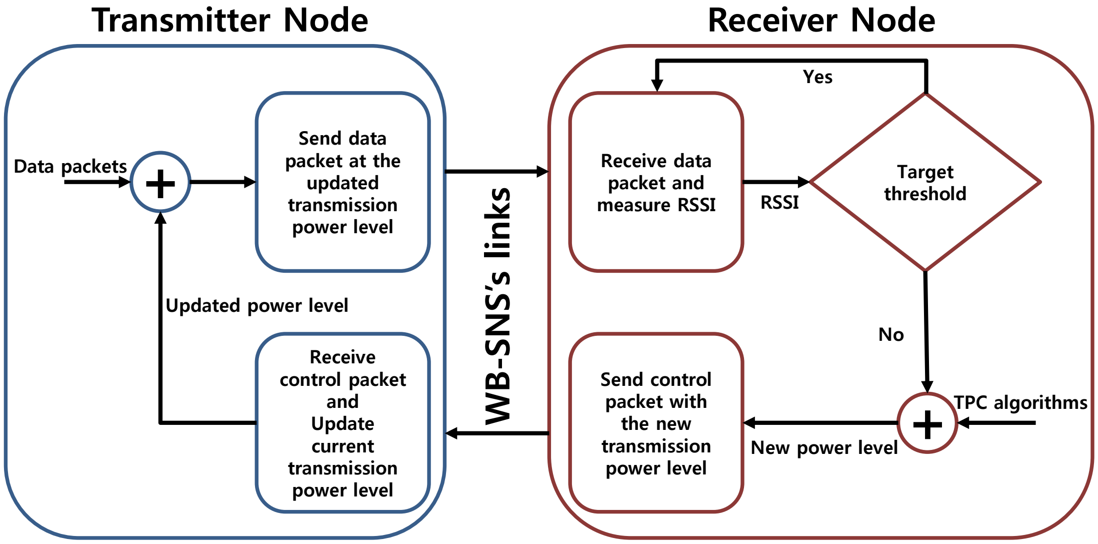

Figure 1. Closed Loop Mechanism [20]

3.2. General Transmission Power Control Model

We demonstrate a TPC model, as shown in Figure 2. In this model, the target RSSI value means the optimal TPL spot that has both a suitable packet delivery rate and energy efficiency. This point is predefined before or adjusted during system operation. A highly defined target point brings high TPL and results in energy inefficiency. Correspondingly, a low target point brings the opposite. The target RSSI margin is a range of desirable thresholds that reduces the number of TPL control packets that occur from the irregular channel environment in WB-SNSs. Its width can be adaptively controlled by system operators. However, if it is extremely large or small, the sensor system can be inefficient in energy consumption or unstable in dynamic environments [20].

In the WB-SNS environment, sensor nodes can be dynamically deployed in, on, or around a human body. Each location has different link characteristics because of varying distances and obstacles between transmitters and receivers. Sensors that are deployed on locations with many obstacles induce excessive energy consumption. On the other hand, sensors that are located in near or line-of-sight positions can induce low energy consumptions. In WB-SNSs, there are also body motions such as standing, walking, and running. Standing is a static environment with good channel characteristics. However, walking and running are dynamic environments with unstable channel characteristics. Dynamic environments induce irregular radio signal patterns. So, in this environment, it is difficult for TPC algorithms to find the desirable TPL.

