Chapter 5: Classic Bluetooth

Time 3 Hours

At the end of this chapter you will understand the basics of Classic Bluetooth and how to create Classic Bluetooth projects on WICED devices.

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# Classic Bluetooth Introduction

As you learned in the previous chapter, BLE is widely used for low power devices that can afford to send data a lower rate in regular bursts. For devices that either require a constant connection (i.e. streaming of data) or higher throughput, Classic Bluetooth is still widely used. Common examples include wireless headsets (streaming audio), hands-free phone headsets, virtual serial port connections for data transfer between devices and human interface devices (mice, keyboards, etc.).

Bluetooth operates in the 2.4 GHz ISM band (2.400 – 2.4835 GHz). In the US, Bluetooth uses 79 channels with 1 MHz spacing between channels. There is a lower guard band of 2 MHz and an upper guard band of 3.5 MHz. Therefore, the channel frequencies are from 2.402 GHz to 2.480 GHz.

Bluetooth devices employ continuous frequency hopping between channels to avoid interference from other devices that operate in the 2.4 GHz ISM band such as microwaves and cordless phones. Depending on the mode, channels are changed either 1600 times per second (normal operation) or 3200 times per second (inquiry and paging).

There are 3 data transfer rates available in Bluetooth. 1 Mbps, 2 Mbps, and 3 Mbps. Each uses a different encoding scheme as shown here:

|  |  |  |
| --- | --- | --- |
| **Mode** | **Speed** | **Modulation** |
| Basic Rate | 1 Mbps | GFSK (Gaussian Frequency Shift Keying) |
| Extended Data Rate | 2 Mbps | π/4 DQPSK (Differential Quadrature Phase Shift Keying) |
| Extended Data Rate | 3 Mbps | 8DPSK (Octal Differential Phase Shift Keying) |

# Profiles

Classic Bluetooth devices communicate with one another by using one or more of a standard set of profiles (often called services) which is maintained by the Bluetooth Special Interest Group (SIG). By using standard profiles, devices only need to determine the profile to use to start communicating rather than having to transmit the communication parameters themselves. A list of Bluetooth Profiles can be found at:

<https://en.wikipedia.org/wiki/List_of_Bluetooth_profiles>

Some of the more commonly used profiles are:

## Advanced Audio Distribution Profile (A2DP)

The A2DP profile is used for streaming multi-media audio. It is used, for example, when streaming audio from a mobile phone to a wireless headset or a car sound system. This profile is often used in conjunction with AVRCP, HSP, or HFP as described below.

The A2DP profile is designed for a unidirectional audio stream of up to 2 channel stereo. There may be more than one A2DP profile on a single device.

## Audio/Video Remote Control Profile (AVRCP)

The AVRCP profile is designed to provide a standard remote-control interface for devices such as televisions, stereo equipment, in-car navigation systems, etc.

There are several versions available depending on the functionality required, each of which is a superset of the previous version.

|  |  |
| --- | --- |
| Version | Functionality |
| 1.0 | Basic remote (play, pause, stop, etc). |
| 1.3 | 1.0 plus metadata (such as artist, track name, etc.) and player state (such as playing, stopped, etc.) |
| 1.4 | 1.3 plus multiple media player browsing including a “Now Playing” list and search capabilities. Also has support for absolute volume. |
| 1.5 | 1.4 plus corrections/clarifications to absolute volume control |
| 1.6 | 1.5 plus browsing and track information. Support for sending cover art through BIP/OBEX (Basic Imaging Profile and Object Exchange Profile) |

## Headset Profile (HSP)

The HSP provides support for headsets including two-way 64 kbit/sec audio and minimal controls for ringing, answer a call, hang up and adjust the volume.

In a typical headset, A2DP will be used when listening to music since it provides the best quality stereo connection, but HSP will be used when making a phone call since it allows two-way communication.

