BSc in Computer Engineering
CMP4204
Wireless Technologies

Lecture 07

Wireless Personal Access Network (WPAN)

Eng Diarmuid O'Briain, CEng, CISSP

Department of Electrical and Computer Engineering,
College of Engineering, Design, Art and Technology,
Makerere University

Table of Contents

Illustration Index

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1. Introduction

A Wireless Personal Access Network (WPAN) is a short-distance wireless network specifically designed to support portable and mobile computing devices such as smartphones, laptops, wireless printers and storage devices, pagers, set-top boxes, and a variety of consumer electronics equipment.

Bluetooth is an example of a wireless PAN that allows devices within close proximity to join together in ad-hoc wireless networks in order to exchange information.

Many smartphones have radio interfaces for the cellular mobile network, WLAN and one for PAN connections.

1.1 Wireless Personal Access Network (WPAN)

WPANs such as Bluetooth provide the bandwidth and convenience to make data exchange practical for mobile devices such as smartphones, tablets and laptops.

Bluetooth overcomes many of the complications of other mobile data systems such as cellular packet data systems, however the reach of a WPAN is typically a few metres.

1.2 Piconets

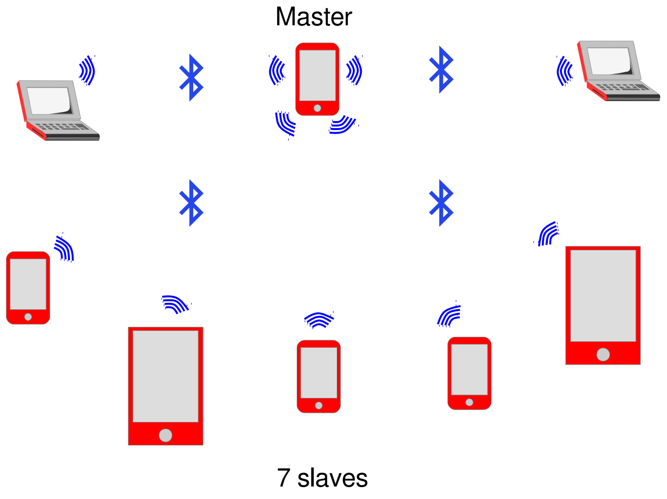

Illustration 1: Piconet

Up to 8 active Bluetooth devices can form or become part of a *Piconet*. Bluetooth allows wireless data connections within the *piconet* to be dynamically added and removed between nearby devices. Because the Bluetooth system hops over 79 channels, the probability of overlapping with another Bluetooth system is less than 1.5%. This allows several Bluetooth *Piconets* to operate in the same area at the same time with minimal interference.

Bluetooth communication designates one of the bluetooth devices as a main controlling *master* unit. Other devices that follow the *master* unit are *slave* units to the master. This allows the Bluetooth system to be non-contention based, in other words no collisions and that once a *slave* is added to the *piconet* it is assigned a specific time period to transmit and this does not overlap with devices within the same *Piconet*.

1.3 Scatternets

A *scatternet* is when a *piconet* is configured to interact with other *piconets* to form a larger network. In a *scatternet* the master in one *piconet* can operate as a *slave* in another *piconet*. This permits cross-Piconet communication. *Scatternets* require synchronisation and the sharing of data transmission bandwidth which in turn makes them less efficient.

2. IEEE 803.15 WPAN

The IEEE 802.15 working group is responsible for the development of the different flavours of bluetooth and has a number of sub-committees.

- 802.15.3
  - High-bandwidth (about 55 Mb/s)
  - Low-power MAC and PHYsical layers.
- 802.15.4
  - Low-bandwidth (about 250 kb/s)
  - Extra-low power MAC and PHYsical layers.

The original functional requirement was published in January 22, 1998, and specified devices with:

- Power management: low current consumption
- Range: 0 - 10 m
- Speed: 19.2 - 100 kb/s
- Small size: 12mm^3 without antenna
- Low cost relative to target device
- Should allow overlap of multiple networks in the same area
- Networking support for a minimum of 16 devices.

IEEE 802.15 WPAN has four task groups:

- Task group 1
  - Based on Bluetooth. Defines PHY and MAC for wireless connectivity with fixed, portable, and moving devices within or entering a personal operating space.
- Task group 2
  - Focused on coexistence of WPAN and 802.11 WLANs.
- Task group 3
  - PHY and MAC layers for high-rate WPANs (higher than 20 Mb/s).
- Task group 4
  - Ultra-low complexity, ultra-low power consuming, ultra-low cost PHY and MAC layer for data rates of up to 200 kb/s.

3. Bluetooth

The bluetooth idea was to create a universal radio interface for ad-hoc wireless connectivity which would interconnect computer and peripherals, handheld devices, Personal Digital Assistants (PDA), cell phones as a replacement of Infrared Data Association (IrDA) devices. Of course in the meantime this list has adjusted as the PDA became obsolete and the smartphone and tablet developed.

