# Ah-Hoc, PAN, WSN, Meshes ...

→ **Introduction**
→ **Bluetooth**
→ **Zigbee**
→ **Ad-Hoc: Routing and Topology Mgmnt**
→ **Meshes: Applications and Specific Problems**

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# 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

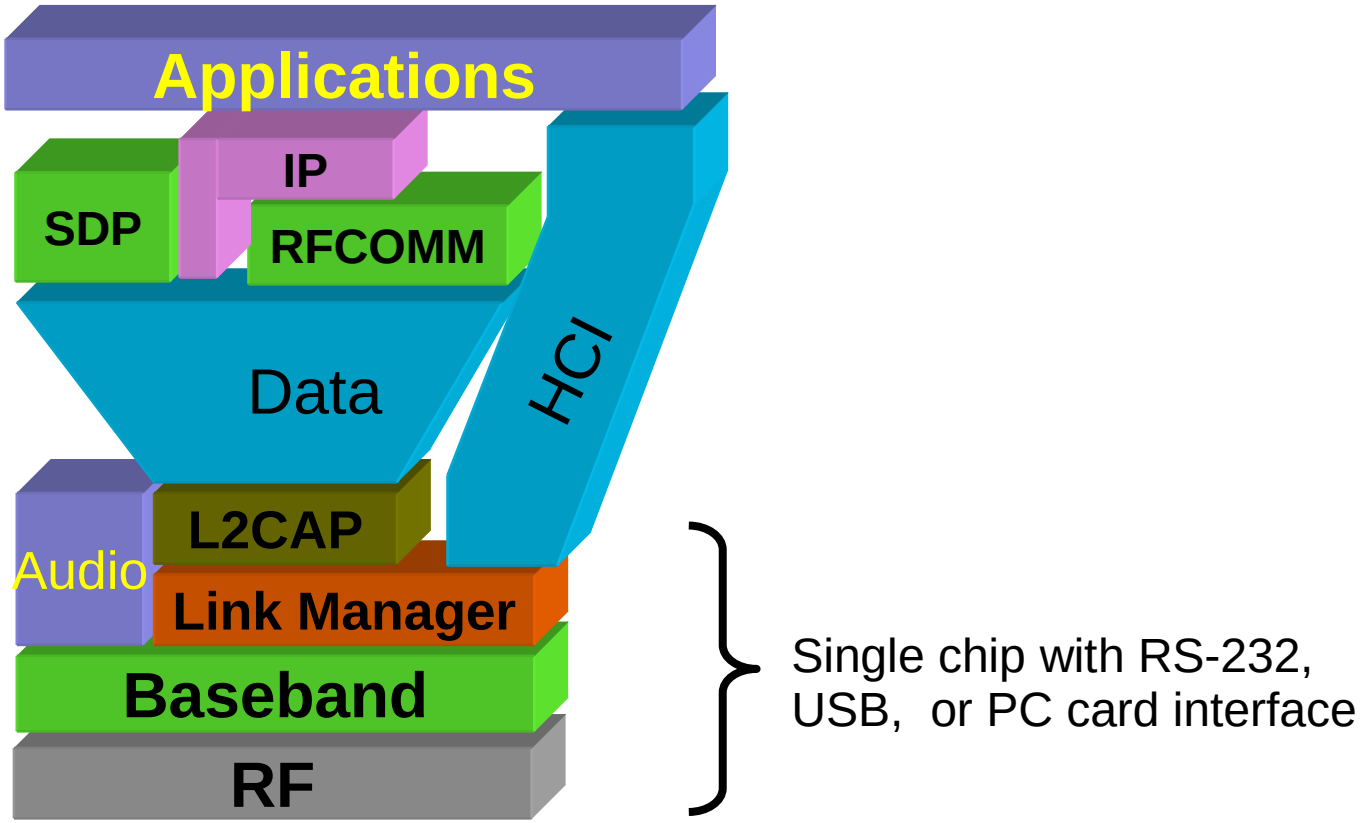
- 802.11
  - Do you know it ☺
- Bluetooth (802.15.1)
  - Master/Slave architecture
  - Optimized for low bandwidth, real time communications
- ZigBee (802.15.4)
  - Meshed architecture
  - Low power consumption
- All use the same ISM bands

# 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?

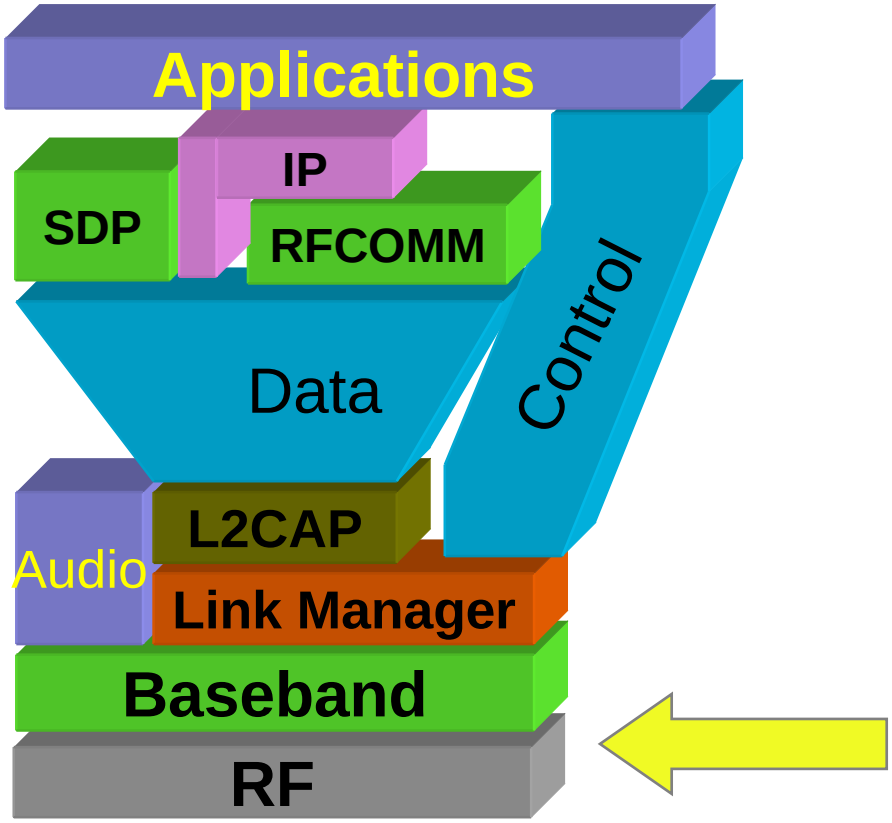
# Bluetooth

# Bluetooth Specifications

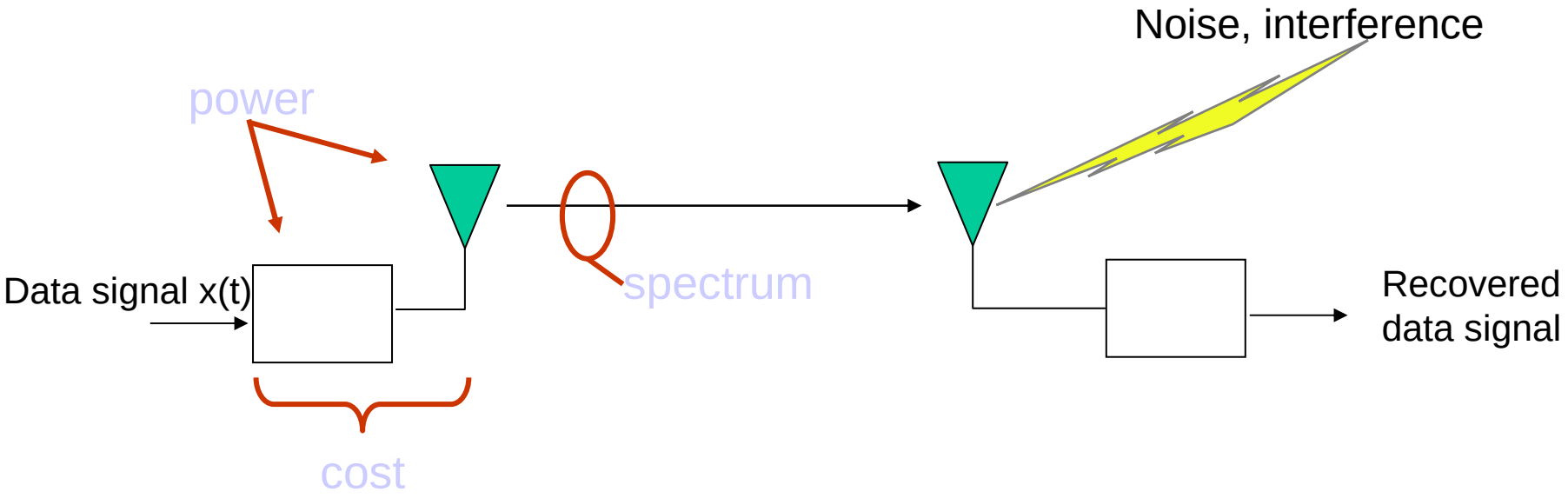



- A hardware/software/protocol description
- An application framework

# Bluetooth Radio Specification



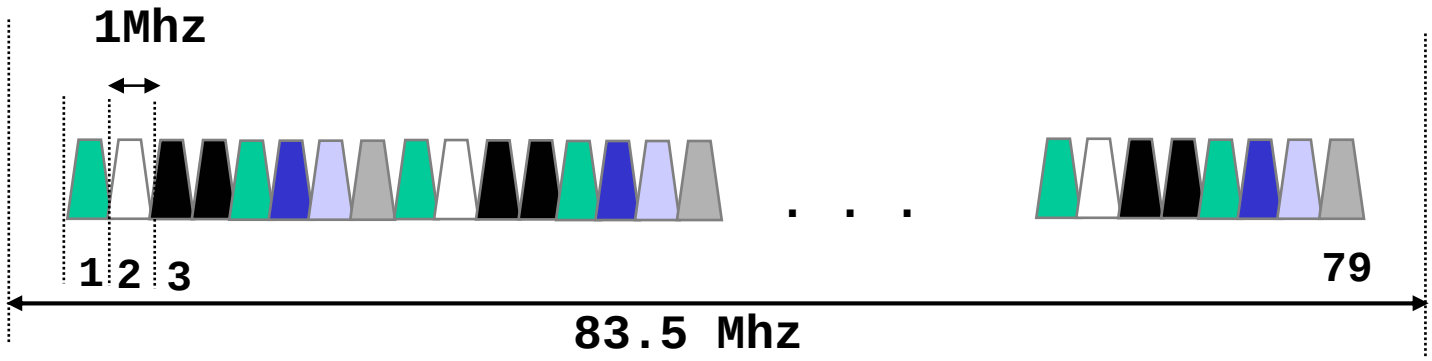
# Design considerations




Goal

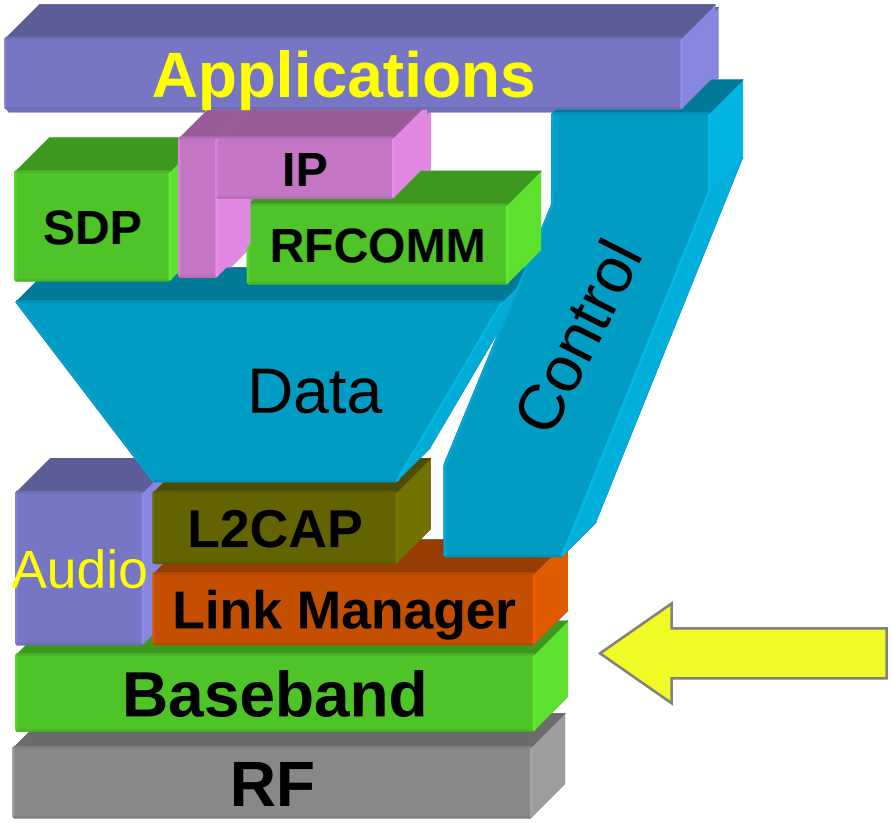
- high bandwidth
- conserve battery power
- cost < $10

# 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)

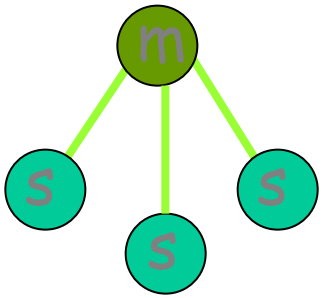
# Baseband


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

# Bluetooth Physical link

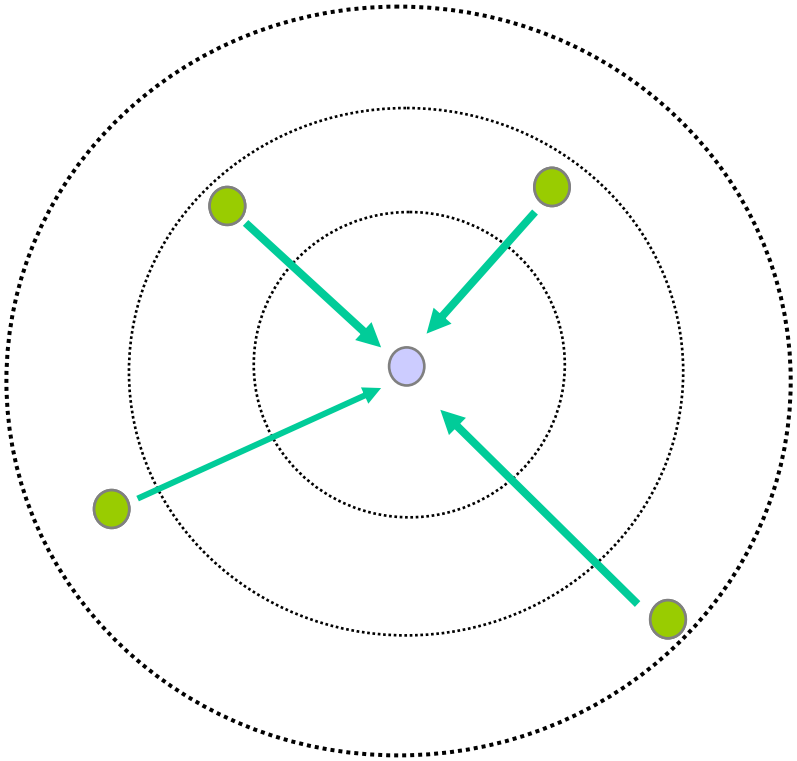
- Point to point link
  - master - slave relationship
  - radios can function as masters or slaves


