Ah-Hoc, PAN, Sensors, ...

→ **Introduction**
→ **Bluetooth**
→ **Zigbee**
→ **Ad-Hoc: Routing and Topology Mgmnt**

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• Thanks: Prof. Mario Gerla, UCLA, for providing most of the material

Ad-Hoc Networks

- Built by the userse themselves to support specific (in time, space, applications) needs
  - Example: using 802.11 BSS as you did in the lab
- Are generally closed, but “gateways” are coming into play to connect them to the resto fo the world
- The key point is the requirement to build and support dynamically the topology “on-th-fly”
  - No network planning
  - No hierarchy
  - No engineering

Sensor/Actuators Networks

- Ad-Hoc networks whose goal is specifically making some kind of measure (sensing) and, in case, react to some change/event (actuating)
- Normally battery powered: one more problem on energy consupmption
- Are the backbone of "Ambient Intelligence" concepts

Personal Networks

- PAN "personal area network"
- IEEE 802.15 sub-project
- Very short range (1-5m) and extremely low power (< 10mw EIRP)
- The goal is connection of devices for "cable replacement"
  - Earphone with cell/HiFi/TV
  - PDA, cell phone, clock, alarm, laptop
  - mouse, keyboard, laptop
  - ...

Technologies

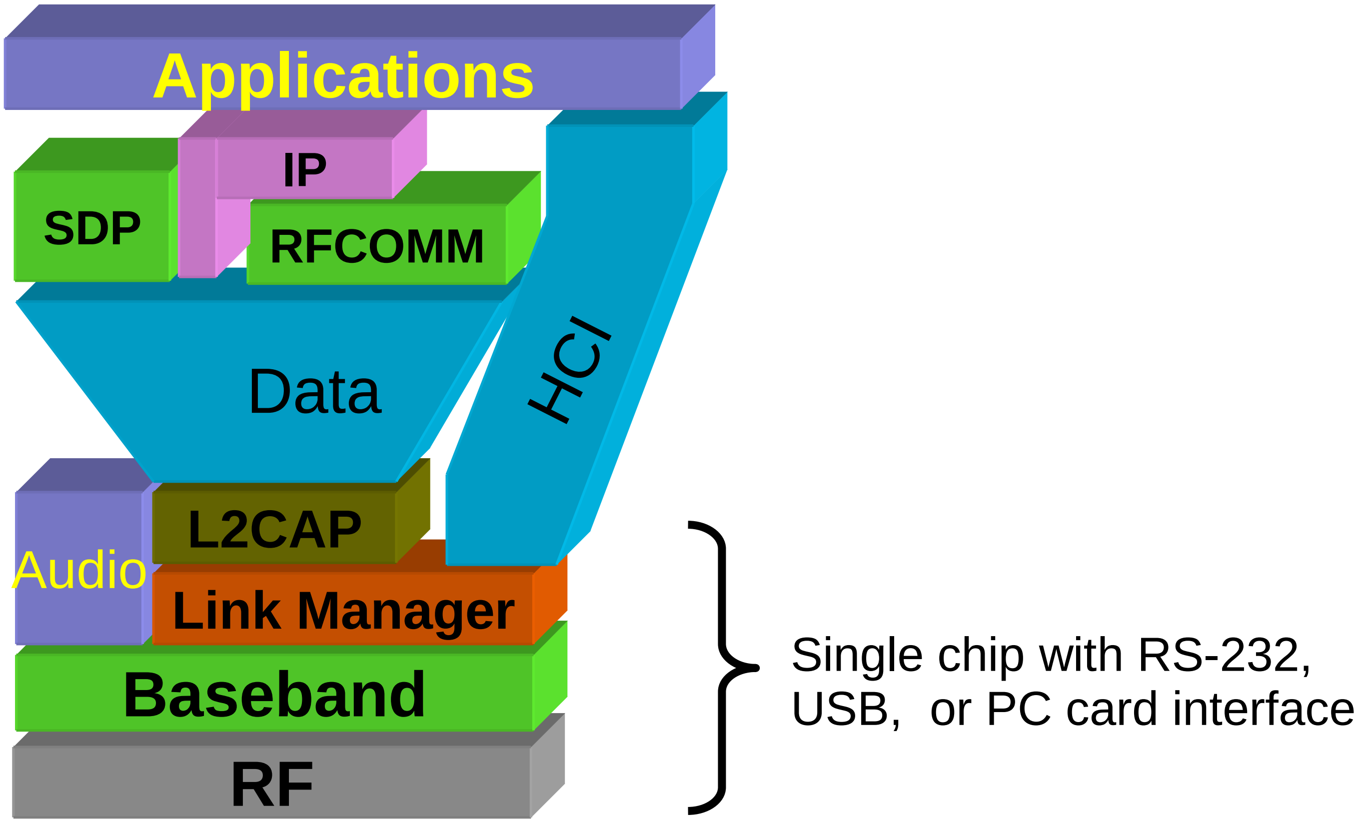
- 802.11
  - Do you know it ☺
- Bluetooth (802.15.1)
  - Master/Slave architecture
  - Optimized for low bandwidth, real time communications
- ZigBee (802.15.4)
  - Meshed architecture
  - Low power consumption
- All use the same ISM bands

Open (Not Yet Standard) Issues

- Routing
  - How to find the best route across a "temporary" network?
  - Coordination of multi-hop transfer
  - Stability of routes
- Topology Management
  - Cooperation among nodes
  - How to reward nodes that use resources for others
- Usage context
  - Ad Hoc Networks were born for military applications
  - Their civilian use is appealing, but do we really need them?

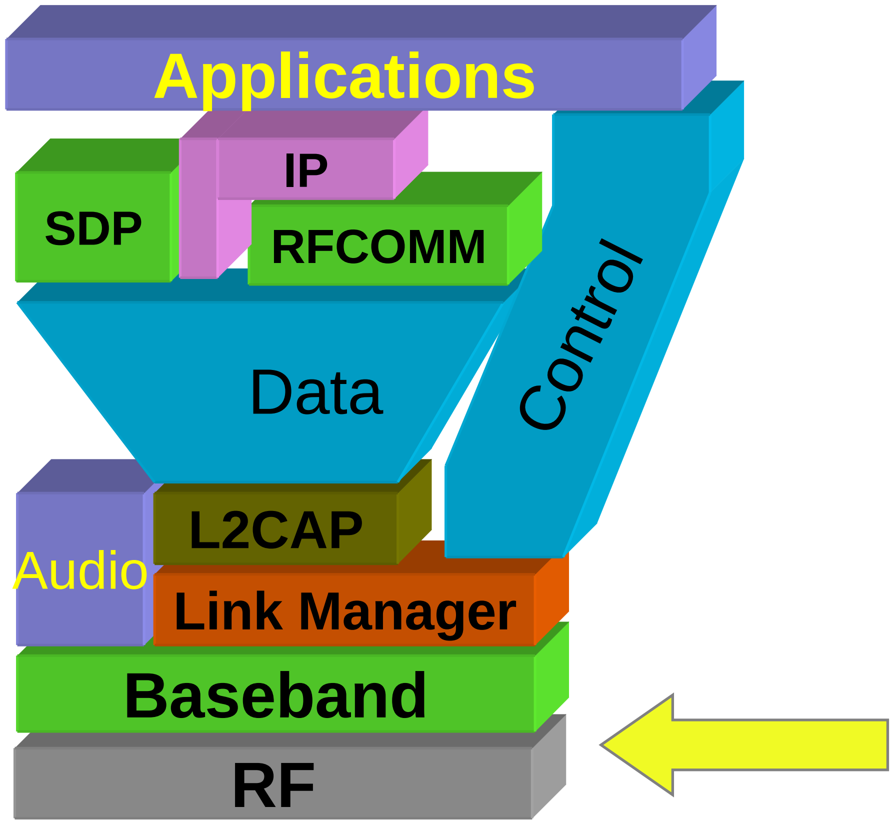
Bluetooth

Bluetooth Specifications

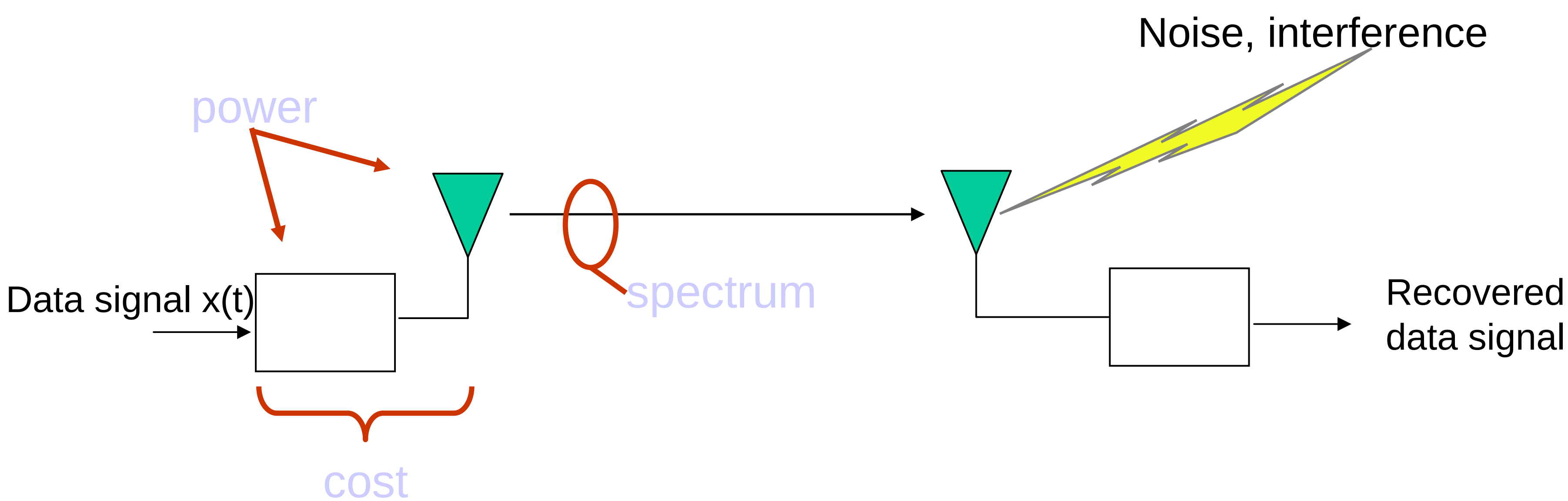


- A hardware/software/protocol description
- An application framework

Bluetooth Radio Specification



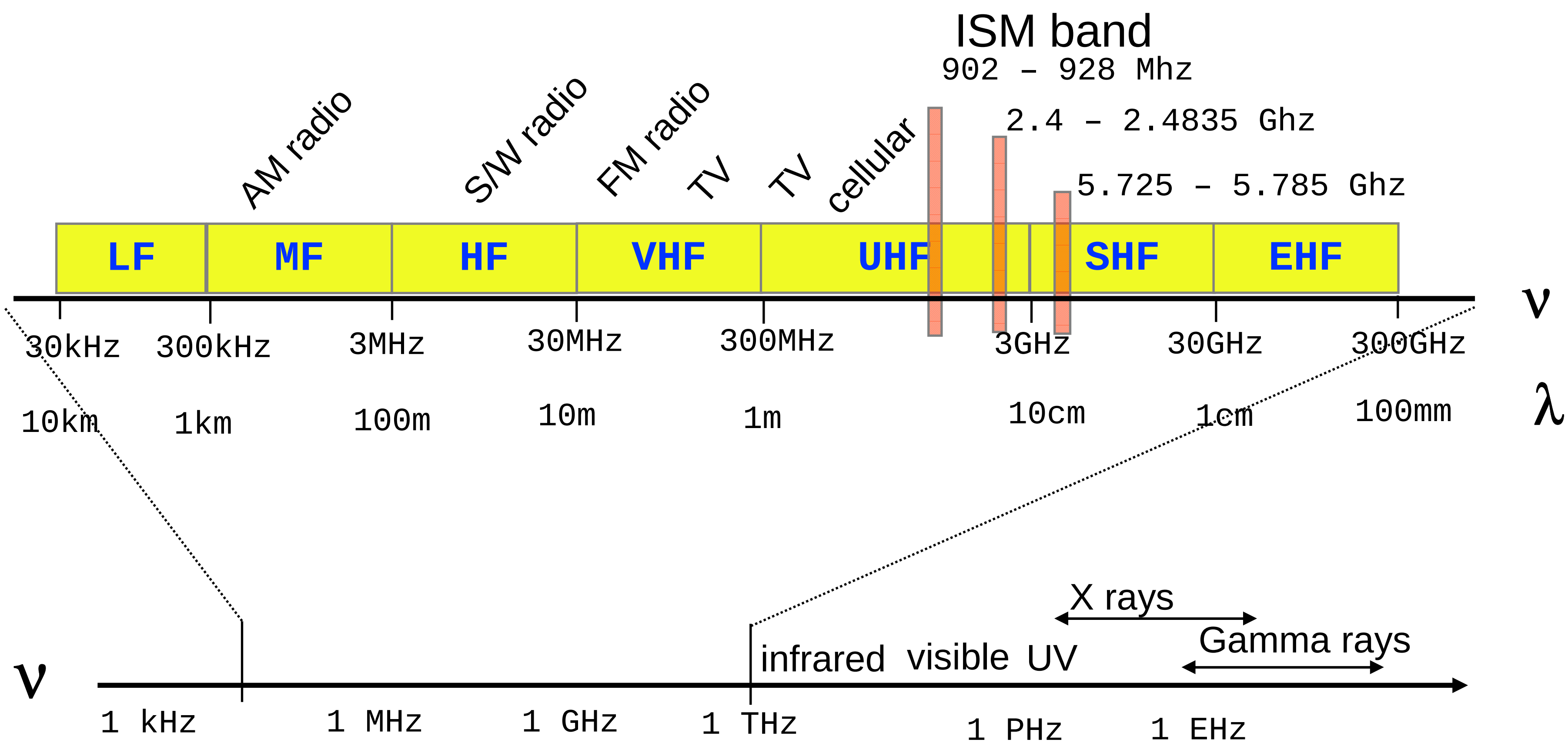
Design considerations



Goal

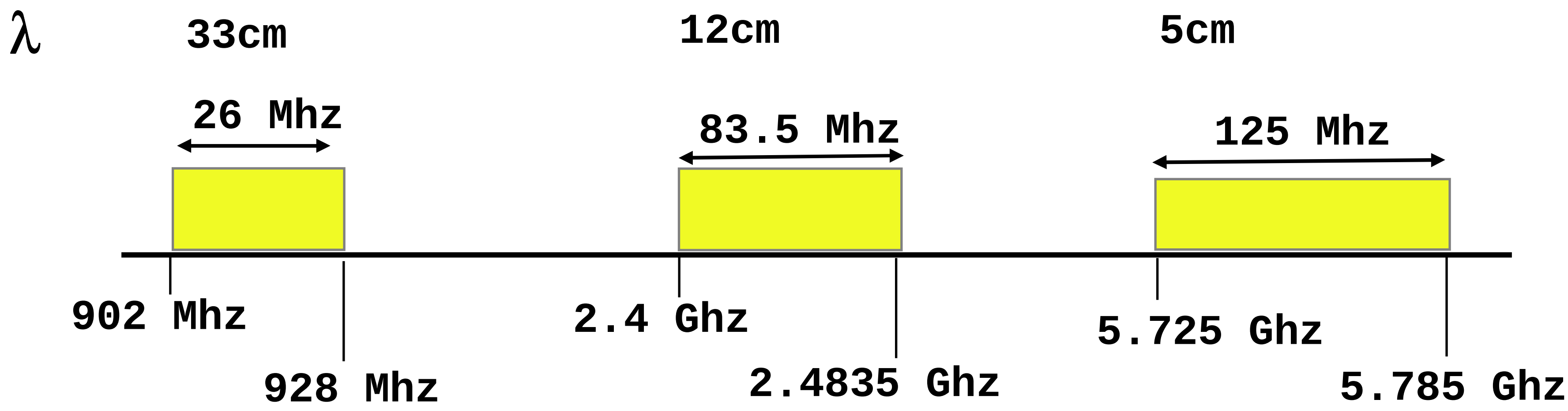
- high bandwidth
- conserve battery power
- cost < $10

EM Spectrum



Propagation characteristics are different in each frequency band

Unlicensed Radio Spectrum

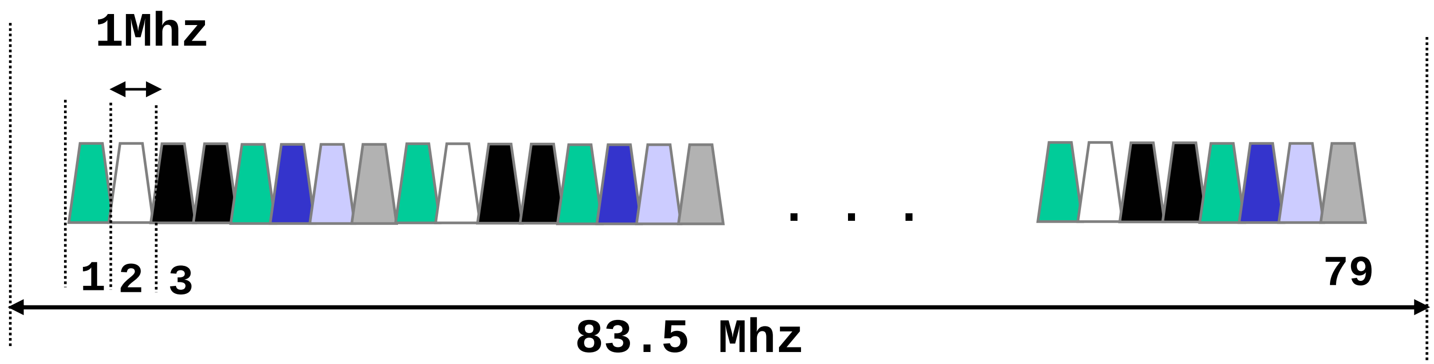


cordless phones
baby monitors
Wireless LANs

802.11
Bluetooth
Microwave oven

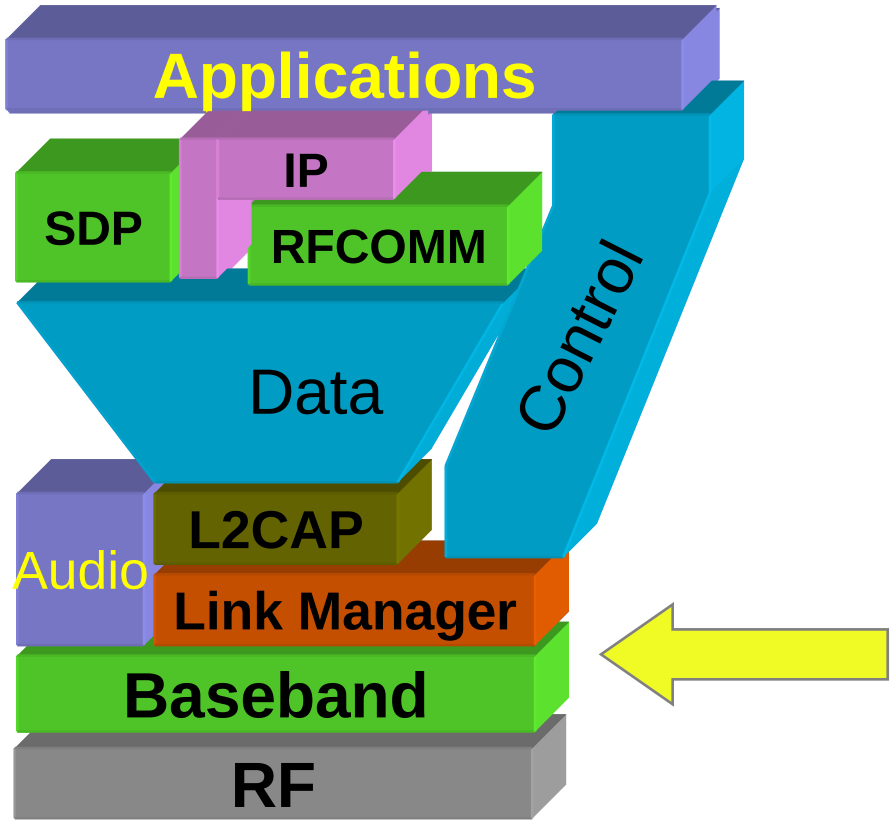
802.11a
HyperLan

Bluetooth radio link



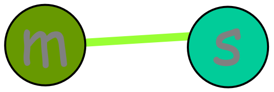
- frequency hopping spread spectrum
  - 2.402 GHz + k MHz, k=0, …, 78
  - 1,600 hops per second
- GFSK modulation
  - 1 Mb/s symbol rate
- transmit power
  - 0 dbm (up to 20dbm with power control)

Baseband

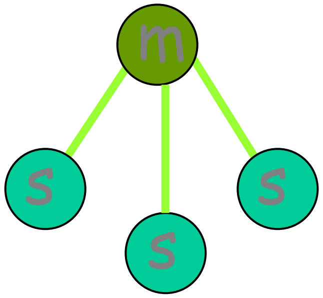

Applications
IP
SDP
RFCOMM
Data
Control
Audio
L2CAP
Link Manager
Baseband
RF

Bluetooth Physical link

- Point to point link
  - master - slave relationship
  - radios can function as masters or slaves

