Lecture 7. ZigBee Communications (07/17)

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ZigBee Communications

ZigBee and 802.15.4
for
Personal Area and Sensor Networks

Z-B

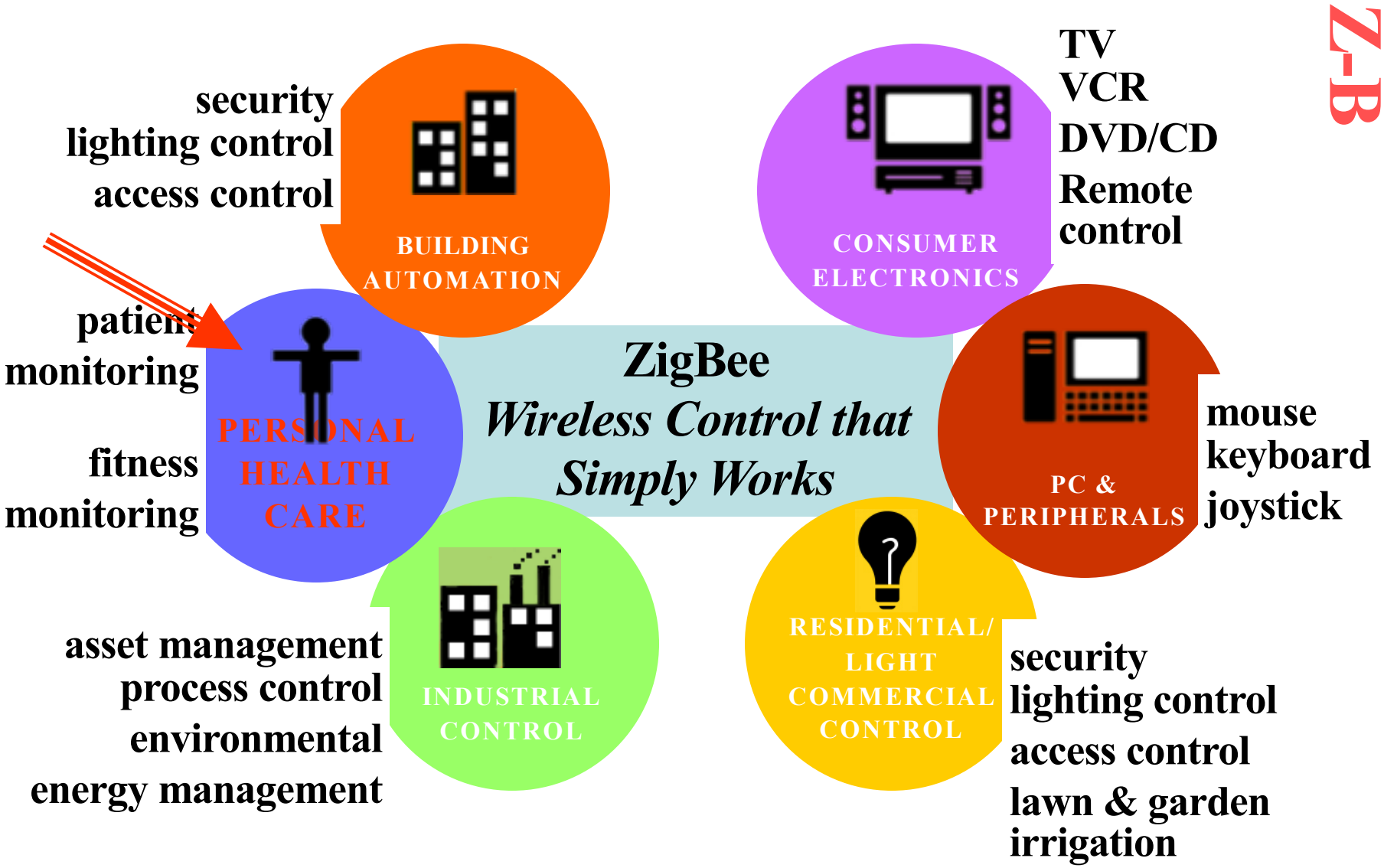
Introduction to ZigBee Communications

Z-B

- **Zigbee** is a subset of the **802.15.4** specification. This standard is completed in May 2003, and defines the specifications of the **PHY** and **MAC** layers for ZigBee.
- The IEEE 802.15.4 specification is manly designed for **command** and **control**, for maximum **200 Kbps** data rate.
- The ZigBee 1.0 specifications were defined in December 2004, and version 1.1 is now in the works.
- The distance about **70 meters.**

Applications:

low data rate wireless applications: sensor monitoring, building and home automation, other applications requiring low power consumption



MAC layer

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- 802.15.4 is a simple packet data protocol for wireless networks
  - **Channel Access**
    - **Carrier Sense Multiple Access with collision avoidance (but, NO RTS / CTS)**
  - **Message acknowledgement**
  - **The system is specified to operate in one of the three license free bands, 27 channels specified:**
    - **2.4 GHz: 16 channels, 250 kbps**
    - **902-928 MHz: 10 channels, 40 kbps**
    - **868.3 MHz : 1 channel, 20 kbps**
    - **Long battery life**

The IEEE 802.15.4 channel structure.

