CHAPTER 3

Bluetooth Lower Layers

3.1 Introduction

The layered architecture of the Bluetooth protocol stack was introduced in the previous chapter. This chapter covers the lower layers of the Bluetooth protocol stack including the Bluetooth Radio, Baseband Controller, Link Manager and Host Controller Interface. These are shown in the bottom half of Figure 3.1.

The Host Controller Interface specification is common for BR/EDR and LE. So the Host Controller Interface will be explained in detail in this chapter for both BR/EDR and LE. Only a few LE specific parts will be explained in Chapter 9.

Some scenarios on how these layers come together to implement certain practical uses are shown toward the end of this chapter.

3.2 Bluetooth Radio

Bluetooth Radio operates in the 2.4 GHz ISM band. It uses a frequency hopping mechanism with 79 channels to combat interference. A Time Division Duplex (TDD) scheme is used for full duplex transmission.

This layer is responsible for the following primary tasks:

1. Transmission and Reception of packets: This includes modulation and demodulation of the packets. Two modulations modes are defined:
    a. Basic Rate: This mode uses a shaped binary FM modulation mechanism and is designed to minimize complexity of the transceiver. It provides a gross air data rate of 1 Mbps.
    b. Enhanced Data Rate: This mode uses Phase Shift Keying (PSK) Modulation and supports higher data rates. The gross air data rate supported is 2 Mbps or 3 Mbps.
2. Support appropriate power class: Three power classes are defined by the Bluetooth specification based on the maximum output power. A higher value of maximum output power leads to a longer range. The device can support the power class most appropriate to its intended use:
    a. Power Class 1: Maximum output power of 100 mW.

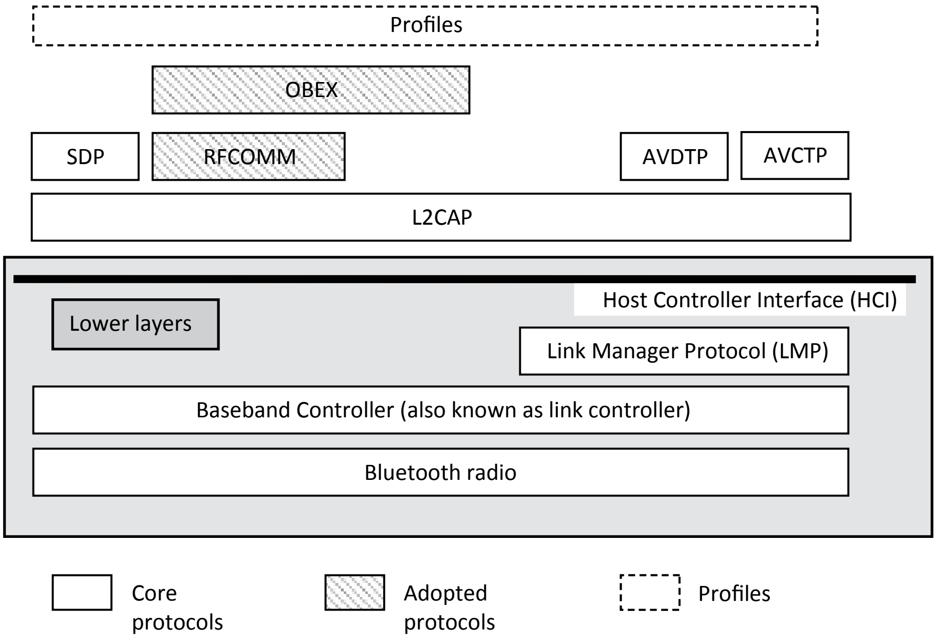

Figure 3.1 Lower layers in Bluetooth protocol stack.

b. Power Class 2: Maximum output power of 2.4 mW.
c. Power Class 3: Maximum output power of 1 mW.

3.2.1 Frequency Band and Hopping

Bluetooth uses the globally unlicensed 2.4 GHz ISM band for communication.

Bluetooth divides the frequency band into 79 channels. Each channel is 1 MHz wide. To combat interference, the Bluetooth devices change channels up to 1600 times per second. So even if there is noise on one channel, the next transmission is on a different channel which may be noise free.

What is ISM?

ISM stands for Industrial, Scientific and Medical radio band. Besides 2.4 GHz, these bands include frequencies in the range of 13.560 MHz, 27.120 MHz, 5.8 GHz, 24.125 GHz and several more. These bands are reserved internationally and do not require any special license to operate.

ISM bands are shared by several devices including Remote control toys, cordless phones, near field communication, wireless LAN, etc. Some microwave ovens also generate interference in these bands. Since these bands may be shared by many devices, different wireless technologies employ different mechanisms to combat interference.

The pattern of changing the channels is pseudo-random so that all devices which are communicating with each other know which frequency to hop to next.

The frequencies of various channels are derived from the formula:

$$f(k) = 2402 + k \text{ MHz}, k = 0, \ldots, 78$$

This is called *frequency hopping*. The set of devices that communicate with each other follow the same hopping pattern so that they can listen to data sent by the other devices. This set of devices is referred to as a piconet which is the fundamental unit of communication in Bluetooth. Piconet will be explained in detail in the next section.

