LECTURE 10

Wireless Local Area Networks and Bluetooth

Wireless LANs

- *Local Area*
- Ubiquitous – WiFi
- Others
  - HIPERLAN?
  - Bluetooth based WLANs
  - IR WLANs
- Started as extensions to wired LANs
  - Still extensions to wired LANs, but increasingly stand-alone LAN solutions (especially in homes)

Topologies

- Infrastructure based (most popular)
  - Connect users to a wired infrastructure network
  - Wireless access network like cellular phone system
  - IEEE 802.11, a, b, g , n, etc.
- Ad-Hoc based networks
  - Provide peer to peer communication – mobiles communicate between each other directly
  - Rapid Deployment (conference room)
  - Bluetooth, IEEE 802.11, a, b, g, n, Zigbee/802.15.4, Proprietary
- Point – to –Point (cable replacement)
- Mesh

Wireless LAN Markets

- Medical
  - Hospitals doctors and nurses have PDA’s
- Education
  - Universities/colleges have campus wide network
- Manufacturing – factories, storage, etc.
- Retail/Small Business
  - Superstores, grocery stores, Walmart, etc. use it for inventory management
- Public Access (Hotels, airports, coffee shops)
  - (T-Mobile has > 2300 in U.S. coffee shops and bookstores, Wayport > 500 hotels, BT 5000 in U.K.)
- Wireless ISPs in many cities and housing developments
- Homes – mobility in and around house
- Market over $4.8 billion in 2005 *source researchmarkets

Spectrum for Wireless LANS

- Licensed Vs. Unlicensed
  - Private yard Vs. Public park
- Industrial Scientific and Medical bands
  - 902-928 MHz
  - 2.4 – 2.4835 GHz
  - 5.725 – 5.875 GHz
- (Unlicensed - National Information Infrastructure Bands) U-NII bands (5-6 GHz) region
  - Three bands of 100 MHz each
    - Band 1: 5.15 - 5.25 GHz
    - Band 2: 5.25 - 5.35 GHz
    - Band 3: 5.725 - 5.825 GHz
- 18-19 GHz licensed available in U.S.
- 17 GHz, 40 GHz and 60 GHz under study

IEEE 802.11 Standard

- The project was initiated in 1990
- The first complete standard was released in 1997
- Supports two topologies: Infrastructure and Ad hoc
- Suite of standards for MAC layer and below
- Main sub-standards IEEE 802.11, a, b, g, n
- Common MAC layer for all sub-standards
- Supports different physical layers at various data rates and frequencies
  - Diffused infrared (802.11)
  - Frequency hopping and direct sequence spread spectrum (802.11)
  - Complementary Code Keying (802.11b)
  - Orthogonal Frequency Division Multiplexing (OFDM) (802.11a, g)
  - Multiple Input Multiple Output & OFDM (802.11n)
  - Is TDD for each physical layer
- Many additional sub-standards studying various aspects

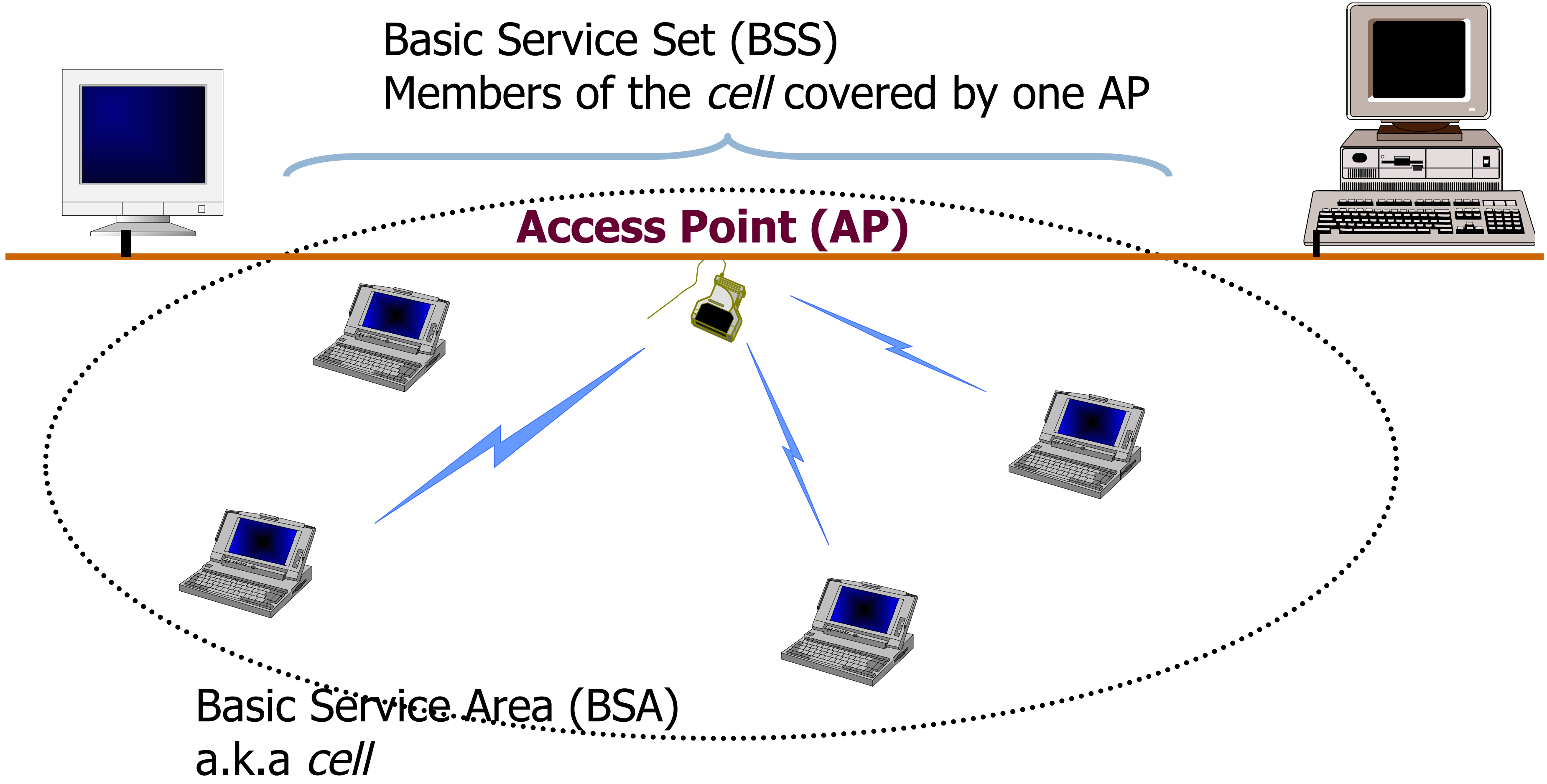
IEEE 802.11 Terminology

- Access Point (AP)
  - Acts as a base station for the wireless LAN and is a bridge between the wirless and wired network
- Basic Service Area (BSA)
  - The coverage area of one access point
- Basic Service Set (BSS)
  - A set of stations controlled by one access point
- Distribution system
  - The fixed (wired) infrastructure used to connect a set of BSS to create an extended service set (ESS)
- Portal(s)
  - The logical point(s) at which non-802.11 packets enter an ESS

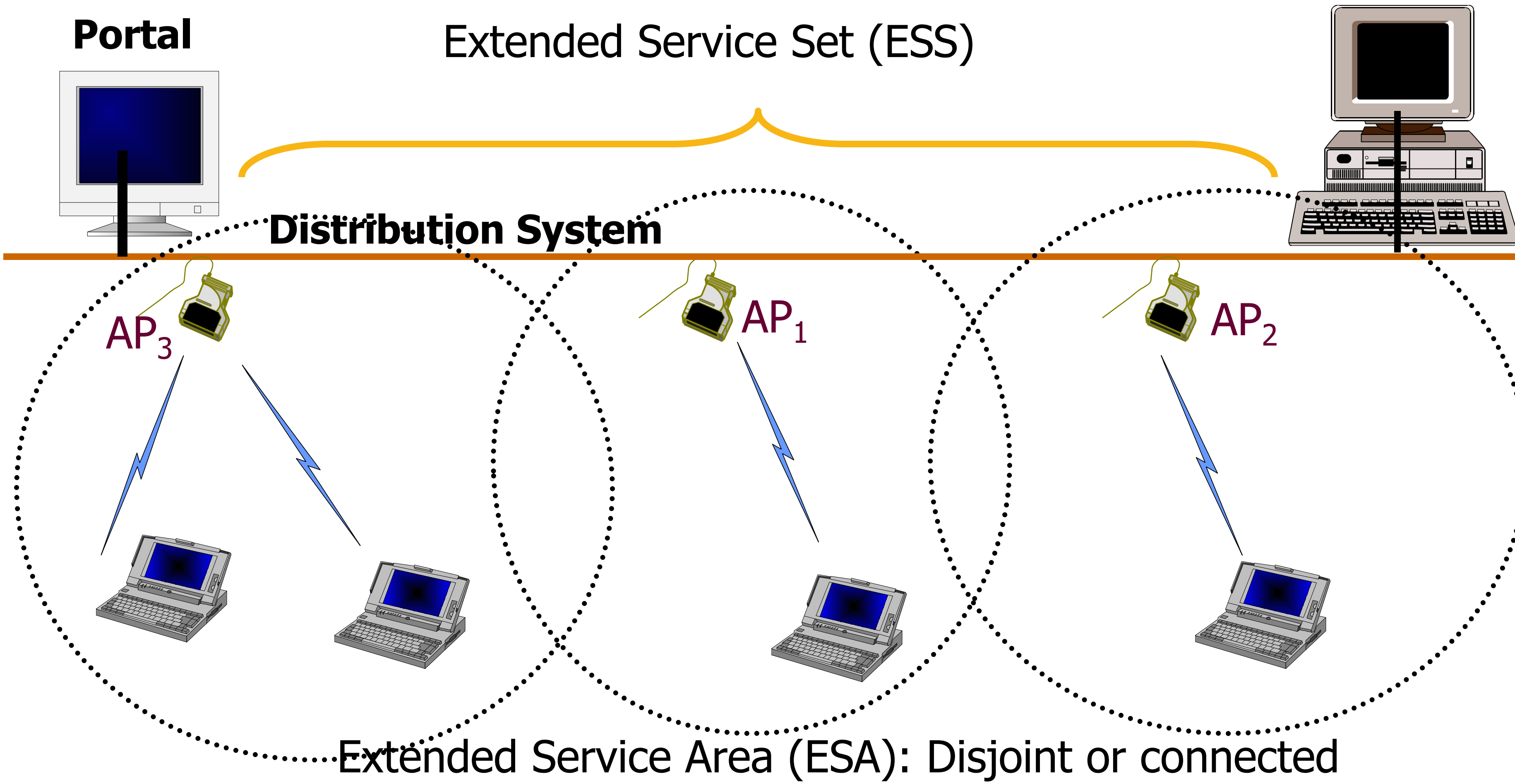
Infrastructure Network Topology

- A wired infrastructure supports communications between mobile hosts (MHs) and between MHs and fixed hosts
- Star topology
  - The BS or AP is the hub
  - Any communication from a MH to another has to be sent through the BS or AP
  - The AP manages user access to the network
  - APs typically mounted on wall or ceiling
  - AC power maybe a problem, power over Ethernet option delivers AC power over UTP (Unshielded Twisted Pair) Ethernet cable
- Designed for multiple APs interconnected to cover larger areas to form ESS