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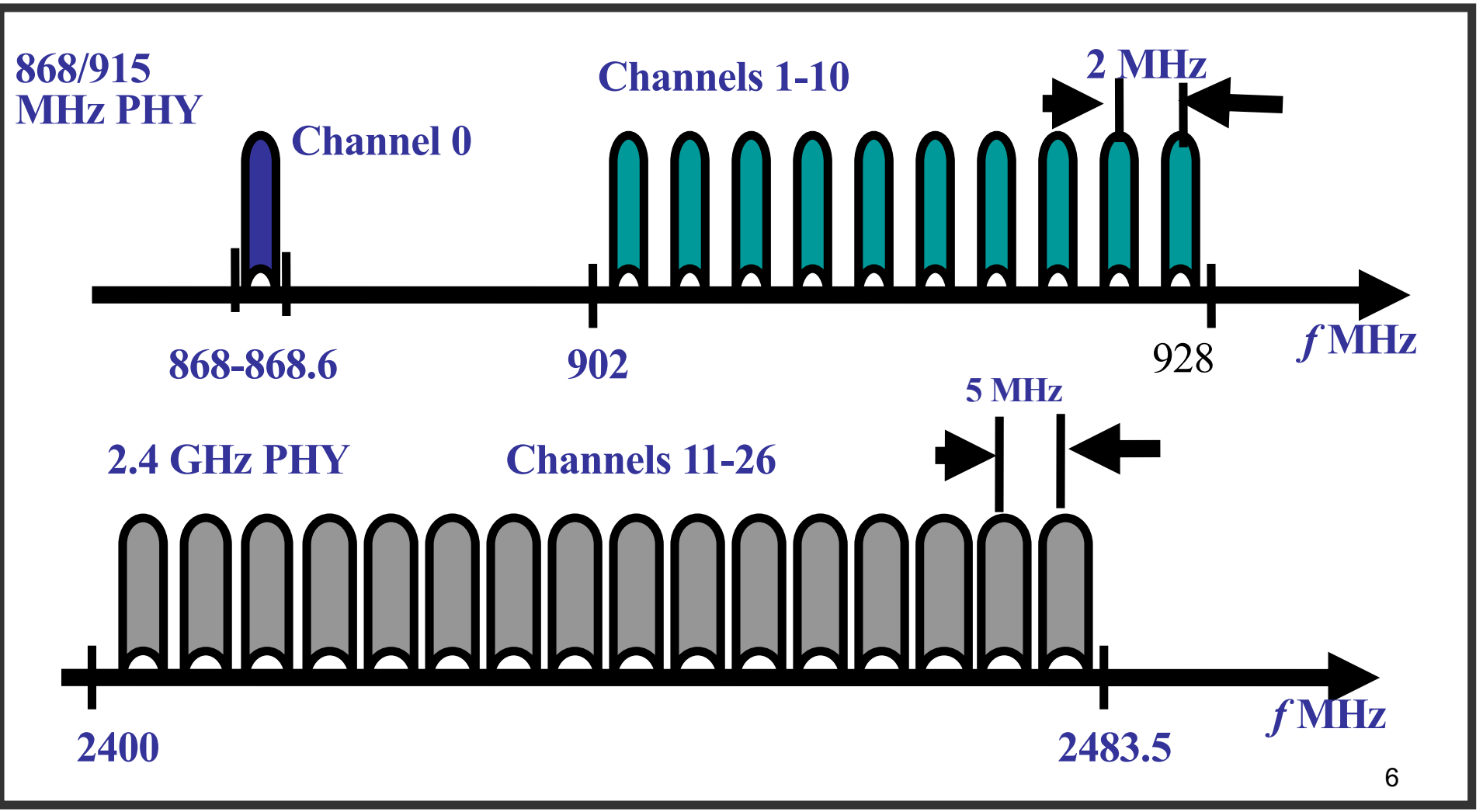
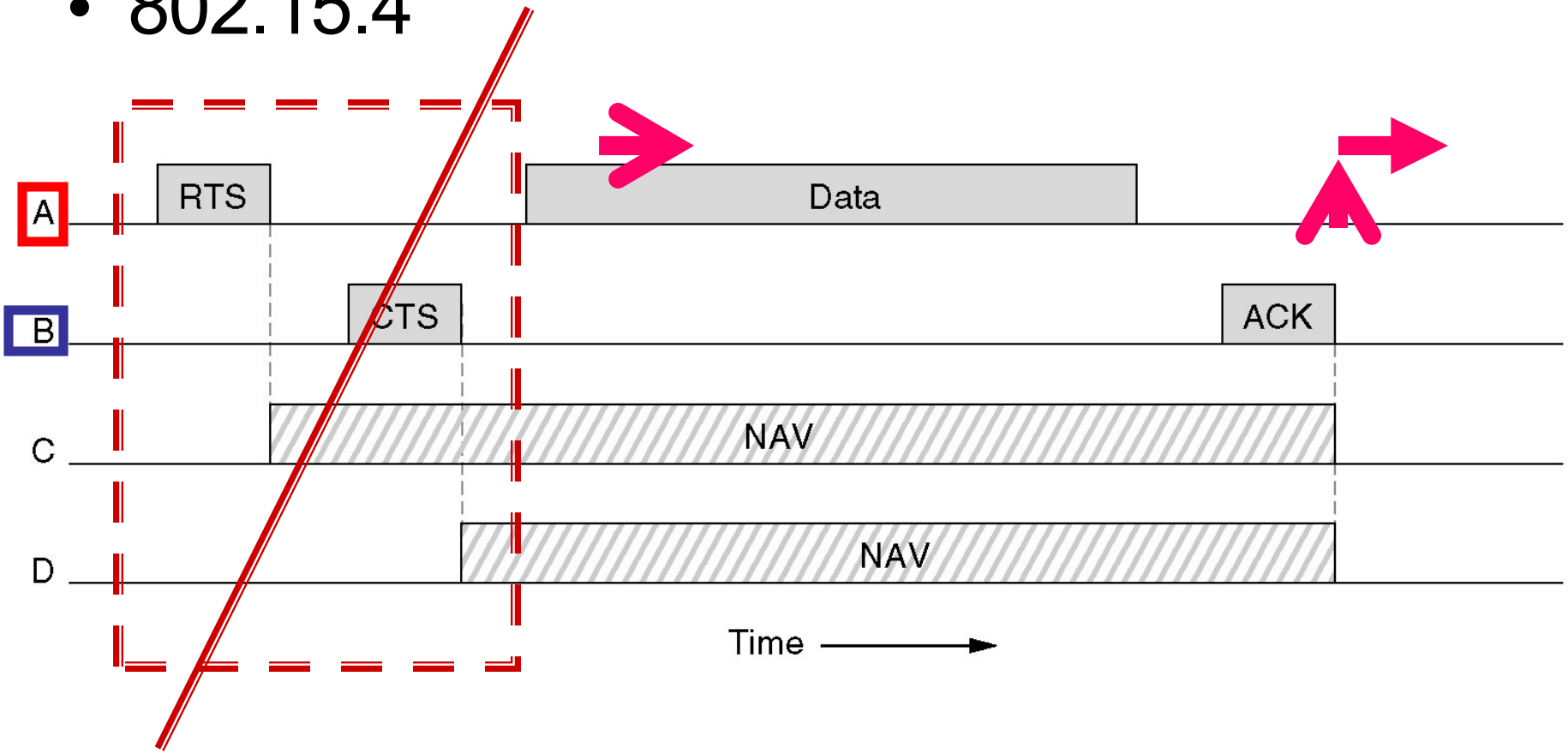