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



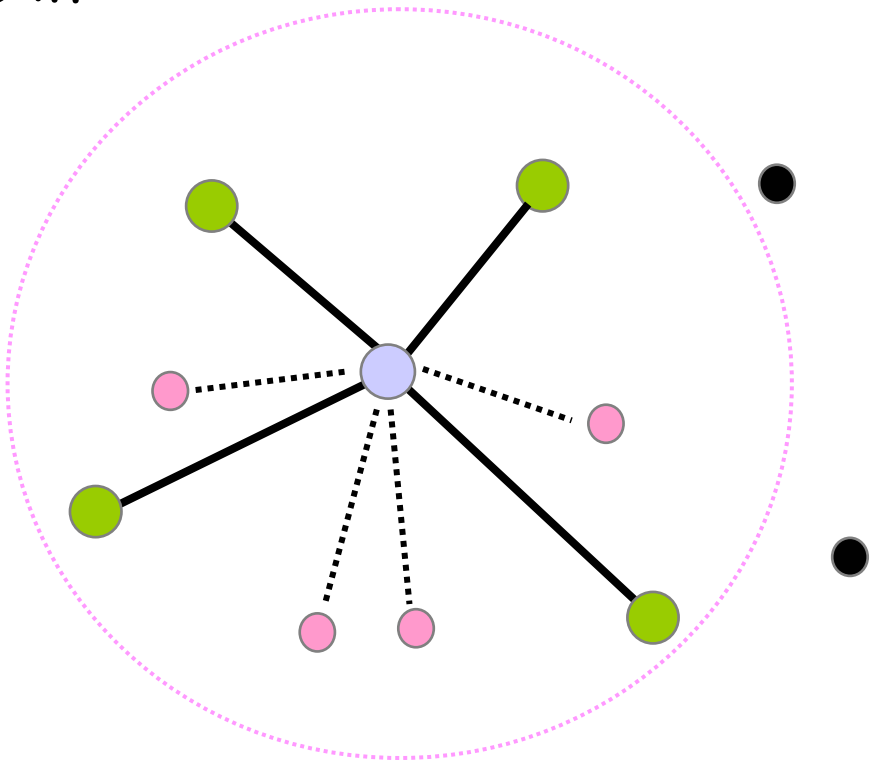
# Connection Setup

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



# Piconet formation

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



Master

Active Slave

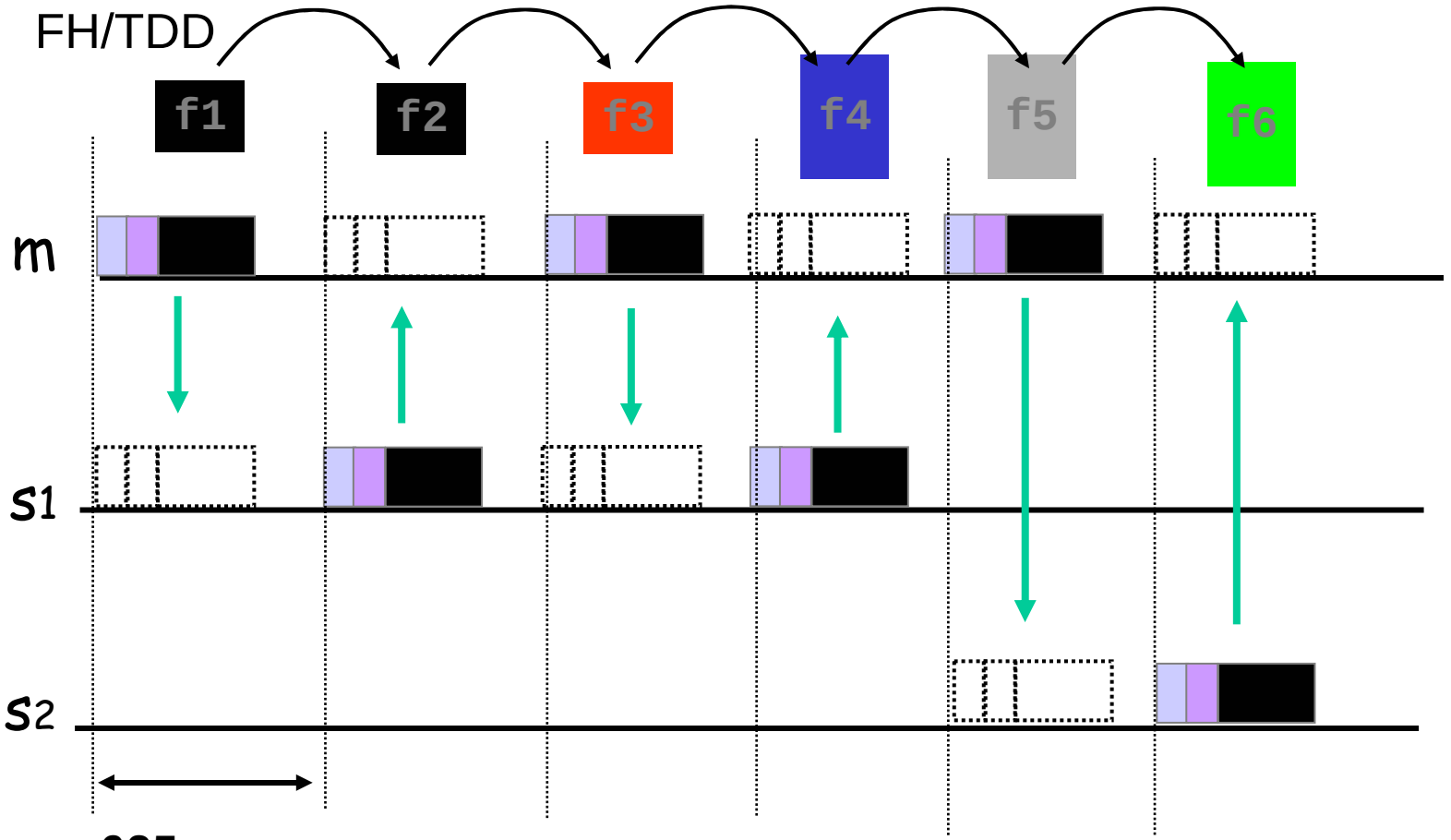
Parked Slave

Standby

# Addressing

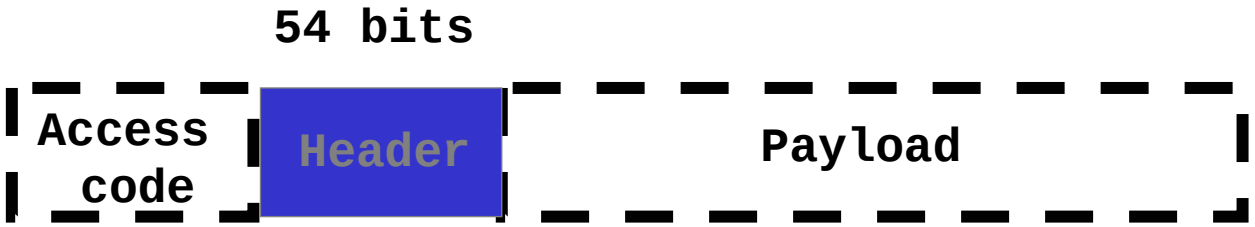
- Bluetooth device address (BD_ADDR)
  - 48 bit IEEE MAC address
- Active Member address (AM_ADDR)
  - 3 bits active slave address
  - all zero broadcast address
- Parked Member address (PM_ADDR)
  - 8 bit parked slave address

