Bluetooth 101

Bluetooth 101+

Training for Plantronics

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Contact Info

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Agenda

- Bluetooth Overview
- Bluetooth Air Interface & Baseband
- Bluetooth Protocol Stack
- Bluetooth Profiles
  - HFP
  - A2DP
  - AVRCP
  - PBAP
- New Bluetooth Standards

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What is Bluetooth?

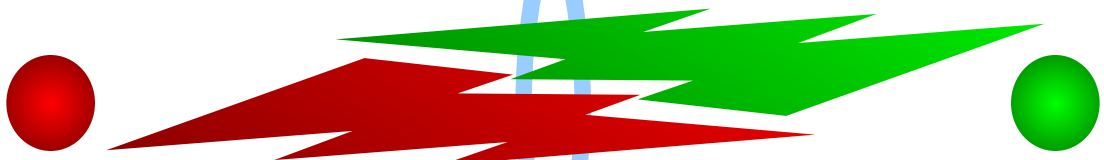
- Robust unlicensed *short range* wireless standard
- It is an open and license free standard for anyone who signs up to be an adopter
- The standard is presided over by the Special Interest Group (SIG)

What does Bluetooth provide?

- Provides point-to-point connections
- Provides ad-hoc networking capabilities
- Bluetooth specification details how the technology works
- Bluetooth Profiles detail how specific applications work to ensure interoperability

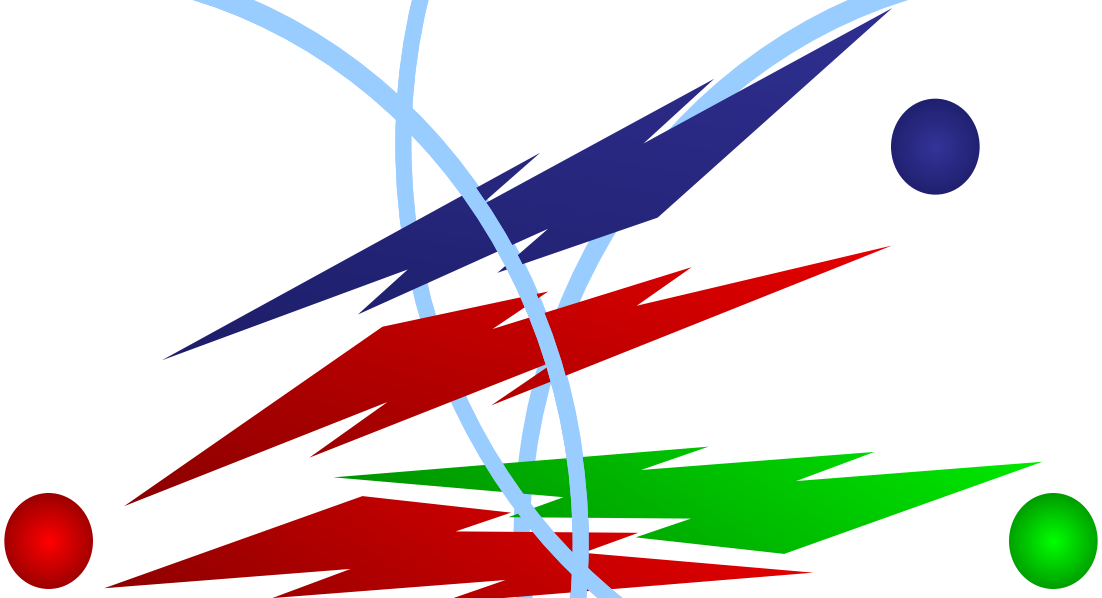
Point-to-point

- Two devices locate each other
- Form a connection and transfer data
- “Wireless cable replacement” scenario
- The device that initiates the connection is called the Master
- Any other devices the Master is connected to are referred to as Slaves



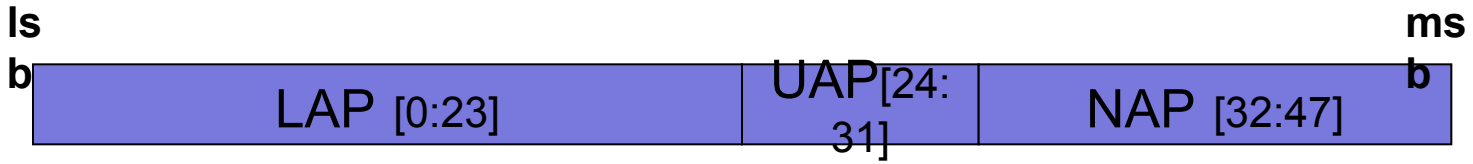
Point-to-multipoint – the Piconet

- Two devices create a point-to-point connection
- A third device comes into range
  - The new device is discovered.
  - It is added to the piconet and data can be transferred



Identifying Bluetooth Devices

- Each Bluetooth device is assigned a unique 48-bit MAC address by the Bluetooth SIG
- This is enough addresses for 281,474,976,710,656 Bluetooth units, this should last a few years even with the optimistic predictions of the analysts!
- The address is split into three parts:
  - LAP: Lower Address Part - used to generate frequency hop pattern and header sync word
  - UAP: Upper Address Part - used to initialize the HEC and CRC engines
  - NAP: Non-significant Address Part - used to seed the encryption engine



Bluetooth Channels

- A master can create two types of logical channel with a slave device:
  - Asynchronous Connection Less (ACL): Packet Switched System provides a reliable data connection with a best effort bandwidth; depends on radio performance and number of devices in the piconet
  - Synchronous Connection Oriented (SCO): Circuit Switched System provides real time unreliable connection with a guaranteed bandwidth; usually used for voice based applications

- The Bluetooth connections are limited to 1Mbps across the air (without EDR)
- This gives a theoretical maximum of ~723kbps of useable data

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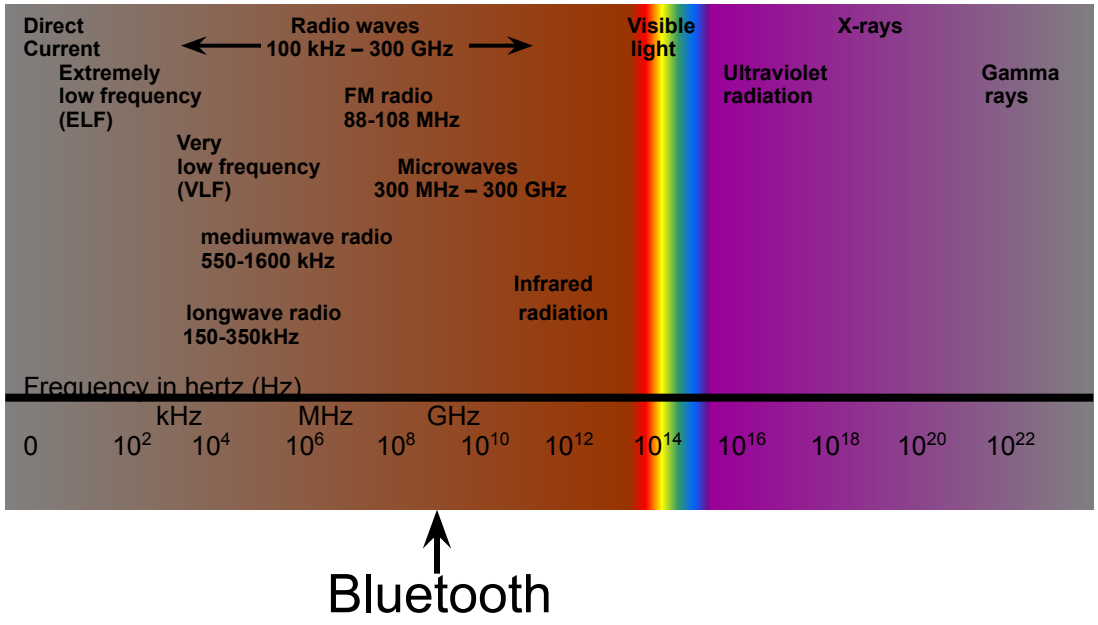
Spectrum Usage

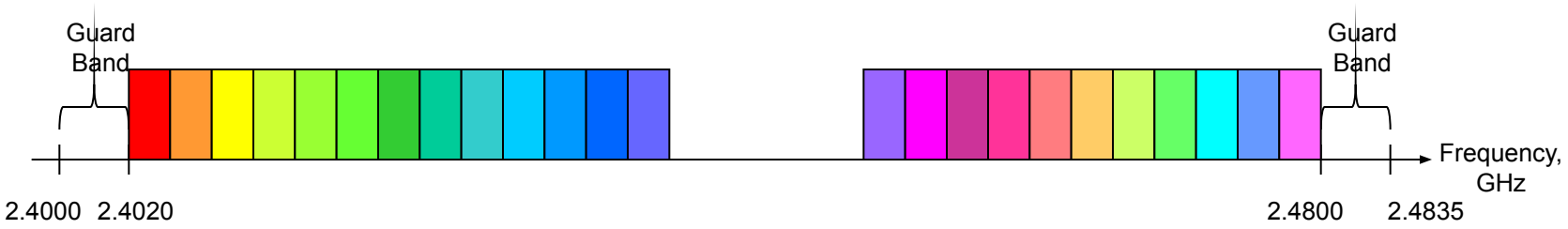
- The 2.4GHz ISM band is a free for all for anyone who wants to use it



- The 2.4GHz ISM Band is also used by:
  - Microwave Ovens
  - Digital Cordless Phones
  - 802.11b/g

Frequency Hopping Spread Spectrum - FHSS

- Bluetooth splits the spectrum up into 79 1MHz wide channels
- The Bluetooth radio changes transmission frequency 1600 times a second for a 1 slot packet type
- The frequency hops follow a pseudo-random sequence that meets the power density requirements for the FCC and other regulatory bodies



Benefits of FHSS

- **Reliability** - If a packet is not correctly received on one channel due to interference it is unlikely that there will be interference on the next channel used to re-transmit the data

- **Low Interference** - Conversely, if Bluetooth is interfering with another system that uses a set of channels, Bluetooth will only use those channels a small proportion of the time

- **Security** - Since the hop pattern is pseudo random it is very difficult for anyone to eavesdrop on the Bluetooth link

Hop Selection and Synchronization

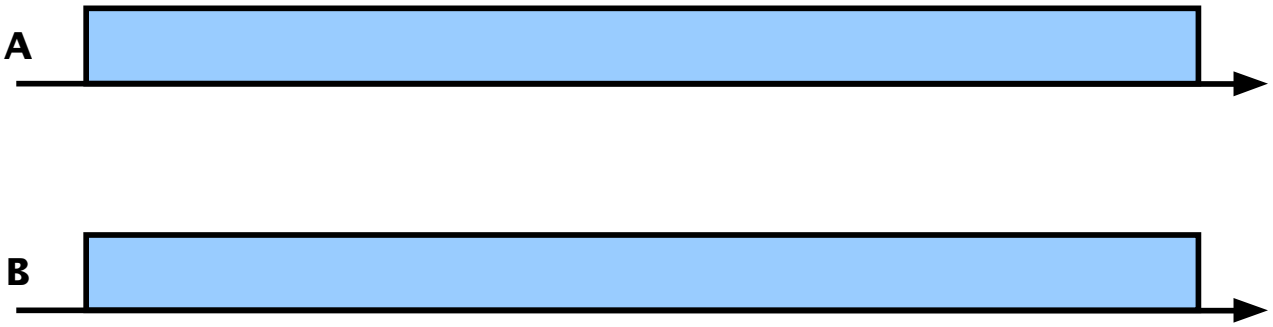
- One frequency hop lasts 625µs, this increment is called a time slot
- Each Bluetooth device has a clock circuit that counts frequency hops
- The address of the master of the piconet is used to seed a frequency hop calculation algorithm
- The phase of the hop sequence is defined by the Bluetooth clock of the master
- Device address and clock phase information is exchanged during connection negotiation
- The slave synchronizes its own clock to the master's during connection so that both devices change frequency at the same time

Adaptive Frequency Hopping

- Introduced in Bluetooth v1.2
- Bluetooth shares the 2.4GHz ISM band with:
  - 802.11b/g Wi-Fi Systems
  - 2.4GHz cordless phones
  - Microwave ovens
- More devices = More interference.
- 802.11b/g does not work well with BT interferers.
- AFH allows BT to avoid known ‘bad’ channels.
- Increased bandwidth, reduced lost data.

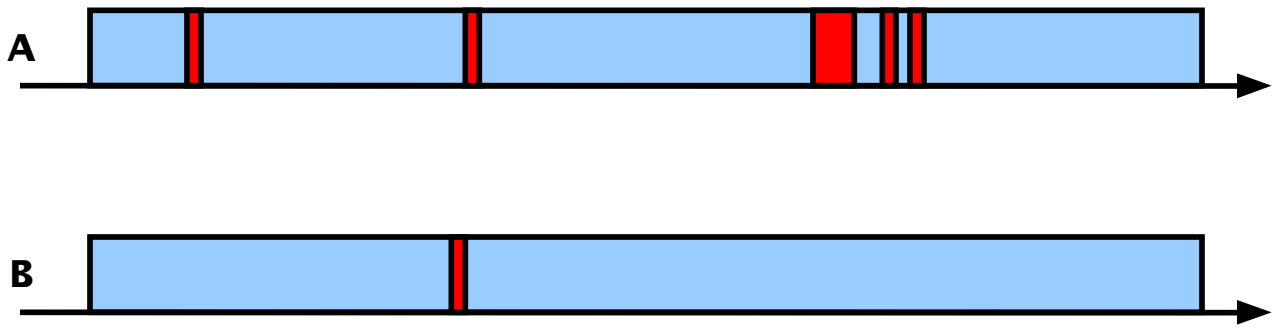
Adaptive Frequency Hopping

- Three steps



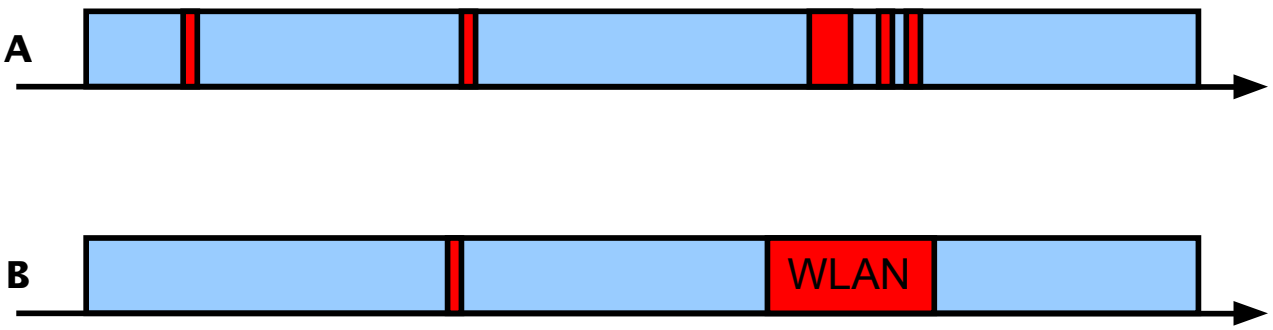
Adaptive Frequency Hopping

- Three steps
  - Identify Bad Channels by monitoring RSSI, BER and/or PER



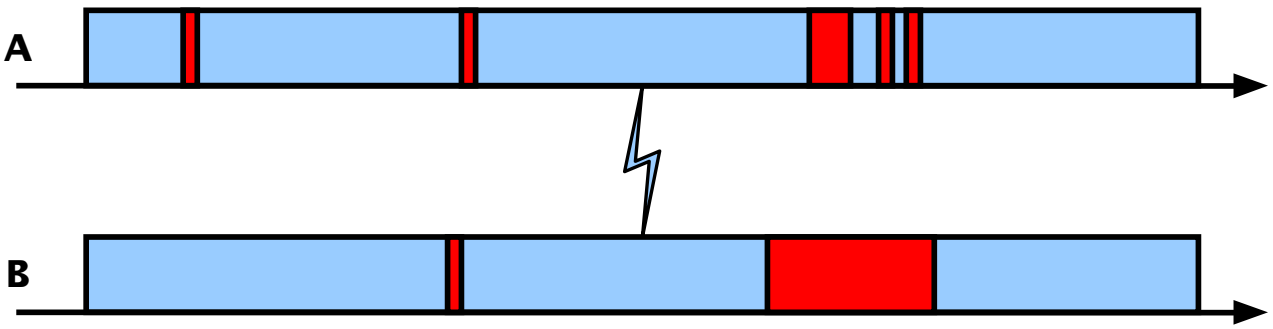
Adaptive Frequency Hopping

- Three steps
  - Identify Bad Channels by monitoring RSSI, BER and/or PER
  - Receive reserved channel usage from host



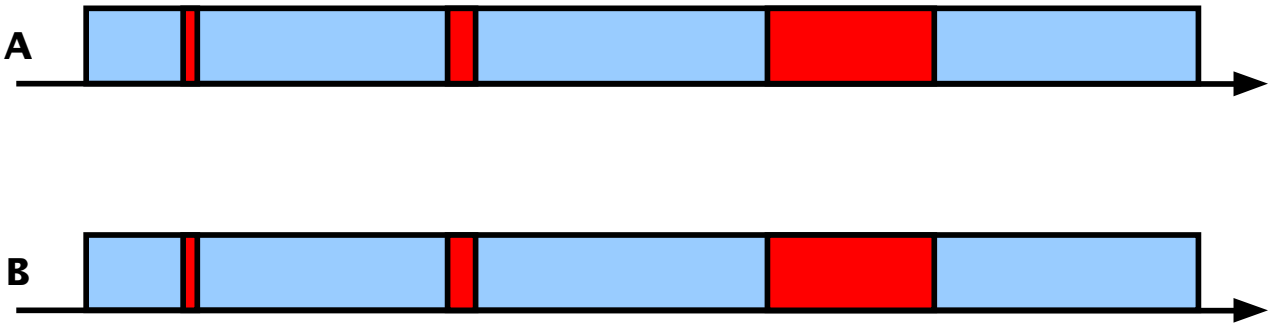
Adaptive Frequency Hopping

- Three steps
  - Identify Bad Channels by monitoring RSSI, BER and/or PER
  - Receive reserved channel usage from host
  - Agree with other devices on Bad Channels



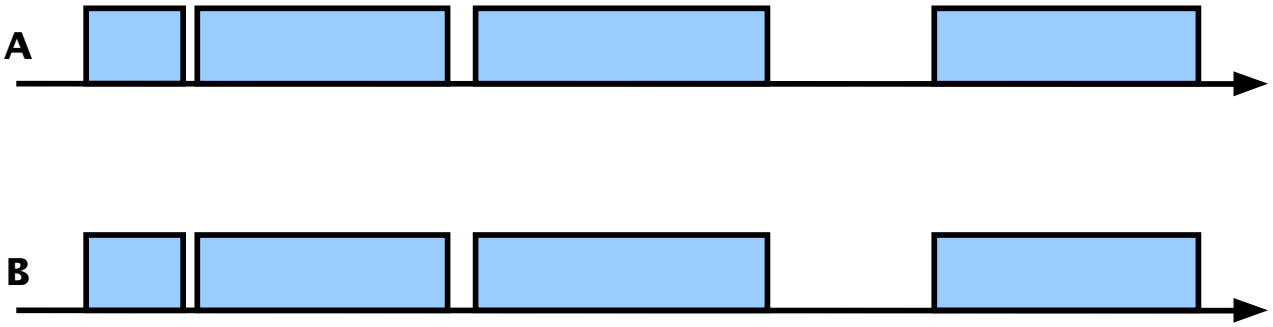
Adaptive Frequency Hopping

- Three steps
  - Identify Bad Channels, monitor RSSI, BER & PER
  - Receive reserved channel usage from host
  - Agree with other devices on Bad Channels



Adaptive Frequency Hopping

- Three steps
  - Identify Bad Channels, monitor RSSI, BER & PER
  - Receive reserved channel usage from host
  - Agree with other devices on Bad Channels
  - Use alternative channels



Adaptive Frequency Hopping

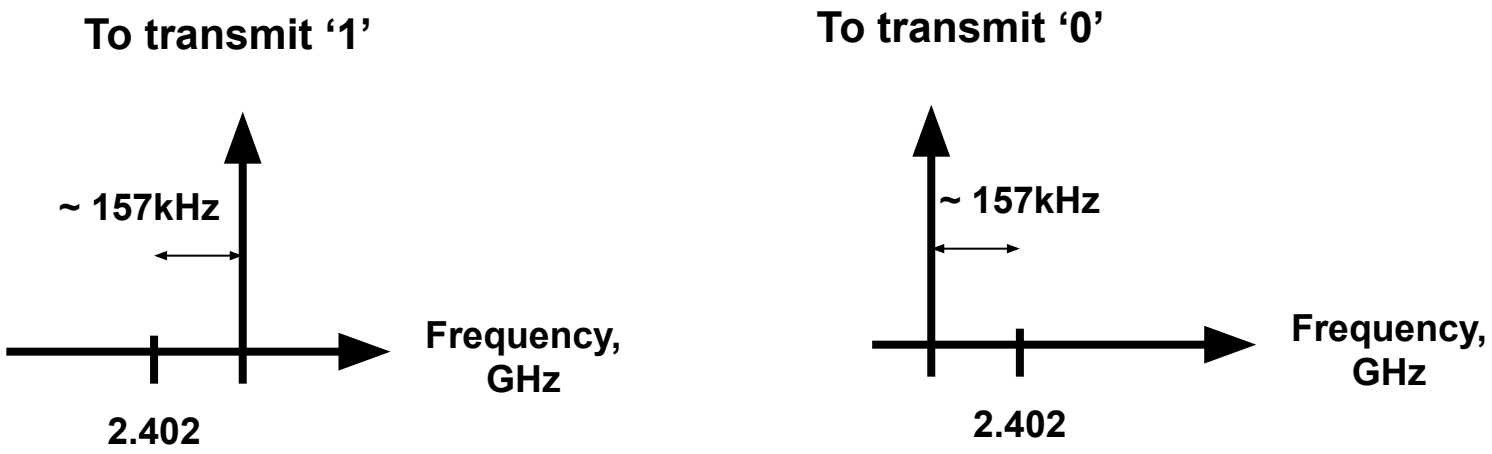
- Benefits:
  - Fewer lost packets = better audio quality
  - Less degradation to Bluetooth and 802.11b/g networks
  - Greater bandwidth efficiency
  - Not backward compatible with v1.1 systems