MAC layer

- 802.15.4



Physical layer

- The 868/915 MHz PHY uses a simple DSSS.
- Binary data is encoded by multiplying each m-sequence by +1 or –1, and the resulting chip sequence is modulated onto the carrier using binary phase shift keying (BPSK).
  - **The modulation techniques according to the band:**
  - **DSSS is used for spreading in all cases.**
  - **For the 868 and 915 MHz bands the modulation is BPSK.**
  - **For the 2.4 GHz band, Offset O-QPSK is employed.**

IEEE 802.15.4 modulation parameters

PHY	Frequency band	Data parameters			Spreading parameters	
		Bit rate (kb/s)	Symbol rate (kbaud)	Modulation	Chip rate (Mchips/ s)	Modulation
868/915	868-868.6 MHz	20	20	BPSK	0.3	BPSK
MHz PHY	902-928 MHz	40	40	BPSK	0.6	BPSK
2.4GHz PHY	2.4-2.4835 GHz	250	62.5	16-ary orthogonal	2.0	0-QPSK

Data transfer

- **Employs 64-bit & 16-bit short addresses**
  - **Network size can be 264 nodes (more than probably is needed)**
  - **Using local addressing, simple networks of more than 65,000 nodes can be configured.**
- **Three devices specified**
  - **Network Coordinator**
  - **Full Function Device (FFD)**
  - **Reduced Function Device (RFD)**

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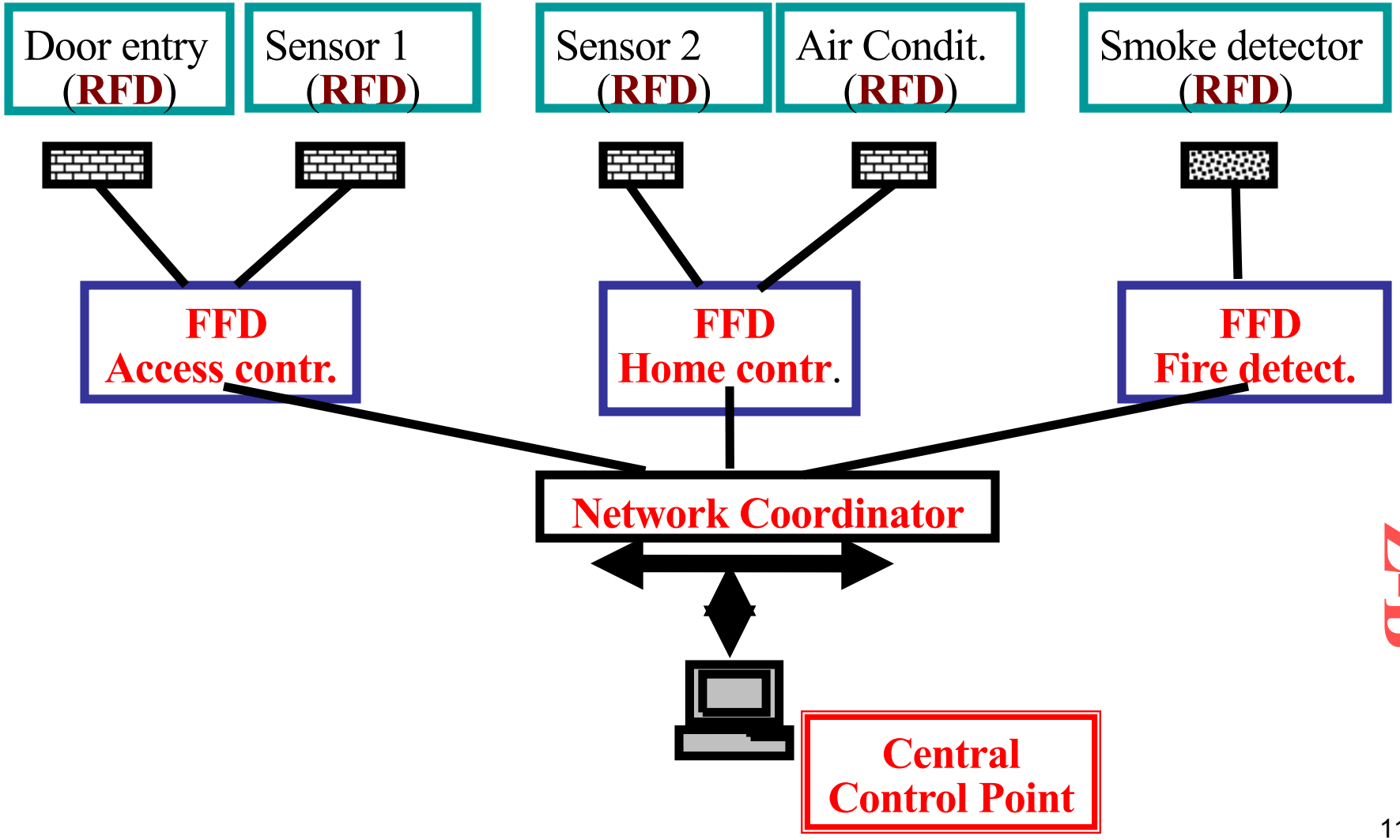
With characters:

- Simple frame structure
- Reliable delivery of data
- Association/disassociation
- **CSMA/CA** channel access. No **RTS** & **CTS**

An example of a Zig-Bee home network



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- Three device types
  - **Network Coordinator**
    - **Maintains overall network knowledge; most sophisticated of the three devices; most memory and computing power**
  - **Full Function Device (FFD)**
    - **Carries full 802.15.4 functionality and all features specified by the standard**
    - **Additional memory, computing power make it ideal for a network router function**
    - **Could also be used in network edge devices**
  - **Reduced Function Device (RFD)**
    - **Carriers limited functionality to control cost and complexity**
    - **General usage will be in network edge devices**
- A ZigBee network is supporting **1 coordinator**, with up to **254 FFDs**, and **thousands of RFDs**.

Network Coordinators

- The main-powered coordinator assumes the most important role in a ZigBee network, acting as the **root of the network tree and bringing to other networks.**
- It has the authority to **establish networks** and perform any **network management** that might be required.
- The coordinator also has **routing capability** and may serve as a **gateway to the Internet** or to other networks, and it can **store information** about the network. Because it contains the most memory, it is the most expansive of the three devices in a ZigBee network.

Reduced-Function device (RFD)

- The **simplest** ZigBee device is the RFD, also referred to as **end device**.
- It is smart enough to talk to the network but has **no routing abilities**.
- End devices are often battery powered. Typical end function as: **thermostats, humidistats, light switches, smoke detectors**, and **other sensors**.
- These end devices **do not form a mesh by themselves**, instead, they are usually asleep in order to conserve their batteries.

Full-Function device (FFD)

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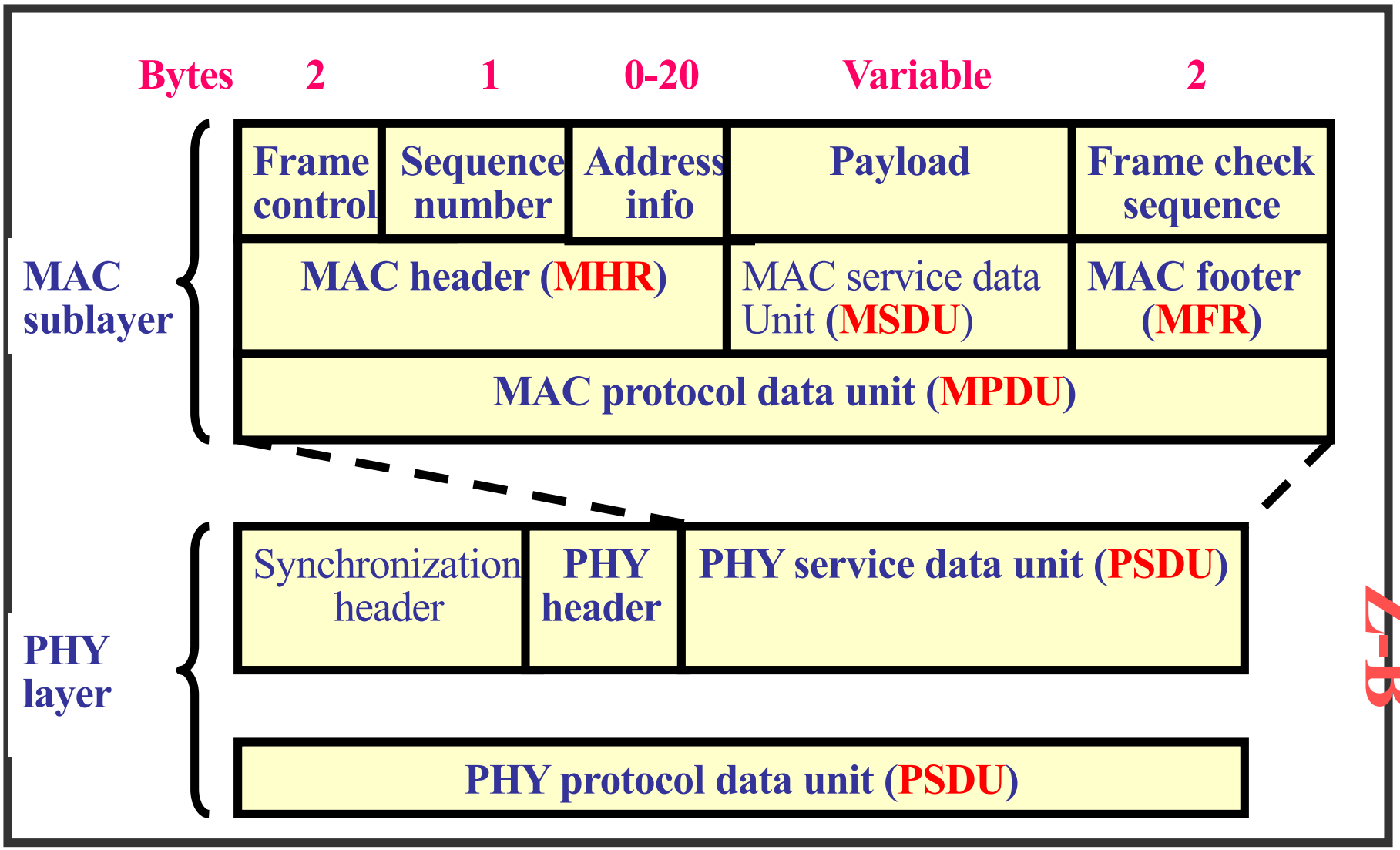
- The FFD, or **router**. It is fully network capable and **powered**.
- FFD can **establish multiple peer-to-peer links** with other routing nodes, and they **accept connections** from FFD devices, performing the role of **intermediate routers**.
- An FFD may serve as a **gateway** to the internet or other networks.