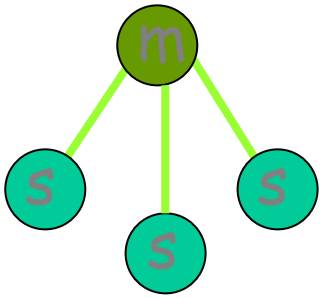
# Piconet channel




**1600 hops/sec**

# Packet Header



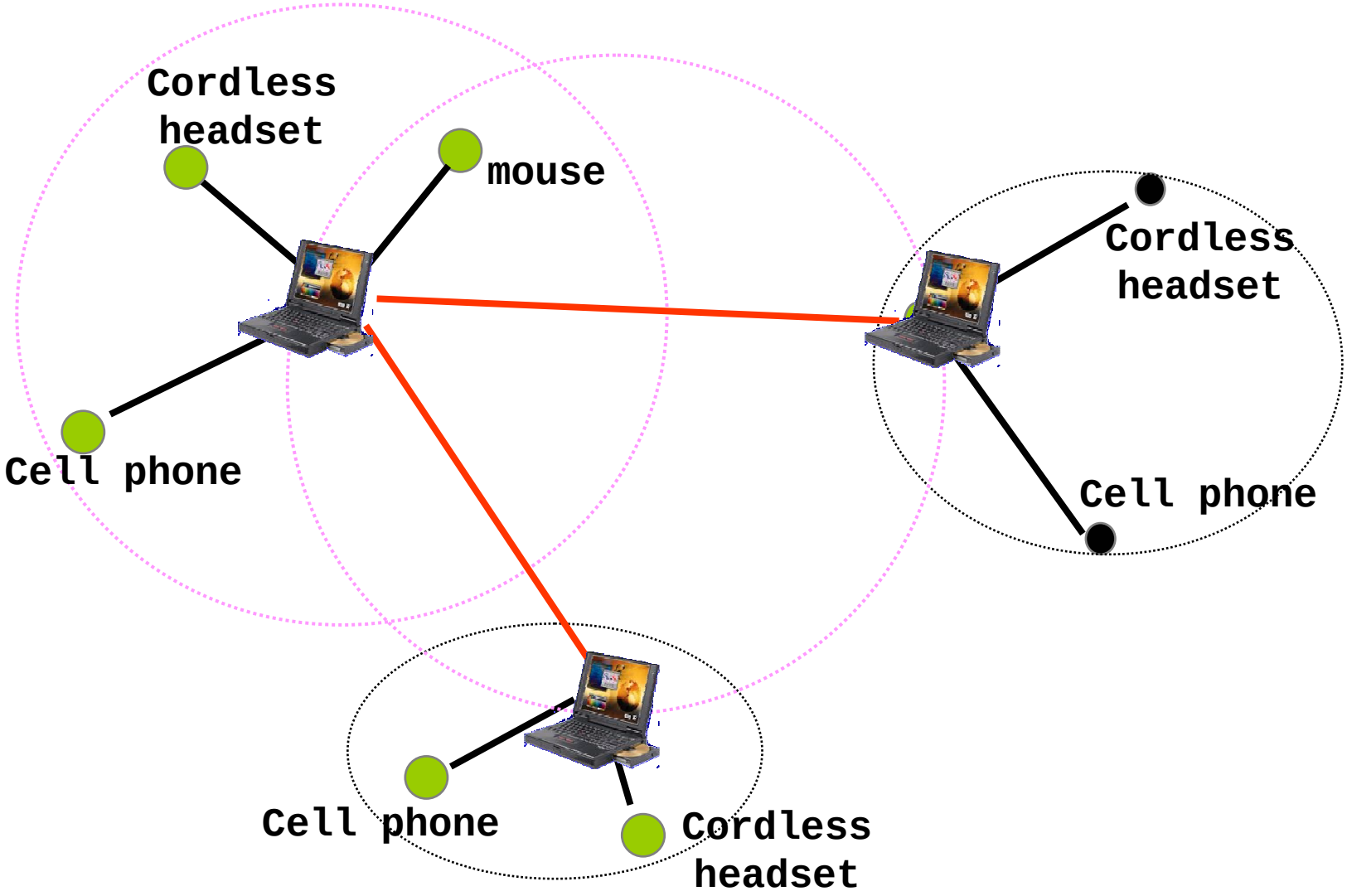

**Purpose**

- 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

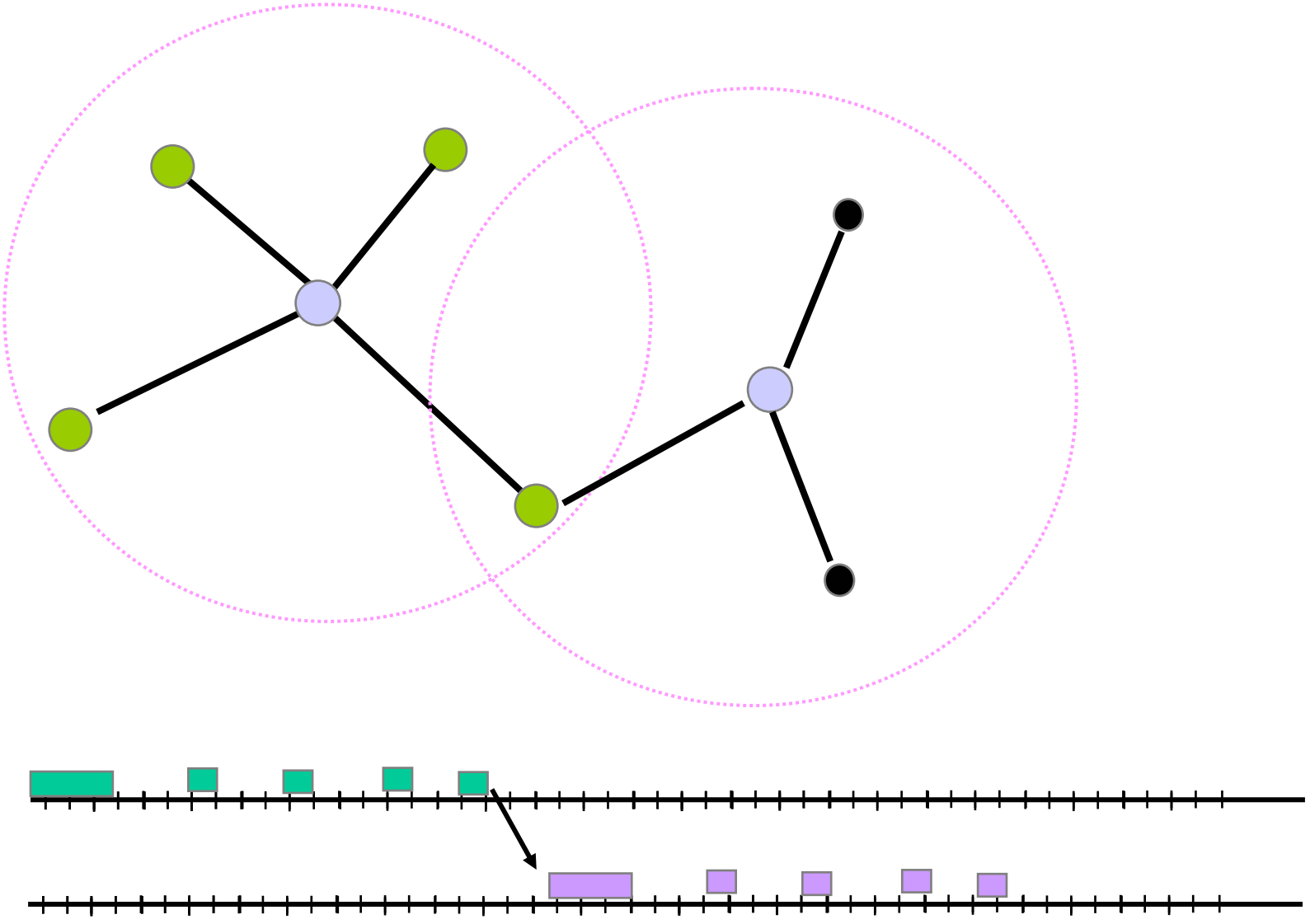
**total 18 bits**

Encode with 1/3 FEC to get 54 bits

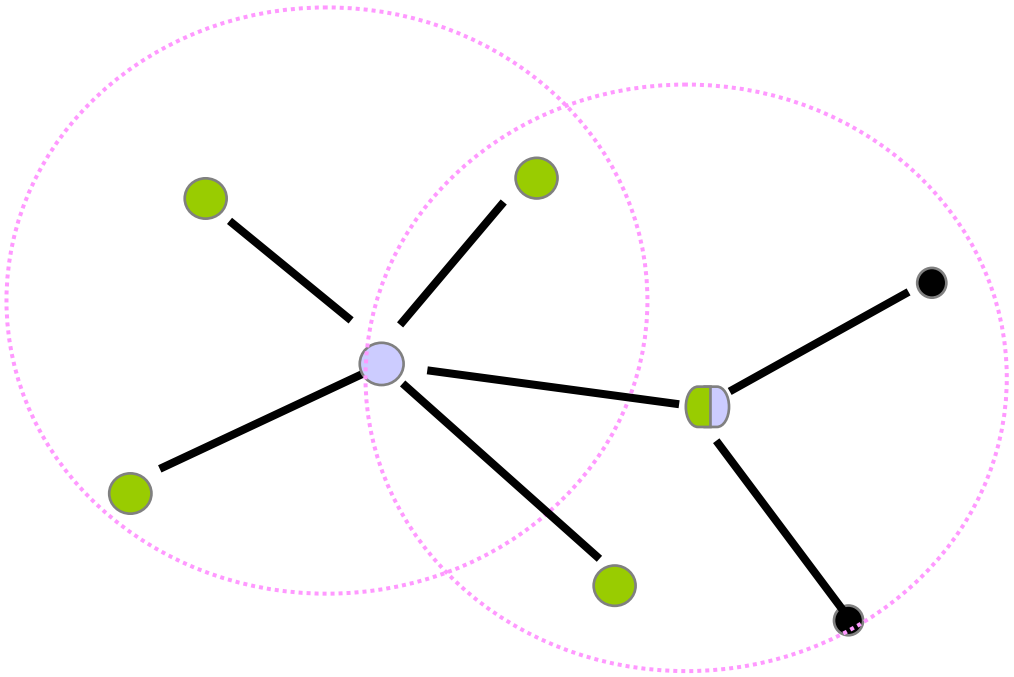
# Inter piconet communication



# Scatternet



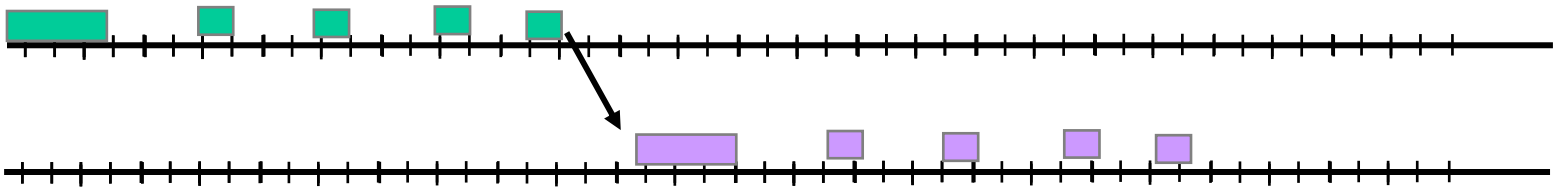
# Scatternet, scenario 2



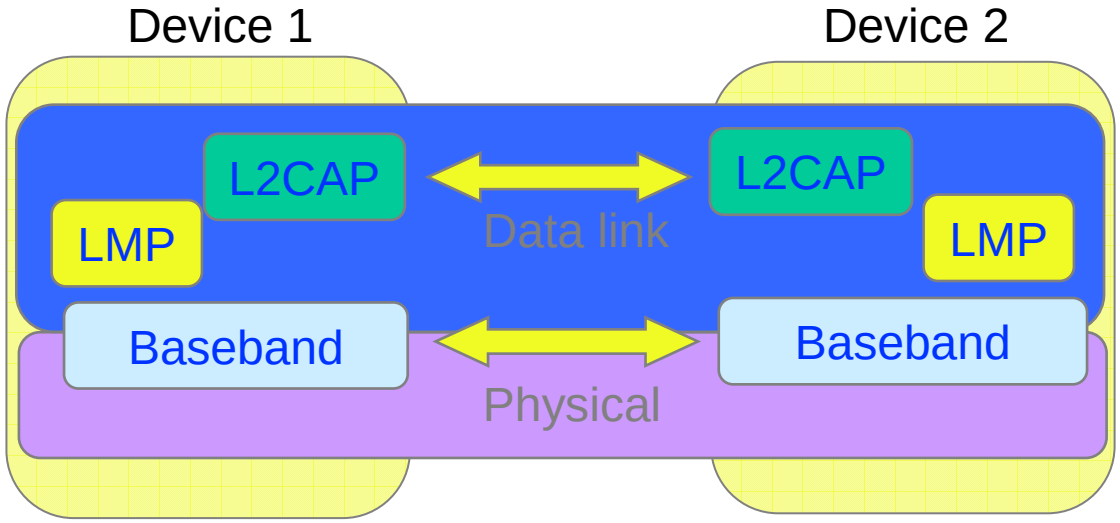
How to schedule presence in two piconets?

Forwarding delay ?

Missed traffic?

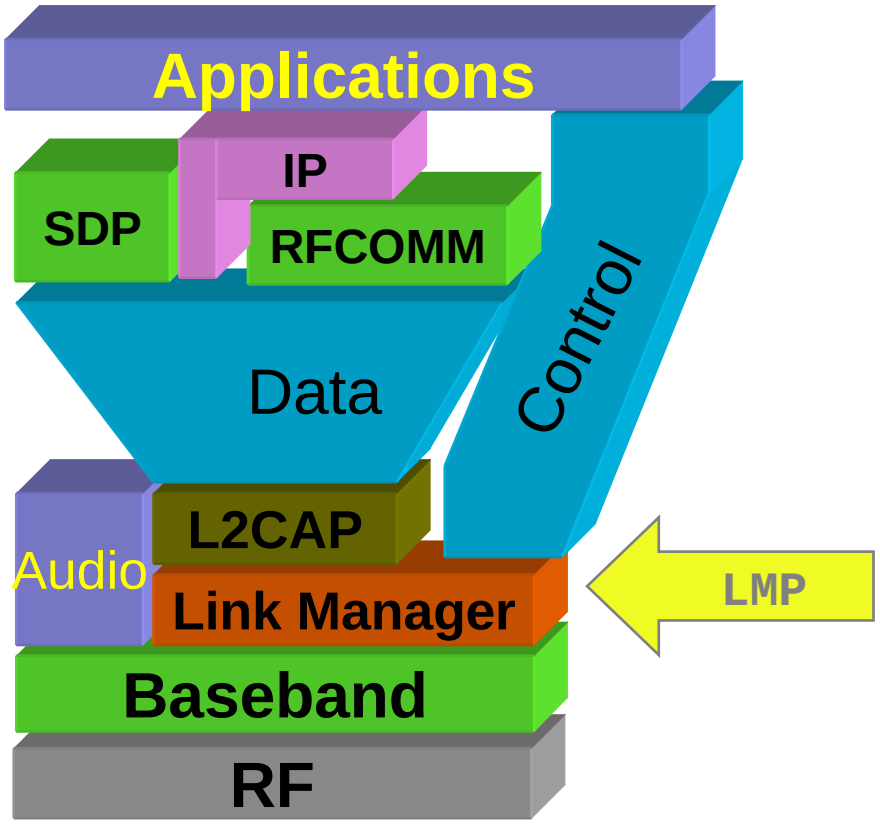


# Baseband: Summary




- 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

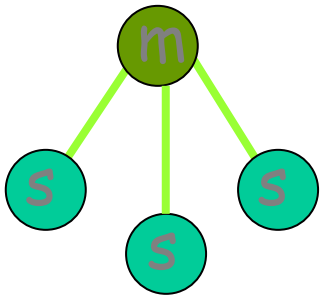


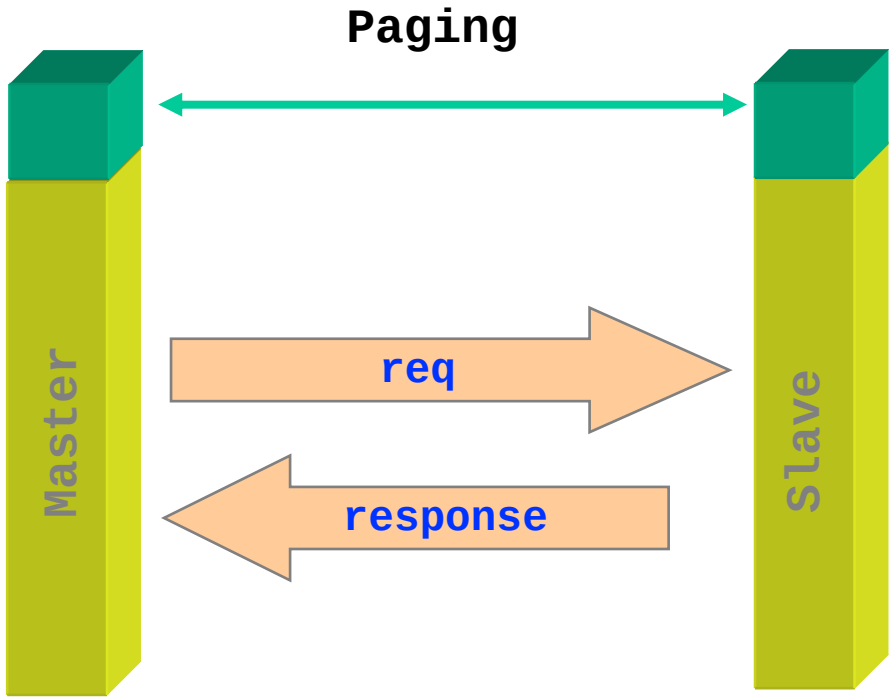

Setup and management of Baseband connections

- Piconet Management
- Link Configuration
- Security

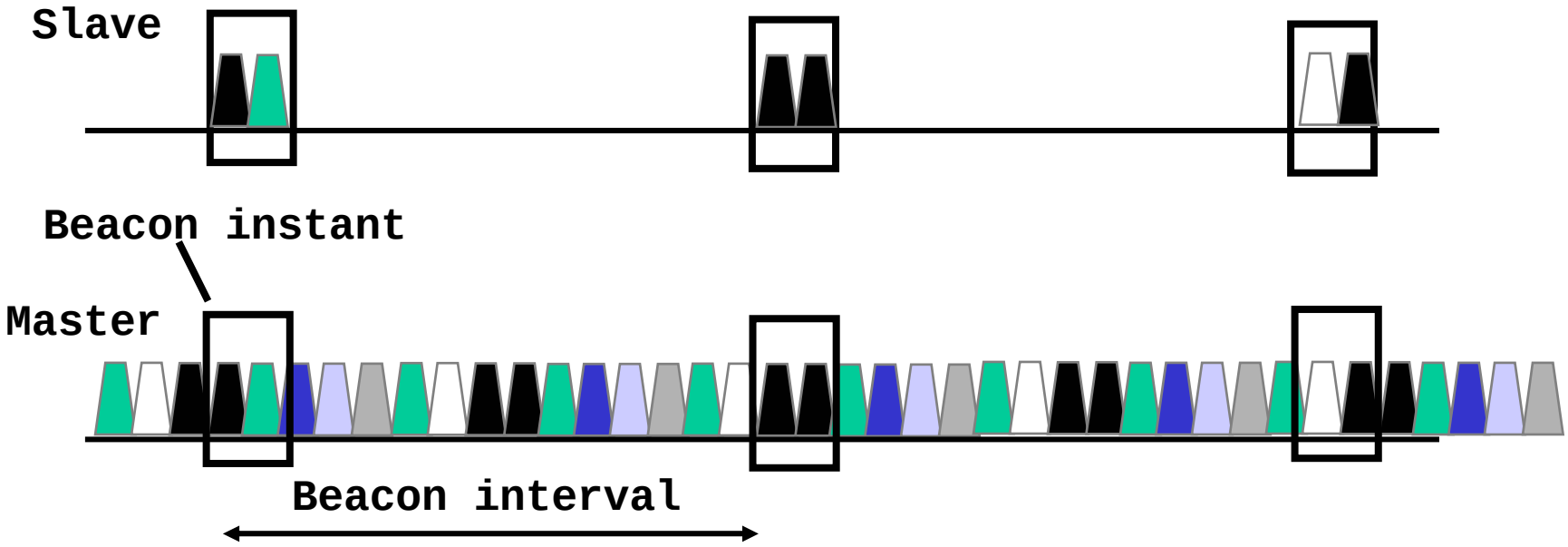
# Piconet Management

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



# Low power mode (Park)

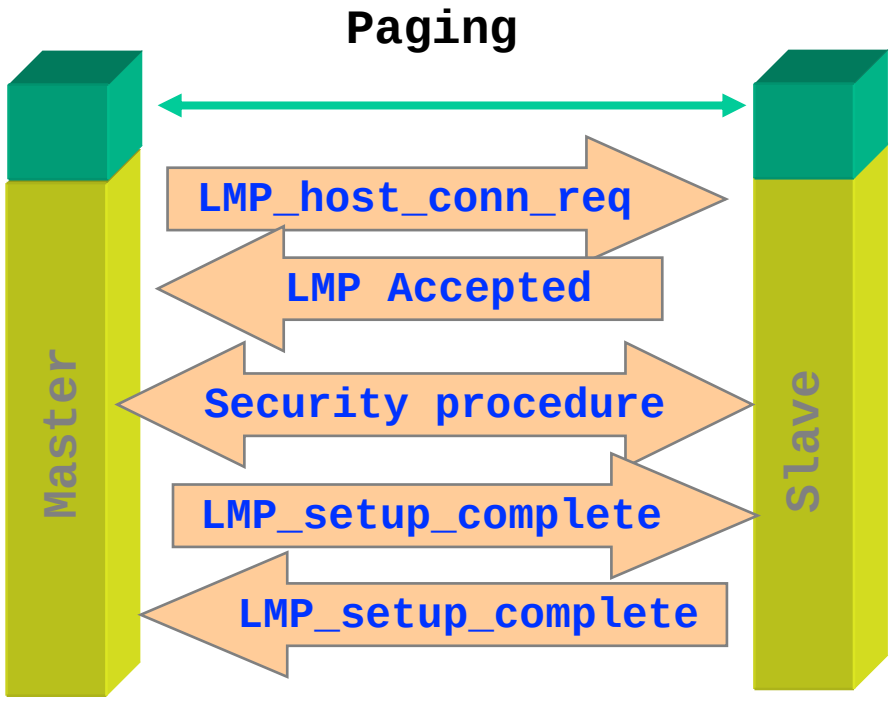



- Power saving + keep more than 7 slaves in a piconet
- Give up active member address, yet maintain synchronization
- Communication via broadcast LMP messages

# Connection establishment & Security

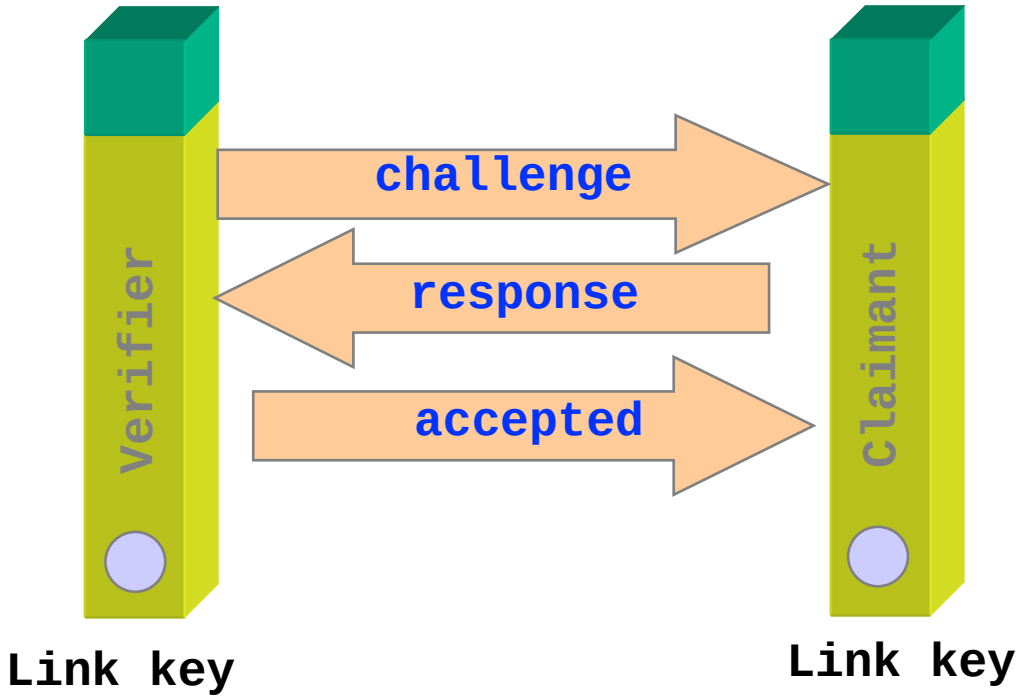
- Goals
  - Authenticated access
    - Only accept connections from trusted devices
  - Privacy of communication
    - prevent eavesdropping