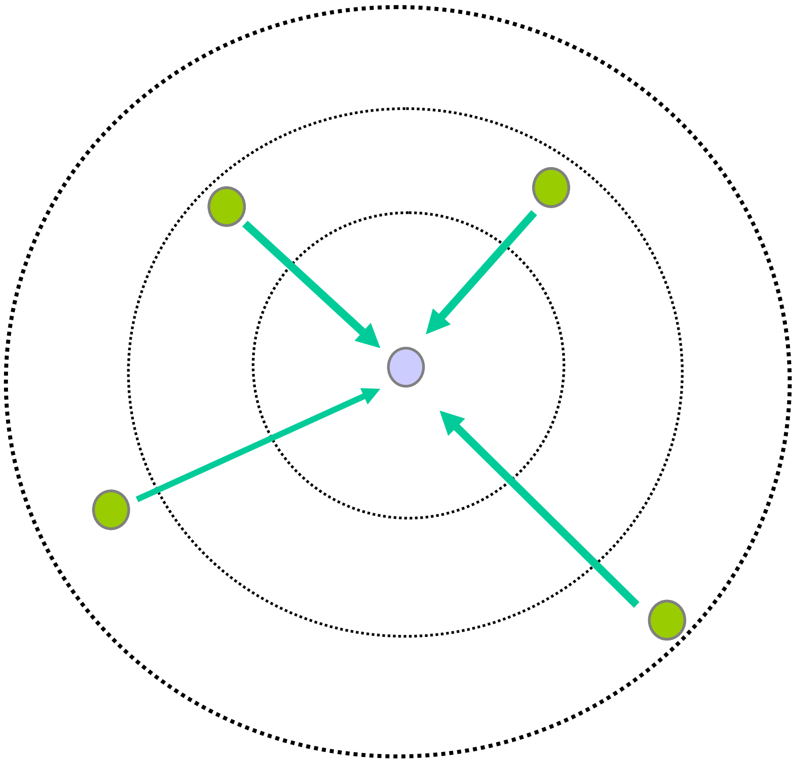


- Piconet
  - Master can connect to 7 slaves
  - Each piconet has max capacity =1 Mbps
  - hopping pattern is determined by the master

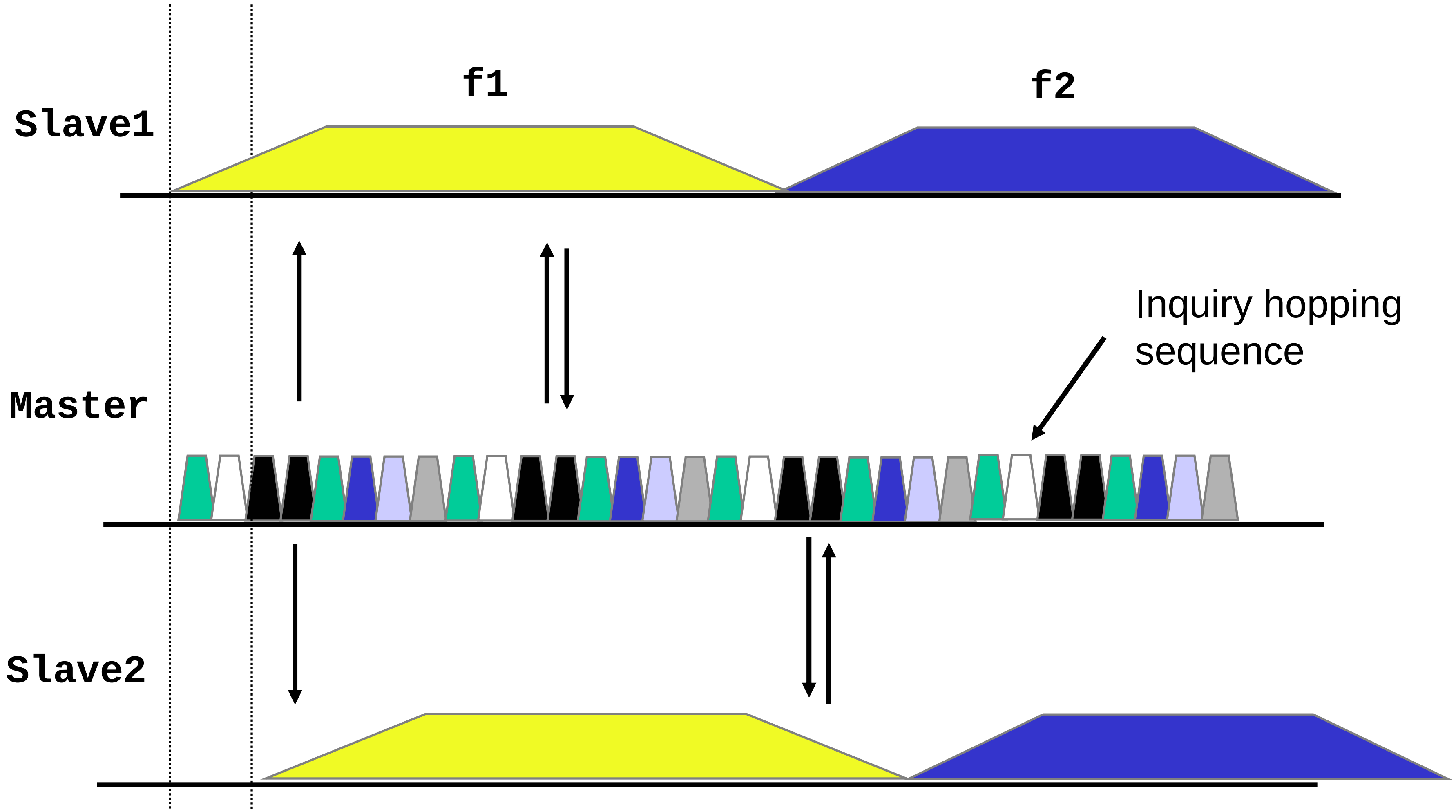


Connection Setup

- Inquiry - scan protocol
  - to learn about the clock offset and device address of other nodes in proximity

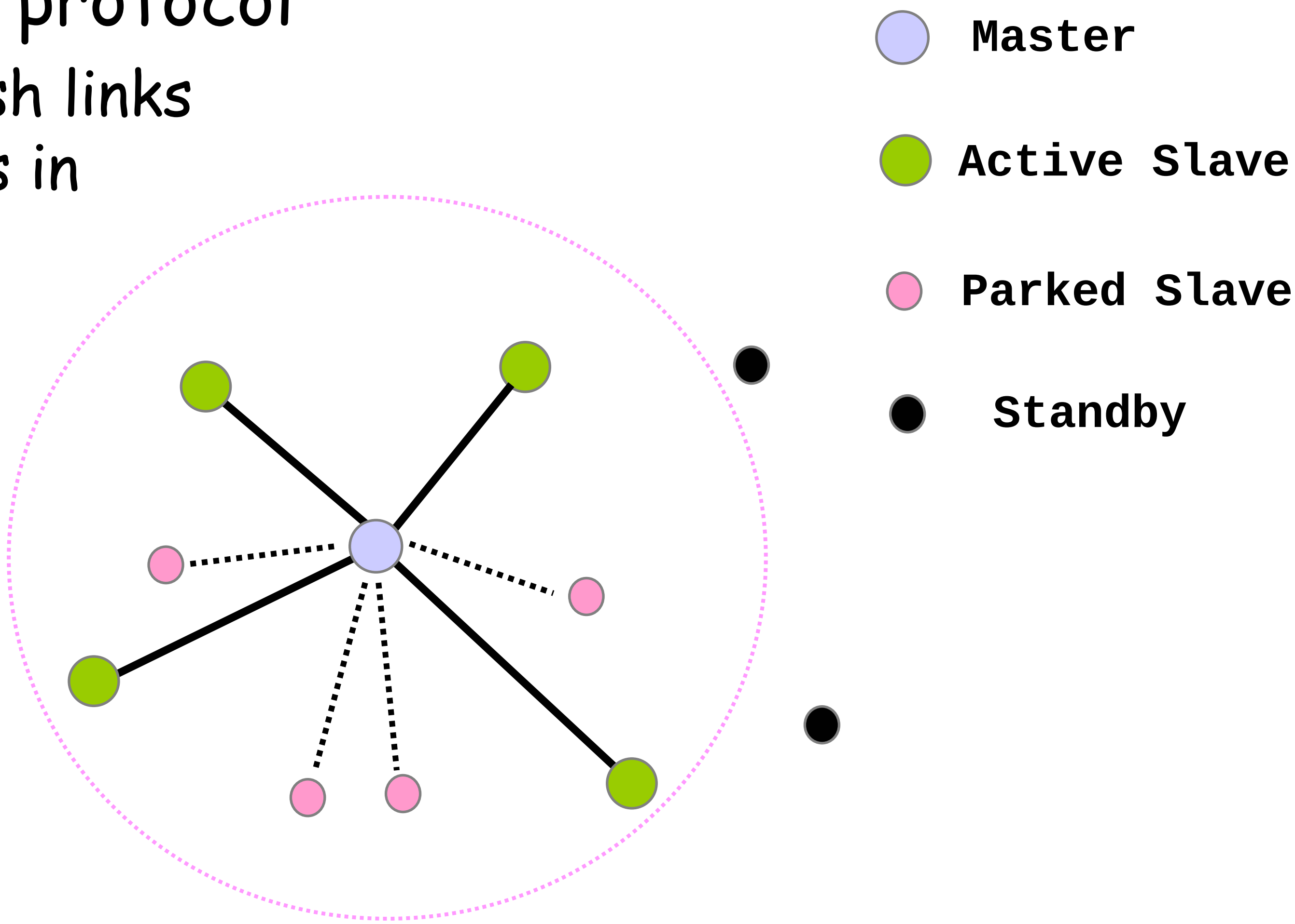


Inquiry on time axis



Piconet formation

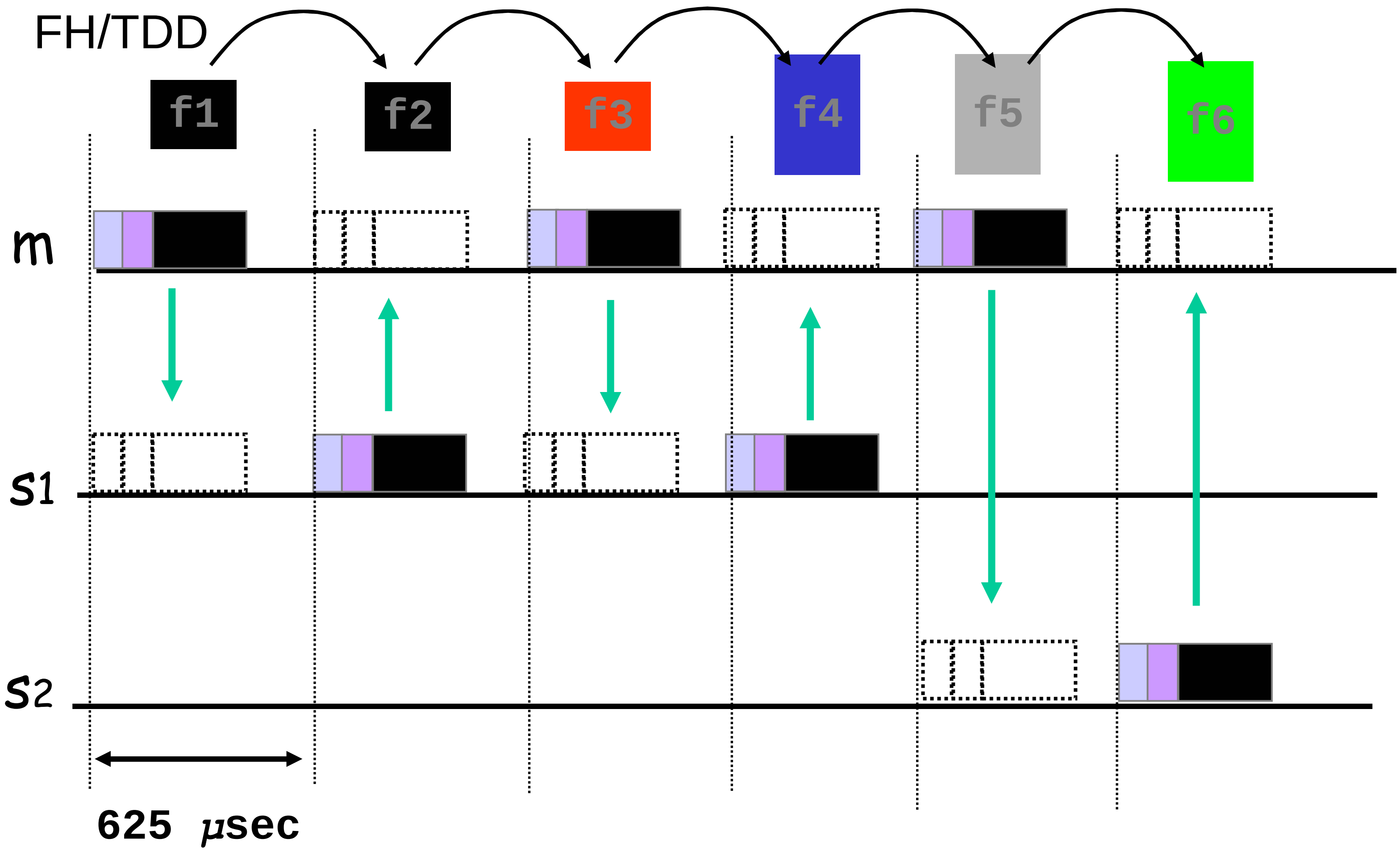
- Page - scan protocol
  - to establish links with nodes in proximity



Addressing

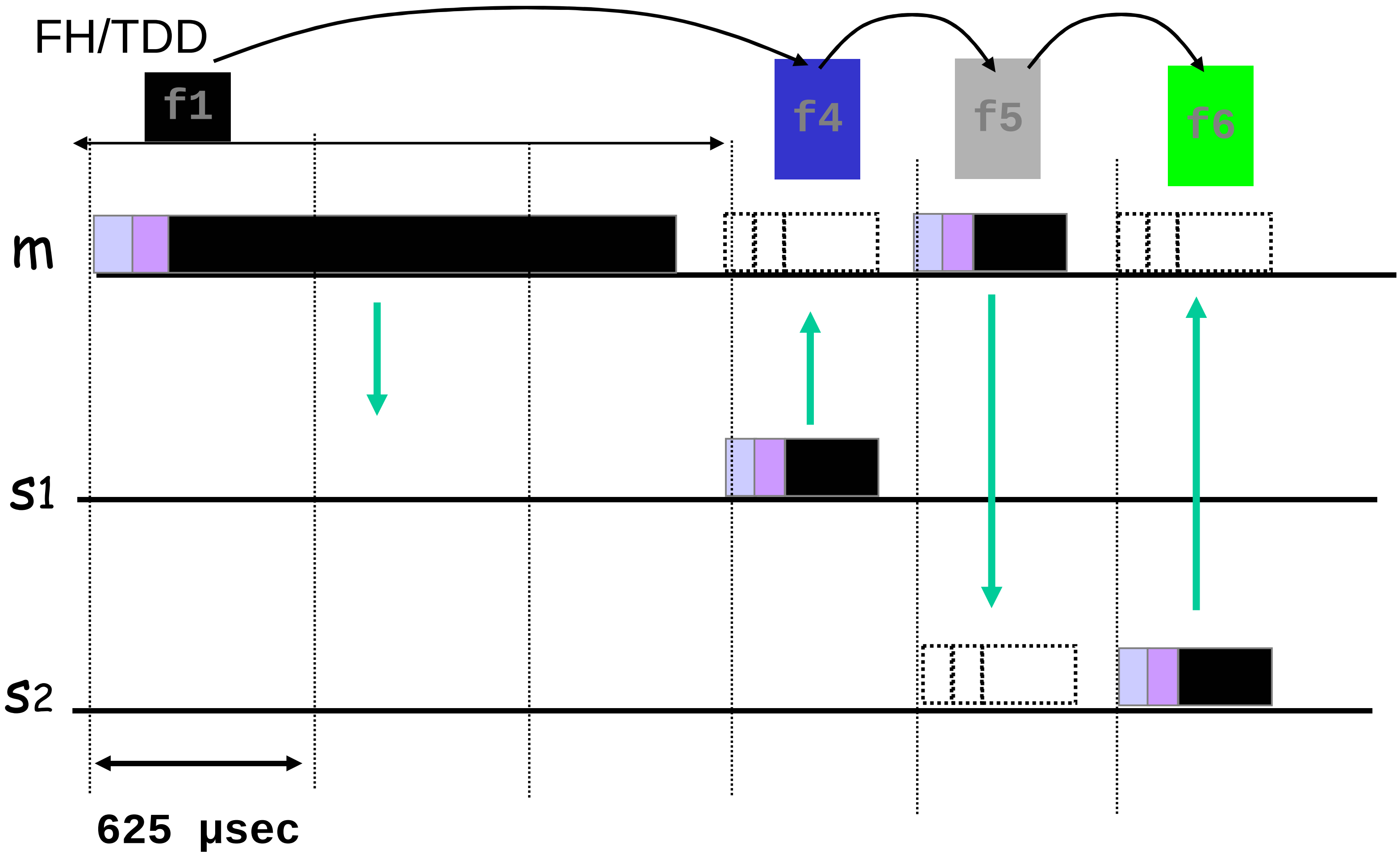
- Bluetooth device address (BD_ADDR)
  - 48 bit IEEE MAC address
- Active Member address (AM_ADDR)
  - 3 bits active slave address
  - all zero broadcast address
- Parked Member address (PM_ADDR)
  - 8 bit parked slave address