Modulation Scheme

- During each hop, data is transmitted using Gaussian Frequency Shift Keying, G-FSK.
- FSK uses two different frequencies to transmit a binary ‘1’ or ‘0’
- For Bluetooth the two frequencies are:
  - $\mathbf{f_c + \Delta}$ for ‘1’
  - $\mathbf{f_c - \Delta}$ for ‘0’ where $\mathbf{f_c}$ = frequency of current hop and $\mathbf{\Delta}$ = ~157kHz

Modulation Example

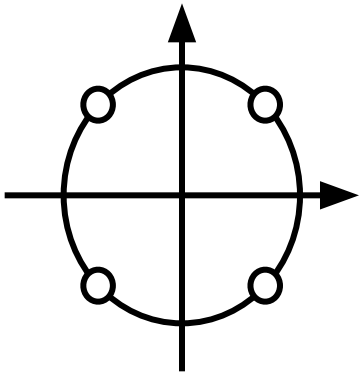
- For channel 0 (Frequency 2.402GHz)



During one time slot the data can change value every 1µs, so the transmit frequency oscillates back and forth around the center channel frequency

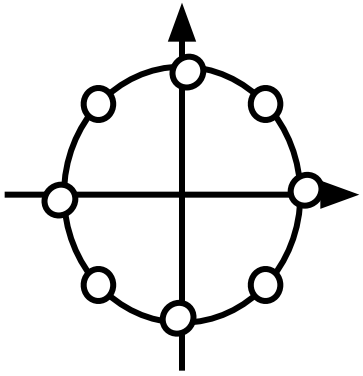
EDR Modulation Schemes

π/4-DQPSK – 2Mbps



1MSps => 2Mbps

8-DPSK – 3Mbps



1MSps => 3Mbps

Bluetooth 2.0 modulation schemes fully backwards compatible w/ Standard Rate

- Same packet timing & structure, major spectral characteristics, and packet negotiation
- Same radio used for all modulation schemes (FSK and PSK)
- Master devices support mixed Piconets by using appropriate packets for each slave

EDR devices must support 1x and 2x data rate, 3x data rate is optional

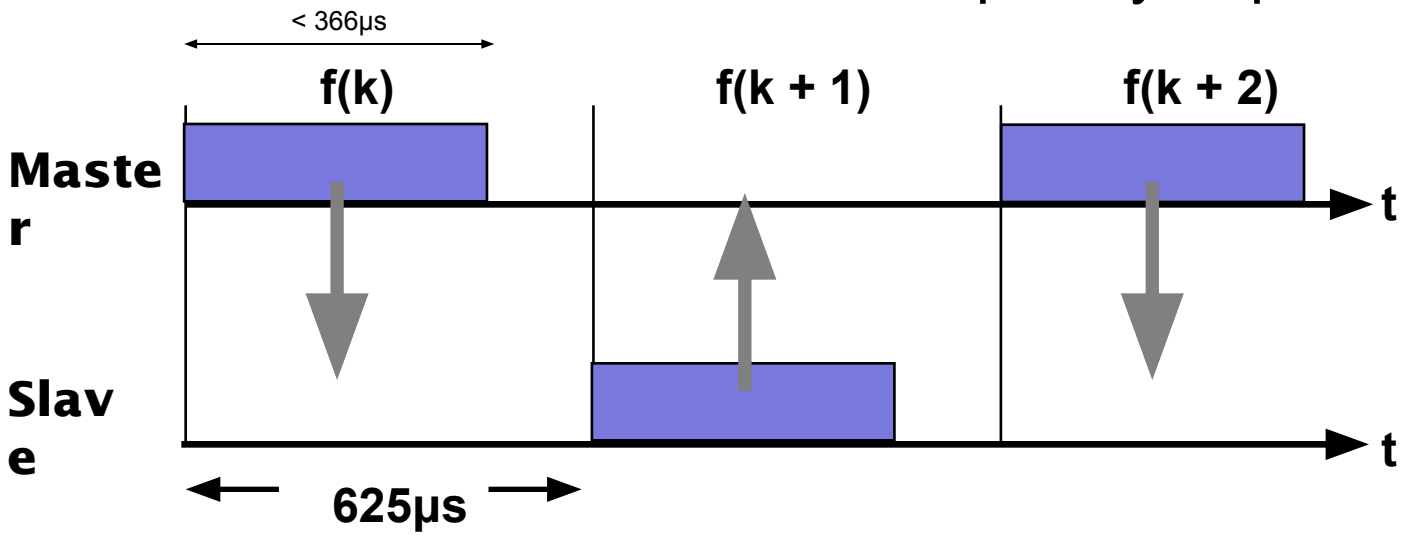
EDR Packets

- v1.2 Packets:

- v2.0 EDR Packets:

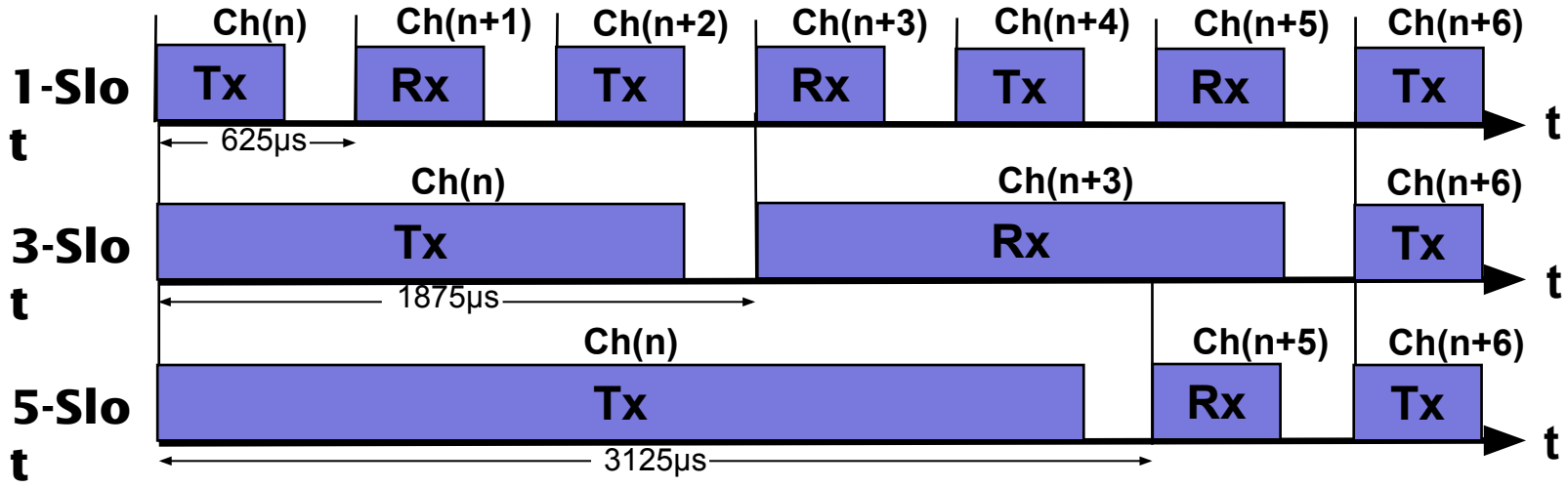
Transmission timing

- A slave can only send data to the master after it has received a valid packet from the master
- Masters transmit in even numbered slots and slaves respond in the next odd numbered slot
- Single slot packets are less then 366µs long to allow the synthesizer to retune to the next frequency hop



Multi-slot packets

- To increase the throughput of the Bluetooth link longer packets are available. These result in less time spent re-tuning the synthesizer and therefore more time spent transferring data
- 1, 3 and 5 slot packets are available for use in a dynamic fashion



Packet Types

- There are 14 *basic rate* packet types defined, split into 4 segments:
  - Common Packets (both ACL & SCO)
  - Single slot packets
  - ACL 3 slot packets
  - ACL 5 slot packets
- Each packet type has a different level of error correction and protection and different size payloads

Forward Error Correction

- Bluetooth defines three levels of forward error correction
- No Error Correction:
  - There is no error correction!
  - Data is just put in the payload and sent
- 1/3 FEC:
  - Each bit is repeated 3 times
  - Majority voting decides bit value
- 2/3 FEC:
  - The data is encoded using a (15,10) shortened hamming code
  - Every 10 bits of data are encoded into 15 bits of data
  - Can correct single bit errors and detect double bit errors

Common Packet Types

ID Packet - consists of the device access code (DAC) or the inquiry access code (IAC). It has a fixed length of 68 bits. Used for Paging, Inquiry and Response routines.

NULL Packet - has no payload data and consists of only the Channel Access Code and the Packet Header, hence fixed length of 126-bits. Used for returning status information, does not need to be acknowledged.

POLL Packet - Similar to the NULL packet, has no payload but does require an acknowledge . Used by piconet master to poll slave devices.

FHS Packet - Special control packet that reveals the BT device address and the clock of the sender. See next slide for more detail of the payload structure.

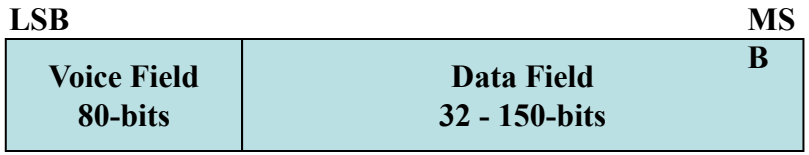
SCO Packets

HV1 Packet - High Quality Voice packet carries 10 bytes of information and 1/3 FEC to 240-bit payload. There is no payload header in this packet. Used for voice transmission and hence never retransmitted and needs no CRC. Carries 1.25ms of speech at 64kbps and needs to be transmitted every two time slots

HV2 Packet - Lower quality voice transmission that carries 20 information bytes protected with 2/3 FEC to 240-bit payload, no CRC. Carries 2.5ms of speech at 64kbps and must be transmitted every four time slots

HV3 Packet - Lowest quality voice packet, carries 30 bytes of info with no FEC or CRC in its 240-bit payload. Carries 3.75ms of speech at 64kbps and needs to be sent every six time slots

DV Packet - This is a combined Data and Voice packet with the payload split as shown below. The voice field is not FEC protected. The Data field contains up to 10-bytes including a 1-byte payload header and a 16-bit CRC. The Data is then encoded with 2/3 FEC. If required the payload is padded with zeroes to ensure that the total number of payload bits is a multiple to 10 prior to FEC coding. The Voice field is never retransmitted but the Data field can be if errors are present



ACL Packets

DM1 Packet - Data - Medium Rate, carries up to 18 information bytes including the 1-byte payload header plus a 16-bit CRC. The data is padded with zeroes to an integer multiple of 10-bits and then 2/3 FEC

DH1 Packet - Similar to the DM1 packet except the payload is not FEC encoded hence higher data rate. The DH1 Packet can carry up to 28 information bytes plus a 16-bit CRC

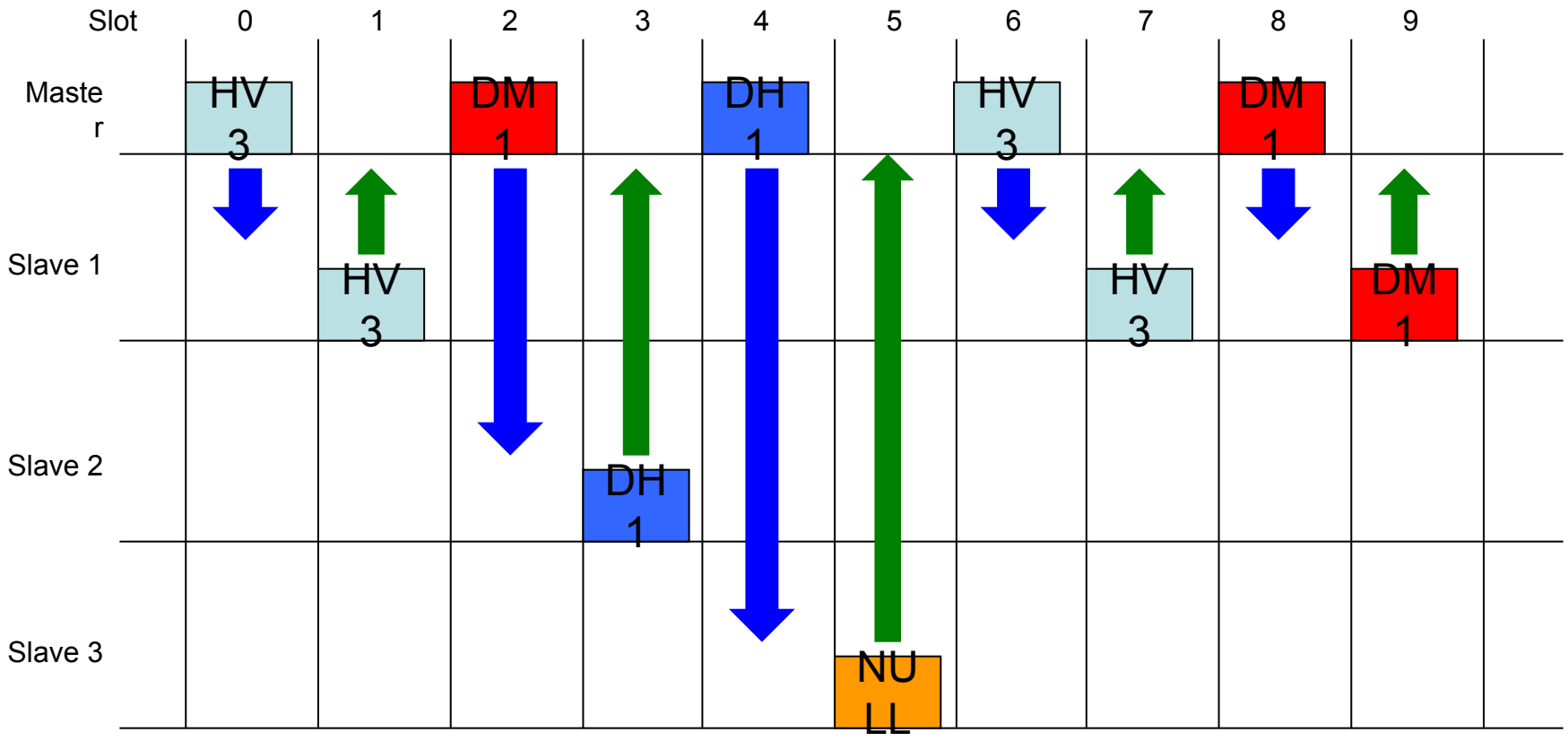
DM3 Packet - This packet is a DM1 packet with an extended payload, up to 3 time slots worth. The payload can contain up to 123 information bytes including a 2 -byte payload header plus a 16-bit CRC

DH3 Packet - This packet is similar to the DM3 packet except that the payload is not FEC encoded. Therefore, it can carry up to 185 information bytes including the 2-byte payload header plus a 16-bit CRC

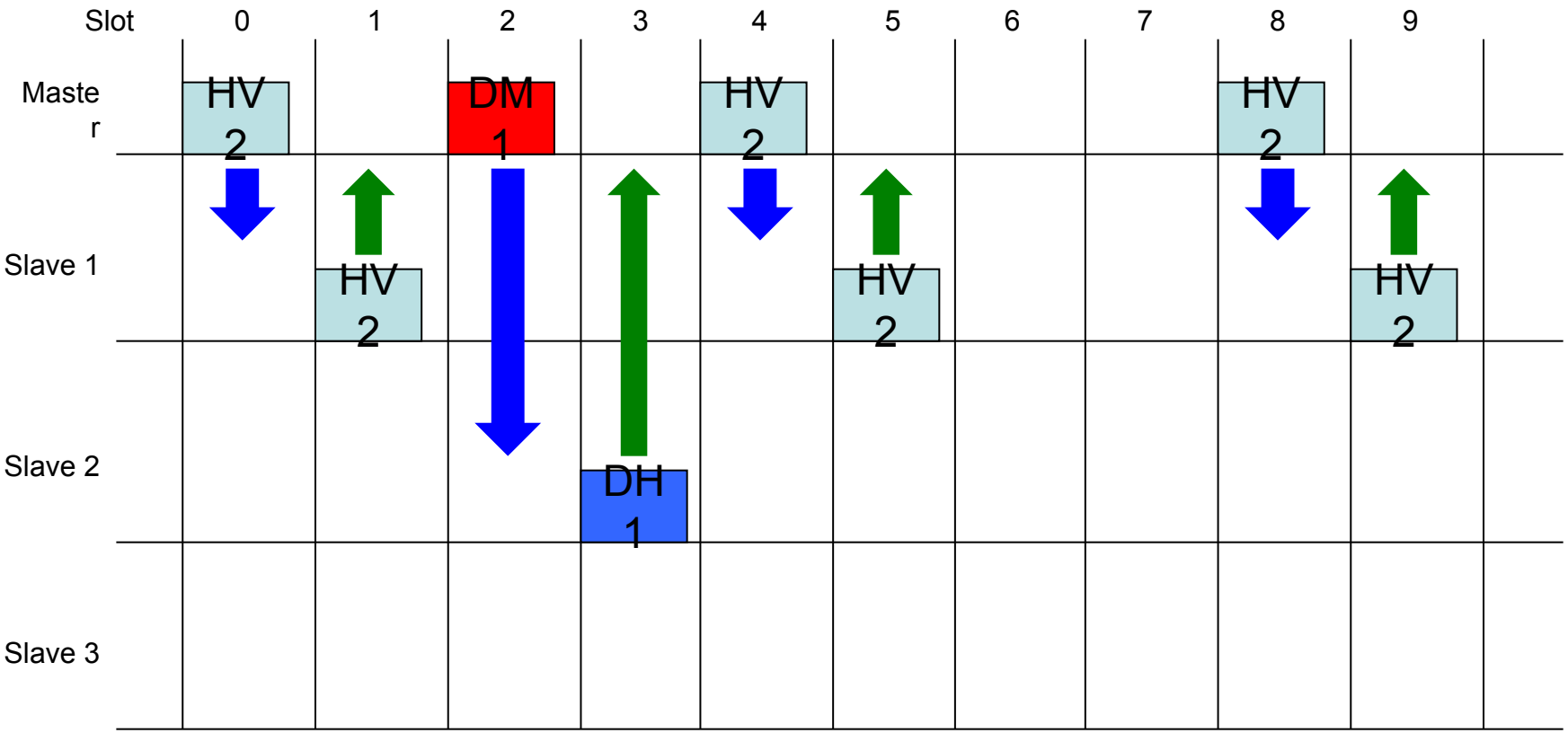
DM5 Packet - This is a DM1 packet with an extended payload, up to 5 time slots. The payload can contain up to 226 information bytes including the 2-byte payload header plus a 16-bit CRC.

DH5 Packet - Similar to the DM5 except that the information is not FEC encoded.Can carry up to 341 information bytes including the 2-byte payload header plus a 16-bit CRC

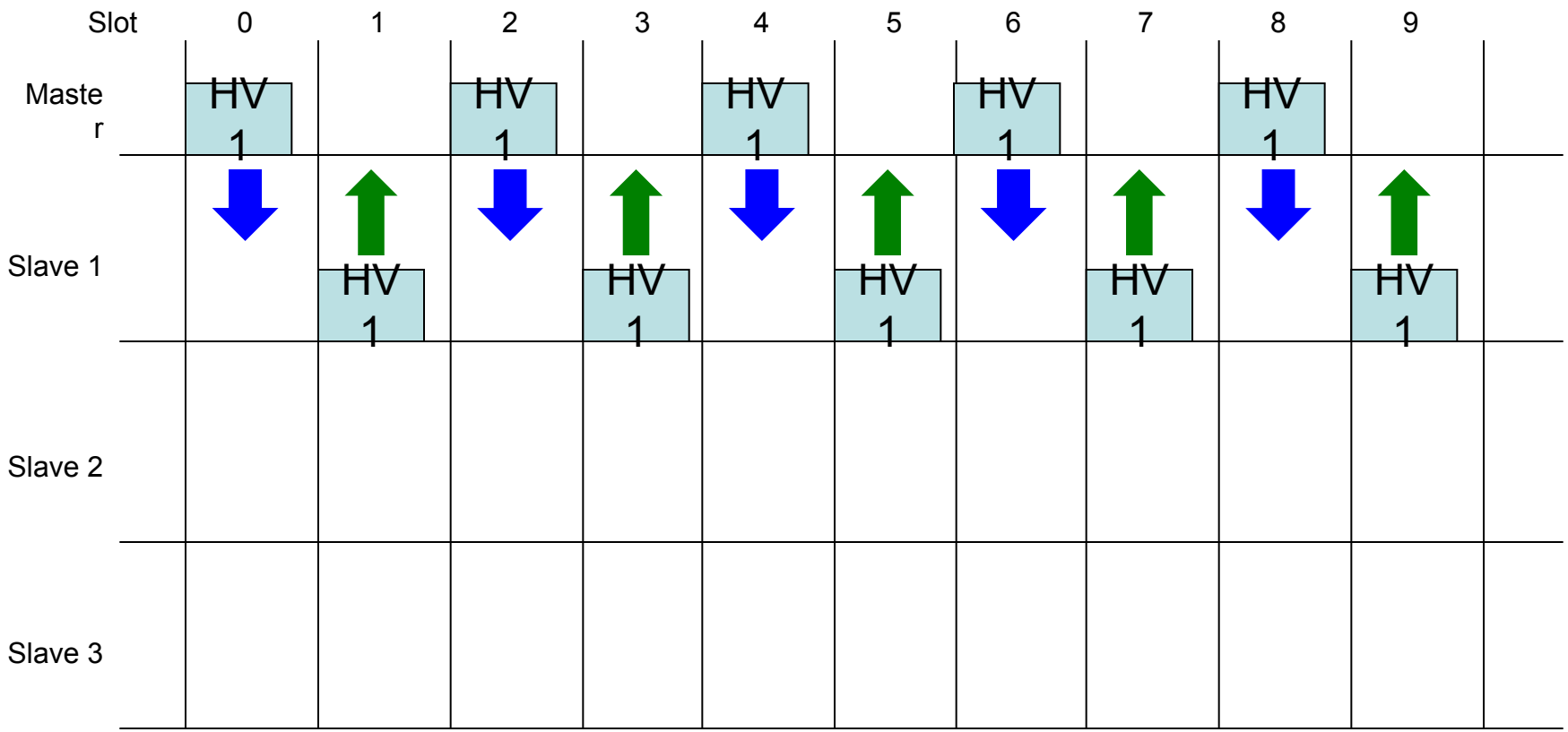
Mixing ACL and HV3 SCO packets



Mixing ACL and HV2 SCO packets



Mixing ACL and HV1 SCO Packets



- One HV1 link ties up all of the Bluetooth bandwidth
- Bluetooth device can't do anything else!

