# Transmission Power Control for IEEE 802.15.6 Body Area Networks

Weidong Gao, Bingli Jiao, Guiliang Yang, Wei Hu, and Jingwen Liu

*Energy consumption is an important issue in body area networks (BANs). In this letter, we propose an energy efficient transmission power control scheme for IEEE 802.15.6 BANs, which can improve energy efficiency by adaptively adjusting the transmit power in an on-demand way to adapt to varying channel environments. Simulations are performed to evaluate the performance, and it is shown that the proposed power control scheme outperforms traditional ones in terms of energy efficiency without significant reliability degradation.*

*Keywords: Body area networks, transmission power control, energy efficiency.*

## I. Introduction

With an increasing number of aged people, long-term unhealthy lifestyles and diets and such chronic diseases as heart disease, stroke, cancer, respiratory ailments, and diabetes are becoming increasingly common, which brings a great threat to residents' health. As [1] demonstrated, chronic diseases are by far the leading cause of mortality in the world, representing about 60% of all deaths. Thanks to body area network (BAN) technology, patients with chronic diseases can be monitored expediently and treated in time before life-threatening problems or events occur. Hence, BAN as a simple and cost effective health monitoring solution has attracted extensive attention in both industry and academia. Equipments used for health monitoring are usually powered by batteries and have to work continuously for a long time, and it is not convenient to recharge or replace the batteries. Therefore, BANs are significantly challenged to realize ultra-low power consumption [2]. Furthermore, ultra-low power consumption can help reduce the specific absorption rate (SAR), which is beneficial to human body safety.

Many power-efficient MAC protocols aiming at low power consumption have been proposed, mainly categorized into low-power listening (LPL) [3], scheduled contention [4], and TDMA [5] mechanisms. Except regarding low power MAC protocol designing, the IEEE 802.15.6 standard [6] was defined from macroscopic and microscopic point-of-view power management strategies for wireless BANs. Domingo [7] studied packet size optimization for BAN to improve energy efficiency. None of the aforementioned works could obtain maximum power saving as they did not specify any energy saving schemes in the wakeup period. Xiao [8] proposed a transmission power control (TPC) algorithm for body area sensor networks; however, the power adjustment range was restricted, and the energy efficiency thus could not be maximized.

As a small step toward low power consumption, in this letter, we present a low complexity and robust power control scheme for BANs, which can significantly reduce power consumption compared to traditional power control schemes without losing reliability and introducing huge signaling overhead.

## II. System Model

As illustrated in Fig. 1, we consider a one-hop star network topology composed of a single hub and multiple nodes connected to the hub. The nodes continually collect body parameters, such as body temperature, heartbeat, and

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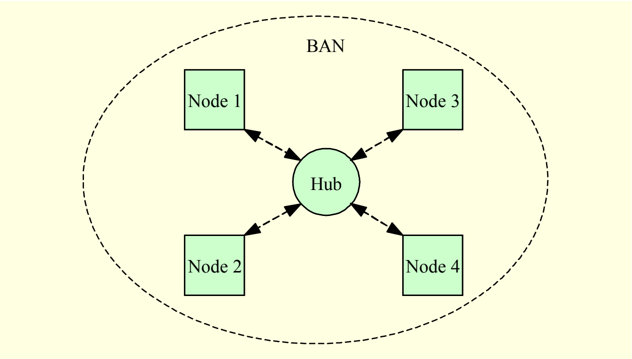

Fig. 1. Network topology.

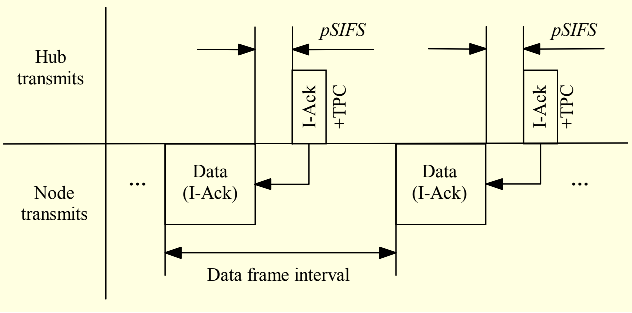

Fig. 2. Periodic data frame transmission and I-Ack.

movement, and transmit them directly to the hub. Considering that the goal of the BAN is to allow the patient equipped with health monitoring devices to move freely, the nodes are permitted to move slowly within the coverage of the hub, which results in fluctuating channel conditions.

