Bluetooth Low Energy-based Adaptive Scheme for IoT Services

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***Abstract*—To adapt to various IoT services, Bluetooth Low Energy (BLE) specification has defined a variety of communication modes, such as advertising, extended advertising, and periodic advertising events. As services' environments, such as the number of users and QoS requirements, are changed, modes of protocols should be also adjusted to meet those services' needs. This paper proposes an adaptive BLE scheme to reflect dynamically changing services' environments. The effectiveness of the proposed scheme is verified through simulation experiments.**

***Index Terms*—Bluetooth Low Energy, BLE, Internet of Things, IoT, Advertising Events, Adaptive Scheme**

I. Introduction

With the development of technology, various Internet of Things (IoT) services have emerged. As a communication protocol widely used in IoT services, Bluetooth Low Energy (BLE) defines three kinds of connectionless (CL) communication methods to meet different service requirements [1].

The first communication method is an Advertising Event-based solution. In this method, a BLE device named Advertiser periodically broadcasts data packets to other surrounding devices named Scanners through Advertising Event. However, only three channels can be used in one Advertising Event, so this method has weak anti-collision capabilities and is only suitable for application scenarios with a relatively small number of users [2]. The second communication method is an Extended Advertising Event-based solution. Extended Advertising Event is the extended version of basic Advertising Event. In an Extended Advertising Event, there are 37 channels that can be used to broadcast data packets. The time and channel used to broadcast the data packet will be transmitted to the scanner through Advertising Event. Compared with the packet in the Advertising Event in the first method, the size of the packet in the second method will be smaller, which will greatly reduce the probability of signal interference. Therefore, the second communication method can be used in application scenarios with more users [3]. Periodic Advertising Event is used in the third communication method. Advertisers periodically broadcast data through Periodic Advertising Event. Information such as the period, the channel map used by Periodic Advertising Event, and so on will be transmitted to the scanner through Extended Advertising Event. After obtaining the relevant information of Periodic Advertising Event, the scanner can periodically obtain the data packets from the advertiser over Periodic Advertising Event [1].

These three BLE communication methods are suitable for IoT applications of different scales. In some services, the scale of users or Quality-of-Service (QoS) requirements is constantly changing. To maintain the user experience, the communication method used should also change accordingly. However, so far almost all existing researches only focus on the performance analysis or optimization of the three Advertising Events, separately [4-12]. In this paper, we propose a scheme that can dynamically select the using communication method to adapt to the current application scenario.

The rest of the paper can be organized as follows. The processes of Advertising Event, Extended Advertising Event, and Periodic Advertising Event are described in Section II. In Section III, the proposed adaptive scheme is illustrated. The numerical results on the proposed scheme are shown in Section IV. Finally, the paper is concluded in Section V.

II. Background

The communication between scanner and advertiser is based on three kinds of advertising event. In this section, we describe the three advertising events in detail.

A. Advertising Event

Advertiser periodically generates Advertising Events [1]. Three channels (index = 37, 38, 39) are used in turn to transmit packets named ADV_IND in each Advertising Event. Data information is contained in ADV_IND. The scanner periodically scans the three channels to obtain ADV_IND as shown in Fig. 1. The period of Advertising Events, T_{AP} consists of two parameters, advertising interval T_{AI} and random delay T_{RD}. T_{AI} shall be in the range of 20 ms to 10,485.759375 s, and T_{RD} is a random value between 0 and 10 ms. The scanning period of the scanner is T_{SI}, the scanning time on each channel is defined as T_{SW}, and the scanner will fall asleep for the rest of the time, as shown in Fig. 1. It should be noted that T_{SW} cannot be greater than T_{SI}, and T_{SI} and

T_{SW} cannot be more than 40.96 s. The transmission time of an ADV_IND is marked as T_{ADV}.

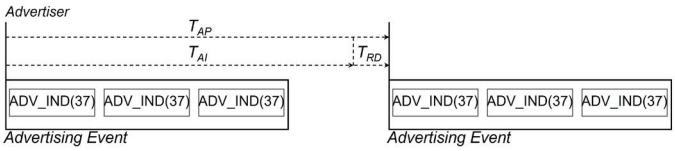

Fig. 1. Advertising Event.