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

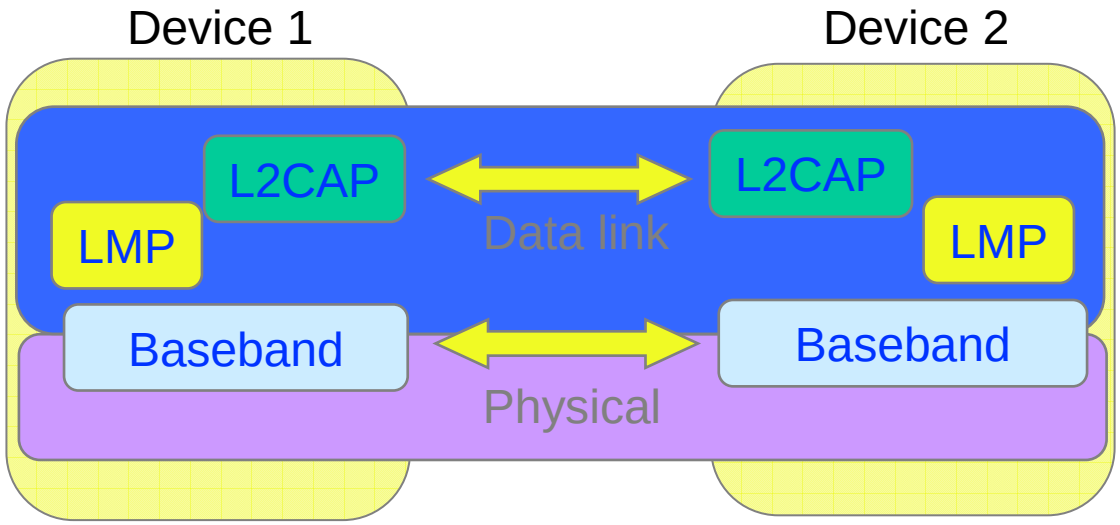


# Authentication

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

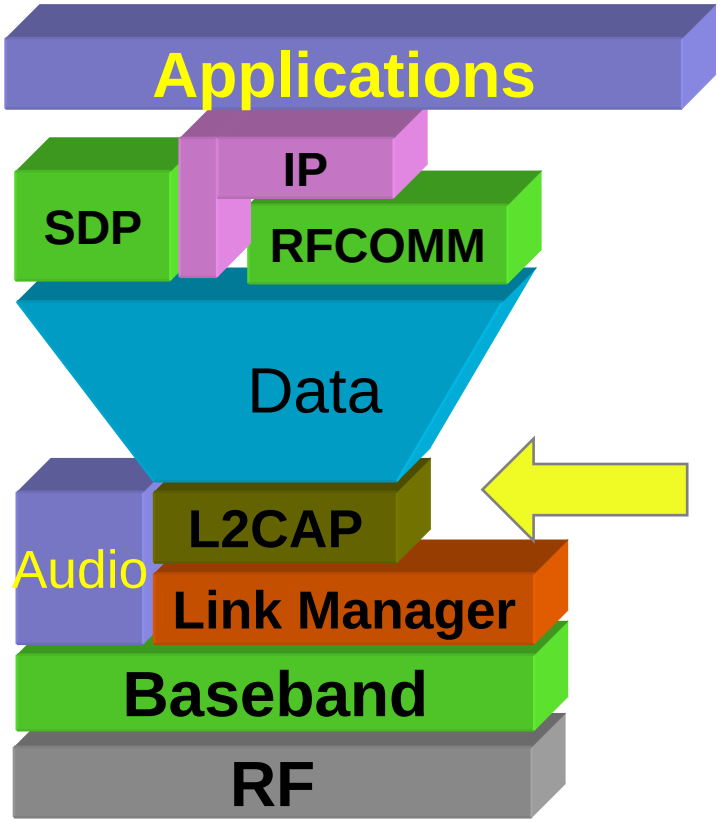


# Link Manager Protocol Summary




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

# L2CAP

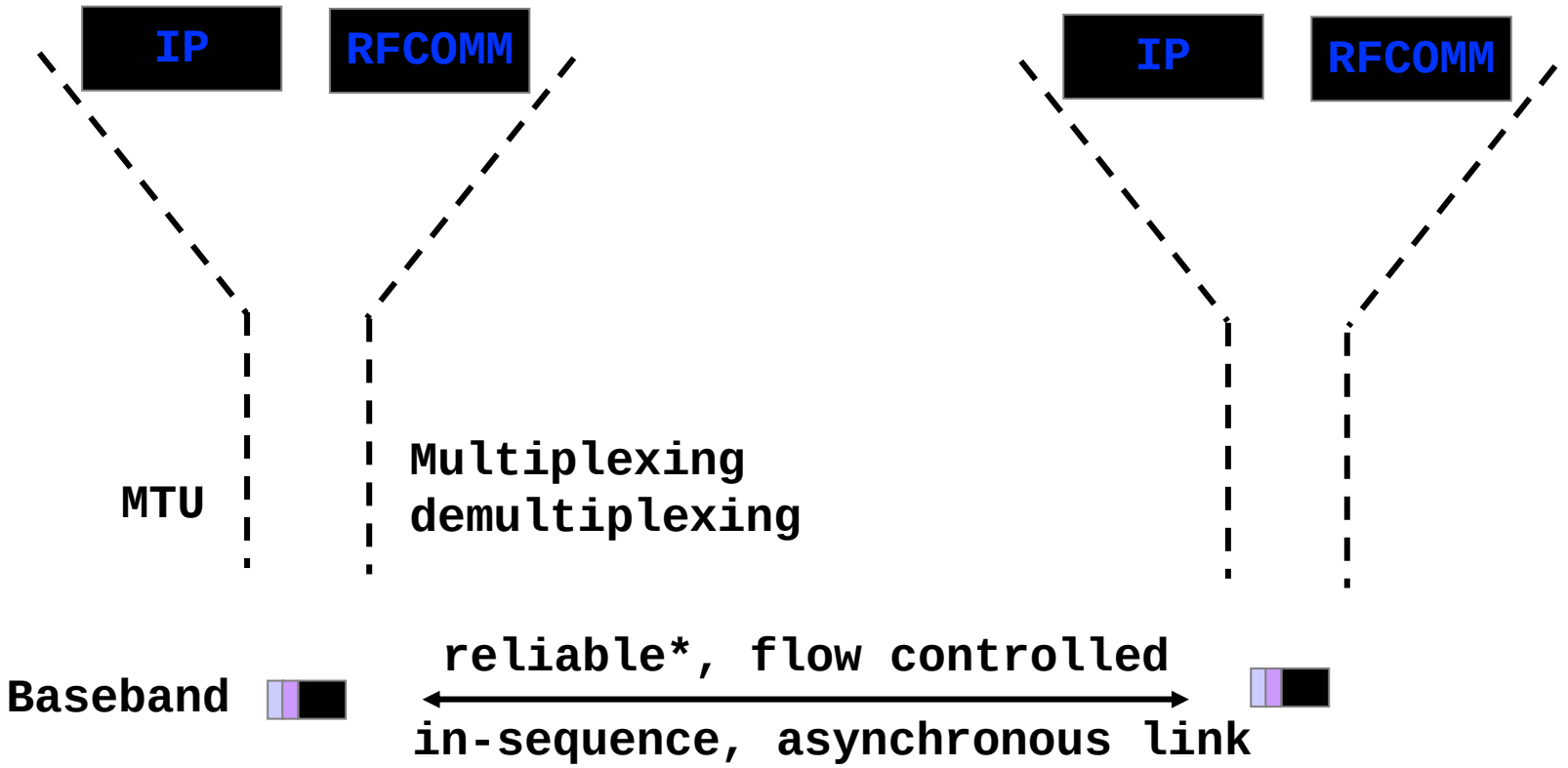



**Logical Link Control and Adaptation Protocol**

L2CAP provides

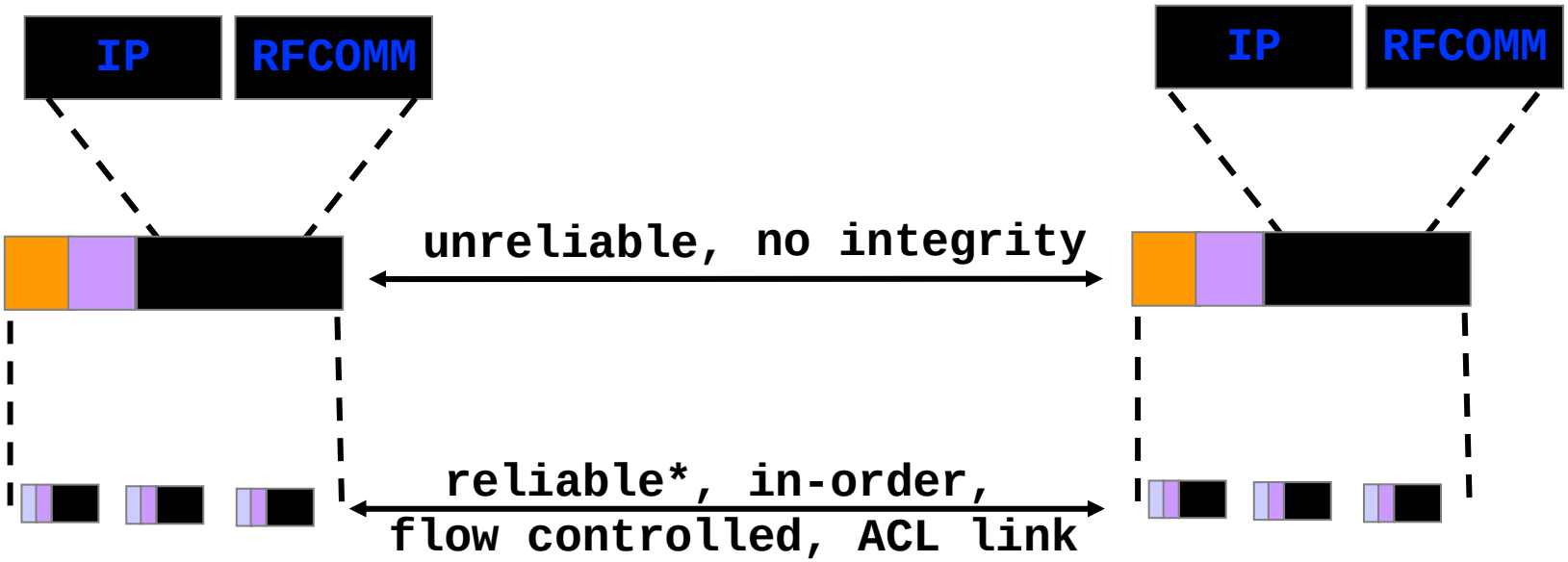
- Protocol multiplexing
- Segmentation and Re-assembly
- Quality of service negotiation

# 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

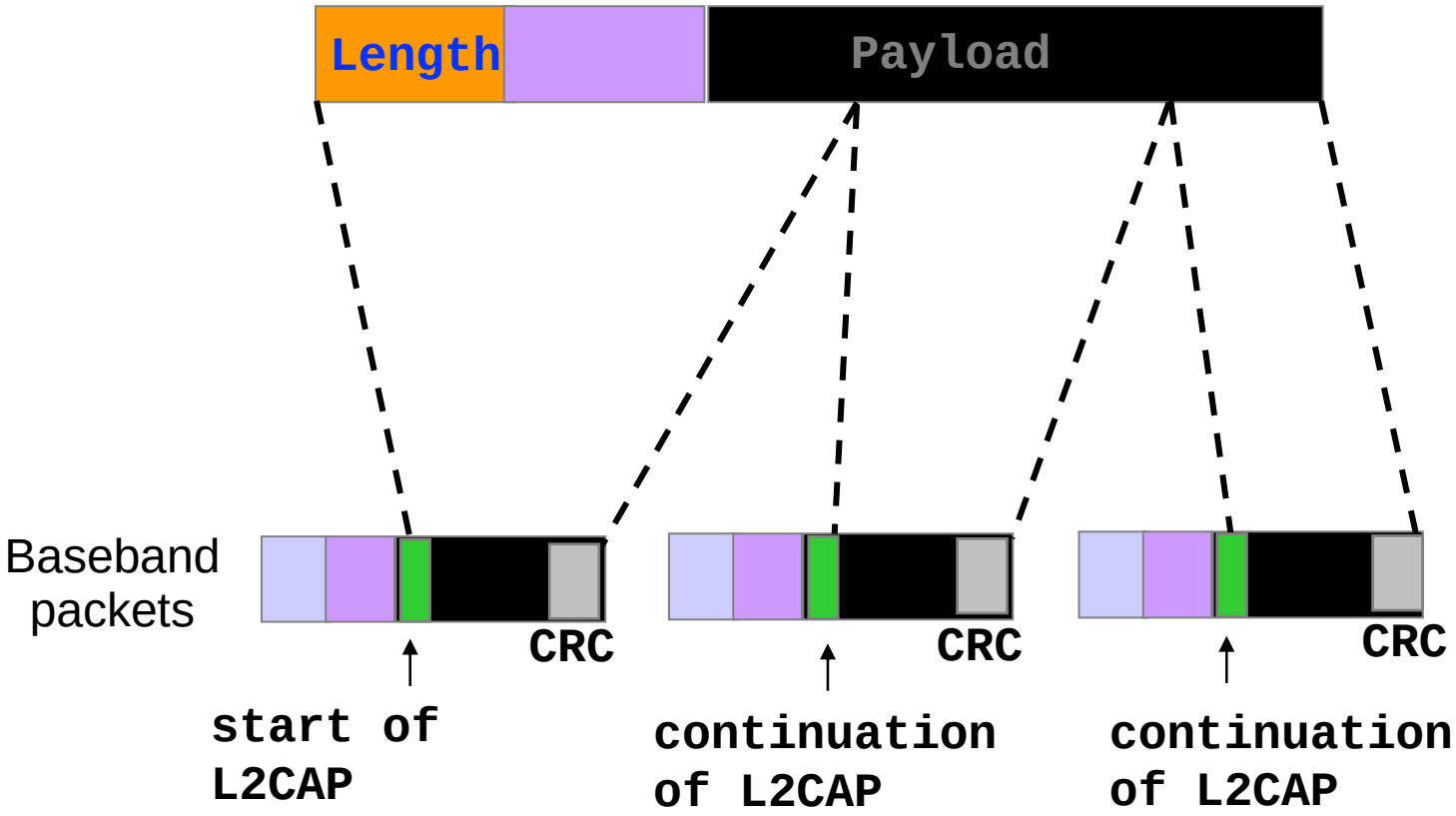



Desired features
- Protocol multiplexing
- Segmentation and re-assembly
- Quality of service