As illustrated in Figure 2, the nodes periodically generate data frames and transmit them to the hub with the Ack policy field in the MAC header set to immediate acknowledgement (I-Ack). As regulated in the IEEE 802.15.6 standard, after the short interframe space period (*pSIFS*) to receive one data frame, the hub will send back an I-Ack frame acknowledging the corresponding data frame. The I-Ack frame may optionally contain a TPC command controlling transmission power for subsequent data frame transmissions. After receiving a TPC, the node will adjust its transmission power and transmit subsequent data frames with the updated transmission power until the whole data frame transmission is completed or new TPCs are received.

## III. Proposed Power Control Scheme

The power control algorithm can be executed by the hub as well as by the nodes. For simplicity, we assume there is only an uplink data transmission (that is, the power control algorithm is performed by the hub). First, the hub computes the average received signal strength indication (RSSI), $\overline{P}_{\mathrm{r}}$, before making any power control decisions. Assume the transmission power for the current data frame is $P_{\mathrm{t}}$ and the corresponding RSSI at the hub is $P_{\mathrm{r}}$. After receiving the data frame, the hub updates the average RSSI, $\overline{P}_{\mathrm{r}}$, according to the following formula:

$$\overline{P}_{\mathrm{r}} = P_{\mathrm{r}} + (1 - \mathit{filtercoeff}) \times \overline{P}_{\mathrm{r}}, \qquad (1)$$

where *filtercoeff* is the filter coefficient for the corresponding RSSI to mitigate the effects of instantaneous channel mutation. Thereafter, the hub compares the value of $\overline{P}_{\mathrm{r}}$ with the predetermined target reception power, $P_{\mathrm{target}}$, and then determines the power control strategies according to the comparison results.

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Algorithm 1: Power control scheme.
Require: $P_{\mathrm{r}}$ {RSSI of the current data frame}
Require: $\overline{P}_{\mathrm{r}}$ {Average RSSI}
Step 1:  If $\overline{P}_{\mathrm{r}} > P_{\mathrm{target}} + \mathit{offset}$ or $\overline{P}_{\mathrm{r}} < P_{\mathrm{target}} - \mathit{offset}$ then
Step 2:    Calculate the transmit power adjustment value as follows:
             $\Delta P = \arg\left\{ \min_{\Delta P_1, \Delta P_2, \ldots \Delta P_N} | P_{\mathrm{target}} - \overline{P}_{\mathrm{r}} - \Delta P_i | \right\}$
           s.t. $\Delta P_i > P_{\mathrm{target}} - \overline{P}_{\mathrm{r}}$
Step 3:  else {$P_{\mathrm{target}} - \mathit{offset} \le \overline{P}_{\mathrm{r}} \le P_{\mathrm{target}} + \mathit{offset}$}
Step 4:    $\Delta P = 0$
Step 5:  end if
           (The following processes are performed by the node.)
Step 6:   if $P_{\mathrm{t}} + \Delta P > P_{\max}$ then
Step 7:     $P_{\mathrm{t}} = P_{\max}$
Step 8:   else if $P_{\mathrm{t}} + \Delta P < P_{\min}$ then
Step 9:       $P_{\mathrm{t}} = P_{\min}$
Step 10:  else $P_{\mathrm{t}} = P_{\mathrm{t}} + \Delta P$
Step 11:  end if
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An additional parameter, *offset*, is introduced to reduce potential signaling overhead and the side effects due to back and forth transmission power adjustment. Assume that for each $N$ value available for selection, there exists $\Delta P_1, \Delta P_2, \ldots, \Delta P_N$, and each value represents a transmission power adjustment level and at least $\lceil \log 2(N) \rceil$ bits are needed to indicate the corresponding value included in the TPC. The pseudocode presented in Algorithm 1 depicts the implementation details of the proposed power control scheme.

