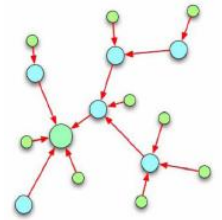


# Wireless Sensor and Actuator Networks: *Technologies, Analysis and Design*

## Air Interfaces: 802.15.4 and Zigbee

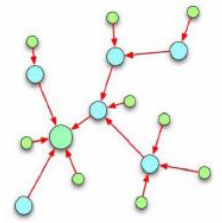
Roberto Verdone

[roberto.verdone@unibo.it](mailto:roberto.verdone@unibo.it)  
<http://www.robertoverdone.org>



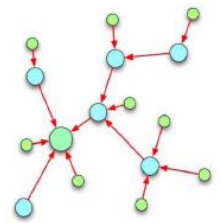
## Outline

1. **IEEE 802.11a/b/g/...**
2. **IEEE 802.15.1 (Bluetooth)**
3. **IEEE 802.15.4 and Above**
4. **IEEE 802.15.4° (UWB)**



# Section 1

## IEEE 802.11a/b/g/...

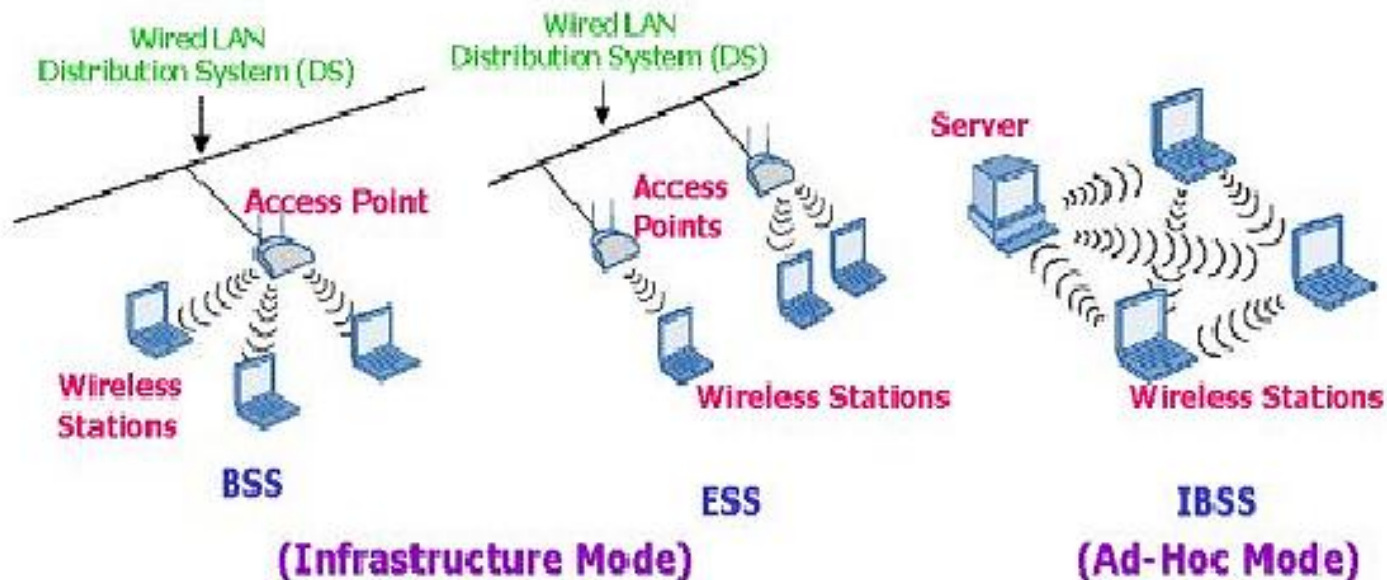


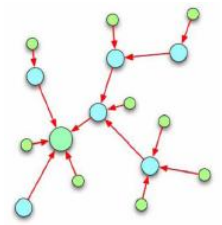
## IEEE 802.11

The IEEE 802.11 groups (a/b/...) standardised different systems, operating in different bands, with various data rates.

802.11 systems are not a good solution for WSNs, as they are not optimised for low-energy and low-complexity devices.

However, they represent a viable solution for wireless ad hoc networks.