The general frame format.



The data is transferred in packets

- These have a maximum size of **128 bytes**, allowing for a maximum payload of **104 bytes**.
- The standard supports **64 bit addresses** as well as **16 bit short addresses**.
- The **64 bit addresses** uniquely identify every device (IP address).
- Once a network is set up, the short addresses can be used and this enables over **65,000 nodes** to be supported.
- It also has an optional superframe structure with a method for time synchronization.
- In addition to this it is recognized that **some messages need to be given a high priority**. This enables these high priority messages to be sent across the network as quickly as possible.

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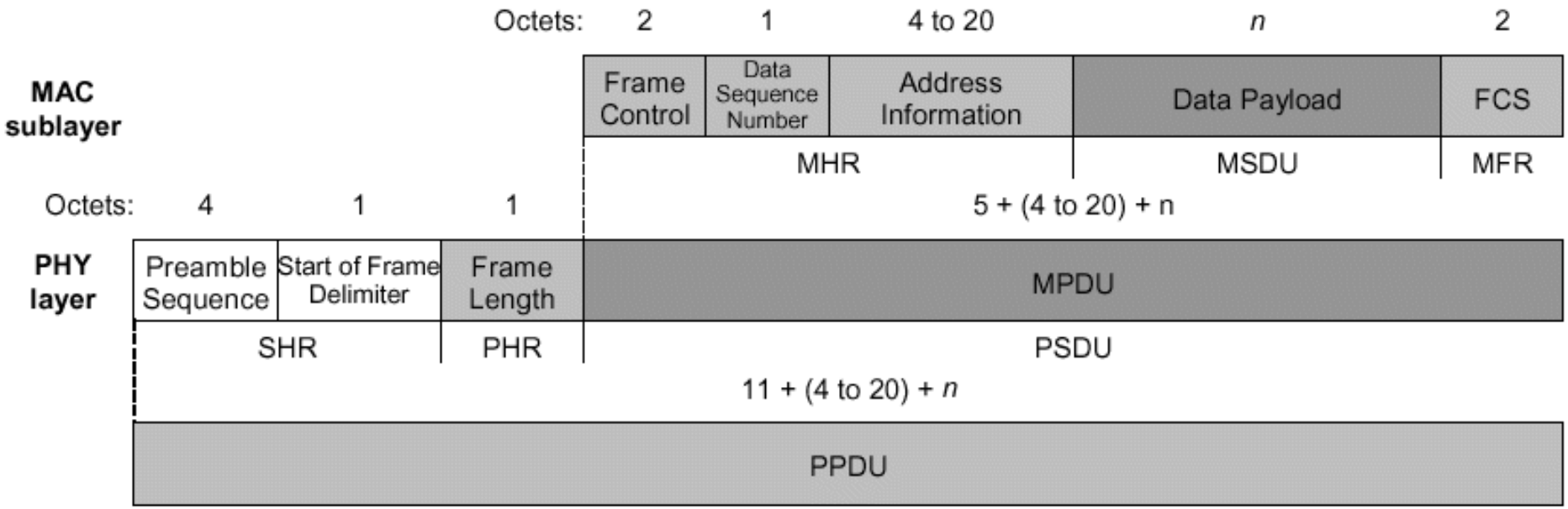
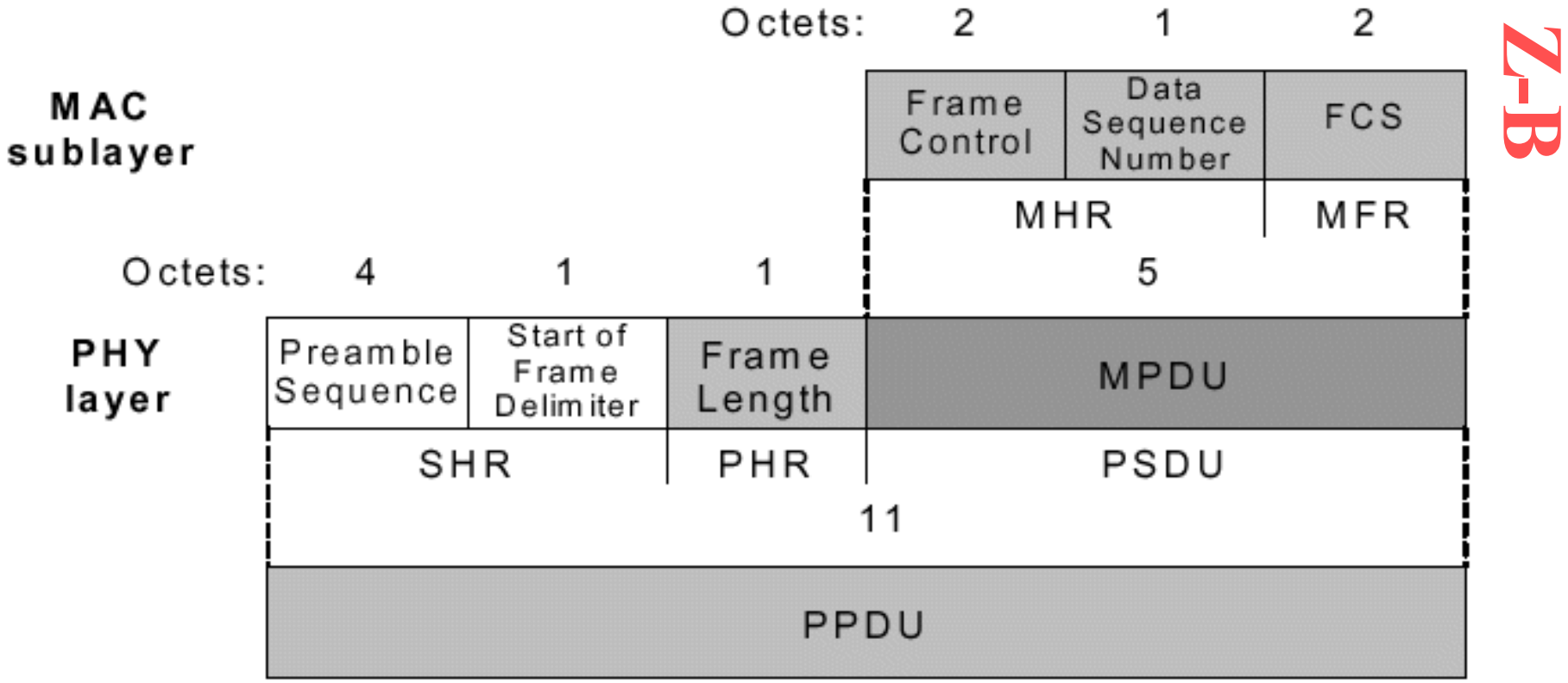
Data Frame format