It was expected that bluetooth would be embedded in other devices with a goal of €5 (20,000 UGX) per device and €50 (200,000 UGX) for USB bluetooth devices in 2002. Devices could work at a short range of about 10m with low power consumption and operate in the Short Range Device (SRD) Industrial, Scientific and Medical (ISM) license free band at 2.45 GHz. Voice and data transmission were expected to have a gross data rate of 1 Mb/s.

3.1 Characteristics of bluetooth

- 2.4 GHz ISM band, 79 RF channels, 1 MHz carrier spacing.
- Channel 0 : 2402 MHz … channel 78: 2480 MHz.
- Modulation: Gaussian Frequency Shift Keying (GFSK).
- Transmit power: 1-100 mW.
- Frequency Hopping Spread Spectrum (FHSS) and Time Division Duplex (TDD).
- Frequency hopping with 1600 hops/s.
- Hopping sequence in a pseudo random fashion, determined by a master.
- Time division duplex for send/receive separation.
- Voice link: Synchronous Connection Oriented (SCO).
- Forward Error Correction (FEC), no retransmission, 64 kb/s duplex, point-to-point, circuit switched.
- Data link – Asynchronous ConnectionLess (ACL).
- Asynchronous, fast acknowledge, point-to-multipoint, up to 433.9 kbit/s symmetric or 723.2/57.6 kbit/s asymmetric, packet switched.

3.2 Frequency band

The 2.4 GHz to 2.483 GHz ISM band was chosen for bluetooth because it is available for use in most countries throughout the world.

3.3 Interference Between Bluetooth and 802.11

The WLAN industry specified three levels of overlapping:

- **Interference**: multiple wireless networks are said to interfere with one another if co-location causes significant performance degradation
- **Coexistence**: multiple wireless networks are said to coexist if they can be co-located without significant impact on performance. It provides for the ability of one system to perform a task in a shared frequency band with other systems that may or may not be using the same rules for operation
- **Interoperation**: provides for an environment with multiple wireless systems to perform a given task using a single set of rules.

3.4 Bluetooth address

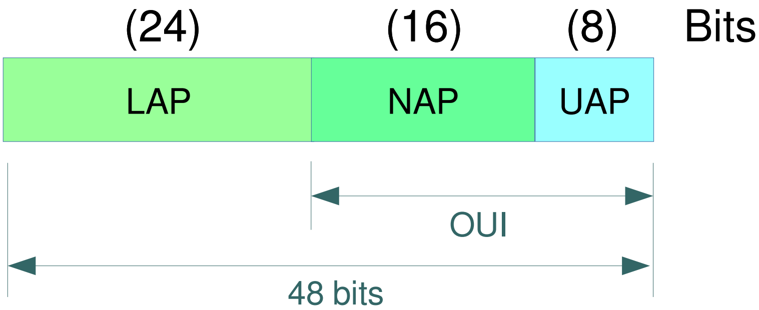

Illustration 2: Bluetooth address (BD_ADDR)

Every Bluetooth device has a unique 48-bit address (BD_ADDR) that is similar to a Medium Access Control (MAC) on an Ethernet Network Interface Card (NIC). In addition to identifying each Bluetooth device, this address is used to determine the frequency hopping pattern that is used by the Bluetooth device.

Illustration 2 demonstrates the structure of the BD_ADDR. The upper 24 bits are formed from the Upper Address Part (UAP) which is defined by the IEEE and the non-significant Address Part (NAP) is also defined by the IEEE and identify the hardware manufacturer, together they are the an Organisation Unique Identifier (OUI) and the Lower Address Part (LAP) of 24 bits that are the device specific identifier assigned by the manufacturer of the device.

3.5 Bluetooth packet

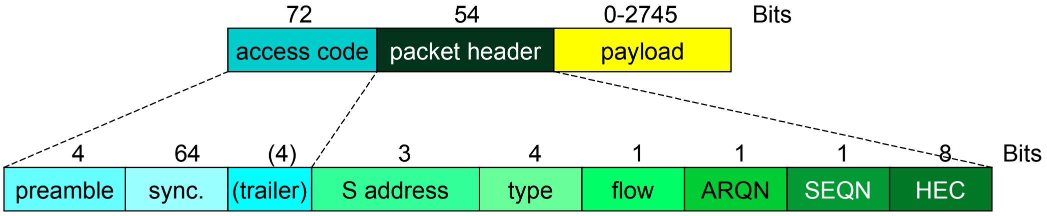

Illustration 3: Bluetooth packet format

The 48 bit address unique to every Bluetooth device is used as the seed to derive the sequence for hopping frequencies of the devices. There are 4 types of access code:

- **Type 1**: identifies a Master (M) terminal and its piconet address
- **Type 2**: identifies a Slave (S) identity used to page a specific Slave (S)
- **Type 3**: Fixed access code reserved for the inquiry process
- **Type 4**: Dedicated access code reserved to identify specific set of devices such as fax machines, printers, or cell phones.

