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Performance Comparisons of Basic and Advanced Neighbor Discovery Processes in BLE 4.2 and 5.0 Specifications

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Abstract

BLE (Bluetooth Low Energy), as one of the most promising technology, has been widely adapted in various IoT (Internet of Things) services. NDP (Neighbor Discovery Process) in BLE networks plays an important role for BLE-based IoT services, which affects the scanning performance and energy consumption directly. Since basic NDP defined in BLE 4.0 specification utilizes only three channels, as the density of BLE objects increases, the possibility of signal collisions also increases and becomes very serious to the IoT services. In order to mitigate the collision probability, an advanced NDP is described in BLE 5.0 specification. In this paper, we analyze the differences between the basic and advanced neighbor discovery processes, and compare their performances by using simulation works. The simulation results show that the discovery delay of advanced NDP is shorter than half of basic NDP.

Keywords: BLE (Bluetooth Low Energy), IoT (Internet of Things), NDP (Neighbor Discovery Process), extended advertising event, BLE 4.2, BLE 5.0

INTRODUCTION

Recently, various Internet of things (IoT) services and applications are emerging, the number of devices connected to the Internet are dramatically growing [1]. To support IoT services, numerous technologies have been developed, such as radio frequency identifiers (RFID), Bluetooth Low Energy (BLE), and so on [2] [3]. With their different features, the technologies are utilized in different environments. Among those, BLE is one of the most promising technologies widely adapted for IoT services. Due to its properties of design simplicity, low power consumption, and suitable transmission range (about up to 100m), BLE has been utilized in various application areas such as indoor localization [4] [5], smart home and automation [6] [7], vehicular applications [8], and so on.

One of the most valuable functions provided by BLE specification is the neighbor discovery process (NDP). The basic NDP (B-NDP) is based on advertising events defined in BLE 4.2 specification [9]. In B-NDP, only three advertising channels are used for advertising events. When there are large number of BLE advertisers in a narrow area, the possibility of collisions of advertising signals increases seriously. The increase of collision probability impact on the NDP performances, such as long discovery delay.

The advanced NDP (A-NDP) has been defined in BLE 5.0 specification [10] recently, which is based on the extended advertising events, and allows more channels to be used for the advertising events. Since A-NDP in BLE 5.0 utilizes more flexible range of parameters for advertising events, it can mitigate the signal collision probability compared to B-NDP when massive number of BLEs are located in a certain narrow range.

Many researches have been done for the analysis of B-NDP performances. Liu et al. [11] introduced a mathematical model to analyze the average discovery delay of a certain BLE advertiser for a given number of BLE advertisers [11]. In [12], the authors analyzed the discovery performance with different BLE parameters such as scanning interval, advertising interval, and so on. However, all the existing literatures have been focus on the B-NDP. Since A-NDP has been defined in BLE 5.0 specification, very recently, there has been no works on A-NDP according to our knowledge on the literature survey.

In this paper, we analyze the different point between B-NDP and A-NDP, and compare the performances between B-NDP and A-NDP using the BLE 4.2/5.0 simulator, which has been extended from our previous works on BLE 4.2 simulator [13].

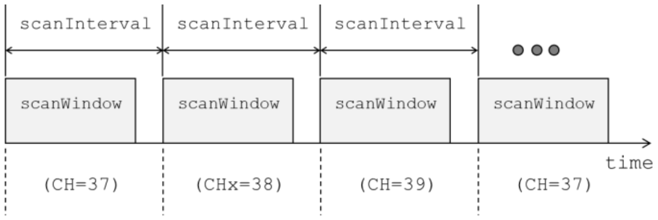
BACKGROUND

There are two types of neighbor discovery processes in BLE 4.2 and 5.0 specifications: B-NDP and A-NDP. Only B-NDP has been defined in BLE 4.2 specification, while both NDPs have been defined in BLE 5.0 specification. Though B-NDP has been included in BLE 5.0, it has different operational ranges of parameters.

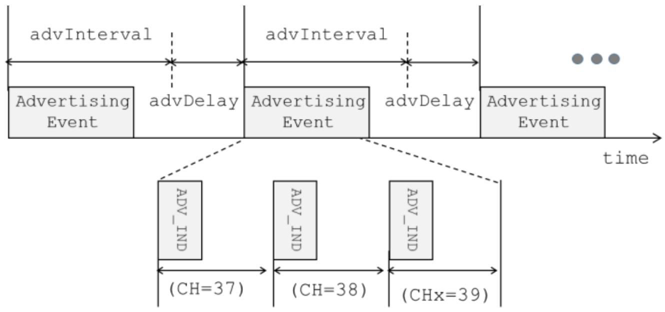
Two kinds of BLE devices are defined for both BLE basic and advanced neighbor discovery processes: scanner and advertiser. Scanner is the device to discover other BLE advertisers. Advertisers are the devices to be discovered by the scanner.

