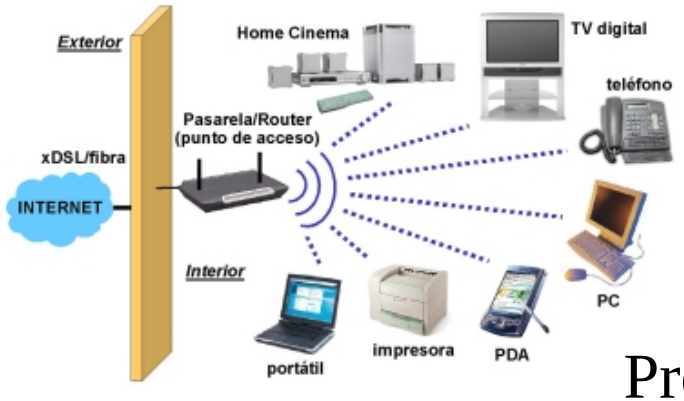
# Wireless Personal Area Networks: Part I

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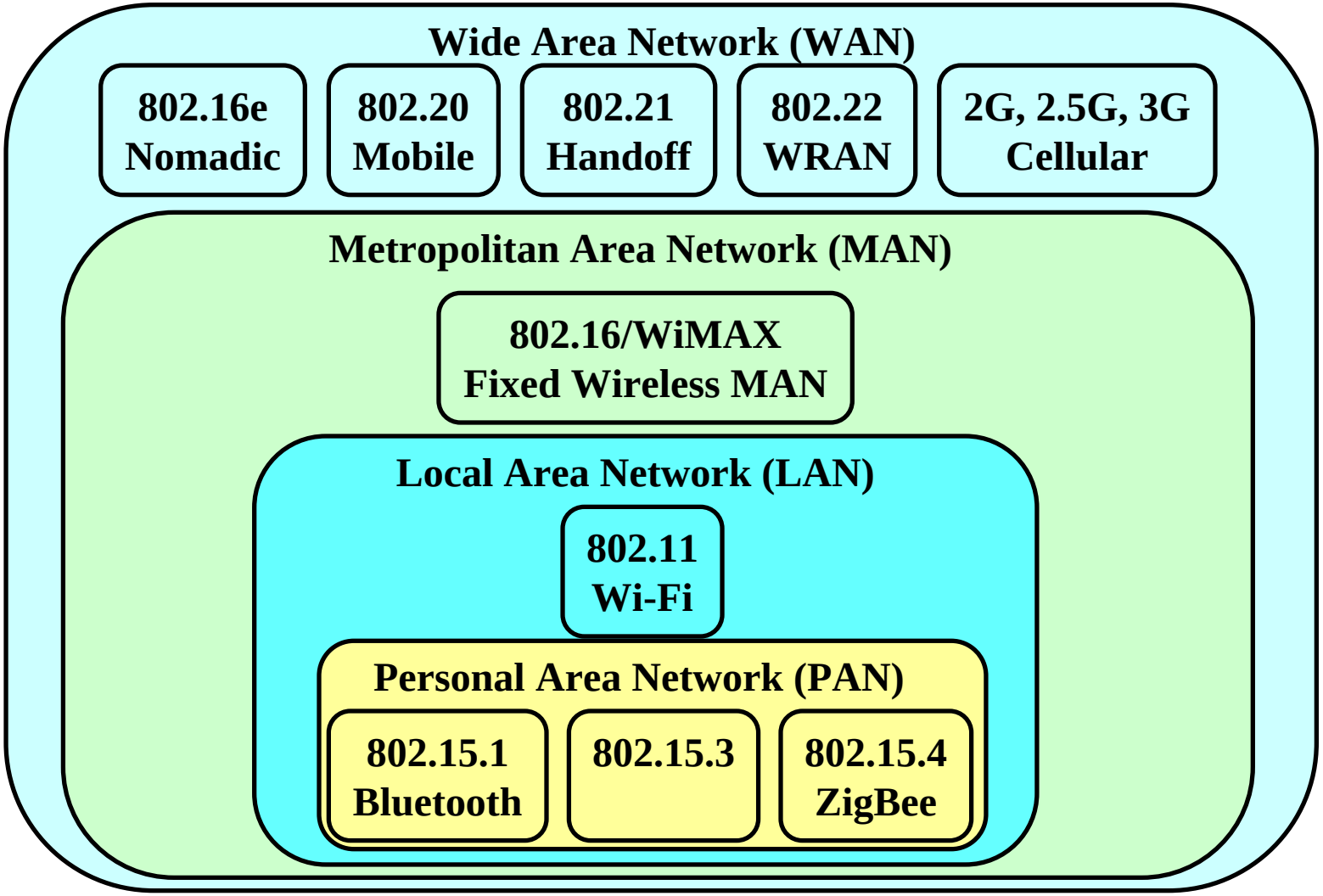
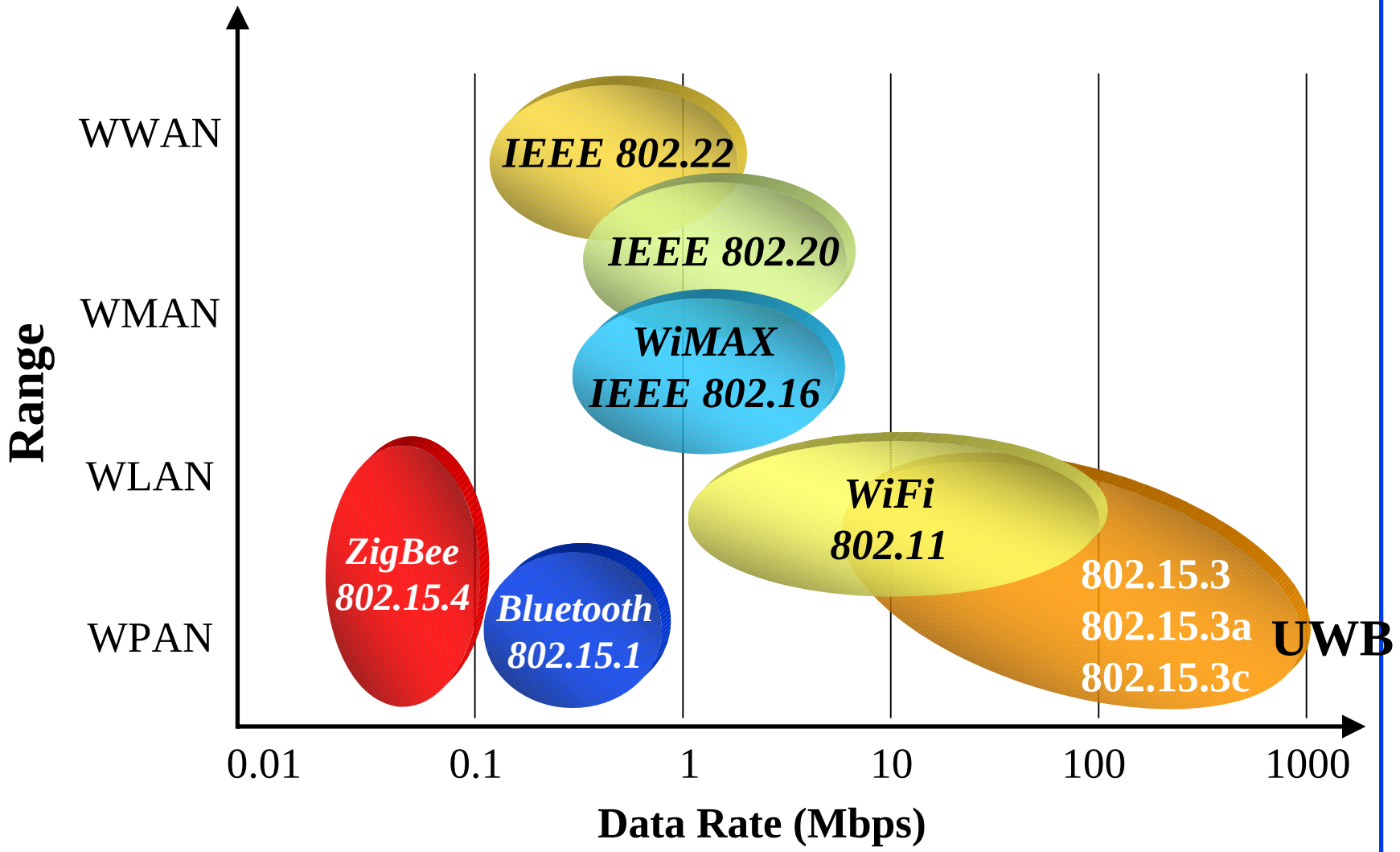
http://www.cse.wustl.edu/~jain/cse574-08/