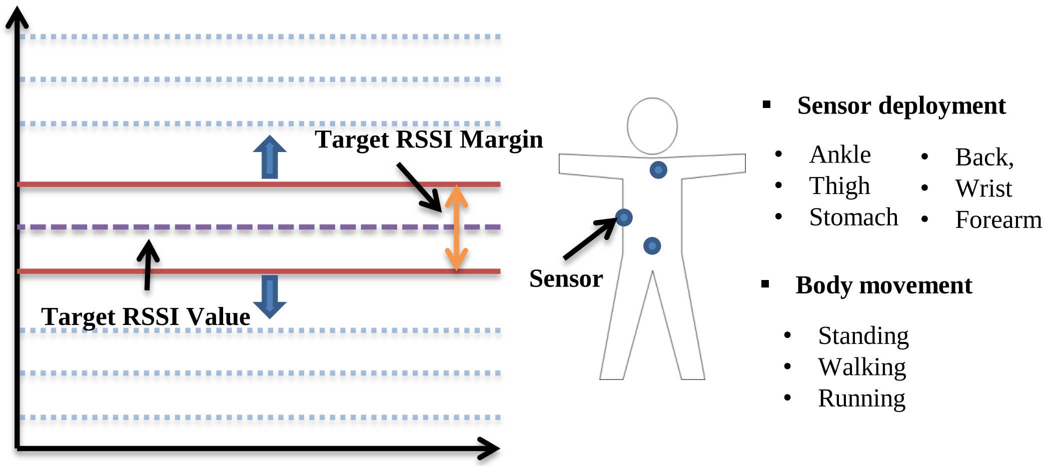

Figure 2. Transmission Power Control Model

4. Experiments

Figure 3 presents our experimental architecture and environments. Our architecture has transmitter node, receiver node, gateway node, host computer, java generator, and TPC processor. In the experiments, we store log data into the receiver node of the stomach and back on the human body for each movement, such as standing, walking, and running.