Z-B



- One of two most basic and important structures in 802.15.4
- Provides up to **104 byte data payload** capacity
- Data sequence numbering to ensure that all **packets are tracked**
- Frame Check Sequence (FCS) ensures that packets received are without error

Acknowledgement Frame Format



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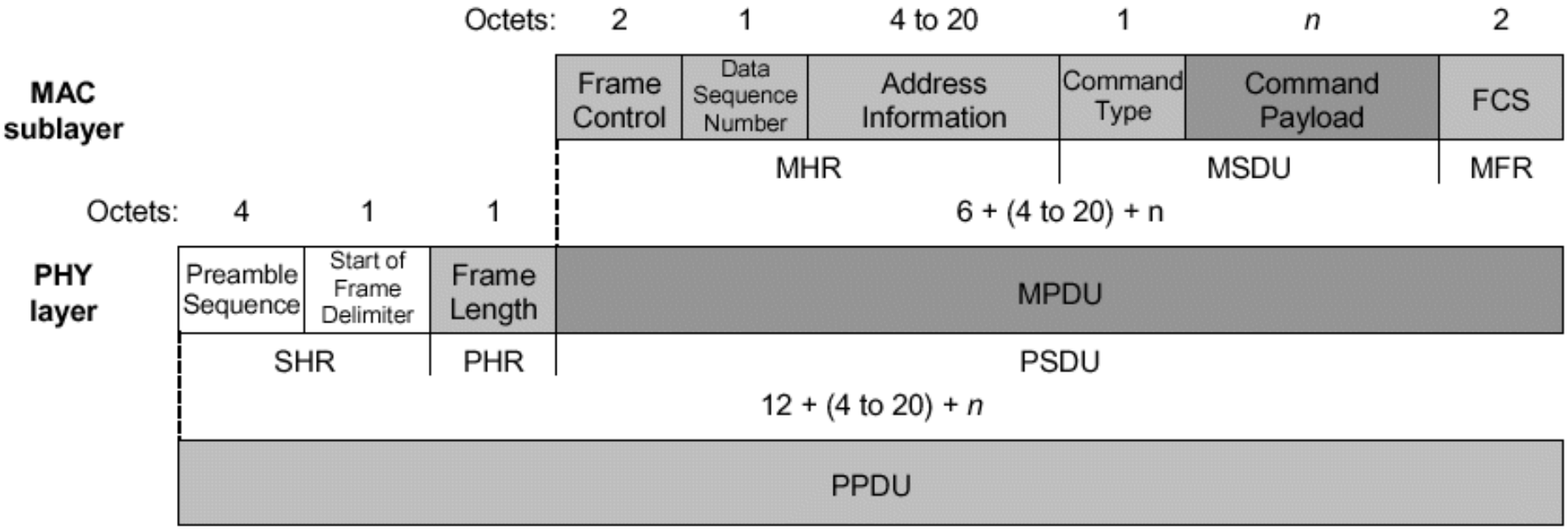
- **Provides active feedback from receiver to sender that packet was received without error**

MAC Command Frame format



- **Mechanism for remote control/configuration of client nodes**
- **Allows a centralized network manager to configure individual clients no matter how large the network**