Piconet channel



1600 hops/sec

Multi slot packets

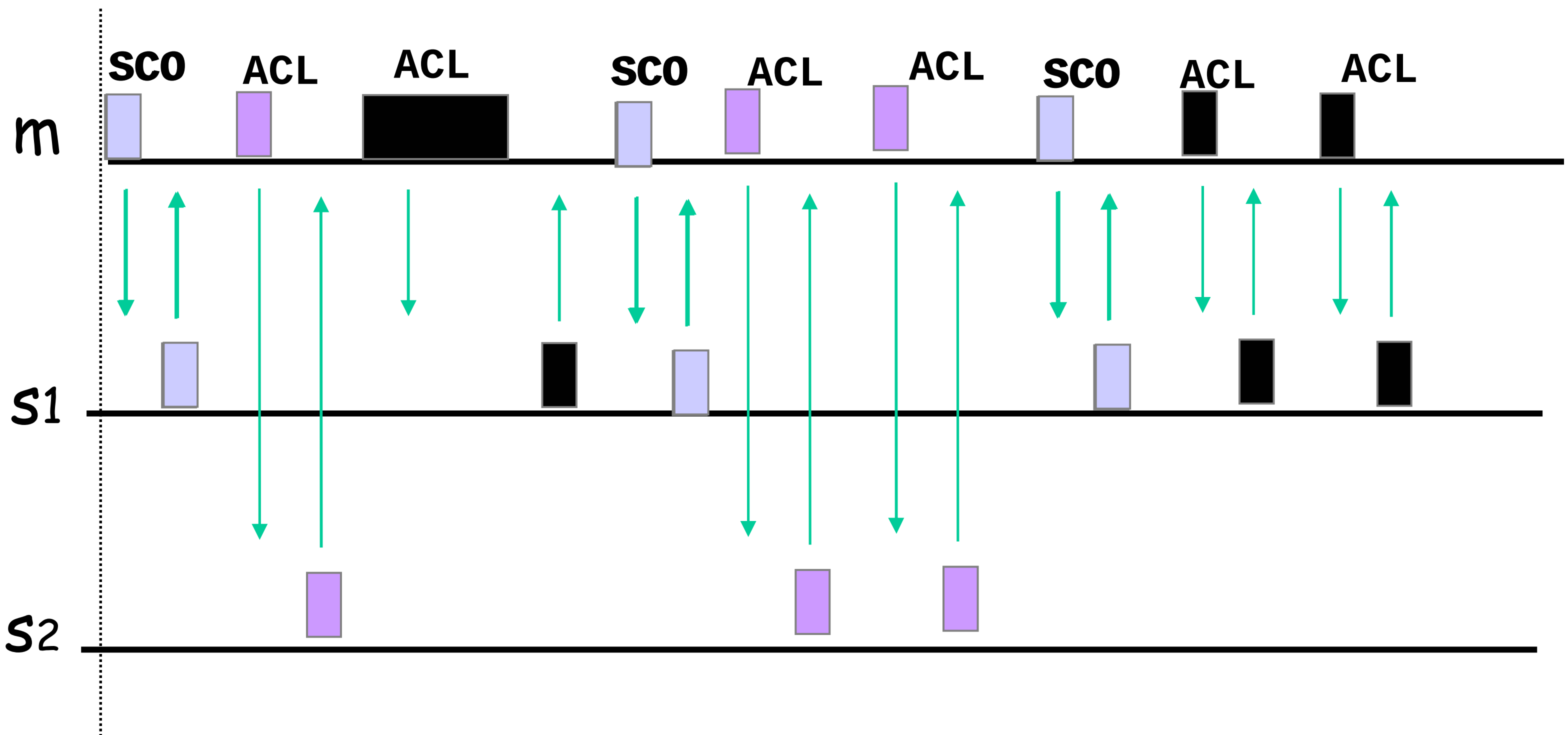


Data rate depends on type of packet

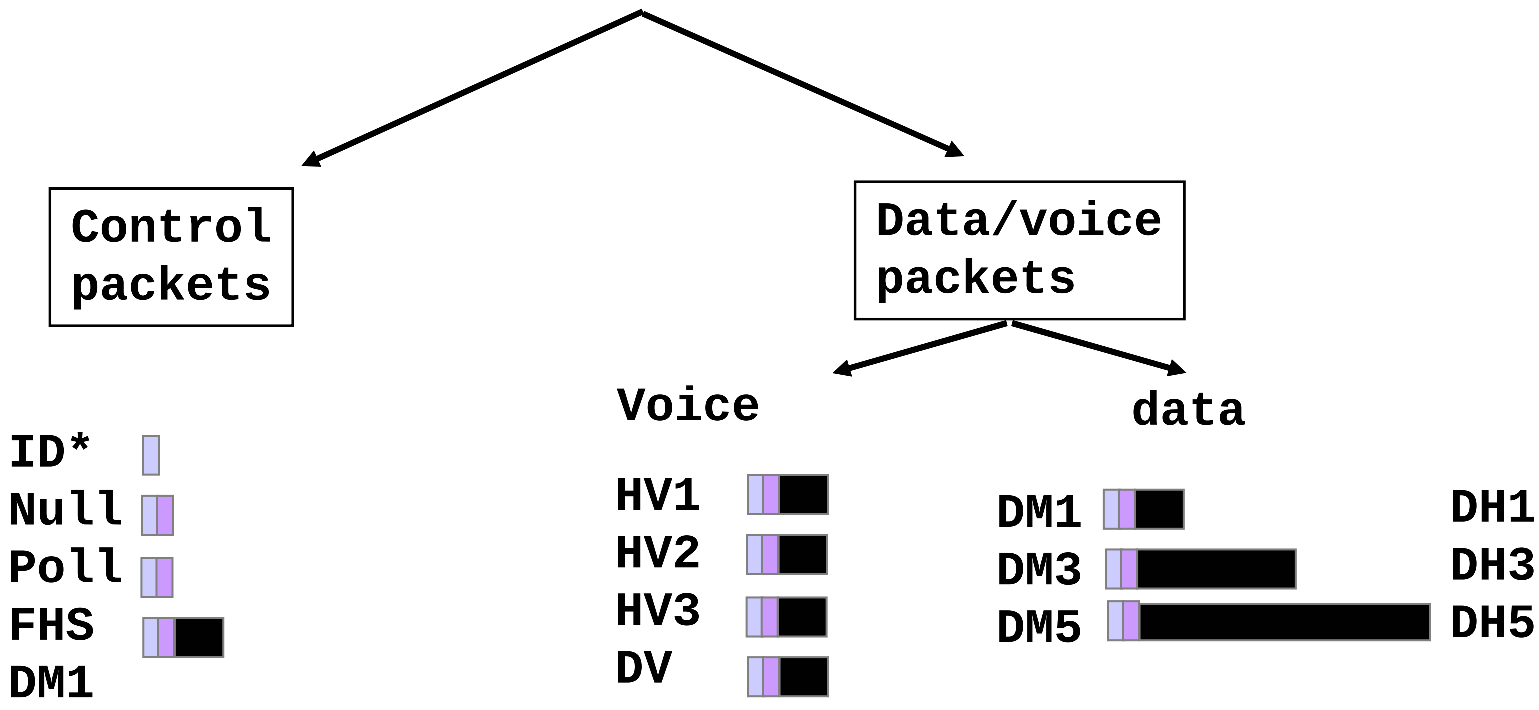
Physical Link Types

- Synchronous Connection Oriented (SCO) Link
  - slot reservation at fixed intervals

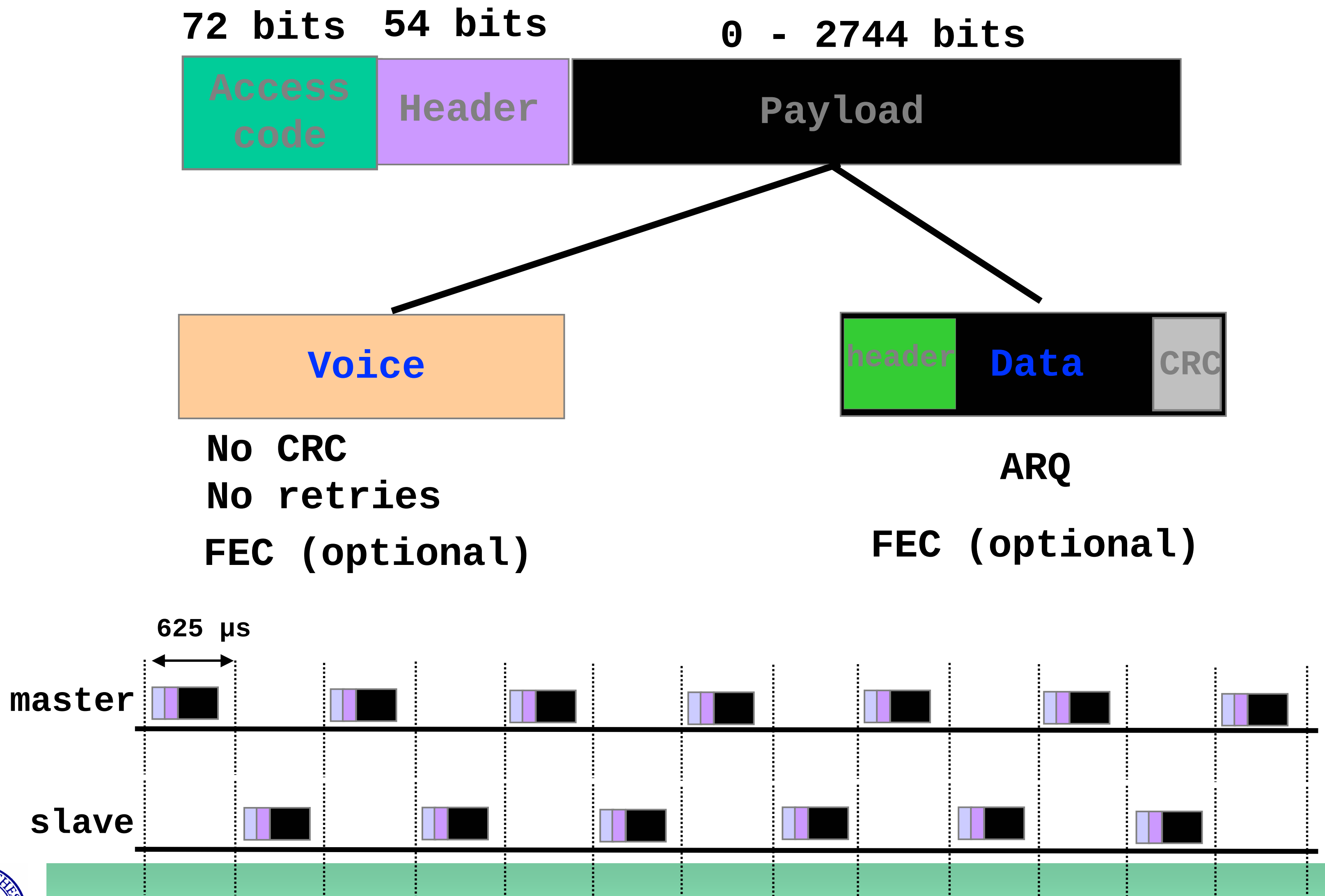
- Asynchronous Connection-less (ACL) Link
  - Polling access method



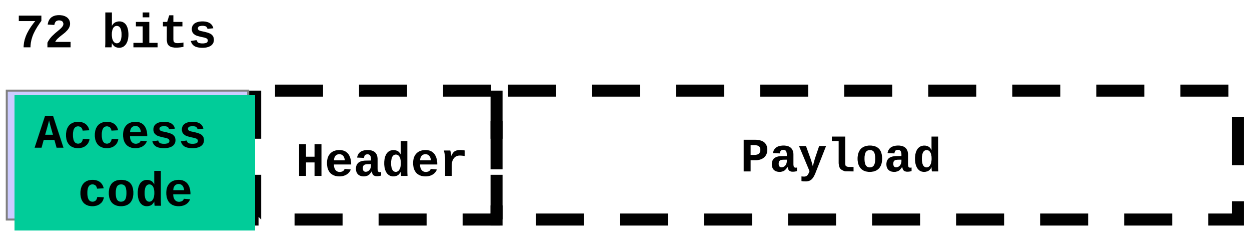
Packet Types



Packet Format



Access Code

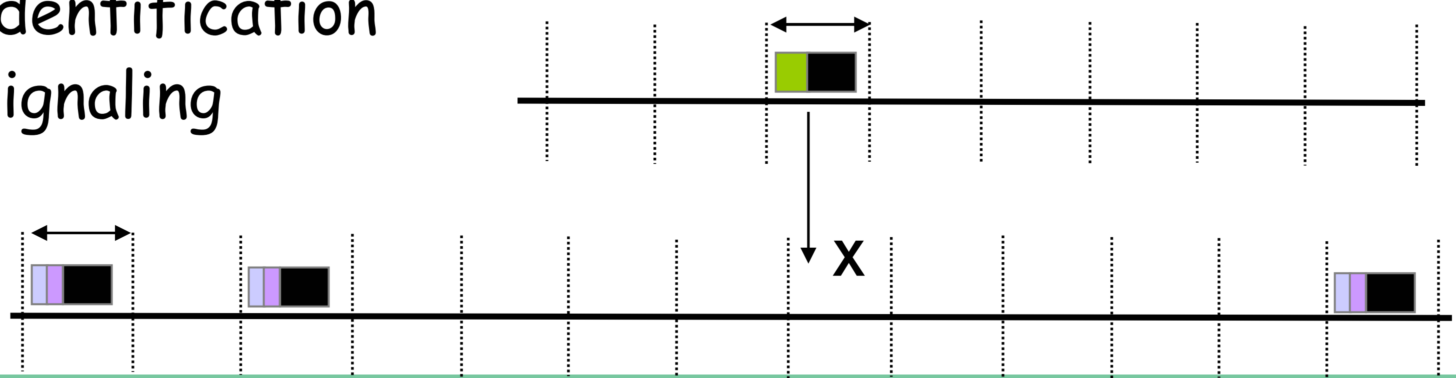


Purpose

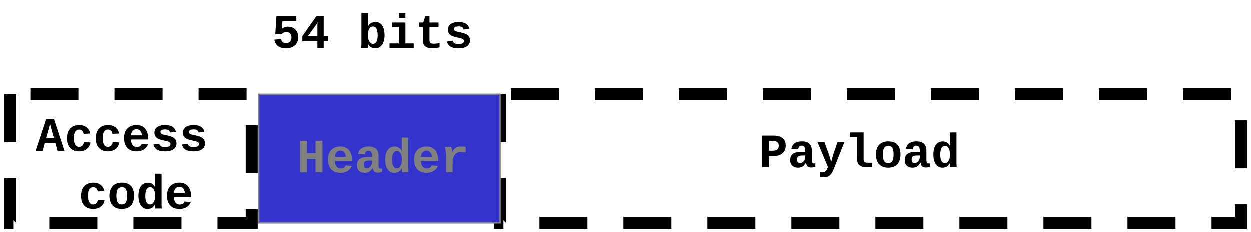
- Synchronization
- DC offset compensation
- Identification
- Signaling

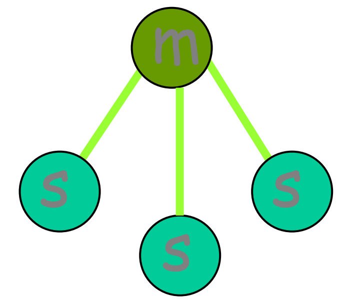
Types

- Channel Access Code (CAC)
- Device Access Code (DAC)
- Inquiry Access Code (IAC)



Packet Header





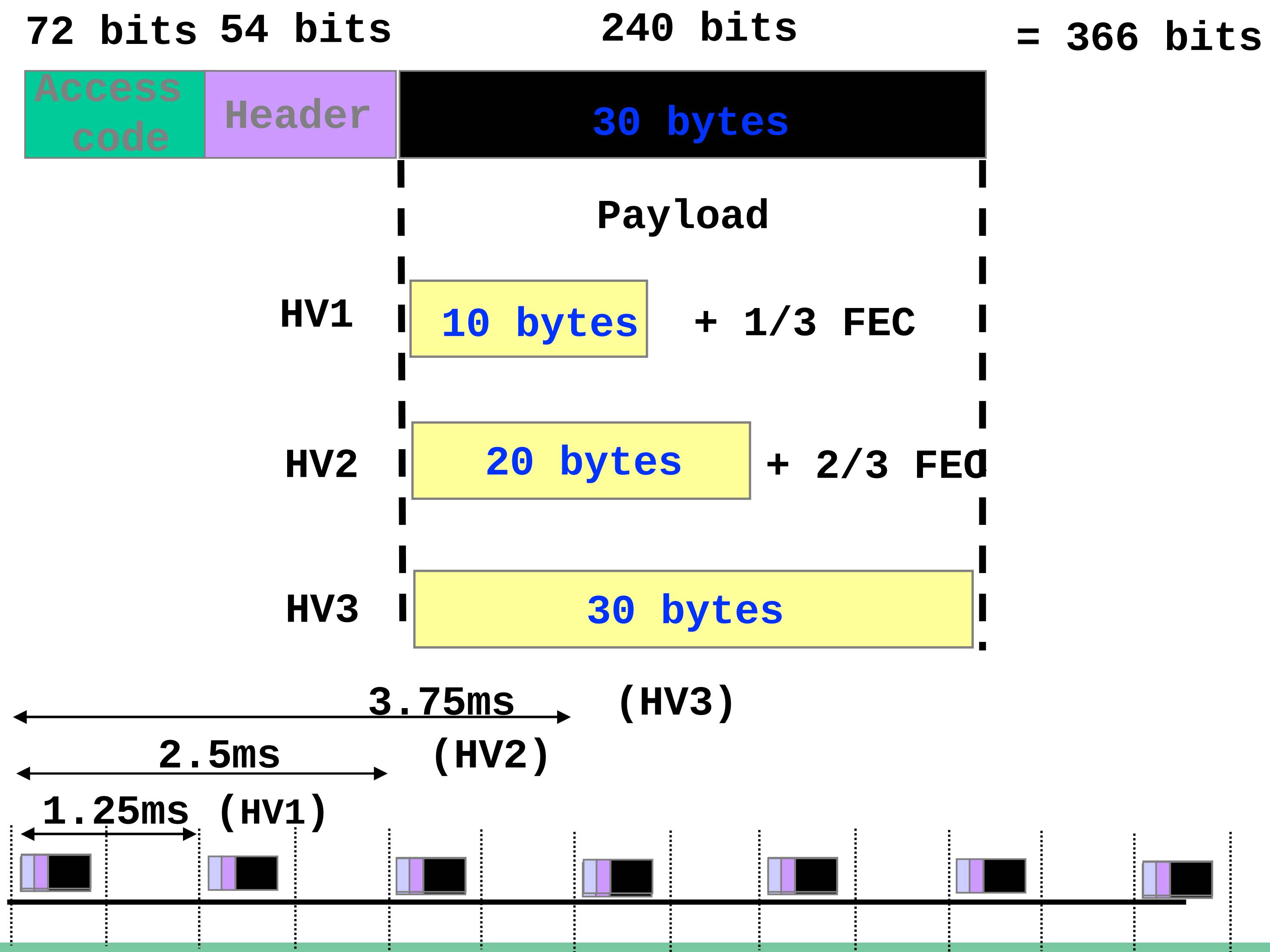
Purpose

- Addressing (3) → Max 7 active slaves
- Packet type (4) → 16 packet types (some unused)
- Flow control (1) → Broadcast packets are not ACKed
- 1-bit ARQ (1) → For filtering retransmitted packets
- Sequencing (1)
- HEC (8) → Verify header integrity

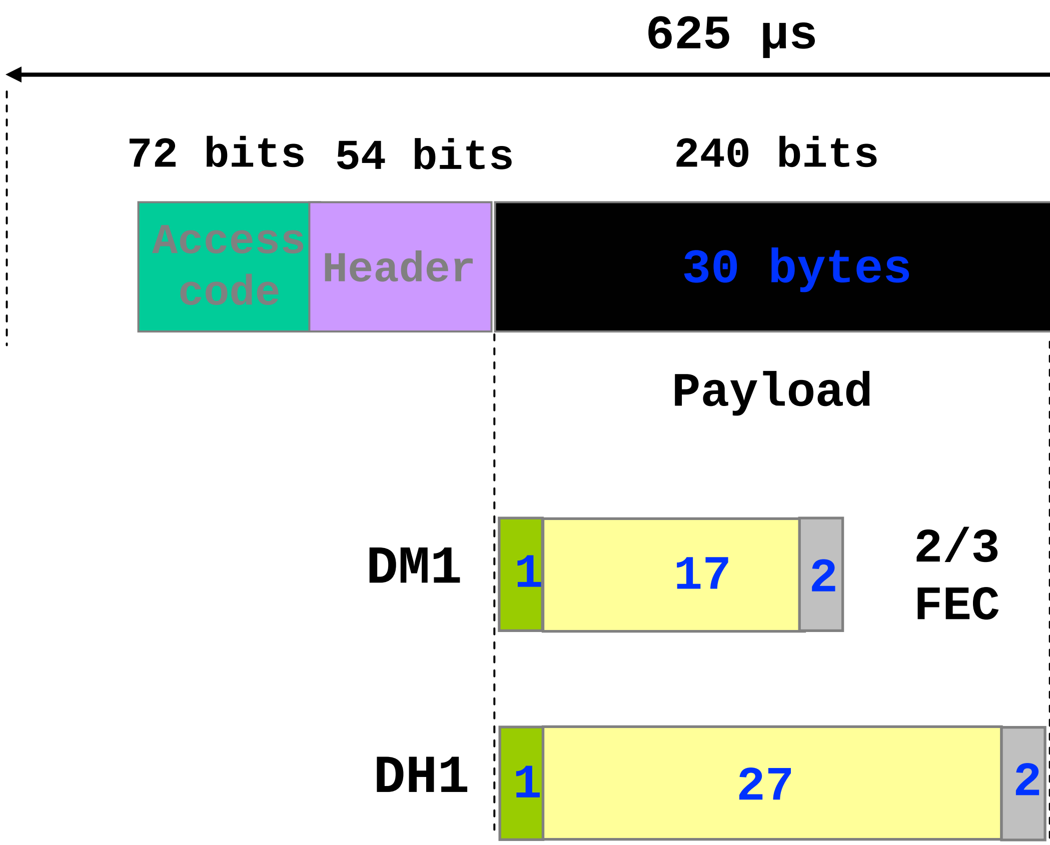
total 18 bits

Encode with 1/3 FEC to get 54 bits

Voice Packets (HV1, HV2, HV3)

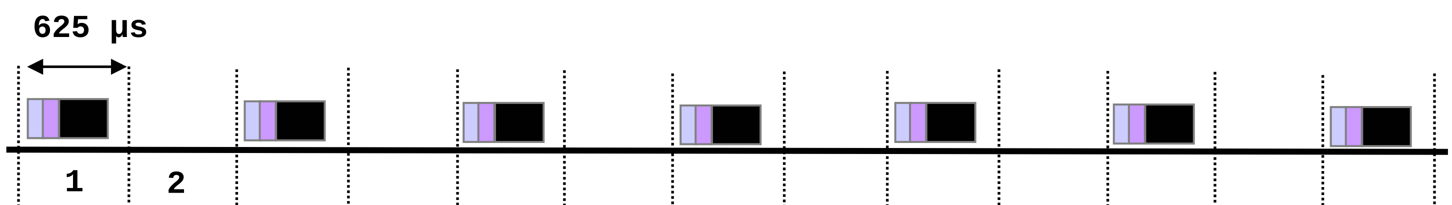


Data rate calculation: DM1 and DH1

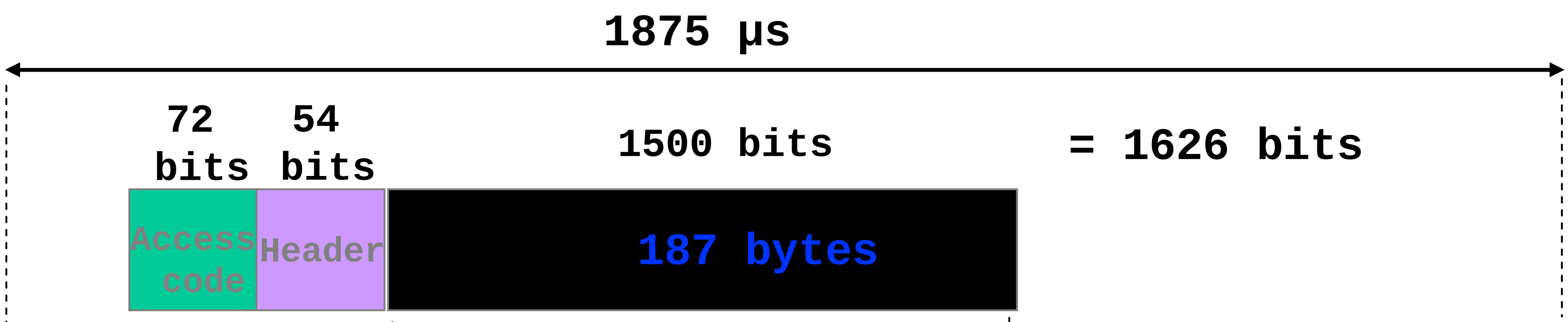


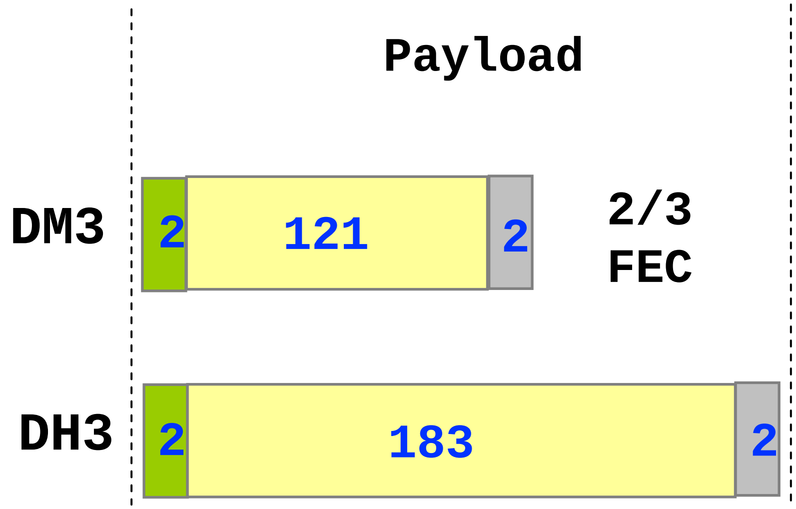
Dir	Size	Freq	Rate
↑	17	1600/2	108.8
↓	17		108.8