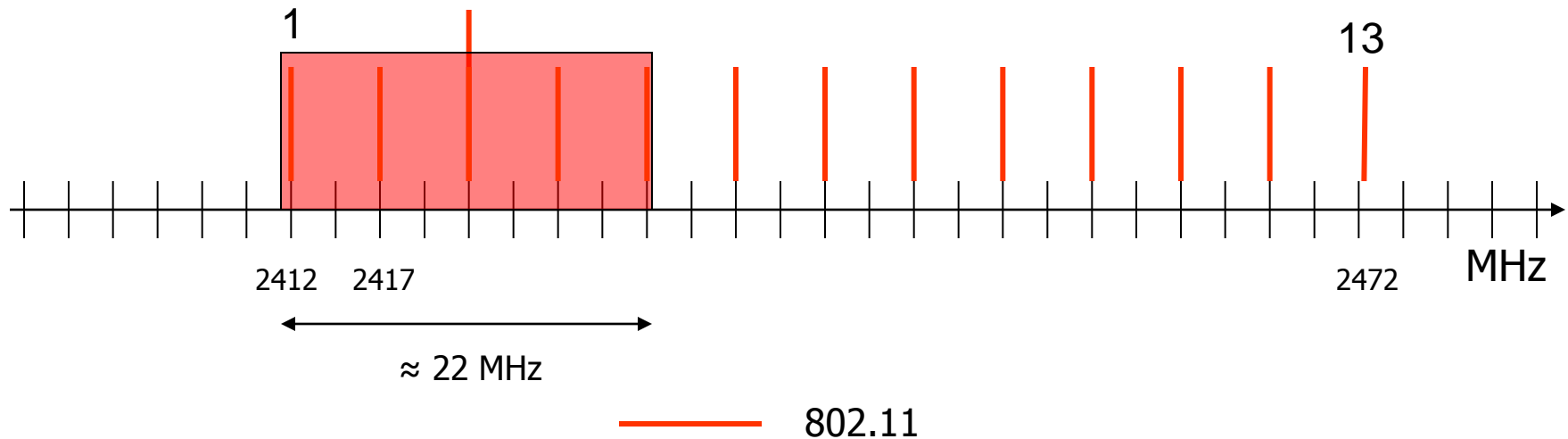


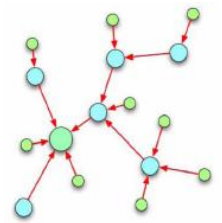


## IEEE 802.11a/b/g - PHY

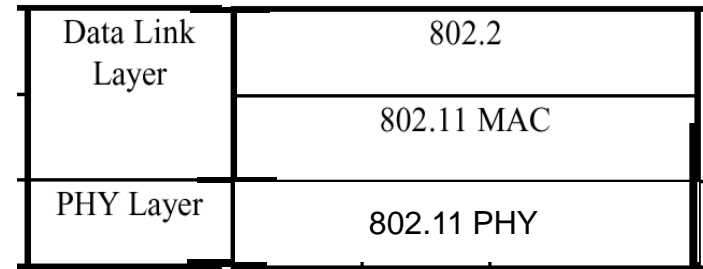
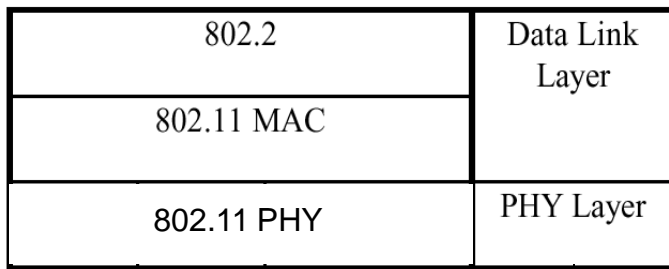
Different Modulation techniques → different nominal P2P bit rates  
Different frequency bands (2.4 GHz, 5.8 GHz)

802.11b	Bandwidth of about 22 MHz @ 2.4 GHz	11 Mbit/s
802.11g	Bandwidth of about 22 MHz @ 2.4 GHz	54 Mbit/s
802.11a	Bandwidth of about 22 MHz @ 5.2 – 5.8 GHz	54 Mbit/s

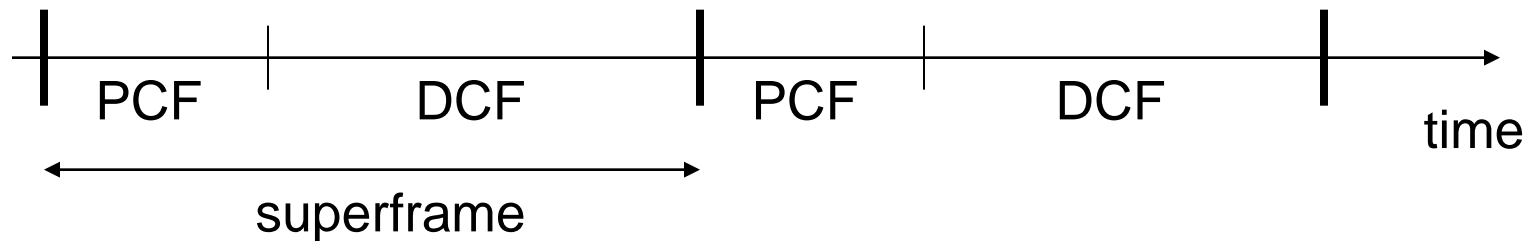




# IEEE 802.11a/b/g



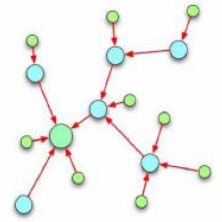
- DCF: contention based (CSMA/CA).
- PCF (optional): collision free



DCF: Distributed Coordination Function

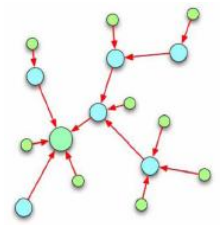
PCF: Point Coordination Function

(polling by Access Point)



# Section 2

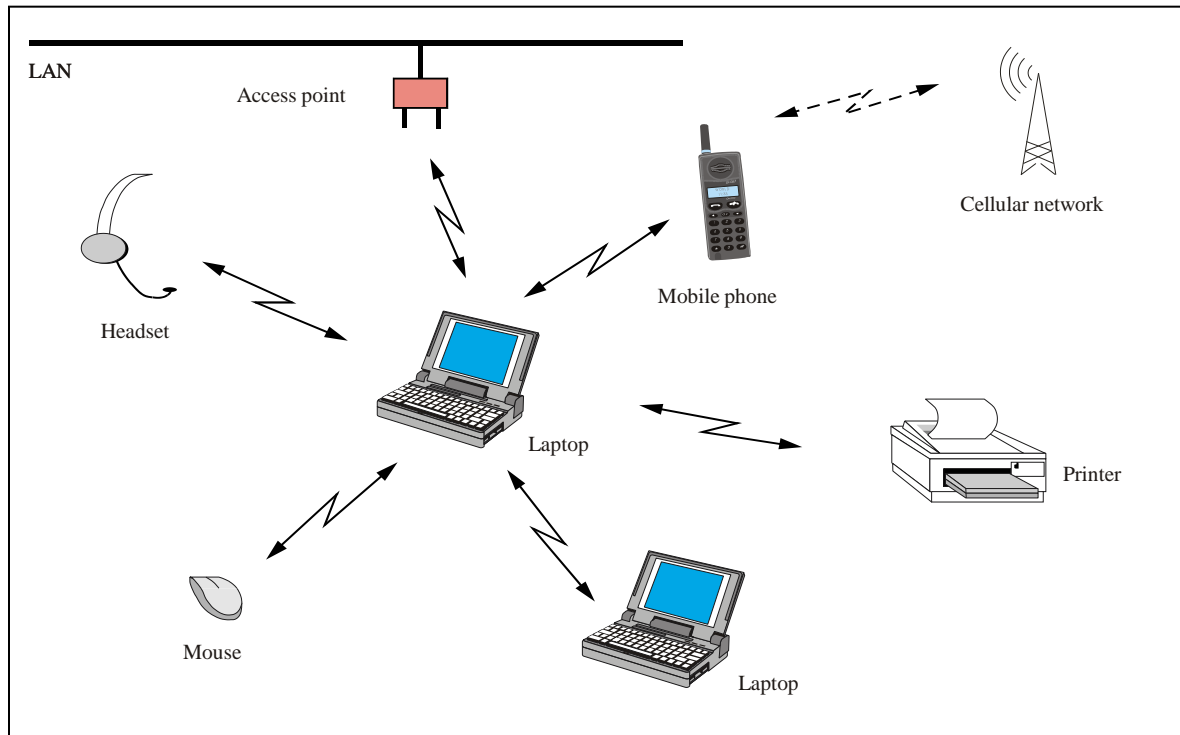
## IEEE802.15.1 (Bluetooth)