Enhanced SCO (eSCO)

- Bluetooth v1.1 SCO connections have serious impact on air interface usage.
  - Limited to 64kbps audio with CVSD encoding
    - CVSD highly susceptible to packet loss
  - No packet re-transmission

- Bluetooth v1.2 added multi-slot SCO packet types
  - allows variable data rates
  - Larger duty cycle allows additional connections, scans, etc
  - Also added CRC, FEC and data re-transmission

Bluetooth 1.2 eSCO Packets

EV3 Packet - Voice packet carries between 1 and 30 information bytes plus a 16-bit CRC code. The bytes are not protected by FEC. The EV3 packet may cover up to a single time slot.

EV4 Packet – Voice packet carries between 1 and 120 information bytes plus a 16-bit CRC code. The EV4 packet may cover to up three time slots. The information plus CRC bits are coded with a rate 2/3 FEC

EV5 Packet – Voice packet carries between 1 and 180 information bytes plus a 16-bit CRC code. The bytes are not protected by FEC. The EV5 packet may cover up to three time slots.

Enhanced SCO (eSCO)

Master packet type	Slave packet types	eSCO period									
		4 slots		6 slots		8 slots		10 slots		12 slots	
		M-S	S-M	M-S	S-M	M-S	S-M	M-S	S-M	M-S	S-M
EV3	EV3	96,0	96,0	**64,0**	**64,0**	48,0	48,0	38,4	38,4	32,0	32,0
EV4	EV3	384,0	96,0	256,0	64,0	192,0	48,0	153,6	38,4	128,0	32,0
EV4	EV4	---	---	256,0	256,0	192,0	192,0	153,6	153,6	128,0	128,0
EV5	EV3	**576,0**	**96,0**	384,0	64,0	288,0	48,0	230,4	38,4	192,0	32,0
EV5	EV5	---	---	**384,0**	**384,0**	288,0	288,0	230,4	230,4	192,0	192,0

max. asymmetric

max. symmetric

SCO

Bluetooth 2.0 EDR ACL Packets

Type	Payload Header (bytes)	User Payload (bytes)	FEC	CRC	Symmetric Max Rate (kbps)	Asymmetric Max Rate (kbps)	
						Forward	Reverse
2-DH1	2	0-54	No	YES	345.6	345.6	345.6
2-DH3	2	0-367	No	YES	782.9	1174.4	172.8
2-DH5	2	0-679	No	YES	869.7	1448.5	115.2
3-DH1	2	0-83	No	YES	531.2	531.2	531.2
3-DH3	2	0-552	No	YES	1177.6	1766.4	235.6
3-DH5	2	0-1021	No	YES	1306.9	2178.1	177.1

Bluetooth 2.0 EDR eSCO Packets

2-EV3 Packet – Similar to EV3 packet, except that the payload is modulated using π/4-DQPSK. It has between 1 and 60 information bytes plus a 16-bit CRC code. The bytes are not protected by FEC. The 2-EV3 packet covers a single time slot.

2-EV5 Packet – Similar to EV5 packet, except that the payload is modulated using π/4-DQPSK. It has between 1 and 360 information bytes plus a 16-bit CRC code. The bytes are not protected by FEC. The 2-EV5 packet may cover up to three time slots.

3-EV3 Packet – Similar to EV3 packet, except that the payload is modulated using 8DPSK. It has between 1 and 90 information bytes plus a 16-bit CRC code. The bytes are not protected by FEC. The 2-EV3 packet covers a single time slot.

3-EV5 Packet – Similar to EV5 packet, except that the payload is modulated using 8DPSK. It has between 1 and 540 information bytes plus a 16-bit CRC code. The bytes are not protected by FEC. The 2-EV5 packet may cover up to three time slots.

Power Classes

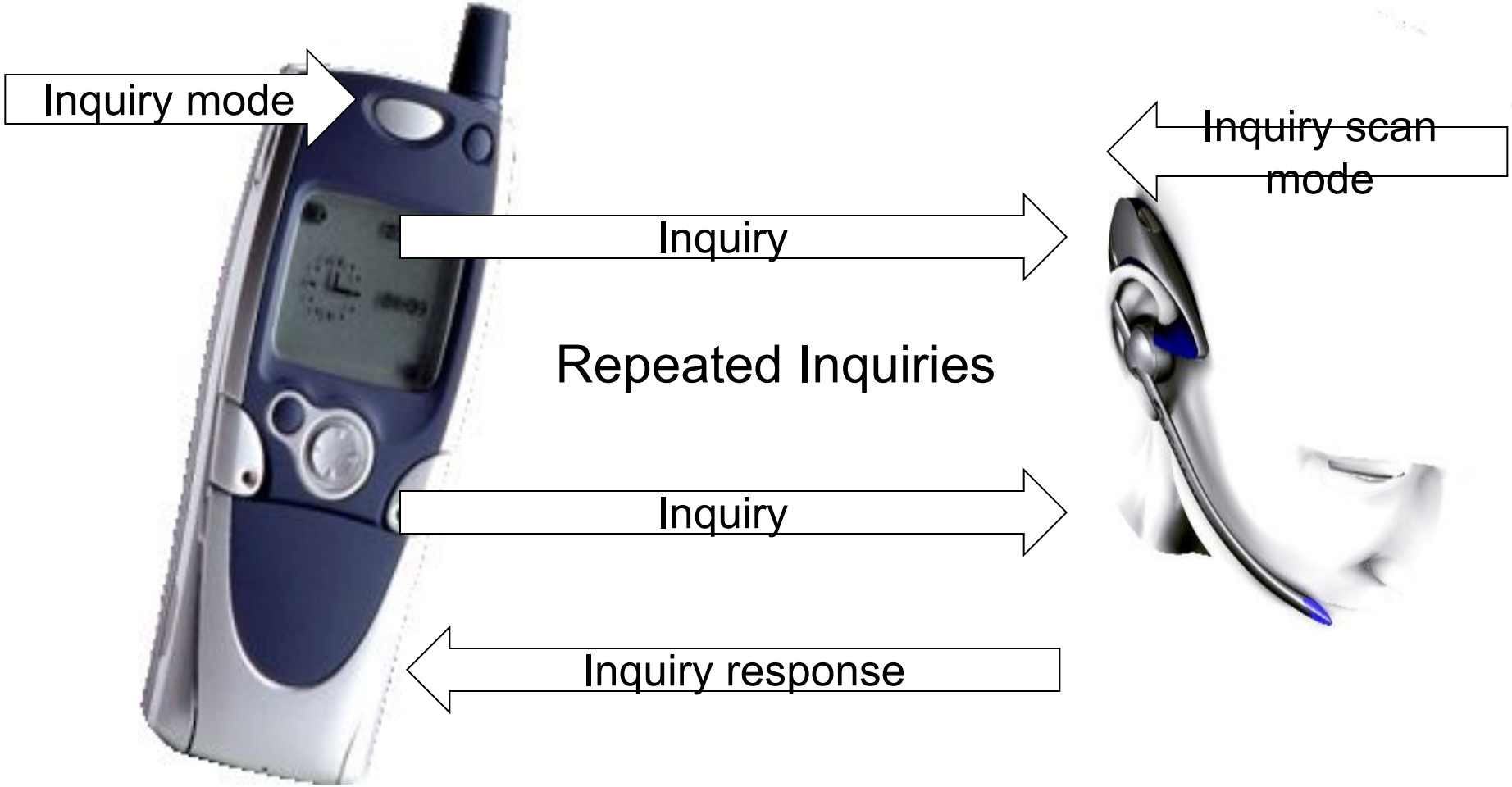
- Bluetooth defines 3 power classes for devices:
  - Class 1: 0dBm to +20dBm (1mW to 100mW)
  - Class 2: -6dBm to +4dBm (250µW to 2.5mW)
  - Class 3: <0dBm (<1mW)

- These power classes translate into approximate distances often used when discussing Bluetooth:
  - Class 1: 100 Meters
  - Class 2: 10 Meters
  - Class 3: <10 Meters

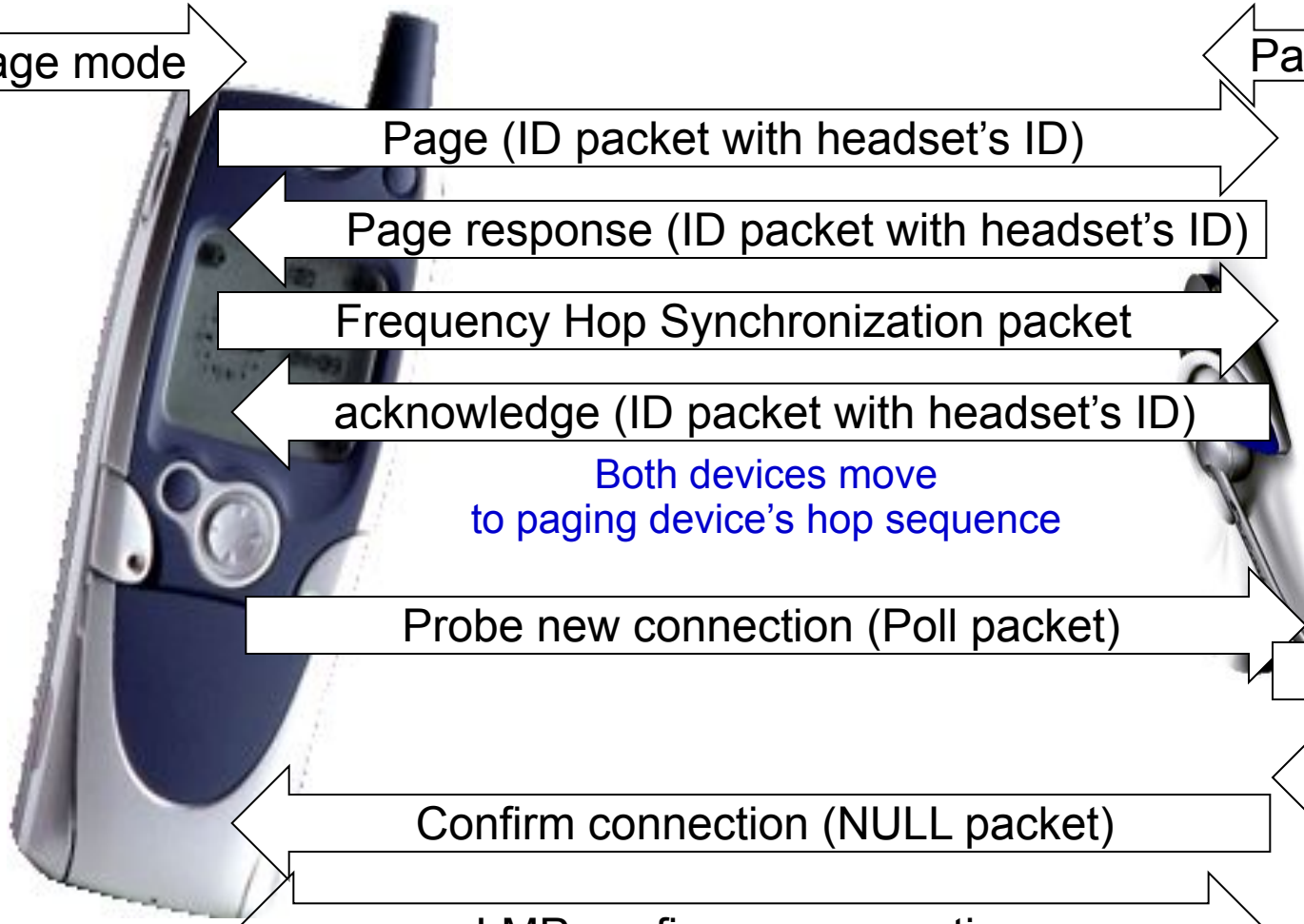
Discovering and Connecting to Other Devices

- For a Bluetooth device to discover new devices that are in range it must perform an inquiry
- A device that wants to be found by another device must be in inquiry scan mode
- Once a device has been found it must be paged to initiate a connection
- A device that wants to be connected to must be in Page Scan Mode.
- A device that wants to connect to a particular device must be in Page Mode

Discovering a Bluetooth Device



Establishing a baseband connection



Secure Simple Pairing (SSP)

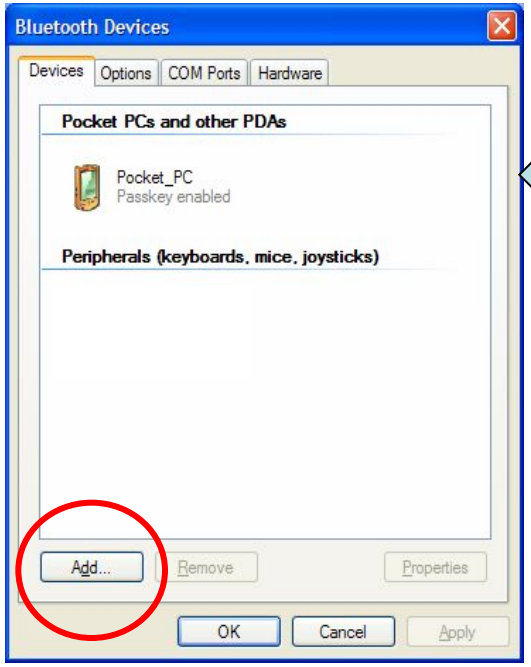
- Feature of Bluetooth 2.1
- Enables easier connectivity between devices and better use of security features

Input/Output Capabilities

- Four I/O capabilities defined
  - Display Only
  - Display Yes/No
  - Keyboard Only
  - No Input No Output
- The I/O capabilities are used to determine which association model is used

“Just Works”

- User chooses to “add a device”

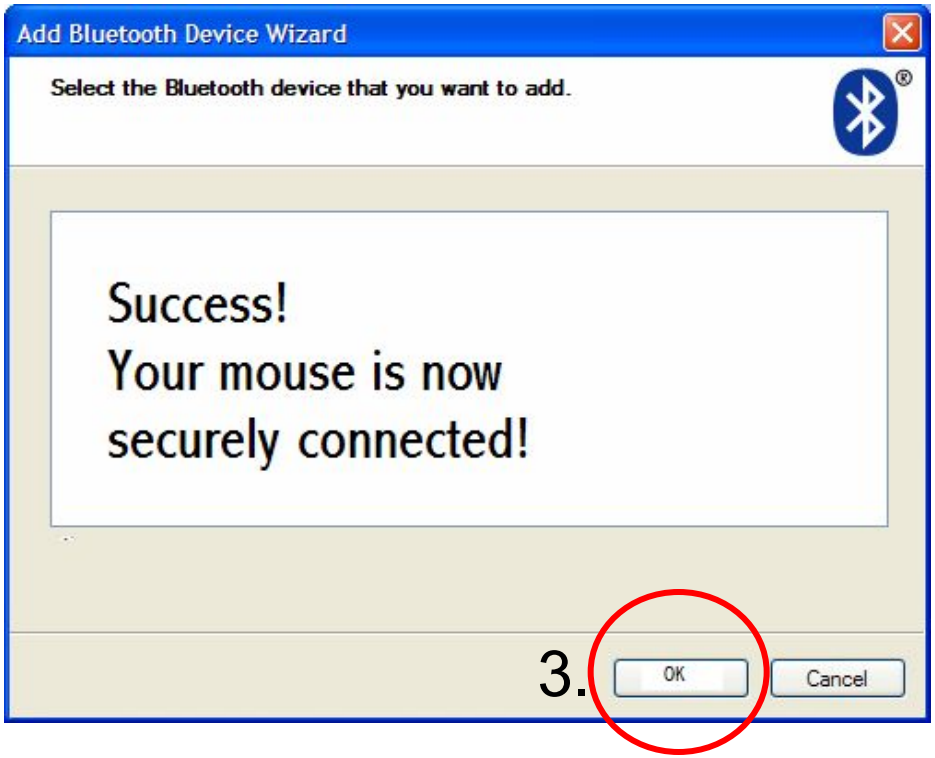


1. User decides to add a wireless Mouse

2. User presses the “CONNECT” button on the Mouse

“Just Works”

- The mouse is automatically selected and paired to the computer – no further user action is required! Data is encrypted.



Numeric Comparison

- Step 1 – User enables technology on PC and activates connection from phone
- Step 2 – User selects “ADD”
- Step 3 – Phone displays ‘laptop’ and asks user if he/she wishes to connect
- Step 4 – Phone displays 6-digit number and asks user to confirm
  - Same for mobile phone to car kit and mobile to stereo headset

User is asked to confirm 6-digit number on both ends

Passkey Entry

- Step 1 – User powers on keyboard and activates connection from phone
- Step 2 – User selects “ADD” on the phone
- Step 3 – Phone displays ‘keyboard’
- Step 4 – User is asked to enter 6-digit number on the keyboard and press “Enter”

User is asked to enter 6-digit number on keyboard

Extended Inquiry Response

- Feature of Bluetooth 2.1
- Problem:
  - Takes a long time to find devices, work out what they are called, and what you can do with them…
- Solution:
  - Include information in the inquiry response
    - Name of Device
    - Profiles supported
    - Etc.
- Side effects
  - Task oriented actions quicker as devices can get filtered quickly
  - Can transmit other information: time, location, etc.