↑	27		172.8
↓	27		172.8



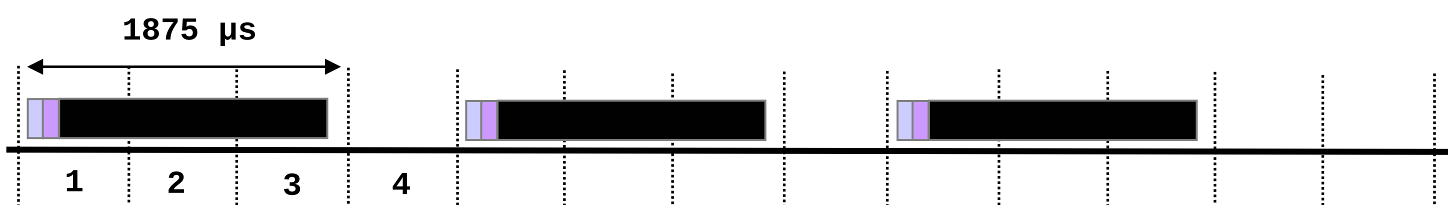
Data rate calculation: DM3 and DH3



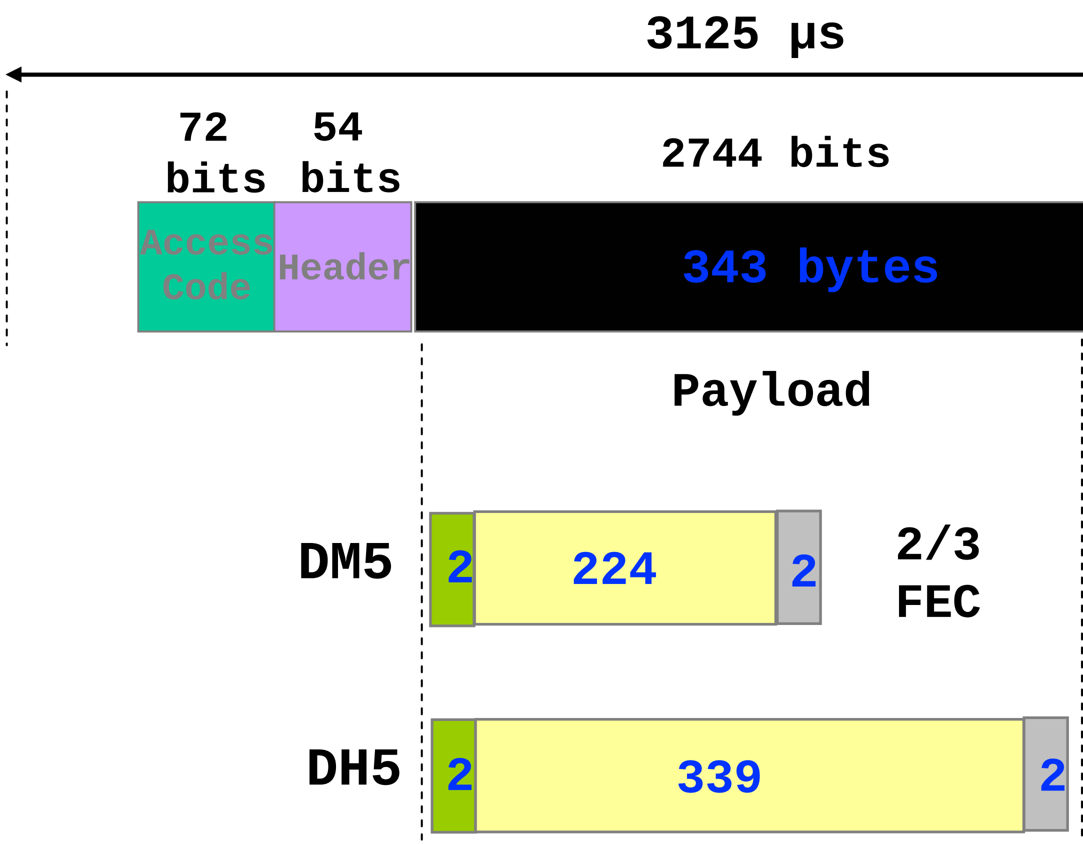


Dir	Size	Freq	Rate
↑	**121**	**1600/4**	**387.2**
↓	**17**		**54.4**

↑	**183**		**585.6**
↓	**27**		**86.4**

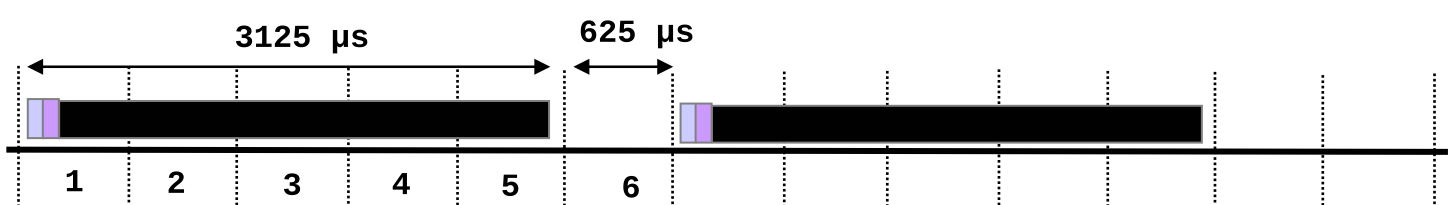


Data rate calculation: DM5 and DH5

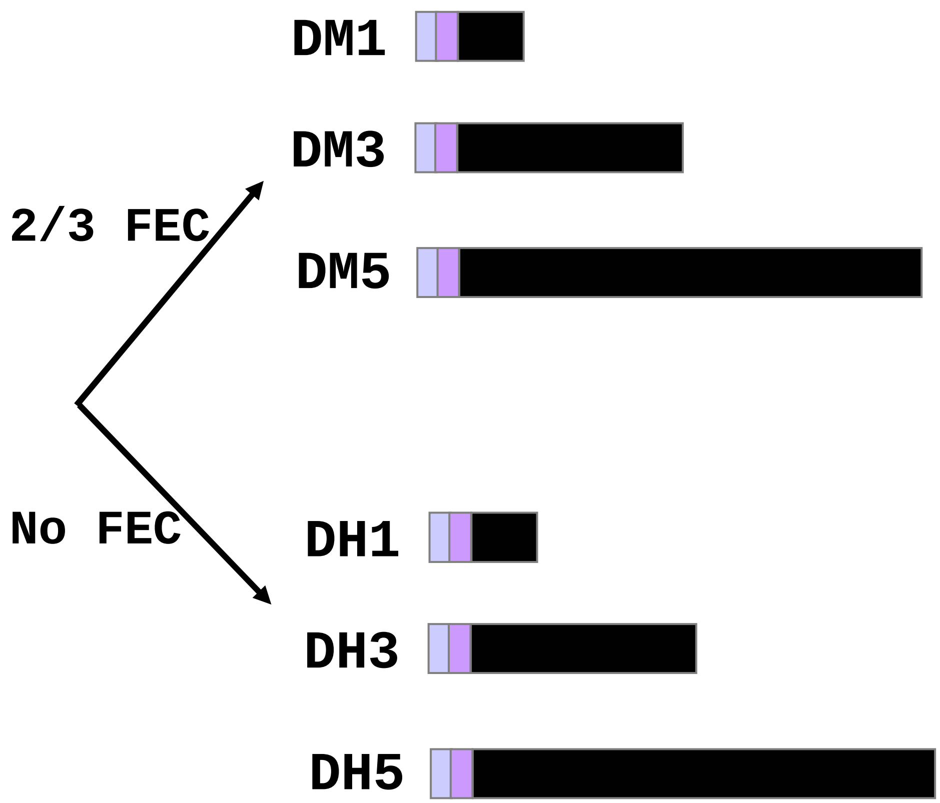


Dir	Size	Freq	Rate
↑	224	1600/6	477.8
↓	17		36.3

↑	339		723.2
↓	27		57.6



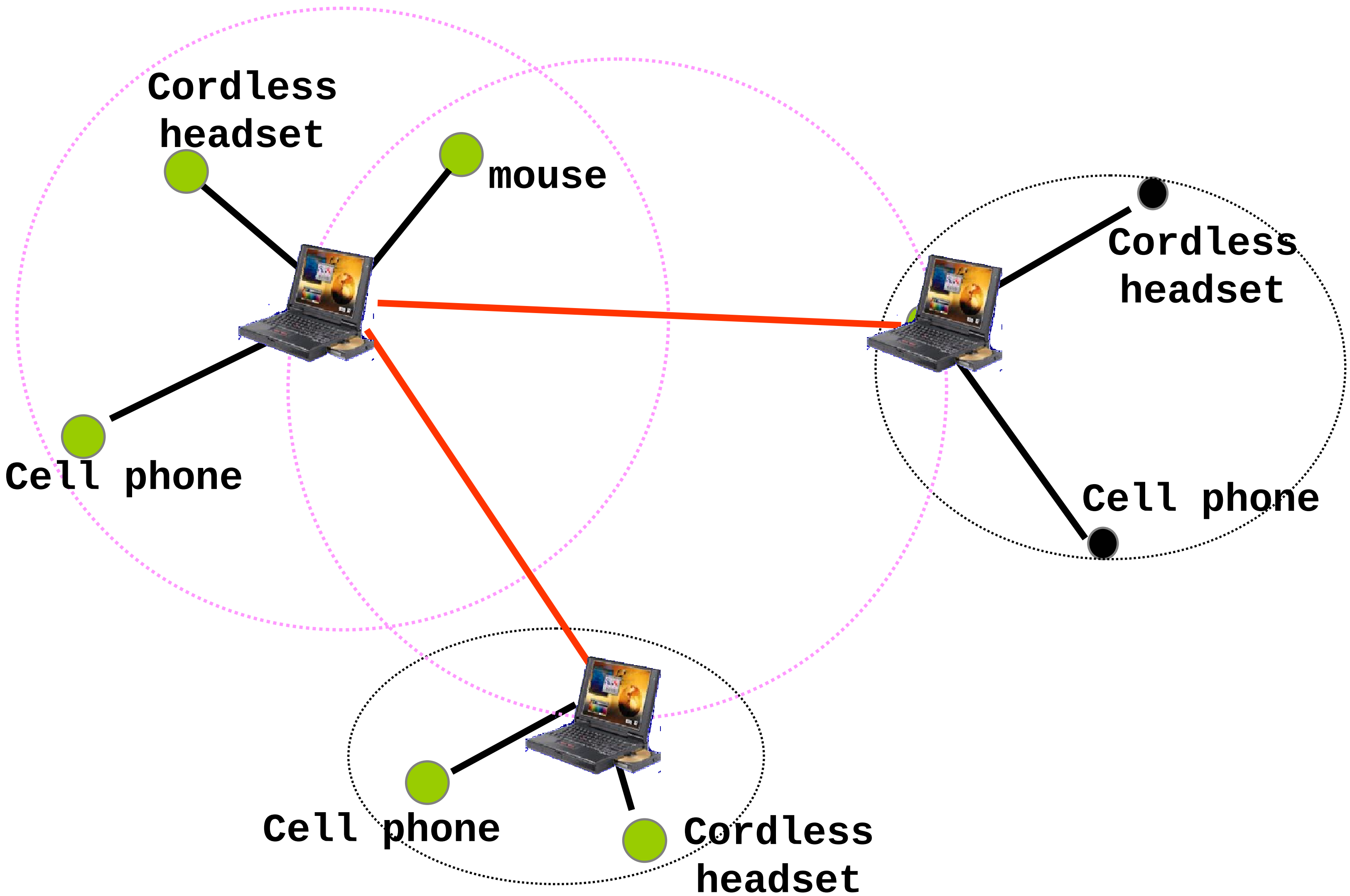
Data Packet Types



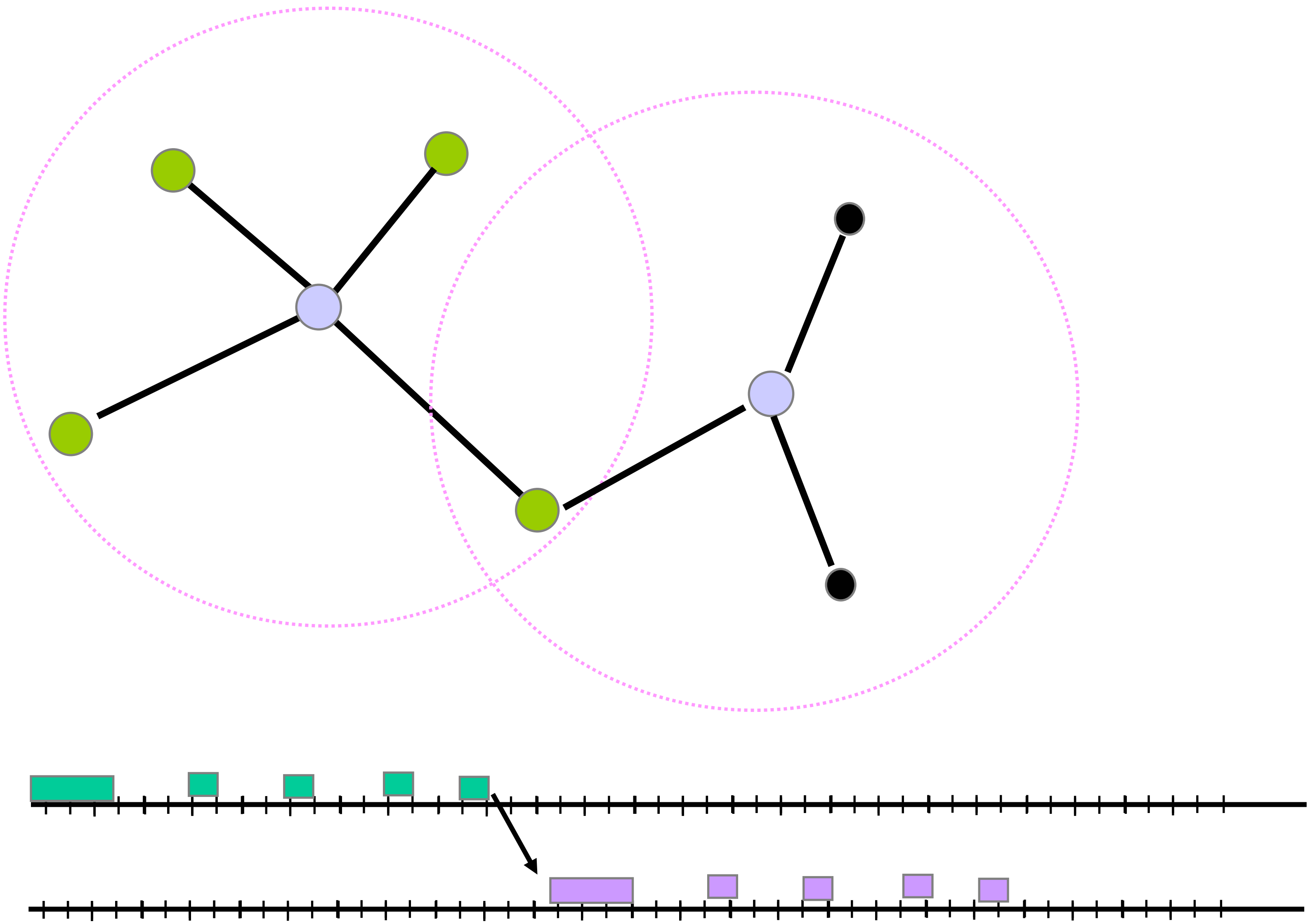
Symmetric	Asymmetric	
108.8	108.8	108.8
258.1	387.2	54.4
286.7	477.8	36.3

Symmetric	Asymmetric	
172.8	172.8	172.8
390.4	585.6	86.4
433.9	723.2	57.6

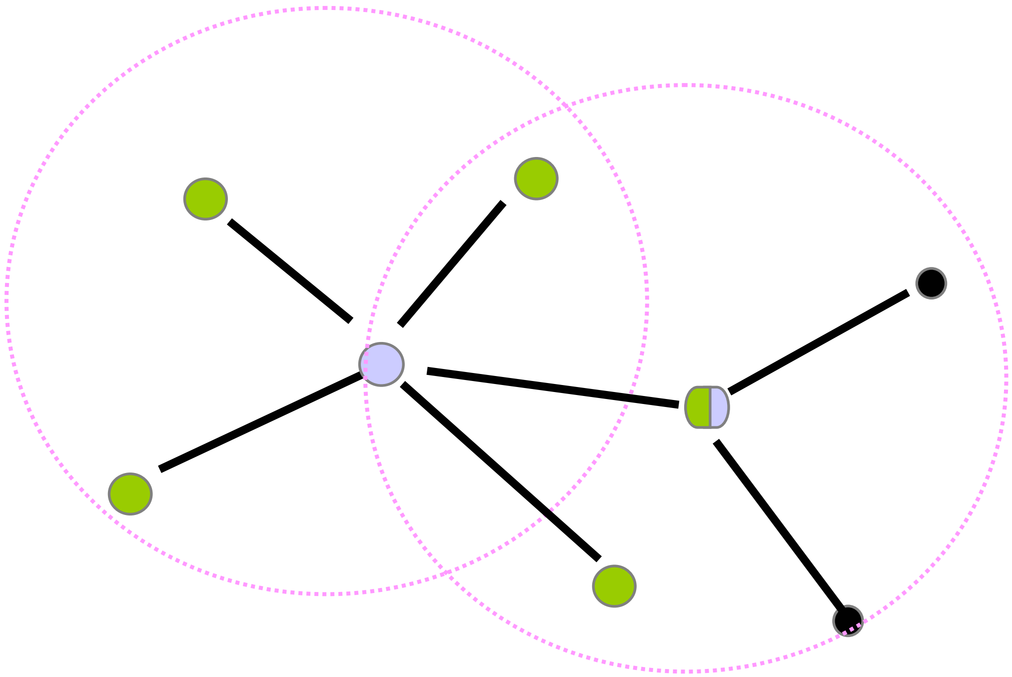
Inter piconet communication



Scatternet



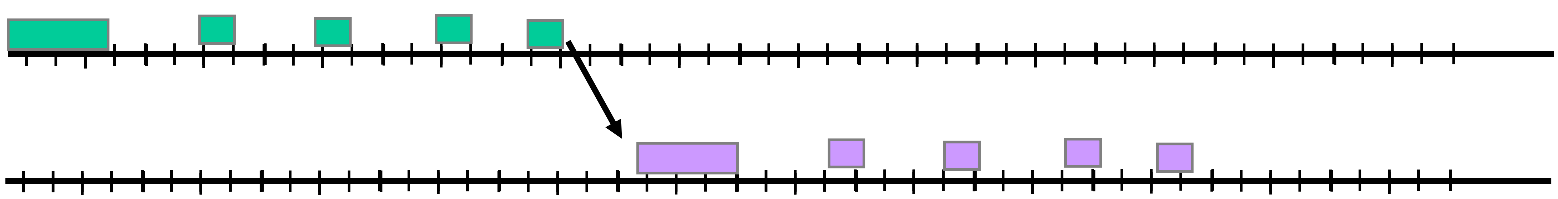
Scatternet, scenario 2



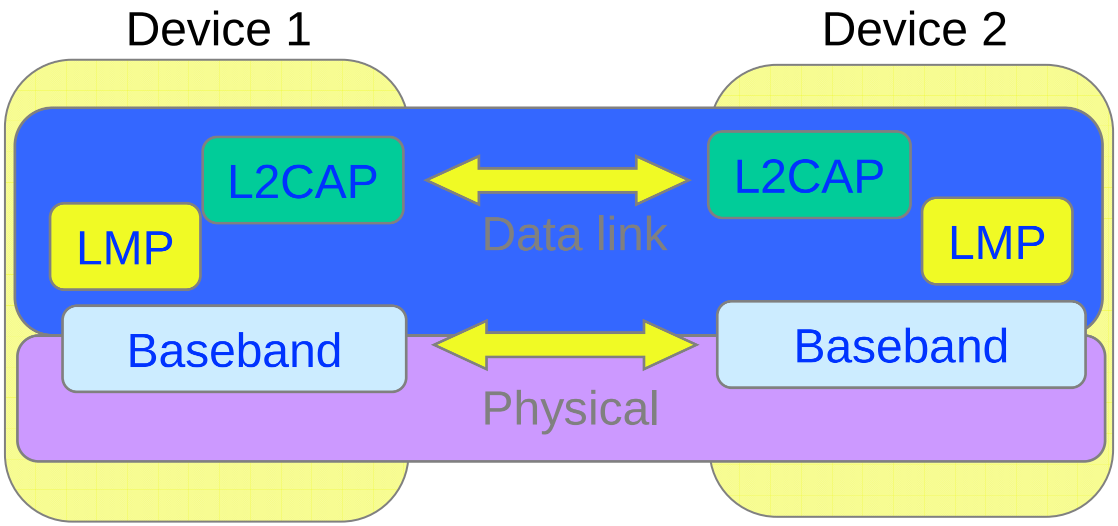
How to schedule presence in two piconets?