- Wireless Standards Overview
- Bluetooth

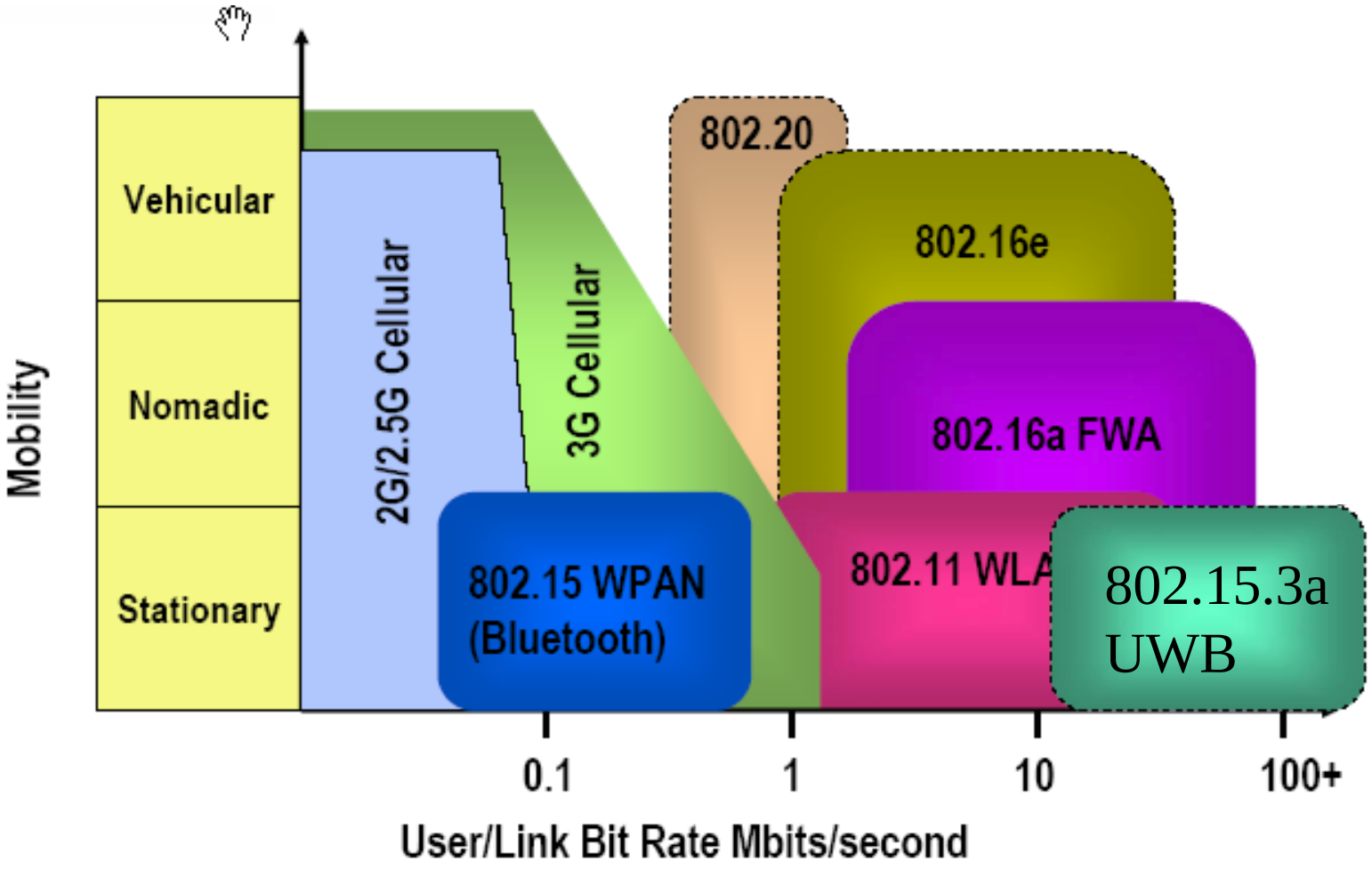
# Wireless Standards



# Distance vs. Data Rate



# Mobility vs. Data Rate



# Bluetooth Products





Headsets Audio Game Controller Keyboard GPS

- Printers, faxes, digital cameras…
- 720 kbps to 10m
- Competes with infrared, which has a range of 1m, requires line of sight and has a low data rate

# Bluetooth

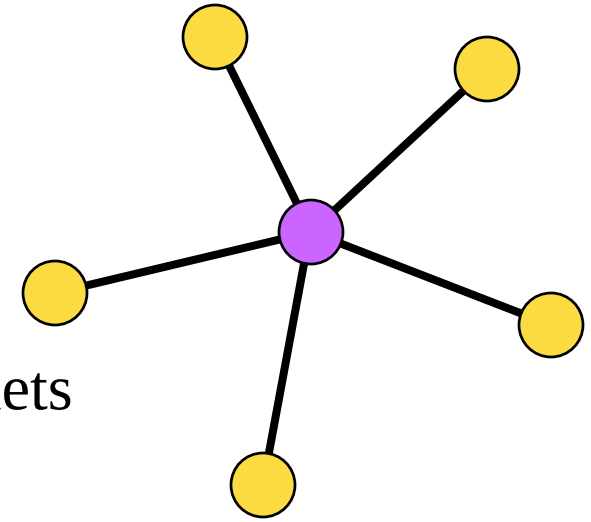
- Started with Ericsson's Bluetooth Project in 1994
- Named after Danish king Herald Blatand (AD 940-981) who was fond of blueberries
- Radio-frequency communication between cell phones over short distances
- Intel, IBM, Nokia, Toshiba, and Ericsson formed Bluetooth SIG in May 1998
- Version 1.0A of the specification came out in late 1999.
- IEEE 802.15.1 approved in early 2002 is based on Bluetooth
- Key Features:
  - Lower Power: 10 μA in standby, 50 mA while transmitting
  - Cheap: $5 per device
  - Small: 9 $mm^2$ single chips