The Header consists or 18 bits repeated 3 times with a 1/3 Forward Error Correction (FEC) code.

S-address allows the addressing the 7 possible S terminals in a piconet. The 4-bit packet type allows for 16 choices of different grade voice systems, 6 of these payload types are Asynchronous Connection-Less (ACL), primarily used for packet data communication, 3 are Synchronous Connection-Oriented (SCO), primarily used for voice communications, 1 is an integrated voice SCO and data ACL packet while 4 are control packets common for both SCO and ACL links.

3.5.1 Control packets

There are 4 control packet types:

- **ID**: occupies half of a slot, and it carries the access code with no data or even a packet type code.
- **NULL**: used for ACK signalling, and there is no ACK for it.
- **POLL**: similar to the NULL, but it has an ACK
  - Both NULL and POLL have the access code and the header, and so they have packet type codes and status report bits
  - Master (M) terminals use the POLL packet to find the Slave (S) terminals in their coverage area.
- **Frequency Hop Synchronisation (FHS)**: carries all the information necessary to synchronise two devices in terms of access code and hopping timing. This packet is used in the inquiry and paging process.

3.6 Data transmission

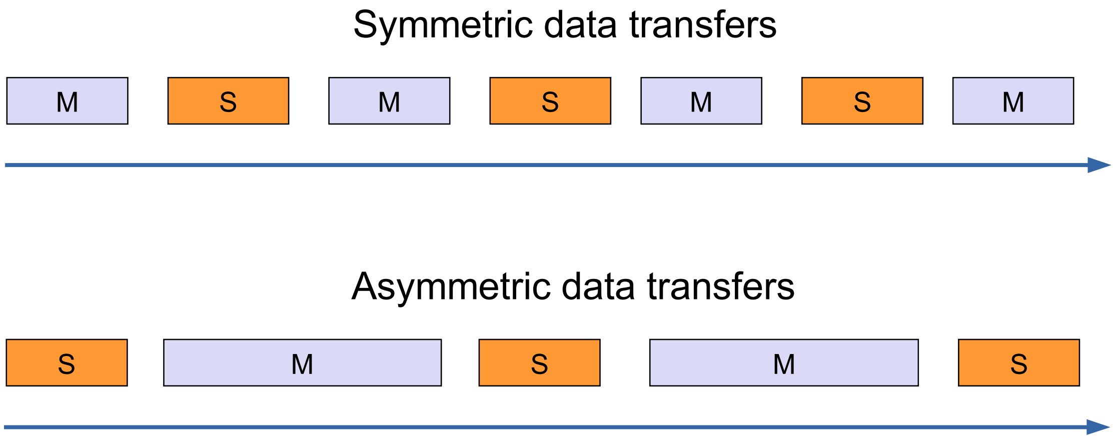

Illustration 4: Data transmission

The radio channel data transmission rate for a single Bluetooth radio channel is 1 Mb/s with over 723.2 kb/s available to any single user. Bluetooth v2.0 provides a data transmission rate to 2 Mb/s to 3 Mb/s dependent on which modulation technology is used. Bluetooth v3.0 provides theoretical data transfer speeds of up to 24 Mb/s but in this case the bluetooth link is used for negotiation and establishment, and the high data rate traffic is carried over a co-located 802.11 link.

The data rate available to each user is less than the radio channel data transmission rate, accounted for because of the control and channel management traffic. Each of the users in a Piconet must also split the total available data transmission rate.

The Bluetooth system allows asymmetrical or symmetrical data rates. i.e. A headset carrying voice requires symmetric 64 kb/s (128 kb/s) but an bluetooth speaker requires more traffic to the speaker so asymmetric is preferable.

Illustration 4 demonstrates how the Bluetooth system can provide symmetrical or asymmetrical data transmission rates. Symmetrical data transmission rates allocate the same bandwidth for each direction while asymmetrical data transmission rates can provide for different transmission rates in each direction.

4. Bluetooth radio

4.1 Frequency Hopping

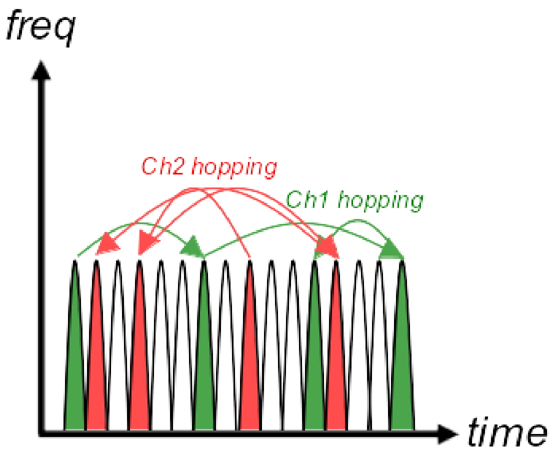

Illustration 5: Frequency Hopping Spread Spectrum (FHSS)