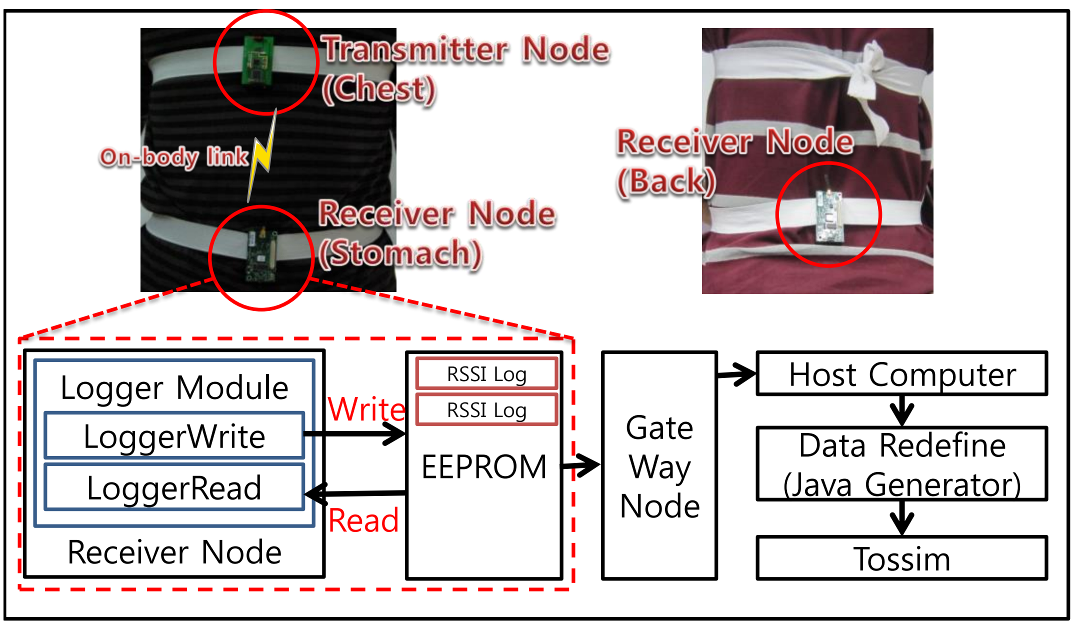

Figure 3. Experimental Architecture and Environments

After experiments, we analyze the experimental results of representative TPC algorithms, based on the RSSI values and transmission power levels (TPL). Figure 4 shows the experimental results of standing. In the graphs, the x-axis represents time lines; the left y-axis is the RSSI values and the right y-axis is the TPLs. In the graph, the red-open square indicates the RSSI, the blue solid square indicates TPLs, and the green dotted lines indicate the target RSSI margins that have max and min RSSI values. The TPL positions of graphs are closely related to the rate of power consumptions because the TPL provides an index of power consumption. In these graphs, the linear algorithm initially needs more time than binary and dynamic algorithms to find the optimal TPL within the target RSSI margins. In addition, after a packet drops, it searches a long time for a desirable TPL. So, the linear algorithm consumes more energy than the binary and the dynamic algorithms for initial setup in a static environment. Therefore, although a linear algorithm certainly finds a desirable TPL in any situations, the binary and the dynamic algorithms have greater energy efficiency than the linear algorithm in a static environment such as standing. Furthermore, we find a different average TPL depending on different sensor placements and, on stomach sensors, a phenomenon called oscillation in the binary algorithm due to high deviation.

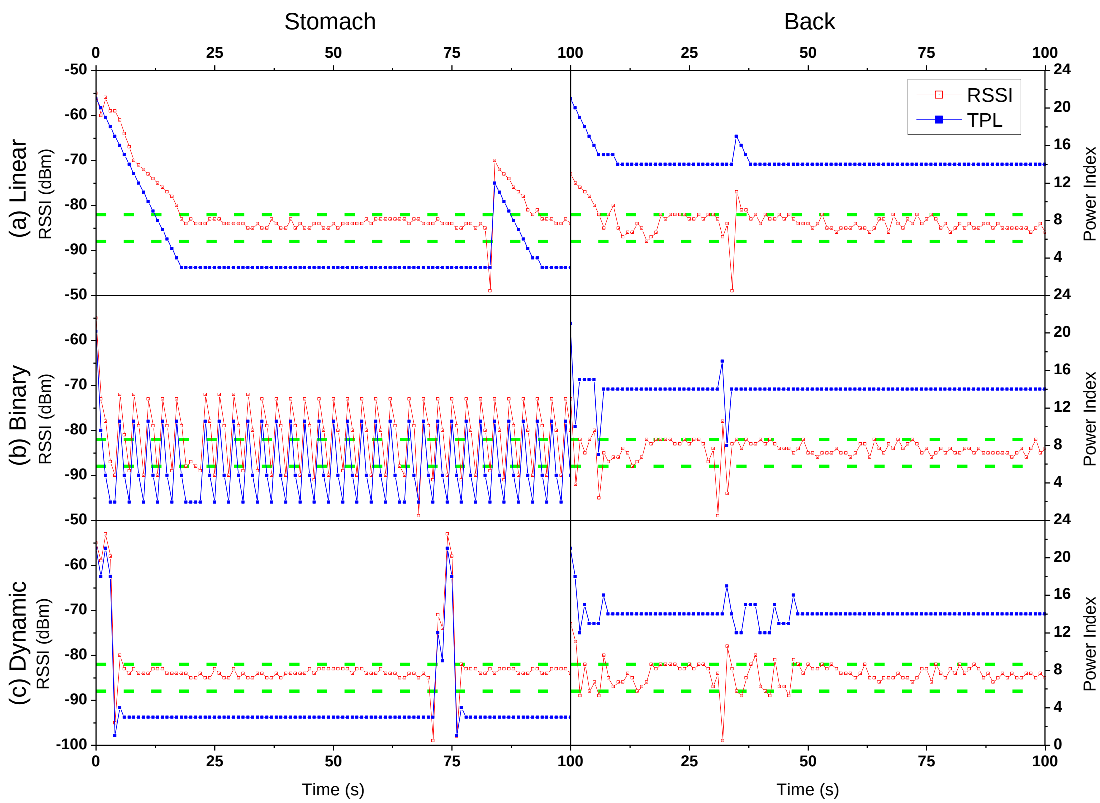

Figure 4. Experimental Results at Standing; (a) Linear, (b) Binary, and (c) Dynamic Algorithm