The power control scheme is characterized by three parameters: $\overline{P}_{\mathrm{r}}$, $P_{\mathrm{target}}$, and *offset*. The basic idea of the power control scheme is that the transmit power is adjusted on demand (that is, the transmit power can be quickly adjusted to an appropriate level). If *offset* for $\overline{P}_{\mathrm{r}}$ is greater than *offset* for $P_{\mathrm{target}}$, the transmit power is decreased to save energy (Step 2). On the other hand, if *offset* for $\overline{P}_{\mathrm{r}}$ falls below that for $P_{\mathrm{target}}$, the transmit power is increased to improve link reliability (Step 2). At the same time, one principle of power adjustment is that some room shall be left to ensure reliable communication. For example, if the calculated power adjustment lies between 2 dB and 3 dB, then 3 dB is assigned to $\Delta P$ and the corresponding index is included in the TPC. Similarly, if the calculated power adjustment lies between –1 dB and –2 dB, then –1 dB is assigned to $\Delta P$ and the corresponding index is included in the TPC. At last, we should also ensure that the power for each transmission shall neither exceed $P_{\max}$ nor drop below $P_{\min}$.

The power control scheme depicted above is easy to implement as only small computational complexity is introduced to the hub and the nodes. Furthermore, the proposed scheme will not introduce huge signaling overhead because only a few bits are piggy-backed on the I-Ack frames.

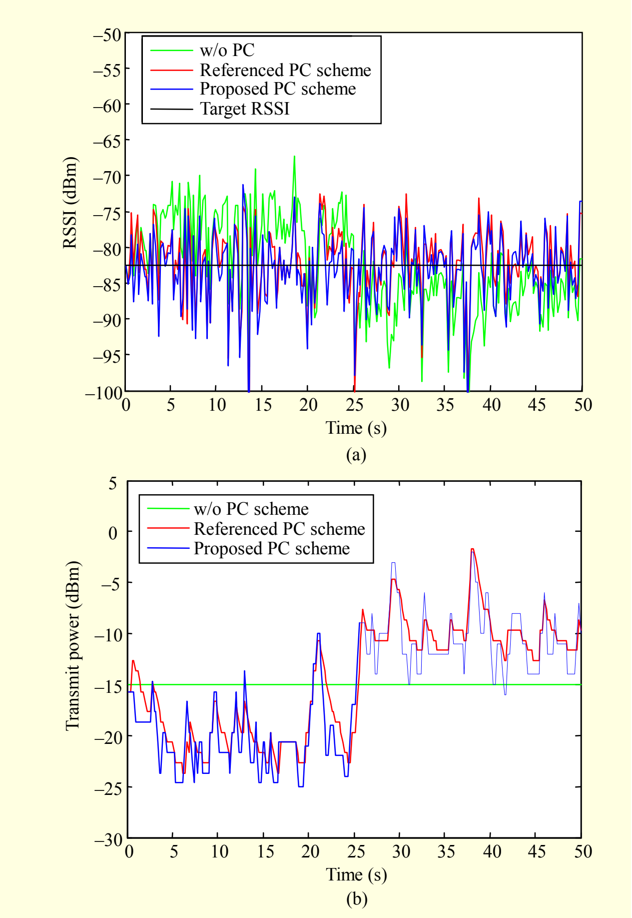
## IV. Performance Evaluation and Discussion

In this section, we evaluate the performance of the proposed power control scheme through simulations with respect to average transmission power per data packet and the standard deviation of the RSSI with the target value. The performance of the constant transmission power scheme and that of the PC scheme represented in [8] are compared. Variable channel environments are considered: during every odd 25 s, the nodes are facing toward the hub (that is, there is line of sight between each node and the hub); during every even 25 s, the nodes are facing away from the hub (that is, the line of sight is blocked). We use the narrowband channel model in [9] to generate BAN channel fading. The detailed simulation parameters are captured and shown in Table 1.

Table 1. Simulation parameters and assumption.

| Parameter | Assumption |
|---|---|
| Carrier frequency | 420 MHz |
| Channel bandwidth | 320 kHz |
| $P_{\text{target}}$ | –82.5 dBm |
| *offset* | 2.5 dB |
| $\Delta P_i$ | {–3, –2, –1, 0, 1, 2, 3, 4} dB |
| Maximum Tx power | 0 dBm |
| Minimum Tx power | –25 dBm |
| Filter coefficient | 0.8 |
| Channel model | IEEE 802.15.6 CM4 [8] |
| Noise PSD | –174 dBm/Hz |
| Noise figure | 5 dB |
| Data frame size | 100 bytes |
| Data frame interval | 200 ms |
| Data rate | 151.8 kb/s |
| Node speed | 1.5 km/h |

Figures 3(a) and 3(b) respectively show the RSSI values and the corresponding transmit power levels in the first 50 s for the three schemes: w/o PC scheme (constant transmit power), referenced PC scheme [8], and the PC scheme proposed in this letter. From the simulation results in Fig. 3(a), it is clear that the constant transmit power scheme cannot adapt to diverse channel conditions and exhibits degraded performance (either wastes energy in the case of suitable channel conditions or loses reliability in the case of poor channel conditions), whereas both PC schemes can maintain the RSSI at a relatively stable level. Furthermore, Fig. 3(b) shows that the transmit power for the proposed PC scheme is lower than that of the referenced PC scheme in most cases. The extra power reduction gain is attributed to the rapid transmit power decline when the channel condition improves.



