**Overview**

- Universal short-range wireless capability
- Uses 2.4-GHz band
- Available globally for unlicensed users
- Devices within 10 m can share up to 720 kbps of capacity
- Supports open-ended list of applications
  - Data, audio, graphics, video

**Bluetooth Application Areas**

- Data and voice access points
- Real-time voice and data transmissions
- Cable replacement
  - Eliminates need for numerous cable attachments for connection
- Ad hoc networking
  - Device with Bluetooth radio can establish connection with another when in range

**Bluetooth Standards Documents**

- Core specifications
  - Details of various layers of Bluetooth protocol architecture
- Profile specifications
  - Use of Bluetooth technology to support various applications

**Protocol Architecture**

- Bluetooth is a layered protocol architecture
  - Core protocols
  - Cable replacement and telephony control protocols
  - Adopted protocols
  - Radio
  - Baseband
  - Link manager protocol (LMP)
  - Logical link control and adaptation protocol (L2CAP)
  - Service discovery protocol (SDP)

- Cable replacement protocol
  - RFCOMM
- Telephony control protocol
  - Telephony control specification – binary (TCS BIN)
- Adopted protocols
  - PPP
  - TCP/UDP/IP
  - OBEX
  - WAE/WAP
Usage Models
- File transfer
- Internet bridge
- LAN access
- Synchronization
- Three-in-one phone
- Headset

Piconets and Scatternets
- Piconet
  - Basic unit of Bluetooth networking
  - Master and one to seven slave devices
  - Master determines channel and phase
- Scatternet
  - Device in one piconet may exist as master or slave in another piconet
  - Allows many devices to share same area
  - Makes efficient use of bandwidth

Wireless Network Configurations
- Radio Specification
  - Classes of transmitters
    - Class 1: Outputs 100 mW for maximum range
      - Power control mandatory
      - Provides greatest distance
    - Class 2: Outputs 2.4 mW at maximum
      - Power control optional
    - Class 3: Nominal output is 1 mW
      - Lowest power

Frequency Hopping in Bluetooth
- Provides resistance to interference and multipath effects
- Provides a form of multiple access among co-located devices in different piconets

Frequency Hopping
- Total bandwidth divided into 1MHz physical channels
- FH occurs by jumping from one channel to another in pseudorandom sequence
- Hopping sequence shared with all devices on piconet
- Piconet access:
  - Bluetooth devices use time division duplex (TDD)
  - Access technique is TDMA
  - FH-TDD-TDMA

![Figure 15.5 Wireless Network Configurations](image.png)
**Frequency Hopping**

- Synchronous connection oriented (SCO)
- Allocates fixed bandwidth between point-to-point connection of master and slave
- Master maintains link using reserved slots
- Master can support three simultaneous links
- Asynchronous connectionless (ACL)
- Point-to-multipoint link between master and all slaves
- Only single ACL link can exist

**Bluetooth Packet Fields**

- Access code – used for timing synchronization, offset compensation, paging, and inquiry
- Header – used to identify packet type and carry protocol control information
- Payload – contains user voice or data and payload header, if present

**Types of Access Codes**

- Channel access code (CAC) – identifies a piconet
- Device access code (DAC) – used for paging and subsequent responses
- Inquiry access code (IAC) – used for inquiry purposes

**Access Code**

- Preamble – used for DC compensation
  - 0101 if LSB of sync word is 0
  - 1010 if LSB of sync word is 1
- Sync word – 64-bits, derived from:
  - 7-bit Barker sequence
  - Lower address part (LAP)
  - Pseudonoise (PN) sequence
- Trailer
  - 0101 if MSB of sync word is 1
  - 1010 if MSB of sync word is 0

**Packet Header Fields**

- AM_ADDR – contains “active mode” address of one of the slaves
- Type – identifies type of packet
- Flow – 1-bit flow control
- ARQN – 1-bit acknowledgment
- SEQN – 1-bit sequential numbering schemes
- Header error control (HEC) – 8-bit error detection code
### Payload Format
- Payload header
  - L_C field – identifies logical channel
  - Flow field – used to control flow at L2CAP level
  - Length field – number of bytes of data
  - Payload body – contains user data
  - CRC – 16-bit CRC code

### Error Correction Schemes
- 1/3 rate FEC (forward error correction)
  - Used on 18-bit packet header, voice field in HV1 packet
- 2/3 rate FEC
  - Used in DM packets, data fields of DV packet, FHS packet and HV2 packet
- ARQ
  - Used with DM and DH packets

### ARQ Scheme Elements
- Error detection – destination detects errors, discards packets
- Positive acknowledgment – destination returns positive acknowledgment
- Retransmission after timeout – source retransmits if packet unacknowledged
- Negative acknowledgment and retransmission – destination returns negative acknowledgement for packets with errors, source retransmits

### Logical Channels
- Link control (LC)
- Link manager (LM)
- User asynchronous (UA)
- User isochronous (UI)
- Use synchronous (US)

### Channel Control
- States of operation of a piconet during link establishment and maintenance
  - Major states
    - Standby – default state
    - Connection – device connected