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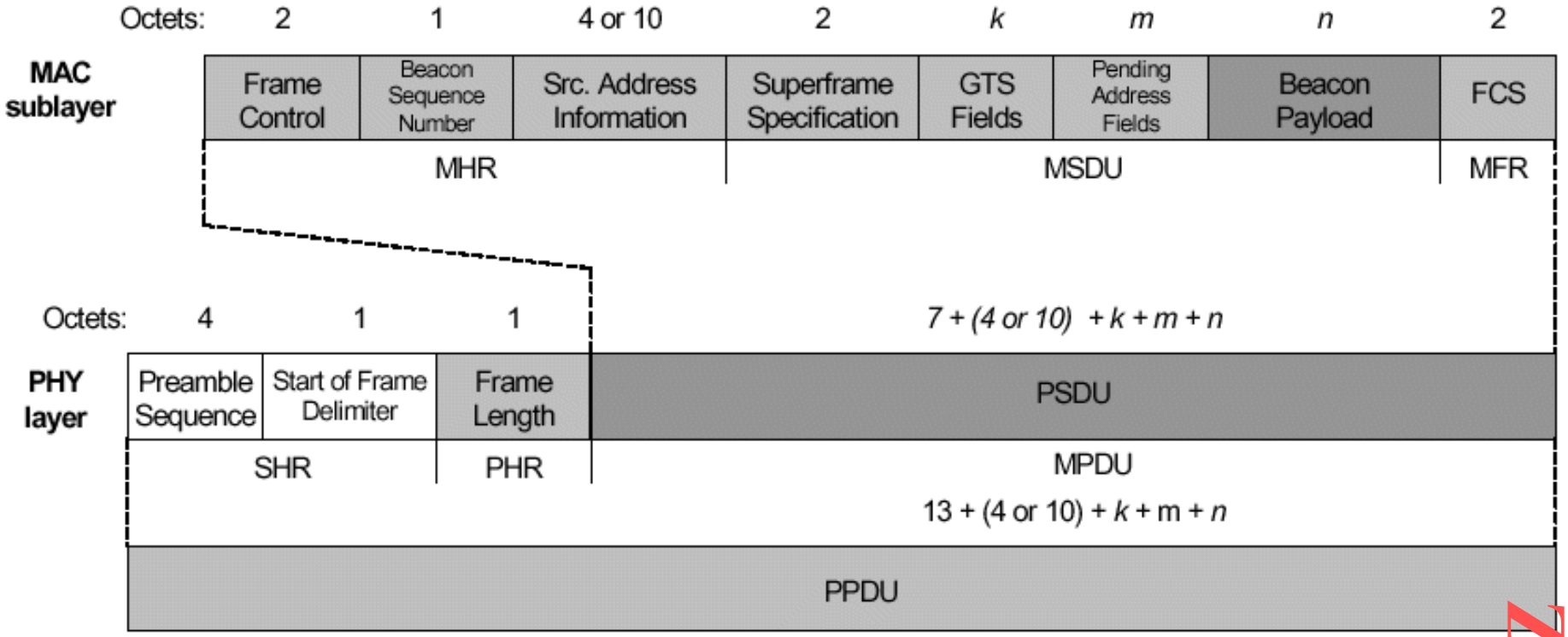
Beacon Frame format



- **Beacons add a new level of functionality to a network**
- **Client devices can wake up only when a beacon is to be broadcast, listen for their address, if not heard, return to sleep**
- **Beacons are important for mesh and cluster tree networks to keep all of the nodes synchronized without requiring nodes to consume precious battery energy listening for long periods of time**

Z-B

ZigBee Operation

- **Non-beacon network**
  - **Standard ALOHA & CSMA-CA communications**
  - **Positive ACK 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 (15.38 ms*2n where $0 \leq n \leq 14$)**
      - » **16 equal-width time slots between beacons**
      - » **Channel access in each time slot is contention free**