# Bluetooth: Details

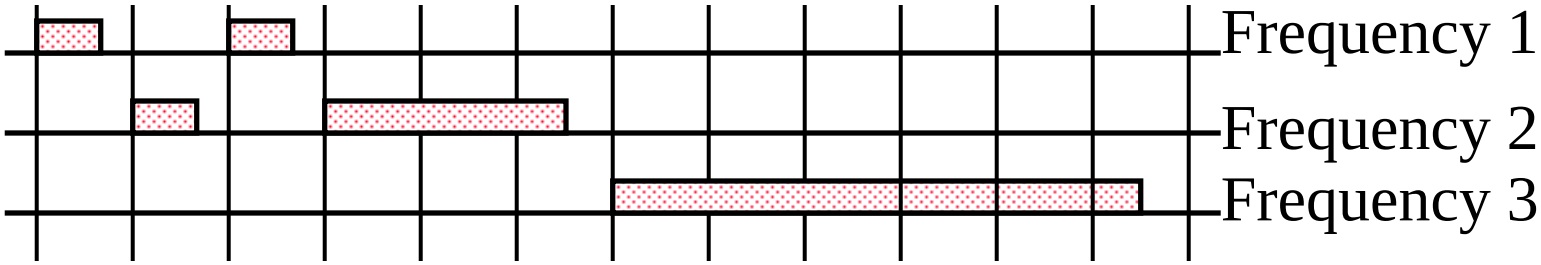
- **Frequency Range:** 2402 - 2480 MHz (total 79 MHz band)
  23 MHz in some countries, e.g., Spain
- **Data Rate:**1 Mbps (Nominal) 720 kbps (User)
- **Channel Bandwidth:**1 MHz
- **Range:** Up to 10 m can be extended further
- **RF hopping:** 1600 times/s ⇒ 625 μs/hop
- **Security:** Challenge/Response Authentication. 128b Encryption
- **TX Output Power:**
  - Class 1: 20 dBm Max. (0.1W) – 100m
  - Class 2: 4 dBm (2.5 mW)
  - **Class 3**: 0 dBm (1mW) – 10m
- **Ref:** http://www.bluetooth.com/
  http://www.bluetooth.org/
  http://grouper.ieee.org/groups/802/15/index.html

# Piconet

- Piconet is formed by a master and many slaves
  - Up to 7 active slaves.
    Slaves can only transmit when requested by master
  - Up to 255 Parked slaves
- Active slaves are polled by master for transmission
- Each station gets a 8-bit parked address
  $\Rightarrow$ 255 parked slaves/piconet
- The parked station can join in 2ms.
- Other stations can join in more time.
- A device can participate in multiple piconets
  $\Rightarrow$ complex schedule