Infrastructure based Architecture

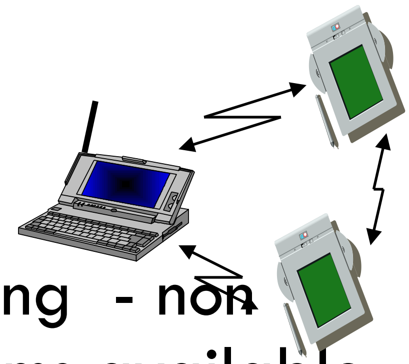


Infrastructure-based Architecture

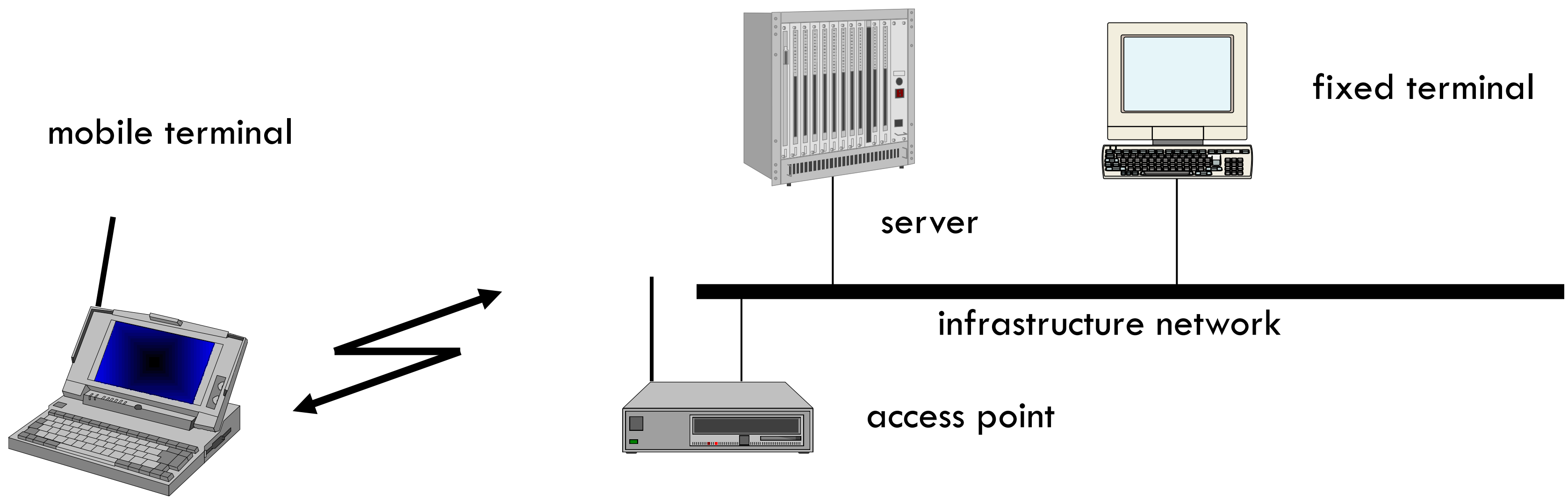


Ad hoc network topology

- Independent Basic Service Set (IBSS)
- Distributed topology
- MHs communicate between each other directly (like walkie-talkies)
- No need for a wired infrastructure
- Suitable for rapid deployment
- Use in conference rooms
- No support for multi-hop ad hoc networking - non standard freeware and proprietary systems available that support multi-hop



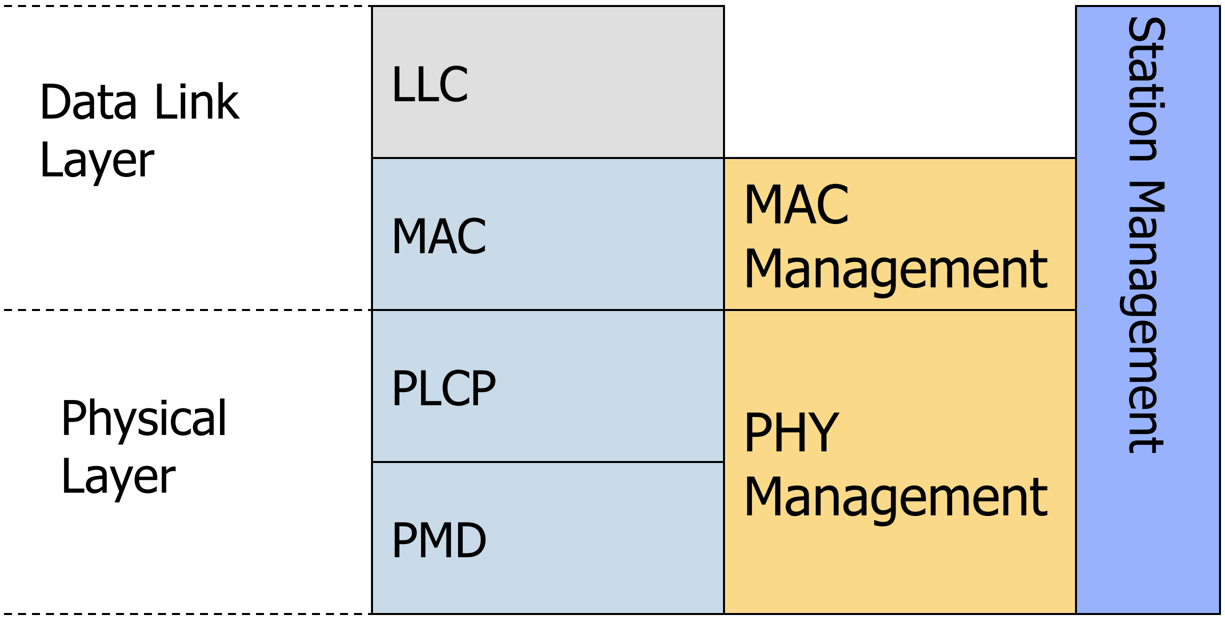
Protocol position of IEEE 802.11



application			application
TCP			TCP
IP			IP
LLC	LLC		LLC
802.11 MAC	802.11 MAC	802.3 MAC	802.3 MAC
802.11 PHY	802.11 PHY	802.3 PHY	802.3 PHY

IEEE 802.11 Protocol Architecture

MAC layer independent of Physical Layer
Physical varies with standard (802.11, 802.11a, etc.)
PLCP: Physical Layer Convergence Protocol
PMD: Physical Medium Dependent



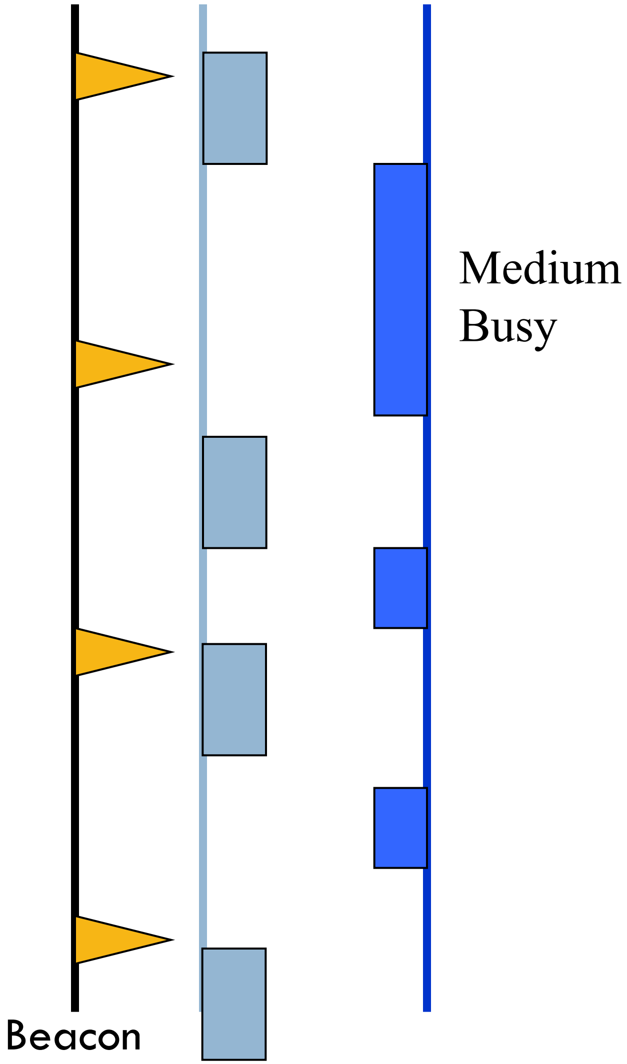
More on the Protocol Stack

- IEEE 802.11 data link layer has two sublayers
  - Logical Link Layer
    - Determined by wired network interface
  - Media Access Control (MAC) layer :
    - Security, reliable data delivery, access control
    - Provides coordination among MSs sharing radio channel

MAC Management Frames in 802.11

- Beacon
  - timestamp, beacon interval, capabilities, ESSID, traffic indication map (TIM)
- Probe
  - ESSID, Capabilities, Supported Rates
- Probe Response
  - same as beacon except for TIM
- Re-association Request
  - Capability, listen interval, ESSID, supported rates, old AP address
- Re-association Response
  - Capability, status code, station ID, supported rates

Beacon



- Beacon is a message that is transmitted quasi-periodically by the access point
- It contains information such as the BSS-ID, timestamp (for synchronization), traffic indication map (for sleep mode), power management, and roaming
- Beacons are always transmitted at the expected beacon interval unless the medium is busy
- RSS measurements are made on the beacon message

Association

- In order to deliver a frame to a MS, the distribution system must know which AP is serving the MS
- Association is a procedure by which a MS "registers" with an AP
- Only after association can a MS send packets through an AP
- How the association information is maintained in the distribution system is NOT specified by the standard