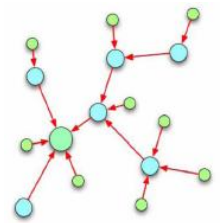
## IEEE 802.15.1 (Bluetooth)

A number of platforms exist implementing Bluetooth technology, that can be used for WSNs.

Bluetooth v1.2 was released in 2005 and provides P2P bit rates up to 720 Kbit/s







## IEEE 802.15.1 (Bluetooth)

ISM BAND @ 2.4 GHz

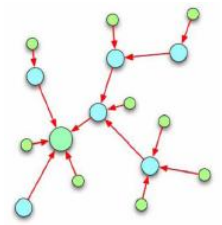
PHY:

GFSK ( $B_b T = 0.5$ )

$0.28 < h < 0.35$

$R_b = 1 \text{ Mb/s}$

CLASSES	OUTPUT POWER	RANGE (free space)
1	20 dBm	~ 100 m
2	4 dBm	~ 50 m
3	0 dBm	~ 10 m

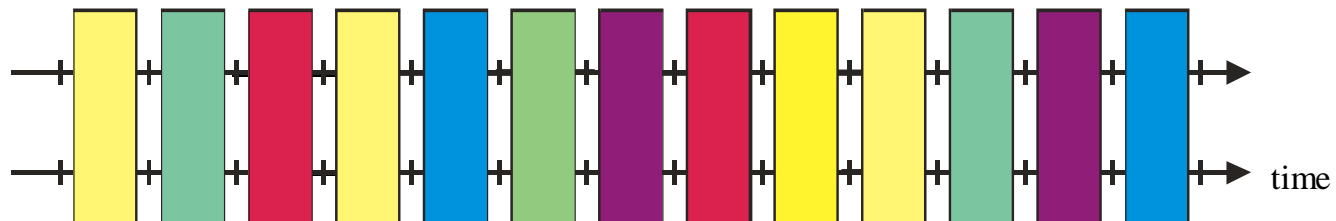
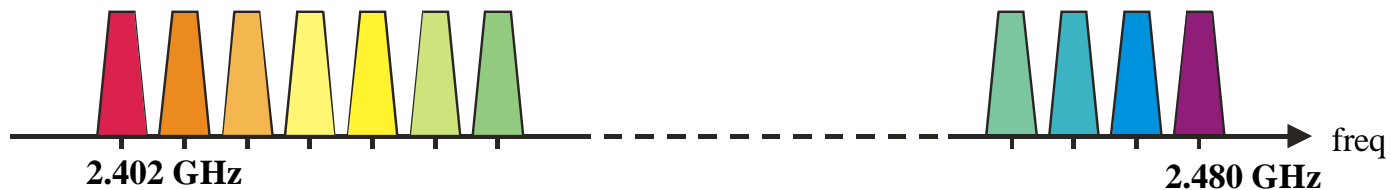


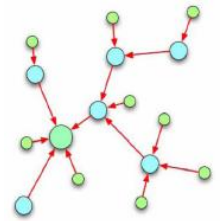
## IEEE 802.15.1 (Bluetooth)

PHY:

79 channels, 1 MHz each ( $f_c = 2402 + K$  MHz;  $K = 0, 1, \dots, 78$ )

Frequency hopping (1600 hops/s)



