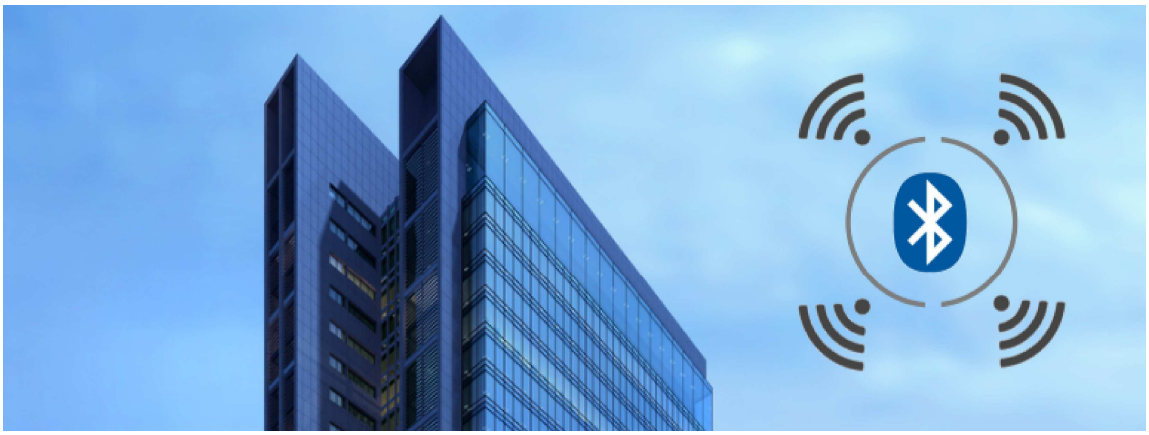

# A BLE Advertising Primer

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BLE Advertising is one of the most important aspects of Bluetooth Low Energy. Understanding how to properly use advertisements can help you lower your power consumption, speed up your connections, and improve reliability. We're going to go over how they work and how to use them.

Bluetooth Smart has two ways of communicating. The first one is using advertisements, where a BLE peripheral device broadcasts packets to every device around it. The receiving device can then act on this information or connect to receive more information. The second way to communicate is to receive packets using a connection, where both the peripheral and central send packets. We will focus on advertisement for several reasons:

- You can't create a connection between two devices without using advertisements. Defining the data and format of advertisement packets is usually the first thing you work on when developing a BLE device.
- A large number of BLE products sleep most of the time, waking up only to advertise and connect when needed. This means advertisements have a big impact on power consumption.
- Users want responsive products, and the advertising interval is critical in quick connections.

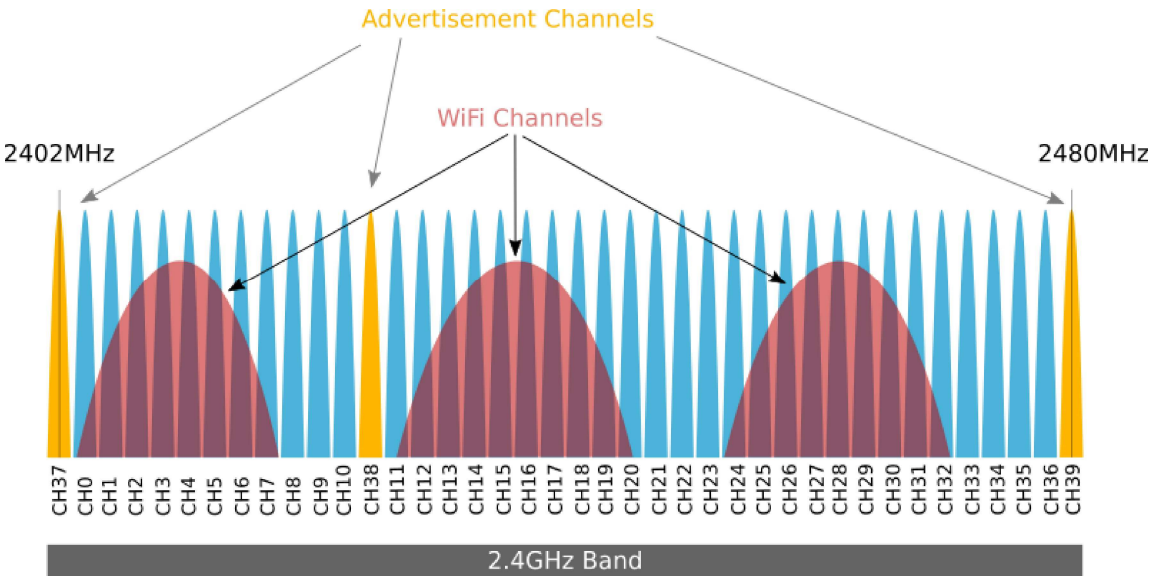
Advertising is by design unidirectional. A **Central** device can't send any data to the Peripheral device without a connection. But a single peripheral can advertise to multiple masters in the area.

