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# Autocorrelation Based Transmission Power Control in WBANs

## **Abstract**

In this paper, we propose an autocorrelation-based transmission power control (A-TPC) method to increase the transmission reliability and reduce the energy consumption. In A-TPC, data packets from multiple sensor nodes are scheduled in the TDMA-fashion. The transmission power level and the slot scheduling are jointly optimized based on a temporal autocorrelation model. The channel datasets collected from real WBAN daily scenarios are imported into our simulation model to evaluate the performance of A-TPC. Simulation results demonstrate that A-TPC significantly improves the transmission reliability and reduces the energy consumption.

## **Keywords**

wbans, transmission, power, control, autocorrelation

## **Disciplines**

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# Autocorrelation Based Transmission Power Control in WBANs

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**Abstract**—In this paper, we propose an autocorrelation-based transmission power control (A-TPC) method to increase the transmission reliability and reduce the energy consumption. In A-TPC, data packets from multiple sensor nodes are scheduled in the TDMA-fashion. The transmission power level and the slot scheduling are jointly optimized based on a temporal autocorrelation model. The channel datasets collected from real WBAN daily scenarios are imported into our simulation model to evaluate the performance of A-TPC. Simulation results demonstrate that A-TPC significantly improves the transmission reliability and reduces the energy consumption.

## I. INTRODUCTION

Transmission power control (TPC) approach refers to the adaptive method which optimizes the transmission power based on the change of channel condition or QoS (Quality of Service) requirements. Due to the peculiarity of WBANs [1], simply adopting the TPC methods designed for other networks, e.g., cellular networks and WSNs (Wireless Sensor Networks), is not appropriate. Spurred by the autocorrelation characteristic of on-body channels, we propose an autocorrelation-based transmission power control (A-TPC) method which jointly optimizes the transmission power level and slot scheduling for real daily WBAN scenarios.

## II. SYSTEM MODEL

We consider a one-hop WBAN composed of  $n$  on-body sensor nodes (denoted as  $SN_1, SN_2, \dots, SN_n$ ) and one hub node, the sensor nodes periodically upload monitoring data to the hub. Figure 1 illustrates the superframe structure, which is split into two phases: Random Access Phase (RAP1) and Managed access phase (MAP). The CSMA/CA access method is adopted by the RAP1 phase to exchange management and control packets. The scheduled upload intervals (SUIs) assigned to the sensor nodes are located in the MAP to upload data packets to the hub. All sensor nodes are allocated with the same length and No Acknowledgment (N-Ack) policy is adopted in the uplink. Moreover, both the hub and the sensor nodes are considered to operate in the half-duplex mode.

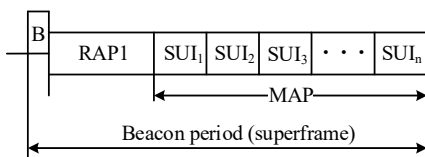


Fig. 1. Superframe structure.

Instead of utilizing the distance-based formula to quantify the path loss [2], we adopt channel gain datasets collected from the real daily scenarios. The portable wireless transceivers introduced in [3], [4] are used to collect the channel gain data. We adopt the energy consumption model in network simulator *Castalia* [5], which is one of the most accurate energy models for WBANs.

## III. THE PROPOSED TPC SCHEME

In A-TPC, all control and calculation operations are carried out on the hub side, as the hub is typically more powerful than the rest of the nodes in terms of storage and computational resources implement. Specifically, A-TPC consists of three main steps, which are summarized as follows:

### A. Channel Information Collection

Upon receiving the data packets from a sensor node, the hub node records the RSSI values. Meanwhile, the hub node knows the transmission power levels for all sensor nodes, it is easy to calculate the channel gain (or path loss) after receiving the RSSI value. By this approach, the hub keeps track of the channel gain from all sensor nodes.

### B. Channel Quality Prediction

We use a “lite version” of the temporal autocorrelation model (TAM) introduced in [6] to predict the channel quality for next superframe. The “lite version” TAM only requires the autocorrelation coefficient between two consecutive superframes. In short, the conditional distribution of channel gain in the next superframe can be expressed by:

$$G_i(S+1) \sim \mathcal{N}((1-\rho_i)\mu_i + \rho_i G_i(S), (1-\rho_i^2)\sigma_i^2) \quad (1)$$

where  $G_i(S)$  and  $G_i(S+1)$  are the channel gains of channel  $SN_i - hub$  at the superframe  $S$  and  $S+1$ , respectively.  $\rho_i$  denotes the autocorrelation coefficient for the two channel gains recorded in the two adjacent superframes. The following parameters:  $G_i(S)$ ,  $\mu_i$ ,  $\sigma_i$  and  $\rho_i$  are required by (1) to estimate the channel quality. Firstly, the latest channel gain record in the previous superframe is chosen as  $G_i(S)$ . Then, the channel gain expectation  $\mu_i$  and standard deviation  $\sigma_i$  can be estimated by the sample mean and sample standard deviation, i.e.,  $\hat{\mu}_i$  and  $\hat{\sigma}_i$ . At last, the autocorrelation coefficient  $\rho_i$  is calculated based on the following equation:

$$\rho_i = \frac{\sum_{x=1}^N (G_i(x) - \hat{\mu}_i)(G_i(x+1) - \hat{\mu}_i)}{\sum_{x=1}^N (G_i(x) - \hat{\mu}_i)^2} \quad (2)$$

where  $G_i(1) \dots G_i(N)$  are sample channel gain values recorded in  $N$  consecutive superframes, and  $N$  is the sample size.