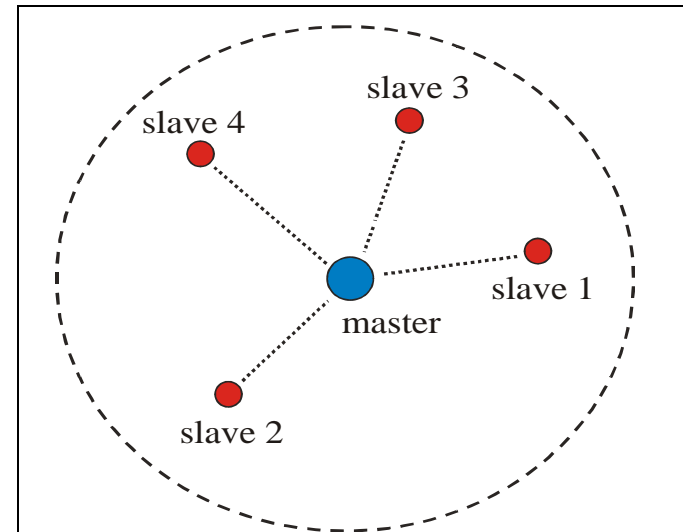


# IEEE 802.15.1 (Bluetooth) – Network Topologies

## PICONET

Star topology

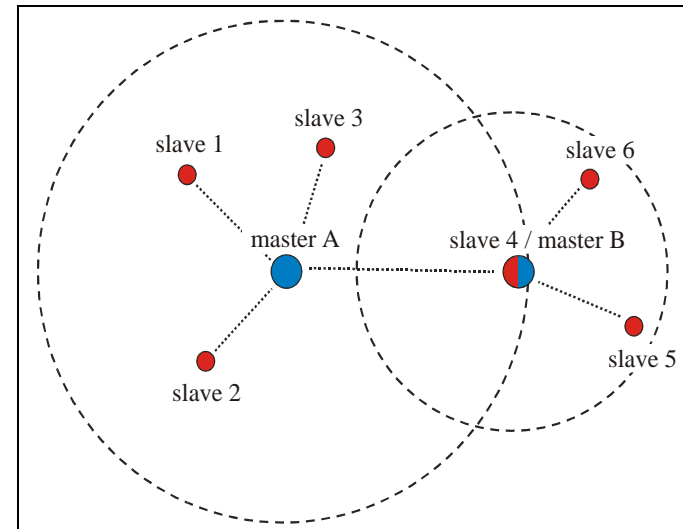
Maximum 7 Slaves

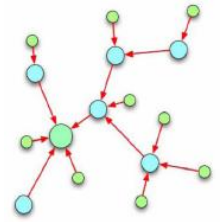


## SCATTERNET

Clusters

Trees





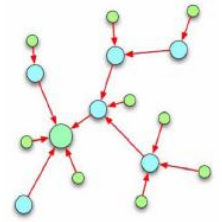
## IEEE802.15.1 (Bluetooth) – After v1.2

802.15.1 v1.2 is not energy efficient. Usually, devices have just two modes: active, and idle.

802.15.1 v2.0 aims at better energy efficiency and Enhanced Data Rate (EDR) through the use of a different modulation format. P2P bit rate up to 2.1 Mbit/s.

802.15.1 v3.0 will use UltraWideBand techniques.

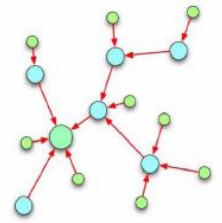
WiBree – a low cost, low distance, low energy, low size option with same PHY as 802.15.1 v1.2