Low Power Modes

- To help reduce power consumption, there are three Bluetooth low power modes
  - Sniff Mode (The most used)
  - Hold Mode
  - Park Mode
- Slaves can request to be placed in any of these modes
- Masters can ask a slave to enter one of these modes
- Masters can also force a slave into one of these modes if it has previously accepted the mode

Sniff Subrating

- Feature of Bluetooth 2.1
- Problem:
  - HID devices want low power and low latency
- Solution:
  - Laptop transmits packets at required latency to mouse to give low latency
  - Mouse ignores laptop most of the time
- Side effects
  - Better scatternet support
  - Mouse has 2-3 times better battery life
  - Keyboard has 10x better battery life

Sniff Mode

- Devices agree upon a time delay during which no communication will occur
- During the silent periods the slave can sleep or perform other functions
- After the silent period the slave wakes up and ‘sniffs’ for a number of slots for its AM_ADR. If there is no data it goes back to sleep
- Any active SCO connections between the devices must still be supported
- Difference between sniff and hold mode:
  - Hold mode is a one shot deal during which no communication occurs
  - Sniff mode defines a repeating period during which no communication occurs

Agenda

- Bluetooth Overview
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  - HFP
  - A2DP
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  - PBAP
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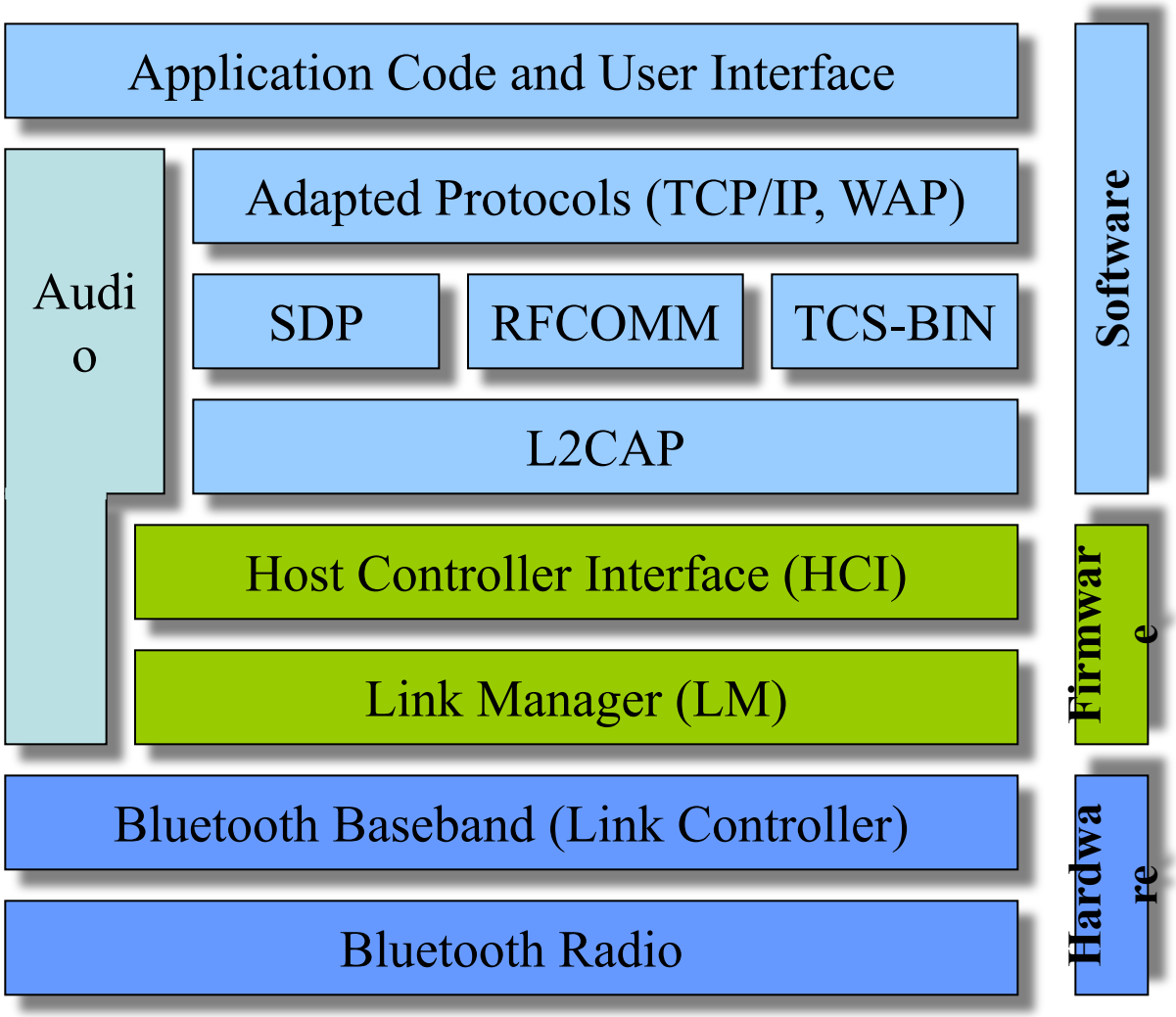
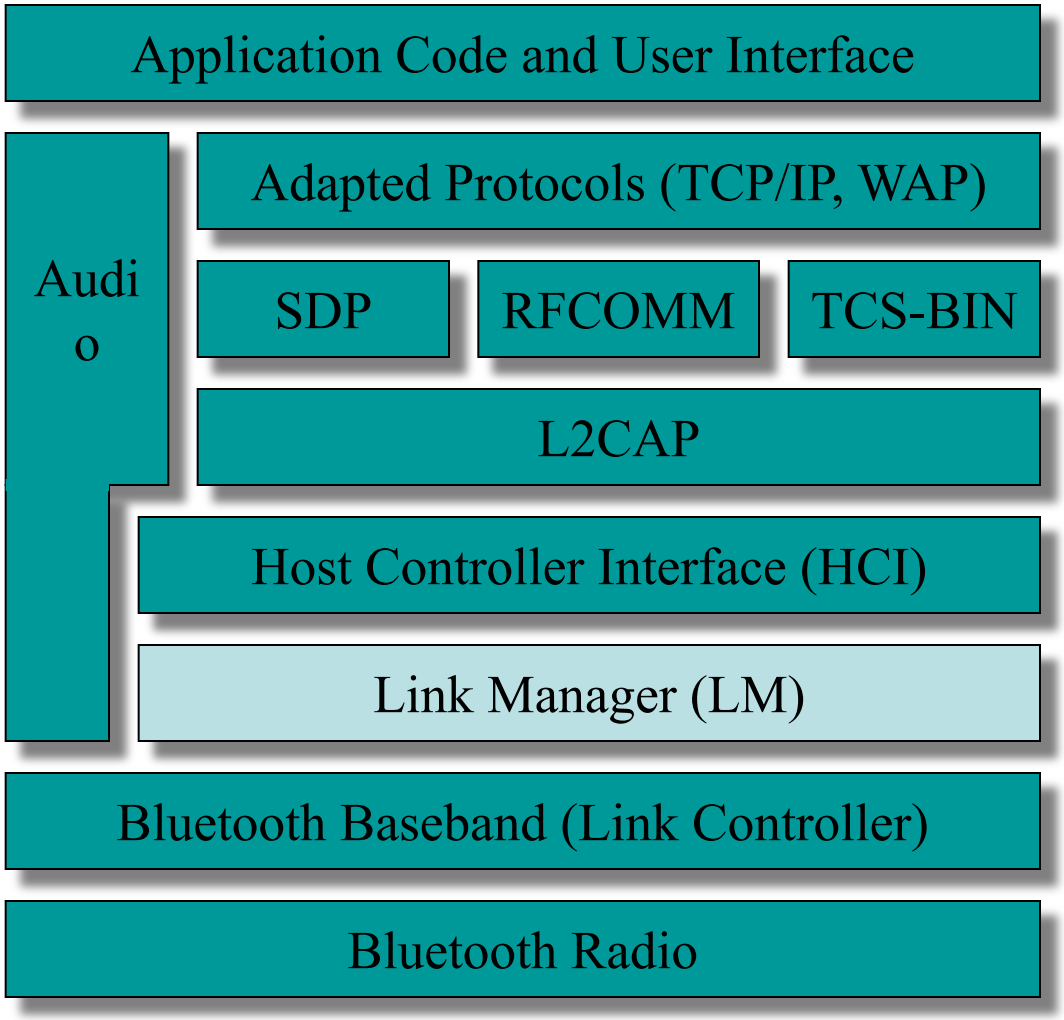
Bluetooth Protocol Stack

- Bluetooth stack is loosely based around the OSI model
- HCI layer is not a real layer, it is a hardware interface
- Audio data bypasses the upper layers and is sent straight to the application



The Link Manager (LM)



The Link Manager (LM)

- Manages link set-up
- Manages security
- Manages piconet connections
- Provides test modes for simplified testing
- Link manager messages have higher priority than user data
- LMP messages are not specifically acknowledged
  - LM assumes LC provides error free link
  - But, LC cannot supply 100% error free link!

The Link Manager (LM) cont

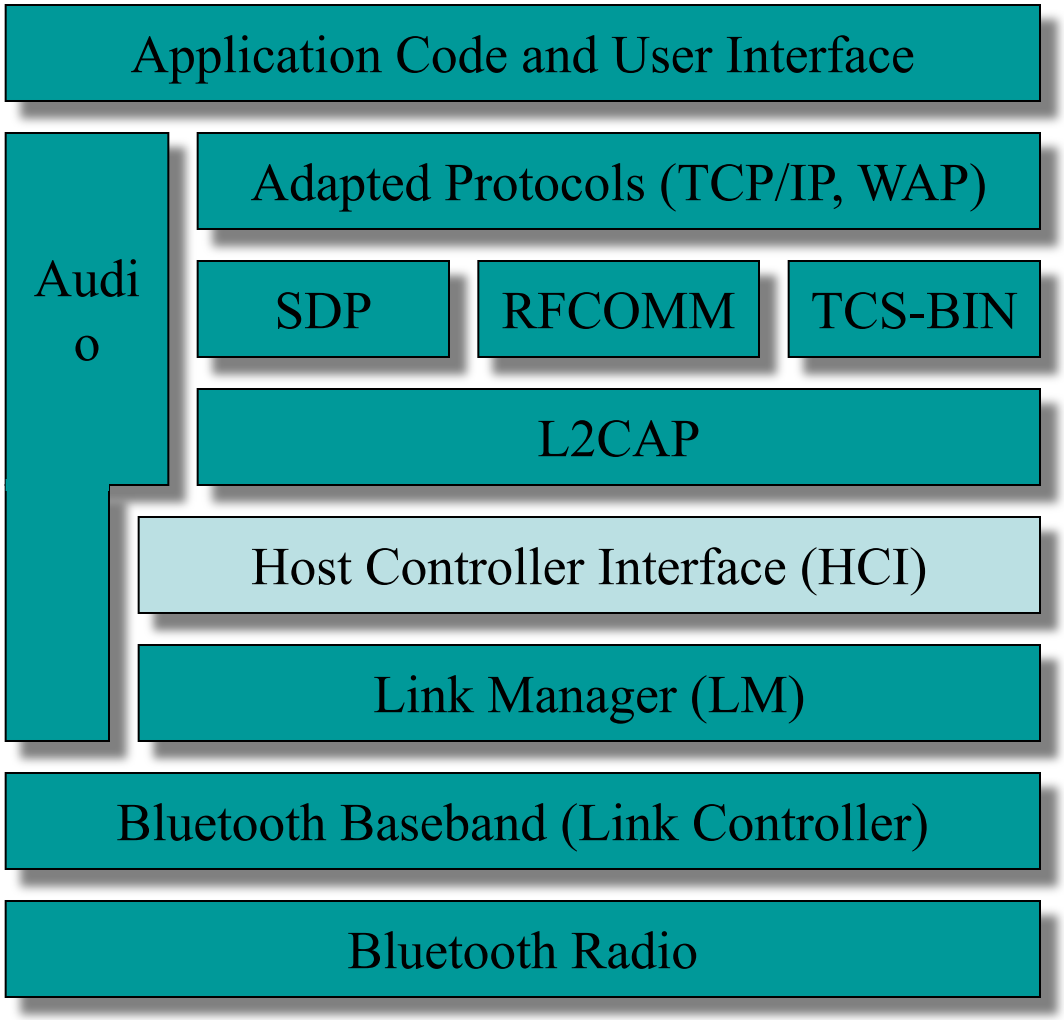
- Link Set-up Procedures:
  - Processes results of Inquiry and Page
  - “Non-connection” oriented commands
    - Device Name, Class of Device, etc.

- Security Procedures:
  - Authentication, Authorization, Encryption
    - Safer+ algorithm up to 128-bit encryption key
    - Remember there are regional encryption laws to abide by!
  - Pairing and Bonding

The Link Manager (LM) cont.

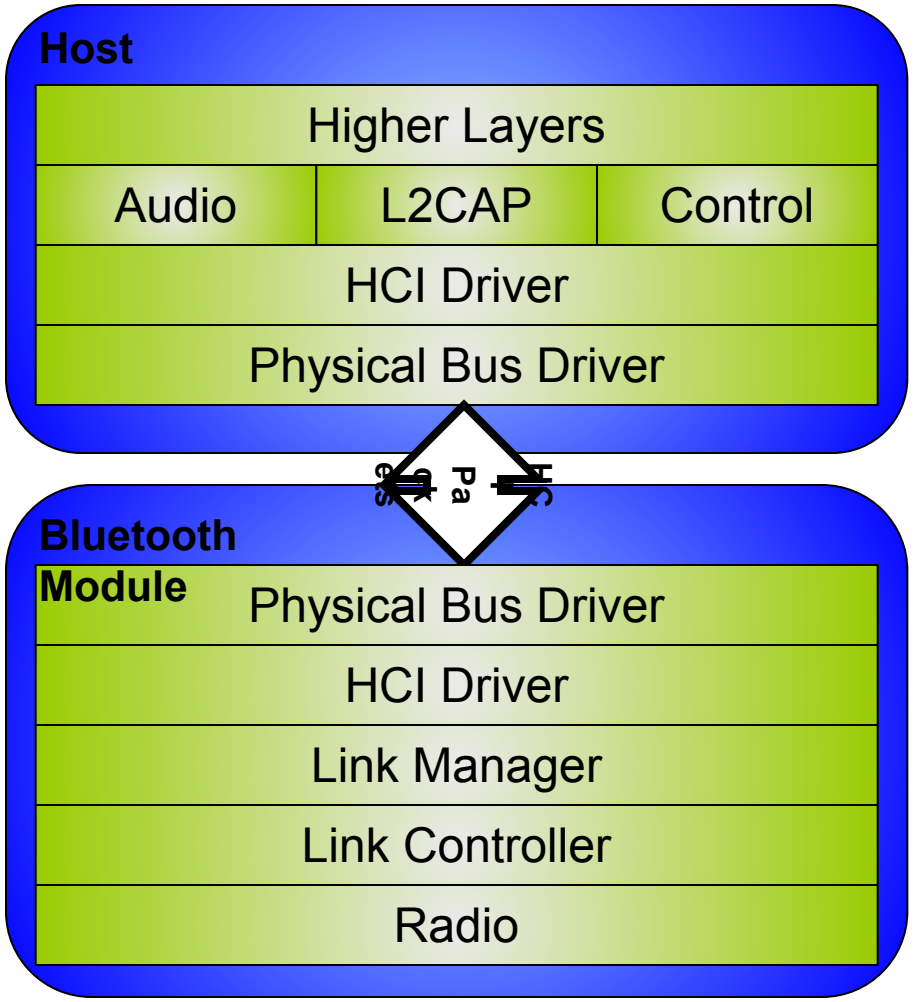
- Piconet Connection Management:
  - Packet type adjustment based on channel quality
    - Switch between 1,3 and 5 slot packets
  - Master-Slave role switching
  - Low Power Modes
    - Sniff, Park and Hold
  - Quality of Service contracts
  - Transmit power control

The Host Controller Interface (HCI)

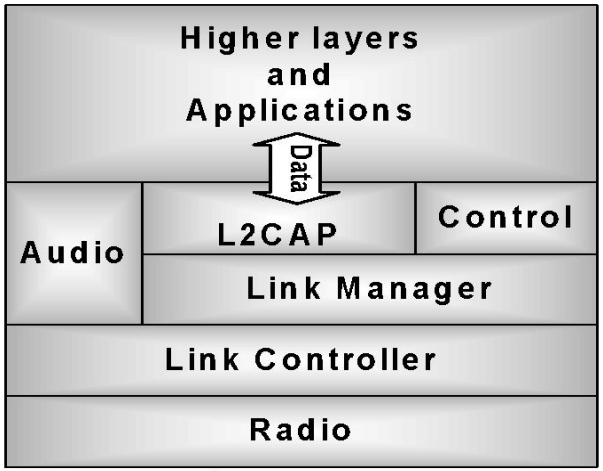


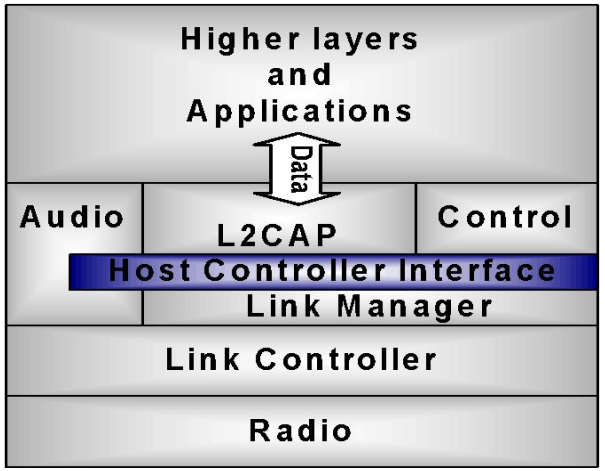
Host Controller Interface (HCI)

- The HCI interface defines a physical connection between a host (e.g. PC) and a host controller (e.g. Bluetooth module)
- The specification defines three interfaces:
  - USB v1.1
  - RS-232
  - UART
- It also defines messages that are passed across the HCI interface



HCI - Not really a layer!





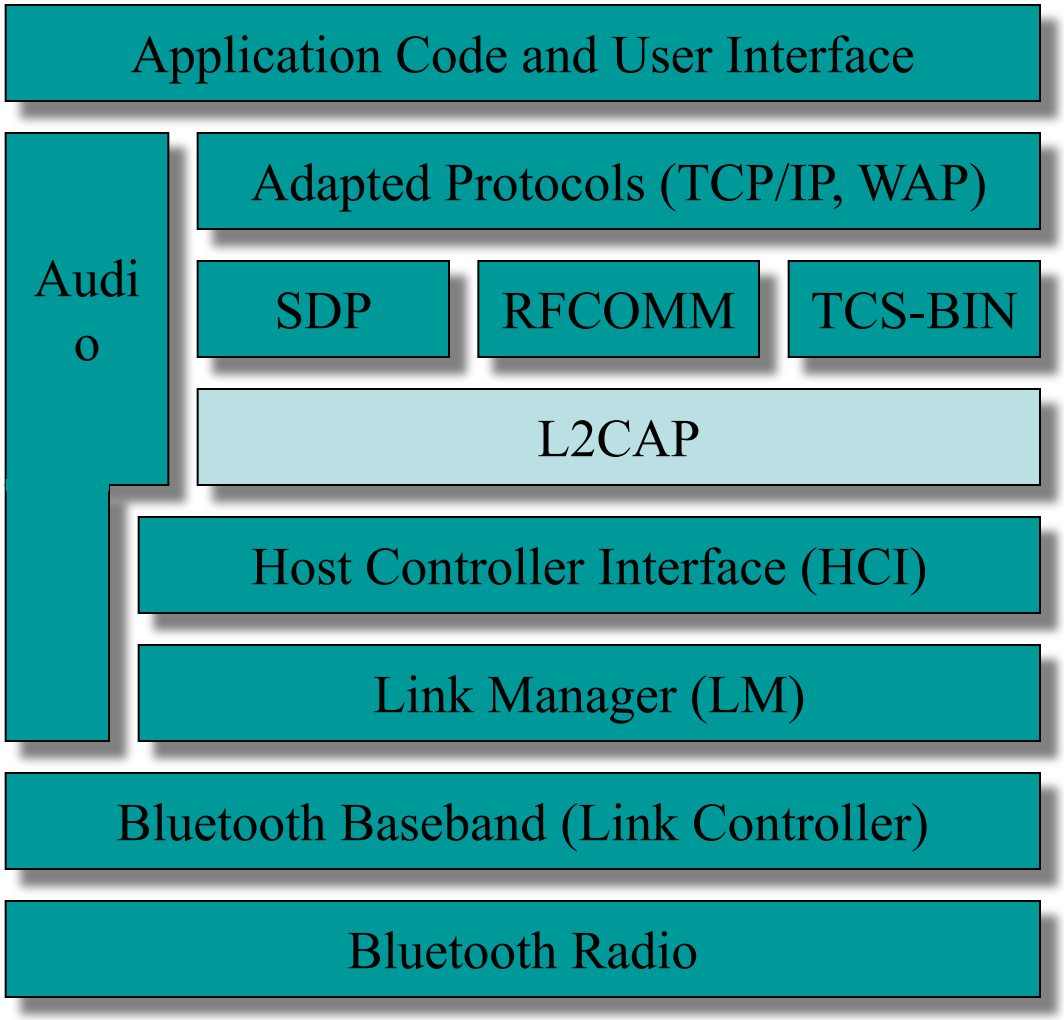
Hostless system

Host based system

HCI cont.