Re-association and Dissociation

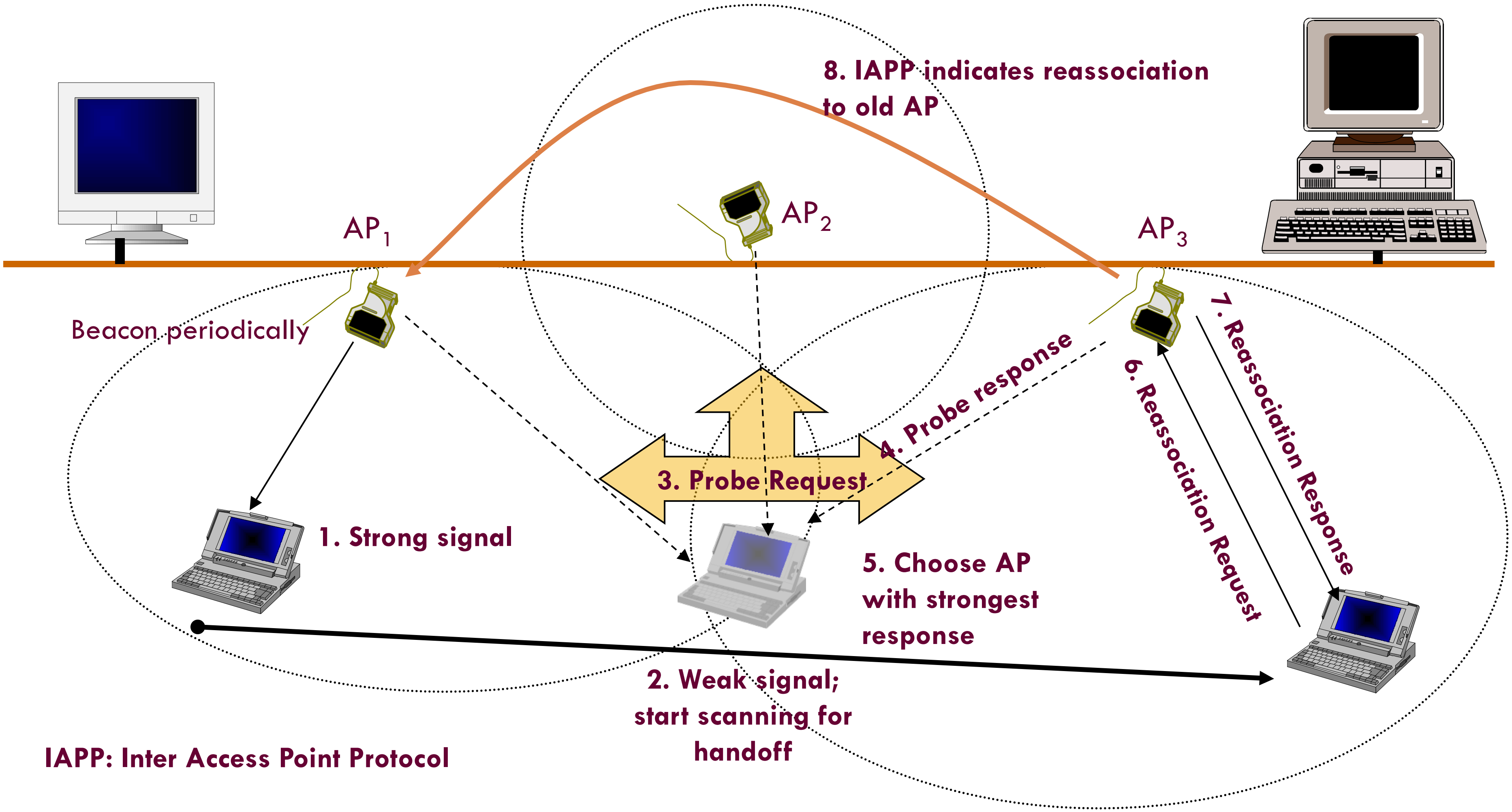
- The ***re-association*** service is used when a MS moves from one BSS to another within the same ESS
- It is always initiated by the MS
- It enables the distribution system to recognize the fact that the MS has moved its association from one AP to another

- The ***dissociation*** service is used to terminate an association
- It may be invoked by either party to an association (the AP or the MS)
- It is a notification and not a request. It cannot be refused
- MSs leaving a BSS will send a dissociation message to the AP which need not be always received

IEEE 802.11 Mobility Types

- No Transition
  - MS is static or moving within a BSA
- BSS Transition
  - The MS moves from one BSS to another within the same ESS
- ESS Transition
  - The MS moves from one BSS to another BSS that is part of a new ESS
  - Upper layer connections may break (needs Mobile IP)

Handoff in 802.11



IAPP: Inter Access Point Protocol

Inter-AP Protocol (802.11f)

- APs register with a “Registration Service” in the distribution system
  - They use the IAPP-INITIATE and IAPP-TERMINATE to register and deregister
- A MS in 802.11 can be associated with only one AP
- When the MS sends a reassociation request and obtains an association frame, the new AP sends an IAPP-MOVE-notify packet to the old AP
  - The old AP address is obtained from the registration service
  - If the registration service cannot be located, the AP will issue an IAPP-ADD-notify packet to the broadcast MAC address on the LAN
- The old AP sends an IAPP-MOVE-response packet with any context information it had for the MS

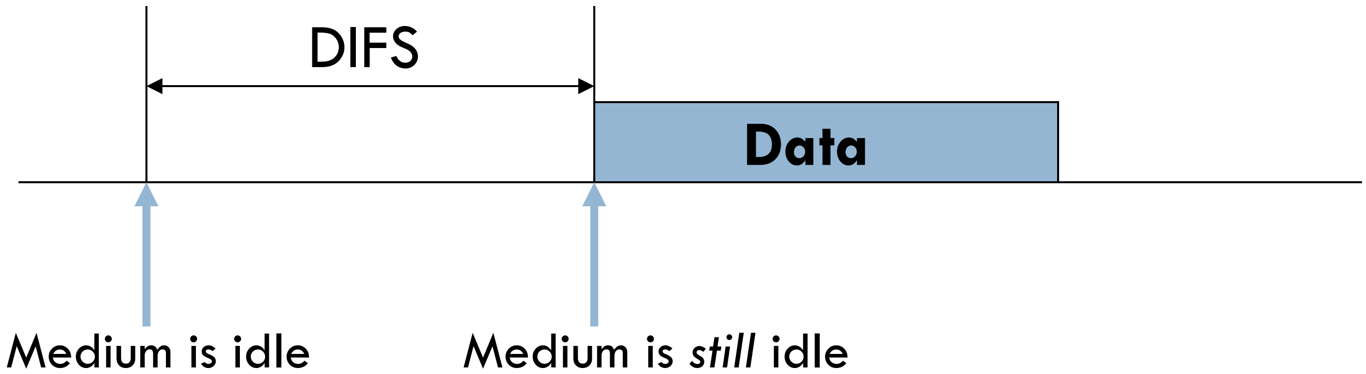
The IEEE 802.11 MAC Layer

- IEEE 802.11 is based on Carrier Sense Multiple Access with Collision Avoidance: CSMA/CA
- Mandatory access mechanism is “asynchronous” based on CSMA/CA and is provided by what is called the Distributed Coordination Function (DCF)
- Optional access mechanism for “time bounded” service is based on polling and is provided by what is called a Point Coordination Function (PCF)

Physical and Virtual Carrier Sensing

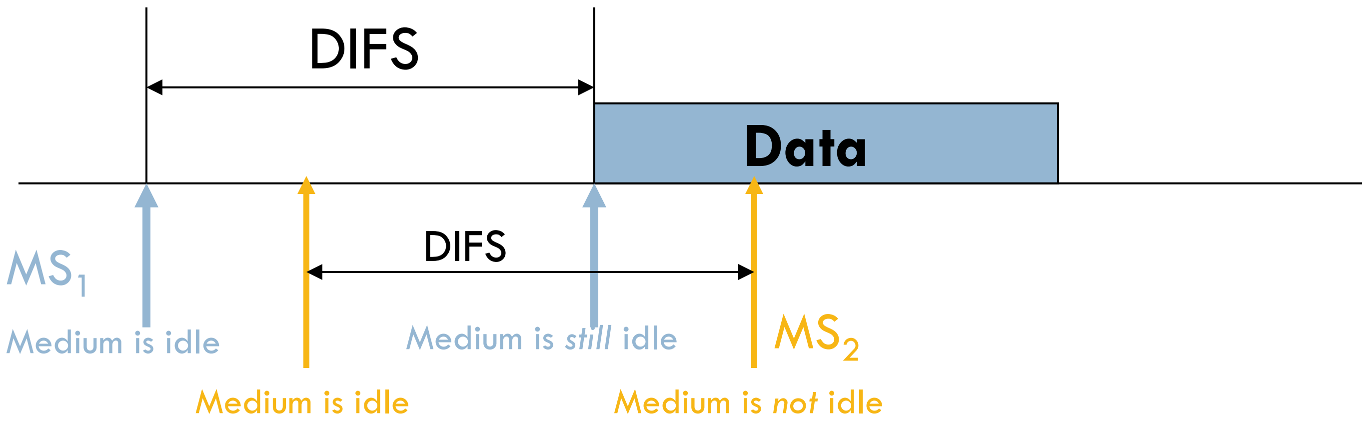
- The physical layer performs a "real" sensing of the air interface to determine if a medium is busy or idle
  - Analyzes detected packets
  - Detects carrier otherwise by RSS
- The MAC layer performs a "virtual" carrier sensing
  - The "length" field is used to set a network allocation vector (NAV)
  - The NAV indicates the amount of time that must elapse before the medium can be expected to be free again
  - The channel will be sampled only after this time elapses (why?)
- The channel is marked busy if either of the physical or virtual carrier sensing mechanisms indicate that the medium is busy

Idle Channel



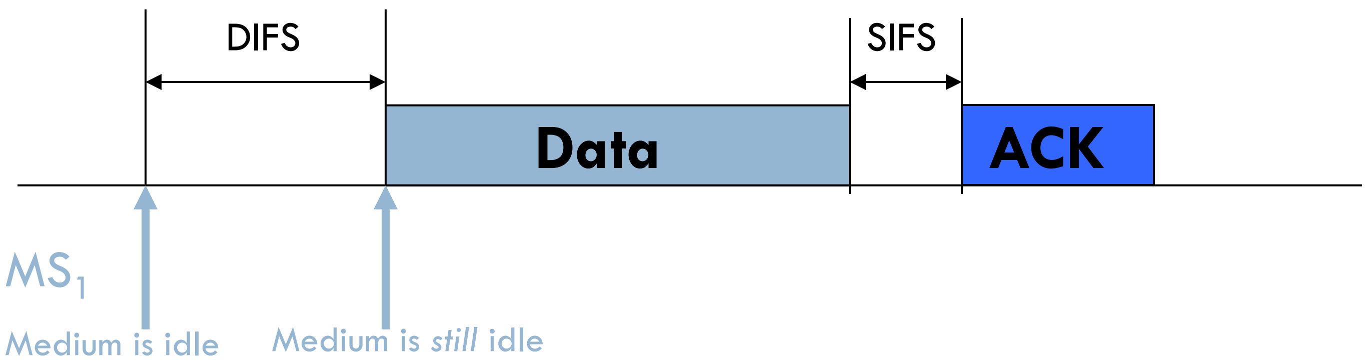
- If the medium is idle, every MS has to wait for a period DIFS (DCF inter-frame spacing) to send DATA
- After waiting for DIFS, if the medium is still idle, the MS can transmit its data frame

How does it help?