3.3 Baseband Controller

The Baseband controller (also referred to as the Link Controller) performs the following major functions:

1. Management of physical channels and links for single or multiple links.
2. Selection of the next hopping frequency for transmitting and receiving packets.
3. Formation of piconet and scatternet.
4. Formation of packets and then giving them to the Bluetooth radio for transmission.
5. Inquiry and Inquiry Scan.
6. Connection and Page Scan.
7. Security (including data encryption).
8. Power management (including low power modes).

3.3.1 Topology—Piconet and Scatternet

Bluetooth supports both point-to-point connections and point-to-multi-point connections. In point-to-point connection, the physical channel is shared by two devices while in point-to-multi-point connection it is shared by multiple devices.

The piconet is the smallest unit of communication in Bluetooth. Two or more devices sharing the physical channel are said to form a piconet. It is characterized by one Master and up to seven active Slaves. All the devices are synchronized to each other in terms of clock and frequency hopping pattern. This common piconet clock is the same as Master's clock and frequency hopping pattern is determined by Bluetooth device address (BD_ADDR) and clock of the Master.

Several piconets may co-exist in proximity with each other without interfering with each other. This is because each piconet will have its own Master and thus its own frequency hopping pattern. The chances of two pseudo random frequency hopping patterns which are hopping on 79 different frequencies to select the same frequency for next transmission are quite remote.

A scatternet is formed when two piconets share a device. The shared device participates in the two piconets in a Time Division Multiplexing manner. So it participates in the first piconet for some time and then participates in the second piconet for the remaining time. Before moving to the second piconet, the device puts itself in low power mode in the first piconet so that the other devices of the first piconet are aware of its temporary absence. This can be extended further to any number of piconets.

Figure 3.2 shows three piconets joined together to form a scatternet. Two scenarios are shown:

- Device M2 is Master in one piconet and Slave in the second piconet.
- Device S7 is Slave in two piconets.

It's not possible for a device to be in a Master in two piconets. Why?

This is because the piconet is defined by the Master's BD_ADDR and clock. So, in effect, all devices that are synchronized with that Master form one single piconet and not two different piconets.

3.3.2 Time Division Duplex

The physical channel is divided into slots in the time domain. Each slot is 625 microseconds and a packet may be sent in 1, 3, or 5 slots depending on the length of the packet. The Master and Slave send the packet alternately in slot pairs. A slot pair starts with a Master transmitting a packet to one of the Slaves. The packet is 1, 3, or 5 slots in length. The response to that packet is received from the Slave (to which the Master had sent the packet) in the next slot. The response packet may also be 1, 3 or 5 slots in length.

The Master can send packets to a Slave in only EVEN Slots. The Slave can send packets to Master only in ODD slots. This is illustrated in Figure 3.3.

3.3.3 Adaptive Frequency Hopping (AFH)

Normal frequency hopping provides some level of protection to interference from other devices in the sense that if another device (whether Bluetooth or not) is using the same RF channel and the data is corrupted due to interference, then the data would be retransmitted next time on the next pseudo random channel. It is possible that the next pseudo random channel is noise free and the packet gets received successfully. This will still lead to loss of throughput since there are retransmissions in case of interference and retransmissions need bandwidth.

The Bluetooth 1.2 specification introduced AFH which helps to increase the immunity of Bluetooth devices against interference generated by other systems in the ISM band.

Also, AFH serves another purpose of reducing the interference caused by Bluetooth on other devices in the ISM band.