# Frequency Hopping Sequences

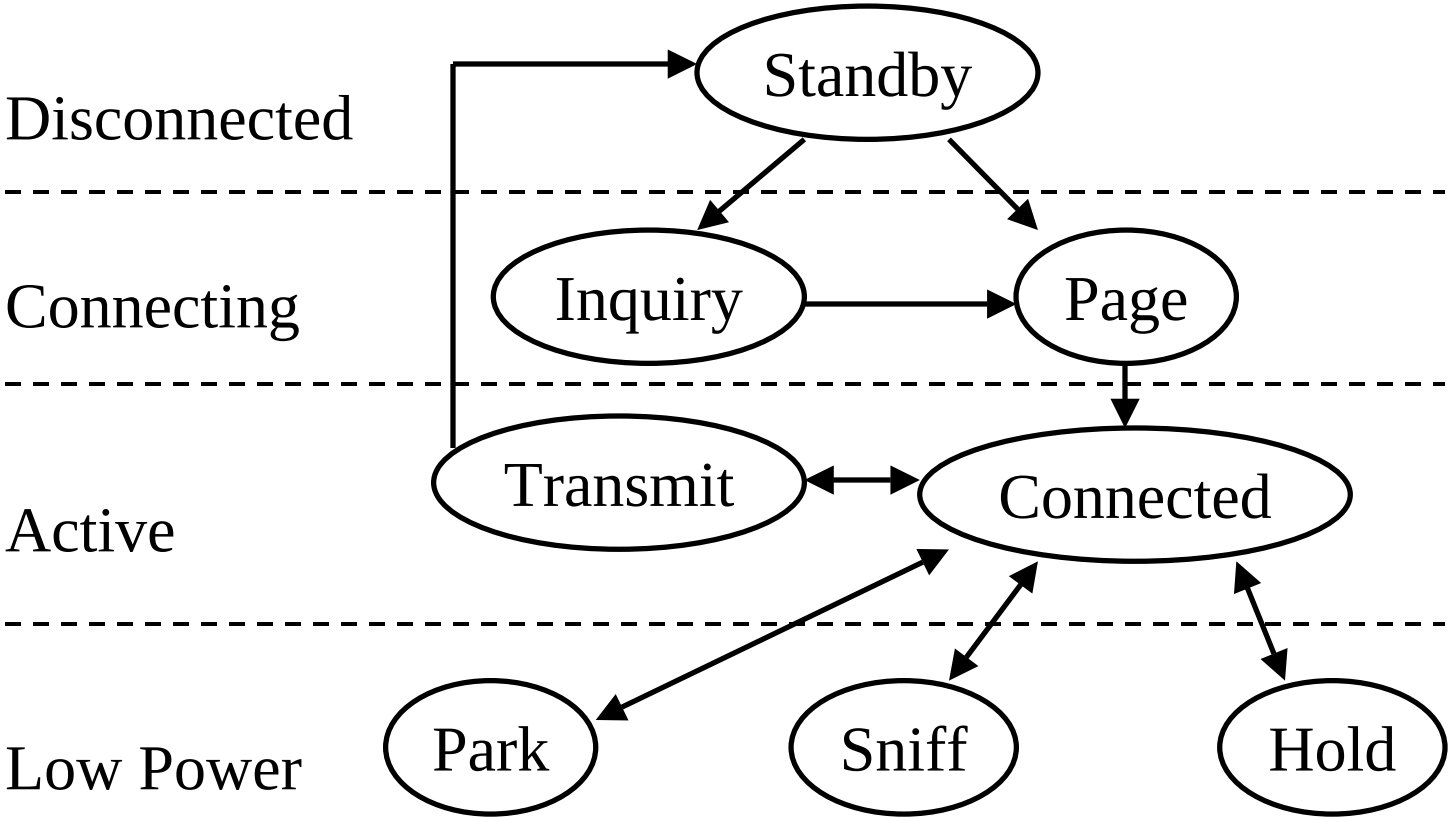



- 625 μs slots
- Time-division duplex (TDD)
  ⇒ Downstream and upstream alternate
- Master starts in even numbered slots only.
- Slaves start in odd numbered slots only
- *lsb* of the clock indicates even or odd
- Slaves can transmit in one slot right after receiving a packet from master
- Packets = 1 slot, 3 slot, or 5 slots long
- The frequency hop is skipped during a packet.

# Bluetooth Packet Format


- Packets can be up to five slots long. 2745 bits.
- Access codes:
  - Channel access code identifies the piconet
  - Device access code for paging requests and response
  - Inquiry access code to discover units
- Header: member address (3b), type code (4b), flow control, ack/nack (1b), sequence number, and header error check (8b) 18b Header is encoded using 1/3 rate FEC resulting in 54b
- Synchronous traffic has periodic reserved slots.
- Other slots can be allocated for asynchronous traffic

# Bluetooth Operational States



# Bluetooth Operational States (Cont)

- **Standby**: Initial state