# BLE Physical Layer

Before we get into how advertisement packets are sent, we want to talk a little about the BLE physical layer. The physical layer is in charge of actually sending the signals over the air. This includes the actual RF radio.

Bluetooth Low Energy shares some similarities with Classic Bluetooth. Both use the 2.4GHz spectrum. Basic Rate (BR) and BLE both use GFSK modulation at 1Mbps, but their modulation index is different. Enhanced Data Rate (EDR) uses a completely different modulation than GFSK. Classic Bluetooth has 79 channels compared to LE's 40 channels. The channels are also spaced differently. Both of these differences make LE and Classic different and incompatible, so they can't communicate. Dual Mode Radios, like the CC256x, support LE and Classic by switching their modulation parameters and the channels on which they're running.

</p> < p>BLEClassicBLEBREDRModulationGFSK 0.45 to 0.55GFSK 0.28 to 0.35DQPSK / 8DSPKData Rate1Mbit/s1 Mbit/s2 and 3 Mbit/sChannels407979Spacing2MHz1MHz-</p> < p>




The 2.4GHz spectrum for Bluetooth extends from 2402MHz to 2480MHz. LE uses 40 1MHz wide channels, numbered 0 to 39. Each is separated by 2MHz.

Channels 37, 38, and 39 are used only for sending advertisement packets. The rest are used for data exchange during a connection. We're interested in what's happening in these 3 channels, and that's what we'll cover here.

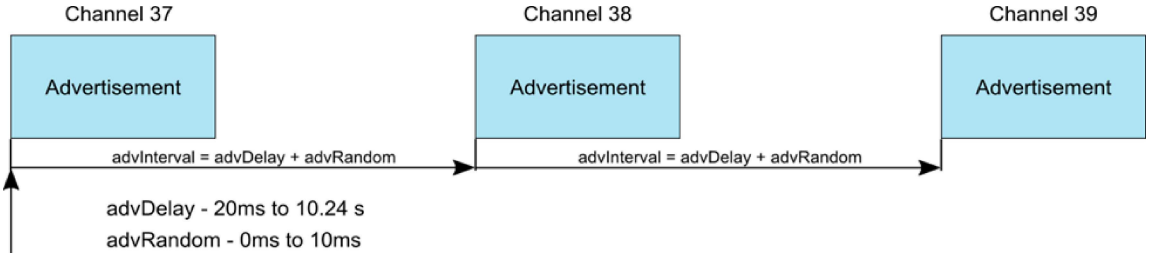
During BLE advertisement, a BLE Peripheral device transmits packets on the 3 advertising channels one after the other. A Central device scanning for devices or beacons will listen to those channels for the advertising packets, which helps it discover devices nearby.

Channels 37, 38 and 39 are spread across the 2.4GHz spectrum on purpose. 37 and 39 are the first and last channels in the band, while 38 is in the middle. If any single advertising channel is blocked, the other channels are likely to be free since they're separated by quite a few MHz of bandwidth.