Frequency Hopping Spread Spectrum (FHSS) systems transmit the signal by varying (hopping) the frequency of the carrier in a pseudo-random manner unique to each user. As can be seen in Illustration 5 each channel is rapidly changing the instantaneous carrier frequency following a pseudo-random pattern. This makes the signal appear like background noise and resistant to interference from narrowband channels. A narrowband radio signal at a certain frequency would only encounter interference 1/75 of the time in the presence of an FHSS signal. Multiple FHSS systems can easily co-exist as well timed pseudo-random frequency generator protocols can ensure they will never interfere with each other. In the case of bluetooth, 79 communication channels can be used. In the face of interference the bluetooth devices will automatically change their hopping pattern to avoid the interference.

4.2 Modulation Types

The initial bluetooth modulation type was highly reliable Frequency Shift Keying (FSK) modulation system called Gaussian Frequency Shift Keying (GFSK) modulation. Frequency changes with GFSK are not sharp changes and it was chosen because instantaneous frequency changes require more expensive electronic components and higher power. Gradual frequency changes as seen in GFSK allow for lower-cost equipment with lower RF leakage as was required by bluetooth. Illustration 6 shows how frequency varies as a result of encoding the binary word (1001101) using 2GFSK.

The illustration also shows the binary word (01001110) sent using 4GFSK, note that only half the signal states are required for this word but there are twice the number of available frequencies.

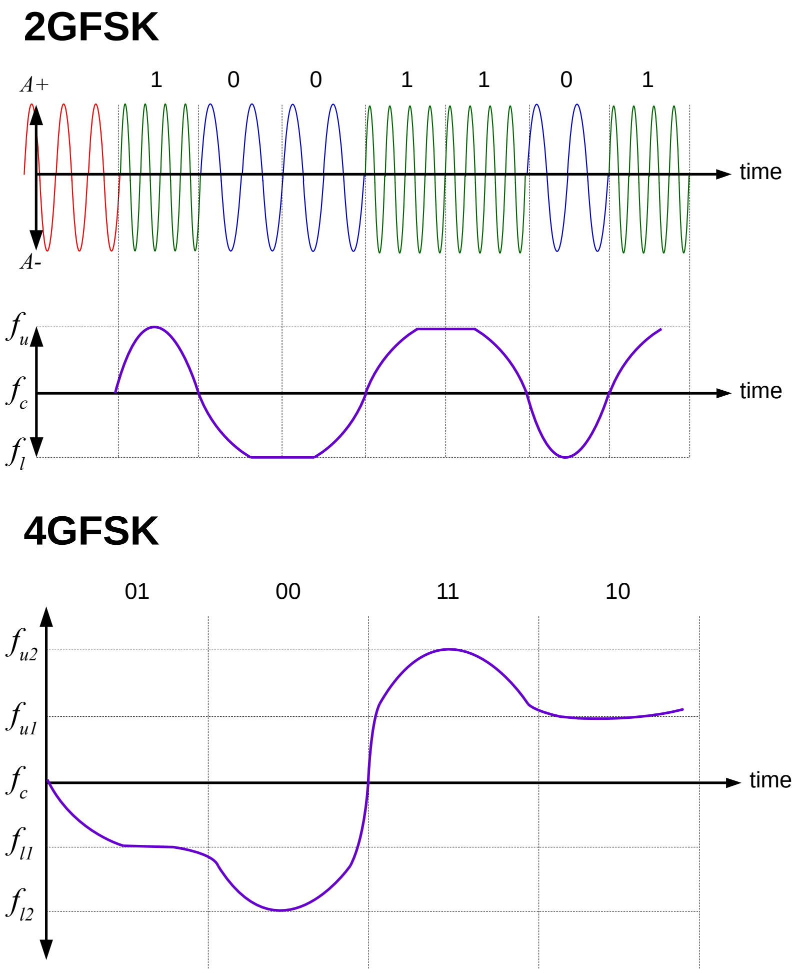

Illustration 6: Gaussian Frequency Shift Keying (GFSK)

Bluetooth systems from version 2.0 and above can use either GFSK, π/4 QPSK or D8PSK. GFSK provides 1 bit per symbol, pi/4 QPSK provides 2 bits per symbol and 8DPSK provides 3 bits per symbol.

4.3 Bluetooth power classes

Class	Max power		Range (m)
	(mW)	DBm	
1	100 mW	20	100
2	2.5 mW	4	10
3	1 mW	0	1
4	0.5 mW	-3	0.5

Illustration 7: Bluetooth classes

Bluetooth devices may have different RF power classification levels. Illustration 7 demonstrates the three different classes. Devices that have an extremely low power level of 1 milliwatt have a very short range of approximately 1m. Bluetooth devices that have a power level of up to 100 milliwatts can provide a transmission range of approximately to 100m. Adjustable dynamic power control that automatically is reduced when enough signal strength is available between Bluetooth devices is a requirement for Class 1.