Forwarding delay ?

Missed traffic?

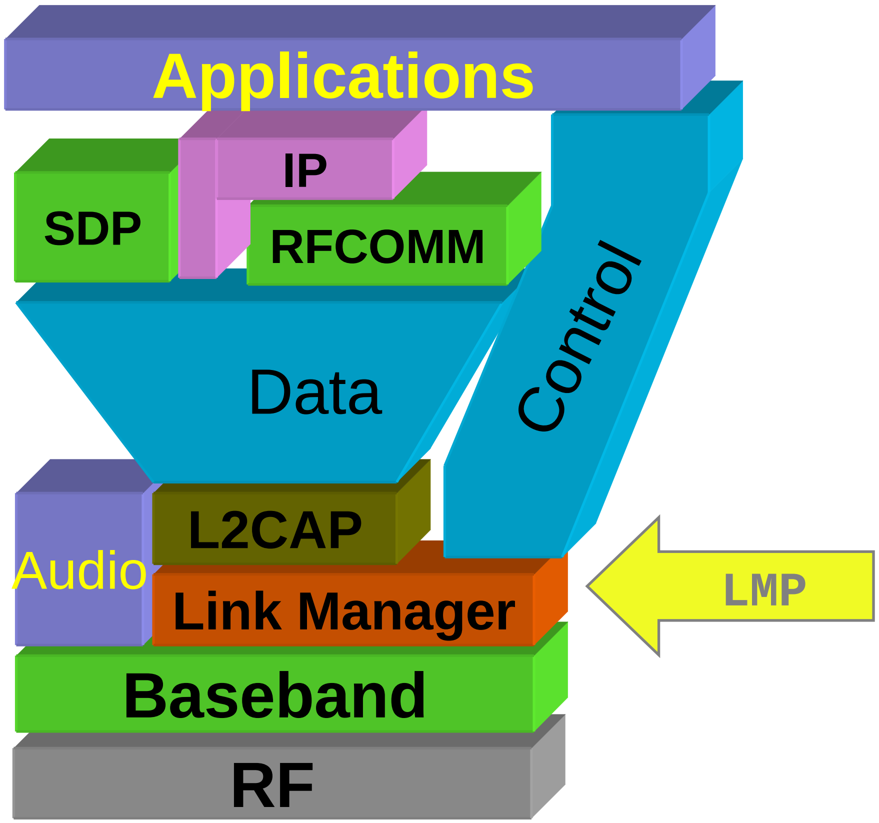


Baseband: Summary



- TDD, frequency hopping physical layer
- Device inquiry and paging
- Two types of links SCO and ACL links
- Multiple packet types (multiple data rates with and without FEC)

Link Manager Protocol

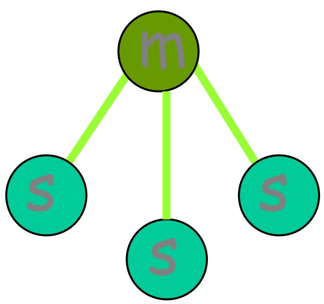


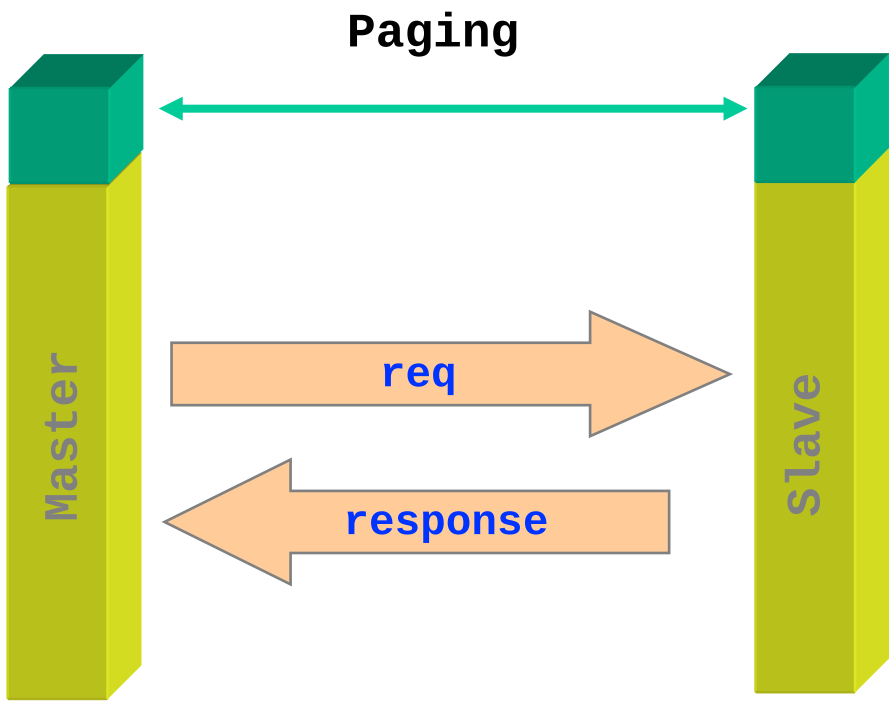
Setup and management of Baseband connections

- Piconet Management
- Link Configuration
- Security

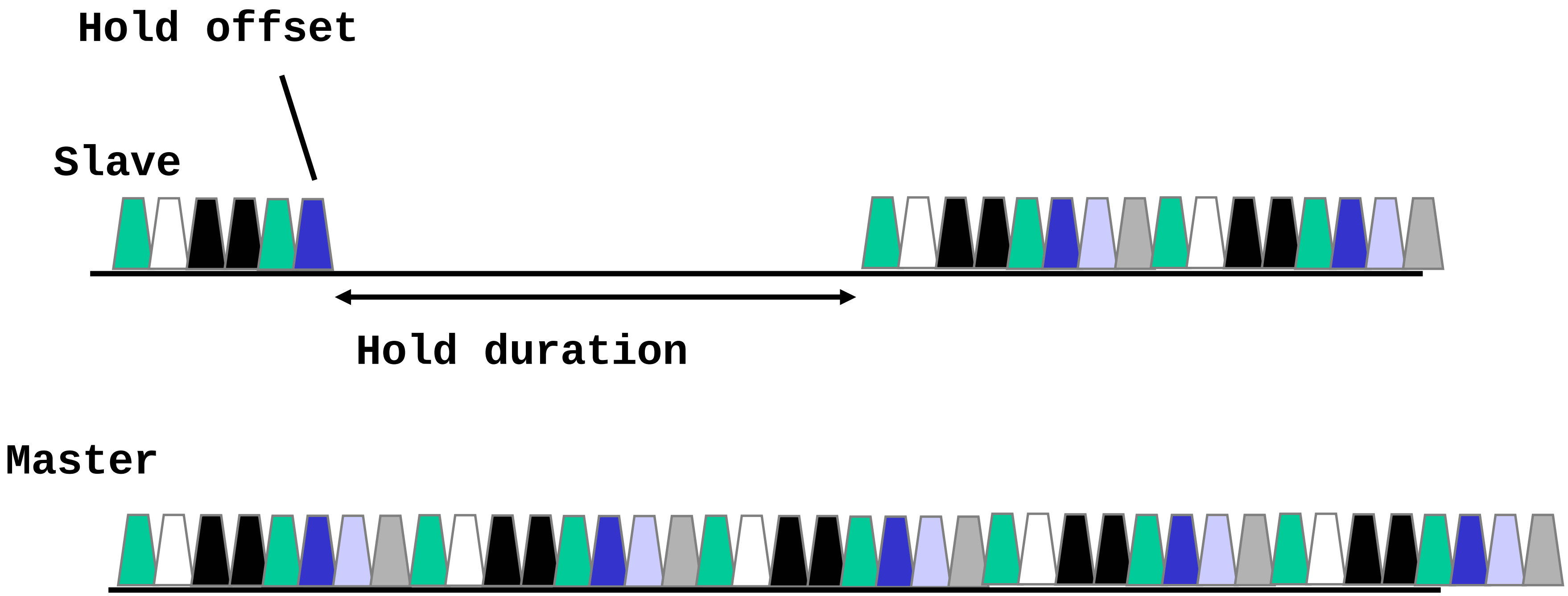
Piconet Management

- Attach and detach slaves
- Master-slave switch
- Establishing SCO links
- Handling of low power modes (Sniff, Hold, Park)

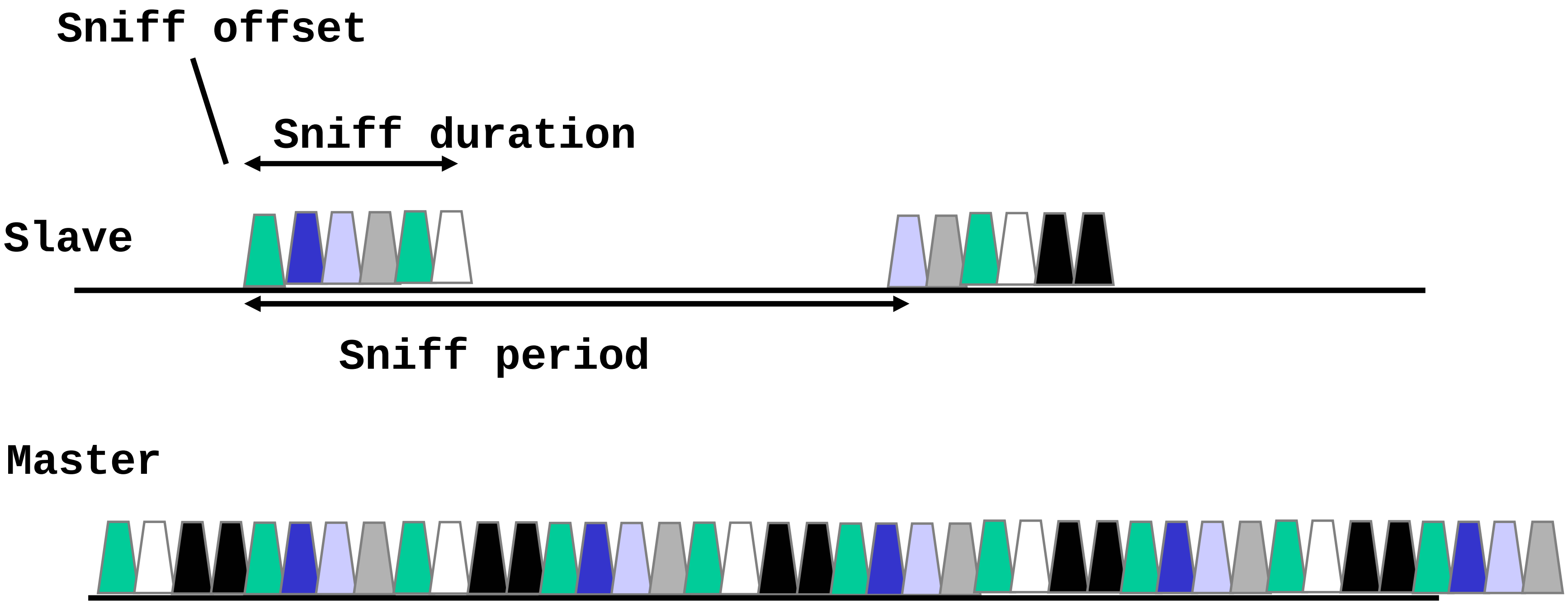




Low power mode (hold)

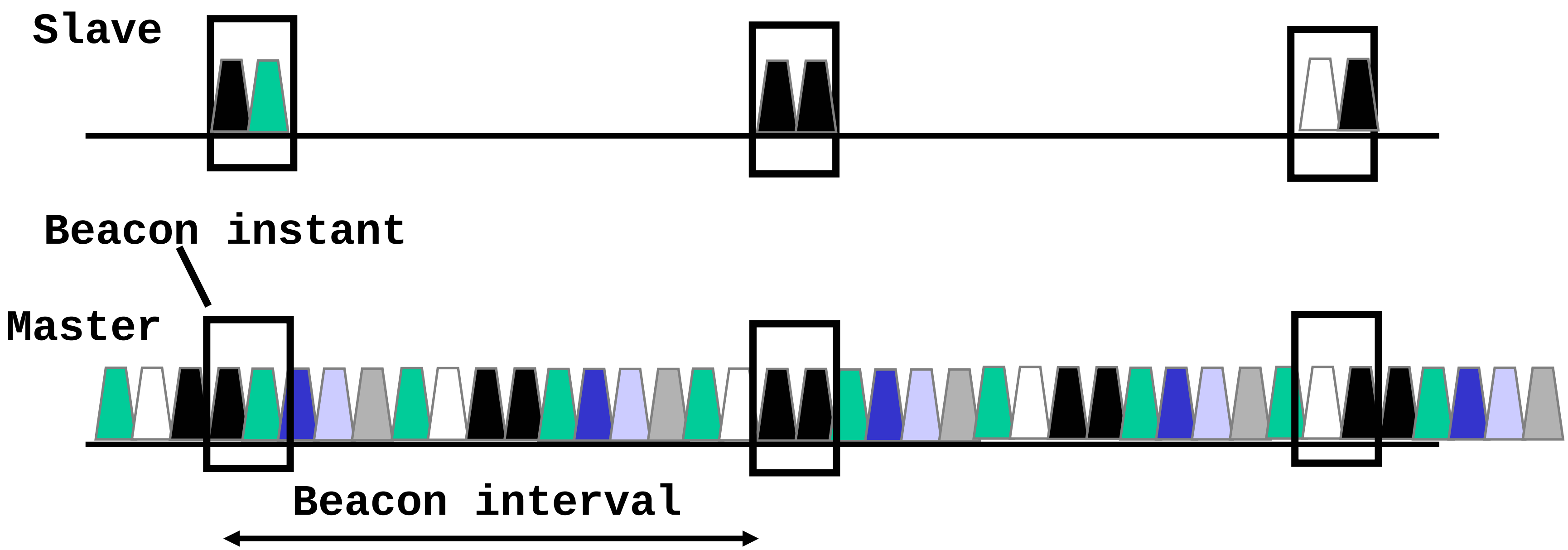


Low power mode (Sniff)



- Traffic reduced to periodic sniff slots

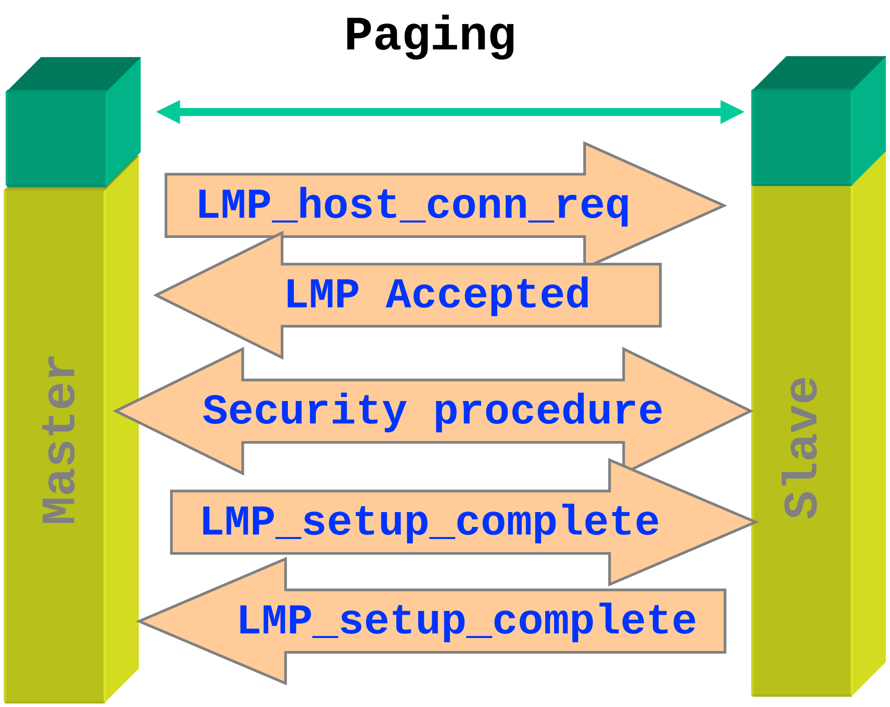
Low power mode (Park)



- Power saving + keep more than 7 slaves in a piconet
- Give up active member address, yet maintain synchronization
- Communication via broadcast LMP messages

Connection establishment & Security

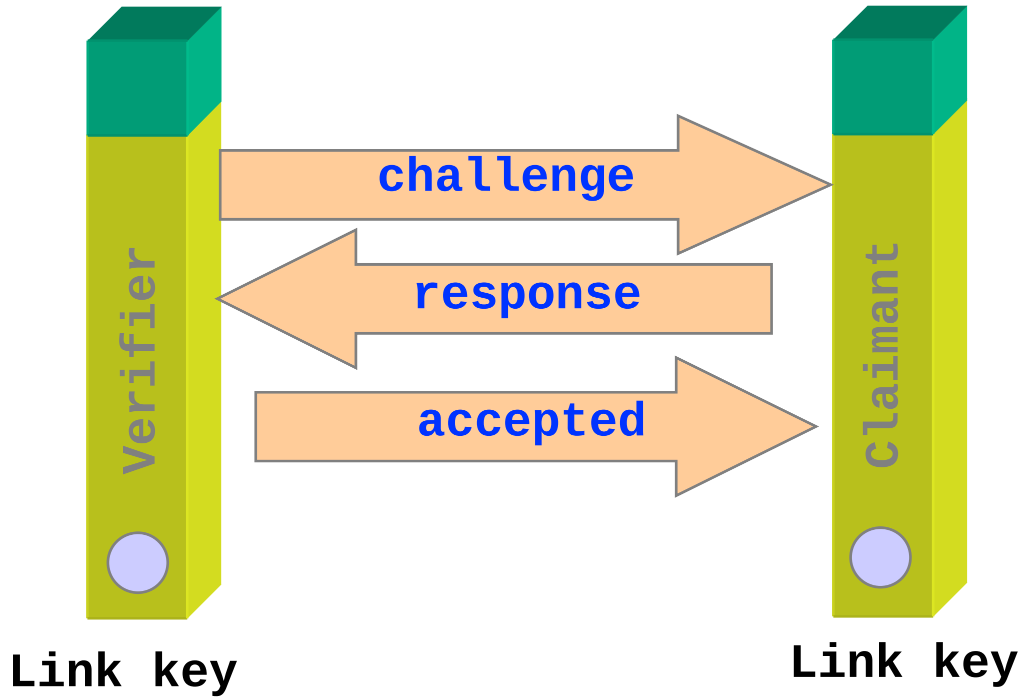
- Goals
  - Authenticated access
    - Only accept connections from trusted devices
  - Privacy of communication
    - prevent eavesdropping



- Constraints
  - Processing and memory limitations
    - $10 headsets, joysticks
  - Cannot rely on PKI
  - Simple user experience

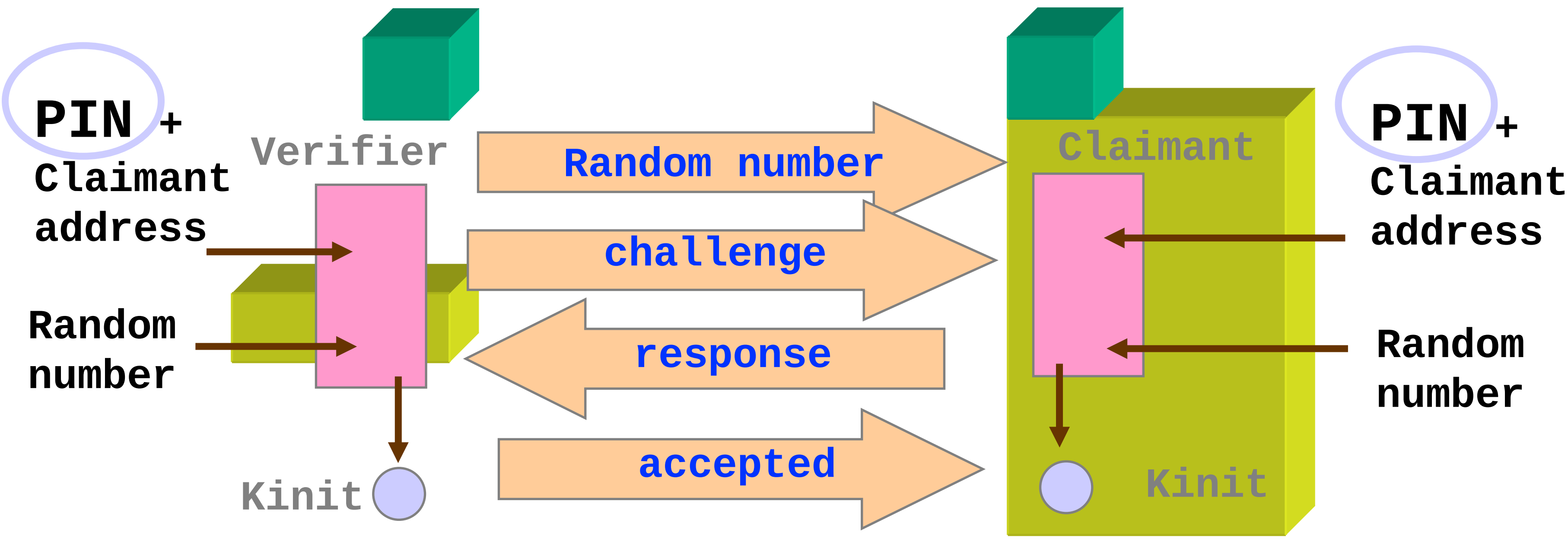
Authentication

- Authentication is based on link key (128 bit shared secret between two devices)
- How can link keys be distributed securely ?