Basic NDP (B-NDP)

Figure 1 illustrates the basic neighbor discovery process for a scanner and an advertiser. As shown in Figure 1 (a), a scanner scans the advertising channels 37, 38 and 39, one by one periodically during a scanning interval (*ScanInterval*), and listens to the information from advertisers during *ScanWindow*. In BLE 4.2 specification [9], the *ScanInterval* and ScanWindow sizes are limited up to 10.24s. As shown in Figure 1 (a), ScanWindow should be less than or equal to *ScanInterval*. Two scanning modes are defined: continuous scanning mode and discontinuous scanning mode. In the continuous scanning mode, *ScanInterval* equal to *ScanWindow*, and the scanner scans each advertising channel without sleeping. On the other hand, in the discontinuous scanning mode, the scanner alternatively repeats scanning in every *ScanInterval* and sleeping for other period of *ScanInterval*. In the discontinuous scanning mode, *ScanWindow* should be shorter than *ScanInterval*.



(a) BLE scanning process



(b) BLE adverting process

Figure 1: Basic Neighbor Discovery Processes (B-NDP)

Figure 1 (b) depicts the adverting process by advertisers. Each advertiser repeats advertisement interval periodically. An advertisement interval consists of a fixed *AdvInterval* and a pseudo-random *AdvDelay*, as shown in Figure 1 (b). In an *AdvInterval*, the advertiser sends advertising packets (ADV_INDs) over each of the three advertising channels 37, 38, and 39 during *AdvEvent* period. Each ADV_PDU contains the advertising data from the advertiser. According to the BLE 4.2 specification, the *AdvInterval* should be an integer multiple of 0.625ms in the range of 20ms to 10.24s, and the *AdvDelay* should be within the range of 0ms to 10ms. In addition, an Advertisement period for each channel should be less than or equal to 10ms.

Advanced NDP (A-NDP)

Figure 2 shows the advertising process in A-NDP. In A-NDP, advertisers utilize three advertising channels, 37, 38, and 39, as same as in B-NDP, to send the advertising packets (ADV_ EXT_IND) during an *AdvEvent* Interval. Unlike in ADV_IND in B-NDP, the advertising data is not contained in ADV_EXT_IND. Instead, the advertising data is included in another packet (AUX_ADV_IND), which contains the related information about AUX_ADV_IND such as offset ($offset_{37}$, $offset_{38}$, $offset_{39}$), channel used for packet transmission (CHX), and so on. An *offset* is defined as the time difference between the starting of the ADV_ EXT_IND over channel *n* (*n*=37, 38, 39) and the starting of the AUX_ADV_IND. Owing to the offset, the scanner can know when AUX_ADV_IND would be send. For AUX_ADV_IND, one of 37 channels CHX (channel_index = 0, 1,…, 36) may be used for packet transmission. With CHX, the scanner also knows which channel would be used for the advertiser to send its AUX_ADV_IND.

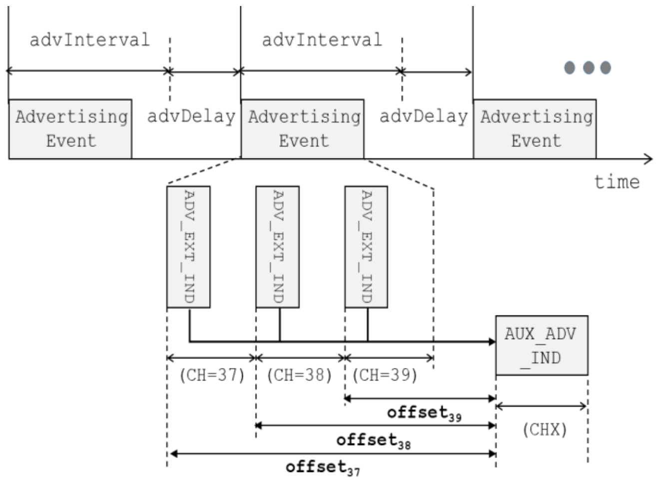


Figure 2: Advertising process in A-NDP

The scanning process in A-NDP is very similar as in Figure 1 (a) except for the followings: At the starting of scanning, the scanner scans on primary advertising channels as shown in Figure 1 (a). After the scanner received ADV_EXT_IND, the information about CHX and offset are obtained. Then, the scanner scans additionally on CHX at the time that the corresponding offset indicates. Also, AUX_ADV_IND could indicate to next following packet.