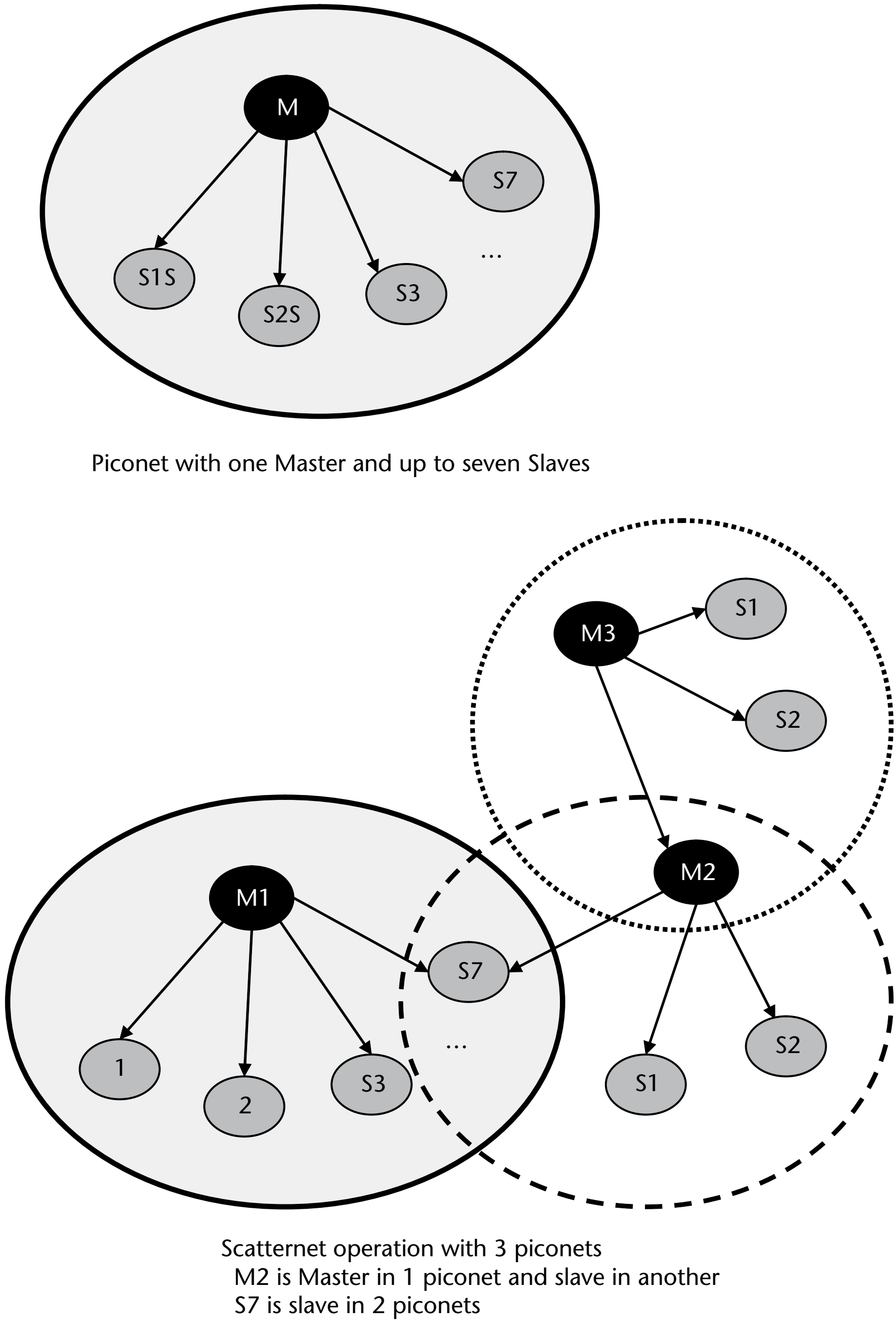

Figure 3.2 Bluetooth topology.

When AFH is enabled, the channels which have interference are marked as unused. The Master informs the unused channels to the Slaves and these channels are excluded from the frequency hopping pattern. So, even though the number of channels on which the frequency hopping occurs decreases, there is no decrease in the throughput. If AFH were not enabled, the frequency hopping would have occurred

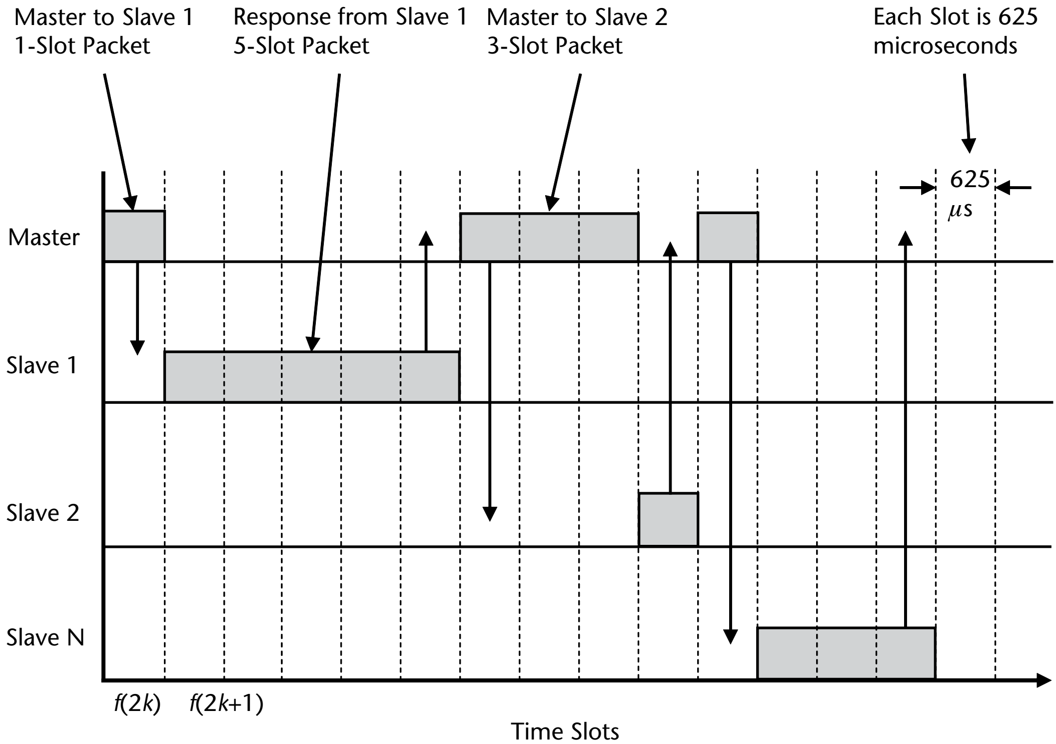

Figure 3.3 Time division duplex.

on some of the bad channels as well and it would have resulted in retransmissions. The retransmissions would have led to decrease in the throughput.