This is especially true since most other devices that interfer with BLE are narrow band. Channel 38 in particular was placed between Wi-Fi channels 1 and 6 so it avoids the Wi-Fi signal. The wide spacing of the advertisement channels helps BLE better manage the interference from Wi-Fi, Classic Bluetooth, Microwaves, Baby Monitors, etc to ensure that advertisements succeed.

## BLE Advertisement Interval

When a BLE peripheral device is in advertising mode, advertising packets are sent periodically on each advertising channel. The time interval between packets has both a fixed interval and a random delay.




You can set the fixed interval from 20ms to 10.24 seconds, in steps of 0.625ms. The random delay is a pseudo-random value from 0ms to 10ms that is automatically added. This randomness helps reduce the possibility of collisions between advertisements of different devices. We mentioned that finding advertisements is critical, so avoiding collisions at all costs is

extremely important. This is just another way Bluetooth Smart uses to improve robustness.

You may be thinking that you would want to advertise on just one or two channels, not all three to save power. Most companies frown on this approach because of the effect from interference. If the channels you selected are blocked, you device won't work. Apple, for example, recommends advertising on all 3 channels, as do other manufacturers.

The advertising interval is separate from the connection interval. So, just because your device is slower to form a connection doesn't prevent you from sending data quickly once the connection is established.

## Advertising Channel PDU

The Advertisement Channel PDU itself has payload that depends on the Advertising PDU type. The figure above shows the ADV_IND payload. This payload has an **Advertisement Address** of 6 bytes and a variable number of advertisement data structures.

After the advertisement address is taken into account (this is typically referred to as the Bluetooth MAC Address although it may change at will), we are left with 37 – 6 = 31 bytes for actual advertisement data structures. This has to fit a length, type and data itself.

We went through a few of the layers, and you can see that BLE encapsulates a lot of data the deeper you go. This gives you a lot of flexibility in supporting different behaviors that best suit your product.

At the lowest level, the advertisement has 31 bytes that can advertise any number of different things. You can see the full list of the Advertisement Data types on the Bluetooth Sig Website , each data type specifies a different standard of data in the payload.

Some of the most commonly used **Advertising Data Types** are:

- 0x06 **Incomplete List of 128-bit Services**: UUIDs of the services provided by the peripheral can be advertised in 128-bit format.
- 0x02 **Incomplete List of 16-bit Service Class UUID**

- 0x08 **Shortened Local Name** and 0x09 **Complete Local Name**

Since the number of advertising data structures is variable, you can combine them as needed.

The most important part of building the advertisement is getting the right information to the Central device (Smartphone or standalone Central device), and this usually depends on what's important for your product. If your product provides unique services, you can advertise those services so that a Smartphone can distinguish your product from others nearby. For example, Beacons have custom data like unique UUIDs, power levels and other characteristics that are important for finding and using beacons.

The Bluetooth SIG also has the 0xFF data type which is manufacturer specific, so you have the flexibility of defining your own custom payload. Apple did this for the iBeacons which combine a standard Advertising data type with a manufacturer specific one.

The defining your own advertisements gives you a lot of power, but it's up to you to find the best way to get to where you want.

## Advertising Bluetooth Services

Although every application is different, advertising the most important or unique services provided by the peripheral is the easiest way to connect to it, and it makes sense in a lot of products. When an iPhone or Android is looking for devices, it can use the custom service UUID to find the exact devices it wants to talk to and filter out other devices. Searching for a specific address can be impossible, but finding devices that have unique IDs is easier.

For example, let's say your product is a small light sensor. You can create a custom service with a unique 128-bit UUID. Then by including the UUID in the advertisement packet, an iPhone can ignore all other devices in the vicinity except your product. This makes finding devices faster since you don't have to connect to each device to discover its capabilities.