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

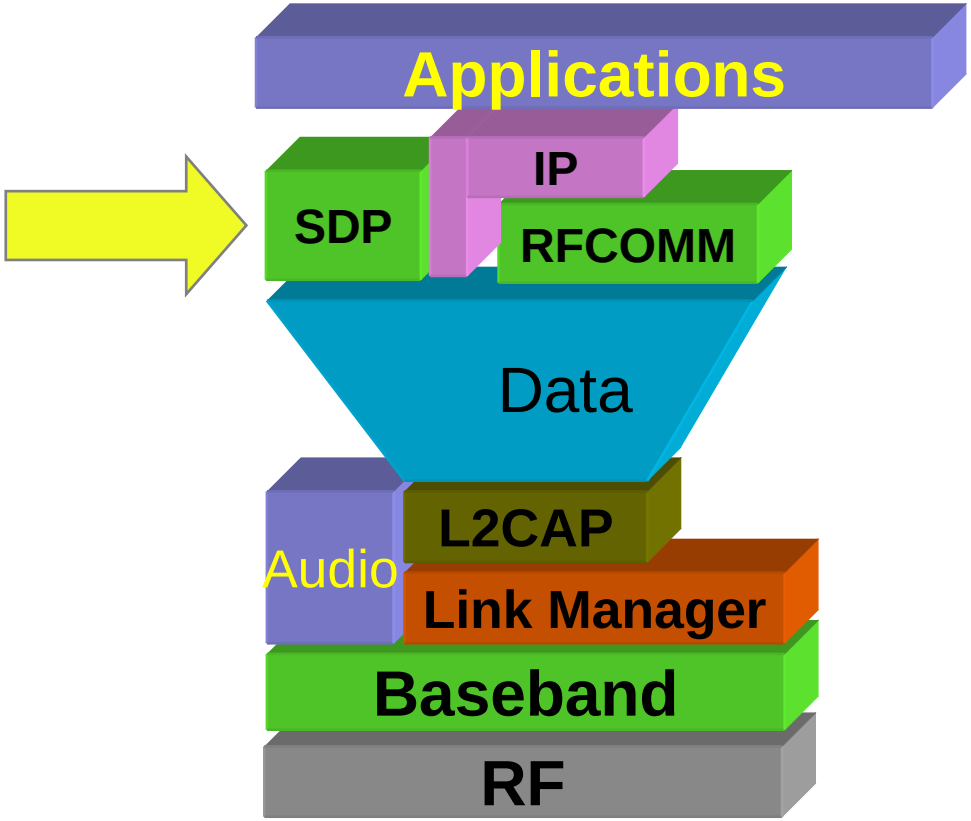
# Segmentation and reassembly

min MTU = 48
672 default




- 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

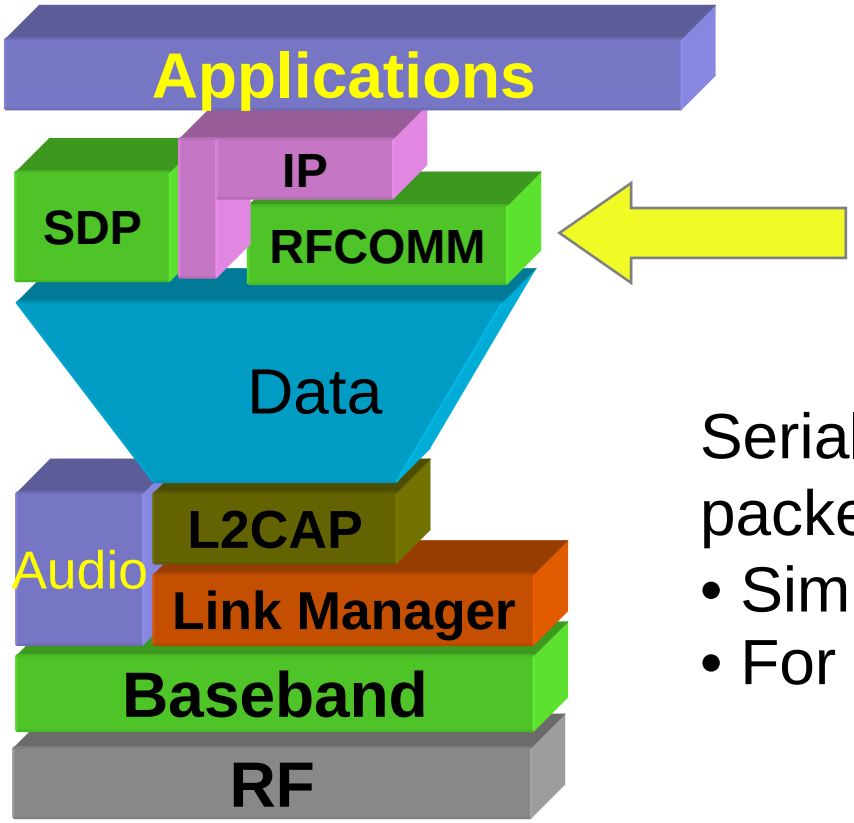
# Bluetooth Service Discovery Protocol



# 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

# ZigBee and 802.15.4 for Personal Area and Sensor Networks

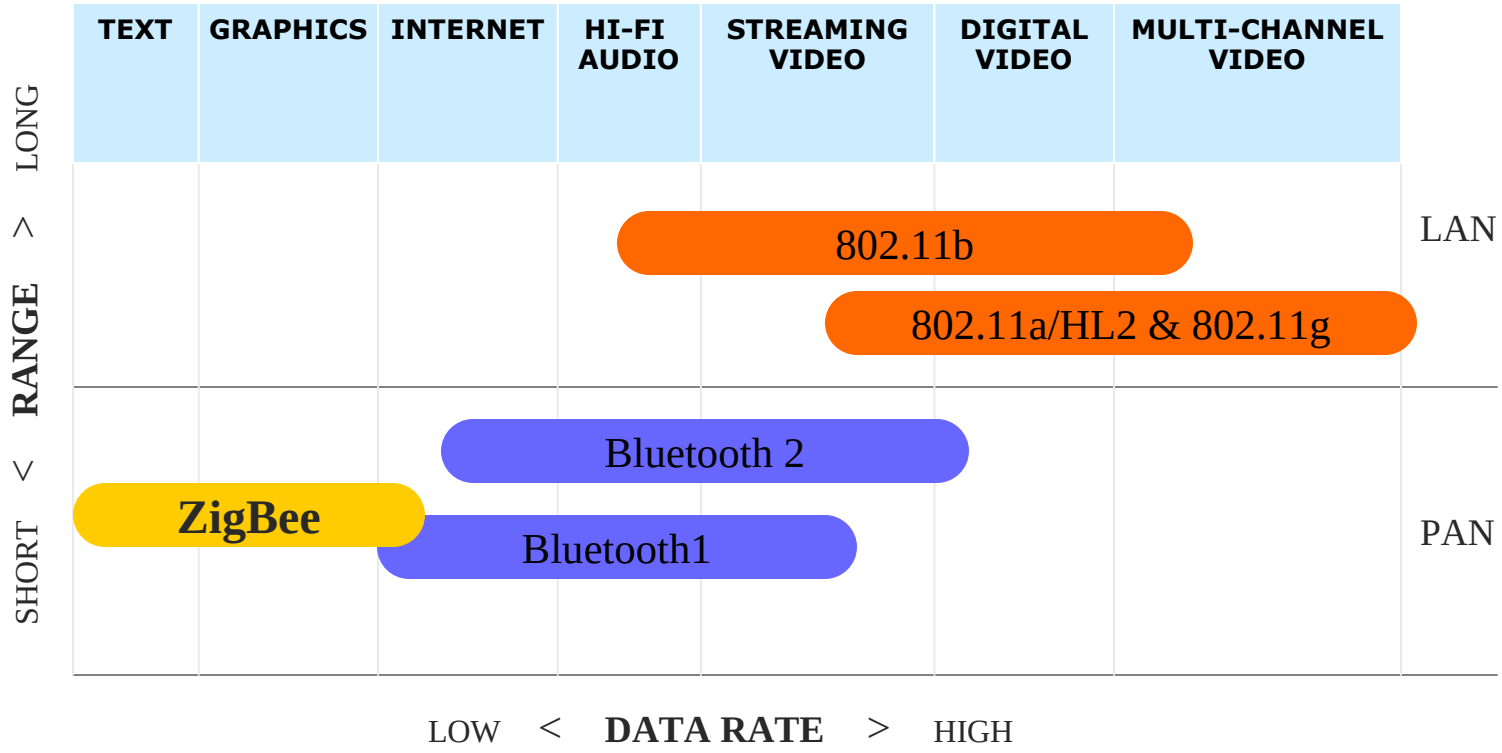
# Outline

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

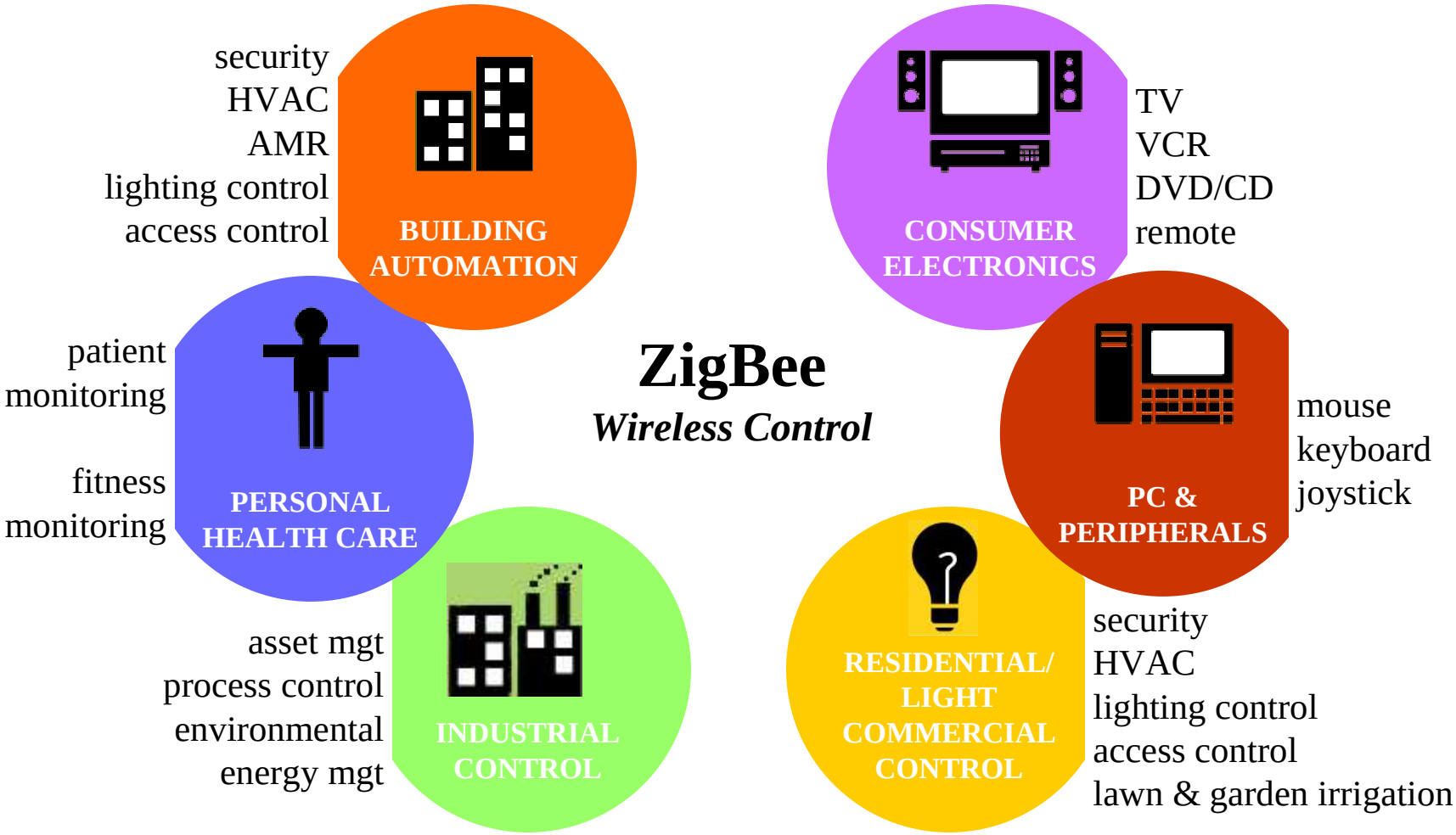
# The ZigBee Alliance Solution

- 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

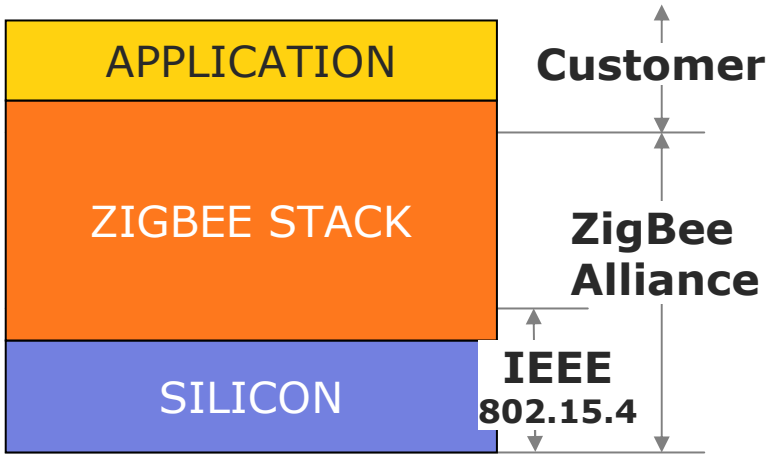


# Applications



# 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



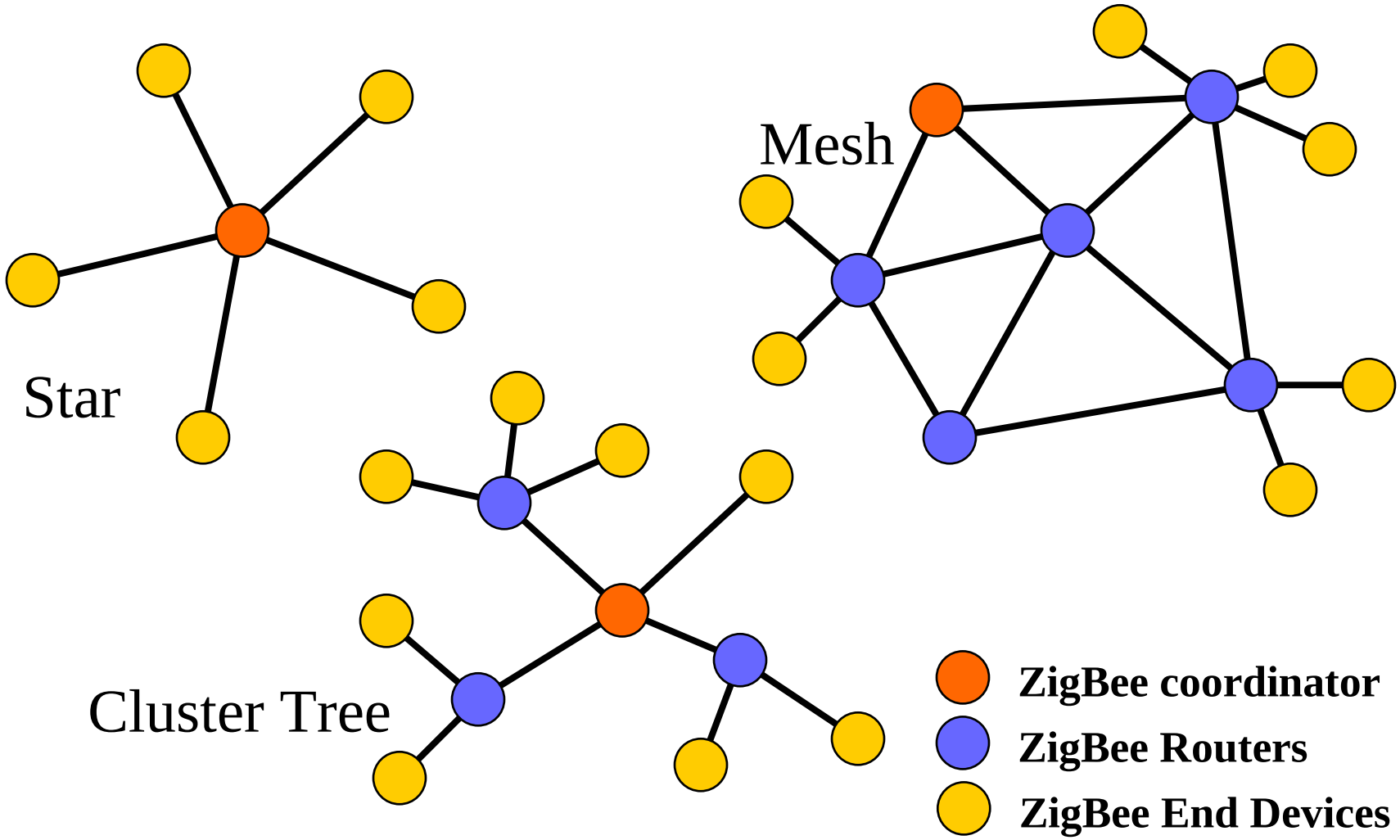
# IEEE 802.15.4 Basics

- 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

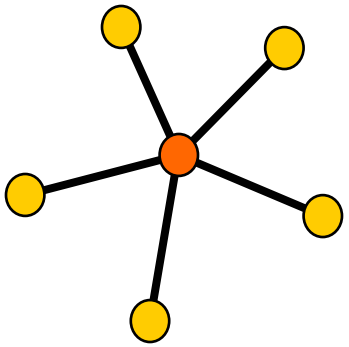
- Two channel access mechanisms
  - Non-beacon network
    - Standard CSMA-CA communications
    - Positive acknowledgement for successfully received packets
  - Beacon-enabled network
    - Superframe structure
      - For dedicated bandwidth and low latency
      - Set up by network coordinator to transmit beacons at predetermined intervals
        - » 15ms to 252sec (15.38ms*2n where $0 \leq n \leq 14$)
        - » 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

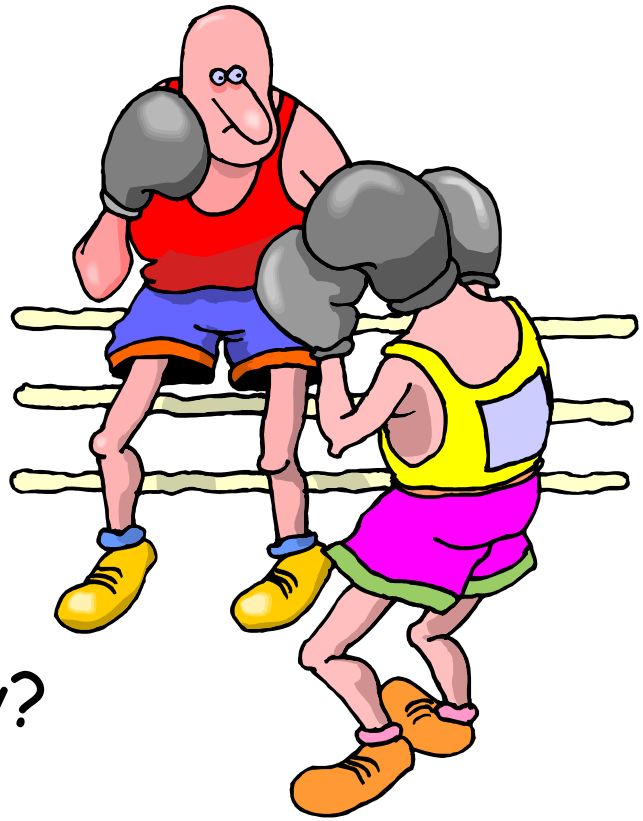
- Commercial or home security
  - Client units (intrusion sensors, motion detectors, glass break detectors, standing water sensors, loud sound detectors, etc)
    - Sleep 99.999% of the time
    - Wake up on a regular yet random basis to announce their continued presence in the network ("12 o'clock and 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

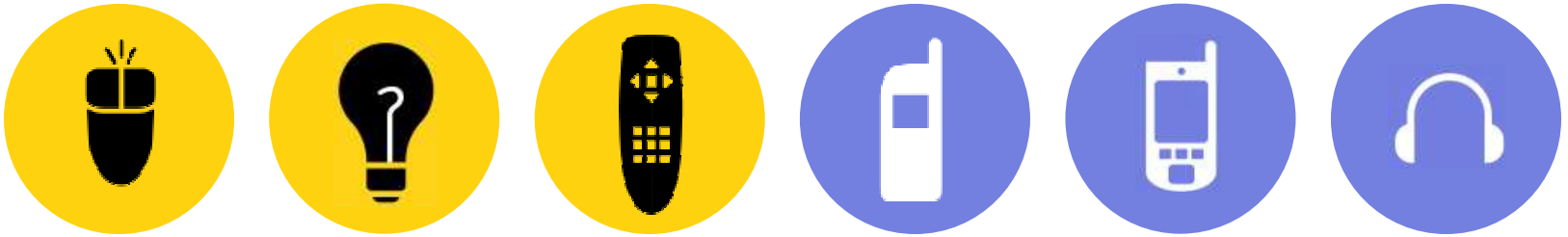


Competitive or Complementary?