COMPARISONS OF PARAMETERS FOR B-NDP AND A-NDP OPERATIONS

The key different points between B-NDP and A-NDP are shown in Table I. As shown in Table I, the range of parameter values for *AdvInterval*, *ScanInterval*, and *ScanWindow* for A-NDP are extended from those for B-NDP.

Table I. Difference between A-NDP and B-NDP

Different point	B-NDP	A-NDP
AdvInterval	20ms~10.24s	20ms ~ 10,485.759375s
ScanInterval	<=10.24s	<=40.96s
ScanWindow	<=10.24s	<=40.96s
Tx_power	-20dBm~10dBm	127dBm~126dBm
Primary Adv. channels	37, 38, 39	37, 38, 39
Secondary Adv. channel	-	0, 1, 2, …, 36
Bit rate	1 Mb/s	125 kb/s, 500 kb/s, 1Mb/s, 2Mb/s
Message capacity	31 Bytes	255 bytes

The maximum range for *AdvInterval* for A-NDP becomes extremely larger up to 10,485.759375s than 10.24s for B-NDP. It is noted that the wider range of *AdvInterval* is, the lower the signal collision rates among advertisers are achieved. In addition, the upper values of *ScanInterval* and *ScanWindow* are increased to 40.96s for A-NDP from 10.24s for B-NDP. The wider range of *ScanInterval* and *ScanWindow* are, the lower the energy consumptions of scanner is.

In A-NDP, advertisers can use higher transmission power for the advertising events, which makes it longer transmission distance up to 4 times of that in B-NDP. This extends the transmission range four times, and larger coverage area.

A-NDP supports various transmission rates of BLE channels while only one bit rate of 1 Mbps is defined for B-NDP. It makes BLE devices to select the most suitable bit rate for different services.

The size of advertising data is extended form 31 bytes for B-NDP to 255 bytes for A-NDP, which allows more advertising data to be transmitted. Also, the advertising data can be sent in AUX_ADV_IND using 37 channels other than the primary 3 advertising channels, which makes the signal collision rate to be remitted effectively.

B-NDP utilizes only three channels, 37, 38, and 39, for advertising events. The use of the three channels may increase the probability of signal collisions seriously when the number of advertisers is very large. This leads long discovery delay.

On the other hand, A-NDP can utilize the whole 40 channels for advertising events. A-NDP manages the 40 channels divided as primary and secondary advertising channels. Three channels of 37, 38, and 39 are defined as the primary advertising channels used for the transmission of ADV_EXT_IND. The size of ADV_EXT_IND for A-NDP is very small compare to that of ADV_IND for B-NDP. With the same bit rate, the transmission time for ADV_EXT_IND is less than it for ADV_IND. In addition, the smaller packet size can mitigate the signal collisions on primary advertising channels.

Other 37 channels, whose indices are 0, 1, …, 36, are utilized as secondary advertising channels. They are used for the transmission of AUX_ADV_IND. Although the packet size of AUX_ADV_IND is big, signal collision is not serious because any of 37 available channels can be used for the packet transmission. When a scanner receives the packet ADV_EXT_IND, it can check whether there exists offset and CHX information. Then, it scans on channel CHX at the offset time that ADV_EXT_IND indicates.

PERFORMANCE EVALUATION RESULTS

We implemented the BLE 4.2 and BLE 5.0 simulator using the Riverbed modeler (formerly, OPNET) [14] for the performance evaluations of B-NDP and A-NDP. We extended our previous BLE 4.2 simulator [13], which has been implemented by using Java code, to be applied to both BLE 4.2 and 5.0 simulations by using the Riverbed modeler. Figure 3 shows the simulation architecture for BLE advertiser and scanner, which consists of upper layer, link layer, and physical layer. The upper layer includes application profiles and host part, and modeled as a simple BLE id generator. The NDP processes are implemented on the Link layer. The physical layer includes 40 channels with BLE PHY features.

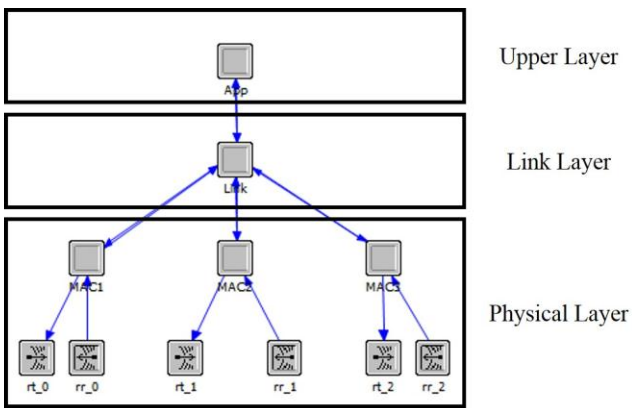


Figure 3: Simulation Architecture for BLE advertiser and scanner

For the performance evaluations, we consider there exist one scanner and given number of advertisers. One of the advertisers are marked as a tagged advertiser, and others are treated as interference resource. The parameters of A-NDP and B-NDP used for the simulations are shown in Table II. The parameter of $S_{Primary}$ is defined as the size of packet on primary channel (ADV_EXT_IND), and $S_{Secondary}$ is the size of packet on secondary channel (AUX_ADV_IND).