B. Extended Advertising Event

There are at least one Advertising Event and a packet named AUX_ADV_IND in an Extended Advertising Event, as shown in Fig. 2. In the Advertising Event, packet named ADV_EXT_IND are transmitted instead of ADV_IND. AUX_ADV_IND is transmitted over one of 37 secondary channels (index = [0, 36]). Different from ADV_IND, ADV_EXT_IND does not contain data information, but only contains transmission information about AUX_ADV_IND, such as channel index, transmission time, and so on. AUX_ADV_IND contains data information. Scanner receives AUX_ADV_IND over the information obtained from ADV_EXT_IND [1]. The transmission time of and ADV_EXT_IND and AUX_ADV_IND are T_{EXT} and T_{AUX}.

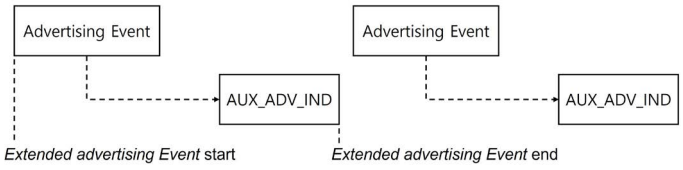

Fig. 2. Extended Advertising Event.

C. Periodic Advertising Event

In each Periodic Advertising Event, at least one packet named AUX_SYNC_IND is sent over one of the 37 channels. The data information is contained in AUX_SYNC_IND. Advertisers generate Periodic Advertising Events with a fixed periodic advertising interval T_{PAI}, as shown in Fig. 3. Periodic Advertising Event generation information, such as T_{PAI}, channel mapping, etc., will be periodically broadcast to the surrounding through Extended Advertising Event. After the scanner obtains these information, it can obtain the data by receiving AUX_SYNC_IND in each Periodic Advertising Event [1]. The Periodic Advertising Interval shall be in the range of 7.5ms to 81.91875 ms. The transmission time of AUX_SYNC_IND is marked as T_{SYNC}.

III. Bluetooth Low Energy-based Adaptive Scheme

In this paper, we assume that the number of scanner is 1, and the number of advertisers is N will vary over time. To simplify the model, we assume $T_{SI} = T_{SW} = 40.96$ ms, and $T_{RD} = 5ms$. In this section we first summarize the analytical models of the three CL communication methods, and then describe the proposed BLE-based adaptive scheme in detail.

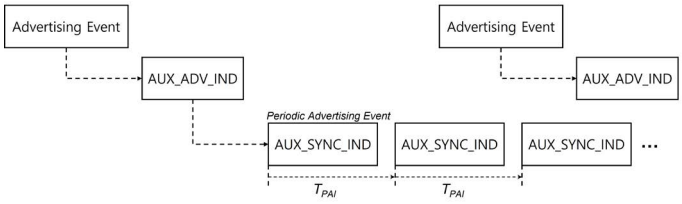

Fig. 3. Periodic Advertising Event.

A. Performance Model

The models of Advertising Event and Extended Advertising Event have been proposed in papers [4] and [5], so we will focus on the discuss of the periodic advertising event in this section.

The period of Periodic Advertising Event is T_{PAI}. In each Periodic Advertising Event, the packet AUX_SYNC_IND is transmitted. The transmission time of an AUX_SYNC_IND is T_{SYNC}, and the transmission process of AUX_SYNC_IND in Periodic Advertising Event is similar to AUX_ADV_IND. They both use 37 channels. So, the collision probability of AUX_SYNC_IND can be calculated as $\frac{2T_{SYNC}}{KT_{PAI}}$. Therefore, referring to the analysis model of extended advertising event, we can easily calculate the successful reception probability p_{succ}^{sync} and average delay of AUX_SYNC_IND T_{delay}^{sync} in Periodic Advertising Event.

B. Adaptive Scheme

In our solution, to satisfy the user experience, the communication method used should be adjusted as the user scale changes. We assume that the current number of users is n. We require that the success transmission probability is not lower than P_{succ}, and the transmission delay is not higher than T_{delay}. In this case, we first consider using the basical Advertising Event. Therefore, we need to substitute the three parameters n, P_{succ}, and T_{delay} into the analysis model of Advertising Event. Then, we can calculate the value of T_{AP}. If there is T_{AP} value that satisfies both formulas 1 and 2, then we can adjust the value of T_{AP} to meet the performance requirement. Otherwise, then we can say that the Advertising Event is not applicable to the current application scenario. In this case, we need to consider to use Extended Advertising Event. Over the same method, we can determine whether the Extended Advertising Event is suitable. If not, we will finally consider using Periodic Advertising Event.