5. Operation

Bluetooth systems operate by allowing devices to discover other nearby Bluetooth devices, creating a connection between the devices, exchanging information that can validate the identify of other devices (security), and adding channel paths between services or application.

- **Device Discovery** - Find other devices if they have been configured to be discoverable and what their capabilities are
- **Device Connection** - Setting up a communication path between devices which can transport information
- **Bluetooth Pairing** - Validating the identity of other devices uses secret keys and security codes
- **Logical Channels** - Sharing the transmission channel for services or applications
- **Service Discovery** – determine the capabilities the connected device has.

5.1 Device Discovery

Device discovery is the processes used to request and receive the address, name, and services of other devices. Device discovery information that is gathered includes the device address, clock setting, class of device, used page scan mode, and names of devices.

Devices must be setup to allow other devices to communicate with them. A discoverable device is a communication device that is within range of another communication device that will respond to an *Inquiry* message. There are two types of discoverable modes: *limited* and *general*. In the first case, a device may be available for discovery for a limited period of time, during temporary conditions, or for a specific event. In the second case, a device may be available for discovery on a continuous basis.

5.2 Connecting

Connecting Bluetooth devices is the process of creating a communication session between devices. To create a connection, a physical channel and a logical channel must be setup. This involves paging, negotiating and accepting connection transmission parameters.

5.2.1 Page Scan (listen)

Creating a connection between Bluetooth devices starts by getting the attention of a device by paging it. To help ensure that messages from a paging device will be received by the paged device, the paging device hops using the hopping sequence of the device that it is paging. This is a unique sequence of 32 paging frequencies and 32 response frequencies based on the device Global ID (BD_ADDR).

Connectible devices periodically listen for page messages for brief periods. A page message contains its own Device Access Code (DAC). Bluetooth devices can briefly listen for inquiry messages, briefly listen for page messages, and still have time to perform many other tasks.

Now that the device knows the address of the Bluetooth device it wants to connect to, the connection process usually takes less than 1-2 seconds. The ability of a device to allow c*onnections* is optional. Bluetooth devices can be programmed to disallow other devices to connect to them, this is called a *non-connectable* state.

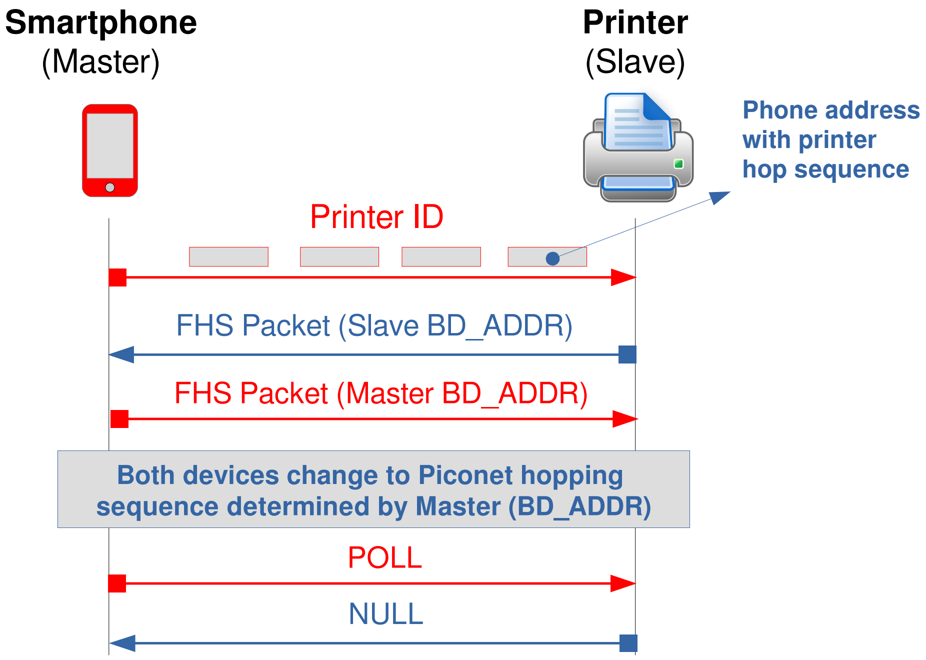
Smartphone
(Master)
Printer
(Slave)
Phone address
with printer
hop sequence
Printer ID
FHS Packet (Slave BD_ADDR)
FHS Packet (Master BD_ADDR)
Both devices change to Piconet hopping
sequence determined by Master (BD_ADDR)
POLL
NULL

Illustration 8: Device connect

Illustration 8 demonstrates how a Bluetooth device can connect to other devices.

The Bluetooth master unit first sends many ID packets using the hopping sequence of the recipient device.

When the printer hears its ID address, it immediately responds with a Frequency Hopping Synchronisation (FHS) packet. This is a special control packet revealing, the BD_ADDR and the clock of the source device. It contains 144 info bits and a 16-bit Cyclic Redundancy Check (CRC).

