Bluetooth 5.0 协议新特性

文档编号	AN1100-0000-A0
关键字	Bluetooth, BLE, 蓝牙, PHY, 广播
摘要	蓝牙联盟于 2016-12-06 日发布最新版的蓝牙 5.0 标准，提供了与时俱进的技术更新。更加面向应用需求和 IoT 发展。本文是对官方的 bluetooth5 标准规范 core_V5.0.pdf 的初步浏览后对更新特性的摘取。

Mars4zhu

目　录

插图索引

表格索引

错误！未找到目录项。

1 概述

蓝牙联盟于 2016-12-06 日发布最新版的蓝牙 5.0 标准，提供了与时俱进的技术更新。更加面向应用需求和 IoT 发展。本文是对官方的 bluetooth5 的标准规范 core_V5.0.pdf 的初步浏览后对更新部分的摘取。

详情：

https://www.bluetooth.com/specifications/bluetooth-core-specification/bluetooth5

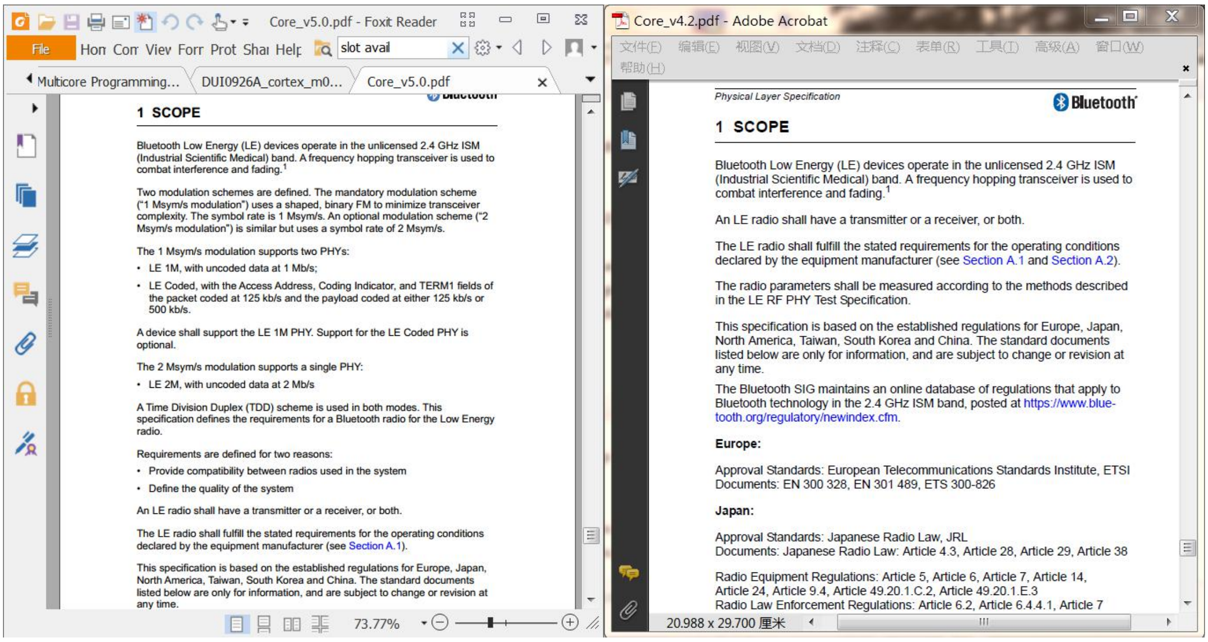

图 1-1 Core_v5.0 与 Core_v4.2 的 pdf 文件对比

1.1. 新特性

(1) 2 倍 BLE 带宽提升：在 BLE4.2 的 1Mbps 的 PHY 增加可选的 LE Coded 调制解调方式，支持 125kbps 和 500kbps，同时增加一个可选的 2Mbps 的 PHY。

(2) 4 倍通讯距离提升：通过上述降低带宽提升通讯距离同时保持功耗不变。而且允许的最大输出功率从之前的 10mW 提升至 100mW。

(3) 8 倍广播数据容量提升：从 BLE4.2 的 31 字节提升至 255 字节，并且可以将原来的 3 个广播通道扩展到 37 个广播通道。增加通道选择算法#2。