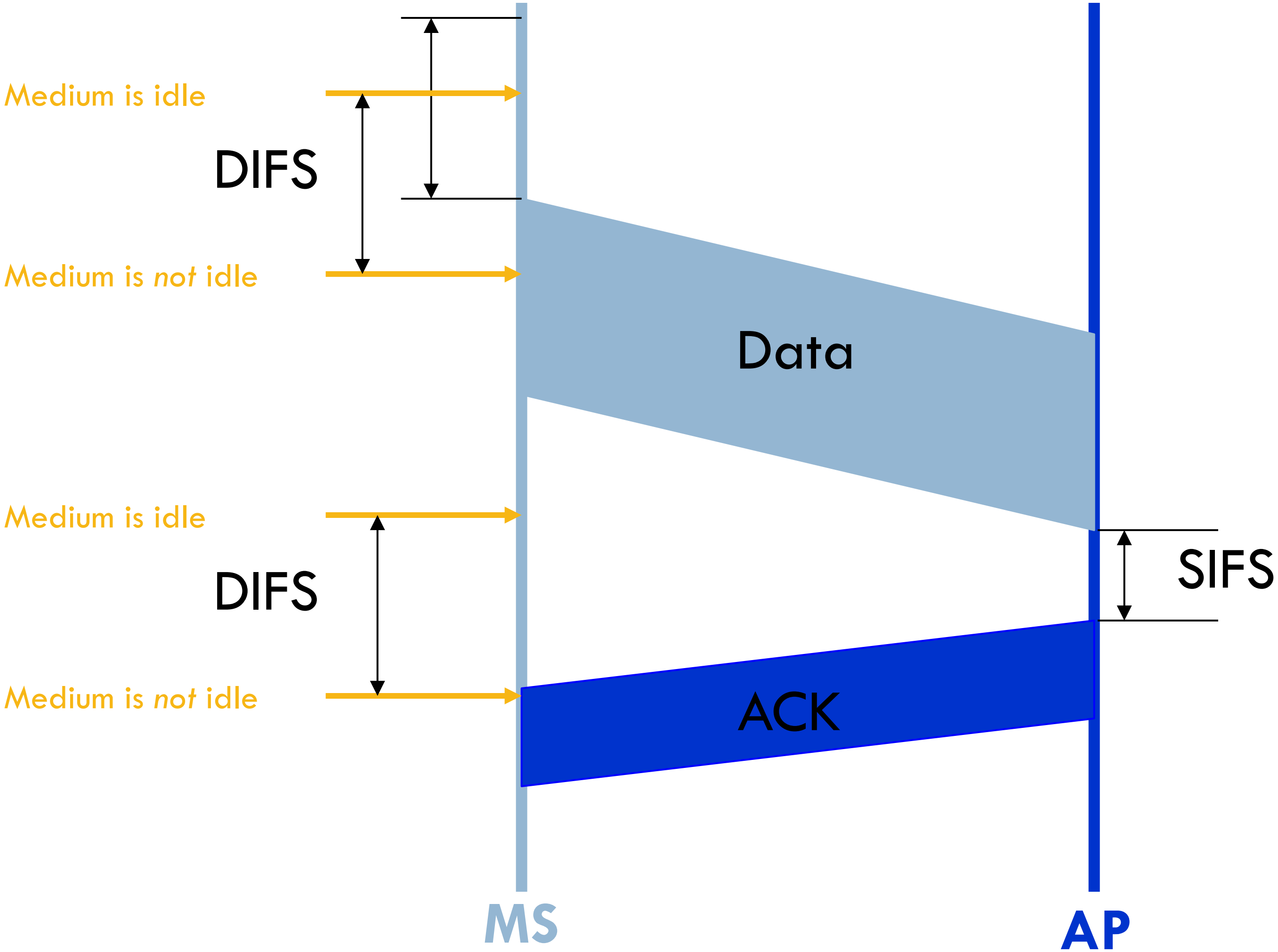
- If a second MS senses the medium to be idle after the first MS, it will find the medium to be busy after DIFS
- It will not transmit => collision is avoided

Acknowledgements

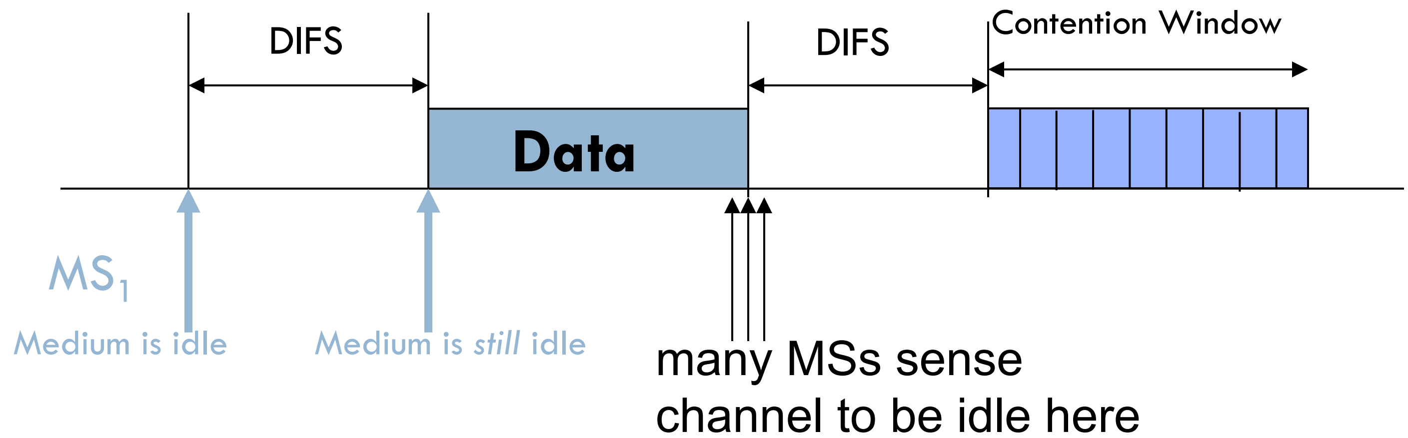


- A short inter-frame spacing (SIFS) is used
  - SIFS is the absolute minimum duration that any MS should wait before transmitting anything
- It is used ONLY for acknowledgements (which will be sent by a receiving MS or AP alone)
- ACKs receive highest priority!
- ACKs will almost always be sent on time

Data Transmission and ACKs



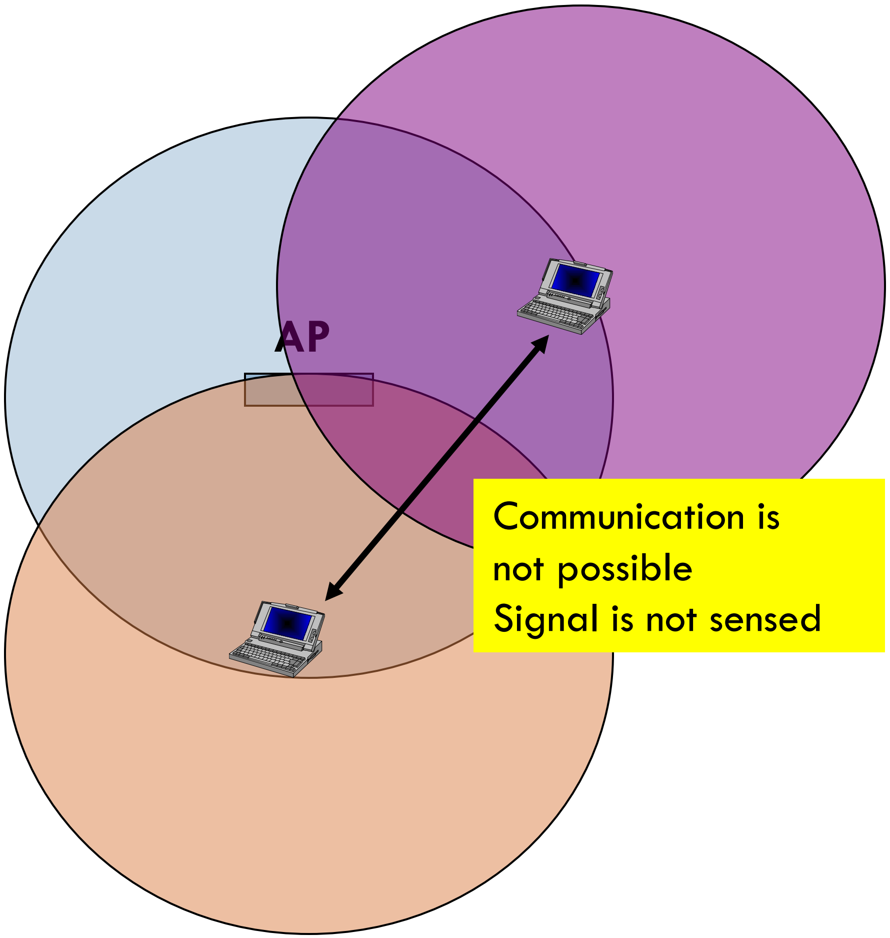
Busy Channel



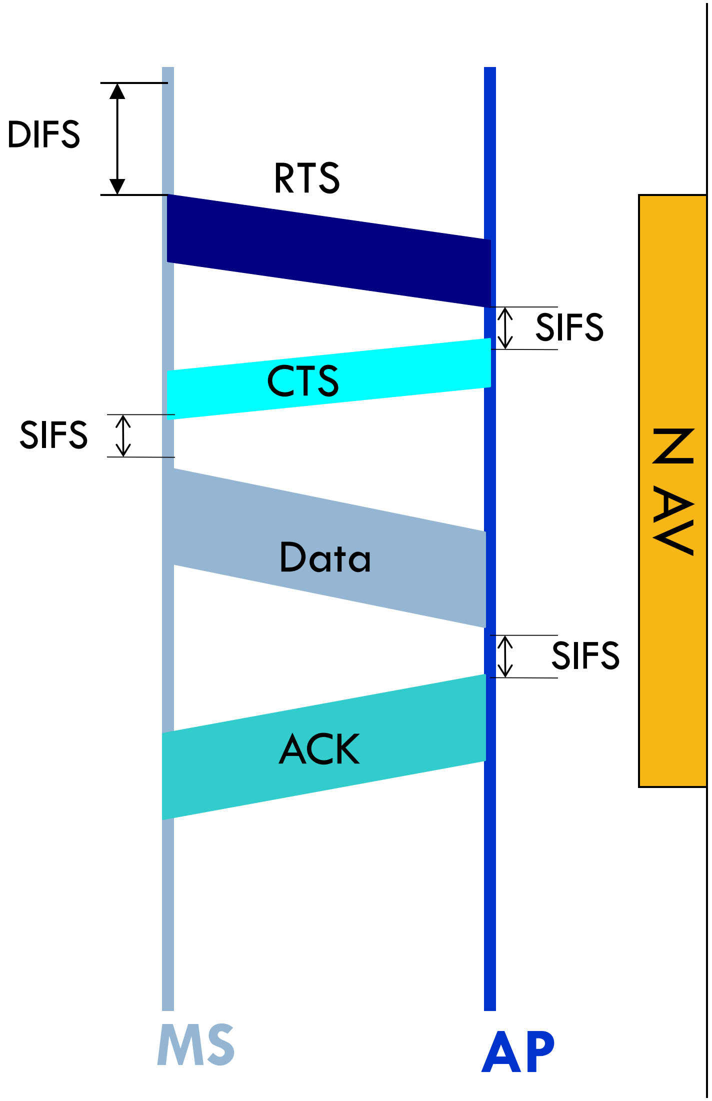
- Each MS has to still wait for a period of DIFS
- Each MS chooses a random time of back-off within a contention window
- Each MS decrements the back-off. Once the back-off value becomes zero, if the medium is idle, the MS can transmit
- The MS with the smallest back-off time will get to transmit
- All other MSs freeze their back-off timers that are "decremented" and start decrementing the timer in the next contention window from that point

When do collisions occur?