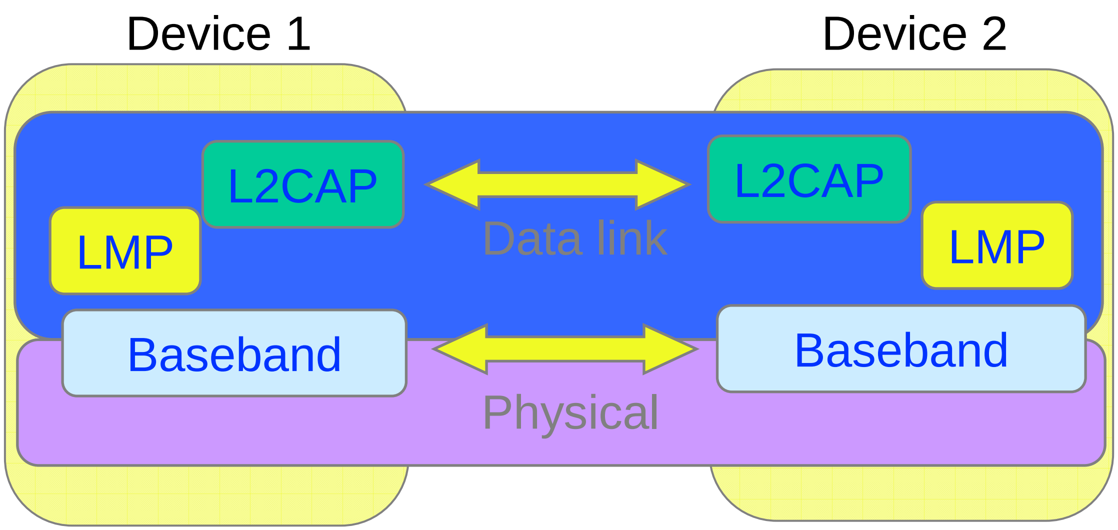


Pairing (key distribution)

- Pairing is a process of establishing a trusted secret channel between two devices (construction of initialization key K_{init})
- K_{init} is then used to distribute unit keys or combination keys

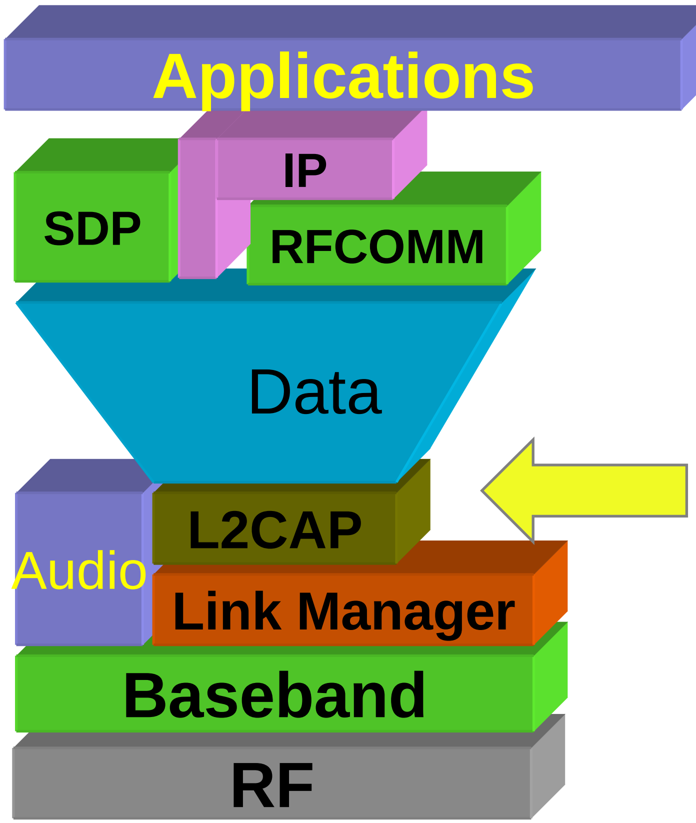


Link Manager Protocol Summary



- Piconet management
- Link configuration
  - Low power modes
  - QoS
  - Packet type selection
- Security: authentication and encryption

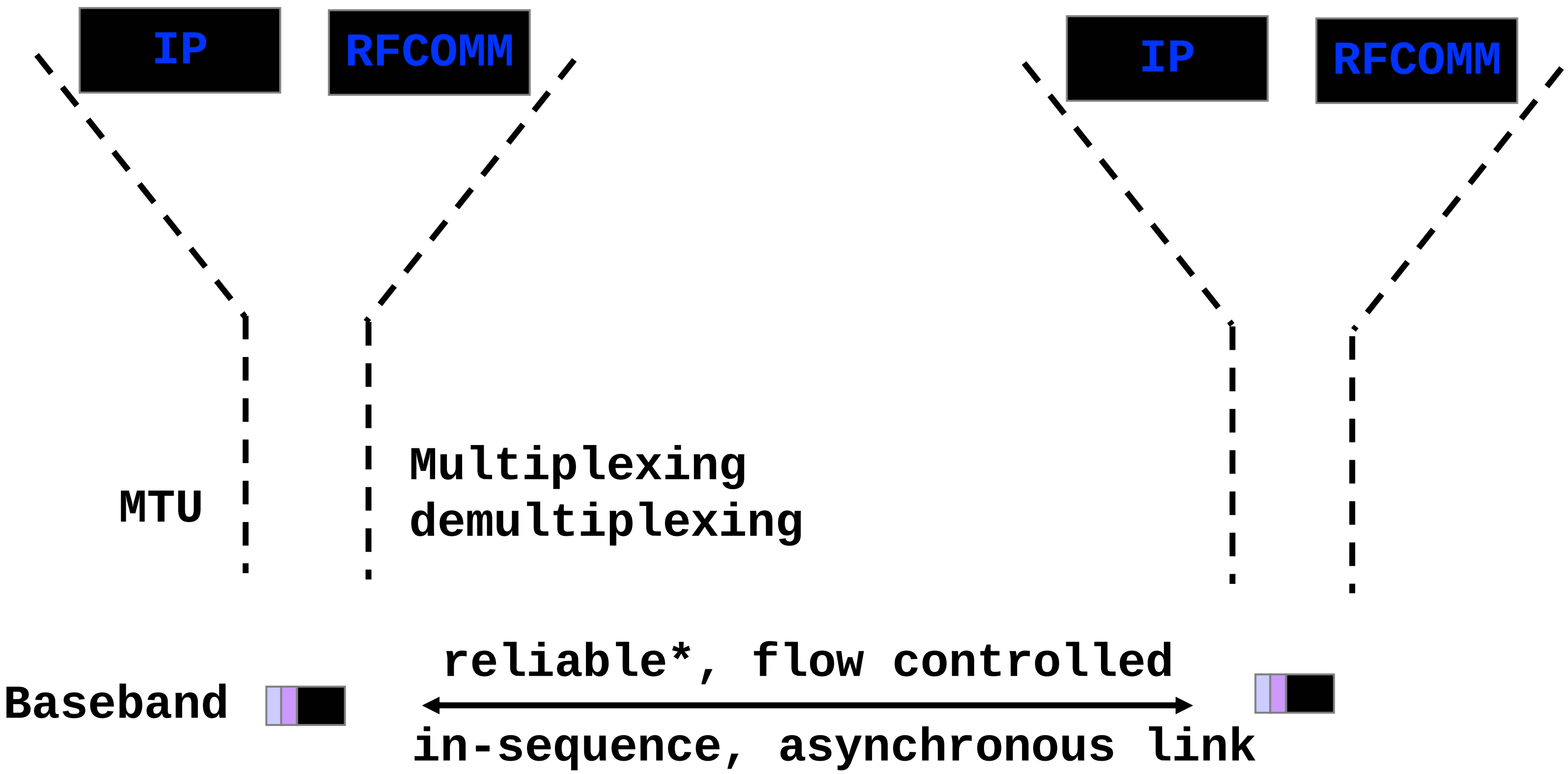
L2CAP



Logical Link Control and Adaptation Protocol

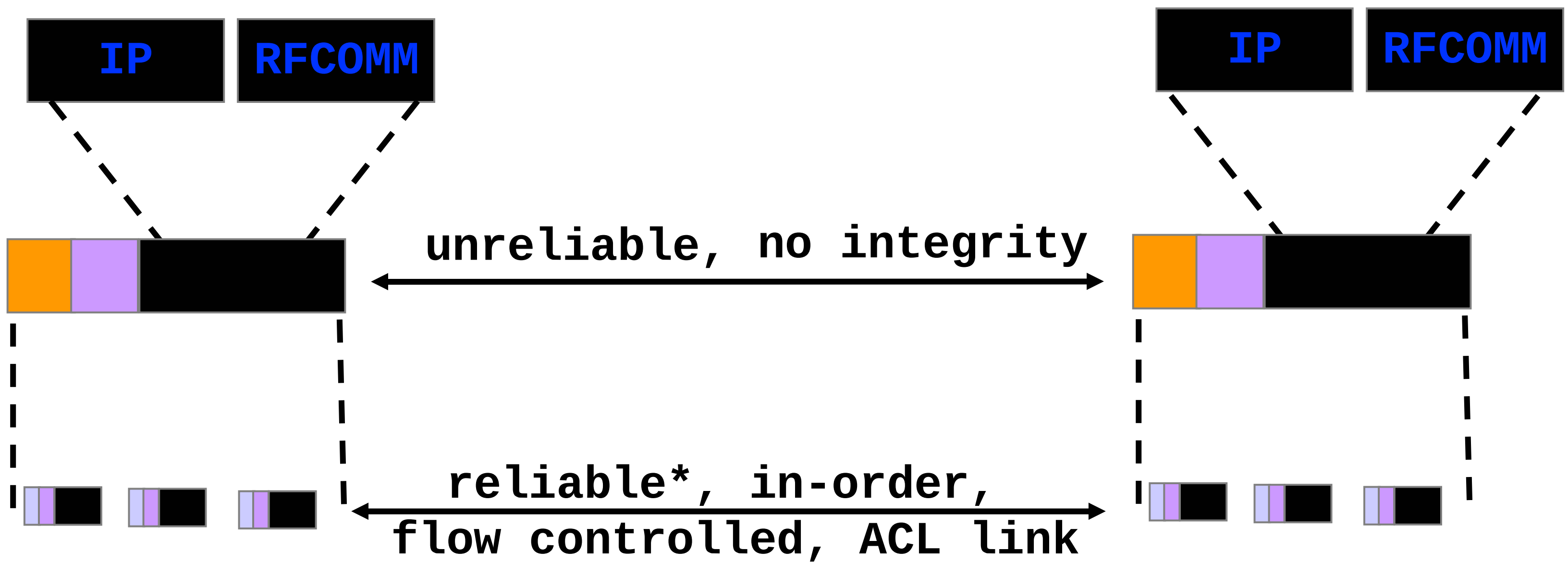
L2CAP provides
- Protocol multiplexing
- Segmentation and Re-assembly
- Quality of service negotiation

Why baseband isn't sufficient



- Baseband packet size is very small (17min, 339 max)
- No protocol-id field in the baseband header

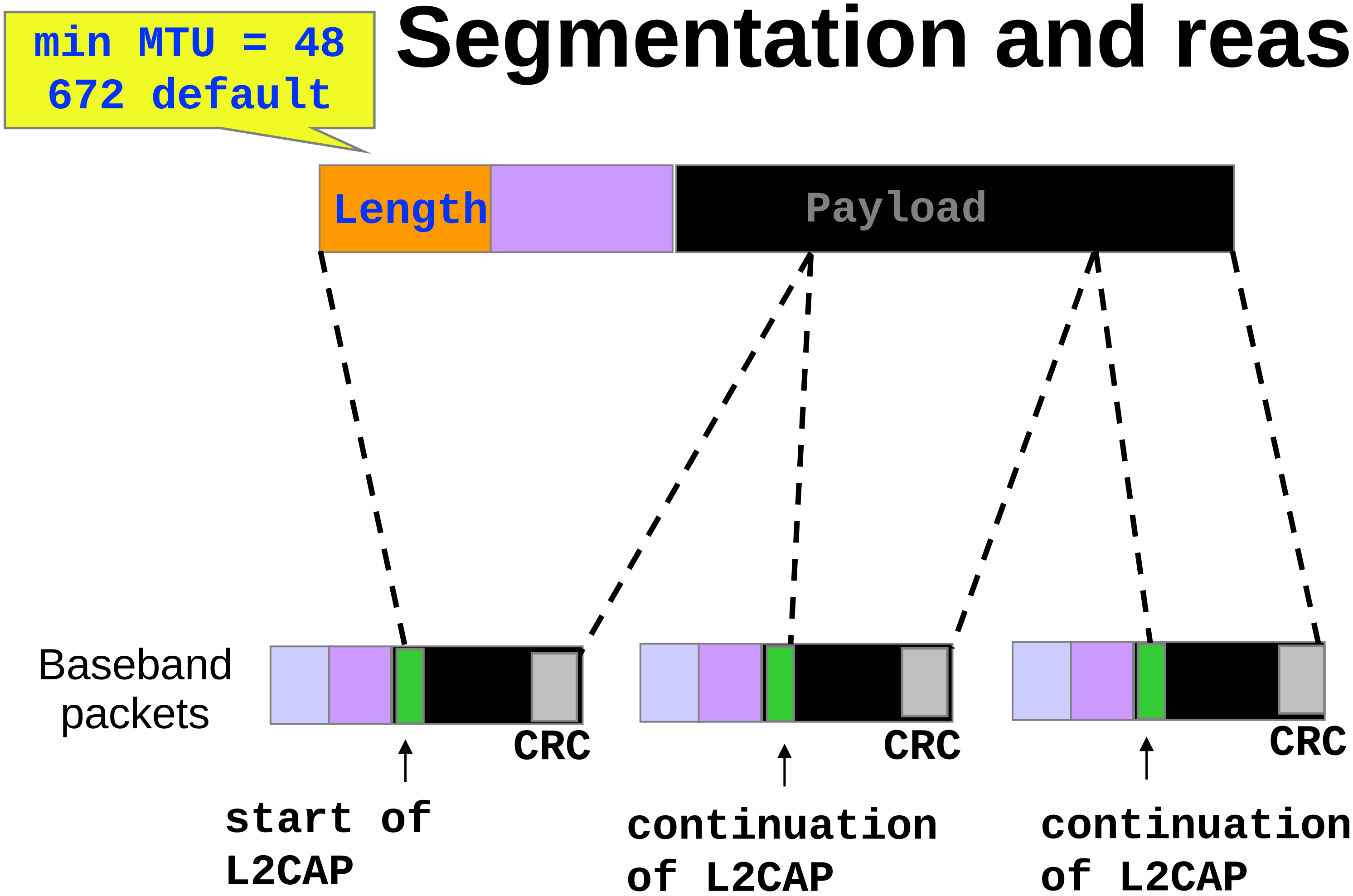
Need a multiprotocol encapsulation layer



Desired features
- Protocol multiplexing
- Segmentation and re-assembly
- Quality of service

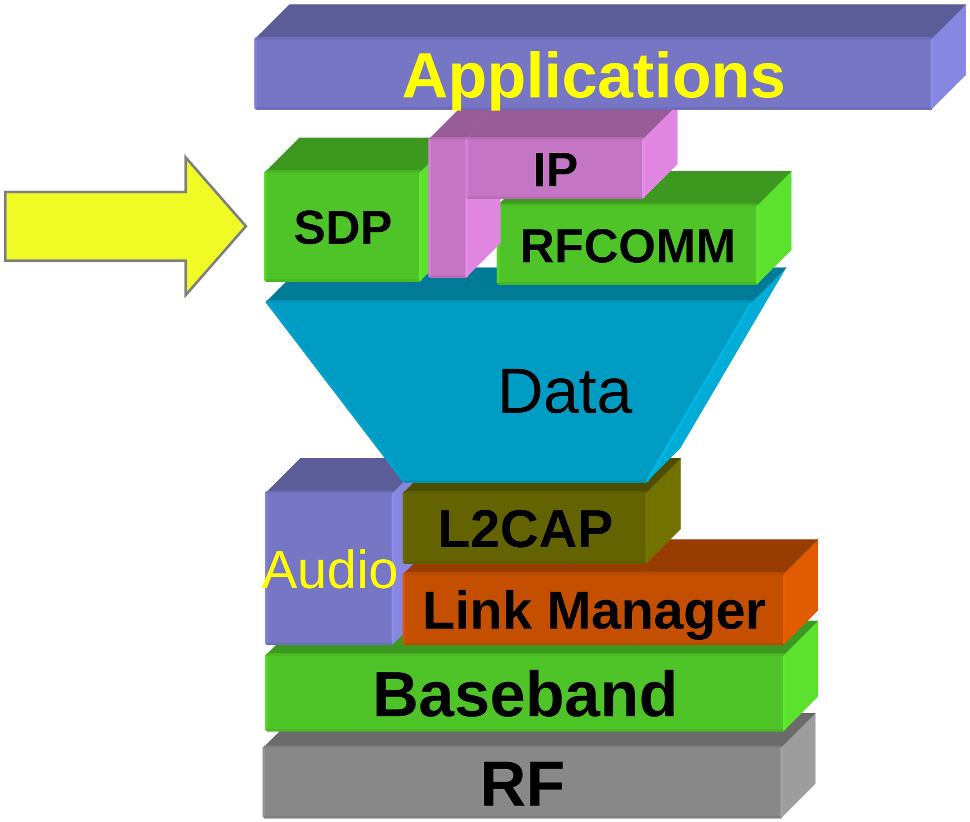
What about
- Reliability?
- Connection oriented or connectionless?
- integrity checks?