This allows the master to send a FHS packet that contains the master's Bluetooth Address (BD_ADDR).

Both the master and slave change their hopping sequence to the Piconet hopping sequence which is determined by the master's BB_ADDR. The master then sends out a POLL message using the new hopping sequence and the slave will typically respond with a NULL response.

5.3 Pairing

Device pairing is the process of associating two devices with each other. During the pairing process, identifying information that is unique to each device is stored in the paired device. After devices have been paired, they can automatically identify each other during future communication sessions. Once a radio channel has been connected a logical channel is established.

5.4 Service Discovery

Service discovery is the process of a bluetooth device making a determination as to the capabilities the connected device has.

To discover the services of another device, a device uses the device address and establish a temporary connection. A service discovery application (LocDev) uses Service Discovery Protocol (SDP) to inquires as to the capabilities of the remote device. Devices may be programmed not to respond to such inquiry messages.

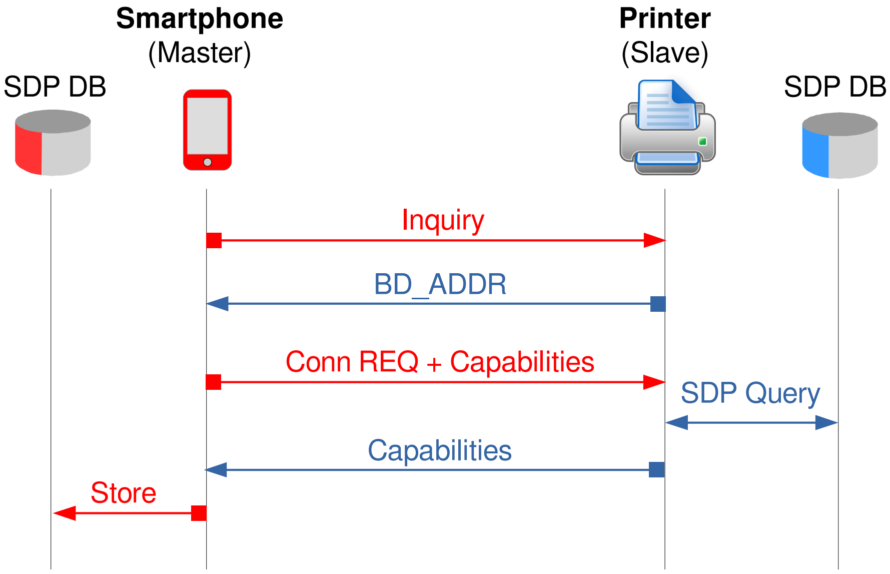

Illustration 9: Service Discovery Protocol

Illustration 9 demonstrates the typical service discovery operation of a smartphone that requires access to a local bluetooth printer. The phone acts as a master unit and sends out a *Type 3 Inquiry* message to a printer which will become the slave unit. The printer responds with its Bluetooth device address (BD_ADDR). The phone sends a connection request plus a capabilities inquiry of the printer. The printer returns the capabilities requested from its SDP database and the phone stores these capabilities in its SDP database. The printer becomes available in the phone printer settings with its capabilities, double-sided, colour etc..

5.5 Modes of Operation

A Bluetooth device may assume any of four connected modes once a connection is present.

Purpose	Mode	Addressing	State	Power	Master to Slave Access Time
Active mode enables master/slave communications in any given frame.	Active	AMA	Connected	High	Any given frame (1250 ms)
Hold mode frees a slave for a predetermined one time hold period.	Hold	AMA	Connected	Low	At end of hold duration (T hold)
Sniff mode frees a slave for predetermined, recurring, fixed time periods.	Sniff	AMA	Connected	Low	At end of sniff intervals (T sniff)
Parking mode enables a master to connect to as many as 255 parked devices in addition to its 7 active devices.	Park	PMA	Parked	Lower	At beacon time intervals (T beacon) plus some reconnection overhead
Standby mode is the default mode for any Bluetooth device.	Standby	None	Standby	Lowest	Paging cycle or Inquiry & Paging cycle (2-10s)

Illustration 10: Bluetooth modes

5.5.1 Active mode

Active mode enables master/slave communications in any given frame. In this mode the device actively participates in the channel and the master allocates transmissions based on demands. This mode supports regular transmissions to maintain device synchronisation. Active mode is limited to 7 devices by the 3-bit Active Member Address (AMA).

5.5.2 Hold Mode

Hold mode frees a slave for a predetermined one time hold period. When connected, the ACL link to a slave can be put in Hold mode such that the slave temporarily does not support ACL packets while SCO links are still supported.

This mode permits the slave to do other things like scanning, paging, inquiring, attending to other piconets, or simply sleeping.

Before entering hold mode the master and slave agree on the time duration for the hold period and the slave unit keeps its AMA. A timer is initialised with the hold timeout value. The slave returns to the Piconet when the timer expires, synchronises to the traffic on the channel and waits for instructions from the master.