### Channel Control
- Interim states for adding new slaves
  - Page – device issued a page (used by master)
  - Page scan – device is listening for a page
  - Master response – master receives a page response from slave
  - Slave response – slave responds to a page from master
  - Inquiry – device has issued an inquiry for identity of devices within range
  - Inquiry scan – device is listening for an inquiry
  - Inquiry response – device receives an inquiry response
### Inquiry Procedure
- Potential master identifies devices in range that wish to participate
- Transmits ID packet with inquiry access code (IAC)
- Occurs in Inquiry state
- Device receives inquiry
- Enters Inquiry Response state
- Returns FHS packet with address and timing information
- Moves to page scan state

### Page Procedure
- Master uses devices address to calculate a page frequency-hopping sequence
- Master pages with ID packet and device access code (DAC) of specific slave
- Slave responds with DAC ID packet
- Master responds with its FHS packet
- Slave confirms receipt with DAC ID
- Slaves moves to Connection state

### Slave Connection State Modes
- **Active** – participates in piconet
  - Listens, transmits and receives packets
- **Sniff** – only listens on specified slots
- **Hold** – does not support ACL packets
  - Reduced power status
  - May still participate in SCO exchanges
- **Park** – does not participate on piconet
  - Still retained as part of piconet

### Bluetooth Audio
- Voice encoding schemes:
  - Pulse code modulation (PCM)
  - Continuously variable slope delta (CVSD) modulation
- Choice of scheme made by link manager
  - Negotiates most appropriate scheme for application

### Bluetooth Link Security
- **Elements**:
  - Authentication – verify claimed identity
  - Encryption – privacy
  - Key management and usage
- Security algorithm parameters:
  - Unit address
  - Secret authentication key
  - Secret privacy key
  - Random number
LMP PDUs

- General response
- Security Service
  - Authentication
  - Pairing
  - Change link key
  - Change current link key
  - Encryption

Time/synchronization
- Clock offset request
- Slot offset information
- Timing accuracy information request

Station capability
- LMP version
- Supported features

Mode control
- Switch master/slave role
- Name request
- Detach
- Hold mode
- Sniff mode
- Park mode
- Power control

- Channel quality-driven change between DM and DH
- Quality of service
- Control of multislot packets
- Paging scheme
- Link supervision

L2CAP

- Provides a link-layer protocol between entities with a number of services
- Relies on lower layer for flow and error control
- Makes use of ACL links, does not support SCO links
- Provides two alternative services to upper-layer protocols
  - Connection service
  - Connection-mode service

L2CAP Logical Channels

- Connectionless
  - Supports connectionless service
  - Each channel is unidirectional
  - Used from master to multiple slaves
- Connection-oriented
  - Supports connection-oriented service
  - Each channel is bidirectional
- Signaling
  - Provides for exchange of signaling messages between L2CAP entities
L2CAP Packet Fields for Connectionless Service

- Length – length of information payload, PSM fields
- Channel ID – 2, indicating connectionless channel
- Protocol/service multiplexer (PSM) – identifies higher-layer recipient for payload
  - Not included in connection-oriented packets
- Information payload – higher-layer user data

Signaling Packet Payload

- Consists of one or more L2CAP commands, each with four fields
  - Code – identifies type of command
  - Identifier – used to match request with reply
  - Length – length of data field for this command
  - Data – additional data for command, if necessary

L2CAP Signaling Command Codes

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x01</td>
<td>Command reject</td>
<td>Reason</td>
</tr>
<tr>
<td>0x02</td>
<td>Connection request</td>
<td>PSM, Source CID</td>
</tr>
<tr>
<td>0x03</td>
<td>Connection response</td>
<td>Destination CID, Source CID, Result, Status</td>
</tr>
<tr>
<td>0x04</td>
<td>Configure request</td>
<td>Destination CID, Flags, Options</td>
</tr>
<tr>
<td>0x05</td>
<td>Configure response</td>
<td>Source CID, Flags, Result, Options</td>
</tr>
<tr>
<td>0x06</td>
<td>Disconnect on request</td>
<td>Destination CID, Source CID</td>
</tr>
<tr>
<td>0x07</td>
<td>Disconnect on response</td>
<td>Destination CID, Source CID</td>
</tr>
<tr>
<td>0x08</td>
<td>Echo request</td>
<td>Data (optional)</td>
</tr>
<tr>
<td>0x09</td>
<td>Echo response</td>
<td>Data (optional)</td>
</tr>
<tr>
<td>0x0A</td>
<td>Information request</td>
<td>InfoType</td>
</tr>
<tr>
<td>0x0B</td>
<td>Information response</td>
<td>InfoType, Result, Data (optional)</td>
</tr>
</tbody>
</table>

L2CAP Signaling Commands

- Command reject command
  - Sent to reject any command
- Connection commands
  - Used to establish new connections
- Configure commands
  - Used to establish a logical link transmission contract between two L2CAP entities
- Disconnection commands
  - Used to terminate logical channel
- Echo commands
  - Used to solicit response from remote L2CAP entity
- Information commands
  - Used to solicit implementation-specific information from remote L2CAP entity

Flow Specification Parameters

- Service type
- Token rate (bytes/second)
- Token bucket size (bytes)
- Peak bandwidth (bytes/second)
- Latency (microseconds)
- Delay variation (microseconds)