- MSs have the same value of the back-off timer
- MSs are not able to hear each other because of the “hidden terminal” effect
- MSs are not able to hear each other because of fading
- Solution: RTS/CTS
  - Also avoids excessive collision time due to long packets



RTS/CTS Mechanism



- RTS-Request to Send (20 bytes)
- CTS-Clear to Send (14 bytes)
- They can be used only prior to transmitting data
- After successful contention for the channel, a MS can send an RTS to the AP
- It gets a CTS in reply after SIFS
- CTS is received by all MSs in the BSS
- They defer to the addressed MS while it transfers data
- If there is a collision, no CTS is received and there is contention again

Large Frames

- Large frames that need fragmentation are transmitted sequentially without new contention
- The channel is automatically reserved till the entire frame is transmitted
- The sequence of events is:
  - Wait for DIFS & CW; Get access to channel OR use RTS/CTS
  - Send first fragment; include number of fragments in the field
    - All other MSs update their NAV based on the number of fragments
    - ACK is received after SIFS
    - The next fragment is transmitted after SIFS
  - If no ACK is received, a fresh contention period is started
- RTS/CTS, if used, is employed only for the first fragment

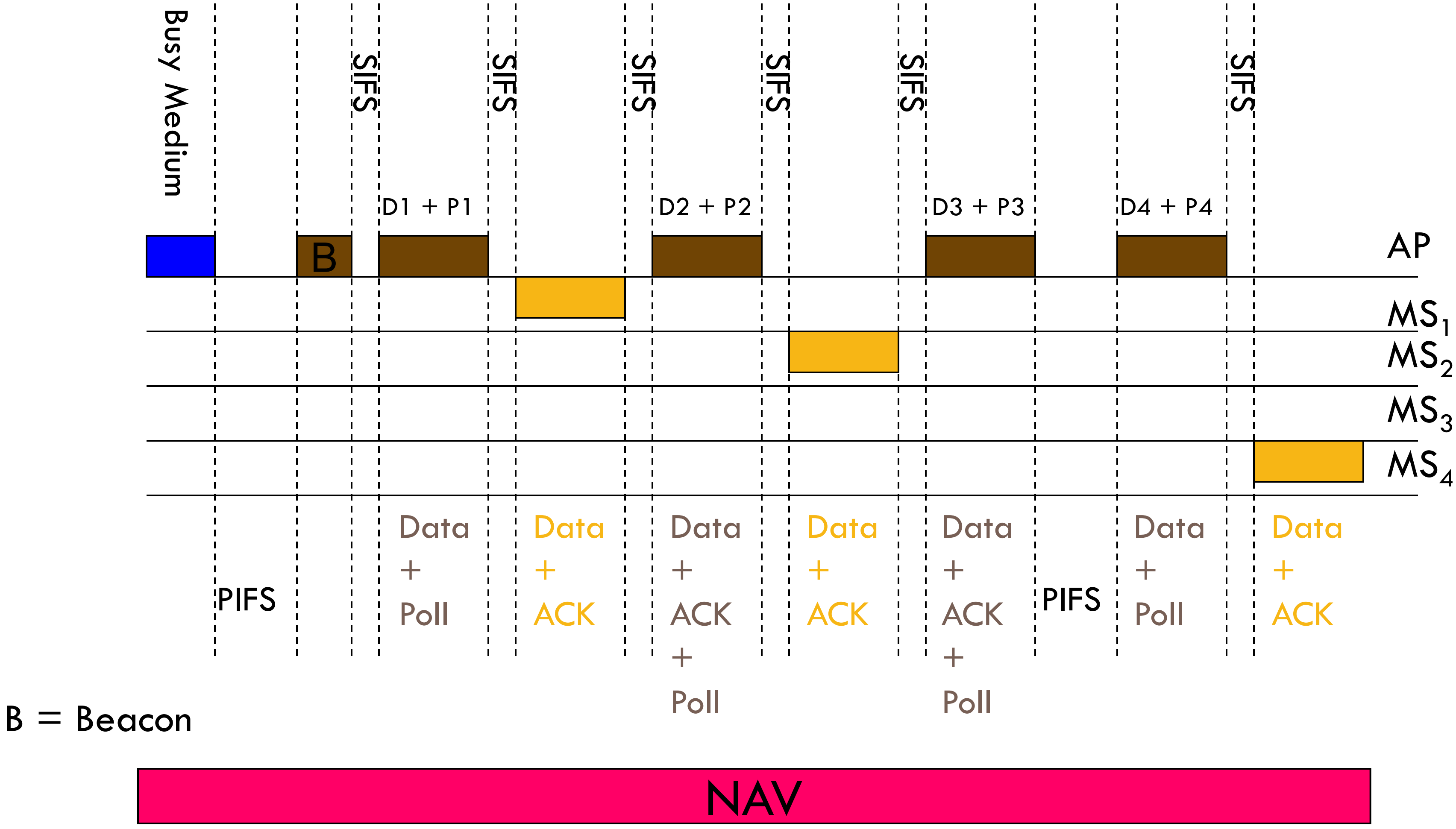
Taking turns protocols

- Token ring or bus
  - Infeasible for wireless networks
    - Errors and self configuration
  - Not widely studied except for IR systems
- Polling
  - A centralized authority polls each MS for data and the MS can respond to the poll if it has anything to transmit
  - If the MS has nothing to transmit or it is inactive, the polling scheme consumes bandwidth unnecessarily
- Can guarantee delays and throughput unlike random access schemes
- Example systems
  - PCF in IEEE 802.11
  - Bluetooth

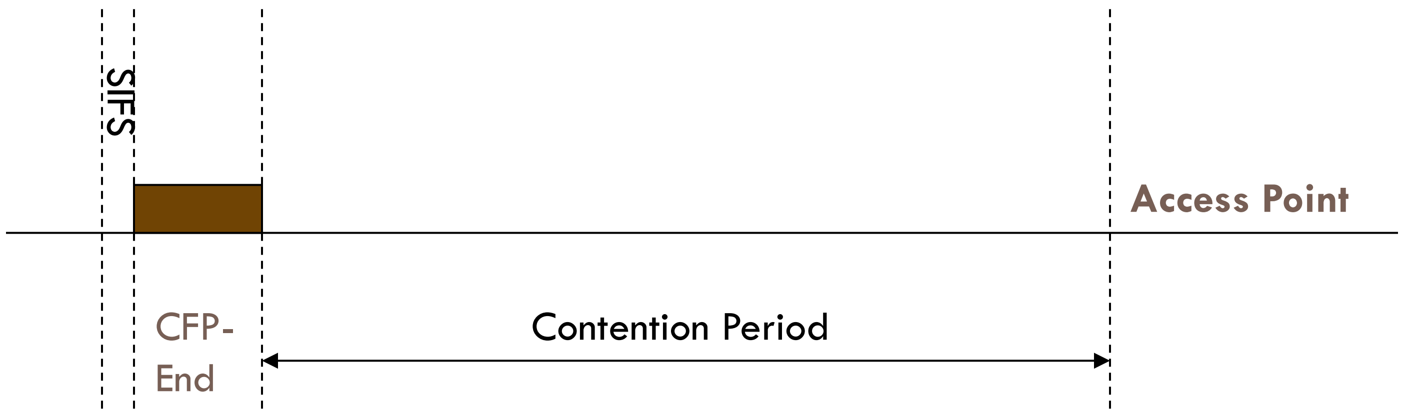
Point Coordination Function (PCF) in IEEE 802.11

- Optional capability to provide "time-bounded" services
- It sits on top of DCF and needs DCF in order to successfully operate
- A point coordinator (the AP)
  - Maintains a list of MSs that should be polled
  - Polls each station and enables them to transmit without contention
  - Ad hoc networks cannot use this function (why?)
- Time (a superframe) is divided into two parts
  - Contention Free Period (CFP)
  - Contention Period (CP)
- A MS must be CFP-aware to access the CFP
- Replies to polling can occur after SIFS

PCF Continued



PCF Continued



- The CFP is dynamically variable
- A MS can transmit to another MS within the CFP
  - In such a case, an ACK from the receiver is given priority over the next polling message
- The AP could transmit data to a non CF-aware MS
  - In such a case, once again, an ACK from the receiver is given priority

Physical Sub-Layers in 802.11

- PLCP maps the MAC frame into an appropriate PHY frame
  - Reduces MAC dependence on PMD
- PLCP frame includes information for synchronization, length of transmission, header error check, frame delimiters, etc.
- The PLCP forms the PMD frame which is different for different physical layers
- The PMD layer specifies the modulation, demodulation, and coding
- Together the two physical sub-layers provide the MAC layer a "clear channel assignment" signal to indicate the busy/idle nature of the channel
- The Physical Management layer fine tunes the channel, modulation, etc. and manages the physical layer MIBs

802.11 Physical Layer Options

- Diffused infrared (802.11)
  - PPM , 1, 2 Mbps, ARQ with CRC, 10m range, cheap
- Frequency hopping spread spectrum (802.11)
  - Random 2.5 hops per second, GMSK modulation, ARQ with CRC, 1, 2 Mbps in 915MHz band
- Direct sequence spread spectrum (802.11)
  - 11 bit spreading Barker code, DBPSK – 1Mbps, DQPSK – 2Mbps, ARQ with CRC, in 915MHz band
- Complementary Code Keying (802.11b)
  - 1,2, 5.5, 11 Mbps - spreading done in modulation channel symbols, error control ARQ with CRC in 20MHz band – 20MHz channels
  - Rate depends on RSS
- Orthogonal Frequency Division Multiplexing (OFDM) (802.11a, g)
  - Parallel sub-channels with adaptive modulation based on SNR – higher data rates up to 54Mbps - 20MHz channels
- OFDM and Multiple Input Multiple Output (802.11n)
  - Multiple antenna and receivers together with OFDM – higher data rates > 100Mbps

802.11a,g

- OFDM: Each subcarrier uses same modulation

Data rate	Modulation	FEC Coding Rate	Data bits per channel symbol
6Mbps	BPSK	1/2	24
9Mbps	BPSK	3/4	36
12Mbps	QPSK	1/2	48
18Mbps	QPSK	3/4	72
24Mbps	16QAM	1/2	96
36Mbps	16QAM	3/4	144
48Mbps	64QAM	2/3	192
54Mbps	64QAM	3/4	216

802.11n

- Approved recently - works in 2.4 and 5 GHz bands
  - 4 to 5 times the data rates of 802.11a,g ➔ 200-300Mbps
- Main Changes
  - Physical layer uses Multiple Input Multiple Output (MIMO) OFDM
    - Has multiple antennas at each end of the channel – provides spatial diversity
    - OFDM part about the same as 802.11a,g – uses 64QAM with 5/6 FEC rate
  - Channel Bonding
    - Combines 2 of the 20MHz 802.11a,g channels to achieve higher data rates
  - Packet Aggregation
    - Reduce overhead by aggregating multiple packets from a single application/user into a common frame

Other 802.11 standards in progress

- 802.11ac
  - Extremely high throughput in frequency bands below 6 GHz
- 802.11ad
  - Extremely high throughput in frequency bands 57-66 GHz
  - Also called WiGig
- 802.11af
  - TV White Spaces Operation