- **Inquiry**: Master sends an inquiry packet. Slaves scan for inquiries and respond with their address and clock after a random delay (CSMA/CA)
- **Page**: Master in page state invites devices to join the piconet. Page message is sent in 3 consecutive slots (3 frequencies). Slave enters page response state and sends page response including its device access code.
- Master informs slave about its clock and address so that slave can participate in piconet. Slave computes the clock offset.
- **Connected**: A short 3-bit logical address is assigned
- **Transmit**:

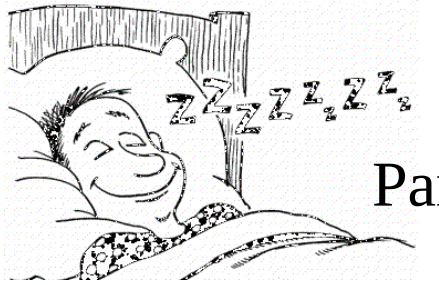
# Energy Management in Bluetooth

Three inactive states:

1. **Hold**: No Asynchronous Connection List (ACL). Synchronous Connection Oriented (SCO) continues.
   Node can do something else: scan, page, inquire
2. **Sniff**: Low-power mode. Slave listens after fixed sniff intervals.
3. **Park**: Very Low-power mode. Gives up its 3-bit active member address and gets an 8-bit parked member address.