# ZigBee and Bluetooth

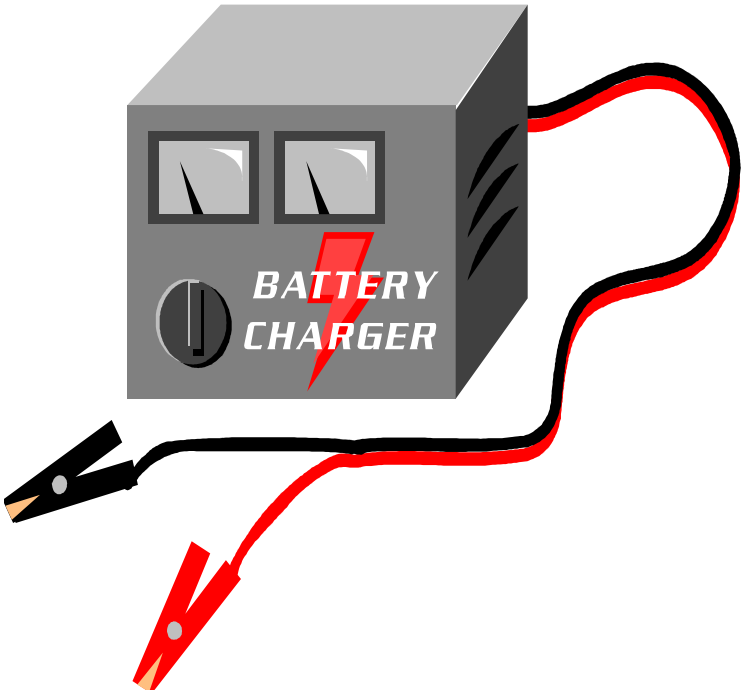
## *Optimized for different applications*

- 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

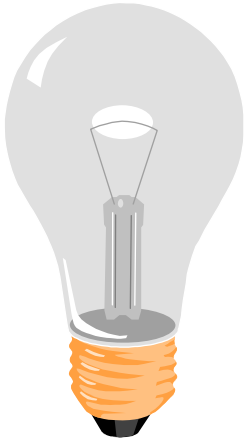
## *Address Different Needs*

- 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

# 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

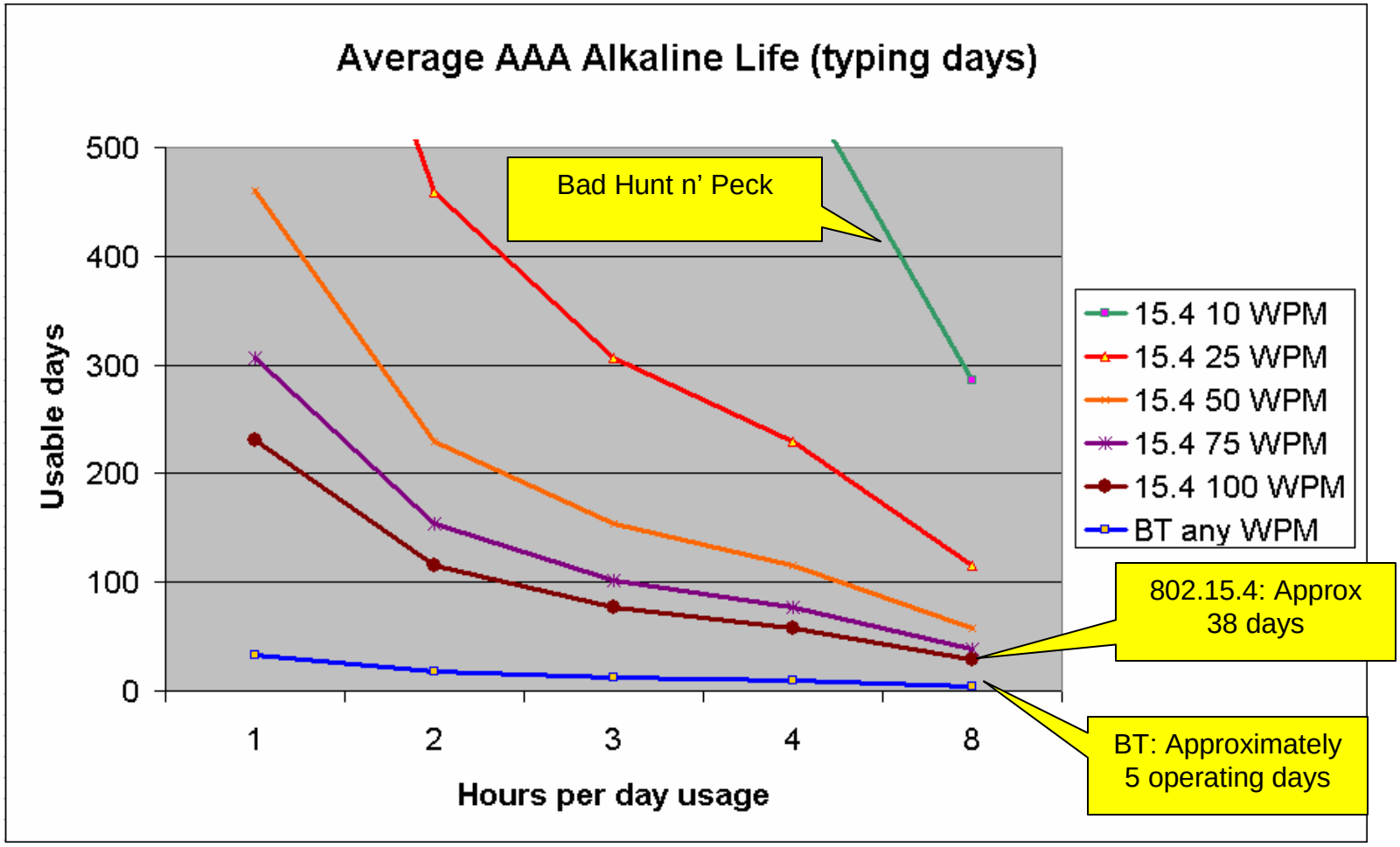
# Wireless Keyboard Using 802.15.4

- 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

# Wireless Mesh Networks

Renato Lo Cigno
www.dit.unitn.it/locigno/didattica/NC/

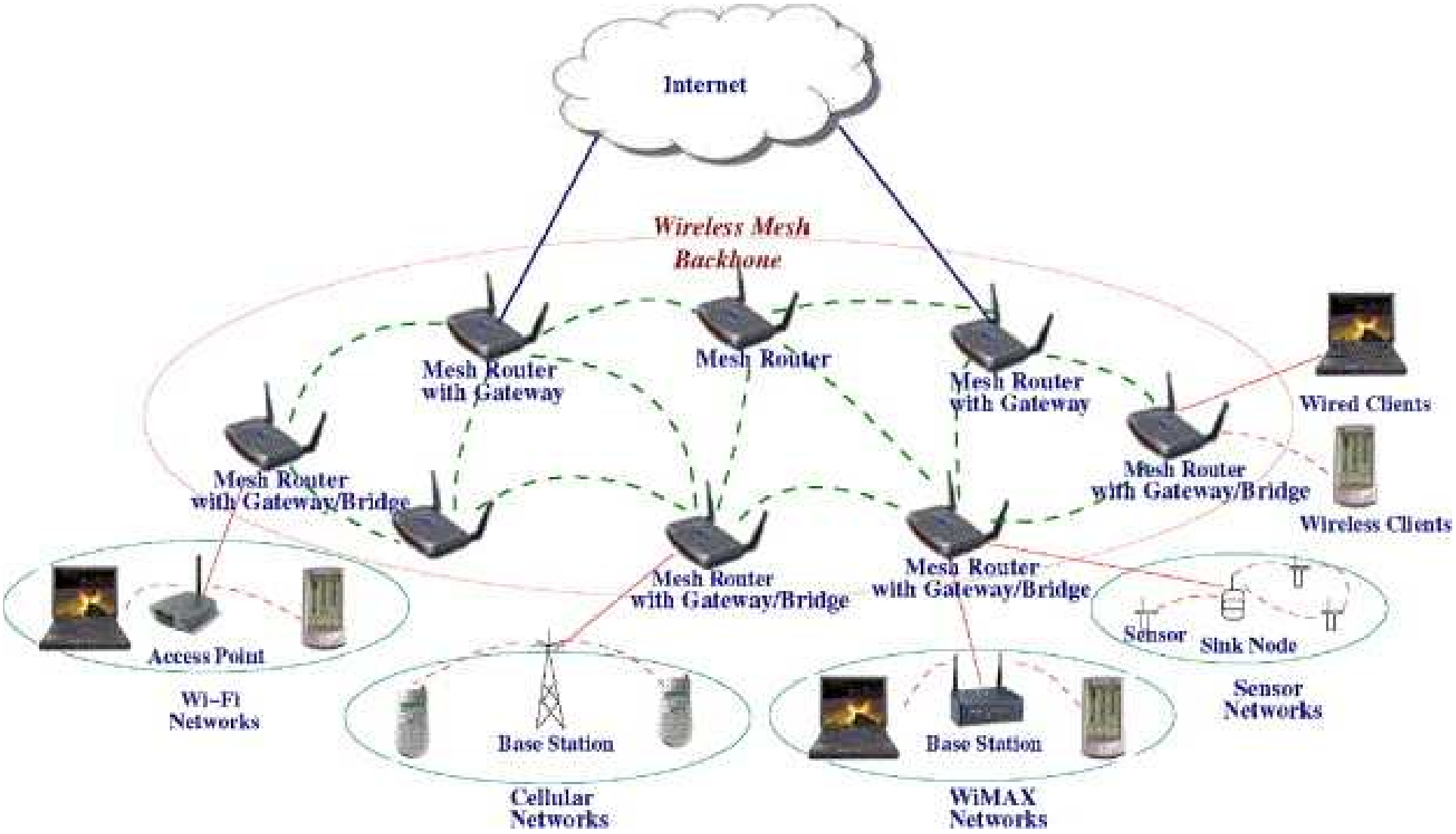
Part of this material (including some pictures) features and are freely reproduced from:
"Ian F.Akyildiz, Xudong Wang,Weilin Wang, 'Wireless mesh networks: a survey', Computer Networks 47 (2005), Elsevier"

Thanks also to Gianni Costanzi for checks and providing figures

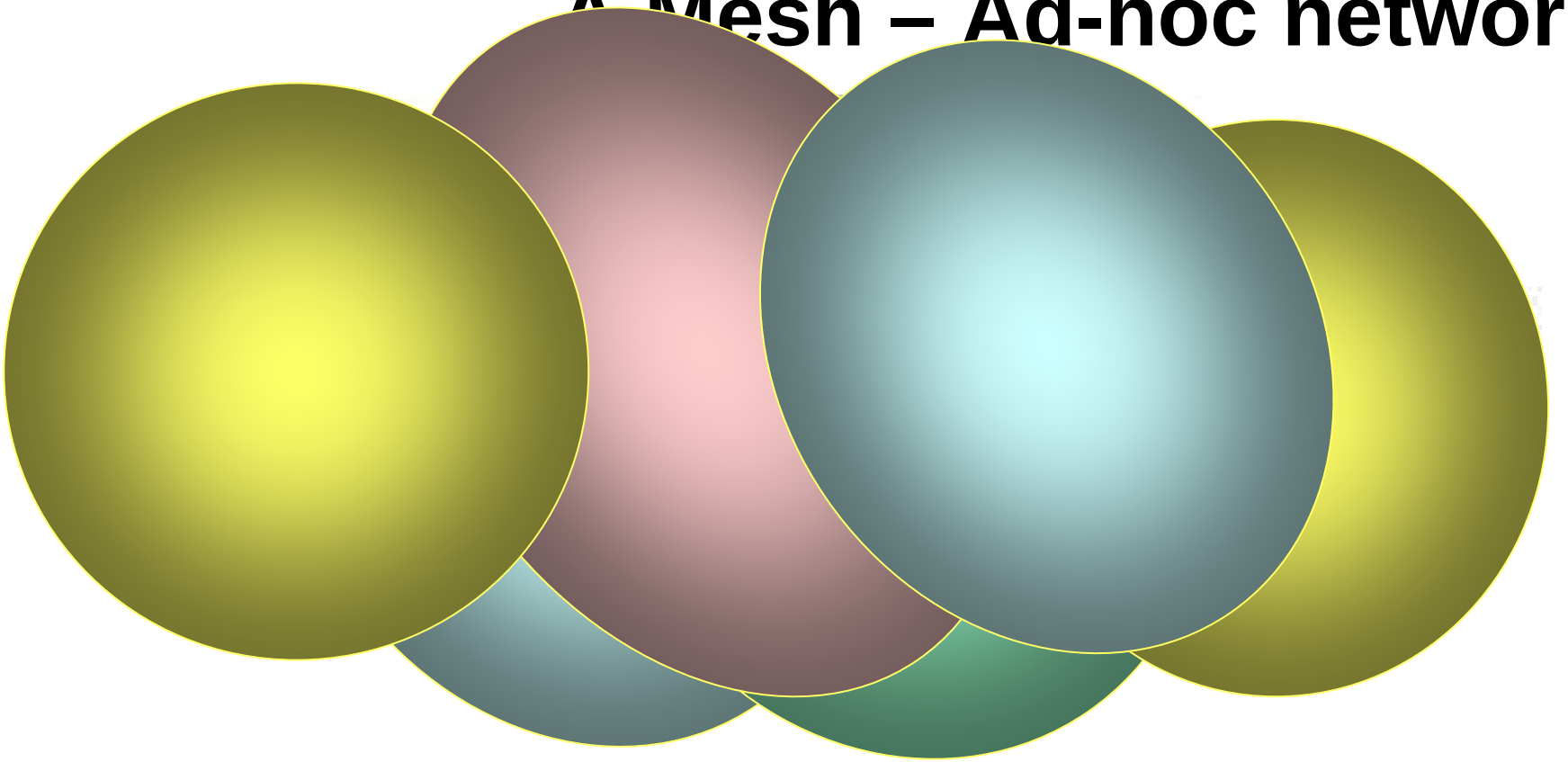
# Ad-Hoc and WMN

- Ad-Hoc network
  - non permanent
  - general purpose or specific (sensors)
  - single or multi-hop, normally mobile
  - may require routing (see AODV and OLSR in the following)
- Wireless Mesh Networks (WMN)
  - more structured than Ad-Hoc
  - may be hierarchical
  - semi-permanent, some nodes are fixed
  - requires routing

# WMN: a general view



# A Mesh – Ad-hoc network



- Ad-Hoc can be meshed
  - non single broadcast channel
  - multi-hop require routing