(4) BR/EDR（传统蓝牙）时间槽可用掩码：检测可用的发送接收的时间槽并通知其他蓝牙设备。

1.3 [VOLS 2, 3, 5, 6 & 7] CORE SYSTEM PACKAGE

Rev	Date	Comments
5.0	Dec 06 2016	• New features added in 5.0: - CSA 5 features (Higher Output Power) - Slot Availability Mask (SAM) - 2 Msym/s PHY for LE - LE Long Range - High Duty Cycle Non-Connectable Advertising - LE Advertising Extensions - LE Channel Selection Algorithm #2 • Park State was deprecated and removed • Errata for v2.0 + EDR, v2.1 + EDR, v3.0 + HS + 4.0 + 4.1 + 4.2 (ESR09, ESR10 and ESR11). See also [Vol 1] Part C, Section 9.4.

图 1-2 5.0 更新简要注释

9 CHANGES FROM v4.2 TO 5.0

9.1 NEW FEATURES

Several new features are introduced in the Bluetooth Core Specification 5.0 Release. The major areas of improvement are:

- Slot Availability Mask (SAM)
- 2 Msym/s PHY for LE
- LE Long Range
- High Duty Cycle Non-Connectable Advertising
- LE Advertising Extensions
- LE Channel Selection Algorithm #2

9.1.1 Features Added in CSA5 - Integrated in v5.0

- Higher Output Power

9.2 DEPRECATED FEATURES

The following features were removed in this version of the specification:

- Park State

9.3 PRIVACY ERRATA

The Privacy errata shown in the table below have been resolved and integrated in this version of the specification.

图 1-3 5.0 更新进一步说明注释

1.2. 期待中的新特性依然不见踪影：

(1) Mesh 网格。扩展的广播数据包最多可包含 255 字节，提供了对组网转发的物

理层基础但是上层规范依然未定义。MESH 网络目前只能各家自定义，百花齐放不兼容导致一盘散沙，打不开物联网的大门。BLE 的 Mesh 组网注定还是各家的”创新“技术，但预计 2017-2018 年左右会推出关芳芳统一标准。

(2) BLE 音频功能。Audio-Over-BLE 似乎不会进入官方标准，各家实现或者采用双模蓝牙。

2 BLE 的物理层 PHY 更新

2.1. 增加 LE Coded 模式和 LE 2M PHY

Two modulation schemes are defined. The mandatory modulation scheme (“1 Msym/s modulation”) uses a shaped, binary FM to minimize transceiver complexity. The symbol rate is 1 Msym/s. An optional modulation scheme (“2 Msym/s modulation”) is similar but uses a symbol rate of 2 Msym/s.

The 1 Msym/s modulation supports two PHYs:

- LE 1M, with uncoded data at 1 Mb/s;
- LE Coded, with the Access Address, Coding Indicator, and TERM1 fields of the packet coded at 125 kb/s and the payload coded at either 125 kb/s or 500 kb/s.

A device shall support the LE 1M PHY. Support for the LE Coded PHY is optional.

The 2 Msym/s modulation supports a single PHY:

- LE 2M, with uncoded data at 2 Mb/s

图 2-1 5.0 的 PHY 更新

2.1.1 参考信号精度要求依然是 0.5%。

4.6 REFERENCE SIGNAL DEFINITION

The reference signal for LE is defined as:

Modulation = GFSK

Modulation index = 0.5 ± 1% for standard modulation index, 0.5 ± 0.5% for stable modulation index

BT = 0.5 ± 1%

Data Bit Rate =

- 1 Mb/s ±1 ppm for the LE 1M PHY
- 2 Mb/s ±1 ppm for the LE 2M PHY
- 125 kb/s ±1 ppm for the LE Coded PHY when using S=8 coding
- 500 kb/s ±1 ppm for the LE Coded PHY when using S=2 coding

Modulating Data for wanted signal = PRBS9

Modulating Data for interfering signal = PRBS15

Frequency accuracy better than ±1 ppm

图 2-2 5.0 的参考信号更新

2.2. 最大传输功率提升至 100mW。

For a transmitter, the output power level at the maximum power setting shall be within the limits defined in Table 3.1.