HIPERLAN-I

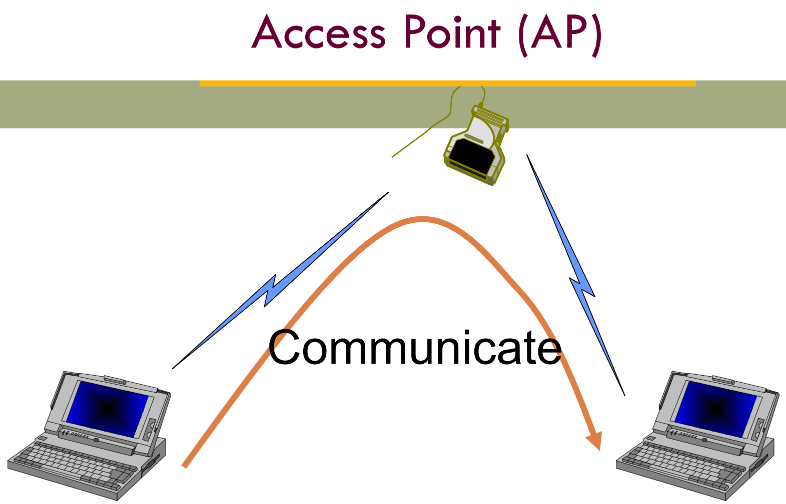
- High Performance Radio LAN
- Not based on any existing products or regulations unlike IEEE 802.11
- ETSI went ahead with a basic set of "functional requirements"
  - Data rates of 23.529 Mbps
  - Coverage of up to 100m
  - Multi-hop ad hoc networking capability
  - Time-bounded services
  - Power saving
- Multi-hop ad-hoc architecture
  - HIPERLAN ID and Node ID are used at the MAC level
- History
  - Early 1992: Work starts on standardization
  - Early 1993: CEPT releases spectrum at 5 GHz
  - June 1995: Draft Standard
  - 1996: Public enquiry is passed
  - Today: No products! ☹
- And yet…

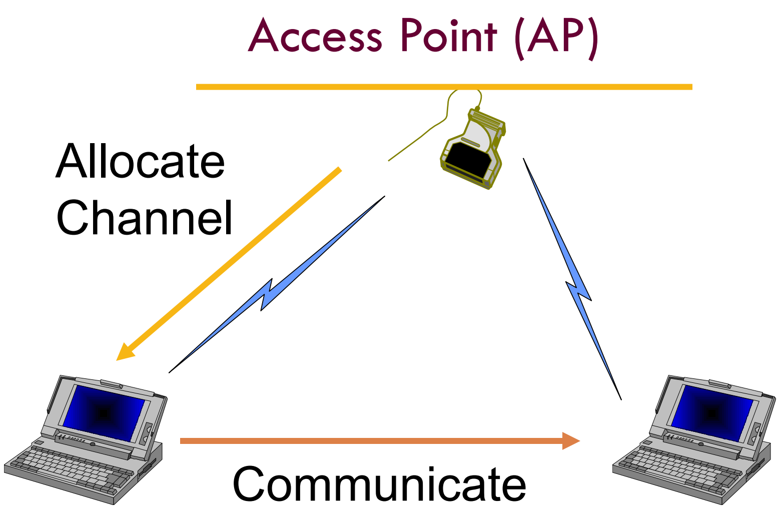
HIPERLAN-2

- Infrastructure is similar to the wide area infrastructures or to 802.11
- Access points and mobile stations
- Uses the 5 GHz bands
- Can support
  - LAN formats (Ethernet)
  - Firewire (IEEE 1394) standard
- TDMA based

HIPERLAN/2

- Two Modes of Operation
- Centralized Mode
  - All traffic goes through the AP like IEEE 802.11
  - Mandatory access method
- Direct Mode
  - The medium access is still centrally managed
  - MSs can communicate directly with each other

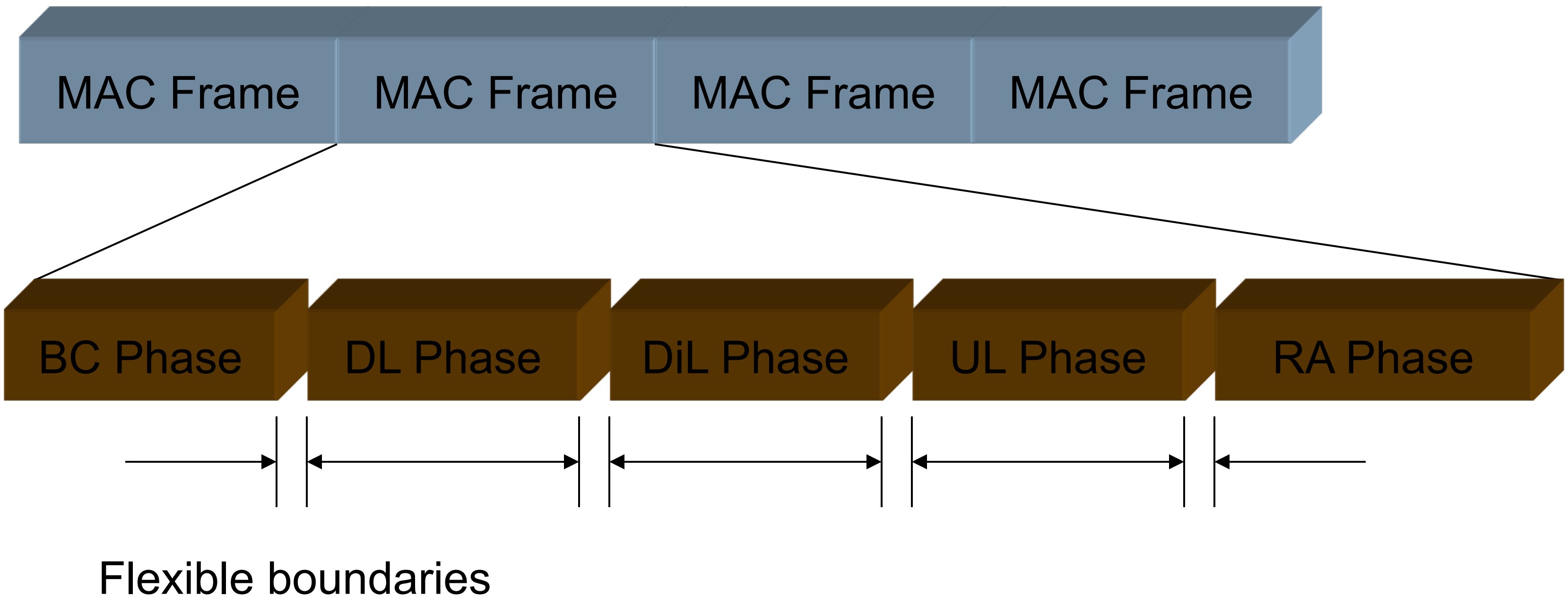




Medium Access in HIPERLAN/2

- TDMA/TDD based
- Broadcast (BC) Phase
  - Carries the BCCH and FCCH (Frame Control Channel)
    - Status, announcements in BCCH
    - Resource grants in the FCCH
- Downlink (DL) Phase
  - Control information and user data
  - Other broadcast information not carried in the BCCH
- Uplink (UL) Phase
  - MSs have to request capacity to transmit control or user data
- Direct Link (DiL) Phase
  - MSs request capacity from the AP
  - They can then communicate directly
- Random Access (RA) Phase
  - Used by MSs with zero capacity to obtain capacity for UL phase
  - New MSs, MSs performing handoff

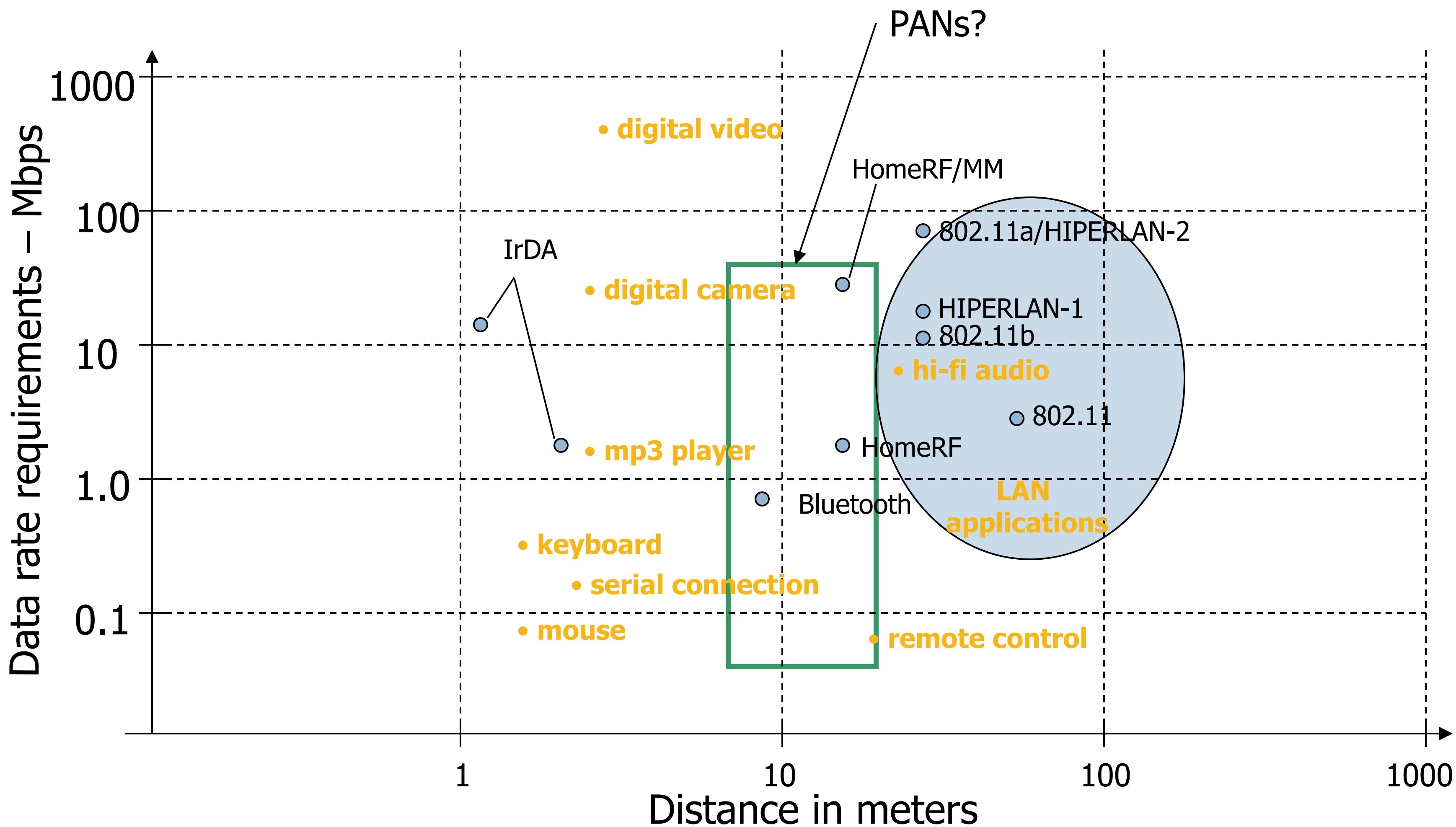
Basic MAC frame format in HIPERLAN/2



Personal Area Networks

- Origins in the BodyLAN project initiated by BBN in the early 1990s
- Networking "personal" devices – sensors, cameras, handheld computers, audio devices, etc. with a range of around 5 feet around a soldier
- Today: Networking digital cameras to cell phones to PDAs to laptops to printers to …

Short range networking – bandwidth versus range



IEEE 802.15

- Started in 1997 as a sub-group of IEEE 802.11
- Initial functional requirements
  - Low power devices
  - Range of 0-10m
  - Low data rates (19.2-100 kbps)
  - Small sizes (0.5 cubic inches)
  - Low cost
  - Multiple networks in the same area
  - Up to 16 separate devices

IEEE 802.15 today

- Four task groups
- Task Group 1
  - Based on Bluetooth
  - PHY and MAC layer design for wirelessly connecting devices entering a *personal operating space* (POS)
  - POS is a 10m space around a person who is stationary or in motion
- Task Group 2
  - Coexistence of WLANs and WPANs
  - Interoperability between a WLAN and WPAN device

IEEE 802.15 today (2)

- Task Group 3
  - Higher data rates (up to 20 Mbps)
  - Motivated by Kodak, Cisco, Motorola
  - Multimedia applications like digital imaging and video
  - Support for UWB
- Task Group 4
  - Low data rates and ultra low power/complexity devices for sensor networking
  - Home automation, smart tags, interactive toys, location tracking, etc.