With AFH, the number of channels in use can be reduced until it reaches 20. Remember that without AFH the number of channels used by Bluetooth is 79.

To use AFH, the Master maintains a channel map in which it classifies a channel as used or unused. It keeps on updating the channel map based on information that it gathers about whether the packets could be transmitted successfully or not on a particular frequency. It can gather this information based on whether it received an acknowledgement of the packet that it sent or not.

The Slaves also help the Master by providing information on whether the channels are good or bad. Based on this information, the Master can mark the channel as used or unused.

AFH is enabled by the Master after a connection is made.

The Master may also request Channel Classification information from the Slave using LMP_channel_classification_req PDU. (The LMP PDUs are exchanged between the link manager of the Master and the link manager of the Slave. These will be explained in detail later). A Slave that supports this feature periodically provides the information on whether the channels are Good, Bad or Unknown using the LMP_channel_classification PDU.

The Master can use this information to update its channel map. It sends the updated channel map to the Slave using the LMP_set_AFH PDU.

The updated channel map is sent to Slaves periodically so that only the channels marked as *used* are used during frequency hopping.

In a piconet it's possible that a Master enables AFH with connection to some Slaves but disables it for some other Slaves. This will especially be the case if some Slaves support Bluetooth 1.2 or newer specification while others support an older version.

3.3.4 Master, Slave Roles and Role Switch

As mentioned earlier, a piconet consists of one Master and up to seven Slaves. The devices in the piconet are synchronized to a common clock and frequency hopping pattern. This synchronization reference is provided by the Master.

When a device decides to connect to another device (maybe after doing an inquiry), it initiates the connection procedure. By default, the device which initiates the connection becomes the Master. It is also possible for the other device (which is acting as Slave) to become the Master by doing a role switch. It can do so either during the connection establishment itself or any time after the connection is established.

The procedure to swap the roles of two devices connected in a piconet is called role switch. It is initiated using the HCI_Switch_Role command. (HCI commands are sent by the host to the controller on the HCI interface to request the controller to take specific action. These will be explained in detail later).

Either of the two devices (Master or the Slave) can initiate a role switch.

> One interesting point to note at this stage is that LE does not allow Role Switch in order to keep things simple. We'll come to that later when we dig deeper into LE.

3.3.5 Channel, Transport and Links

The Bluetooth data transport system follows a layered architecture. This is shown in Figure 3.4. The lowest layer comprises the physical channel that provides the communication mechanism between the devices on a Time Division Duplex channel. At the top, L2CAP channels provide communication channels for upper layers of the protocol stack to exchange data. Each of the layers is explained in the following sections going from bottom to top.

3.3.5.1 Physical Channel

The physical channel is the lowest architectural layer for communication in Bluetooth. It is characterized by the pseudo-random frequency hopping sequence, the specific slot timing of the transmissions, the access code and the packet header encoding. This means that for two or more devices to communicate with each other, their radios must be tuned to the same RF frequency at the same time. Besides this, the radios must be in range to listen to each other's transmissions.

When a device is synchronized to the timing, frequency and access code of a physical channel it is said to be connected to that channel.

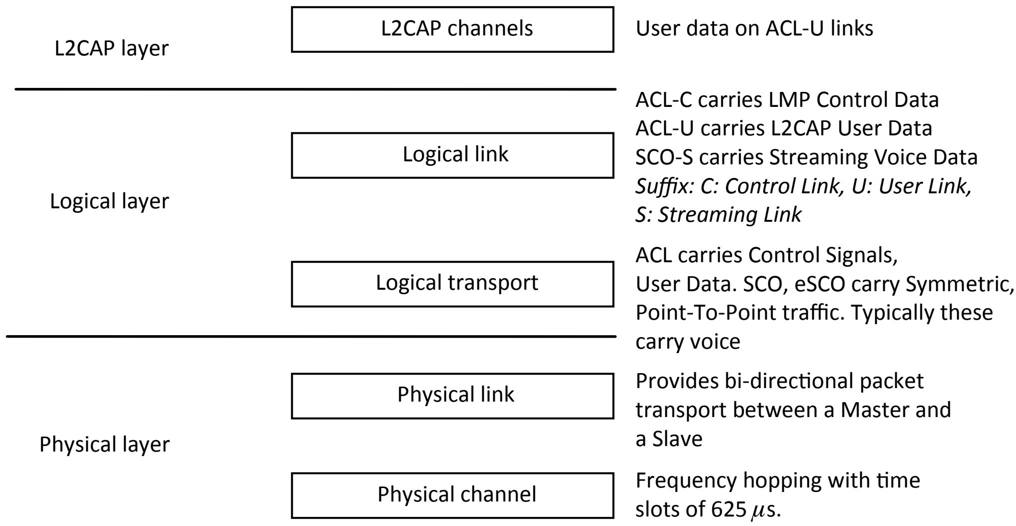

Figure 3.4 Data transport architecture.

The physical channel is subdivided into time units called slots. Each slot is 625 μs and full duplex transmission is achieved using Time Division Duplex (TDD) scheme. A packet may occupy 1, 3, or 5 slots depending on the packet type. As mentioned earlier a frequency hopping scheme is used and each packet is transmitted on the next pseudo-random frequency. The frequency hop occurs once per packet and not once per time slot.