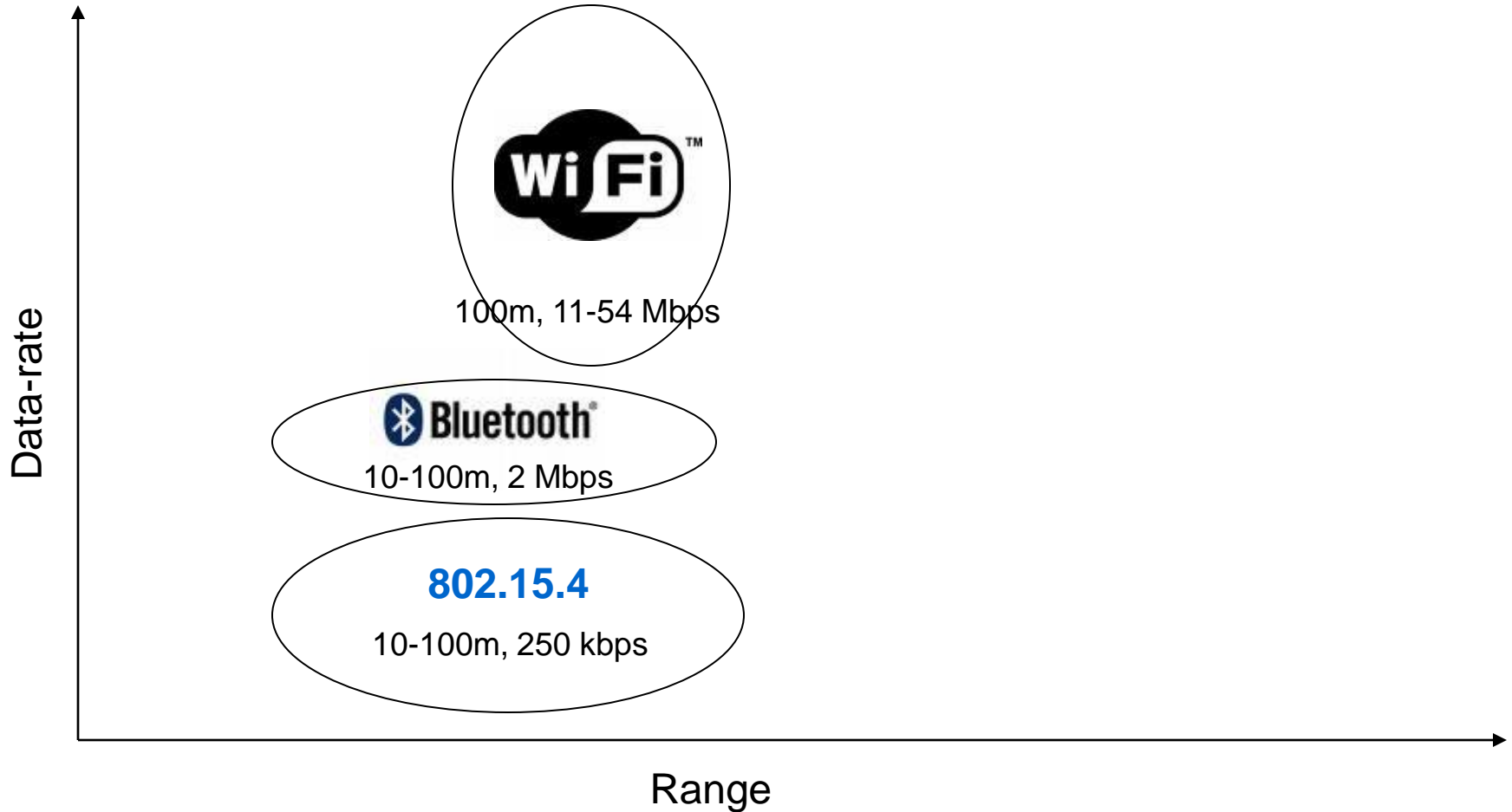
# Section 3

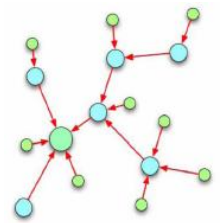
## IEEE 802.15.4 and Above

802.15.4  
Zigbee  
6lowpan



# IEEE 802.15.4

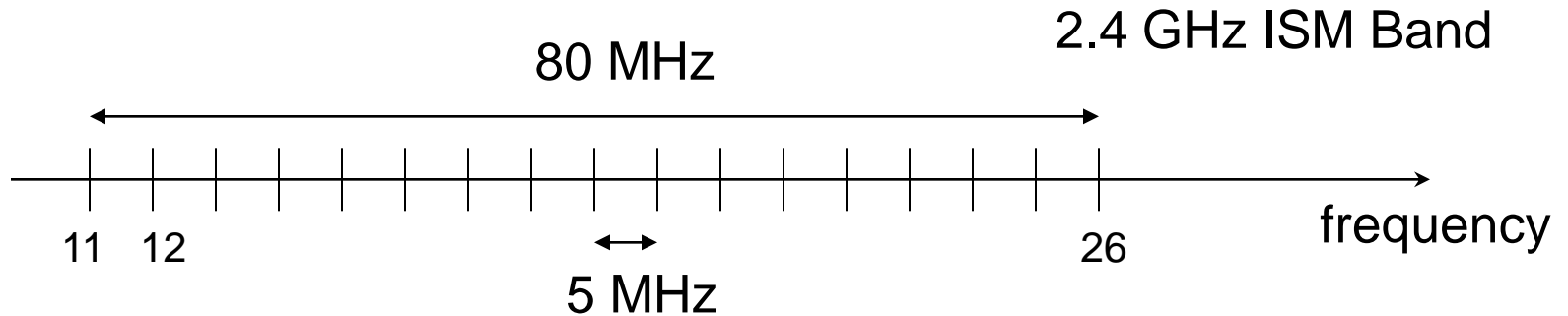


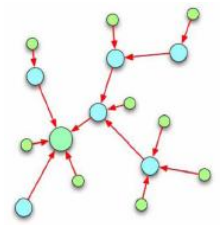


# IEEE 802.15.4 - Bands

PHY	Frequency Band	Channels	parameters		parameters		
			Chip rate	Modulation	Bit rate	Symbol rate	From bits to symbols
800/915 MHz	868-870 MHz	0	300 kchip/s	BPSK	20 kb/s	20 kbaud	Binary
	902- 928 MHz	From 1 to 10	600 kchip/s	BPSK	40 kb/s	40 kbaud	Binary
2.4 GHz	2.4-2.4835 GHz	From 11 to 26	2.0 Mchip/s	O-QPSK	250 kb/s	62.5 kbaud	16-ary Orthogonal

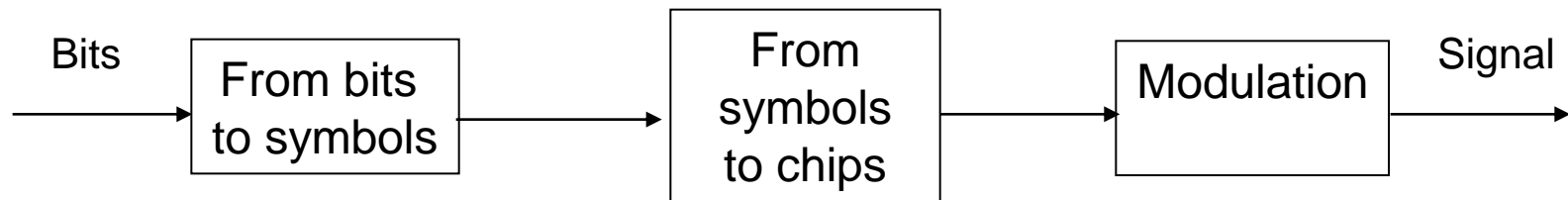
16 channels, 5 MHz each



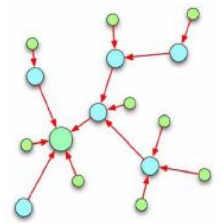


# IEEE 802.15.4 - PHY

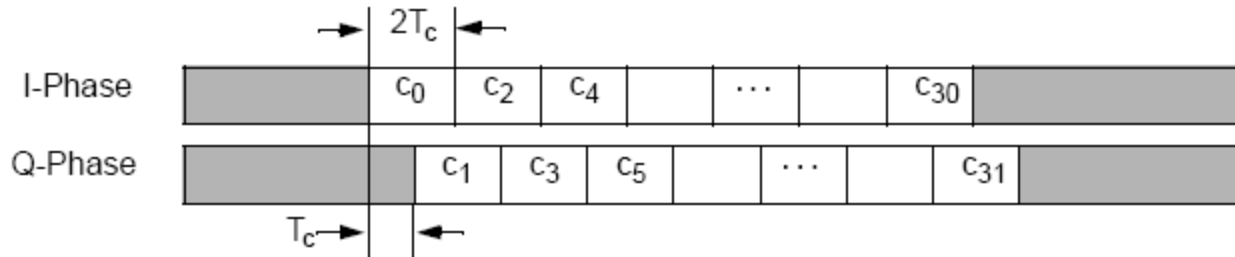
PHY	Frequency Band	Channels	parameters		parameters		
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800/915 MHz	868-870 MHz	0	300 kchip/s	BPSK	20 kb/s	20 kbaud	Binary
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2.4 GHz	2.4-2.4835 GHz	From 11 to 26	2.0 Mchip/s	O-QPSK	250 kb/s	62.5 kbaud	16-ary Orthogonal