5.5.3 Sniff mode

Sniff mode is a process of listening for specific types of command that occur periodically and the mode frees a slave for predetermined, recurring, fixed time periods. It provides a connected slave a recurring series of free time such that the master can only communicate during specified Sniff time slots with the slave in this mode. Again the slave is freed to do other things like scanning, paging, inquiring, attending to other piconets, or simply sleeping. During this mode, the slave unit keeps its active member address (AMA).

5.5.4 Parking mode

Parking mode enables a master to connect to as many as 255 parked devices in addition to its 7 active devices. A parked slave remains synchronised to the Piconet but does not actively participate. The parked slave surrenders its AMA for a Parked Member Address (PMA) and an 8 bit Access Request Address (ARA) which permits up to 255 parked devices per Piconet. The PMA and ARA are used for Master/Slave and Slave/Master communications at Beacon intervals. By swapping active and parked slaves in and out of a piconet, the number of slaves connected can be much larger with up to 7 Active slaves with 3-bit AMAs and up to 255 Parked slaves with the 8-bit PMAs.

The Beacon channel supports Piconet access of parked slaves. When being parked a slave is given a beacon period and can be changed at a Beacon interval. Beacon transmissions can extend over multiple Slots in a Beacon Train. Beacon Slots must have master-to-slave traffic and if there is no information to be sent null packets are transmitted by the master. If this beacon signal contains the address of the parked device, the device will reactivate and become part of the piconet again. The maximum time period that can be assigned for hold, sniff, or park sleep mode is 65,440 slots (approximately 40 seconds).

5.5.5 Standby mode

Standby mode is the default mode for any Bluetooth device.

By changing modes Bluetooth devices can adjust the power, performance, and number of attached devices to the Piconet.

5.6 Protocol Layers

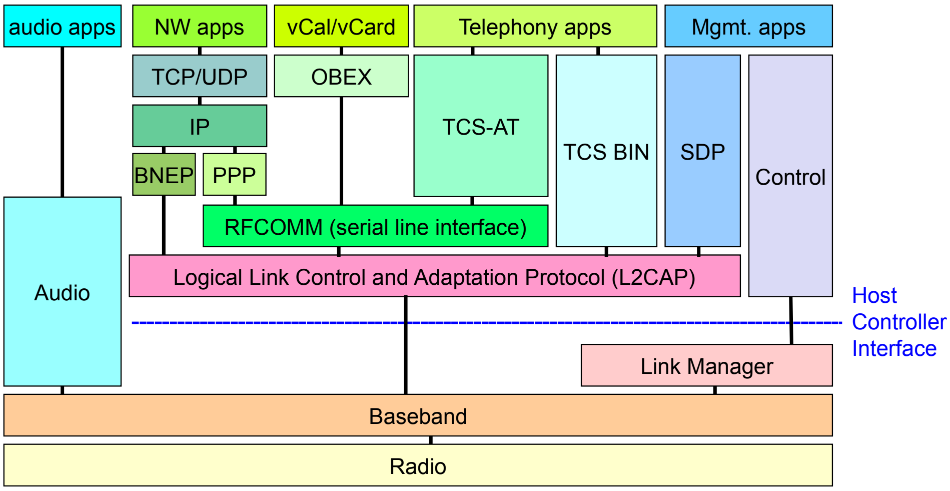

Illustration 11: Protocol layers

Illustration 11 demonstrates the inter-relationship between the different protocols involved in bluetooth. Some of the layers associated with the Bluetooth system include the Baseband Layer (PHYsical Layer), Link layer, Host Controller Interface (HCI), Logical Link Control Applications Protocol (L2CAP), RF COMMunications protocol (RFCOMM), OBject EXchange (OBEX), and service discovery.

- **Link Manager** (LM)
  - The Link Manager software entity carries out link setup, authentication, link configuration, and other protocols.
- **Link Manager Protocol** (LMP)
  - LMP is used for link setup and control. LMP messages are interpreted and filtered out by the Link Manager on the receiving side and are not propagated to higher layers.
- **Host Controller Interface** (HCI)
  - An application layer which provides a command interface to the LM and Baseband layers.
- **Logical Link Control Applications Protocol** (L2CAP)
  - Supports higher level protocol multiplexing, packet segmentation and reassembly, and the conveying of quality of service information.
- **RF COMMunications protocol** (RFCOMM),
  - Serial Cable Emulation Protocol.
- **OBject EXchange** (OBEX)
  - Communications protocol that facilitates the exchange of binary objects between devices like business cards, data, even applications.