Four physical channels are defined:

- *Basic Piconet Channel:* This channel is used for communication between devices in a piconet.
- *Adapted Piconet Channel:* This is similar to basic piconet channel and is used with devices that have AFH enabled.
- *Inquiry Scan Channel:* This channel is used for discovering the devices.
- *Page Scan Channel:* This channel is used for creating connections with the devices.

A device can use only one physical channel at a time and has to use time division multiplexing between the channels to support other channels if it has to support multiple concurrent operations.

For example, if a device is already connected to another device but still needs to be in discoverable mode so that other devices can discover it. It already has a physical channel established with another device which is either the basic piconet channel or adapted piconet channel depending on whether AFH is enabled on that channel. To support discoverable mode along with the physical channel, it has to use time division multiplexing to support the inquiry scan channel. This feature would be useful when forming a scatternet or adding more devices to the piconet.

3.3.5.2 Physical Link

A physical link defines the baseband to baseband connection at the lowest level. The physical link is what actually carries the data physically over the channel. There can be only one physical link between two Bluetooth devices. This means that if we consider two devices—one Master and the other Slave—there will be only one physical link between these two devices although at a logical level there could be two or more links on top of it. (Logical links are explained in the next section.)

Within a physical channel, a physical link is established between any two devices that transmit packets. In a piconet, a physical link is formed between the Master and each Slave. It is not permitted to form a physical link between two Slaves.

It is worthwhile to note that Bluetooth does not support direct communication between two Slaves. If the two Slaves need to talk, then they should disconnect from their respective piconets and form a separate piconet with one of them acting as the Master and the other acting as a Slave.

A physical link is always associated with exactly one physical channel.The physical link supports link supervision so that a connection loss can be detected. This could happen, for example, when the device moves out of range or one of the devices is powered off. The physical link also supports encryption of the packets that are transmitted.

3.3.5.3 Logical Transport

A logical transport is formed on a physical link to transfer control signals and synchronous or asynchronous user data. The following three Logical Transports are most commonly used.

1. Asynchronous Connection Oriented (ACL) Logical Transport.
2. Synchronous Connection Oriented (SCO) Logical Transport.
3. Extended Synchronous Connection Oriented (eSCO) Logical Transport.

Asynchronous Connection Oriented (ACL) Logical Transport

The Asynchronous Connection Oriented (ACL) transport is used to carry control signals, user data and broadcast traffic. It provides a packet-switched connection between the Master and all Slaves that are active in the piconet. The default ACL connection is created when a device joins a piconet. This transport is used to send data in bursts whenever data is ready and whenever a slot is available and not reserved for the synchronous connection oriented transport.

Between a Master and a Slave only one single ACL logical transport is created. The higher layer protocols multiplex their data on top of this logical transport. Packet retransmissions are supported on the ACL transport to ensure data integrity when the packets are delivered to the application on the receiver side.

If a SCO or eSCO transport exists between the Master and the Slave, then the time slots are first allocated to the SCO or eSCO transport. (This is because SCO and eSCO slots carry time bounded data like voice which need guaranteed bandwidth.) The remaining slots are reserved for the ACL transport. (The SCO and eSCO transports are covered in the next section.)

You might be wondering why the acronym is ACL and not ACO?

This is for historical reasons. In previous versions of the Bluetooth specification (Prior to Core Spec 1.2) this link was called Asynchronous Connection Less and abbreviated as ACL. That abbreviation still continues…

Synchronous Connection Oriented (SCO) Logical Transport

The Synchronous Connection Oriented (SCO) transport provides support for continuous transfer of data. It reserves time slots on the physical channel at the time of establishment of the connection so it can be considered as a circuit-switched connection. It is a symmetric point-to-point link between a Master and a particular Slave. SCO links carry 64 kb/s of information in both directions. Typically this is useful in transporting voice streams where timing of the data is as important as the data content.

If a data packet is corrupted during transmission it is not retransmitted. This is suitable for voice data since if there are retransmissions, these would introduce delays. Hence the retransmitted packets may arrive too late to be played. On the other hand if the average number of dropped packets is not too high, it may not lead to noticeable degradation in the user experience.

Unlike ACL logical transport, the SCO (and eSCO) logical transports do not support multiplexed logical links on top of them. So there is no further layering of any stack components above SCO (and eSCO) logical transport.

A Master may support up to three SCO links to the same Slave or to different Slaves. A Slave may support up to three SCO links from the same Master or two SCO links if the links originate from different Masters. (SCO links can originate from different Masters in the scatternet topology where a Slave is connected to two Masters in two different piconets.)

A Master can support an ACL transport and a SCO transport simultaneously with the Slave. One practical example of this is when connecting to a mono headset from a mobile phone. The mobile phone establishes both the ACL transport as well as the SCO transport with the headset. The ACL transport is used to carry commands to create a connection to the headset, increase/decrease volume, disconnect, etc. while the SCO transport is used to carry the voice traffic.

In theory the Master can support up to 3 SCO transports simultaneously with an ACL transport to the Slave. In practice this is not used much. Most of the practical implementations use only one SCO link to transfer voice data along with ACL link to transfer control data.