## Hands-Free Profile (HFP)

The HFP is commonly used to allow car hands-free kits to communicate with mobile phones. It provides relatively low-quality monaural audio to allow the user to control some features of their phone such as making calls, playing music, etc. It is often used with other profiles such as A2DP to provide high quality audio streaming.

## Human Interface Device Profile (HID)

The HID is used for devices such as mice, keyboards, and joysticks.

## Serial Port Profile (SPP)

The SPP emulates a serial cable to provide a means for setting up virtual seral ports to connect two Bluetooth devices.

Need more info here…

# Stack

As with most complex systems, the Bluetooth stack is broken into layers as shown below.



# Network

## Piconets and Scatternets

Bluetooth devices communicate using a Master-Slave protocol. A single master can communicate with up to 7 slaves in a “piconet” in the older spec and up to 14 slaves on two different logical links (more on that later) in the newer spec. At any given time, data can be transferred between the master and one slave device (except when using broadcast mode). The master decides which slave to address. Usually the master will switch between slaves in a round-robin fashion.



Two or more piconets can connect to form a “scatternet”. In a scatternet, devices can have different roles in different piconets. For example, a device can be a master in one piconet and a slave in another.



## Device Address (BD\_ADDR)

Each Bluetooth device has a unique 48-bit address. The 24 least significant bits are the lower address part (LAP), the next 8 bits are the upper address part (UAP), and the final 16 most significant bits are the non-significant address part (NAP).

Need explanation of the 3 parts – is the LAP assigned by the company and the UAP/NAP assigned by SIG for a given company?

There are 64 LAP values reserved for the inquiry process (discussed later). These values must not be used for any BD\_ADDR. The reserved values are:

|  |  |
| --- | --- |
| **LAP Range** | **Purpose** |
| 0x9E8B00 | Dedicated Inquiry |
| 0x9E8B01 – 0x9E8B32 | Reserved for future use |
| 0x9E8B33 | General Inquiry |
| 0x9E8B34 - 0x9E8B3F | Reserved for future use |

## Piconet Clocks

Each device has a 28-bit timer which counts at 3.2 kHz (period = 312.5µs) to be used as a clock. Therefore, the timer wraps around every 23 hours and 18 minutes.

In a piconet, the clock from the master is called the piconet clock. All timing signals are derived from the piconet clock. The clock for each slave is its own internal timer with an offset used to synchronize it to the piconet clock.

## Channel (Frequency) Hopping Sequence

The sequence used for channel hopping is determined by the 28 least significant bits of the BD\_ADDR of the master. The current channel for the hopping sequence (a.k.a. the phase) is determined by the 27 most significant bits of the piconet clock. That is why each slave’s clock must be synchronized to the piconet clock. Otherwise, the slave and master would not hop to the same channels.

Since the piconet clock is 3.2 kHz and the phase uses the upper 27 of the 28 bits of the piconet clock, that means hopping happens at rate 1.6 kHz (i.e. 1600 times per second or once every 625 µs).

## Time slots

Communications between master/slave on a piconet are divided into 625 µs time slots. The slots are numbered using the most significant 27 bits of the piconet clock. The master uses even numbered time slots to send packets while the slave uses odd numbered time slots. Since hopping also happens every 625 µs, each time slot uses a different channel from the hop sequence.

Picture

In addition to standard single slot packets, there are multi-slot packets of 3 or 5 slots. In the case of a multi-slot packet, the channel stays the same for the entire packet but the channel will jump to the next frequency in the sequence once that packet is finished. For example, if a 3-slot packet uses the 5th channel in the hopping sequence, the packet after the 3-slot packet will use the 8th channel.

Picture

An adapted frequency hopping sequence may use fewer than all 79 channels (but at least 20). In that case, the channel used by the slave is the same as the channel used by the preceding master time slot. As with the multi-slot packets, the next channel will jump to the appropriate frequency in the sequence. For example, if the master uses the 5th channel for a single slot packet using adapted frequency hopping, the slave will also use the 5th channel and the next master packet will use the 7th channel.