- Independent of hardware implementation
- Standard interface to Link Manager and Link Controller
- HCI Command groups:
  - Link Control (Inquiry, Paging, Encryption, etc.)
  - Link Policy (Hold, Sniff, Park, QoS)
  - Host Controller and Baseband Commands (PINs, event masks, timeouts, etc.)
  - Informational Parameters (Device address, country code, buffers)
  - Status (Link Quality, RSSI, Failed connections)
  - Testing (Test mode commands)
  - Vendor specific commands

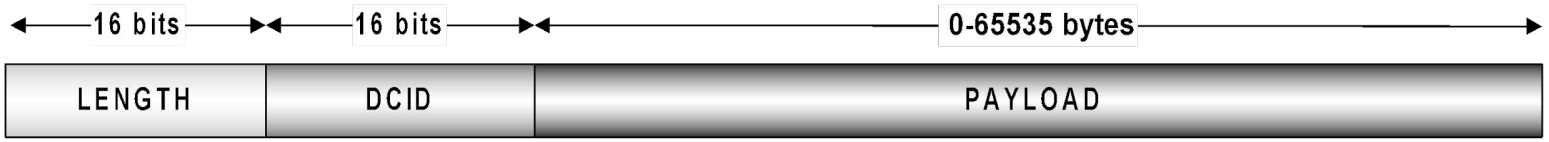
Logical Link Control and Adaptation Protocol (L2CAP)



Logical Link Control and Adaptation Protocol (L2CAP)

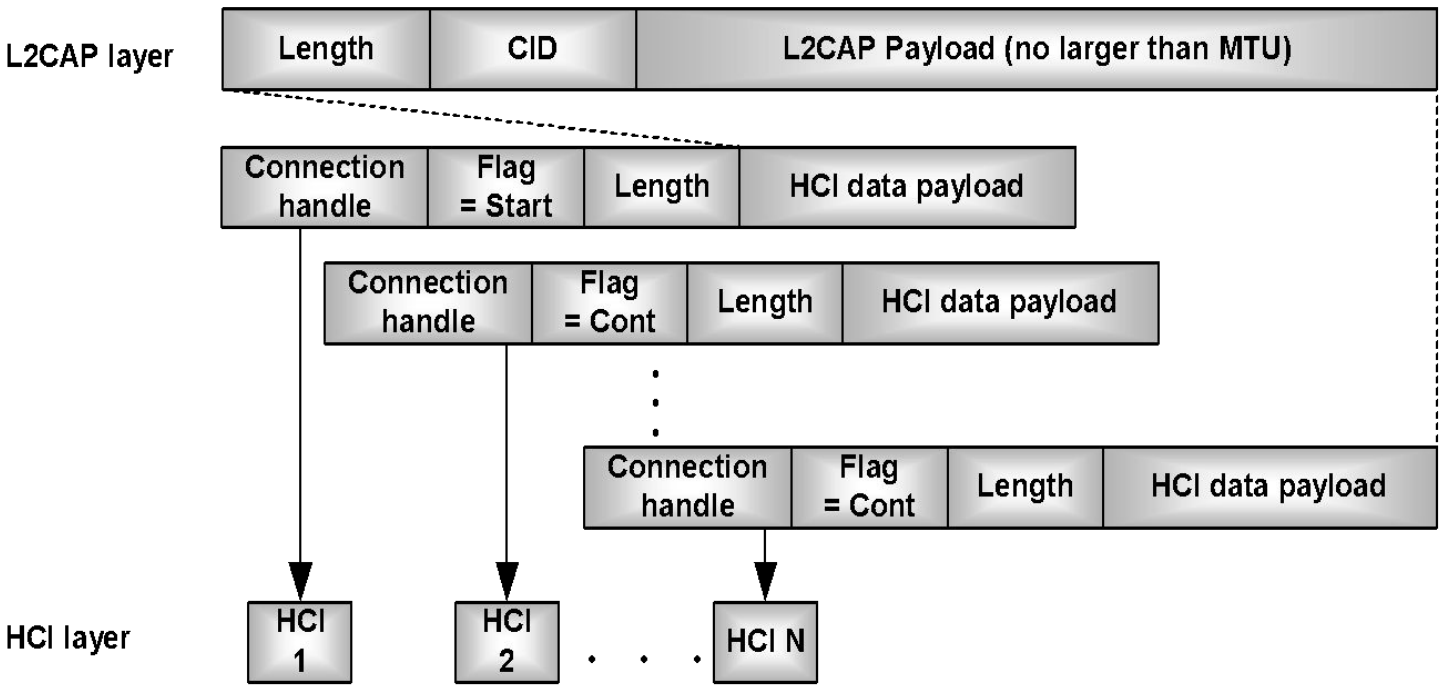
- Logical Link Control
  - Multiplexing: many logical links onto one physical link
- Adaptation
  - Segmentation & reassembly: adapts large packets to baseband size
- Protocol
  - A well defined set of signaling rules understood by all devices

L2CAP Multiplexing



- L2CAP adds a Destination Channel ID to every packet
- The DCID is used to identify and direct packets to the appropriate handler

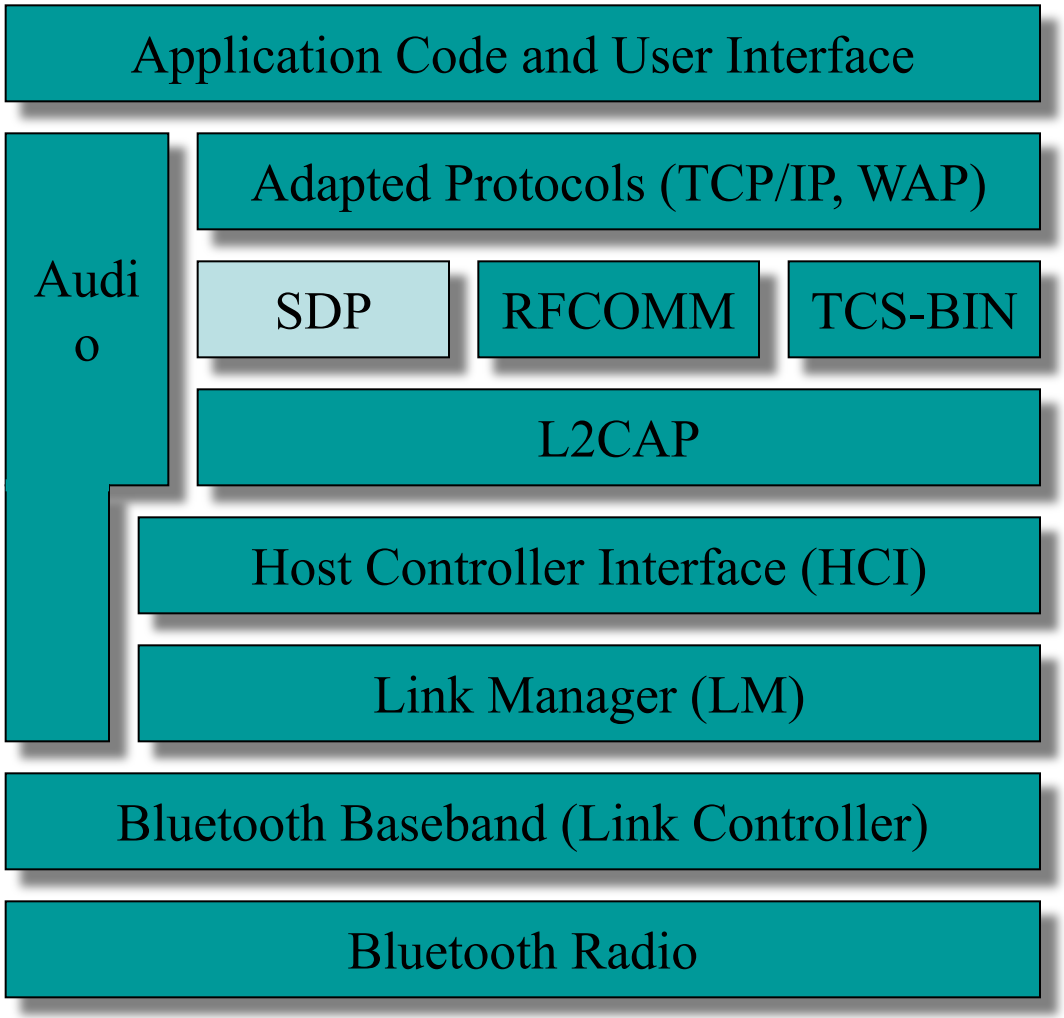
L2CAP Segmentation and Reassembly



L2CAP Quality of Service

- No Traffic
  - This level indicates that no traffic will be sent out. Traffic will be incoming only
- Best Effort
  - Default level of service for all links
  - All values included in the QoS request should be viewed as hints and may be entirely ignored
- Guaranteed
  - Remote device will attempt to honor the service level
  - Cannot overcome radio level interference
  - Not likely to be able to be maintained under poor radio conditions.
  - Best level of QoS for adding multiple connections

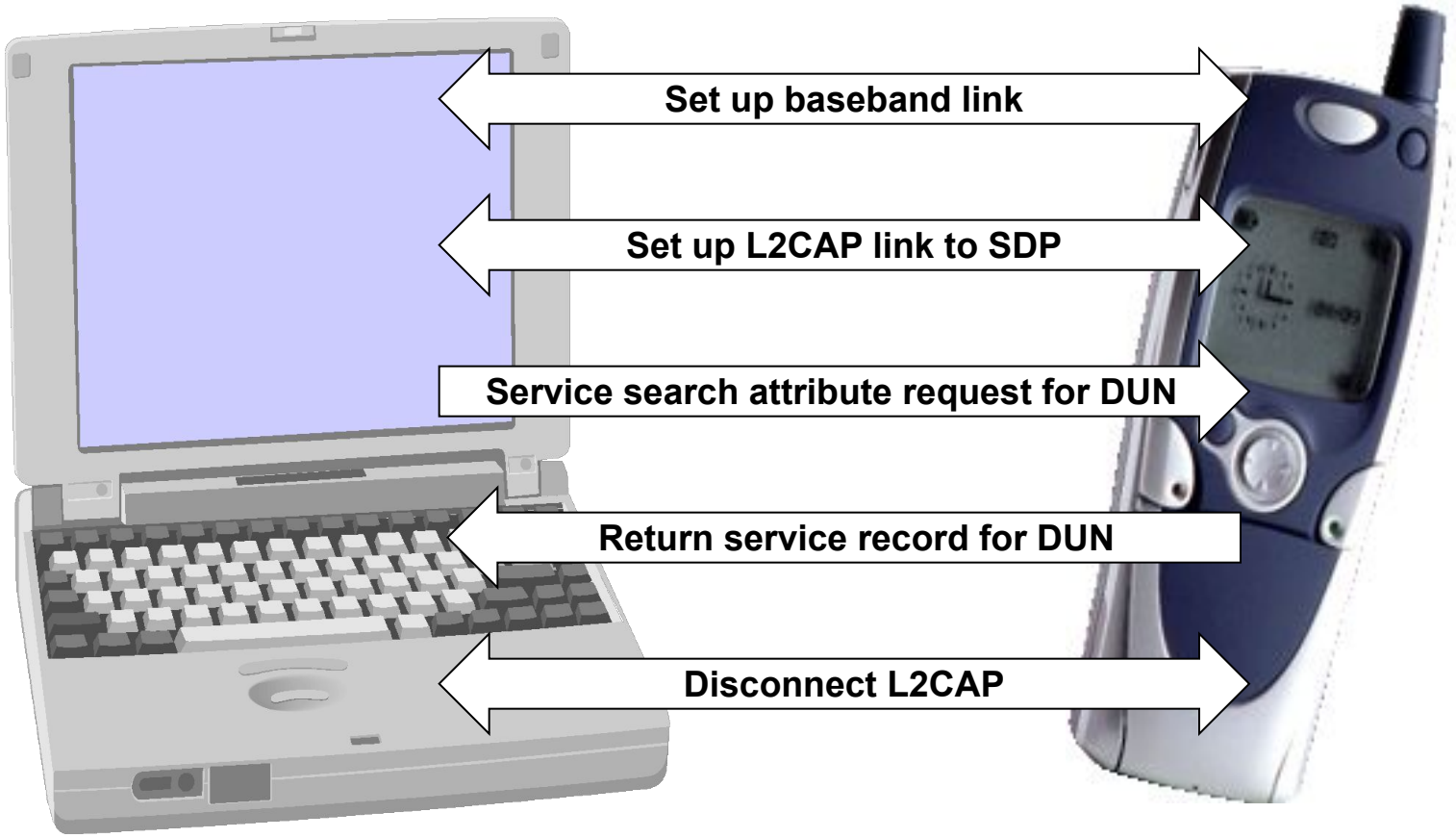
Service Discovery Protocol (SDP)



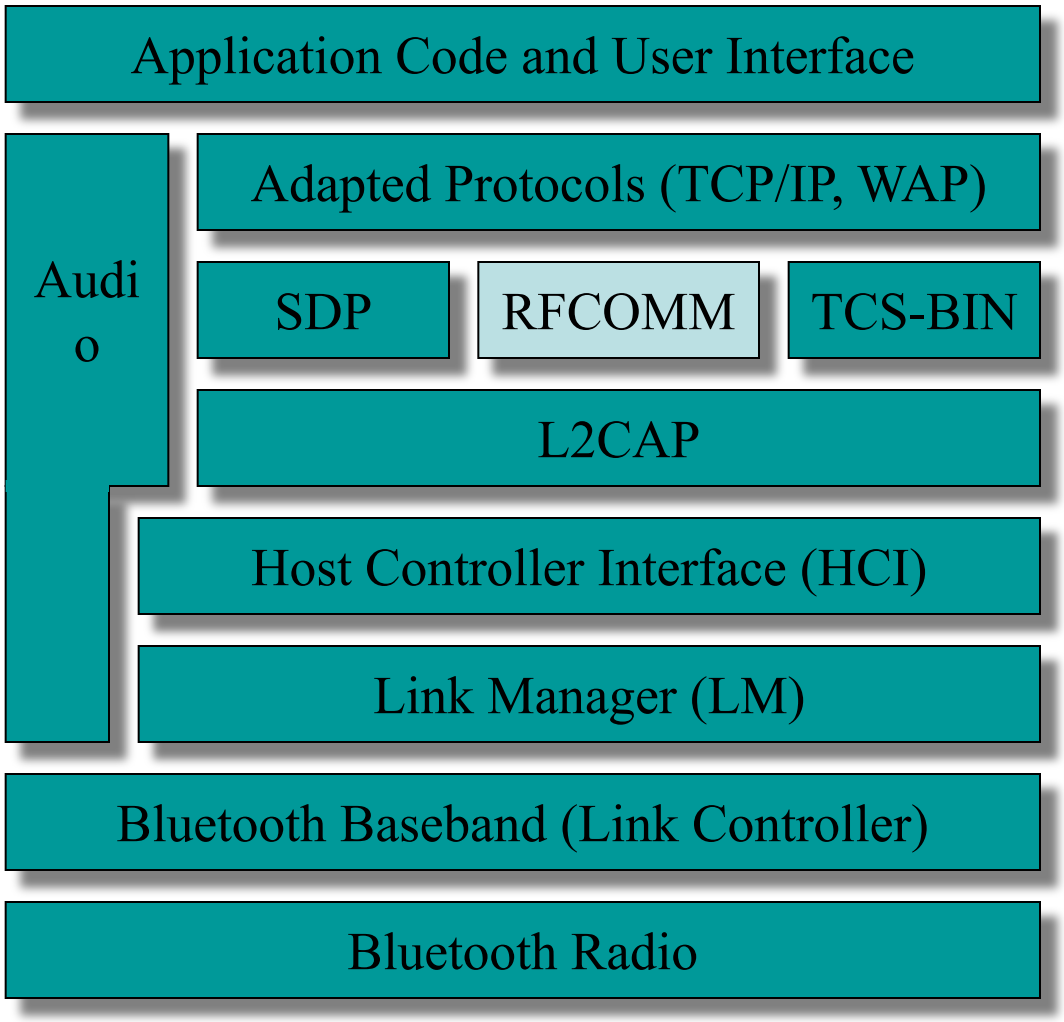
Service Discovery Protocol (SDP)

- SDP servers maintain a database on services offered
  - Made up of service records.
  - Servers maintain their own database, there is no central registry.
- SDP allows clients to search for services.
  - based on attributes and service classes.
- SDP uses connections set up via the usual Inquiry and Paging operations.

SDP Example



RFCOMM



RFCOMM

- Serial cable replacement
  - Up to 60 emulated serial port connections per RFCOMM session
  - Depending on implementation, multiple RFCOMM sessions are possible
- Large base of legacy applications using serial communications
- Uses GSM TS 07.10 standard
- Credit Based Flow Control
  - Negotiated credit tokens determine data flow
- RS-232 control signal emulation
- RS-232 flow control emulation
  - Software (Xon/Xoff)
  - Hardware (CTS/RTS)

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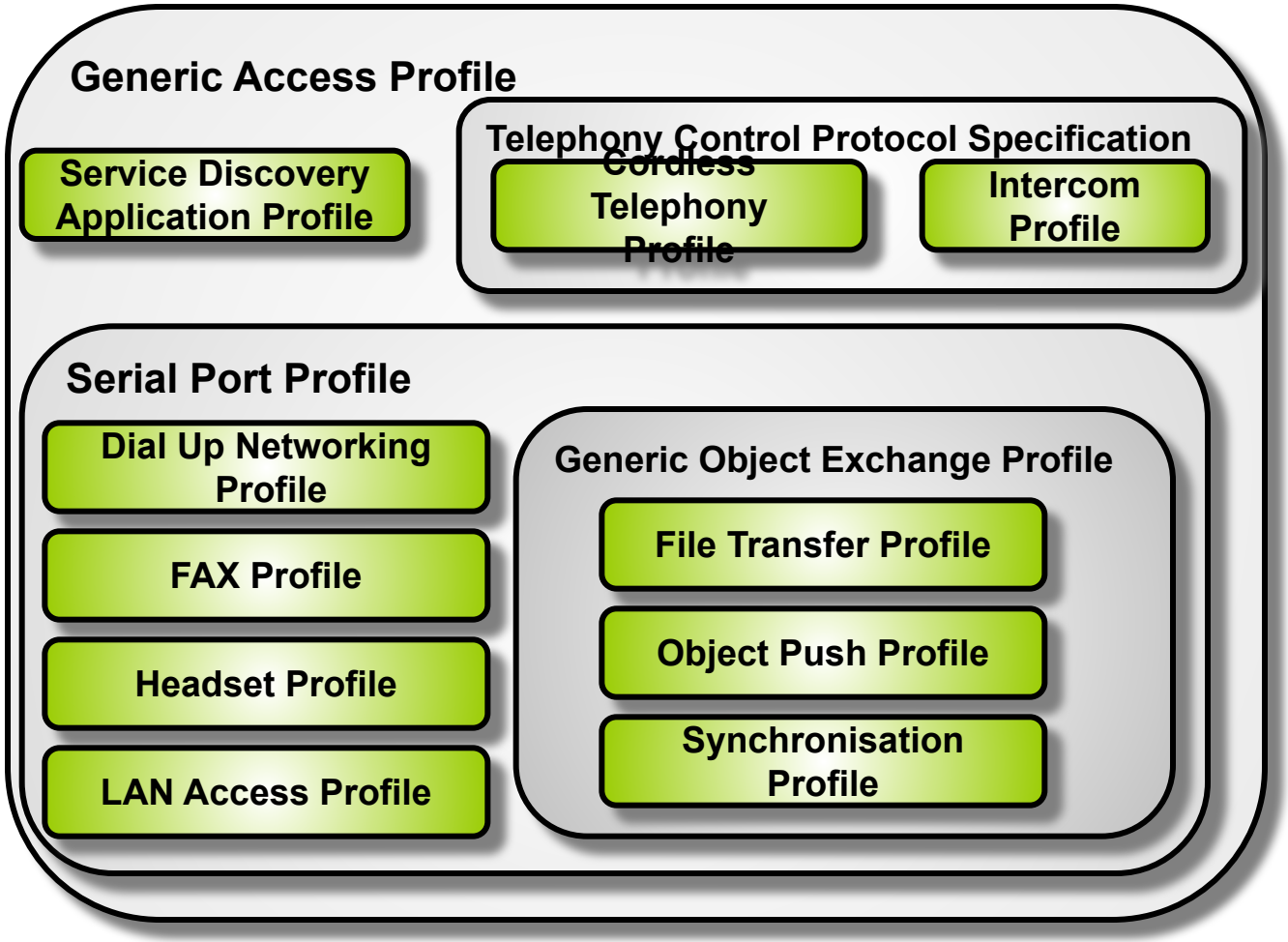
Bluetooth Profiles

- Basic set of standards for common usage models.
  - Reduces set of requirements for each usage model.

- Ensures interoperability
  - Radio Level – ensures devices can contact each other.
  - Protocol Level – ensures devices can communicate.
  - User/usage Level:
    - Ensures application can interoperate.
    - Ensures user can interact with the device.

Bluetooth foundation profiles



Generic Access Profile

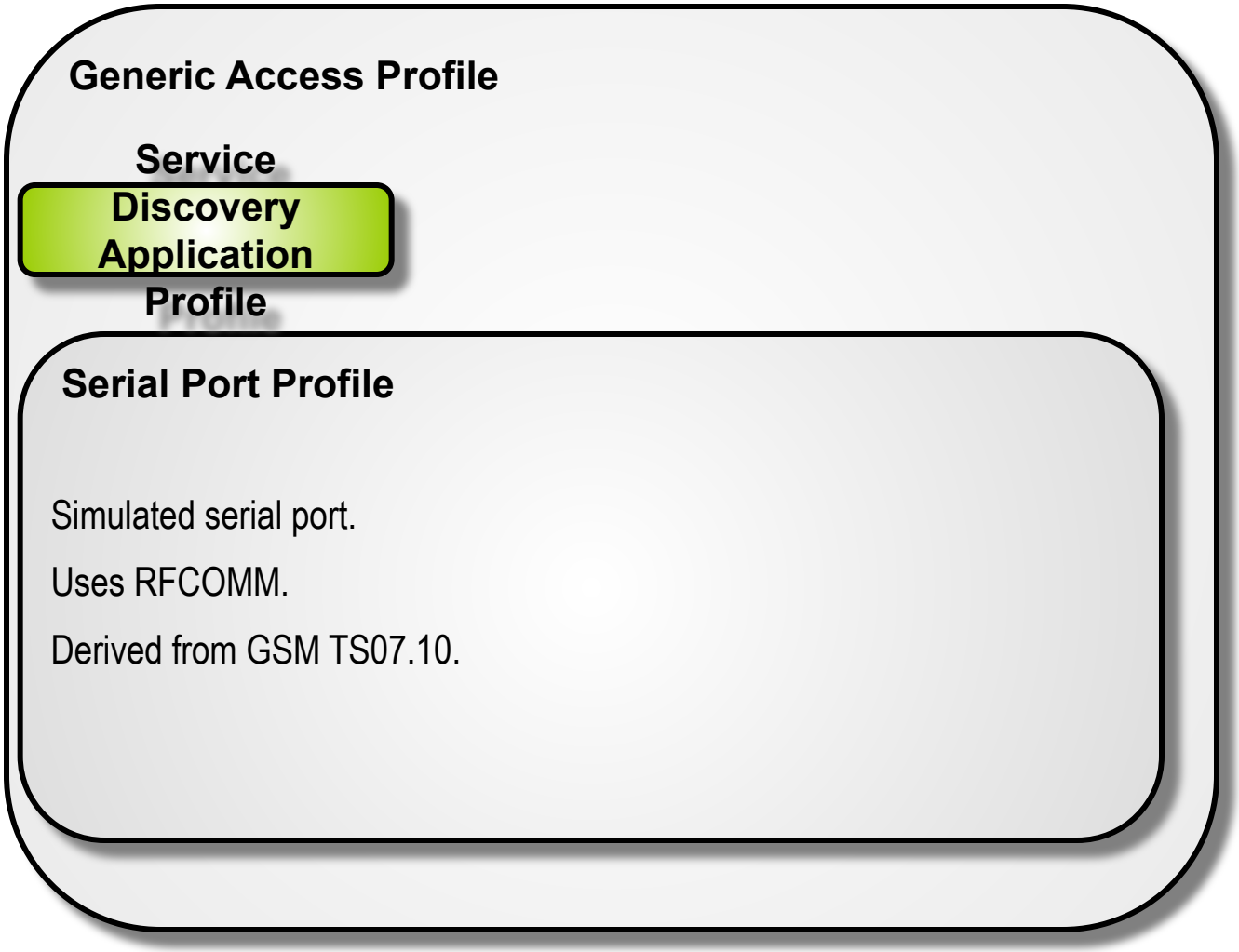
Generic Access Profile

defines:

- generic procedures for discovering Bluetooth devices.
- link management aspects of connecting to Bluetooth devices.
- procedures related to security levels.
- Common formats for parameters accessible on the user interface level (naming conventions).