Extended Synchronous Connection Oriented (eSCO) Logical Transport

The extended synchronous connection oriented (eSCO) link is a symmetric or asymmetric point-to-point link between a Master and a particular Slave. This is in contrast to SCO link which supports only symmetric traffic. The eSCO logical transport also reserves slots similar to SCO logical transport and can be considered as a circuit-switched connection.

The support for eSCO Logical Transport was added from version 1.2 of the Bluetooth specification as an enhancement to the functionality of the SCO Logical Transport.

It offers the following extensions over the SCO link:

- The transmission may be symmetric or asymmetric in the case of eSCO while it's only symmetric in the case of SCO. This means that in the case of eSCO it's possible to use 3-slot packets in one direction and 1-slot packet in the reverse direction.
- eSCO logical transport provides better reliability (and voice quality) by providing a limited number of retransmissions of packets that get corrupted. The retransmission slots are allocated right after the reserved slots and are used only if needed. This offers better voice quality as compared to SCO transport. The number of retransmission slots is limited to ensure that the timing constraints of voice data are still met in case of retransmissions and that packets don't arrive too late to be played.
- eSCO provides higher data rates as compared to SCO links. This is achieved by introducing additional eSCO packet types related to Enhanced Data Rate.
- eSCO is used to transfer not only 64 kb/s voice packets, but also any other types of packets which require constant traffic. For example the eSCO Logical Transport is used to transfer *Wide Band Speech* data.

What is Wide Band Speech (WBS)?

The bandwidth of the sound signals used in telephony is limited to about 200–3400 Hz. This is referred to as Narrow Band Speech. As per Nyquist sampling theorem, it is sampled at the rate of 8 KHz. (The Nyquist sampling theorem is beyond the scope of this book. In brief it states that if a signal is band limited at B Hz, then it can be perfectly reconstructed from a sequence of samples if the sampling frequency is greater than 2 * B samples per second).

The 200–3400 Hz limitation on the bandwidth imposes a limit on the communication quality in Narrow Band Speech.

Most of the frequencies in speech signals are present below 7000 Hz. So increasing this bandwidth to 50–7000 Hz increases the naturalness of speech and gives the feeling of face-to-face communication. This is referred to as Wide Band Speech and is quite frequently used in cellular systems, voice over IP, etc. The signal is sampled at the rate of 16 KHz in the case of Wide Band Speech.

The 3G systems support Wide Band Speech and since the audio may be routed to a Bluetooth headset, the Bluetooth headsets also need to support Wide Band Speech to ensure that the voice quality is not degraded when routing the call over a Bluetooth link.

3.3.5.4 Logical Links

The logical links are supported on top of the logical transport. Five types of logical links are defined. These are described in Table 3.1.

The LC (link control) Logical link is carried in the packet headers. It contains low level information like acknowledgment/repeat request (ARQ), flow control and payload characterization. All other links are carried in the packet payloads.

The control ACL (ACL-C) logical link carries the control information between the link managers and the Master and Slave(s). It has a higher priority than ACL-U logical link.

The user ACL link (ACL-U) is used to carry user data. This link is used by the L2CAP layer. For example this link is used for transferring a file during a file transfer using FTP profile. (We will discuss L2CAP layer and FTP profile in the next chapter.)

The SCO-S link is supported on top of the SCO logical transport. Each SCO-S link is supported by a single SCO logical transport. Same is the case for eSCO-S logical link which is supported on top of the eSCO logical transport.

Most of the time the C, U, or S suffix is dropped and the links are just referred to as ACL, SCO, and eSCO, links. This does not lead to any ambiguity since the type of links being used is clear from the context. For example, if link manager data is being transferred then ACL would mean ACL-C logical link. Similarly if user data (L2CAP) is being transferred, ACL would mean ACL-U logical link. Some practical scenarios are explained in the Figure 3.5 for a better understanding of these links.

Scenario 1 shows a file transfer between a mobile phone and laptop. In this scenario, an ACL link is established between these two devices and the file transfer happens on this link.

Scenario 2 is a bit more complex. It shows a connection between a mobile phone and mono headset and routing of an audio call (from the cellular network) on the Bluetooth link to the headset. In this scenario, the initial connection establishment happens on the ACL link. Once the two devices are ready to exchange audio (For example, when the user presses the button on the headset to accept incoming call), the SCO or eSCO link is established.

Scenario 3 shows the case where a stereo headset is connected to a mobile phone and a music file (MP3) is streamed over the Bluetooth link. The MP3 file is

Table 3.1 Types of Logical Links

Link Type	*Traffic Type*	*Carrier*
Link Control (LC)	Low level link control information.	Mapped in the packet header and carried in every packet. (Except identity packet since it does not have a packet header).
ACL Control (ACL-C)	Control information between the link manager layers of Master and Slave(s).	Mostly ACL logical transport. May also be carried in data part of DV packets on SCO. (DV will be discussed later).
User Asynchronous/ Isochronous (ACL-U)	Asynchronous or isochronous user information between L2CAP layers	
User Synchronous (SCO-S)	Synchronous user information	SCO logical transport
User Extended Synchronous (eSCO-S)	Synchronous user information	eSCO logical transport