This is also good when it comes to power savings. New generations of Smartphones are making more and more of the decisions and filtering on the low level. They do this because it's more energy efficient to discard an advertisement packet early on if it's not used than it is to inform the OS

and the user of it and discarding it later. But the phone needs to have information about what to filter which the application has to provide, and it depends on unique UUIDs for services or device addresses.

Once you start working with BLE devices, you'll quickly realize that UUIDs are critical. Services,Characteristics and other items use UUID to uniquely identify them.

UUIDs are nothing more than unique 128-bit (16 byte) numbers:

**75BEB663-74FC-4871-9737-AD184157450E**

It's typical to arrange the UUID in the format above  4-2-2-2-6. Each pair of characters actually indicate a hexadecimal number. So 75 above is actually 0x75.

To avoid constantly transmitting 16 bytes which can be wasteful (Bluetooth is very limited in the amount of data and 16 bytes are significant), the Bluetooth SIG has adopted a standard UUID base. This base forms the first 96 bits (12 bytes)  of the 128-bit UUID. The rest of the bits are defined by the Bluetooth SIG:

**XXXXXXXX-0000-1000-8000-00805F9B34FB**

The top 32-bits are up to you. For 16-bit UUIDs, the bottom 16-bits remain 0. For example the short form 16-bit UUID for the Heart Rate Service is:

**0x180D**

In reality this represents a 128-bit UUID:

**0000180D-0000-1000-8000-00805F9B34FB**

If you're using existing services or profiles that were specified by the Bluetooth SIG, you can avoid using the full 128-bit UUID. But, custom services need a fully defined 128-bit UUID.

## Creating UUIDs

The only important thing about UUIDs is that they'd be unique.

You can randomly generate them in various ways. One website that can generate them is Online UUID Generator. In Mac OS X you can use the uuidgen utility from the command line for the same thing.

Because of the number of bits, it's unlikely that you'll ever generate a similar UUID as anyone else. It's most important that you avoid the Bluetooth SIG base in custom UUIDs.

## Optimizing BLE Advertisements for Power and Latency

One of the most critical things to realize is the big tradeoff between power consumption and latency. Every advertisement consumes power. The BLE radio has to power up and transmit.  The less advertisements, the longer the system runs from a set of batteries. So is setting the advertisement interval to 10 seconds a good idea?

Well, let's assume that a user wants to connect to the peripheral. Can you wait 10 seconds? A long interval can be very frustrating to a user, especially if the environment has interference and packets get lost. So, making the interval too large is bad for user experience. Somewhere in the middle, around 500ms to 1 second is a sweet spot for most products. In some of the Applications we've developed, we've increased it, but only after careful consideration. Some systems that don't have users in the loop, so it's easier to do.

When you're building your advertisement packets, you also need to consider that more bytes mean higher power consumption. Each byte in the advertisement packet forces the radio to stay on longer to transmit, which uses more energy. In some cases, reducing the number of bytes in the advertisement to the bare minimum can help squeeze everything from the Coin Cell battery.

## BLE Advertisements and the Smartphone

Bluetooth Smart was designed to allow peripherals to be extremely low power. It does this partially by placing a lot of the burden on the

smartphone, with the assumption that a smartphone has a larger battery and is easily recharged. But in real products you want to avoid causing significant battery drain on the smartphone. Enabling Bluetooth drains the battery faster, and some users will end up disabling Bluetooth in frustration. This is a problem for most products that want to provide the user with a fast experience.

Much of the power used by smartphones comes from scanning for advertisements.  Because of this, Android and iOS limit significantly the scanning, especially background scanning.

While your App is in the foreground, you basically have complete control of the BLE and you have a high priority. It makes sense because Apple and Google know you want to show data quickly to the user, so there's no point in delaying it.

Once your application is in the background, looking for nearby devices (if your application supports it), the OS usually downgrades the priority. This is done in a few ways:

- The scanning interval increases, so it takes longer to discover a peripheral device that is advertising. This is especially true if, for example, there is no BLE app in the foreground scanning.
- The OS will generate less advertisement discovery events, such as multiple discoveries of the same device.