Table II. Experimental Parameters

Parameter	A-NDP	B-NDP
AdvInterval	1.28s	1.28s
ScanWindow	0.64s	0.64s
AdvDelay	[0, 10ms]	[0, 10ms]
$Offset_{37}$	0.05s	X
$S_{Primary}$	192 bits	376 bits
$S_{Secondary}$	360 bits	X
Bit rate	1 Mb/s	1 Mb/s

Discovery delay is the time from the tagged advertiser start advertising to it is discovered by the scanner. Figure 4 shows the discovery delay when the number of advertisers is one. In this case, interference resource is not present. The advertiser can be discovered successfully when the advertising channel matches with scanning channel. So, the discovery delay of A-NDP and B-NDP is similar. Also, when *ScanInterval* is set as some particular value such as 9s, the discovery delay is very long. This is because the packet ADV_EXT_IND is difficult to drop into *ScanWindow*, and be received in this case.

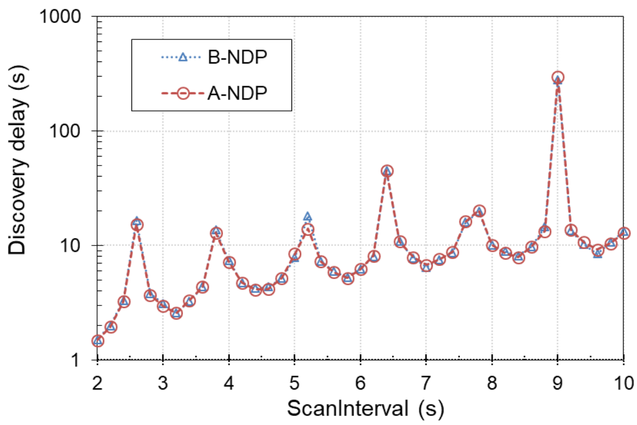


Figure 4: Discovery delay when one advertiser is present

Figure 5 shows the discovery delay with different number of advertisers. One of these advertisers is marked as tagged advertisers. At here, parameter *ScanInterval* is 3s. When the number of advertisers is few, we can find the performance of A-NDP and B-NDP are similar. With few advertisers, the signal collision rate is slight enough, and can be ignored. When the number of advertisers is more than 150, the discovery delay of B-NDP is longer than A-NDP. With the increasing of the number of advertisers, this difference is enlarged. When the number of advertisers is 2000, we can find the discovery delay of B-NDP (20s) is almost two times of A-NDP (11s).

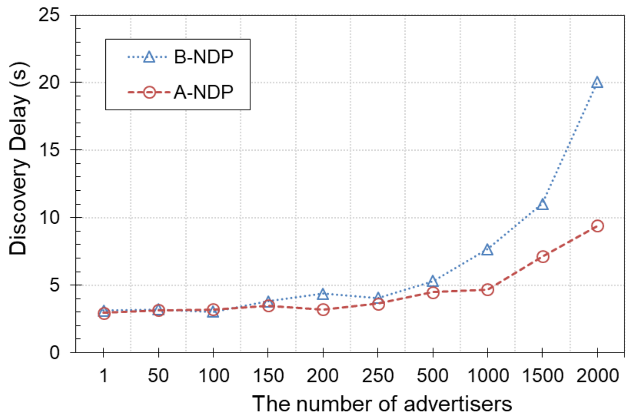


Figure 5: Discovery delay with different number of advertisers

CONCLUSION

In this paper, we analyzed the different points between the B-NDP and A-NDP described in BLE 4.2 and 5.0 specifications, respectively. As mentioned earlier, BLE 5.0 improves the NDP operations compared to BLE 4.2. To evaluate the performances of B-NDP and A-NDP, we carried out simulations using the simulator based on the Riverbed modeler. The simulation results showed that the use of A-NDP has several advantages compared to B-NDP.

The performances on NDP for BLE 4.2 specifications have been done in many other researches. However, since BLE 5.0 has been recently announced, and the devices follow the new BLE 5.0 specification has not appeared yet. Even the performance evaluation work has not been done effectively yet. This is also our first work on BLE 5.0. With the start of this work, we will do further works for more detail analysis on the BLE-based IoT services.

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