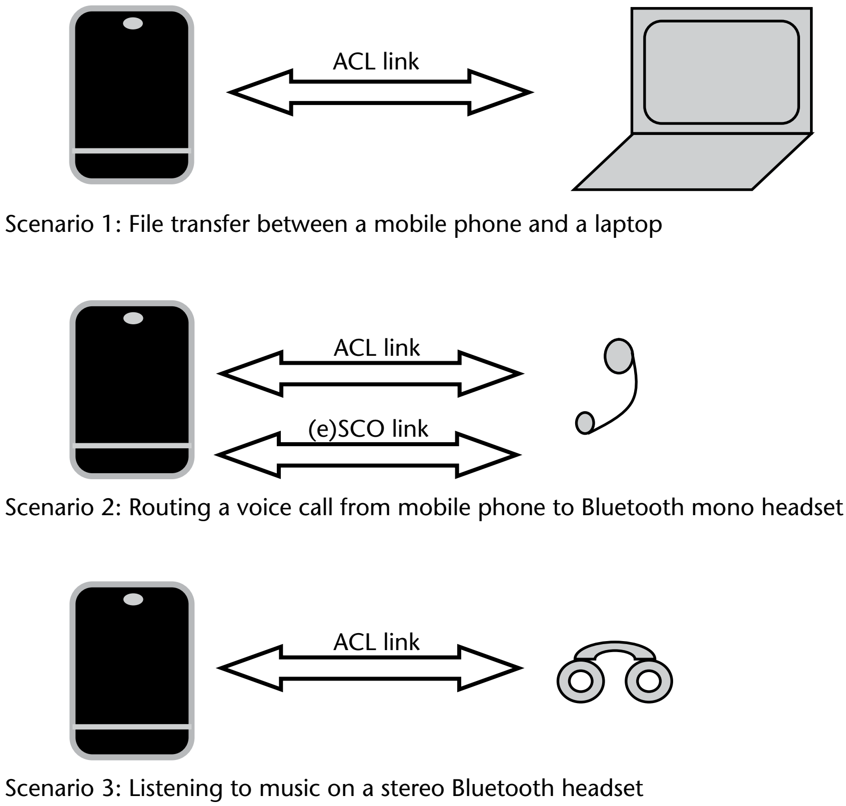

Figure 3.5 Usage of different link types.

generally encoded in a different format by the mobile phone (by default Bluetooth specification specifies the usage of an SBC codec) and then streamed on the ACL link.

The link to transfer *music* should not be confused with the link to transfer *voice*. Music links require much higher bandwidth as compared to voice links. This is because voice is sampled at 8 KHz (or 16 KHz for Wideband speech) while music is sampled at (up to) 48 KHz.

The SCO link has bandwidth to carry only 8 KHz voice. This can be enhanced to 16 KHz by using eSCO links. This is still not sufficient for music links.

So music is transferred over ACL links that provide a much higher bandwidth. In fact even in the case of ACL links, the bandwidth is not sufficient to transfer raw music. So the music file is first encoded and then transmitted. It is decoded after reception and then played back.

If this is not clear at this stage, just hang on and we will revisit the subject when we discuss Bluetooth profiles and in particular the A2DP profile in the next chapter.

3.3.6 Packet Format

The format of BR and EDR packets is shown in Figure 3.6.

All transmissions begin with an access code. This is the only mandatory part of a packet; all other parts are optional. It is used for synchronization, DC Offset compensation, and identification. All packets sent on the same physical channel are preceded by the same access code. It indicates the arrival of a packet on the receiver side.

Three different access codes are defined:

- *Device Access Code (DAC):* This is used during pre-connection phase when the devices are trying to connect to each other.
- *Channel Access Code (CAC):* This is used when the devices are connected and is prefixed to all packets that are exchanged between the devices in a piconet. The receiver uses this code to check if the packet belongs to the piconet that it is in or not.
- *Inquiry Access Code (IAC):* This is used during the inquiry phase when the devices try to find out other devices in the Bluetooth vicinity.

The packet header contains the following information:

- *Logical Transport Address (LT_ADDR):* Indicates the logical transport address of the destination device.
- *Packet Type (TYPE):* Various packet types are defined for ACL, SCO and eSCO logical transports. These will be explained in detail in the next section.
- *Flow control (FLOW):* To start and stop the flow of packets depending on whether the receiver is capable of receiving more packets or not. (For example if the buffers in the receiver are full, then this bit will be used to indicate to the transmitter to stop sending further packets)
- *Acknowledgment (ARQN):* Positive or negative acknowledgment to indicate the transmitter of a successful transfer of payload data after checking the CRC.
- *Sequence Number (SEQN):* Sequential numbering of packets to ensure that packets are received in the correct order.
- *Header Error Check (HEC):* To check the header integrity on reception. If the HEC is incorrect on the receiver side, the entire packet is discarded.

ACCESS CODE	HEADER	PAYLOAD

Standard Basic Rate (BR) packet format

ACCESS CODE	HEADER	GUARD	SYNC	PAYLOAD	TRAILER

Standard Enhanced Data Rate (EDR) packet format

Figure 3.6 BR and EDR packet formats.