- Packets for parked stations are broadcast to 3-bit zero address.

Sniff 

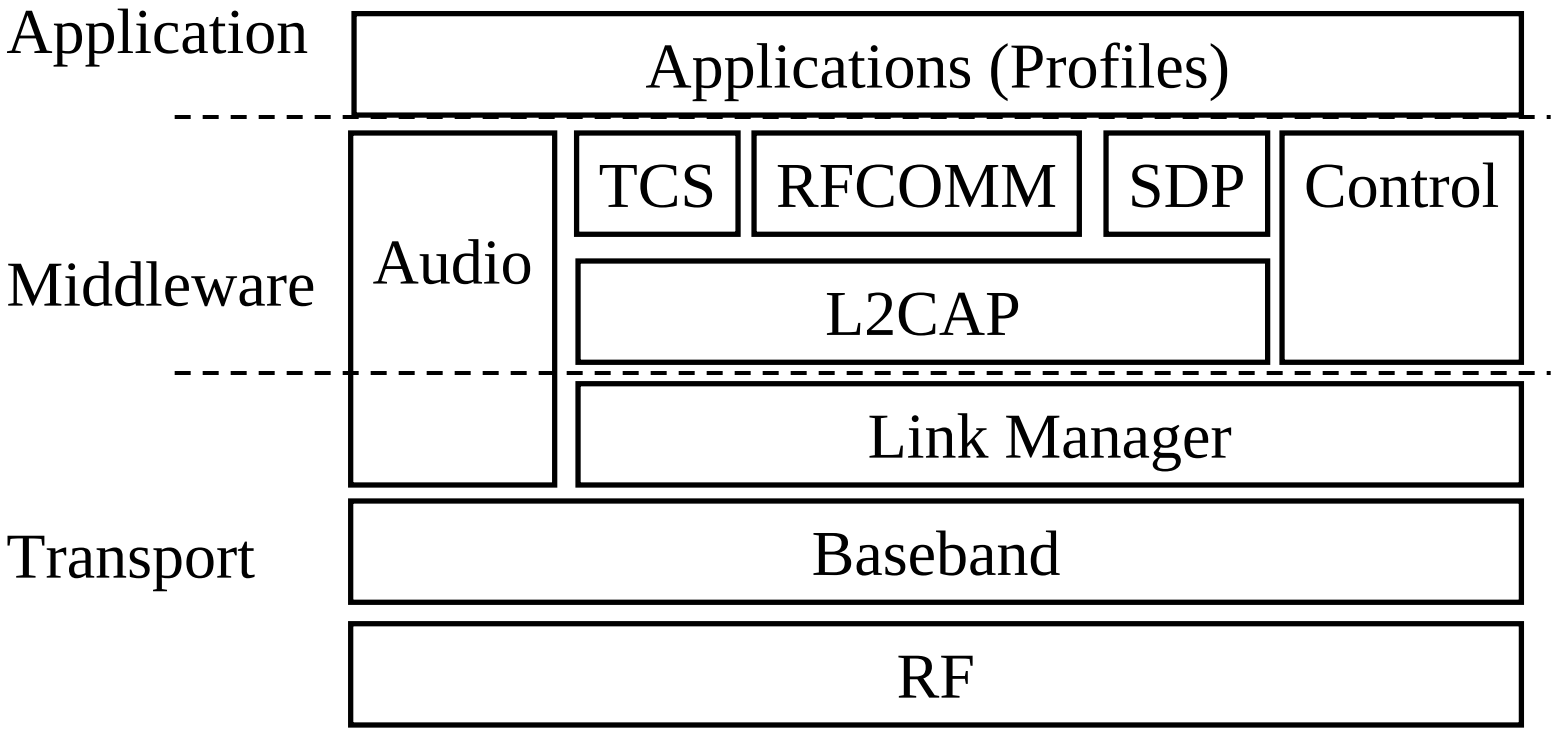


Park

# Power per MB

| Type | Bit rate | TX Power | mJoules/MB |
|---|---|---|---|
| 802.11b | 11Mb | 50mW | 36.4 |
| 802.11g | 54Mb | 50mW | 7.4 |
| 802.11a | 54Mb | 200mW | 29.6 |
| 802.15.1 | 1Mb | 1mW | 8.0 |
| 802.15.3 | 55Mb | 200uW | 0.03 |