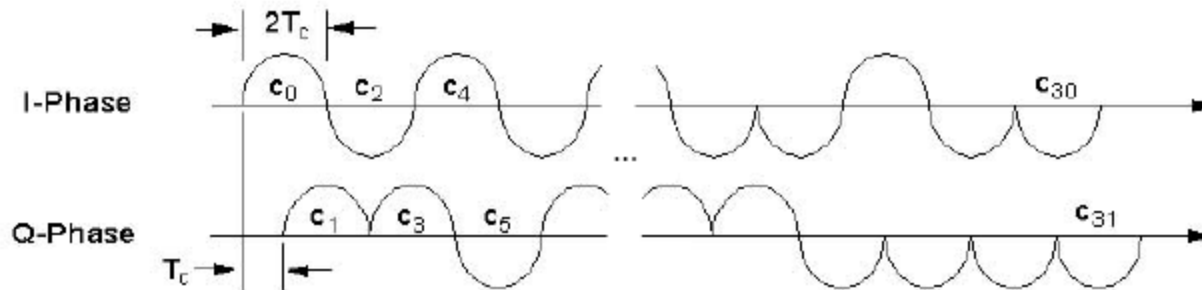




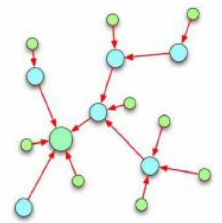
# IEEE 802.15.4 - PHY



$$p(t) = \begin{cases} \sin\left(\pi \frac{t}{2T_c}\right), & 0 \leq t \leq 2T_c \end{cases}$$



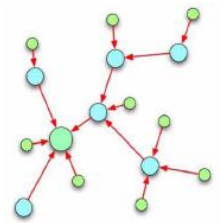
**MSK**



# IEEE 802.15.4 - PHY

Table 20—Symbol-to-chip mapping

Data symbol (decimal)	Data symbol (binary) ( $b_0, b_1, b_2, b_3$ )	Chip values ( $c_0 c_1 \dots c_{30} c_{31}$ )
0	0000	11011001110000110101001000101110
1	1000	11101101100111000011010100100010
2	0100	00101110110110011100001101010010
3	1100	00100010111011011001110000110101
4	0010	01010010001011101101100111000011
5	1010	00110101001000101110110110011100
6	0110	11000011010100100010111011011001
7	1110	10011100001101010010001011101101
8	0001	10001100100101100000011101111011
9	1001	10111000110010010110000001110111
10	0101	01111011100011001001011000000111
11	1101	01110111101110001100100101100000
12	0011	00000111011110111000110010010110
13	1011	01100000011101111011100011001001
14	0111	10010110000001110111101110001100
15	1111	11001001011000000111011110111000