Bluetooth

- Specifies the complete system from the radio level up to the application level
- Protocol stack is partly in hardware and partly in software running on a microprocessor
- Embedded devices
  - Low power
  - Low cost

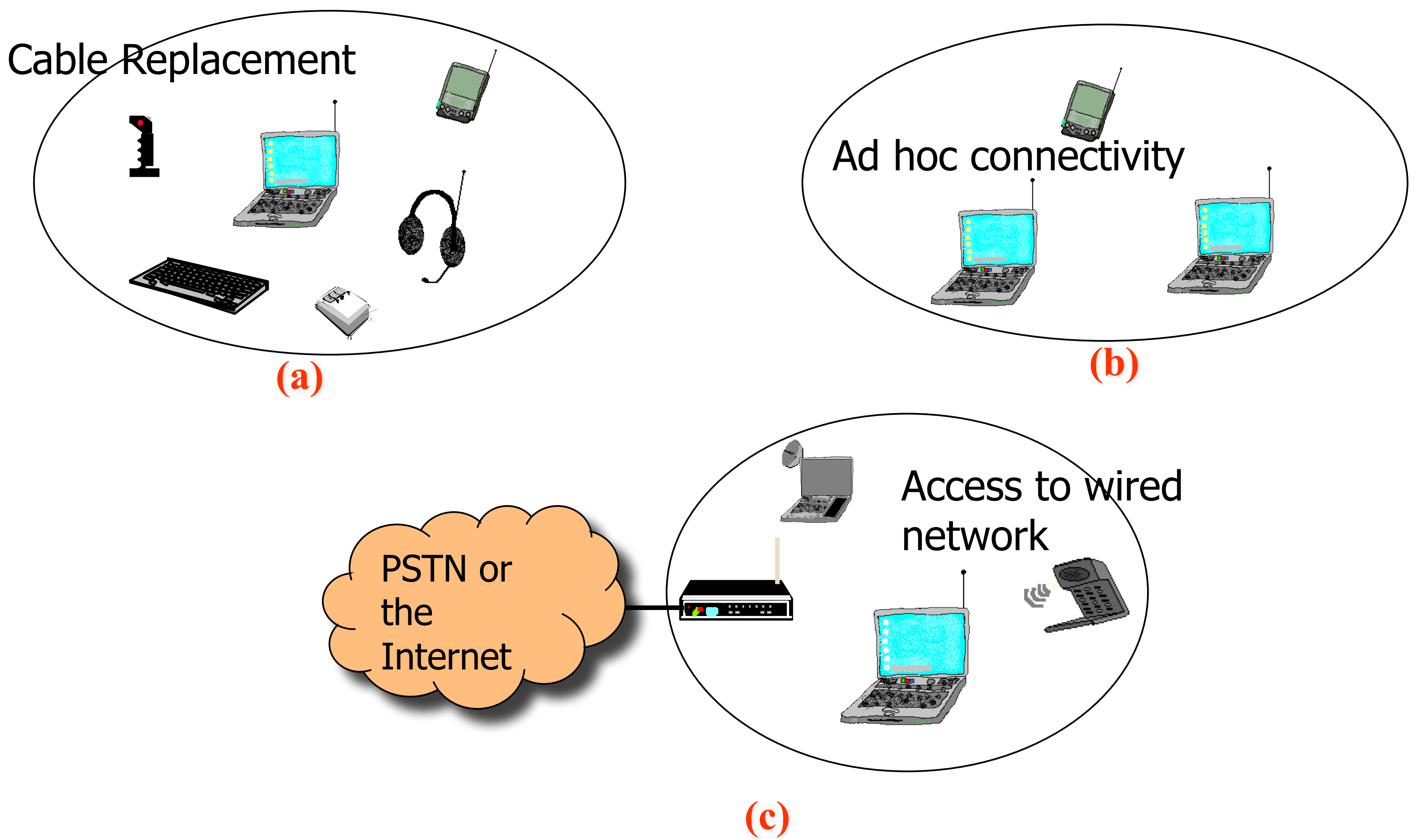
Bluetooth History

- 1994 : Ericsson started a study for feasibility of wireless interface between mobile phones and their accessories
- Feb 1998 : Ericsson, Nokia, IBM, Toshiba, Intel formed a special interest group (SIG) to focus on the development of such solutions
- Dec 1999 : Specification (v1.0b) was released by Bluetooth SIG
  - Merge with another SIG formed by 3Com, Microsoft, Lucent, and Motorola
- 2002: Around 1,800 companies as Bluetooth SIG members

Bluetooth History

- Complicated specification and continual changes delay products
- Most commercial products have Bluetooth available
  - Laptops
  - Cell phones
  - PDAs
- Today:
  - Built-in Bluetooth chip to ship in millions of cellular phones
  - Several millions of other communication devices
    - Cameras, headsets, microphones, keyboards etc.

Applications of Bluetooth



Some basics of Bluetooth

- Operates in the same 2.4 GHz bands as IEEE 802.11b
- It employs *frequency hopping* spread spectrum
  - Channels are 1 MHz wide
  - The modulation scheme is GFSK for a raw data rate of 1 Mbps on the air
- A basic time slot is defined as 625 microseconds
- A Bluetooth packet can occupy one, three or five slots
  - Sometimes a transmission is half a slot
- The frequency is changed **every** packet

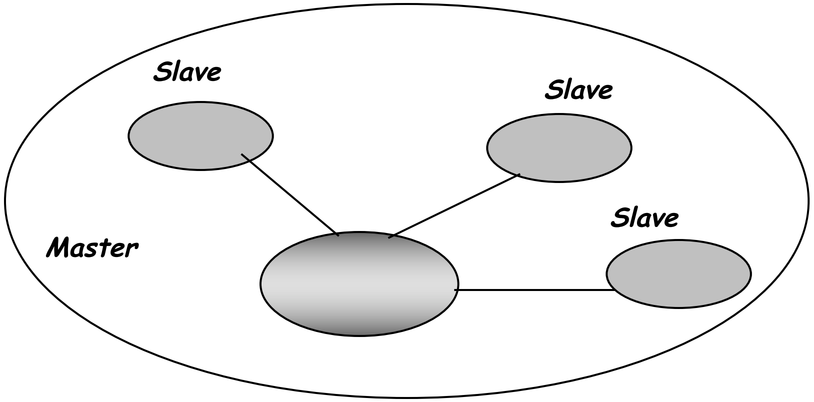
Bluetooth Device Address

- Each Bluetooth device has a 48 bit IEEE MAC address
  - Called the Bluetooth Device Address (BD_ADDR)
- This MAC address is split into three parts
  - The Non-significant Address Part (NAP)
    - Used for encryption seed
  - The Upper Address part (UAP)
    - Used for error correction seed initialization and FH sequence generation
  - The Lower Address Part (LAP)
    - Used for FH sequence generation

Bluetooth connections

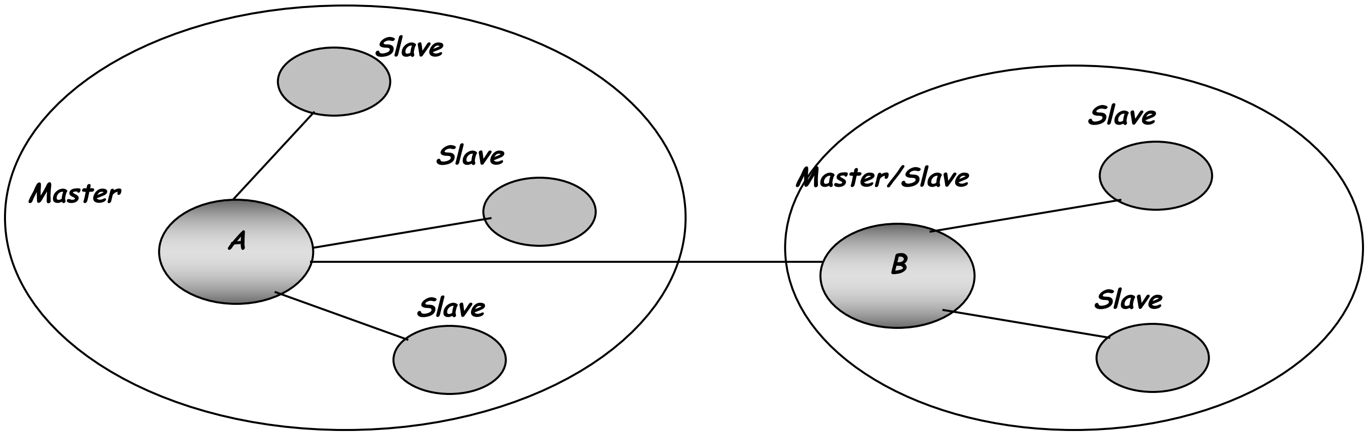
- Synchronous connection-oriented (SCO) link
  - “Circuit-switched”
    - periodic single-slot packet assignment
  - Symmetric 64 kbps full-duplex
  - Up to three simultaneous links
- Asynchronous connection-less (ACL) link
  - Packet data
  - Asymmetric bandwidth
    - Variable packet size (1-5 slots)
      - Maximum 723.2 kbps (57.6 kbps return channel)
      - 108.8 - 433.9 kbps (symmetric)

Bluetooth Architecture



- Scattered Ad-hoc topology
- A "cell" or "piconet" is defined by a Master device
  - The master controls the frequency hopping sequence
  - The master also controls the transmission within its piconet
- There is NO contention within a piconet
- There is interference between piconets

Bluetooth Architecture (2)



- A device can belong to several piconets
- A device can be the master of only one piconet (why?)
- A device can be the master of one piconet and slave of another piconet or a slave in different piconets

Bluetooth Architecture (3)

- The Master device is the device that initiates an exchange of data
- The Slave device is a device that responds to the Master
  - Slaves use the frequency hopping pattern specified by the Master
- A slave can transmit ONLY in response to a Master
- A Master device can simultaneously control seven slave devices and might have up to 200 active slave devices in a piconet
- Two piconets interfere with each other
  - This is like CDMA using FH-SS

Bluetooth Power Control

- Three classes of devices exist
  - Class 1: 100 mW (20 dBm)
  - Class 2: 2.5 mW (4 dBm)
  - Class 3: 1 mW (0 dBm)
- Mixture of devices can exist in a piconet
- Range of devices is subject to their class
- Mandatory power control is implemented
  - Steps of 2 dB to 8 dB
  - Only the power required for adequate RSS is to be used
  - Based on feedback (closed loop) using link management protocol control commands