Z-B

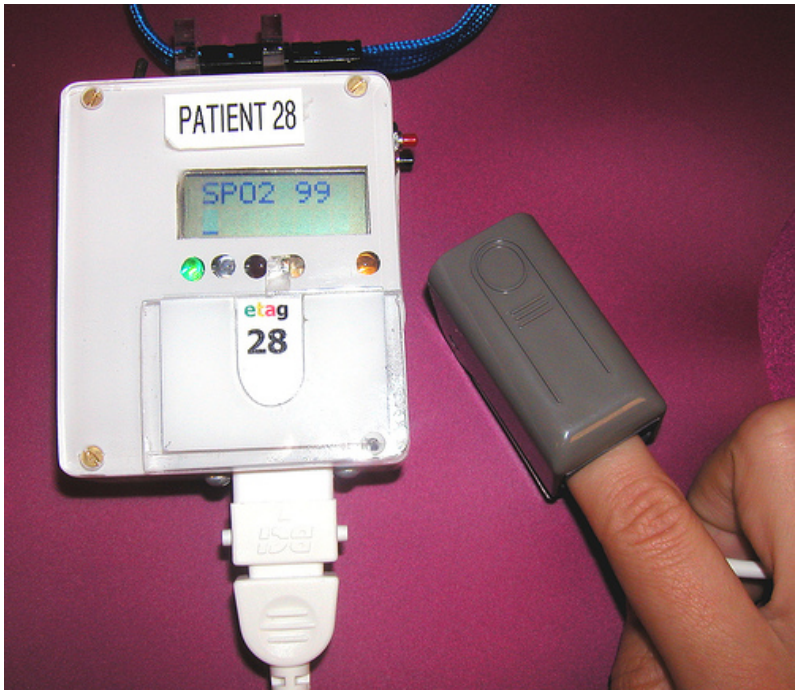
ZigBee General Characteristics

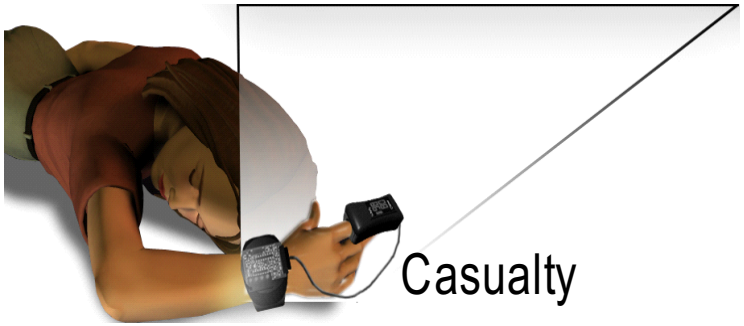
Z-B

Specification	802.15.4
Data rate	200 Kbps
Distance about	70 meters
MAC, Non-beacon	CSMA/CA, but no RTS/CRS
MAC Beacon-enabled	slotted CSMA/CA, with super-frames
Bands and Channels	868-1; 915 MHz-10 BPSK; 2.4 GHz-16 O-QPSK
Three devices	Network Coordinator-1; FFD- 254; RFD-1000
Packet size	128 bytes
Payload size	104 bytes
IEEE addresses	64 bit; short addresses 16 bit; 65,000 nodes
transmit Set up	15ms to 252sec, 16 width between beacons
Encoding	DSSS- 11 chips/ symbol
Network join time	30ms typically
Sleeping / to active	15ms typically
Active channel access	15ms typically

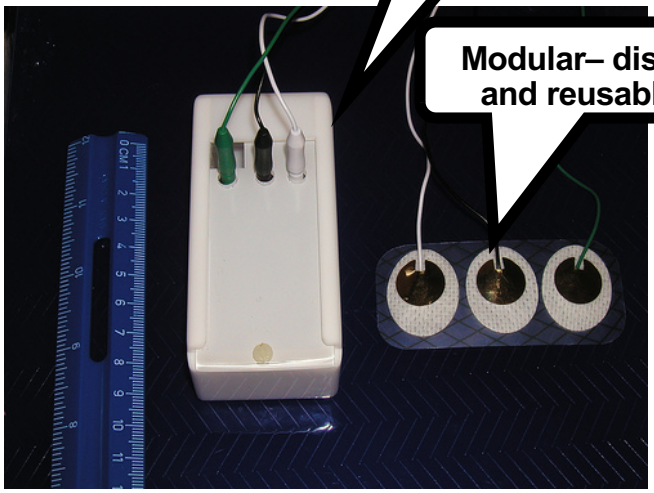
Zig Bee Application Scenarios: Noninvasive Biomedical Sensors

Z-B





Blood Pressure

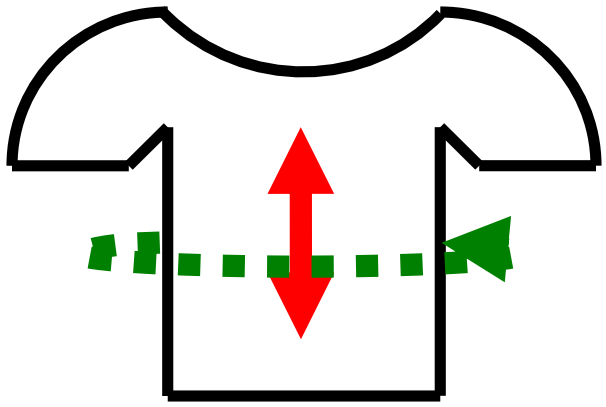


2 Lead EKG

Body Sensor Network Communication

Z-B

– Non-invasive biomedical sensors
  - Body Area Networks (BANs) have different properties than traditional wireless sensor networks (WSN).
  - Path loss affected by power level, antenna design, arm motion, and path orientation (along or across body).
  - Task: *Determine wireless propagation around the body*
– In-vivo biomedical sensors
  - Path loss due to interference from the body
  - Task: *Determine wireless propagation from within the body.*



Displaying Two Modes of Travel, Along the Body (Solid Line) and Around the Body (Dotted Line), in a Wireless Body Area Network

Z-B

ZigBee and Bluetooth

B-T

Optimized for different applications

- **ZigBee 802.15.4**
  - **Smaller packets over large network**
  - **Mostly Static networks with many, infrequently used devices**
  - **Home automation, toys, remote controls, etc.**
- **Bluetooth 802.15**
  - **Larger packets over small network**
  - **Ad-hoc networks**
  - **File transfer**
  - **Screen graphics, pictures, hands-free audio, Mobile phones, headsets, PDAs, etc.**

Transceiver Comparisons

Z-B

- **Instantaneous Power Consumption**
  - 15.4 Transceivers are "similar" to Bluetooth Transceivers
    - **802.15.4**
      - **O-QPSK with shaping (Offset QPSK)**
      - **Max data rate 250 kbps over the air**
      - **2 M.chips/s over the Direct Sequence Spread Spectrum (62.5ksps*32 spread)**
      - **-90 dBm sensitivity**
    - **Bluetooth 802.15**
      - **FSK**
      - **Max data rate 720 kbps over the air**
      - **1 Msps over the Frequency Hop Spread Spectrum (79 channels @ 1600 hps)**
      - **-85dBm sensitivity**

ZigBee and Bluetooth (cont)

Z-B

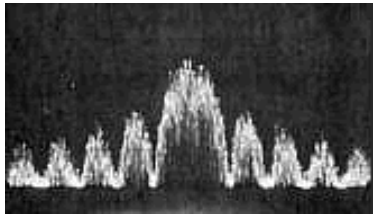
Air interface

- **ZigBee**
- **DSSS- 11 chips/ symbol**
- **62.5 K symbols/s**
- **4 Bits/ symbol**
- **Peak Information Rate**
- **~128 Kbit/second**

Bluetooth

- **FHSS**
- **1 M Symbol / second**
- **Peak Information Rate**

~720 Kbit / second



ZigBee and Bluetooth (cont)

Timing Considerations

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- **ZigBee:**
- **Network join time = 30ms** typically
- **Sleeping slave changing to active = 15ms**
- **Active slave channel access time = 15ms**

Bluetooth:

- **Network join time = >3s**
- **Sleeping slave changing to active = 3s typically**
- **Active slave channel access time = 2ms typically**

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**

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