# IEEE 802.15.4 - PHY

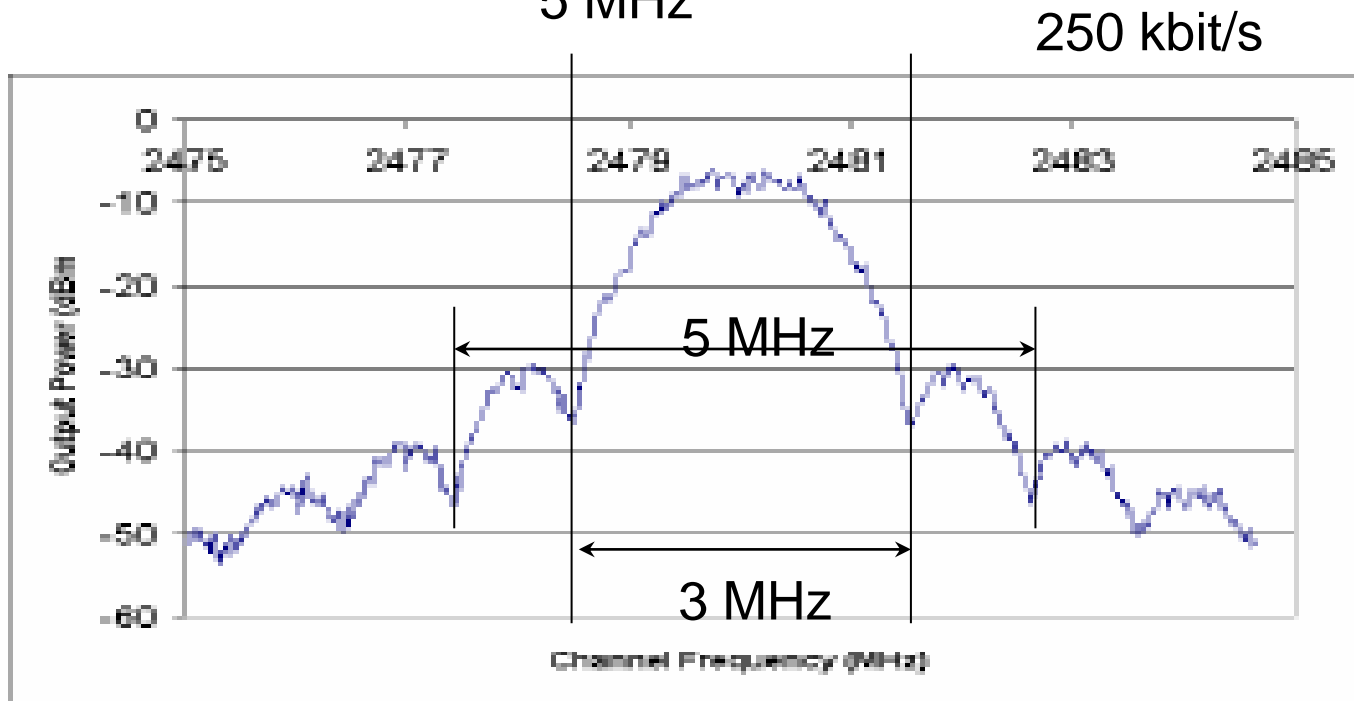
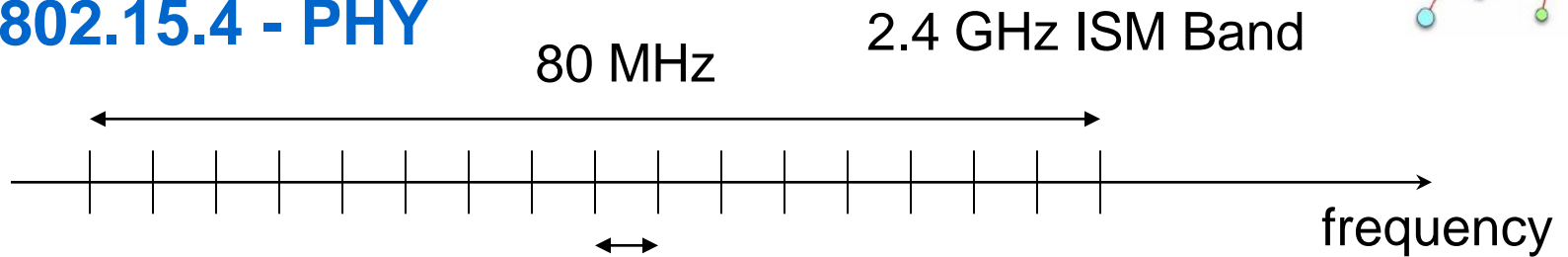
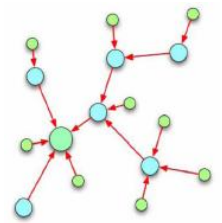
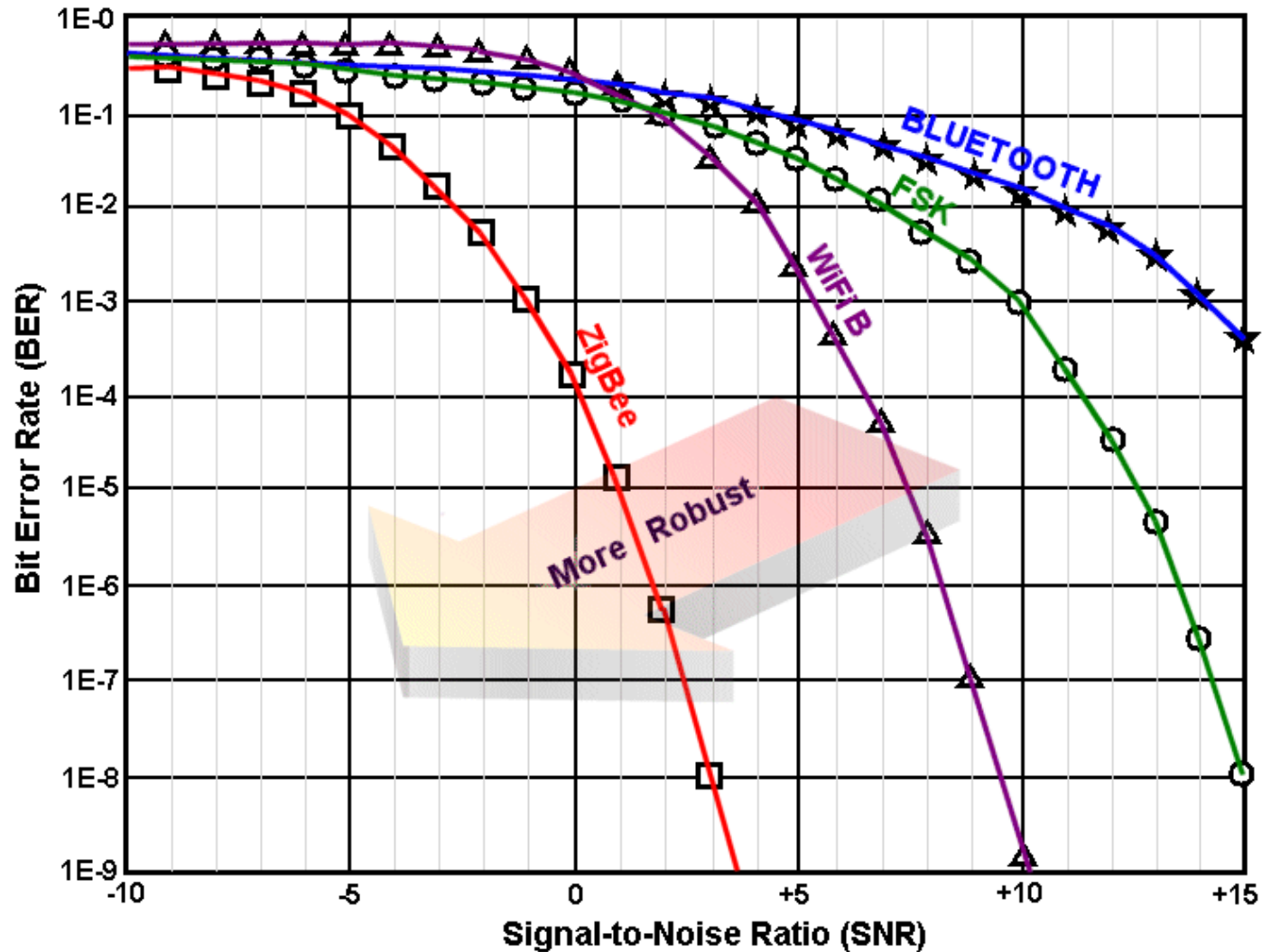


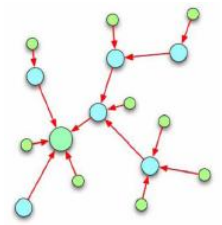
Figure 4. Modulated ZigBee Spectrum

Maximum Transmission Range about 100 mt (ground level)