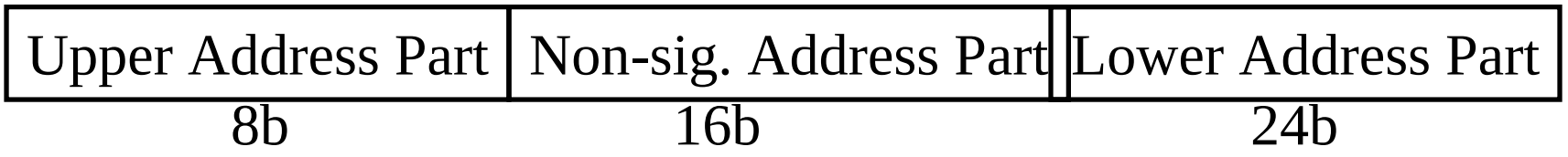
# Bluetooth Protocol Stack




- RF = Frequency hopping GFSK modulation
- Baseband: Frequency hop selection, connection, MAC

# Baseband Layer

- Each device has a 48-bit IEEE MAC address
- 3 parts:
  - Lower address part (LAP) – 24 bits
  - Upper address part (UAP) – 8 bits
  - Non-significant address part (NAP) - 16 bits
- UAP+NAP = Organizationally Unique Identifier (OUI) from IEEE
- LAP is used in identifying the piconet and other operations
- Clock runs at 3200 cycles/sec or 312.5 μs (twice the hop rate)



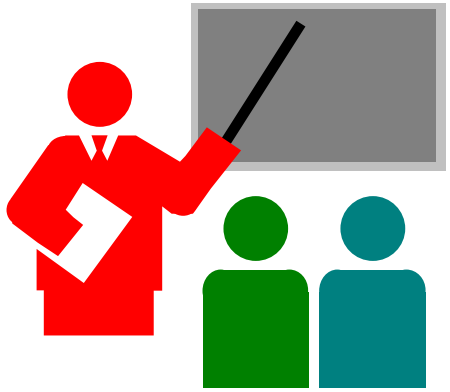
# Bluetooth Protocol Stack (Cont)

- Logical Link Control and Adaptation Protocol (L2CAP)
  - Protocol multiplexing
  - Segmentation and reassembly
  - Controls peak bandwidth, latency, and delay variation
- Host Controller Interface
- RFCOMM Layer:
  - Presents a virtual serial port
  - Sets up a connection to another RFCOMM
- Service Discovery Protocol (SDP): Each device has one SDP which acts as a server and client for service discovery messages
- IrDA Interoperability protocols: Allow existing IrDA applications to work w/o changes

# Bluetooth Protocol Stack (Cont)

- IrDA object Exchange (IrOBEX) and Infrared Mobile Communication (IrMC) for synchronization
- Audio is carried over 64 kbps over SCO links over baseband
- Telephony control specification binary (TCS-BIN) implements call control including group management (multiple extensions, call forwarding, and group calls)
- Application Profiles: Set of algorithms, options, and parameters. Standard profiles: Headset, Cordless telephony, Intercom, LAN, Fax, Serial line (RS232 and USB).

# Summary



1. Wireless personal area networks are used for 1-10m communications
2. Medium rate: Bluetooth – 720 kbps, uses Frequency hopping, has application specific profiles

# Homework 8

- Submit answer to the following Problem:
  Assume that in one slot in Bluetooth 256 bits of payload could be transmitted. How many slots are needed if the payload size is (a) 512 bits, (b) 728 bits, and (c) 1024 bits. Assume that the non-payload portions do not change.