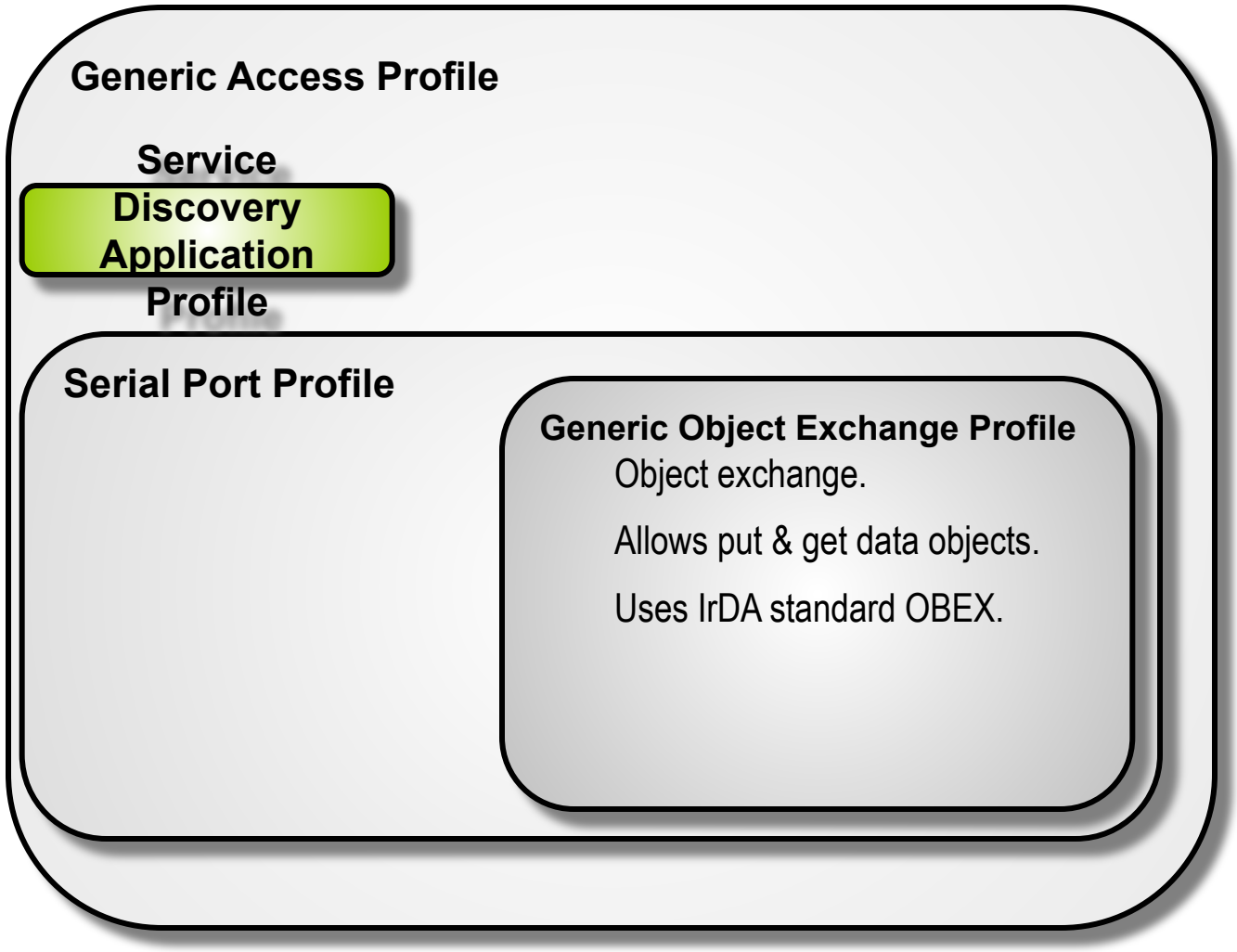
All other profiles rest on Generic Access Profile.

Profile building blocks



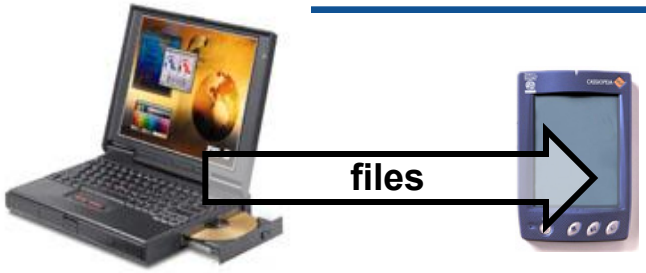
Serial Port Profiles

Profile Building blocks

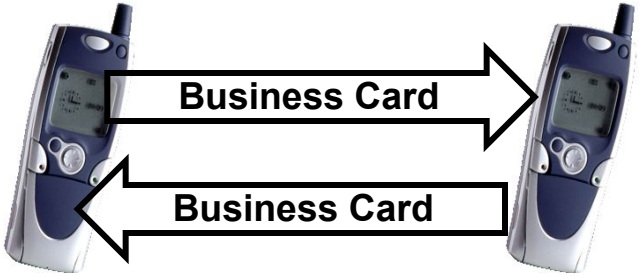


OBEX Profiles

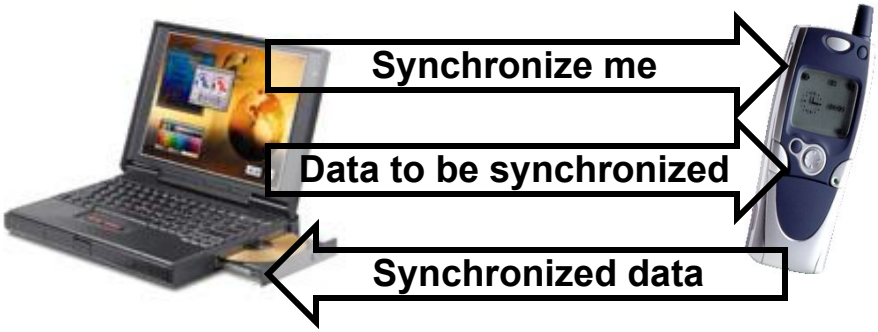
- File Transfer



- Object Push



- Synchronisation



Profiles

- A2DP- Advanced Audio Distribution Profile
- AVRCP - A/V Remote Control Profile
- BIP - Basic Imaging Profile
- BPP - Basic Printing Profile
- CTP - Cordless Telephony Profile
- DID - Device ID Profile
- DUN - Dial-Up Networking Profile
- FAX - Fax Profile
- FTP - File Transfer Profile
- GAVDP - Generic A/V Distribution Profile
- GOEP - Generic Object Exchange Profile
- HCRP - Hardcopy Cable Replacement Profile
- HDP - Health Device Profile
- HFP - Hands-Free Profile
- HSP - Headset Profile
- HID - Human Interface Device Profile
- ICP - Intercom Profile
- MAP - Message Access Profile
- OPP - Object Push Profile
- PAN - Personal Area Network Profile
- PBAP - Phone Book Access Profile
- SAP - SIM Access Profile
- SDAP - Service Discovery Application Profile
- SPP - Serial Port Profile
- SYNCH - Synchronization Profile
- VDP - Video Distribution Profile

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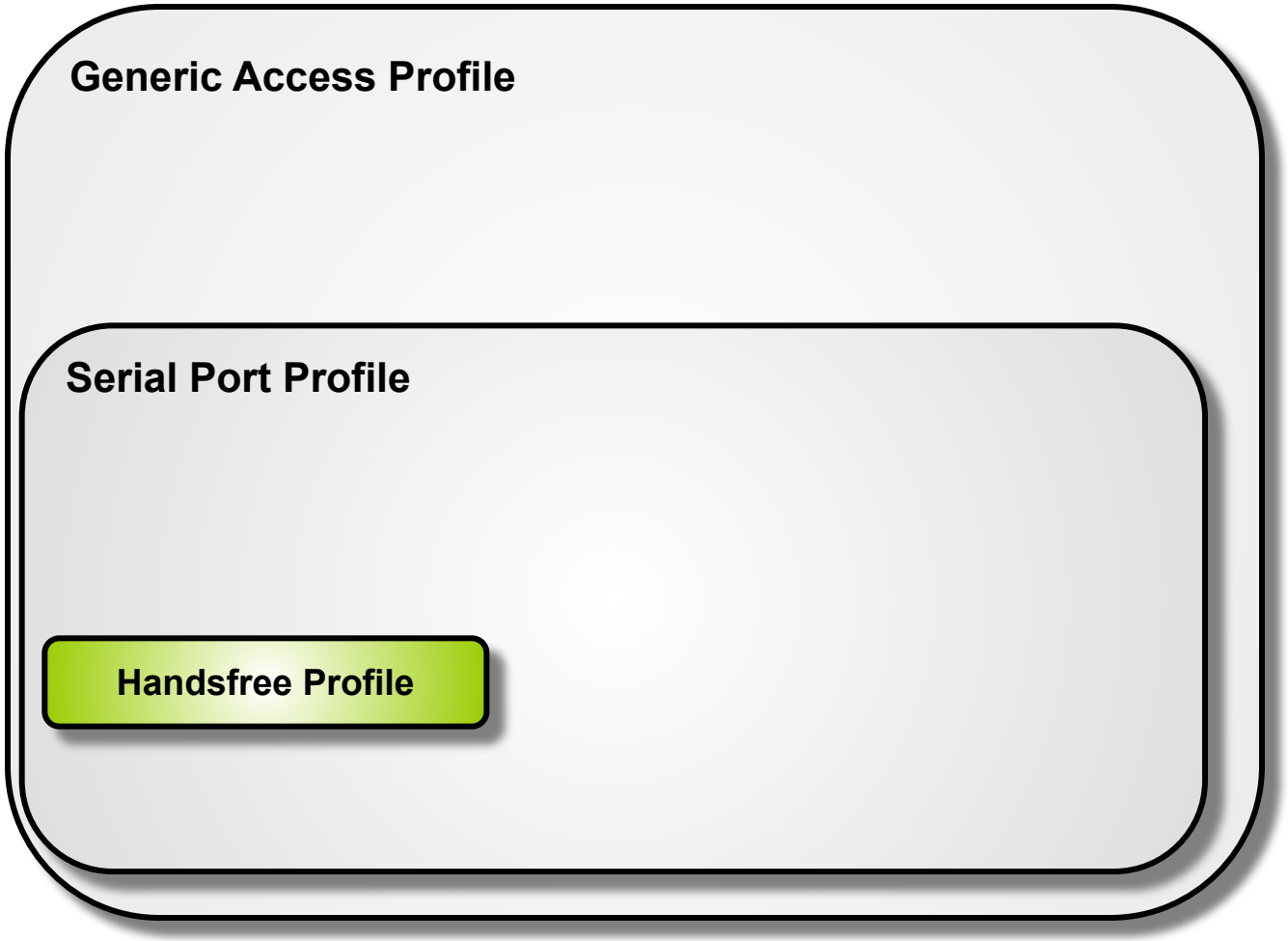
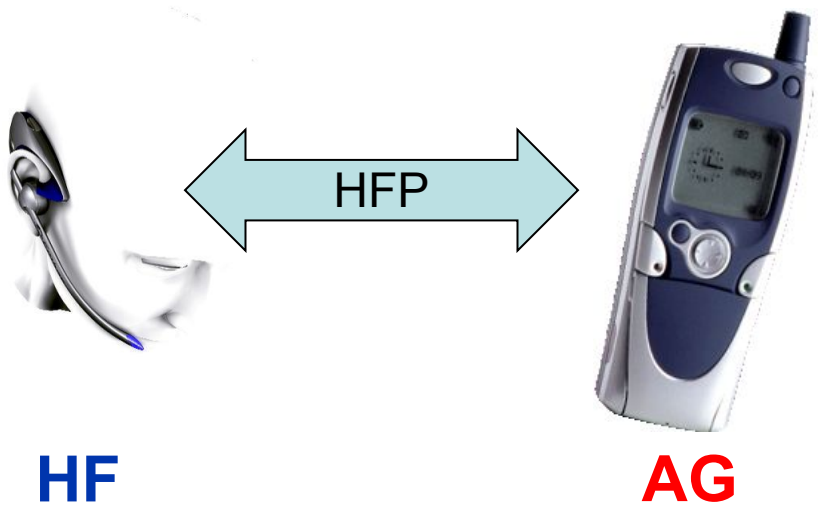
HFP Profile Dependency



Configuration and Roles

- Audio Gateway (AG)
  - gateway for the audio input/output
  - typically a cell phone
- Hands-Free Unit (HF)
  - AG's remote audio input/output
  - means of remote control



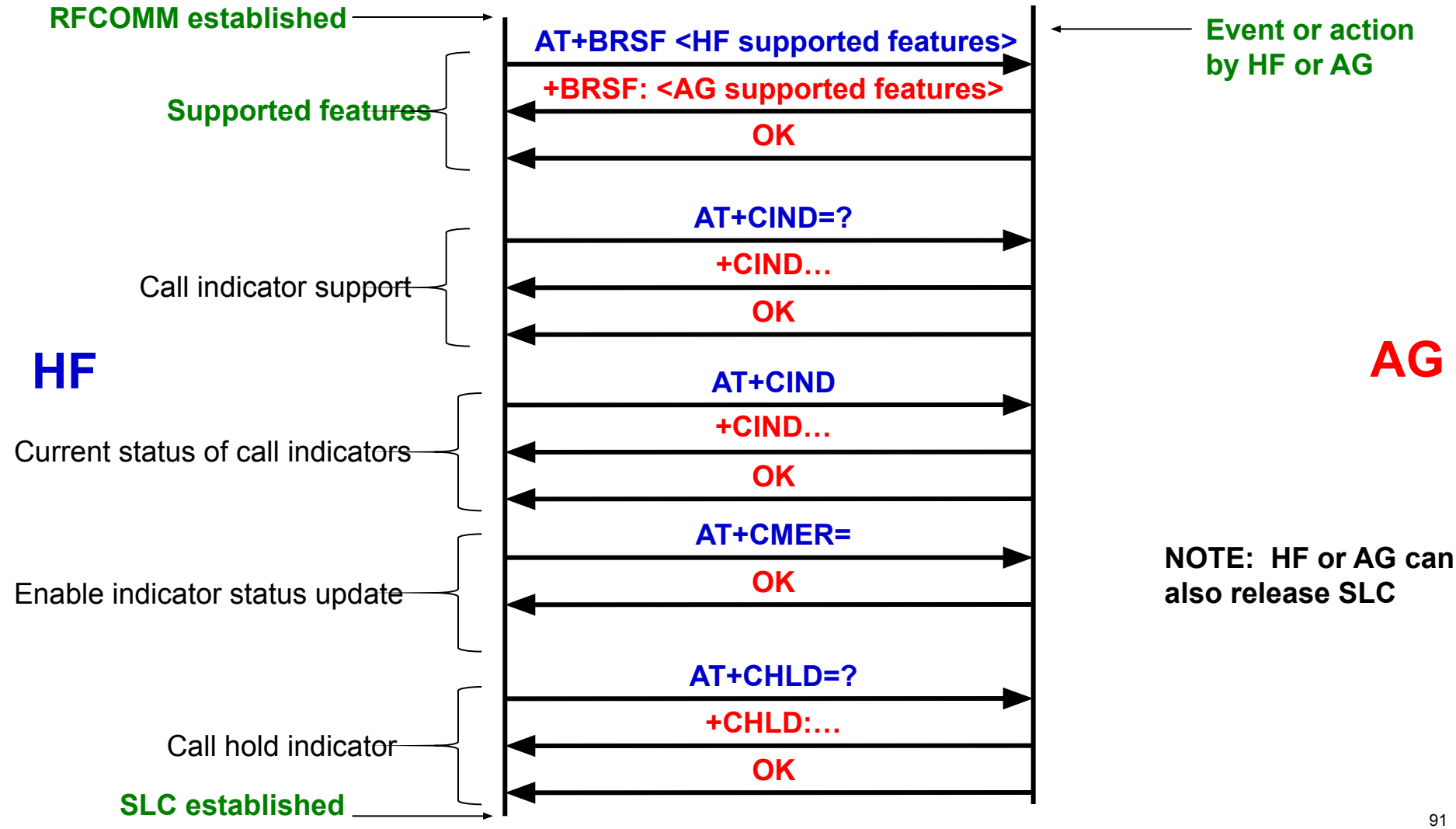
Feature Requirements

- Must support CVSD
- Only one audio connection per service level connection (SLC)
- Can have an SLC without an audio connection
- Must have an SLC with an audio connection

See specification for complete list of features and required support

Feature	HF support
Phone status information	M
Audio Connection handling	M
Accept incoming call	M
Reject incoming call	M
Terminate a call	M
Place a call (# supplied by HF)	O
Memory dial	O
Last number redial	O
Call waiting notification	O
Three way calling	O
Volume control	O
VR activation	O

Establishing a Service Level Connection

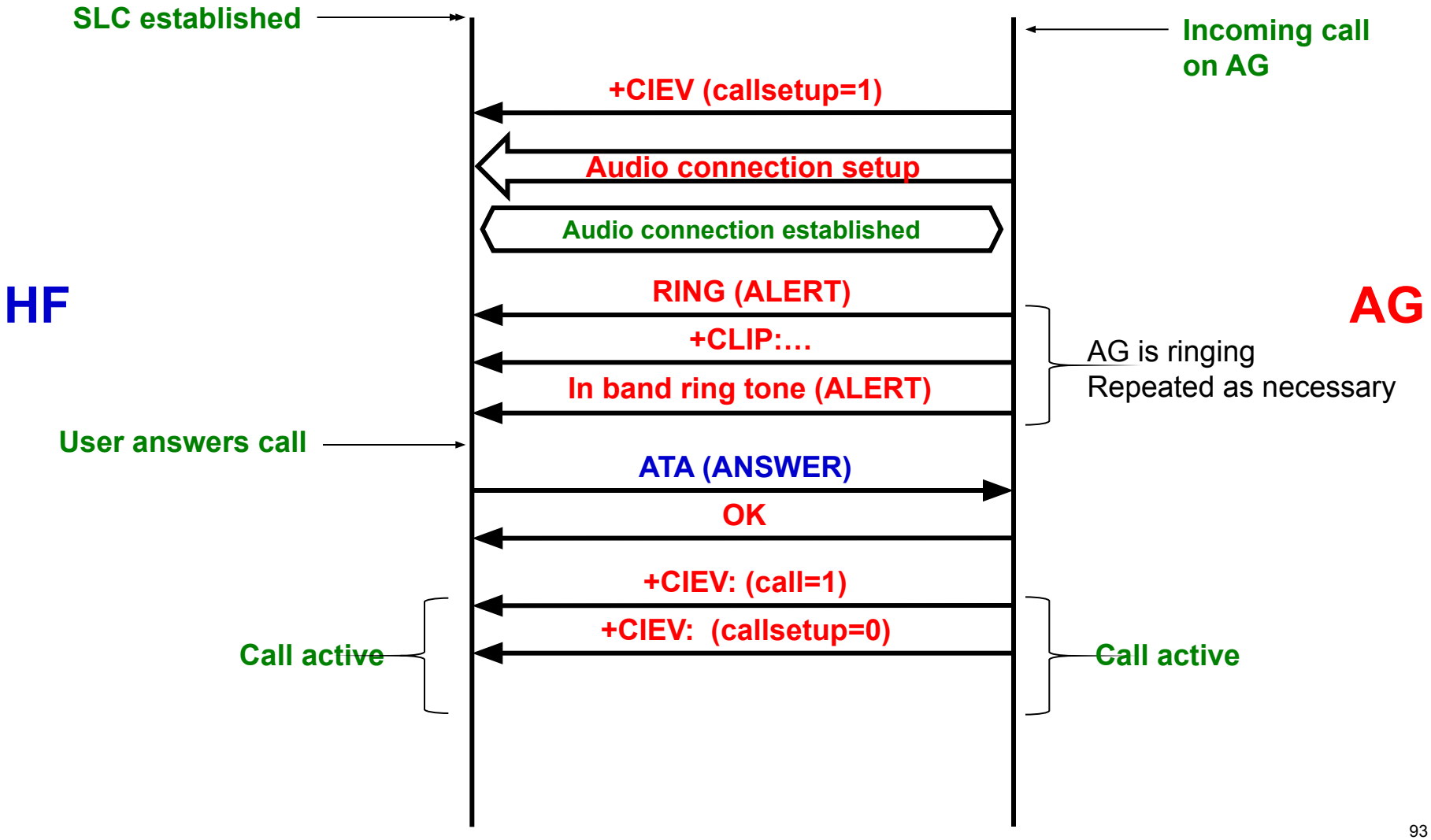


Transferring Status Information

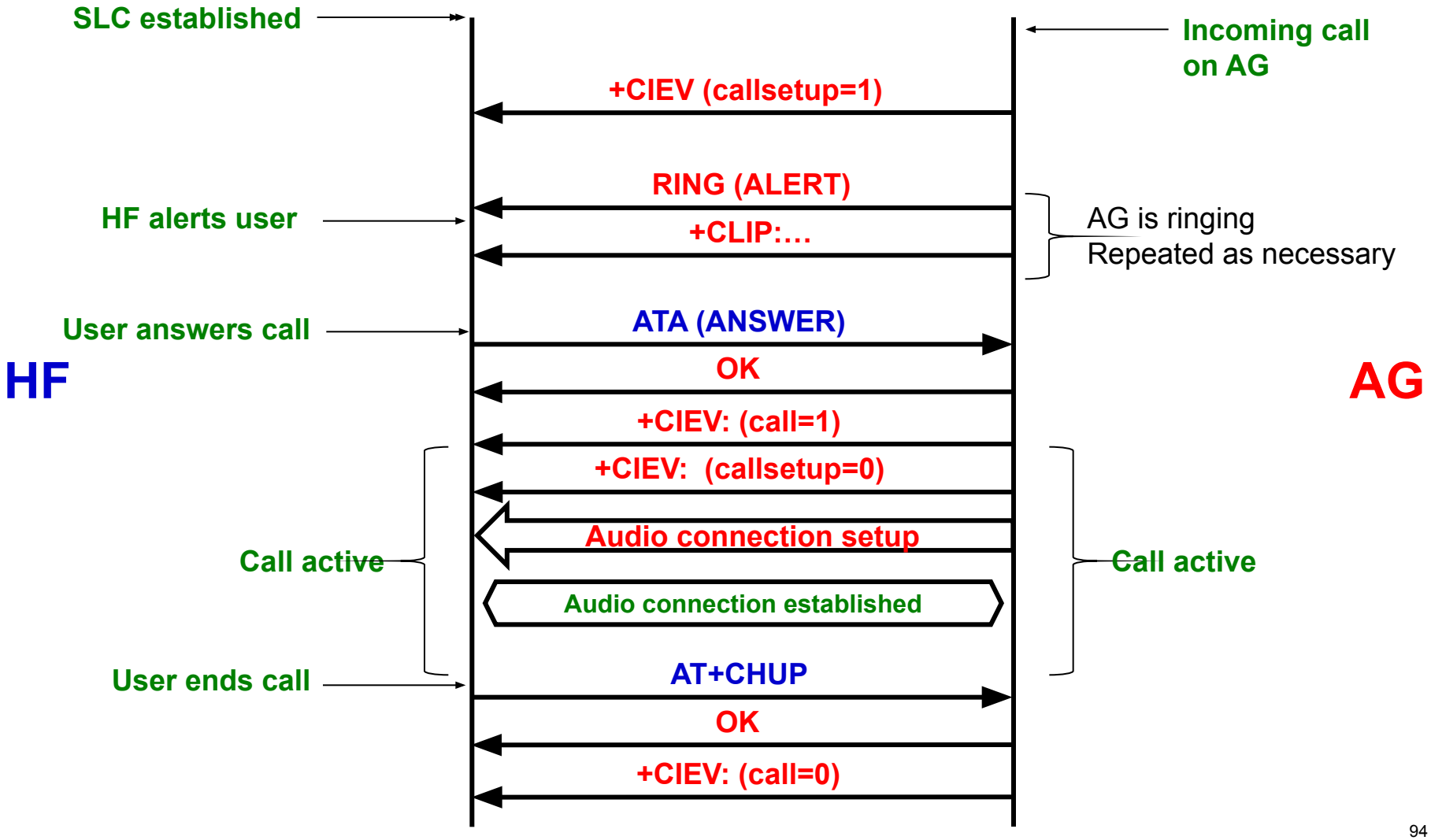
Unsolicited events can be reported from AG to HF