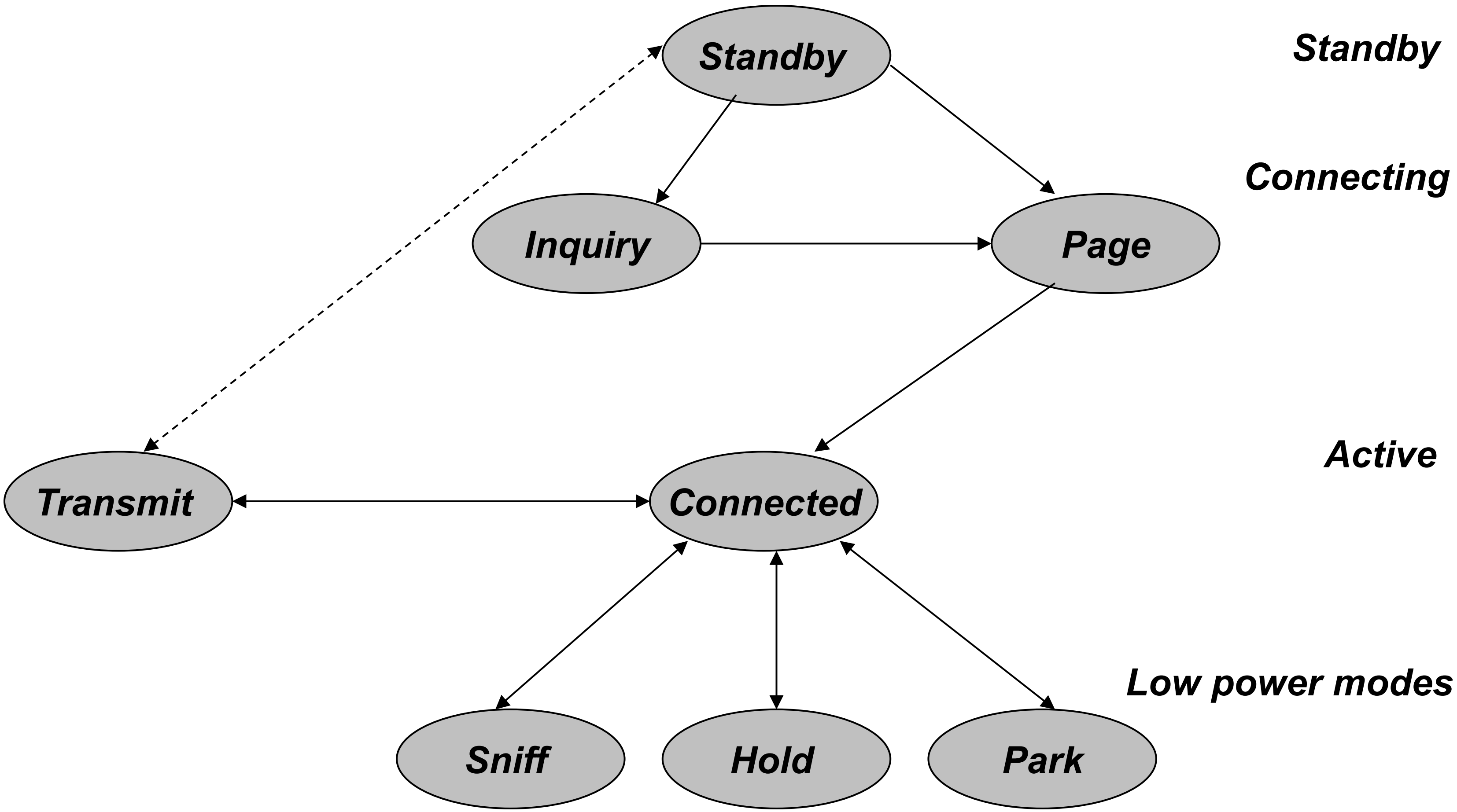
Discovering Bluetooth Devices

- Device A wishes to discover what Bluetooth devices exist in its vicinity and what services they offer
- It performs an "inquiry" procedure
  - It transmits a series of inquiry packets on different frequencies and awaits a response
  - Devices scanning for inquiries use a sliding correlator to detect such inquiries
  - If an inquiry is detected by a scanning device it responds with a "frequency hop synchronization" (FHS) packet that enables completion of a successful connection

Paging a slave device

- Paging is similar to "inquiry" except that the slave address is known
  - Hence an estimated slave clock/frequency hopping pattern is known
  - The page packet is transmitted at the expected frequency of the slave
- The Master sends a page train with a duration of 10 ms covering 16 frequency hops, repeating the paging train if necessary
- The Slave listens for its own device access code (DAC) for the duration of a scan window
- The Slave sends a "slave response" when its own DAC is heard
- The Master sends a "master response" using a FHS packet
- The Slave responds to the master with its own DAC using the Master's clock included in FHS packet
- Connection is established

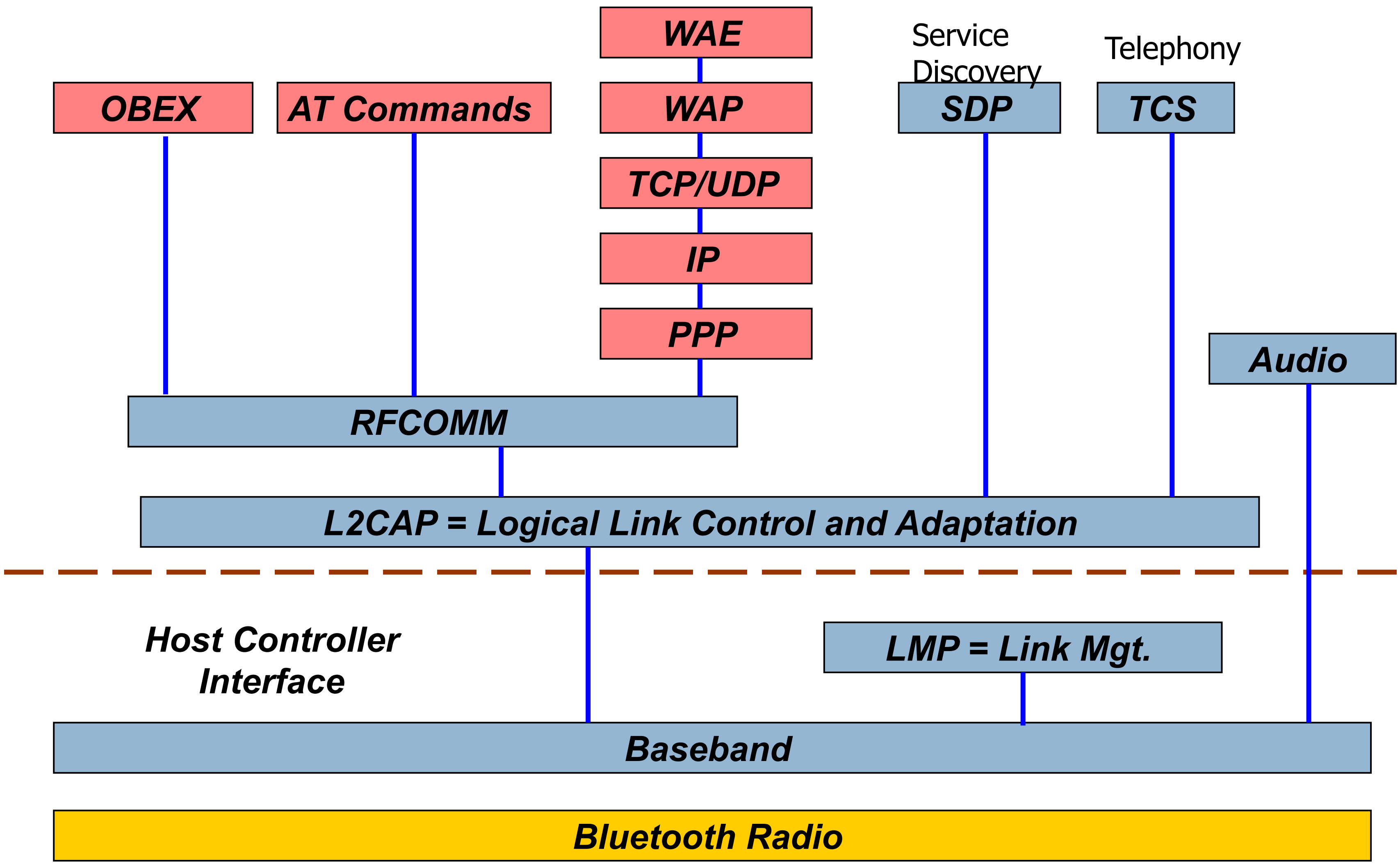
Bluetooth connection states



Connection States (2)

- Standby (default)
  - Waiting to join a piconet
- Inquire
  - Discover device within range or find out unknown destination address
- Page
  - Establish actual connection using device access code (DAC)
- Connected
  - Actively on a piconet (master or slave)
- Park/Hold/Sniff
  - Low-power connected states
  - Hold mode stops traffic for a specified period of time
  - Sniff mode reduces traffic to periodic sniff slots
  - Park mode gives up its active member address and ceases to be a member of the piconet

Example Protocol Stack



Service Discovery

- After “inquiry” or “paging” an ACL or SCO is set up
- SCO (Synchronous Connection Oriented) is used for telephony or audio (time-bounded applications) but usually an ACL is set up between the master and slave
- Using the ACL (Asynchronous Connection Less), the Master can set up an L2CAP connection with the slave
  - L2CAP allows several protocols to be multiplexed over it using a Protocol and Service Multiplexor (PSM) number
  - Service Discovery Protocol (SDP) uses a PSM of 1

Service Discovery (2)

- A scanning device (slave) usually has a service discovery server
- The master's service discovery client can use SDP to obtain the services that slave devices within the piconet can offer
- The Master can then decide what slave devices to communicate with and what services to employ

Link Manager

- The Link manager manages the following operations
  - Attaching slaves to the piconet
    - Allocates an active member address to a slave
  - Breaks connections to slaves
  - Establishes SCO or ACL links
  - Changes the connection state of devices (like sniff, park or hold)
- Uses the Link Management Protocol (LMP) to connect between devices

Other modules

- OBEX – objects exchanged using Bluetooth – similar to http.
- AT commands – Attention Terminal commands – similar to keystrokes etc.
- RFCOMM – for Radio Frequency communication – a set of serial ports that link to the L2CAP layer.
- Bluetooth supports the Wireless Application Environment (WAE) and the Wireless Application Protocol (WAP)

State of Bluetooth

- Bluetooth shipped in over a 1 Billion devices
- Bluetooth challenges
  - Reduce Cost ~$5 a port vs cable
  - Conflicts with other devices in radio spectrum
  - Limited security
- Most of the focus in the standards group is on other 802.15 tasks
  - IEEE 802.15.4 for low power, low data rate , cheap, WPANs (Zigbee)
  - IEEE 802.15.5 Mesh Networking WPANs
  - IEEE 802.15.3 for high data rate WPANs (WiMedia) 802.15.3a focus is Ultra WideBand (UWB) WPANs