Minimum Output Power	Maximum Output Power
0.01 mW (-20 dBm)	100 mW (+20 dBm)

Table 3.1: Transmission power

Devices shall not exceed the maximum allowed transmit power levels set by the regulatory bodies that have jurisdiction over the locales in which the device is to be sold or intended to operate. Implementers should be aware that the maximum transmit power level permitted under a given set of regulations might not be the same for all modulation modes.

Note: The maximum output power for LE in v4.0, v4.1, and v4.2 is 10 mW.

图 2-3 5.0 的最大输出功率更新

2.2.1 同时提出对输出功率的分级。

Bluetooth devices may be informatively classified into power classes based on the highest output power the LE PHY supports, as defined in Table 3.2.

Power Class	Maximum Output Power (P_{max})	Minimum Output Power[1]
1	100 mW (+20 dBm)	10 mW (+10 dBm)
1.5	10 mW (+10 dBm)	0.01 mW (-20 dBm)
2	2.5 mW (+4 dBm)	0.01 mW (-20 dBm)
3	1 mW (0 dBm)	0.01 mW (-20 dBm)

Table 3.2: LE PHY power classes

图 2-4 5.0 的功率分级

3 BLE 广播通道的更新

3.1. 可以将原来的 37 个数据通道演变为第二广播通道

RF Channel	RF Center Frequency	Channel Index	Channel Type		
			Data	Primary Advertising	Secondary Advertising
0	2402 MHz	37		•	
1	2404 MHz	0	•		•
2	2406 MHz	1	•		•
...	...	...	...	...	...
11	2424 MHz	10	•		•
12	2426 MHz	38		•	
13	2428 MHz	11	•		•
14	2430 MHz	12	•		•
...	...	...	...	...	...
38	2478 MHz	36	•		•
39	2480 MHz	39		•	

Table 1.2: Mapping of PHY Channel to Channel Index and Channel Type

图 3-1 5.0 的广播通道更新

3.2. 通道选择算法在原有的#1 算法上增加#2 算法。

3.2.1 #1 算法

4.5.8.2 Channel Selection Algorithm #1

Channel Selection Algorithm #1 only supports channel selection for connection events.

Channel Selection Algorithm #1 consists of two stages: calculation of the unmapped channel index followed by mapping this index to a data channel index from the set of *used channels*.

The *unmappedChannel* and *lastUnmappedChannel* are the unmapped channel indices of two consecutive connection events. The *unmappedChannel* is the unmapped channel index for the current connection event. The *lastUnmappedChannel* is the unmapped channel index of the previous connection event. The *lastUnmappedChannel* shall be 0 for the first connection event of a connection.

At the start of a connection event, *unmappedChannel* shall be calculated using the following basic algorithm:

unmappedChannel = (*lastUnmappedChannel* + *hopIncrement*) mod 37

图 3-2 5.0 的通道选择#1 算法（1）

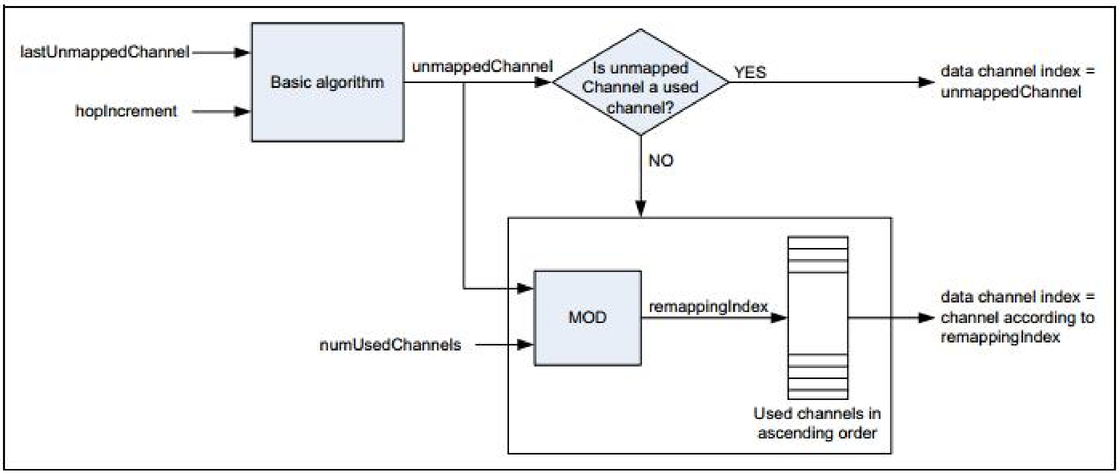

Figure 4.32: Block diagram of data Channel Selection Algorithm #1

图 3-3 5.0 的通道选择#1 算法（2）

3.2.2 #2 算法

The algorithm makes use of the following inputs and basic components:

- The 6-bit input *N* is the number of channels classified as *Used* channels.
- The 16-bit input *channelIdentifier* is fixed for any given connection or periodic advertising; it is calculated from the Access Address by:
  channelIdentifier = (Access $Address_{31-16}$) XOR (Access $Address_{15-0}$)
- The 16-bit input *counter* changes for each event. For data connections it is the connection event counter *connEventCounter* defined in Section 4.5.1. For periodic advertising it is the event counter *paEventCounter* defined in Section 4.4.3.4.

The "XOR" operation always refers to a 16-bit bit-wise XOR.

The symbol $\lfloor\ \rfloor$ is used to represent the floor function (the greatest integer less than or equal to the argument).

The permutation operation consists of separately bit-reversing the lower 8 input bits and upper 8 input bits, as illustrated in Figure 4.34.

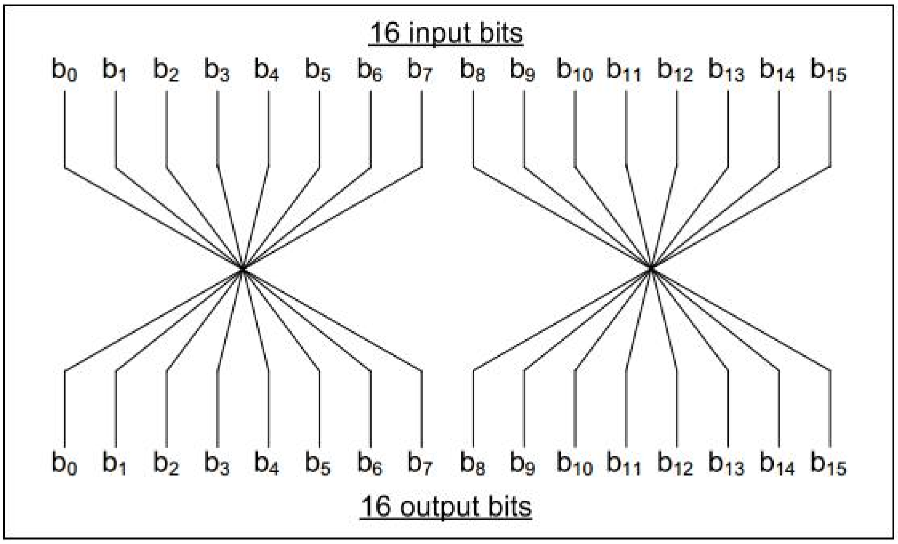

Figure 4.34: Permutation operation

图 3-4 5.0 的通道选择#2 算法（1）

The Multiply, Add, and Modulo (MAM) block performs a multiplication operation, an addition operation, and a modulo operation, as illustrated in Figure 4.35.

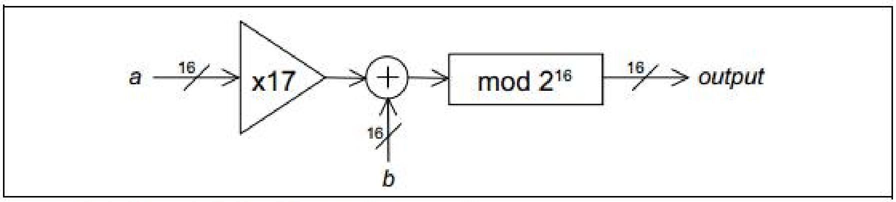

Figure 4.35: Multiply, Add, and Modulo block operation

The output of the MAM operation, given inputs *a* and *b*, is:

$$output = (17 \times a + b) \bmod 2^{16}$$

A *remapping table* is built that contains all the *used channels* in ascending order, indexed from zero.