Segmentation and reassembly



- cannot cope with re-ordering or loss
- mixing of multiple L2CAP fragments not allowed
- If the start of L2CAP packet is not acked, the rest should be discarded

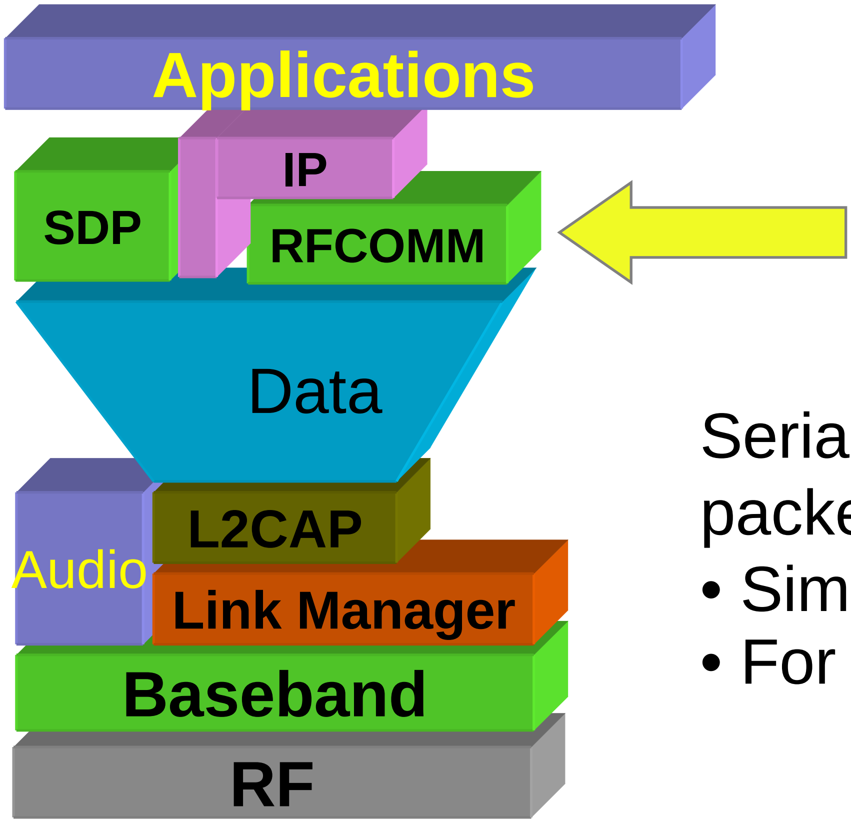
Bluetooth Service Discovery Protocol



Example usage of SDP

- Establish L2CAP connection to remote device
- Query for services
  - search for specific class of service, or
  - browse for services
- Retrieve attributes that detail how to connect to the service
- Establish a separate (non-SDP) connection to use the service

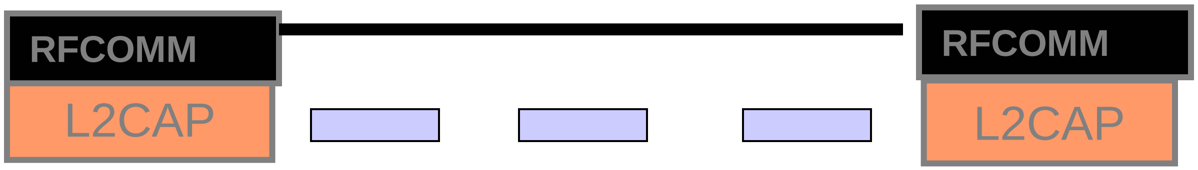
Serial Port Emulation using RFCOMM



Serial Port emulation on top of a packet oriented link

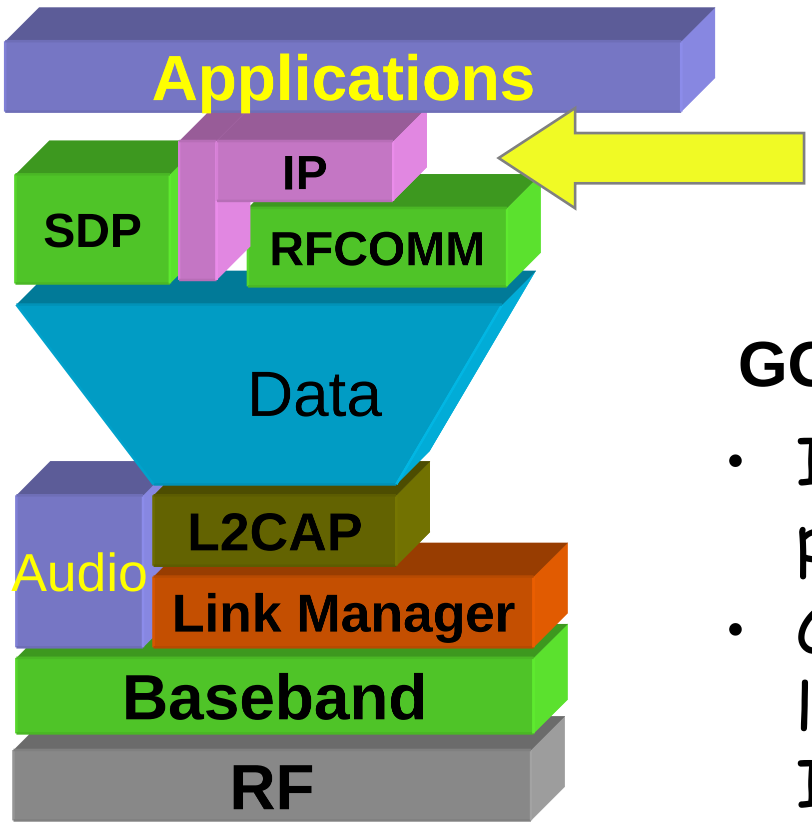
- Similar to HDLC
- For supporting legacy apps

Serial line emulation over packet based MAC



- Design considerations
  - framing: assemble bit stream into bytes and, subsequently, into packets
  - transport: in-sequence, reliable delivery of serial stream
  - control signals: RTS, CTS, DTR

IP over Bluetooth V 1.0

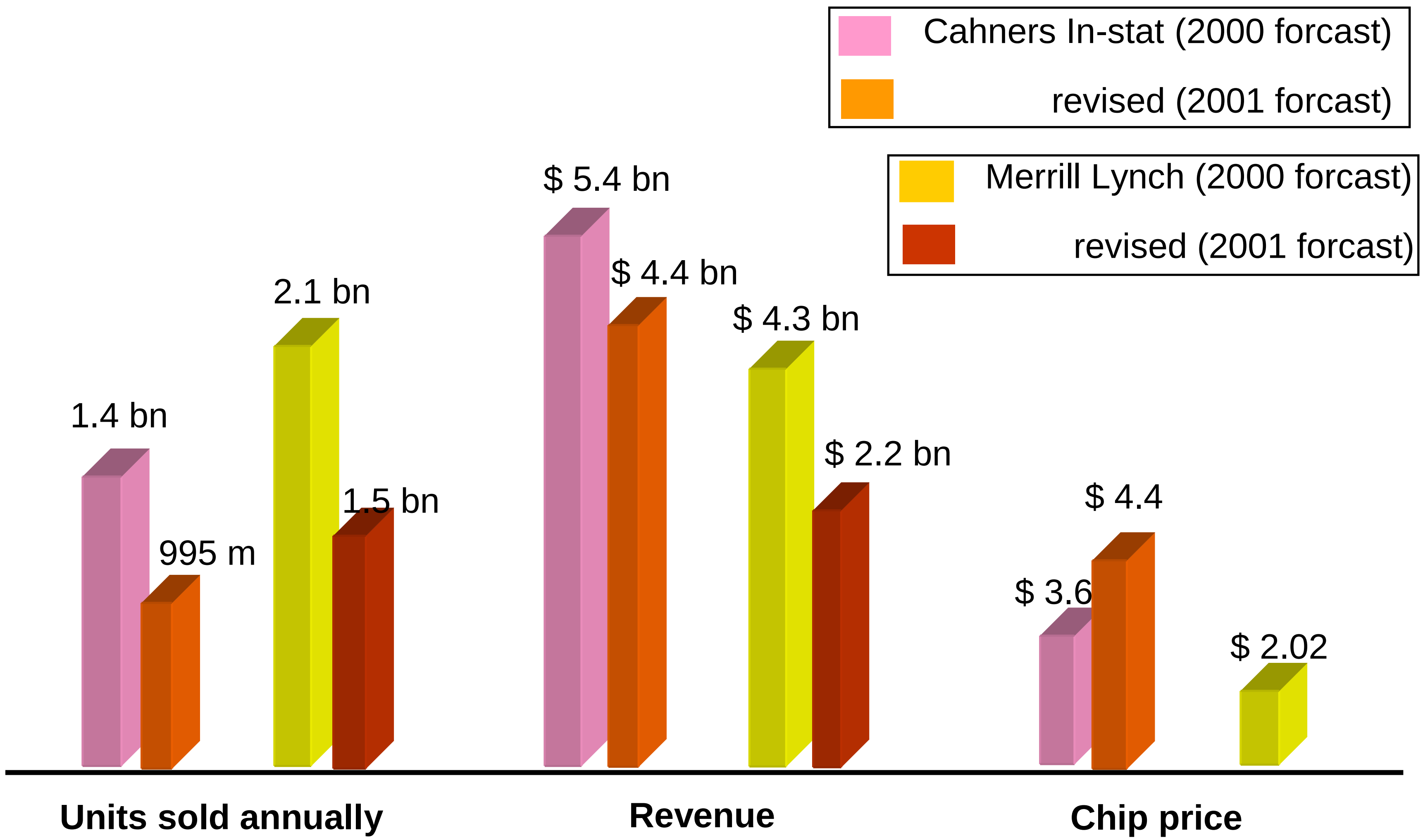


GOALS

- Internet access using cell phones
- Connect PDA devices & laptop computers to the Internet via LAN access points

Bluetooth Current Market Outlook

Market Forcasts for year 2005



Biggest challenges facing Bluetooth

- Interoperability
  - Always a challenge for any new technology
- Hyped up expectations
- Out of the box ease of use
- Cost target $5
  - well below that
- Critical mass
  - one billion devices sold by Nov.2006
- RF in silicon
- Conflicting interests – business and engineering

Value to carriers: Synchronization and Push

- More bits over the air
- Utilization of unused capacity during non-busy periods
- Higher barrier for switching service providers

Value to carriers: Cell phone as an IP gateway

Will Pilot and cell phone eventually merge?

- More bits over the air
- Enhanced user experience
  - Palmpilot has a better UI than a cell phone
- Growth into other vertical markets

Value to carriers: Call handoff

Threat or opportunity?

Cordless base

- More attractive calling plans
- Alleviate system load during peak periods
- Serve more users with fewer resources

ZigBee and 802.15.4
for
Personal Area
and
Sensor Networks

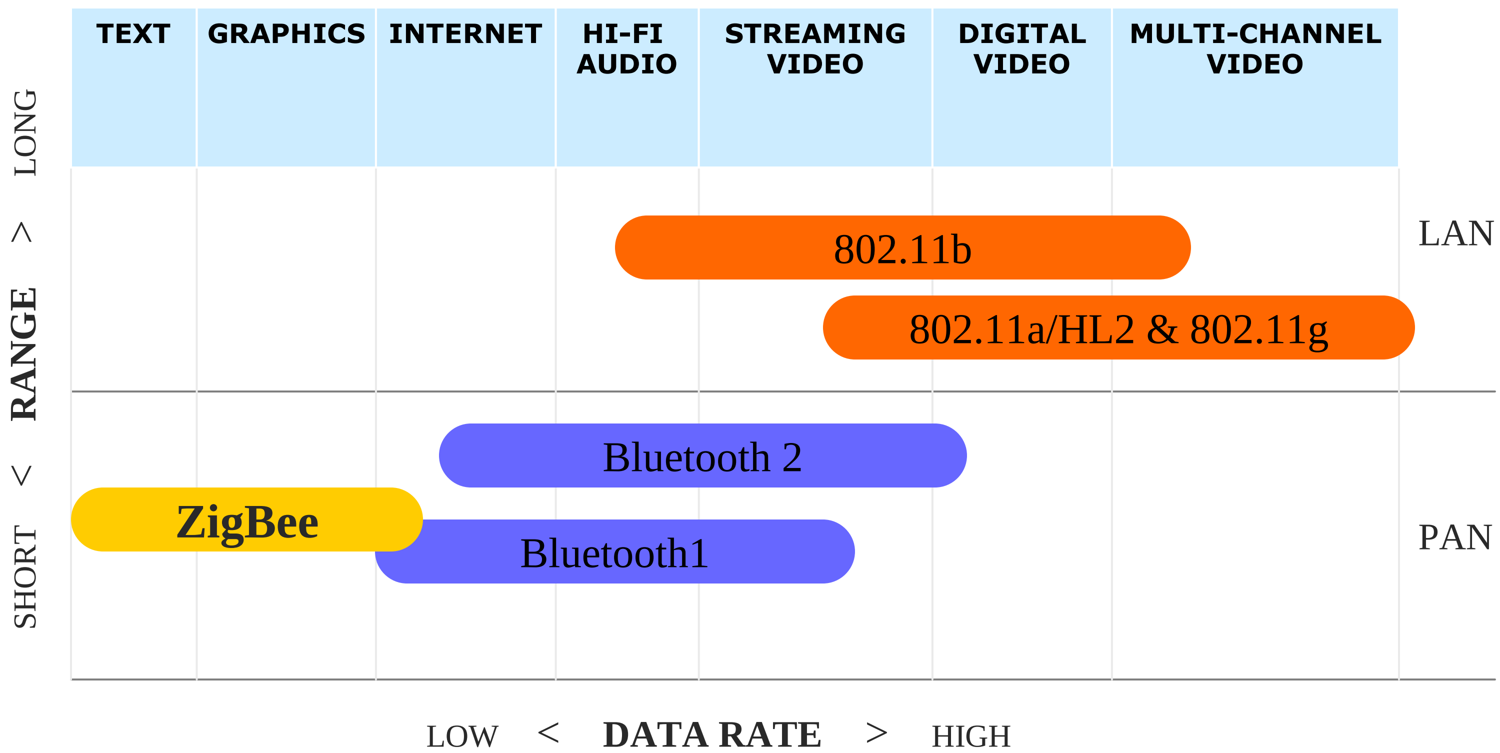
Outline

- ZigBee and 802.15.4 solution
- ZigBee vs Bluetooth
- Applications
- Conclusions

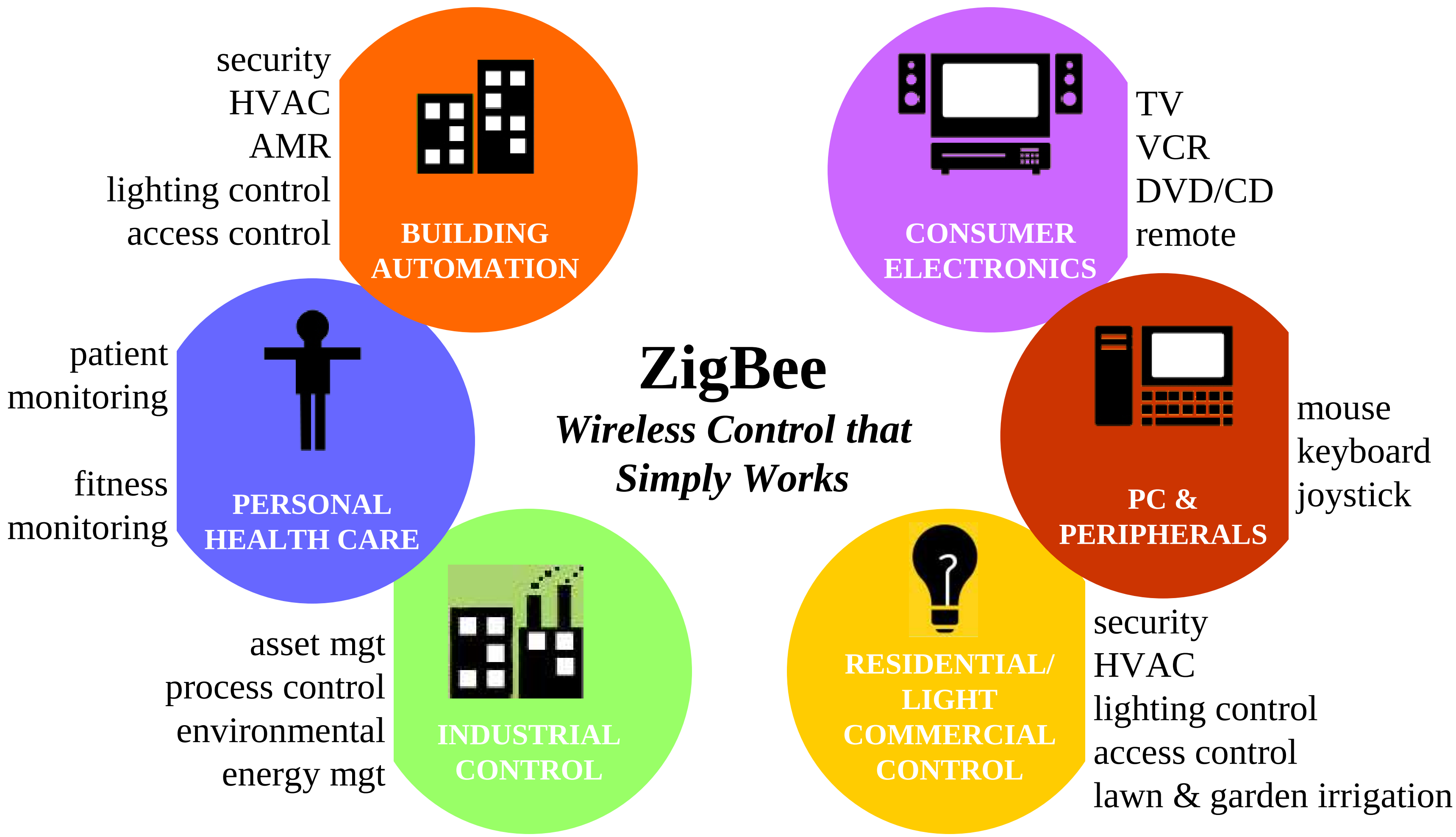
The ZigBee Alliance Solution

- Targeted at home and building automation and controls, consumer electronics, PC peripherals, medical monitoring, and toys
- Industry standard through application profiles running over IEEE 802.15.4 radios
- Primary drivers are simplicity, long battery life, networking capabilities, reliability, and cost
- Alliance provides interoperability and certification testing

The Wireless Market

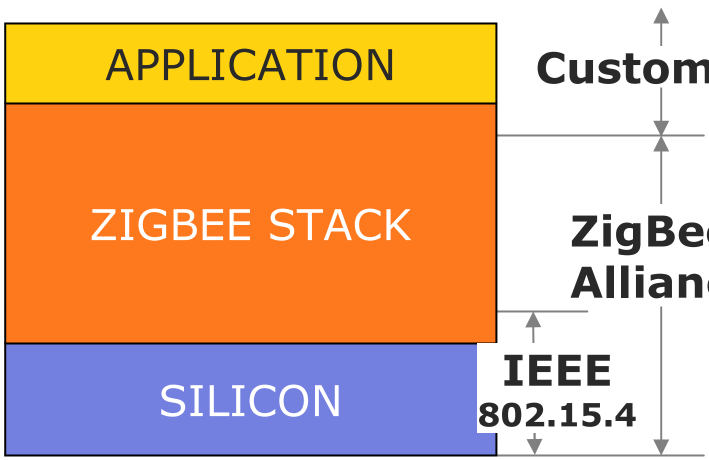


Applications



Development of the Standard

- ZigBee Alliance
  - 50+ companies: semiconductor mfrs, IP providers, OEMs, etc.
  - Defining upper layers of protocol stack: from network to application, including application profiles
  - First profiles published mid 2003
- IEEE 802.15.4 Working Group
  - Defining lower layers of protocol stack: MAC and PHY released May 2003



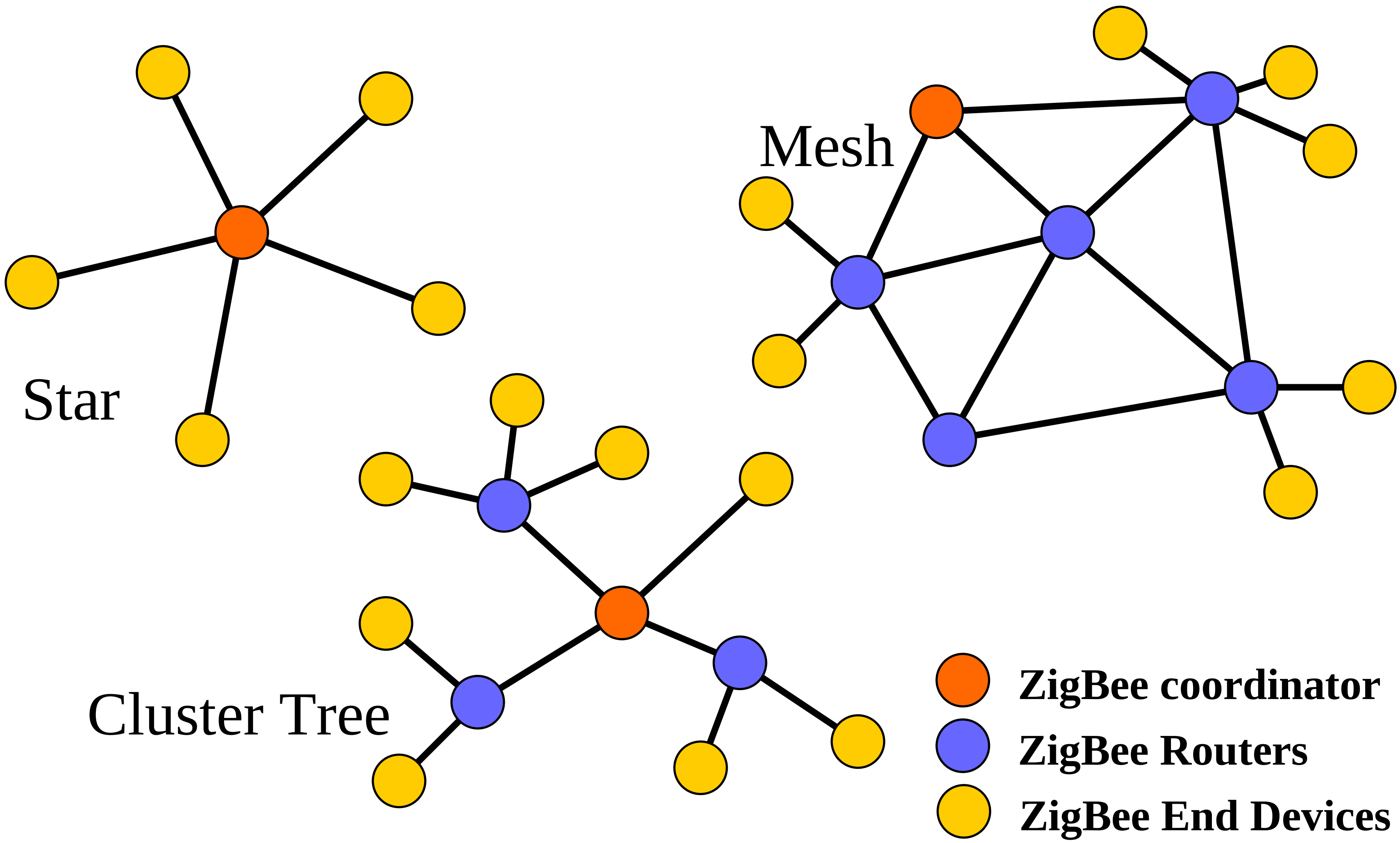
IEEE 802.15.4 Basics

- 802.15.4 is a simple packet data protocol for lightweight wireless networks
  - Channel Access is via Carrier Sense Multiple Access with collision avoidance and optional time slotting
  - Message acknowledgement and an optional beacon structure
  - Multi-level security
  - Three bands, 27 channels specified
    - 2.4 GHz: 16 channels, 250 kbps
    - 868.3 MHz : 1 channel, 20 kbps
    - 902-928 MHz: 10 channels, 40 kbps
  - Works well for
    - Long battery life, selectable latency for controllers, sensors, remote monitoring and portable electronics
  - Configured for maximum battery life, has the potential to last as long as the shelf life of most batteries

IEEE 802.15.4 Device Types

- Three device types
  - Network Coordinator
    - Maintains overall network knowledge; most sophisticated of the three types; most memory and computing power
  - Full Function Device
    - Carries full 802.15.4 functionality and all features
    - Additional memory, computing power make it ideal for a network router function
    - Could also be used in network edge devices (where the network touches the real world)
  - Reduced Function Device
    - Carriers limited (as specified by the standard) functionality to control cost and complexity
    - General usage will be in network edge devices
- All of these devices can be no more complicated than the transceiver, a simple 8-bit MCU and a pair of AAA batteries!