The payload contains the data that is to be transferred along with the CRC. The data can have asynchronous data field, synchronous data field or both. The ACL data packets have the asynchronous data field and the SCO/eSCO packets have the synchronous data field. There are a special DV packet types which are defined as a part of SCO packet types. These have both asynchronous and synchronous data field.

For EDR packets, GUARD and SYNC fields are placed before the payload and a TRAILER field is placed after the payload. This is because EDR packets use a different modulation scheme for the payload to achieve higher data rates. These fields are used to facilitate the change in the modulation scheme just before payload data is transmitted.

3.3.7 Packet Types

Different logical transports use different packet types. As mentioned in the previous section, the TYPE field within the packet header is used to indicate the various packet types. Before getting into the details of the packet types, it's important to understand the nomenclature. Figure 3.7 shows the significance of each of the alphabets in the packet types 3DH5 and 2EV3.

The Packet types can be classified into 3 broad categories:

1. Link Control Packets.

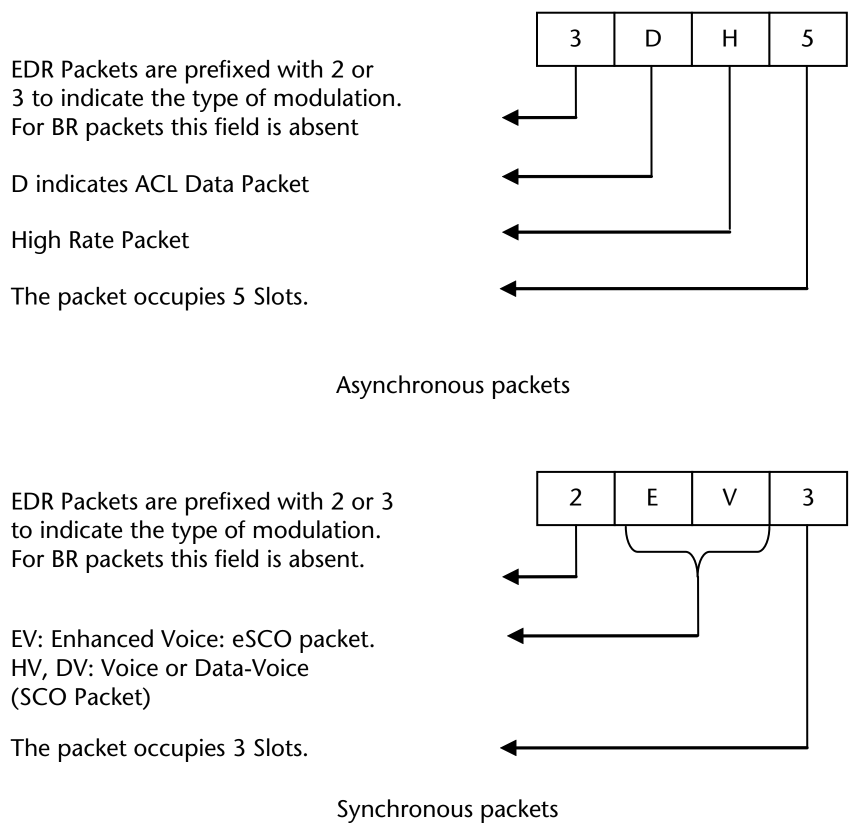

Figure 3.7 Packet nomenclature.

2. ACL Packets.
3. Synchronous Packets.

These are briefly described in the following sections.

3.3.7.1 Link Control Packet Types

There are 5 link control packet types:

- ID;
- NULL;
- POLL;
- FHS;
- DM1.

The ID (Identity) packet is used before connection establishment. It's a very robust packet and contains the device access code (DAC) or inquiry access code (IAC). It does not have a packet header of payload.

The NULL packet has no payload. It is generally used to indicate success of the previous transmission or status of receive buffer. Typically this is used when a Slave receives a packet from the Master and it has to acknowledge that packet but it has no data to send back to the Master. So the Slave uses the NULL packet to acknowledge. The Slave also uses the NULL packet to indicate to the Master if its receive buffers are full. The Master will then halt transmissions till the time the Slave empties its buffers to receive further packets. The default packet type for data is NULL. This is used if there is no data to be sent. The NULL packet itself is not required to be acknowledged by the Master.

The POLL packet is quite similar to the NULL packet. It also does not have a payload. It is sent only by the Master. The Master generally uses this packet to poll the Slaves to first detect whether they are still present and secondly to check if they have any data to send. Unlike the NULL packet, the POLL packet must be

Table 3.2 Summary of Link Control Packets

Type	*Remarks*
ID	Identity (ID) packet. This packet is used before connection establishment to pass on an address.
NULL	The NULL packet has no payload. It is generally used to indicate success of previous transmission or status of Rx buffer.
POLL	The POLL packet has no payload. It is generally used by the Master to poll the Slaves. The Slave responds to this with a packet. If it doesn't have any information to send, it responds with a NULL packet.
FHS	The Frequency Hop Synchronization (FHS) contains real time clock information. It is used for frequency hop synchronization before the piconet channel has been established or when existing piconet changes to a new piconet (by means of a role switch).
DM1	The DM1 (Data Medium Rate 1-slot) packet type is used to carry control packets and data packets.