Picture

The master initiates any changes to or from adapted frequency hopping or to a different adapted frequency hopping scheme by sending an AFH command. The slave(s) must then send an acknowledge (ACK).

An example of time slot usage for multiple slaves on one piconet is shown here:

Picture

# Logical Transports (Links)

There are five types of link supported in Bluetooth. Each is discussed in detail in the following sections.

1. Synchronous Connection-Oriented (SCO)
2. Extended Synchronous Connection-Oriented (eSCO)
3. Asynchronous Connection-Oriented (ACL)
4. Active Slave Broadcast (ASB)
5. Parked Slave Broadcast (PSB)

## Synchronous Connection-Oriented (SCO)

An SCO link is a point-to-point link between the master and a specific slave. This type of link can be used for time critical data such as voice. Some time slots are reserved for both the master and the slave. SCO packets are never re-transmitted. A master can support up to three simultaneous SCO links (either to one slave or to different slaves).

## Extended Synchronous Connection-Oriented (eSCO)

The eSCO link is similar to SCO except that re-transmission is allowed. Since it allows time for re-transmission without losing time synchronization, this type of link is useful for higher-quality streaming than a standard SCO link.

It uses a 3-bit device address (LT\_ADDR) so that all 7 devices on a piconet can be addressed. The LT\_ADDR is used with retransmitted messages so that the slaves can identify them.

eSCO links support both BR and EDR.

## Asynchronous Connection-Less (ACL)

An ACL link is used for asynchronous communication. This type of link is useful for non-time critical data. Like eSCO, it uses a 3-bit address (LT\_ADDR) so it can address all 7 devices on a piconet. Note that the LT\_ADDR for eSCO and the LT\_ADDR for ACL are not the same so a master can have 7 eSCO links and 7 ACL links.

## Active Slave Broadcast (ASB)

An ASB link is used for a master to send broadcast packets to all active slaves connected to a piconet. An acknowledgement is not necessary for ASB packets.

## Parked Slave Broadcast (PSB)

A PSB link is used for a master to send broadcast packets to all parked slaves on a piconet (more on the parked state later). There can be up to 255 parked slaves on a piconet even though a maximum 14 can be active at a time.

PSB is the only link between a master and a parked slave.

# States and State Transitions

The Bluetooth device states are shown in the figure below.



As shown above, a device starts in the Standby state. In order to become Connected, it must go through ether Inquiry and then Paging (if the address is unknown), or just Paging (if the address is known). Once it is Connected, a device can Transmit and Receive data. Three different low power states (Sniff, Hold, and Park) can be used for devices that do not need to stay Connected but which don’t want to go all the way back to Standby.

## Inquiry

Inquiry is used for a master to discover nearby Bluetooth devices. The master enters Inquiry mode to discover nearby Bluetooth devices. Each Bluetooth device that wants to be discoverable will occasionally enter the Inquiry Scan state to allow it to be discovered by the master.

The master transmits messages either for general or dedicated inquiry. A general inquiry message is used to find any nearby discoverable Bluetooth devices. A dedicated inquiry message is used to discover a specific group of devices.

Inquiry messages consist of just a 68-bit access code. The General Inquiry Access Code (GIAC) is generated by running a specific algorithm on the 24-bit General Inquiry LAP (0x9E8B33). The Dedicated Inquiry Access Code (DIAC) is generated by running a specific algorithm on the 24-bit Dedicated Inquiry LAP (0x9EB00).

The master sends a series of inquiry messages over 32 hop frequencies with a hop rate of 3200 times per second. Since the hop rate is 2X the normal hop rate, each 625us slot has either 2 Tx messages from the master or potentially two Rx messages from the slave.

Picture from page 63.