Android and iOS each handle this separately, so it's important to understand what effect running in the background has on your device and connection.

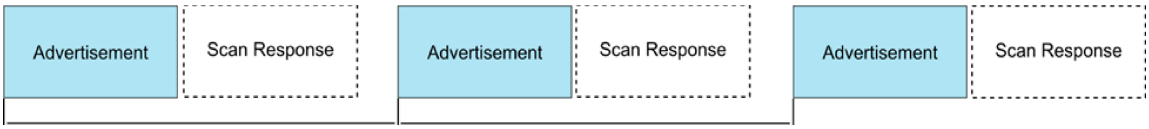
## Scan Response

We already mentioned that the advertisement packet has 31 data bytes available for you to use. This isn't much, especially when you consider that a 128-bit UUID takes 16-bytes. If you want to include more information, your only choice is to respond to scan responses.

When a a smartphone scans for advertisements, it can also request more information from the advertising device without forming a connection. This

is done through a Scan Request which is a special packet that is sent to the peripheral. The BLE peripheral receives the Scan Request and responds with a Scan response.

The Scan Response packet has the same packet format as the advertisement, with the exception of the type on the higher layer indicating it's a scan response instead of an advertisement. So your scan response can provide the device name or other services you didn't mention in the advertising packet.




The scan response comes with a catch. If scan responses are enabled in a peripheral device, the device has to keep the radio in RX mode after it sent the advertisement to be able to receive the scan request packet. This has to be done even if there is no device out there that will actually send one (because the peripheral doesn't know who is really out there). This means more energy consumed. For very low power applications, consider disabling the scan response if not absolutely needed.

You can see the format for the iBeacon packets. These packets use the basic BLE format, with some specific fields. Let's go through them one by one.

The advertisement packet contains the Bluetooth MAC address and the payload. The payload is composed of two AD Structures, the first one gives generic information using the Flags Data Type, and the second is the Apple specific iBeacon information.

## Flags Advertising Data Type

This packet has data type 0x01 indicating various flags. The length is 2 because there are two bytes, the data type and the actual flag value. The flag value has several bits indicating the capabilities of the iBeacon:

Bit0 – Indicates LE Limited Discoverable Mode

Bit1 – Indicates LE General Discoverable Mode

Bit 2 – Indicates whether BR/EDR is supported. This is used if your iBeacon is Dual Mode device

Bit3 – Indicates whether LE and BR/EDR Controller operates simultaneously

Bit4 – Indicates whether LE and BR/EDR Host operates simultaneously

Most iBeacons are single mode devices BR/EDR is not used. For iBeacons, General discoverability mode is used.

### iBeacon Data Type

The most important advertisement data type is the second one. The first byte indicates the number of bytes, 0x1A for a total of 26 bytes, 25 for payload and one for the type. The AD type is the Manufacturer Specific 0xFF, so Apple has defined their own Advertisement Data.

The first two bytes indicate the company identifier 0x4C00. You can see identifiers for other companies as well.

The second two bytes are beacon advertisement indicators. These are always 0x02 and 0x15.

The critical fields are the iBeacon proximity UUID which uniquely identifies the iBeacon followed by a major and minor fields.

Each iBeacon has to have a unique UUID so that an iPhone app can know exactly where it is located relative to one or more iBeacons.

Finally, there is also a 2's complement of the calibrated TX power that can be used to improve location accuracy knowing the power level of the beacon.

There's nothing stopping you from creating your own beacons with a different manufacturer format. The problem is that Apple specifically detects iBeacons with the particular format, so there won't be any interoperability.

## Conclusion

We've covered some of the most popular BLE and Bluetooth devices, their specifications and some of the key aspects to keep in mind when making a decision.

As always, there are many details and concerns that come into play when creating a BLE product. We're committed to help you get it done right, so feel free to get in touch with us to discuss.