In order to dynamically adjust the advertising event used, we need to know the number of users in the current application in real time. However, how to know the number of current users is an issue. In the paper [2], we have analyzed the relationship between the density of successfully received packets and the number of surrounding advertisers. Therefore, by measuring the number of advertisements successfully received over a period of time, we can estimate the number of current advertisers.

IV. Simulation Results

In this section, we will verify the effectiveness of the proposed scheme through the simulator described in the paper [12]. First of all, we assume that $T_{SI} = T_{SW} = 40.96$ s, T_{ADV} = 0.376 ms, T_{EXT} = 0.144 ms, T_{AUX} = 0.408 ms, T_{SYNC} = 0.408 ms, $P_{succ} = 0.9$, and $T_{delay} = 0.5$ s.

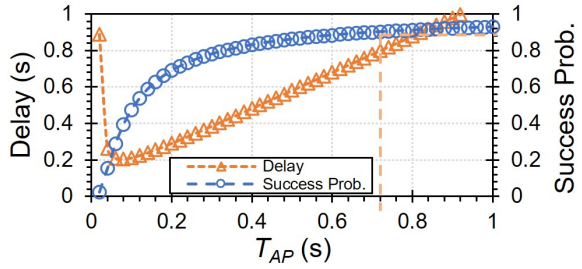

Fig. 4. Success probability and Delay of Advertising Event.

Figs. 4, 5, and 6 shows the success probability and delay of the three Advertising Events when the number of advertisers is 100. We can find that when T_{AP} is greater than 0.7 s, the success probability is greater than P_{succ}, but the delay is greater than T_{delay}, as shown in Fig. 4. Therefore, in this case, the basic Advertising Event is not suitable for current situation. In Fig. 5, we can find when the value of T_{AP} is between 0.3 s and 0.48 s, transmission success probability is greater than Psucc, and delay is less than T_{delay}. So, in this case Extended Advertising Event can be used, and T_{AP} can be set between 0.3 s and 0.48 s. As the result in [5], we know that the greater T_{AP}, the lower energy consumption. So, to save energy, T_{AP} can be set as 0.48 s. In Fig. 5, when T_{AP} is between 0.3 ms and 0.5 s, the requirements are satisfied.

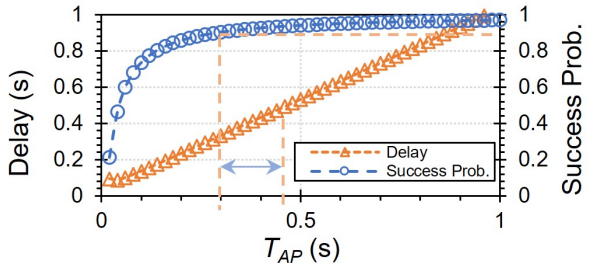

Fig. 5. Success probability and Delay of Extended Advertising Event.

Compare Figs 5 and 6, we can see both Extended Advertising Event and Periodic Advertising Event satisfy the performance requirement. However, As shown in Figs. 2 and 3, the process of Periodic Advertising Event is more complete than that of Extended Advertising Event, when means the Periodic Advertising Event may cause more energy consumption. Therefore, in this paper, we let Extended Advertising Event have greater priority than Periodic Advertising Event.

V. Conclusion

In this paper, we proposed an quick estimation scheme for the number of surrounding advertisers, and analyzed the performance of basic Advertising Event, Extended Advertising Event, and Periodic Advertising Event, respectively. Based on the estimated number of advertisers surrounding we proposed an BLE-based adaptive scheme for IoT services, which can dynamically change the using event for current application environment to satisfy the required performance.

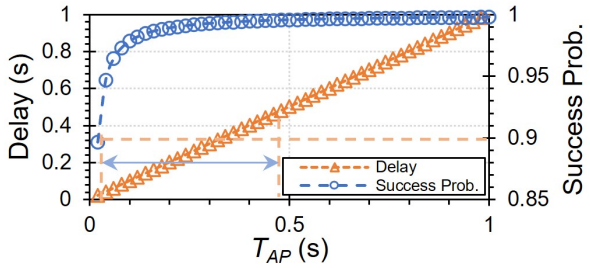

Fig. 6. Success probability and Delay of Periodic advertising Event.

Acknowledgment

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