图 3-5 5.0 的通道选择#2 算法（2）

4.5.8.3.3 Unmapped Event Channel Selection

The unmapped event channel selection process consists of two stages. First, the unsigned pseudo-random number *prn_e* is generated, after which the unmapped channel index *unmappedChannel* is derived from *prn_e*.

The first stage shall be as shown in Figure 4.36.

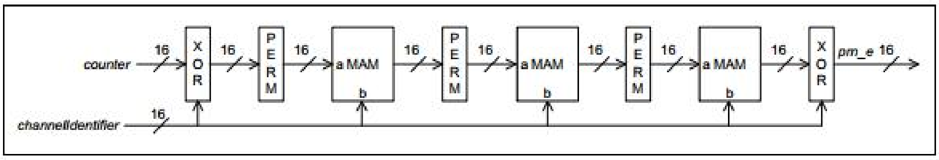

Figure 4.36: Event pseudo-random number generation

unmappedChannel is then calculated as *prn_e* modulo 37. A block diagram of the overall process is shown in Figure 4.37.

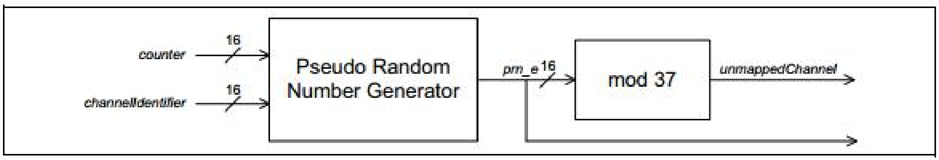

Figure 4.37: Unmapped channel selection process

图 3-6 5.0 的通道选择#2 算法（3）

4.5.8.3.4 Event Mapping to Used Channel Index

If *unmappedChannel* is the channel index of a *used channel* according to the channel map, it is used as the channel index for the event. If *unmappedChannel* is the index of an *unused channel* according to the channel map, then the channel index for the event is calculated from *prn_e* and *N* (the number of used channels) by first calculating the value *remappingIndex* as:

$$remappingindex = \left\lfloor \left(\frac{N * prn\_e}{2^{16}} \right) \right\rfloor$$

and then using *remappingIndex* as an index into the remapping table to obtain the channel index for the event.

The overall process is illustrated in Figure 4.38.

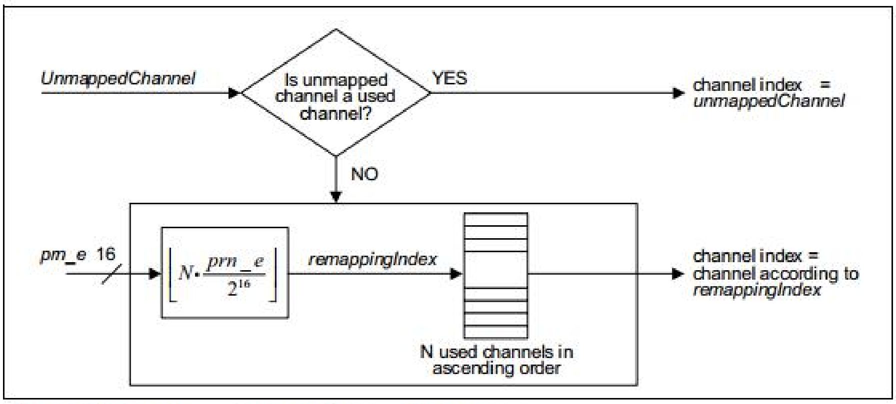

Figure 4.38: Event mapping to used channel index process

图 3-7 5.0 的通道选择#2 算法（4）

4 BLE 广播数据相关更新

4.1. 广播数据包提升至 255 字节。

2.3 ADVERTISING CHANNEL PDU

The advertising channel PDU has a 16-bit header and a variable size payload. Its format is as shown in Figure 2.4. The 16-bit Header field of the advertising channel PDU is as shown in Figure 2.5.