# Hierarchical meshes

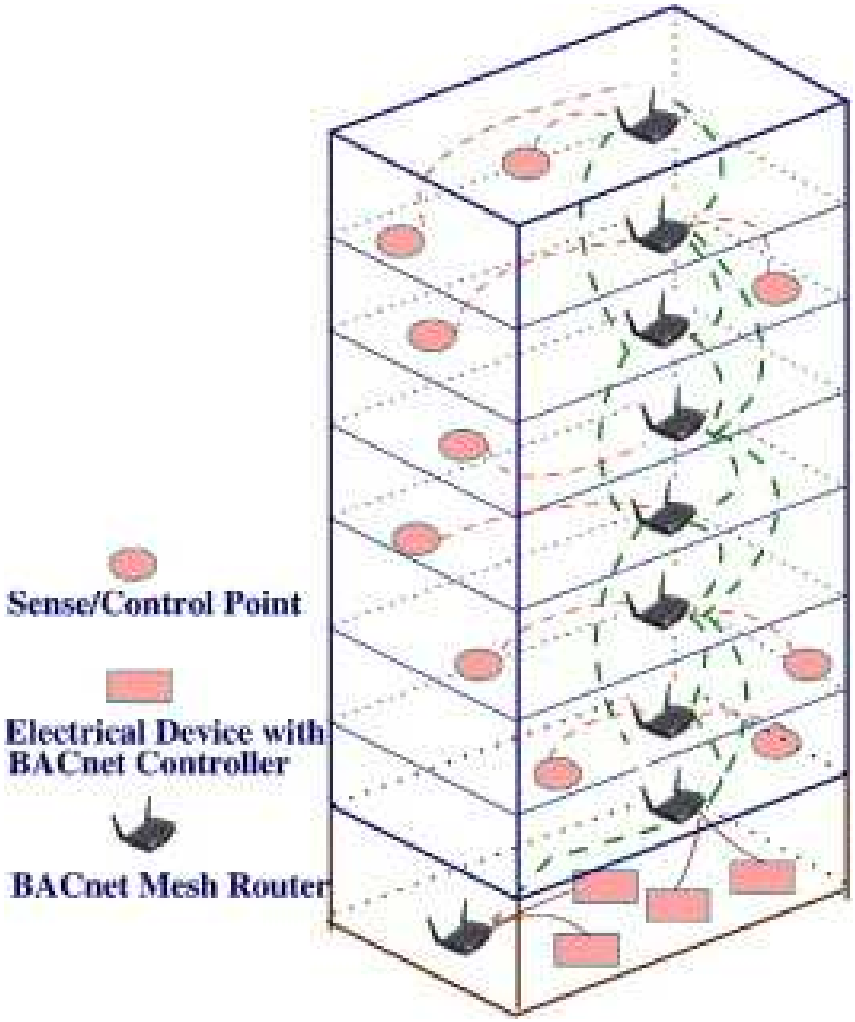
# Hierarchical meshes

- Capacity of the backbone
- Routing strategies
  - Gateway selection
    - client level
    - backbone level
- Backbone of fixed nodes
  - multi-km links -> easy and cheap coverage
  - replace wireless "closed" backbones
  - Nomadic access vs. static access

# Domestic Mesh

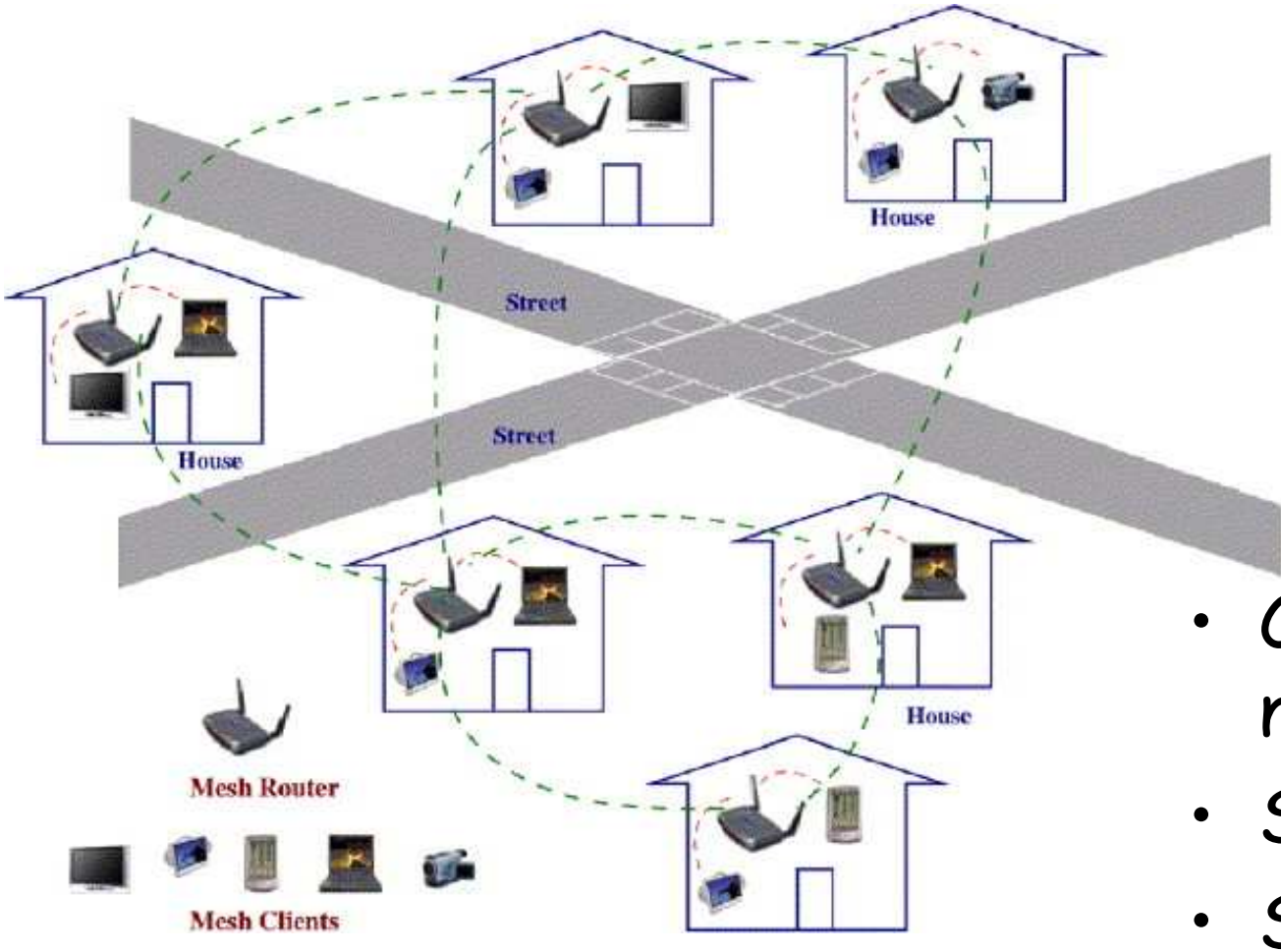

- Simplify home cabling
- Can support anti-intrusion
- Distribute e.g. IPTV

# Building automation



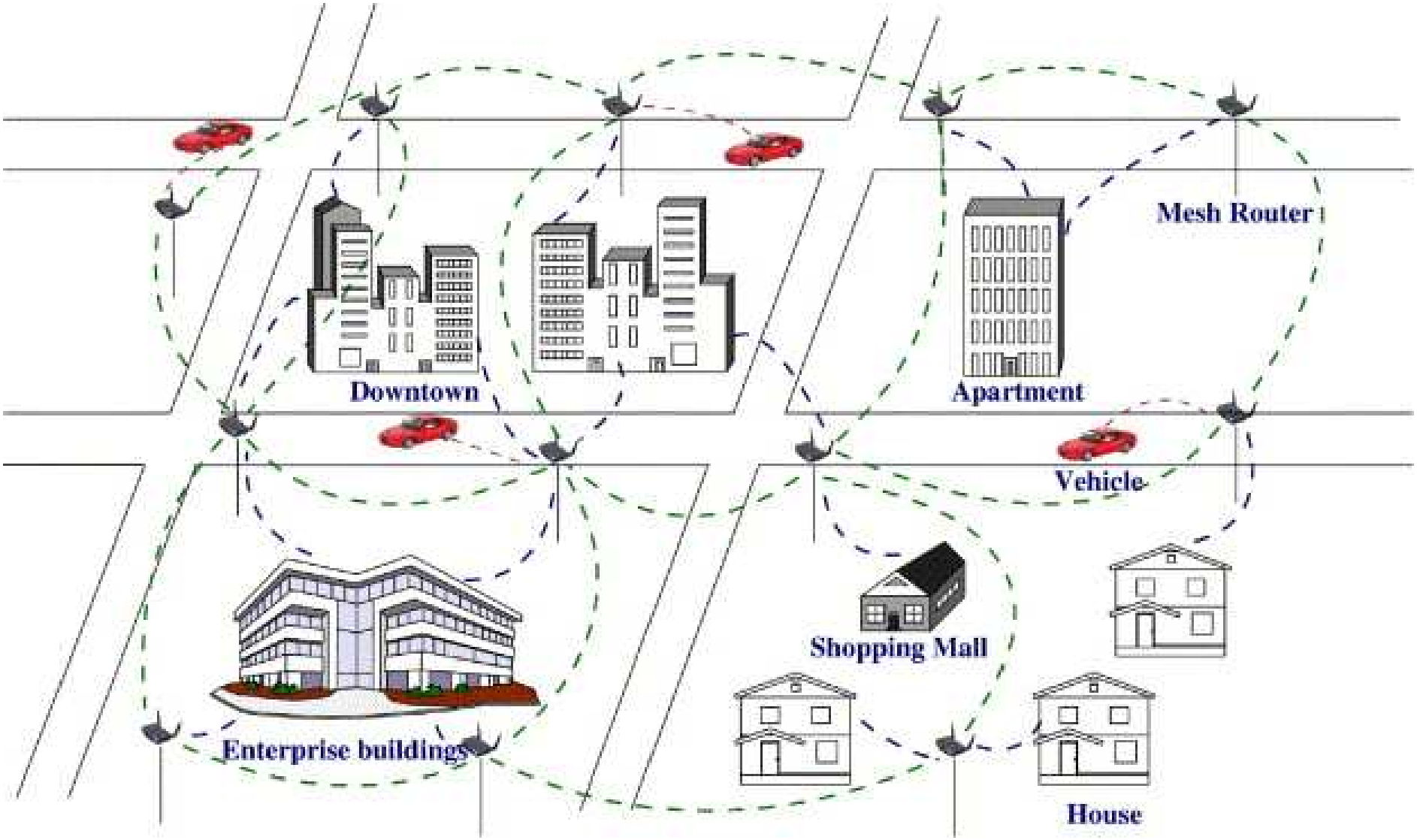

- Simplify cabling
- Allow central control
  - vs. pure sensor/actuator networking where information is not propagated
- Simple, static routing
- Reliability concerns

# Multi-home meshes




- Community networks
- Social networks
- SOHO support
- Nomadic access

# Vehicular-metropolitan networks

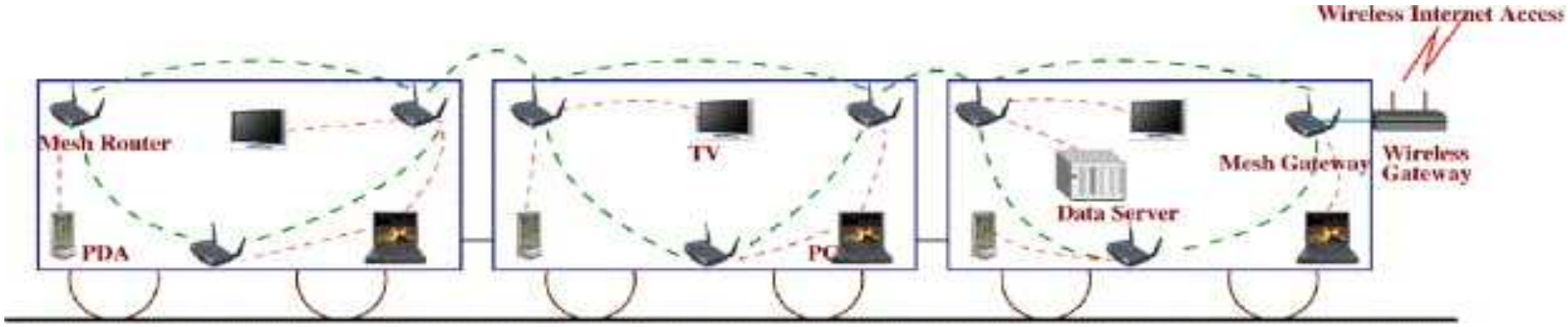


# Vehicular-metropolitan networks

- Mainly infrastructure-to-vehicle
  - cooperative driving is a different (though related) story
- Traffic control & congestion management
  - A22 is "selling" as the "future" 73 messaging panels on close to 300 km ...
- Turism, advertisement, local information
- Nomadic communication with pedestrians too

- In U.S. some commercial experiments are already available

# Train & Planes networks

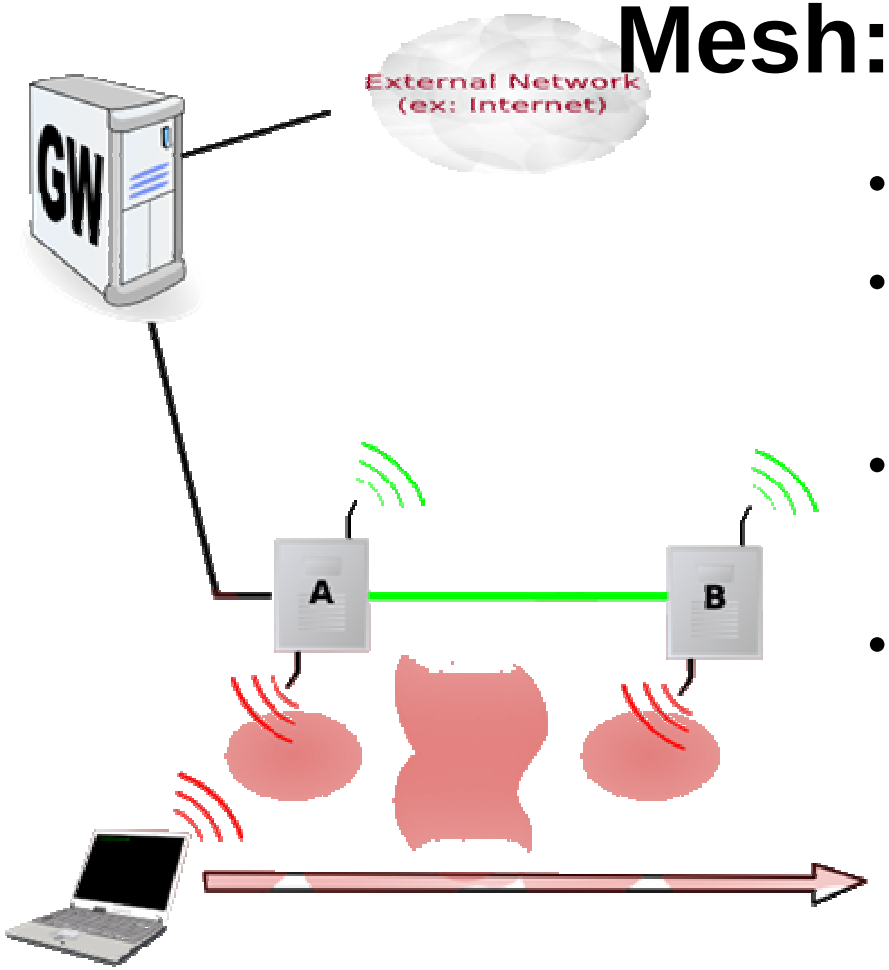



- Cellular networks?
  - capacity problems in "dense" environments
  - cannot "reach" planes
  - problems with very high speed
- Collect the traffic locally then interconnect from a single – non energy constrained point

# Mesh project & sites

- Community Networks & around
  - Seattle Wireless (http://www.seattlewireless.net/)
  - Roofnet at MIT (http://pdos.csail.mit.edu/roofnet/)
  - TFA at Rice (http://tfa.rice.edu)
  - Tuscolo Mesh (http://tuscolomesh.ninux.org/joomla)
  - Georgia Tech (http://www.ece.gatech.edu/research/labs/bwn/mesh/index.html)
  - ...
  - Pergine Valsugana
  - ...
  - Trentino Networks