The 32 hopping channels and sequence are generated from the LAP for general inquiry with 4 leading 0’s (0x09E8B33) and the 27 most significant bits of the piconet clock.

The recommended timing relationship between the master performing an inquiry and the slave entering inquiry scan mode is as follows:

|  |  |
| --- | --- |
| Value | Description |
| 10.24 sec | Time span that master performs an inquiry |
| 10.625 ms | Minimum time slave is in the Inquiry Scan mode |
| 2.56 sec | Maximum time for slave before entering Inquiry Scan mode again |

## Paging

Paging is used for a Bluetooth master to connect to a Bluetooth slave. The master is the “paging device” and will be in the Page mode while the slave is the “paged device” and will periodically enter the Page Scan mode to look for paging messages. Like inquiry, the master sends a series of paging messages over 32 hop frequencies with a hop rate of 3200 times per second.

Picture from page 72.

The 32 hopping channels and sequence are generated from the 28 least significant bits of the BD\_ADDR of the device being paged (i.e. the slave that the master wants to connect to).

The recommended timing for a slave to enter page scan mode is as follows:

|  |  |
| --- | --- |
| Value | Description |
| 10.625 ms | Minimum time slave is in the Page Scan mode |
| 2.56 sec | Maximum time for slave before entering Page Scan mode again |

## Sniff

In the Sniff state, a slave still listens but it does so at a reduced rate. This is applicable to ACL links but not to SCO or eSCO links due to the time-sensitive nature of data on those links. While not listening, a slave in Sniff may engage in activity on another piconet or it may enter a reduced power mode.

When a slave is in the Sniff state, the master can only transmit to it in specified time slots that start at sniff anchor points. These anchor points are spaced with an interval of Tsniff.

Picture from page 139

## Hold

In the Hold state, capacity is made available for other tasks such as scanning, paging, inquiry, or engaging with another piconet. The slave device can also enter a low power mode during Hold. ACL links do not support Hold mode but already established SCO or eSCO links do.

Prior to entering Hold, the master and slave agree on the length of time that the slave will remain in Hold mode.

## Park

In the Park state, the slave does not participate on the piconet channel but remains synchronized to the channel. The slave gives up its LT\_ADDR before entering Park and receives two new addresses:

PM\_ADDR: 8-bit Parked Member Address

AR\_ADDR: 8-bit Access Request Address

The PM\_ADDR is used when the master initiates an unpark procedure while the AR\_ADDR is used when the slave initiates an unpark procedure. The master can also unpark a slave by using its 48-bit BD\_ADDR.

All messages to parked slaves must be sent using broadcast packets (i.e. LT\_ADDR = 0).

To keep parked slaves synchronized, the master sends a beacon train consisting of one or more equidistant beacon slots sent periodically.

Pic from 145

Access windows are provided between the periodic beacon slots when a slave can request to be unparked.

Picture from 146

# Packets

Picture of BR/EDR packet structure from page 81/82 of the presentation.

Packets – BR, EDR, packet types (segment-1, -2, -3, -4, ID, NULL, POLL, FHS, SCO (HV1, 2, 3, DV), eSCO, ACL, etc.)

Does the packets section belong in the logical transports section? Should we even get to this much detail on packets?

# Pairing and Bonding

# Security

# Using Bluetooth in WICED Studio

WICED Bluetooth Designer Wizard

# Advanced Topics

Combo BT/BLE

# Exercise(s)

* 1. Serial Port Profile (SPP) ???
  2. Human Interface Device Profile (HID) ???
  3. Headset Profile (HSP) ???
  4. Hands-Free Profile (HFP) ???
  5. Combo Bluetooth/BLE: SPP + BLE Custom CapSense ???

# Related Example “Apps”

|  |  |
| --- | --- |
| **App Name** | **Function** |
| snip.bt.spp |  |
| snip.bt.a2dp\_sink |  |
| demo.headset |  |
| demo.hid |  |
|  |  |

# Recommended Reading