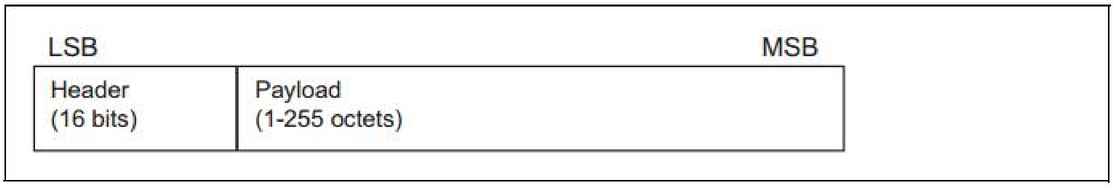

Figure 2.4: Advertising channel PDU

图 4-1 5.0 的广播通道 PDU 定义

4.2. 广播数据包类型增加。

LSB					MSB
PDU Type (4 bits)	RFU (1 bit)	ChSel (1 bit)	TxAdd (1 bit)	RxAdd (1 bit)	Length (8 bits)

Figure 2.5: Advertising channel PDU Header

The PDU Type field of the advertising channel PDU that is contained in the header indicates the PDU type as defined in Table 2.3. This table also shows which channel and which PHYs the packet may appear on.

PDU Type	PDU Name	Channel	Permitted PHYs		
			LE 1M	LE 2M	LE Coded
0000b	ADV_IND	Primary Advertising	•		
0001b	ADV_DIRECT_IND	Primary Advertising	•		
0010b	ADV_NONCONN_IND	Primary Advertising	•		
0011b	SCAN_REQ	Primary Advertising	•		
	AUX_SCAN_REQ	Secondary Advertising	•	•	•
0100b	SCAN_RSP	Primary Advertising	•		
0101b	CONNECT_IND	Primary Advertising	•		
	AUX_CONNECT_REQ	Secondary Advertising	•	•	•
0110b	ADV_SCAN_IND	Primary Advertising	•		

Table 2.3: Advertising channel PDU Header's PDU Type field encoding

图 4-2 5.0 的广播数据包类型定义

4.3. 广播数据包的 PHY 层对应。

PDU Type	PDU Name	Channel	Permitted PHYs		
			LE 1M	LE 2M	LE Coded
0111b	ADV_EXT_IND	Primary Advertising	•		•
	AUX_ADV_IND	Secondary Advertising	•	•	•
	AUX_SCAN_RSP	Secondary Advertising	•	•	•
	AUX_SYNC_IND	Secondary Advertising	•	•	•
	AUX_CHAIN_IND	Secondary Advertising	•	•	•
1000b	AUX_CONNECT_RSP	Secondary Advertising	•	•	•
All other values	Reserved for Future Use				

Table 2.3: Advertising channel PDU Header's PDU Type field encoding

图 4-3 5.0 的广播数据包与 PHY 层通道

5 BR/EDR（传统蓝牙）提供时间槽可用掩码。

8.6.11 Slot Availability Mask (SAM)

Slot Availability Mask (SAM) allows two Bluetooth devices to indicate to each other the availability of their time slots for transmission and reception. From the baseband point of view, SAM provides a map - the SAM slot map - which marks the availability of Bluetooth slots. The availability arises from either external conditions (e.g., MWS coexistence) or internal conditions (e.g., topology management for scatternets). The SAM slot map marks each slot using one of four type codes defined in [Vol 2] Part C, Section 5.2 and repeated for convenience in Table 8.7.

Slot type code	Meaning
0	The slot is not available for either transmission or reception
1	The slot is available for transmission but not reception
2	The slot is available for reception but not transmission
3	The slot is available for both transmission and reception

Table 8.7: SAM Slot Types

Note: A master may mark master-to-slave slots available for reception and slave-to-master slots available for transmission, because such slots may be used in this way for multi-slot packets; similarly for a slave. A SAM slot map with all slots set to type 3 is equivalent to not using SAM and simply performing normal scheduling.

Figure 8.16 shows an example of a SAM slot map. The master-to-slave slots are labeled with the letter 'M' and slave-to-master slots with the letter 'S'.

Bluetooth Slot	M	S	M	S	M	S	M		M	S	M	S
Can Transmit	×	×	✓	✓	✓	×	×		✓	✓	✓	×
Can Receive	✓	×	×	×	×	✓	✓		✓	✓	✓	✓
Type Code	2	0	1	1	1	2	2		3	3	3	2

Figure 8.16: An example of a SAM slot map

图 5-1 5.0 的 SAM 定义

6 版本历史（Revision History）

版本号	发布时间	内容
A0	2016-10-08	初次编写