- **Telephony Control Specification** (TCS)
  - TCS-AT - A set of AT-commands by which a mobile phone and modem can be controlled in the multiple usage models. It is also used for fax services, dial-up networking and headset profiles.
- **TCS BIN** (Binary) - Bluetooth Telephony Control protocol used for cordless telephony profiles.
- **Service Discovery Protocol** (SDP)
  - SDP is a protocol for applications to discover which services are available and to determine the characteristics of those available services.
- **Bluetooth Network Encapsulation Protocol** (BNEP)
  - BNEP is used in Personal Area Networking Profile (PAN).
  - It transports common networking protocols over bluetooth media such as IPv4 and IPv6.
  - Its packet format is based on Ethernet framing as defined by IEEE 802.3. It runs on L2CAP. BNEP is used by the Personal Area Networking Profile (PAN).

6. Bluetooth Versions

Bluetooth has continued to improve and additional features supported by the higher versions are optional and do not affect the encoding and transmission of audio. Higher versions of Bluetooth are backward compatible and will default to the available features of that Bluetooth connection.

Version	Optional Features					Backwards Compatible
	Basic rate (BR)	Enhanced Data Rate (EDR)	High Speed (HS)	Low Energy (LE)	Slot Availability Masking (SAM)	
1	Yes	No	No	No	No	Yes
2	Yes	Yes	No	No	No	Yes
3	Yes	Yes	Yes	No	No	Yes
4	Yes	Yes	Yes	Yes	No	Yes
5	Yes	Yes	Yes	Yes	Yes	No

6.1 Bluetooth Version 1

The basic Bluetooth rate with no additional/optional profiles or codecs. This version of Bluetooth is obsolete and was rarely implemented on mobile devices due to its limited speed of 1 Mb/s and difficulty pairing.

6.2 Bluetooth Version 2

The most popular variant of Bluetooth, especially in the earlier days when phones were not as advanced. It supports Enhanced Data Rates (EDR) up to 3 MB/s, and the v2.1 variant significantly simplified the pairing procedure making it a more practical for commercial use.

6.3 Bluetooth Version 3

An improvement on the speed limitations of v2.1, with the optional High-Speed (HS) feature, which allows the Bluetooth module to transmit over an adjacent radio 802.11 channel. However, v3 consumes a lot more power than v2.

6.4 Bluetooth Version 4

v4 has the high-speed capability of v3 but also comes with a Low Energy (LE) feature to collect data from the sensors of low rate devices. This feature allows the Bluetooth module to reduce power consumption with connected devices like wearable smartwatches, heart monitors, mobile phones and smart headphones.

6.4.1 Bluetooth Low Energy

Bluetooth Low Energy (Bluetooth LE, BLE) is a wireless PAN technology is aimed at applications in the healthcare, fitness, beacons, security, and home entertainment industries. Compared to Classic Bluetooth, BLE provides considerably reduced power consumption and cost while maintaining a similar communication range.

It is predicted that by 2018 more than 90% of Bluetooth-enabled smartphones will support BLE.

BLE however is not backward-compatible with the previous Bluetooth protocols (Classic). The Bluetooth 4.0 specification permits devices to implement either or both of the BLE and Classic systems.

BLE uses the same 2.4 GHz radio frequencies as Classic Bluetooth, which allows dual-mode devices to share a single radio antenna.

6.5 Bluetooth Version 5

Incorporating features for the Internet of Things (IoT). With twice the bandwidth of v4 LE and 4 times the range. It also has a new feature called Slot Availability Masking (SAM) which can detect and prevent interference on neighbouring bands for a more efficient use of broadcasting channels.

Version	Modulation	Max speed	Max range
1	GFSK	1 Mb/s	10 m
2	GFSK, π/4-DQPSK, 8DPSK	3 Mb/s	10 m
3	GFSK, π/4-DQPSK, 8DPSK (802.11g)	24 Mb/s	10 m
4	GFSK, π/4-DQPSK, 8DPSK (802.11n)	24 Mb/s	60 m
5	GFSK, π/4-DQPSK, 8DPSK (802.11n)	50 Mb/s	240 m

6.5.1 Mesh networks

Mesh networks let devices communicate over longer distances because each device in the network can act as a relay. As an example, suppose a sensor is at too great a distance to communicate with directly. With Bluetooth 5 mesh networking, the controller (a phone app perhaps) simply communicates with the closest device within the mesh network and the messages are relayed to and from the device. The key challenge to implement this in Bluetooth is interoperability of devices from multiple vendors. Even today, many Bluetooth applications are 1:1, meaning a device only needs to work properly with a few leading smartphones to cover most user applications. With Bluetooth 5 devices that are intended to work within mesh networks.

Bluetooth 5 will be good for consumers and IoT vendors; it's expected to see significant increases in adoption in low energy, low data rate, short-range applications. There will be new challenges with interoperability and parametric testing, but equipment vendors are already gearing up and test solutions are now available to help with early designs.

7. Self-test Quiz

1. Briefly describe the four types of bluetooth packet.
2. What is the difference between the AMA and PMA addresses ?
3. What is a disadvantage of a scatternet ?
4. Describe the process of device discovery and paring.
5. Describe the process of service discovery.
6. What is the function of BNEP ?
7. What are the additional features of Bluetooth v5 ?