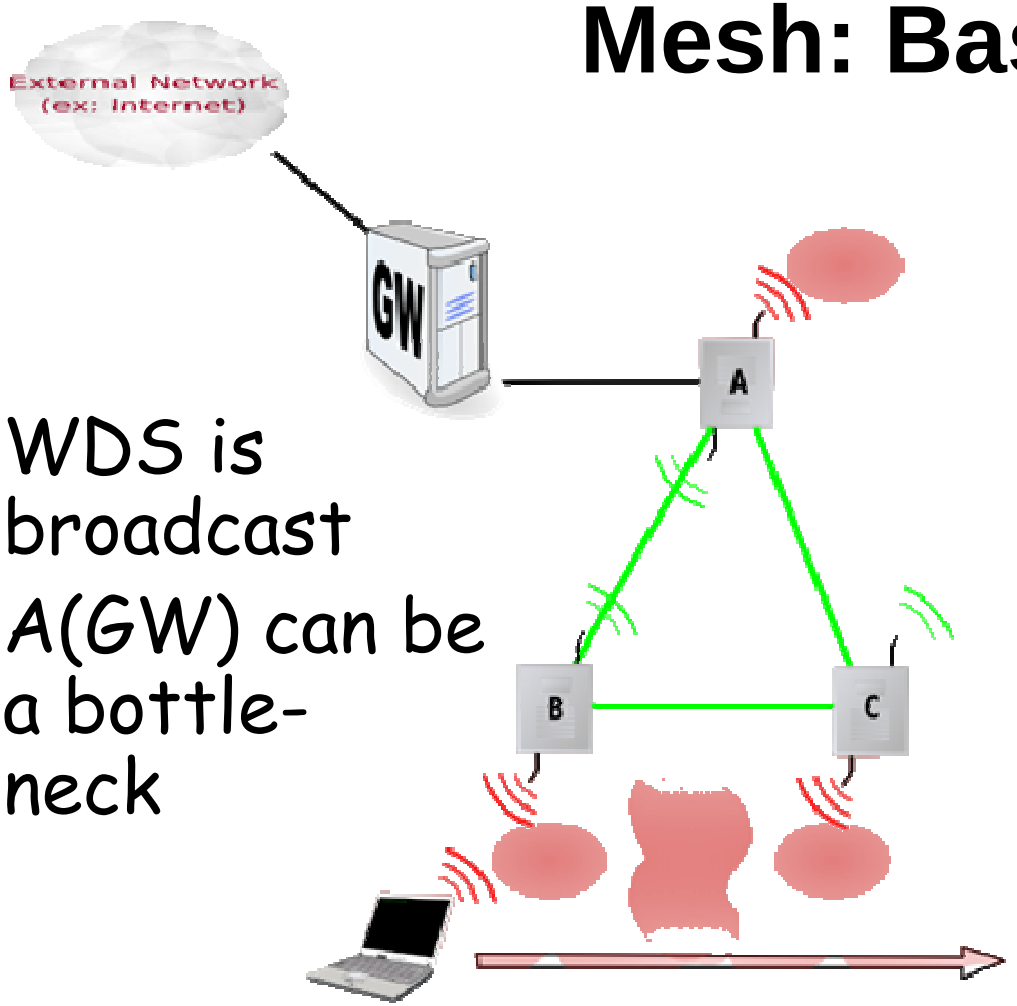
# Mesh: Basic scenarios (1)




- Extended WLAN access
- Simple configuration
  - no routing
- Simple 802.11 handover support
- Double radio guarantees good performance

- Single radio creates resource conflicts
  - 3 BSS on the same channel
  - suitable for low-cost low-performance

# Mesh: Basic scenarios (2)

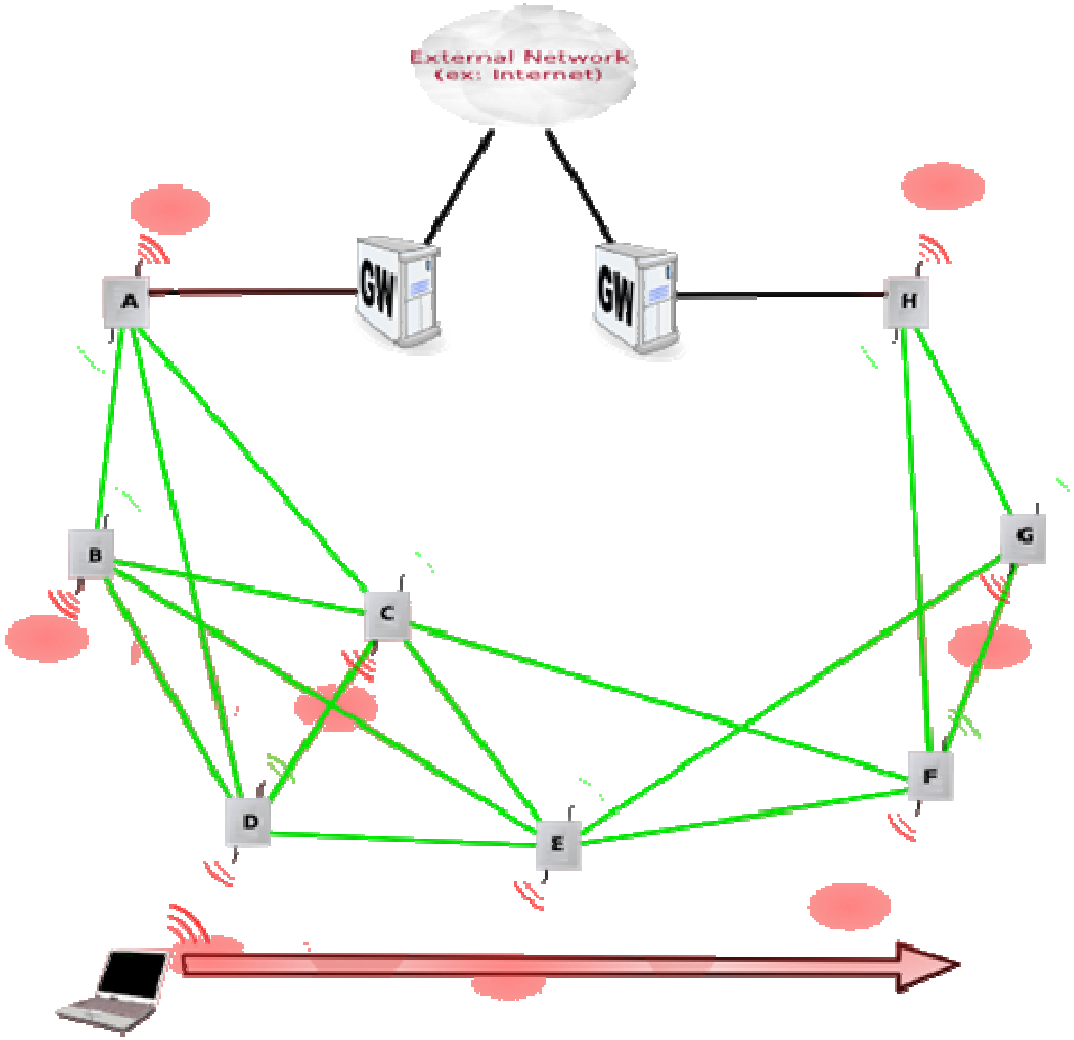


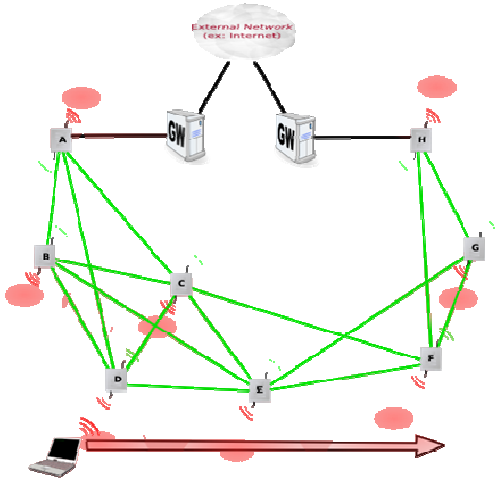

- WDS is broadcast
- A(GW) can be a bottle-neck

- Extended WLAN access
- Routing required
- Simple 802.11 handover support
- Double radio guarantees good performance

- Single radio creates serious resource conflicts
  - n+1 BSS on the same channel

# Mesh: Basic scenarios (3)



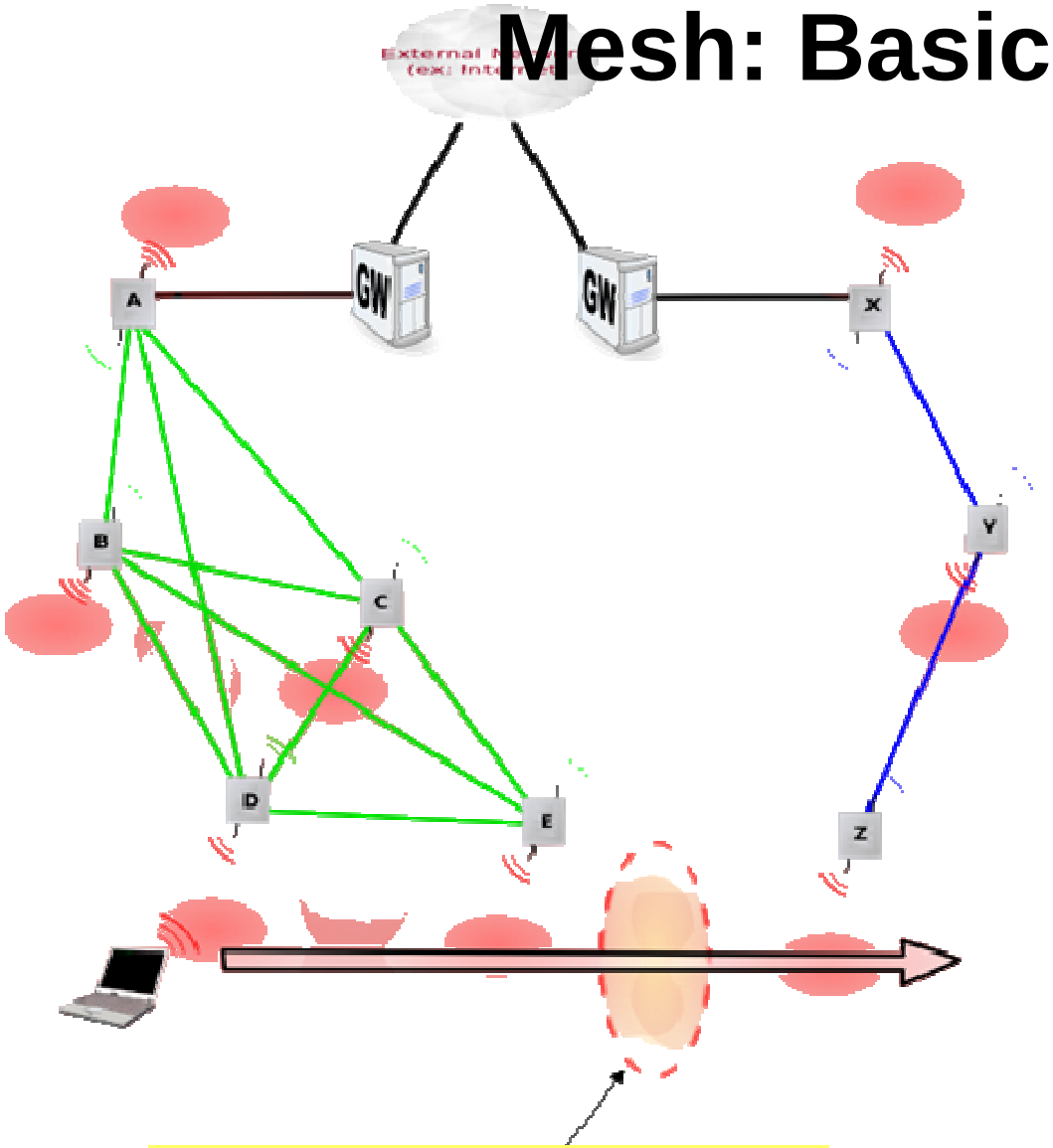



# Mesh: Basic scenarios (3)

- Extended WLAN access
- Basic infrastructuring
- Single radio operation very difficult

- Multiple external gateways
  - sophisticated, flow-based routing
- Non standard handover support
  - flow based routing requires exporting the context
  - address management require coordination
- WDS may be multi-hop
  - How many channels?
- Point-to-point and broadcast channels in WDS

# Mesh: Basic scenarios (3)




- Address management (DHCP) is a problem
- Flow-based routing may be impossible
- Joining/splitting of partitions is an open issue

Moving between BSS belonging to different Mesh/WDS

# Mesh – Ad-Hoc: AODV

Ad-hoc On-demand Distance Vector routing – rfc3561

- DV (see RIP) protocol for next-hop based routing
- On-Demand: maintains routes only for nodes that are communicating
- Must build routes when requested
- Route Request (RREQ) are flooded through the network
- Nodes set-up reverse path pointers to the source
  - AODV assumes symmetric links

# Mesh – Ad-Hoc: AODV

- The intended receiver sends back a Route Reply (RR)
- RR follow the reverse path set-up by intermediate nodes (unicast) establishing a shortest path route memorized by intermediate nodes
- Paths expire if not used
  - protocol & transmission overhead
  - guarantee of stability in dynamic, non reliable networks
- Usual DV problems
  - count to infinity, slow convergence, ...

# Mesh – Ad-Hoc: AODV

- Next-hop based (other proposals are based on source routing)
- "Flat" protocol: all nodes are equal
- Can manage only one route per s-d pair
  - can be inefficient in presence of highly variable link quality and persistence
- Good for sporadic communications
- Bad for high mobility
  - slow convergence
  - difficulty in understanding topology changes.

# Mesh – Ad-Hoc: AOMDV

## Ad-Hoc On-demand Multipath Distance Vector Routing in Ad Hoc Networks

- An extension to AODV
- AOMDV computes multiple loop-free and link-disjoint paths
- Using "Advertised Hop-count" guarantees Loop-freedom
  - A variable, which is defined as the maximum hop count for all the paths. A node only accepts an alternate path to the destination if it has a lower hop count than the advertised hop count for that destination
- Link-disjointness of multiple paths is achieved by using a particular property of flooding
- Performance comparison of AOMDV with AODV shows that
  - AOMDV improves the end-to-end delay, often more than a factor of two
  - AOMDV reduces routing overheads by about 20%

# Mesh – Ad-Hoc: OLSR

Optimized Link-State Routing Protocol (rfc3626)

- Proactive, link-state routing protocol
- Based on the notion of MultiPoint Relay (MPR)
- Three main components:
  - Neighbor Sensing mechanism
  - MPR Flooding mechanism
  - topology Discovery (diffusion) mechanism.

- Auxilary features of OLSR:
  - network association - connecting OLSR to other networks

# Mesh – Ad-Hoc: OLSR

Basic neighbor sensing:

- periodic exchange of HELLO messages;
- HELLO messages list neighbors + "neighbor quality"
  - HEARD - link may be asymmetric
  - SYM - link is confirmed to be symmetric
  - MPR - link is confirmed to be symmetric AND neighbor selected as MPR
- Providing:
  - topology information up to two hops
  - MPR selector information notification

# Mesh – Ad-Hoc: OLSR

- Each node selects from among its neighbors an MPR set such that
  - an emitted flooding message, relayed by the MPR nodes, can be received by all nodes in the 2-hop neighborhood

- Goals:
  - reduce flooding overhead (select minimal sets)
  - provide optimal flooding distances

# Mesh – Ad-Hoc: OLSR

- Exchanges topology information with other nodes of the network regularly
- MPRs announce their status periodically in control messages.
- In route calculation, the MPRs are used to form the route from a given node to any destination in the network
- Uses MPRs to facilitate efficient flooding of control messages

# Mesh Networks: 802.11s

- Working group to deliver a standard for 802.11(& around) base Mesh Networks
  - Interactions with 802.11p dedicated to vehicular networks

- Tries to define a framework to support a Mesh network as a standard extended WLAN with routing that goes beyond the standard minimum spanning tree of 802.1 interconnection

# Device Classes in 802.11s

- Mesh Point (MP)
  - a point able to relay messages
- Mesh AP (MAP)
  - a MP able to provide services to STAs
- Mesh Portal (MPP)
  - a MAP connected to a wired LAN
  - normally called a gateway and assumed to access the internet

# Routing in 802.11s

- Hybrid Wireless Mesh Protocol (HWMP) - Mandatory
  - AODV derived link-state protocol
  - Based on trees for proaction and efficiency
  - Add on-demand features (like AODV)
- Radio Aware OLSR (RA-OLSR) – Optional
  - Radio aware metrics added to MPRs in OLSR
  - optional fish-eye routing capabilities
  - association and discovery protocols for topology discovery and buildup