Figure 5 shows the experimental results of the back sensor with diverse motions, such as standing, walking, and running. In these graphs, we found that TPC algorithms have individually different RSSI patterns in different human motions. As seen in Figure 4 and Figure 5, the experimental results of standing, which reflect a static environment, show that binary and dynamic algorithms are better than the linear algorithm. On the other hand, in dynamic environments such as walking and running, the binary and the dynamic algorithms wander out of the target RSSI margins to search for a desirable

TPL. However, at this time, the linear algorithm remains stably in the vicinity of a desirable TPL without generating excessive control packets. Therefore, in a dynamic environment, the linear algorithm is better than the other algorithms. Through the above results, we know that the binary and the dynamic algorithms are better in a static environment, but the linear algorithm is better in a dynamic environment. As a result, we need a new TPC algorithm that adaptively works well in diverse environments.

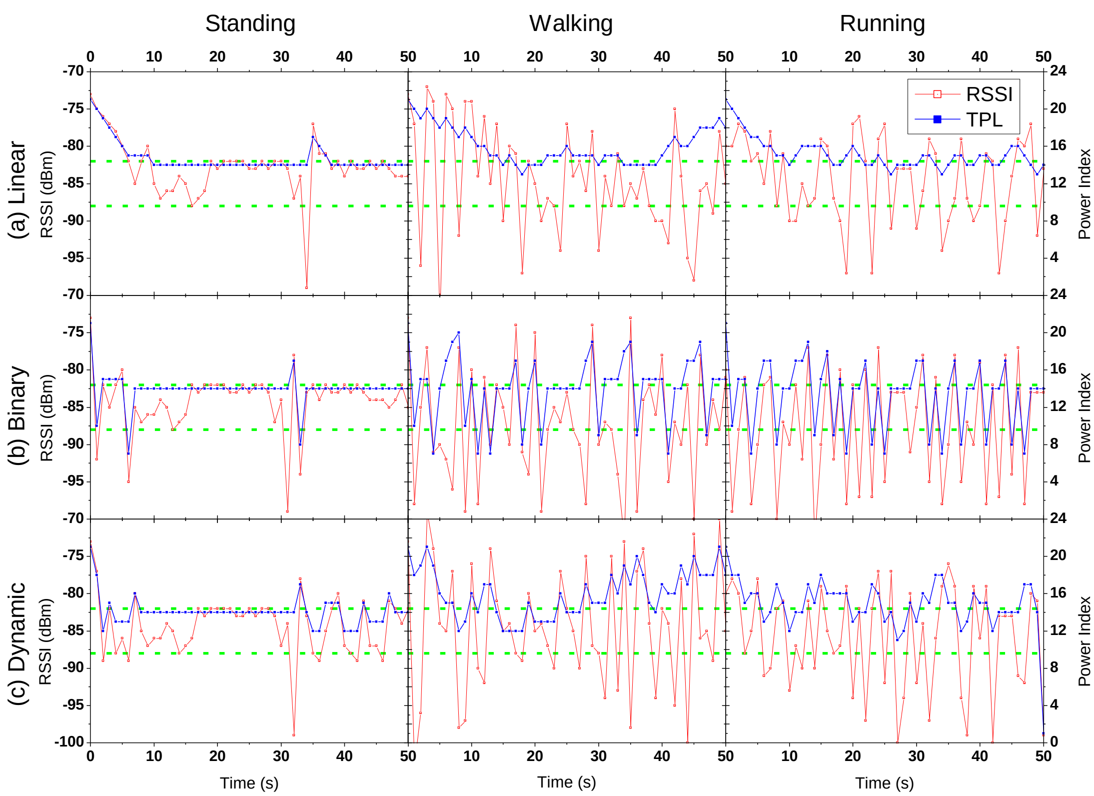

Figure 5. Experimental Results with Diverse Movements on Back Placement; (a) Linear, (b) Binary, and (c) Dynamic Algorithms