(a)

(b)

Fig. 3. (a) RSSI and (b) transmit power for each data frame.

We adopt the sensor device lifetime (SDL) metric to quantitatively compare the energy consumption performance for the PC schemes. SDL is defined as the maximum time that the sensor can continuously work without changing or charging the battery under the given battery capacity. We are only interested in analyzing the energy consumed during transmission; the energy consumed during reception is ignored.

Table 2. Transmit power distribution for three schemes.

| Tx level | Tx power (dBm) | Ratio (%) | | |
|---|---|---|---|---|
| | | w/o PC | Referenced PC | Proposed PC |
| 0 | 0 - –6 | 0 | 1.6 | 1.6 |
| 1 | –6 - –8 | 0 | 5.2 | 3.2 |
| 2 | –8 - –10 | 0 | 10.4 | 4.4 |
| 3 | –10 - –12 | 0 | 16.4 | 10.8 |
| 4 | –12 - –14 | 0 | 12.0 | 19.6 |
| 5 | –14 - –16 | 100.0 | 4.4 | 4.4 |
| 6 | –16 - –20 | 0 | 12.0 | 15.2 |
| 7 | –20 - –25 | 0 | 38.0 | 40.8 |
| Total | | 100.0 | 100.0 | 100.0 |

So, SDL can be calculated as $SDL = N_f \times DFI$, where $N_f$ is the maximum number of data frames that can be transmitted and $DFI$ is the data frame interval (200 ms). $N_f$ can be obtained by solving the following two inequations: $UQ - \sum_{i=1}^{N_f}(P_{t_i} \cdot T) \geq 0$ and $UQ - \sum_{i=1}^{N_f+1}(P_{t_i} \cdot T) < 0$, where $U$ is the operating voltage whose value is 1.5 V, $Q$ is the battery capacity whose value is 50 mAh, $P_{t_i}$ is the transmit power for the $i$-th data frame, and $T$ is the transmit time for a single data frame. Simulation results show that the proposed PC scheme's SDL is 1,851 days, whereas the referenced PC scheme's SDL is 1,647 days (that is, about an extra 12.4% gain can be achieved by using the proposed PC scheme).

Table 2 lists the transmit power distribution for the data frames. Clearly, the transmissions made with the proposed PC scheme save more energy than those made with the referenced PC scheme. For example, 80% of the transmissions are below –12 dBm for the proposed scheme versus 66% for the referenced scheme.

Low power transmissions should not remarkably degrade the reception performance. We calculate the standard deviation of RSSIs with $P_{\text{target}}$ for the three schemes to evaluate the quantitative reception performance:

$$\sigma = \sqrt{\frac{1}{M}\sum_{i=1}^{M}\left(P_{r_i} - P_{\text{target}}\right)^2}. \qquad (2)$$

The normalized standard deviation of RSSIs with $P_{\text{target}}$ for the referenced PC scheme, the proposed PC scheme, and constant transmit power scheme is 0.78, 0.76, and 1.00, respectively. These results validate that power control can undoubtedly help converge the reception power to a steady level (that is, the target RSSI). Furthermore, the standard deviation loss for the proposed PC scheme due to a rapid transmission power adjustment is less than 3%, which will not lead to significant reception performance degradation.

## V. Conclusion

In this letter we studied a power control scheme for IEEE 802.15.6 body area networks (BANs), wherein the transmit power can be adjusted to adapt to the channel variations. We investigated the benefits of the proposed power control scheme with respect to average power consumption per data frame and standard deviation of the RSSI with the target value. Simulation results showed that a remarkable average power reduction can be achieved by adopting the proposed PC scheme; meanwhile, there is only a slight loss in standard deviation of the RSSI with the target value. Our work verified that transmission power control is an effective power saving technique to use in realistic BAN deployments.

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