ZigBee Topology Models



MAC Options

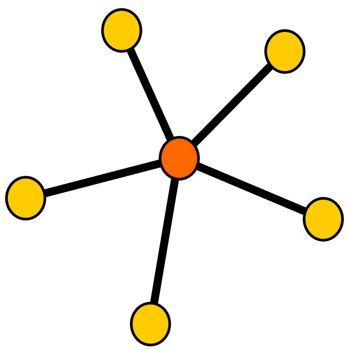
- Two channel access mechanisms
  - Non-beacon network
    - Standard CSMA-CA communications
    - Positive acknowledgement for successfully received packets
  - Beacon-enabled network
    - Superframe structure
      - For dedicated bandwidth and low latency
      - Set up by network coordinator to transmit beacons at predetermined intervals
        - » 15ms to 252sec (15.38ms*2n where $0 \le n \le 14$)
        - » 16 equal-width time slots between beacons
        - » Channel access in each time slot is contention free

Non-Beacon vs Beacon Modes

- Non-Beacon Mode
  - A simple, traditional multiple access system used in simple peer and near-peer networks
  - Think of it like a two-way radio network, where each client is autonomous and can initiate a conversation at will, but could interfere with others unintentionally
  - However, the recipient may not hear the call or the channel might already be in use
- Beacon Mode
  - A very powerful mechanism for controlling power consumption in extended networks like cluster tree or mesh
  - Allows all clients in a local piece of the network the ability to know when to communicate with each other
  - Here, the two-way radio network has a central dispatcher who manages the channel and arranges the calls
- As you'll see, the primary value will be in system power consumption

Example of Non-Beacon Network

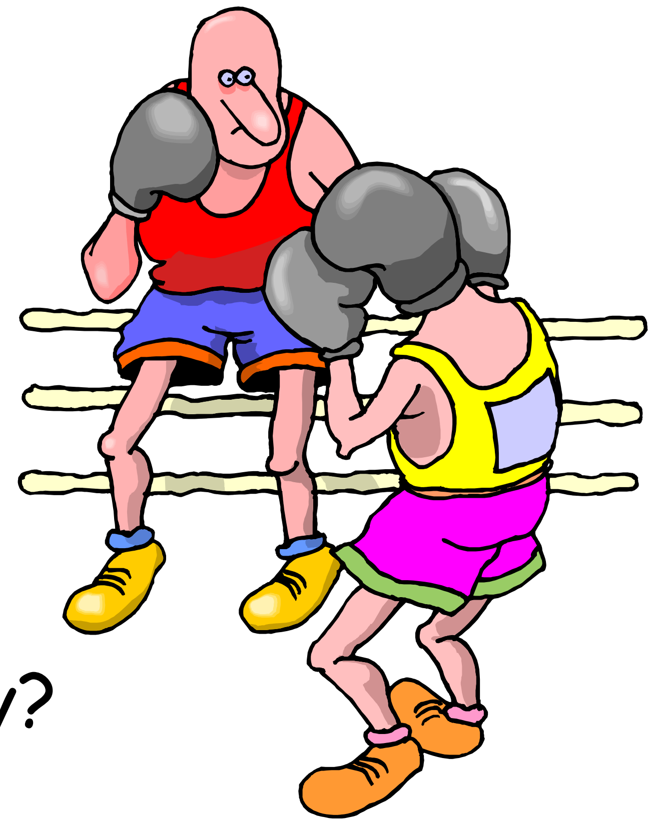
- Commercial or home security
  - Client units (intrusion sensors, motion detectors, glass break detectors, standing water sensors, loud sound detectors, etc)
    - Sleep 99.999% of the time
    - Wake up on a regular yet random basis to announce their continued presence in the network ("12 o'clock and all's well")
    - When an event occurs, the sensor wakes up instantly and transmits the alert ("Somebody's on the front porch")
  - The ZigBee Coordinator, mains powered, has its receiver on all the time and so can wait to hear from each of these station.



Example of Beacon Network

- Now make the ZigBee Coordinator battery-operated also
  - All units in system are now battery-operated
  - Client registration to the network
    - Client unit when first powered up listens for the ZigBee Coordinator's network beacon (interval between 0.015 and 252 seconds)
    - Register with the coordinator and look for any messages directed to it
    - Return to sleep, awaking on a schedule specified by the ZigBee Coordinator
    - Once client communications are completed, ZigBee coordinator also returns to sleep

ZigBee and Bluetooth



Competitive or Complementary?

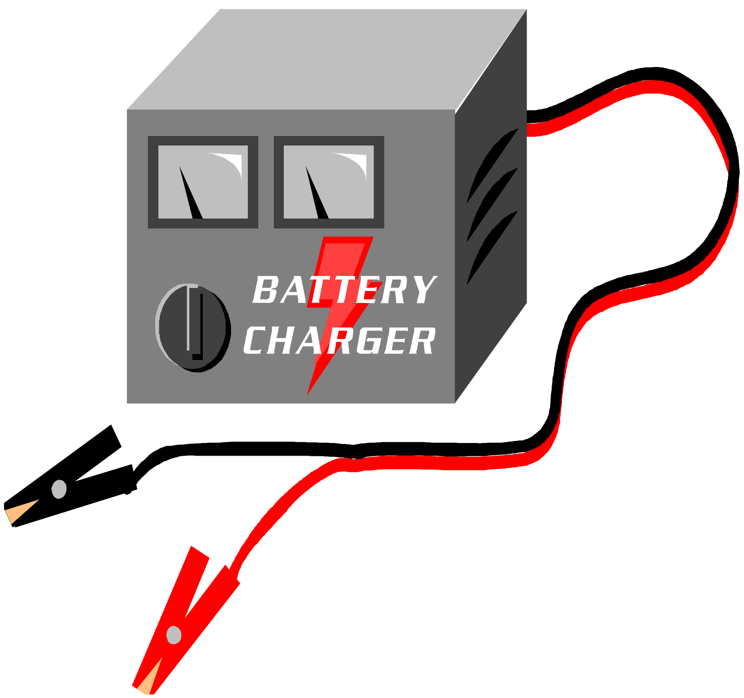
ZigBee and Bluetooth

Optimized for different applications

- ZigBee
  - Smaller packets over large network
  - Mostly Static networks with many, infrequently used devices
  - Home automation, toys, remote controls, etc.
- Bluetooth
  - Larger packets over small network
  - Ad-hoc networks
  - File transfer
  - Screen graphics, pictures, hands-free audio, Mobile phones, headsets, PDAs, etc.

ZigBee and Bluetooth

Address Different Needs

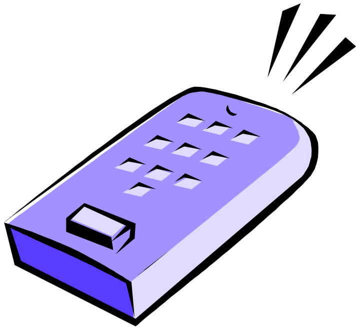


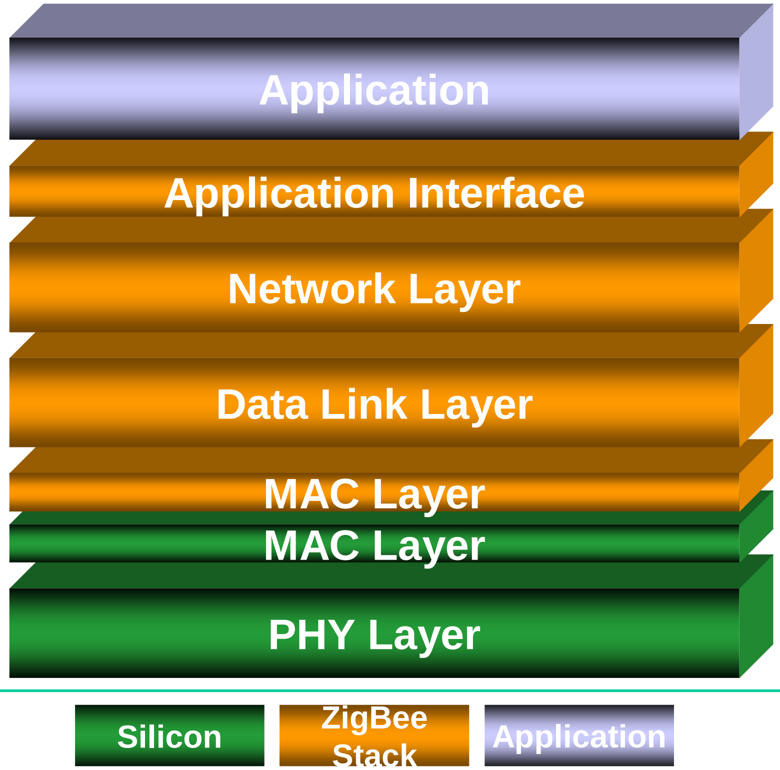
- Bluetooth is a cable replacement for items like Phones, Laptop Computers, Headsets
- Bluetooth expects regular charging
  - Target is to use <10% of host power

ZigBee and Bluetooth

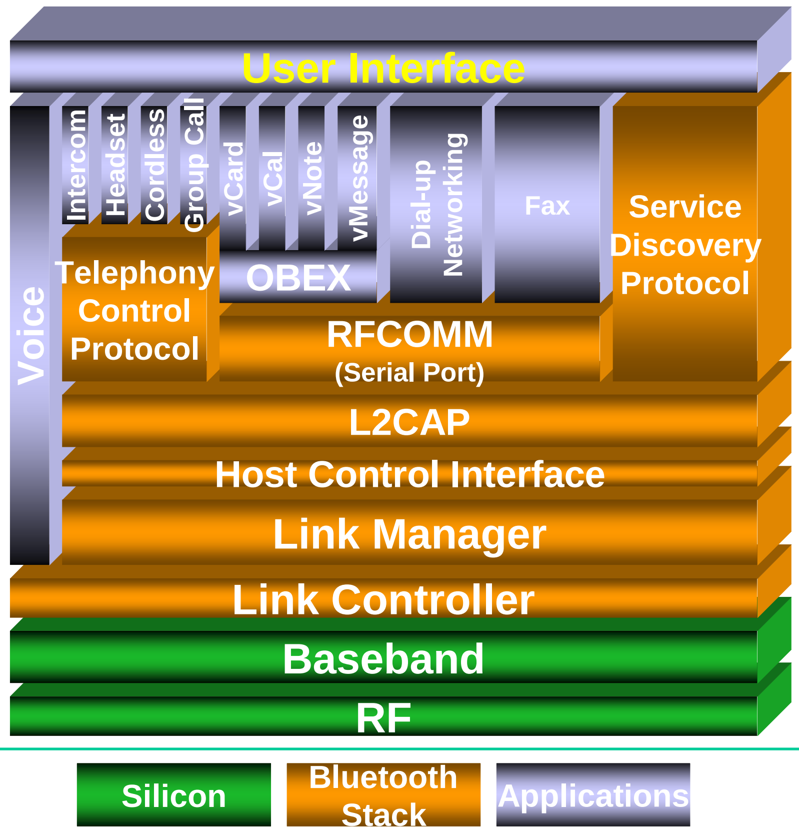
Address Different Needs

- ZigBee is better for devices where the battery is 'rarely' replaced
  - Targets are :
    - Tiny fraction of host power
    - New opportunities where wireless not yet used





Zigbee



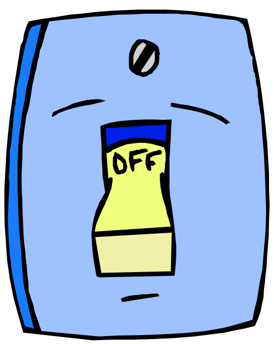
Bluetooth

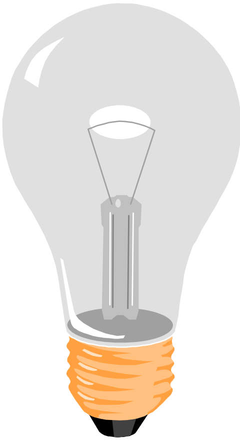
Protocol Stack Comparison

An Application Example

Battery Life & Latency in a Light Switch

- **Wireless Light switch**
  - Easy for Builders to Install
- **A Bluetooth Implementation would:**
  - use the inquiry procedure to find the light each time the switch was operated.





Light switch using Bluetooth

- **Inquiry procedure to locate light each time switch is operated**
  - Bluetooth 1.1 = up to 10 seconds typical
  - Bluetooth 1.2 = several seconds even if optimized

  - **Unacceptable latency**

Light switch using ZigBee

- With DSSS interface, only need to perform CSMA before transmitting
  - Only 200 μs of latency
  - Highly efficient use of battery power

ZigBee offers longer battery life and lower latency than a Bluetooth equivalent

Wireless Keyboard

- Battery-operated keyboard
  - Part of a device group including a mouse or trackball, sketchpad, other human input devices
  - Each device has a unique ID
  - Device set includes a USB to wireless interface dongle
    - Dongle powered continuously from computer
  - Keyboard does not have ON/OFF switch
  - Power modes
    - Keyboard normally in lowest power mode
    - Upon first keystroke, wakes up and stays in a "more aware" state until 5 seconds of inactivity have passes, then transitions back to lowest power mode

Keyboard Usage

- Typing Rates
  - 10, 25, 50, 75 and 100 words per minute
- Typing Pattern
  - Theoretical: Type continuously until battery is depleted
    - Measures total number of hours based upon available battery energy

Wireless Keyboard Using 802.15.4

- 802.15.4 Operation Parameters
  - Star network
  - Non-beacon mode (CSMA-CA)
  - USB Dongle is a PAN Coordinator Full Functional Device (FFD)
  - Keyboard is a Reduced Function Device (RFD)
  - Power Modes
    - Quiescent Mode used for lowest power state
      - » First keystroke latency is approx 25ms
    - Idle mode used for "more aware" state
      - » Keystroke latency 8-12 ms latency

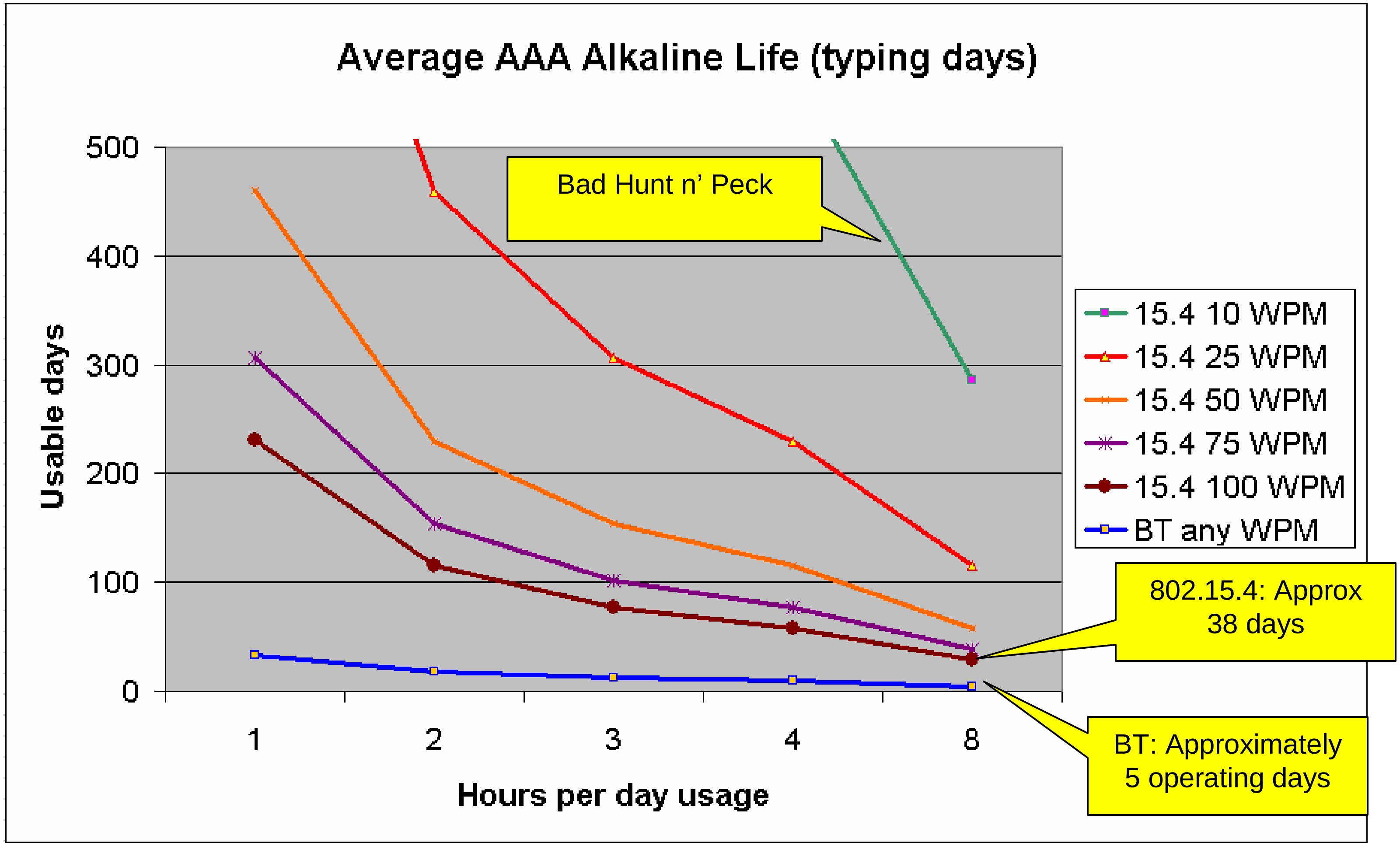
Wireless Keyboard Using 802.15.4

- 802.15.4 Chipset Parameters
  - Motorola 802.15.4 Transceiver and HCS08 MCU
  - Battery operating voltage 2.0 – 3.6 V
    - All required regulation internal to ICs
    - Nearly all available energy usable with end of life voltage at 2.0 volts

Wireless Keyboard Using Bluetooth

- Bluetooth Operation Parameters
  - Piconet network
  - USB Dongle is piconet Master
  - Keyboard is a piconet Slave
  - Power Modes
    - Park mode used for lowest power state
      - » 1.28 second park interval
      - » First keystroke latency is 1.28s
    - Sniff mode used for "more aware" state
      - » 15ms sniff interval
      - » 15ms latency

BT vs. 15.4 Keyboard Comparison



Why BT and ZigBee are so different?

- Bluetooth and 802.15.4 transceiver physical characteristics are very similar
- Protocols are substantially different and designed for different purposes
- 802.15.4 designed for low to very low duty cycle static and dynamic environments with many active nodes
- Bluetooth designed for high QoS, variety of duty cycles, moderate data rates in fairly static simple networks with limited active nodes
- Bluetooth costs and system performance are in line with 3rd and 4th generation products hitting market while 1st generation 15.4 products will be appearing only late this year