- Service
- Call status
- Call setup
- Call hold status
- Signal
- Roam status
- Battery level

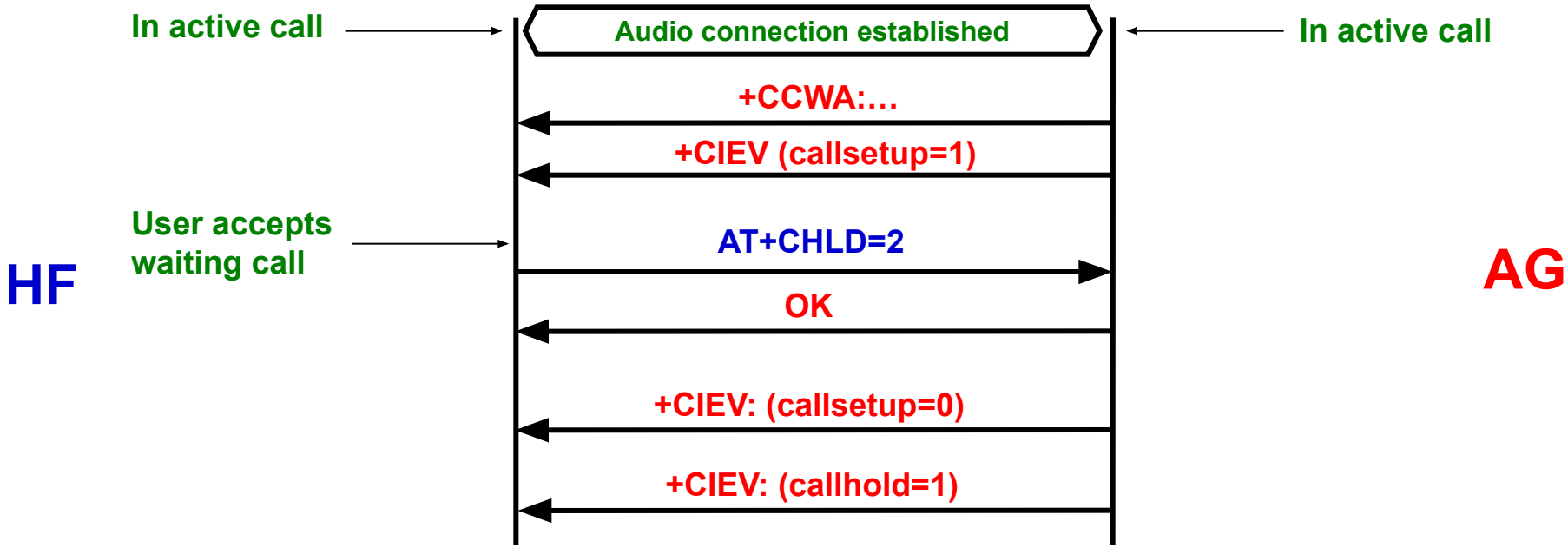
Answering a call - in-band ring tone



Answer/end call – no in-band ring tone



Three-way call – hold active/accept waiting



Call Control

- Audio connection setup
- Audio connection release
- Answer incoming call from AG
- Change in-band ring tone setting
- Reject incoming call from HF
- Reject incoming call from AG
- Audio connection transfer toward HF
- Audio connection transfer toward AG
- Place call with phone number supplied by HF
- Memory dialing from HF
- Last number re-dial from HF
- Call waiting notification activation
- Three way calling – third party called from HF
- Calling line identification notification
- Disabling EC/NR
- Voice recognition activation
- Remote volume control

See specification for examples of these, and other use cases

Common AT Command and Result Codes

AT Command HF→ AG	Function	Result Codes HF ← AG
ATA	Answer call	
ATD	Dial call	
AT+CCWA	Call Waiting	+CCWA
AT+CHLD	Call hold & multiparty	
AT+CHUP	Hang up (and reject)	
AT+CIND	Call indicators	+CIND
AT+CLIP	Calling line identification	+CLIP
AT+CMER	Event reporting activation	+CIEV
AT+BLDN	Last dialed number	
AT+BVRA	Voice recognition	+BVRA
AT+BRSF	Retrieve supported features	+BRSF
AT+NREC	Enable/disable NR/EC	
AT+VGM	Set gain of microphone	+VGM
AT+VGS	Set gain of speaker	+VGS
AT+BTRH	Response & hold	+BTRH

AG may also send the following result codes:

- ERROR
- OK
- NO CARRIER
- BUSY
- NO ANSWER
- DELAYED
- BLACKLISTED
- RING

See specification for complete list of commands and result codes

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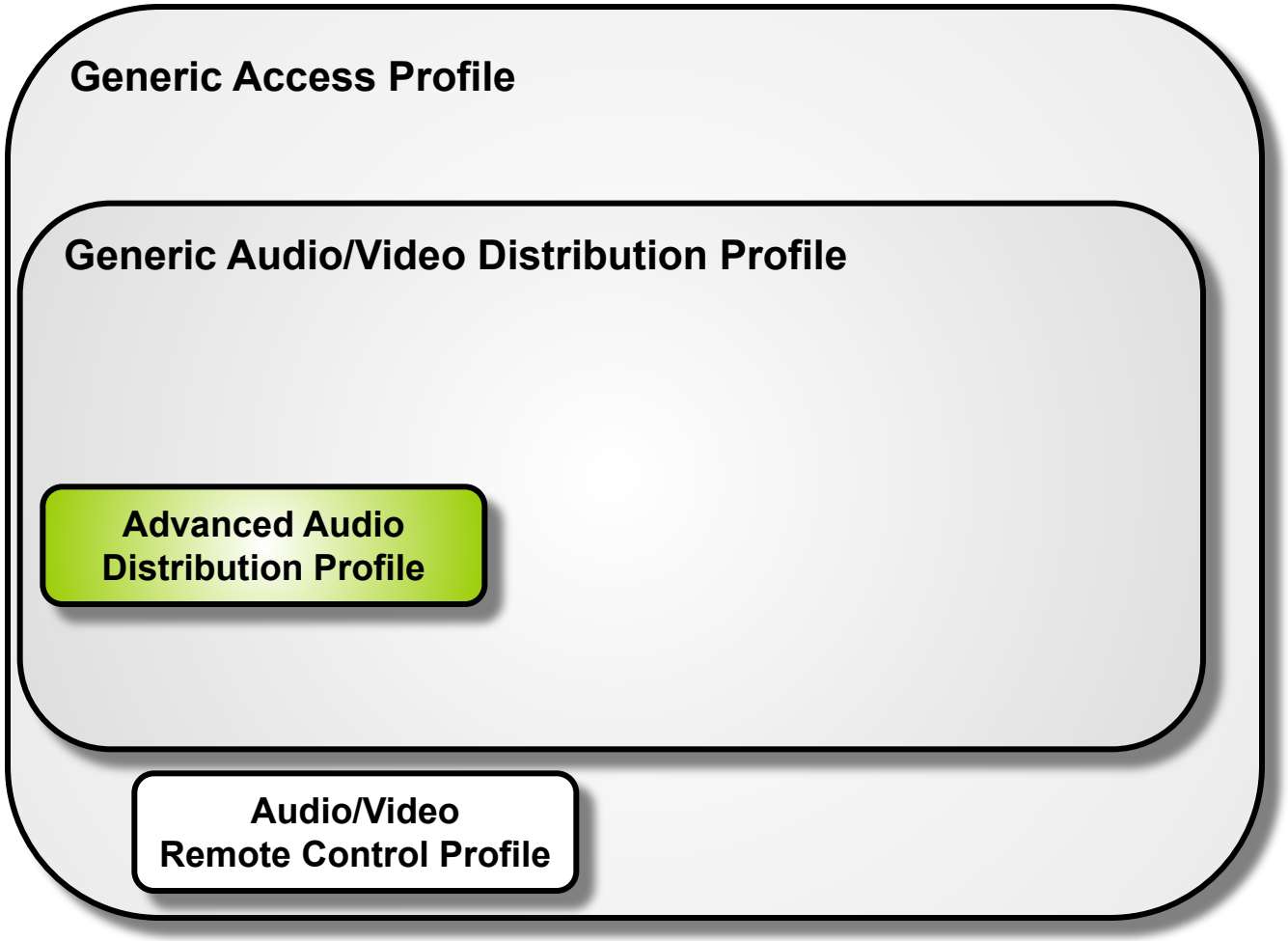
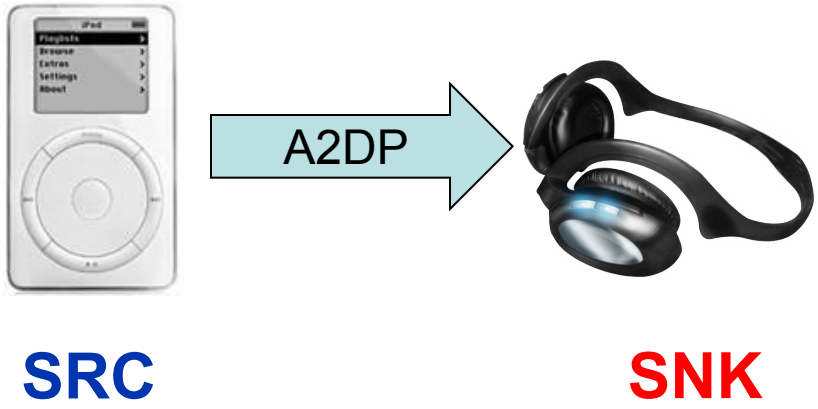
A2DP Profile Dependency



Configuration and Roles

- Source (SRC)
  - Source of digital audio stream that is delivered to the sink of the piconet
  - Media player, phone, PC
- Sink (SNK)
  - Acts as a sink of the digital audio stream that is delivered by the source
  - Stereo headset, wireless speakers, car audio system



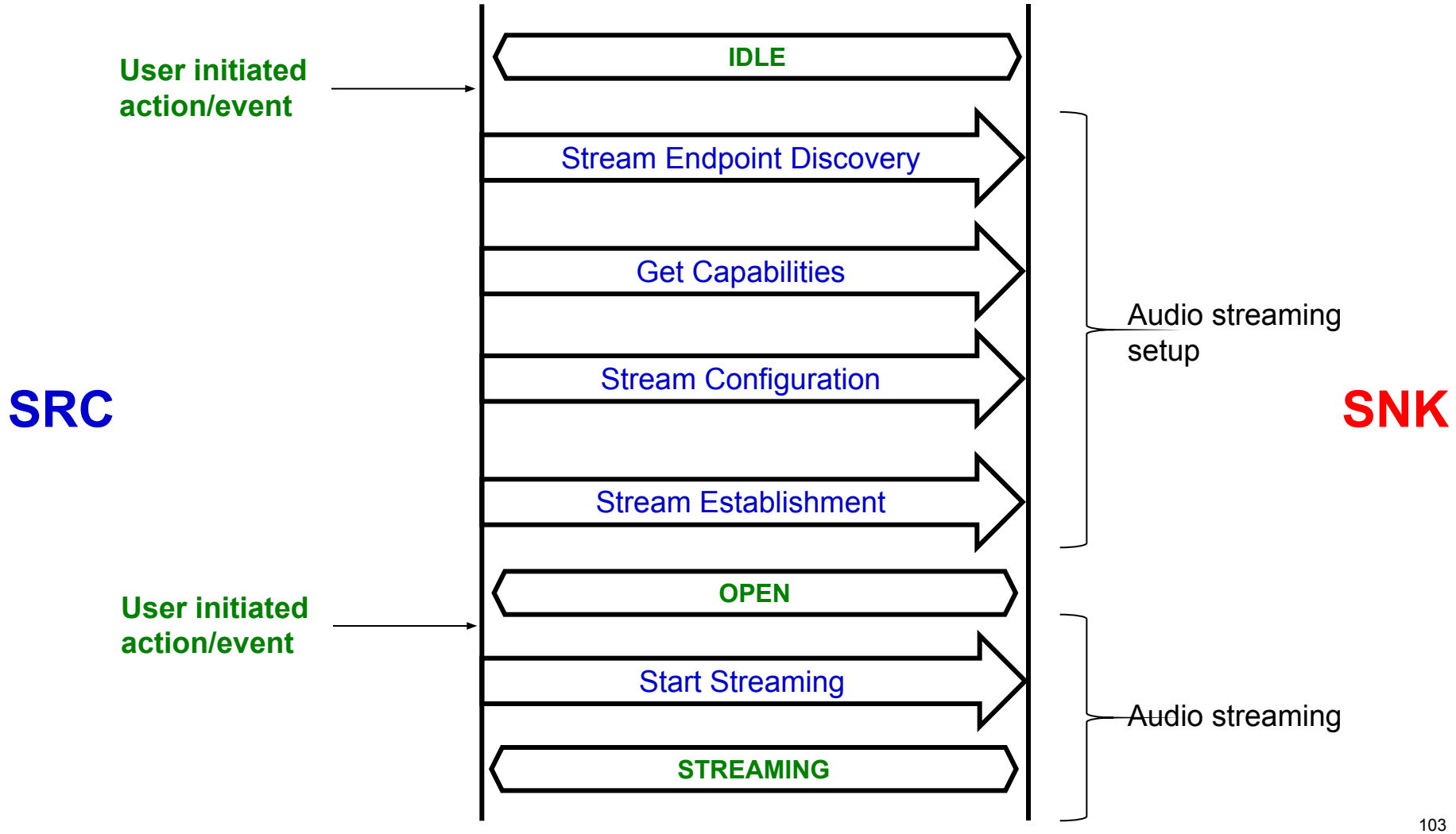
Audio Codec Interoperability Requirements

- Must support SBC
- Optional support for MP3, AAC, ATRAC
- Support can be extended to non-A2DP codecs

Codec Specific Information Elements

- AVDTP signaling procedure negotiates codec parameters
- Parameters part of Codec Specific Information Elements
  - Sampling frequencies
  - Channel modes (mono, dual channel, stereo, joint stereo)
  - Bit rates
  - Other information specific to selected codecs

AVDTP Signaling Procedures



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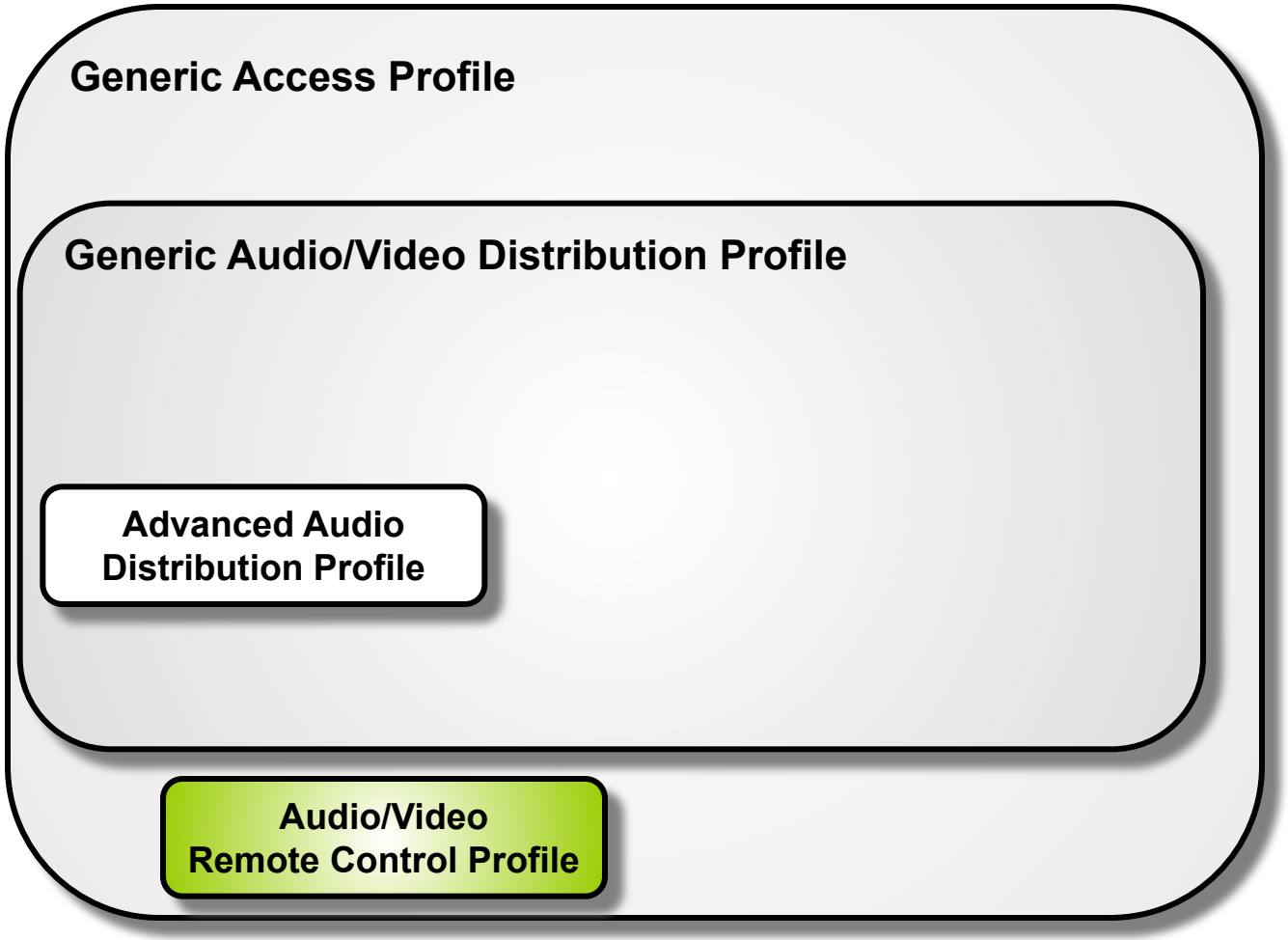
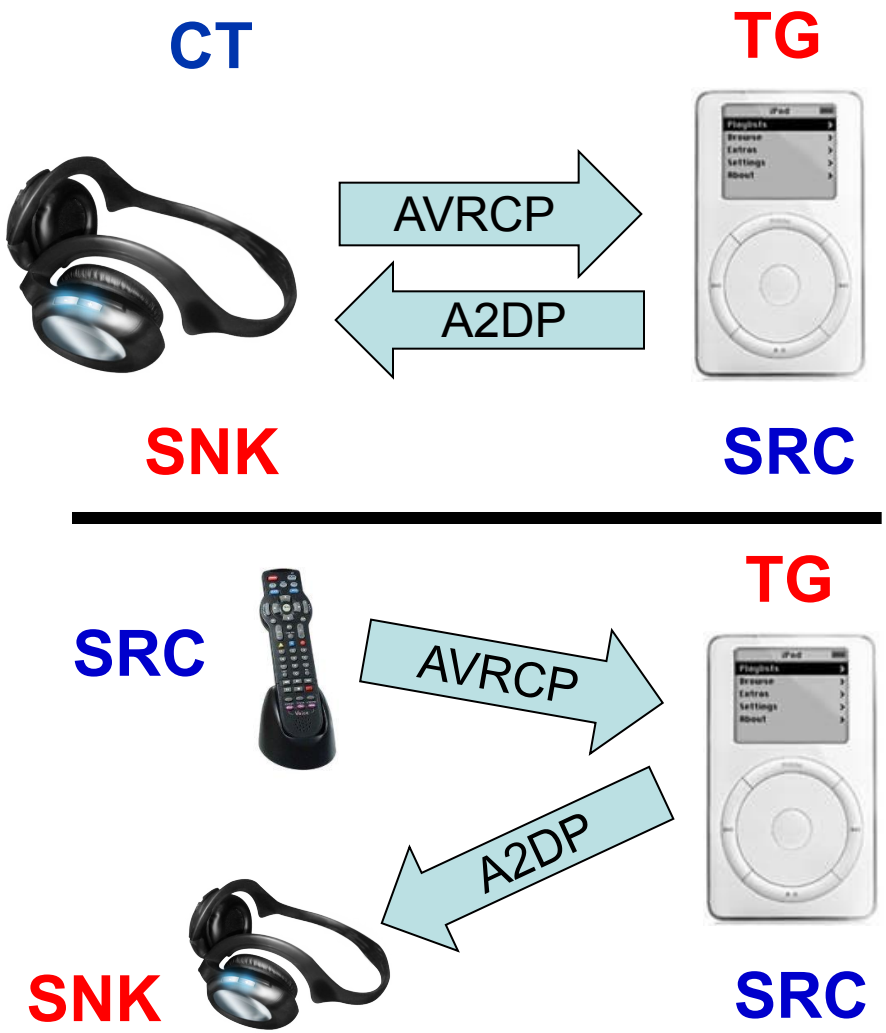
AVRCP Profile Dependency