### C. Transmission Power Control

At the beginning of each superframe, the hub calculates  $G_i(S)$ ,  $\hat{\mu}_i$ ,  $\hat{\sigma}_i$  and  $\rho_i$  for each channel. Then Algorithm 1 is carried out to decide the transmission power level and slot scheduling for the current superframe. These decisions are embedded into the beacon packet which would be broadcasted to all sensor nodes to execute the configurations.

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#### Algorithm 1: Adaptive transmission power control

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**Input:** The known channel gains in last superframe, i.e.,  $G_1(S), G_2(S), \dots, G_n(S)$ .  
**Input:** Autocorrelation coefficients between two consecutive superframe, i.e.,  $\rho_1, \rho_2, \dots, \rho_n$ .  
**Input:** Sample means, i.e.,  $\hat{\mu}_1, \hat{\mu}_2, \dots, \hat{\mu}_n$ .  
**Input:** Sample standard deviations, i.e.,  $\hat{\sigma}_1, \hat{\sigma}_2, \dots, \hat{\sigma}_n$ .  
**Output:** The transmission power levels of  $n$  sensor nodes for the current superframe, i.e.,  $TX_1(S+1), TX_2(S+1), \dots, TX_n(S+1)$ .  
**Output:** The scheduled SUI orders of  $n$  sensor nodes for the current superframe, i.e.,  $O_1(S+1), O_2(S+1), \dots, O_n(S+1)$ .

- 1 Define  
 $Txlevel = [-25, -15, -10, -7, -5, -3, -1, 0]$ ;
- 2 **for**  $i \leftarrow 1$  **to**  $n$  **do**
- 3      $\hat{G}_i(S+1) = (1 - \rho_i)\hat{\mu}_i + \rho_i G_i(S)$ ;
- 4 **end**
- 5 Sorting array  $\hat{G}_1(S+1), \hat{G}_2(S+1), \dots, \hat{G}_n(S+1)$  with the greatest in front;
- 6  $O_i(S+1) =$  the order of  $\hat{G}_i(S+1)$  in the sorted array;
- 7 **for**  $i \leftarrow 1$  **to**  $n$  **do**
- 8      $M_i(S+1) = \hat{\sigma}_i \times (BasicMargin + O_i(S+1) \times GradientMargin)$ ;
- 9      $TX_i(S+1) = \underset{x}{\text{argmin}} TxLevel[x] \geq (Rx_{sensitivity} - \hat{G}_i(S+1) + M_i(S+1))$ ;
- 10 **end**

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## IV. PERFORMANCE EVALUATION

The channel dataset collected from real WBAN scenarios is imported into the simulation model, and the dataset contains channel gains of five sensors. We compare the performance of A-TPC with the following three methods:

- 1) **Static:** The hub does not adjust the transmission power (remain 0 dBm) and the SUIs order for sensor nodes.
- 2) **Xiao's:** The method adapts the transmission power level according to the estimated average RSSI value [7].
- 3) **Ideal:** The hub controls the transmission power based on the exact channel gain value. Note that the ideal method is infeasible in real WBANs.

Figure 2 shows the performance of average packet loss ratio (PLR) when the Rx sensitivity in the hub varies. It can be seen from the figure that the PLR performance of A-TPC is close to the ideal method and much lower than the Xiao's scheme.

Figure 3 shows the energy efficiency. As shown in the figure, the energy efficiency of A-TPC is much higher than the static method and better than that of Xiao's method.

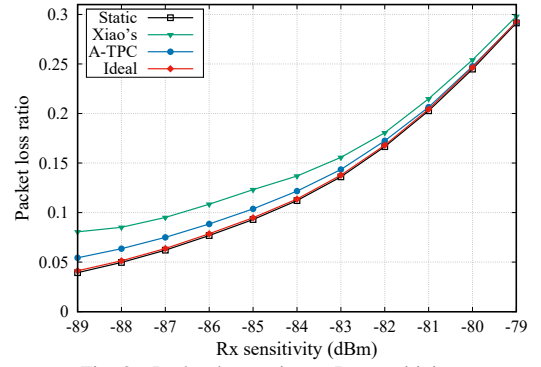


Fig. 2. Packet loss ratio vs. Rx sensitivity.

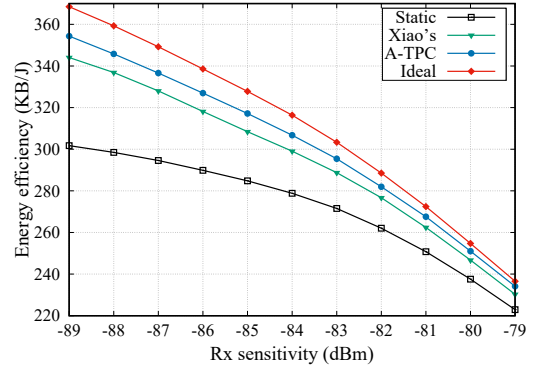


Fig. 3. Energy efficiency vs. Rx sensitivity.

## V. CONCLUSION

Motivated by the significant autocorrelation characteristic of on-body channels in the daily WBAN scenarios, we propose an autocorrelation-based transmission scheme, named A-TPC, in which transmission power control and slot scheduling are jointly optimized based on a temporal autocorrelation model. We evaluate the performance of the newly proposed scheme by importing the channel dataset collected from real WBAN daily scenarios into our simulation model. Simulation results demonstrate that compared to classical method, A-TPC achieves a better performance in terms of packet loss ratio and energy efficiency.

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