As seen in Table 1 and 2, we arrange diverse energy elements such as total energy, data energy, control energy, packet delivery rate (PDR), and control packet delivery rate (CPDR). These results are separated into human motions and sensor placements. In Table 1, we show the experimental results at two different sensor placements: stomach and back. In this table, we find the dynamic algorithm is better than the linear and the binary algorithms in placement of the stomach. At this time, although the binary algorithm is also faster, as is the dynamic, its energy efficiency is bad due to oscillation phenomenon, making it difficult for sensor nodes to find desirable TPL and to wander around the target RSSI margin. However, in back placement, the energy efficiency of the dynamic algorithm is not better than the other two algorithms. This is because a linear equation does not fit well in a bad channel with high deviations. In Table 2, we show the experimental results at each motion on the back placement. In Table 2, the energy consumption of the linear algorithm is lower than the binary and the dynamic algorithms in walking and running. Moreover, its PDR is also higher than the others. Particularly, the dynamic algorithm in this situation is very inefficient due to continually sending unnecessary control packets. Through the above analysis, we know that the linear algorithm is good in a dynamic environment, but bad in a static one. On the other hand, the binary algorithm quickly finds the desirabsle TPL in a static environment, but it sometimes causes the oscillation phenomenon to occur. Furthermore, the dynamic algorithm is better than the binary algorithm on a good channel in a static environment, but not better than the other algorithms on a bad channel with high RSSI deviations. This is because it is energy inefficient in a dynamic environment due to excessive control packets. Therefore, we can conclude that there is no TPC algorithm that performs well in all of the diverse environments.

Table 1. Performance Summary of TPC Algorithms of Standing

Algorithm	Placement	Total Energy (mJ)	Data Energy (mJ)	Control Energy (mJ)	PDR	CPDR
Linear	Stomach	35.73	26.00	9.73	98.3%	16.7%
	Back	42.39	40.24	2.15	99%	3.7%
Binary	Stomach	78.63	26.85	51.78	98.9%	88.9%
	Back	41.37	40.03	1.34	98.9%	2.3%
Dynamic	Stomach	31.22	26.56	4.66	98.1%	8%
	Back	44.70	40.97	3.73	99.1%	6.4%

Table 2. Performance Summary of TPC Algorithms on Back Sensor Placement

Algorithm	Motion	Total Energy (mJ)	Data Energy (mJ)	Control Energy (mJ)	PDR	CPDR
Linear	Standing	42.39	40.24	2.15	99%	3.7%
	Walking	79.91	43.86	36.05	98.7%	61.9%
	Running	79.80	43.52	36.28	98.9%	62.3%
Binary	Standing	41.37	40.03	1.34	98.9%	2.3%
	Walking	83.92	41.52	42.40	95.4%	72.8%
	Running	85.22	41.25	43.97	95.4%	75.5%
Dynamic	Standing	44.70	40.97	3.73	99.1%	6.4%
	Walking	148.94	72.47	76.47	97%	131.3%
	Running	153.77	73.40	80.37	96.3%	138%

4. Conclusion

In this paper, we compared representative TPC algorithms through real sensor experiments. Through the comparison, we knew that the linear algorithm is better in a dynamic environment than in a static environment. On the other hand, the binary algorithm is good in a static environment except for the regions that produce the oscillation phenomenon. Lastly, the dynamic algorithm has good energy efficiency where a linear equation can easily be made. However, in a dynamic environment, the binary and the dynamic algorithms consume excessive energy. Therefore, these analysis results indicate that the feasible TPC algorithms must consider diverse environments with various elements such as sensor placements and body motions.

For future works, we will propose a new TPC algorithm that works well in both static and dynamic environments. Then, we will consider the relationship between TPC algorithms and MAC algorithms in WB-SNSs. Lastly, we will develop a plan to merge our TPC algorithm and a new MAC algorithm.

Acknowledgements

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