Configuration and Roles

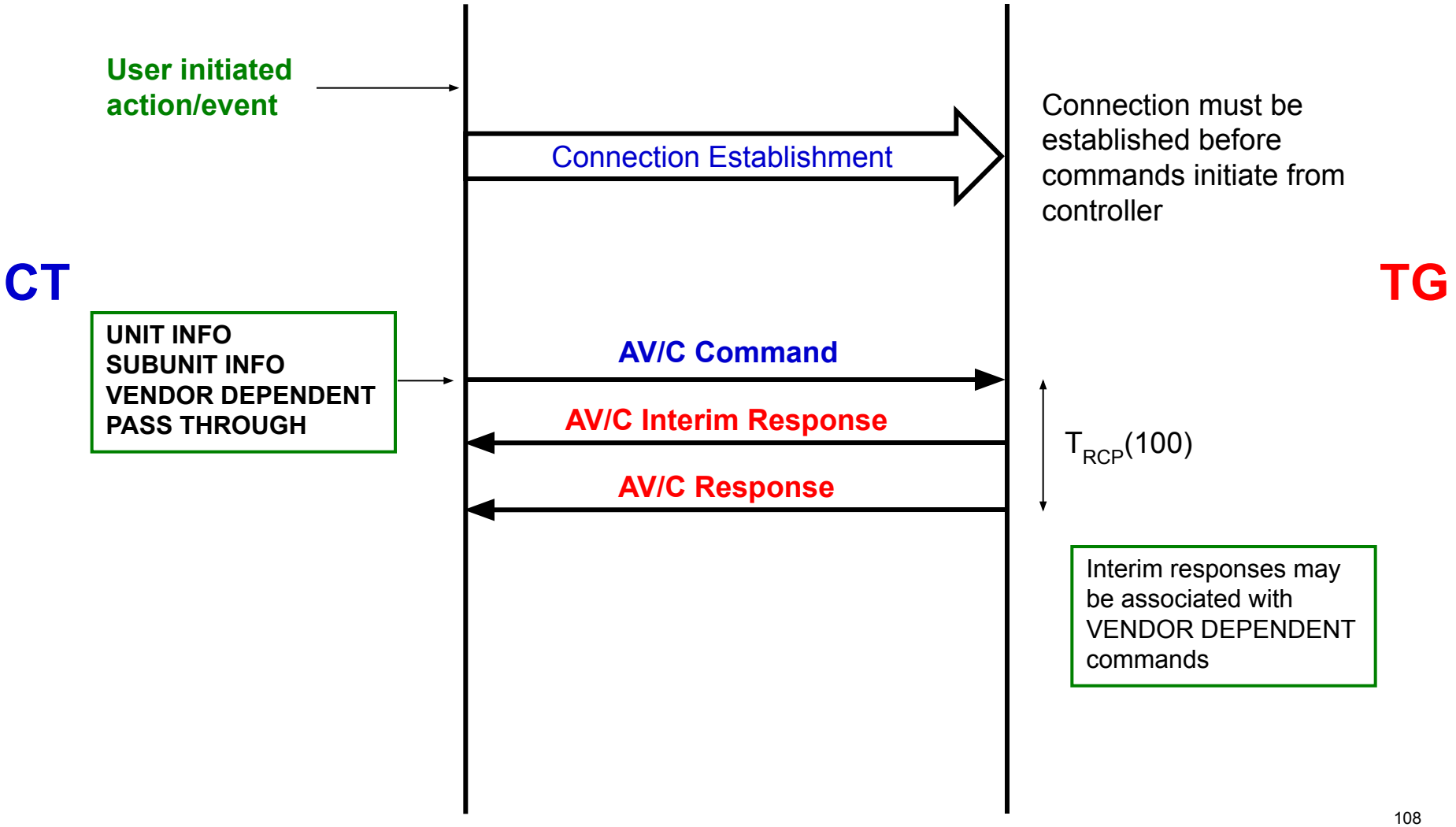
- Controller (CT)
  - Initiates transaction by sending command to target
  - Headsets, remote controls
- Target (TG)
  - Receives command and generates a response frame
  - Media player, TV, tuner



Feature Requirements

Feature	CT support	TG support
Connection establishment for control	M	O
Release connection for control	M	M
Sending UNIT INFO command	O	X
Receiving UNIT INFO command	X	M
Sending SUBUNIT INFO command	O	X
Receiving SUBUNIT INFO command	X	M
Sending VENDOR DEPENDENT command	O	X
Receiving VENDOR DEPENDENT command	X	O
Sending PASS THROUGH command	M	X
Receiving PASS THROUGH command	X	M

Procedure of AV/C Command



AV/C Command Types

- UNIT INFO
  - 1394 Trade Association AV/C Digital Interface Command Set
- SUBUNIT INFO
  - 1394 Trade Association AV/C Digital Interface Command Set
- VENDOR DEPENDENT
  - Allows own set of AV/C commands
- PASS THROUGH
  - Used to transfer user operation information from CT to Panel subunit of TG

A/V Categories

- A/V categories specified to ensure interoperability

- Four Categories
  - Player/Recorder
  - Monitor/Amplifier
  - Tuner
  - Menu

- Each category has operations which are:
  - Mandatory for the TG
  - Optional
  - Not supported

- It is mandatory for CT to support
  - At least one category
  - At least one operation

Supported Operations in TG

Operation	Player/recorder	Monitor/Amplifier	Tuner	Menu
Select				M
Up				M
Down				M
Left				M
Right				M
Root Menu				M
Channel up			M	
Channel down			M	
Volume up		M		
Volume down		M		
Play	M			
Stop	M			
Fast forward	M			
Rewind	M			

See specification for complete list of operations

Newer AVRCP Versions

- AVRCP 1.3 - adds support for metadata
  - Query capabilities
  - Query application settings
  - Attributes for currently selected media track
  - Event notifications
  - Continuation (i.e. segmentation/re-assembly)
  - Group navigation

- AVRCP 1.4
  - Media player selection
  - Browsing
  - Searching
  - Advanced volume control

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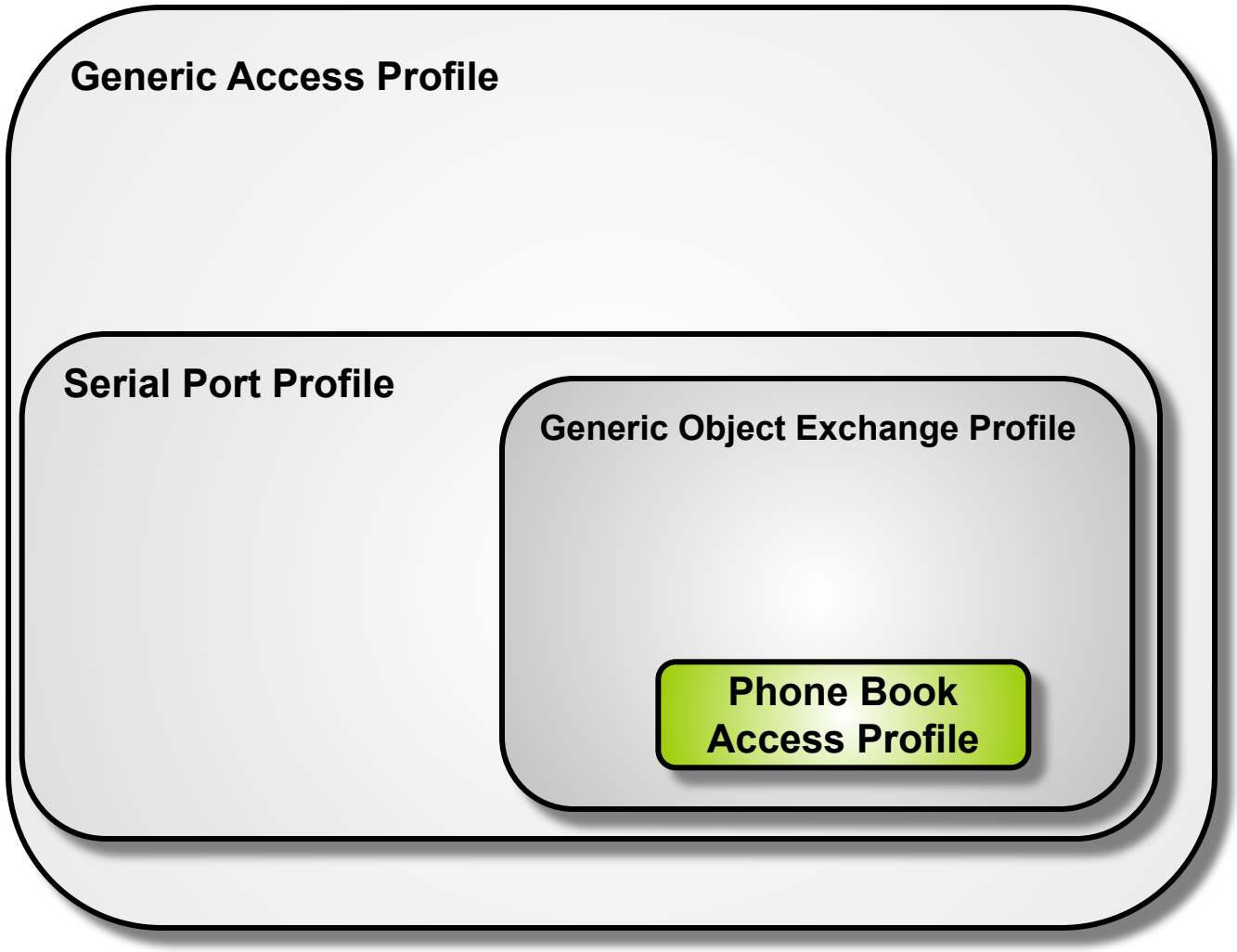
PBAP Profile Dependencies

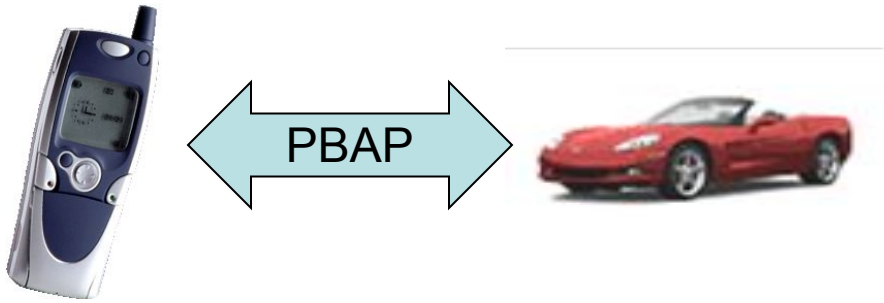


PBAP Overview

- Client-server interaction model
- Tailored for hands-free usage case
- Read only – cannot alter content
- More feature-rich than OPP

Configuration and Roles

- Phone book Server Equipment (PSE)
  - Contains source phonebook objects
  - Phone
- Phone book client equipment (PCE)
  - Retrieves phone book objects from server
  - Accessory in automobile, car kit, headset



Phone Book Objects and Representations

- Based upon IR Mobile Communications specification

- Five types of phone book objects
  - Main phone book – entries are vCard 2.1 or 3.0 in XML format
  - Incoming call history
  - Outgoing call history
  - Missed call history
  - Combined call history

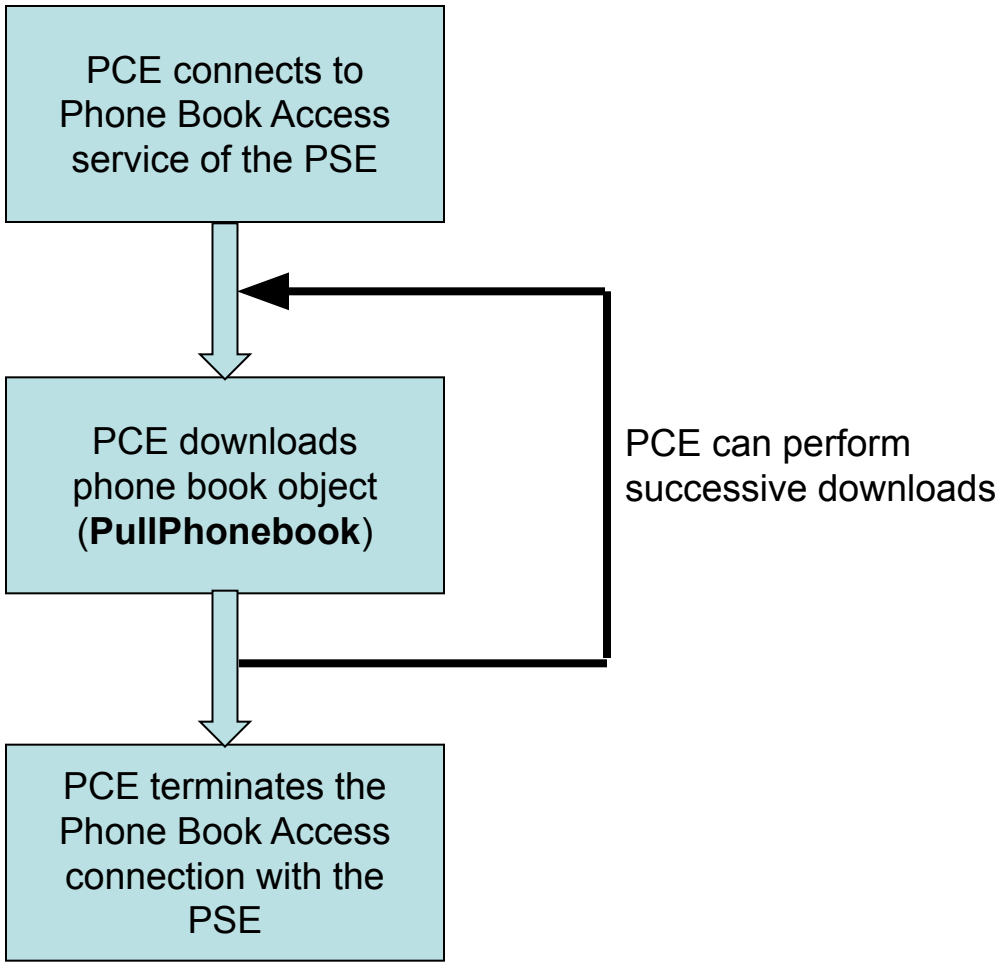
- Object representations
  - File representation
  - Folder representation

PBAP Features and Functions

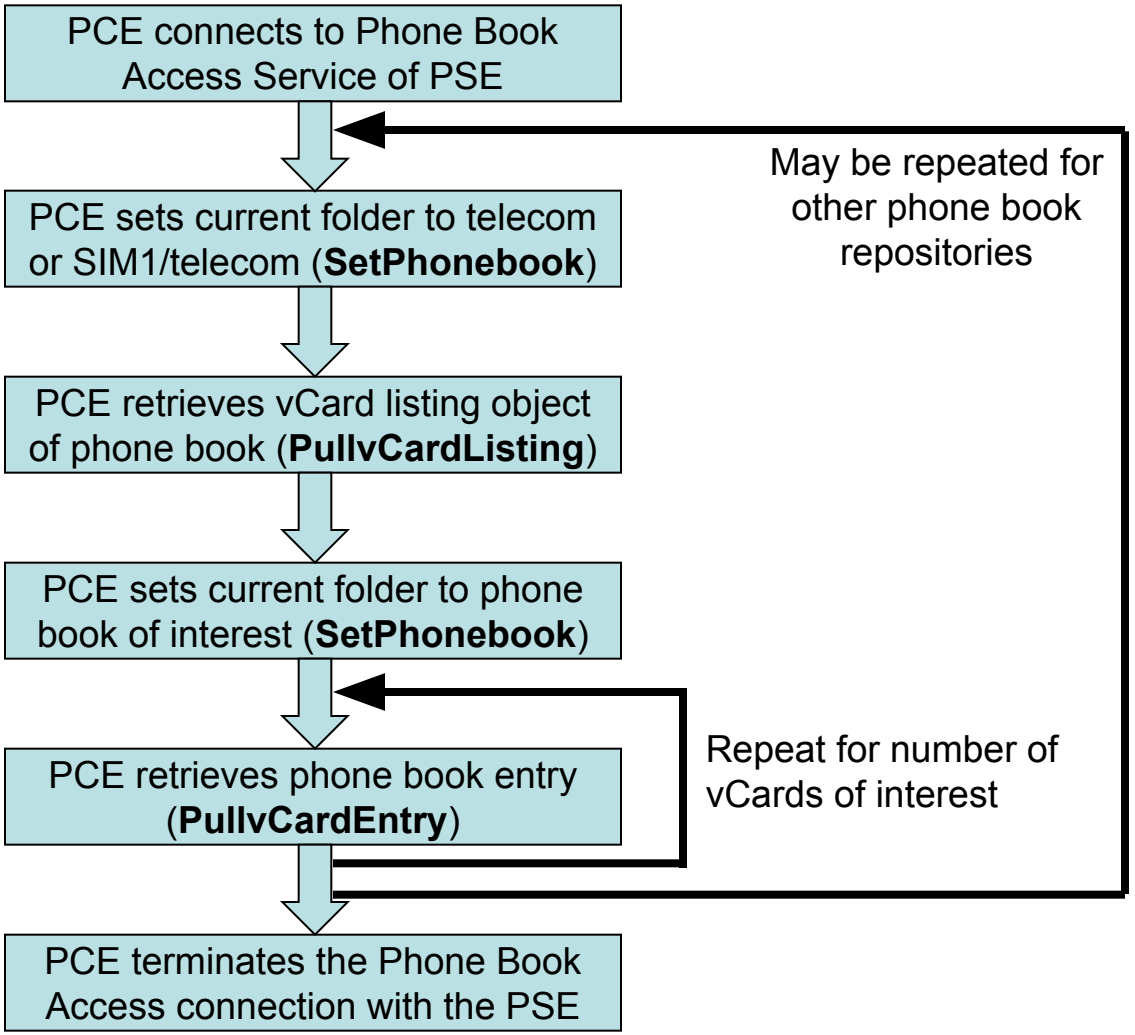
Feature	Function	PCE	PSE
Download	PullPhoneBook	*	M
Browsing	SetPhoneBook	*	M
	PullvCardListing	*	M
	PullvCardEntry	*	M

PCE must support either Download or Browsing feature and functions associated with that feature

Phone Book Download Sequence Example



Phone Book Browsing Sequence Example



Agenda

- Bluetooth Overview
- Bluetooth Air Interface & Baseband
- Bluetooth Protocol Stack
- Bluetooth Profiles
  - HFP
  - A2DP
  - AVRCP
  - PBAP
- New Bluetooth Standards

Bluetooth 3.0+HS

- Alternate MAC/PHY (AMP)
  - Enables high speed using other radio technologies (e.g. 802.11)
  - Bluetooth Basic Rate acts as control channel
    - Can use 802.11 as high speed bearer channel when needed
- Enhanced Power Control
  - Faster and more responsive power control

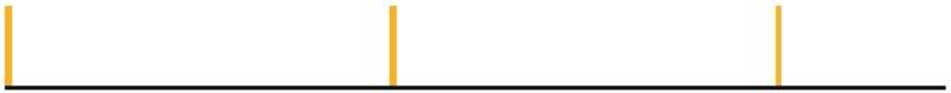
Bluetooth 4.0 (BTle)

- Used to transfer simple data sets between compact devices
- Opens up whole new classes of Bluetooth applications
  - watches, sneakers, TV remote controls, medical sensors, etc.
- Takes less time to make a connection than conventional Bluetooth.
- Consumes approximately 98% less power than Bluetooth Basic Rate

Why is Bluetooth low energy low power?

- Bluetooth
  - Listens frequently
  - Listens for a longer tin
  - On 1%

- Bluetooth low energy
  - Transmits quickly
  - Listens quickly
  - Turned off 99.9% of the time



Why is Bluetooth low energy low power?

Bluetooth	Bluetooth low energy
Paging – 20ms	Advertising – 2ms
LMP Negotiation – 100ms	Connect Request – 1ms
L2CAP Negotiation – 100ms	
Send Application Data – 150ms	Send Application Data – 3ms