# IEEE 802.15.4 - PHY

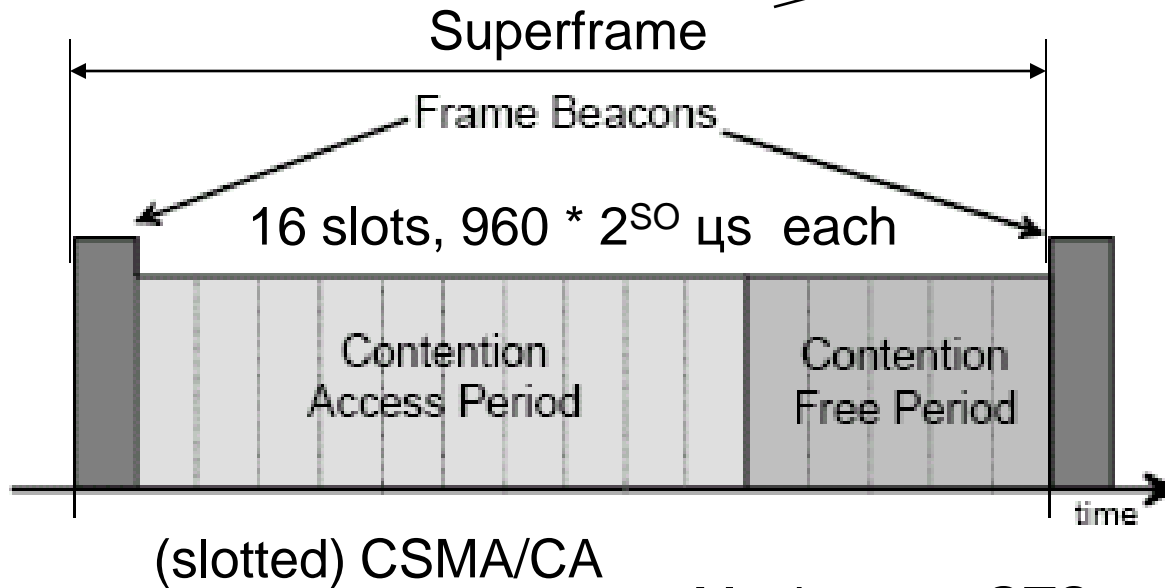




# IEEE 802.15.4 - MAC

## Beacon-Enabled Mode

Approx. duration: 15 ms – 250 s

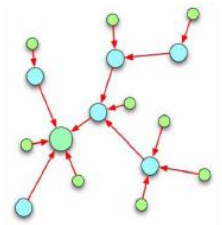


SO = 0, 1, ..., 14  
[Superframe Order]

Maximum 7 GTSs  
(Granted Time Slots)

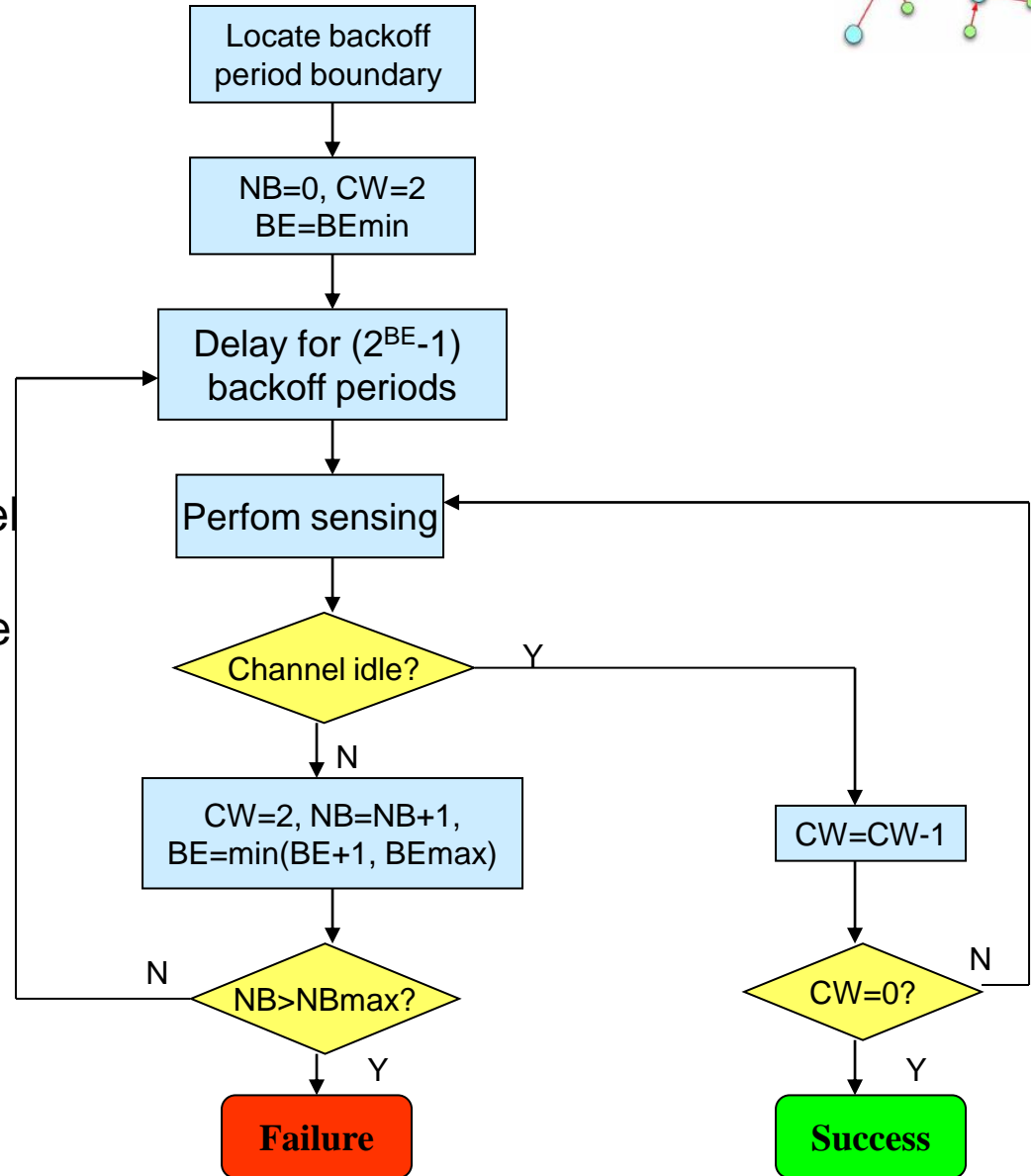
## Non Beacon-Enabled Mode

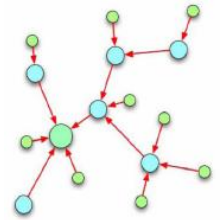
Only CAP, with (unslotted) CSMA/CA



# Beacon-Enabled Mode: slotted CSMA/CA

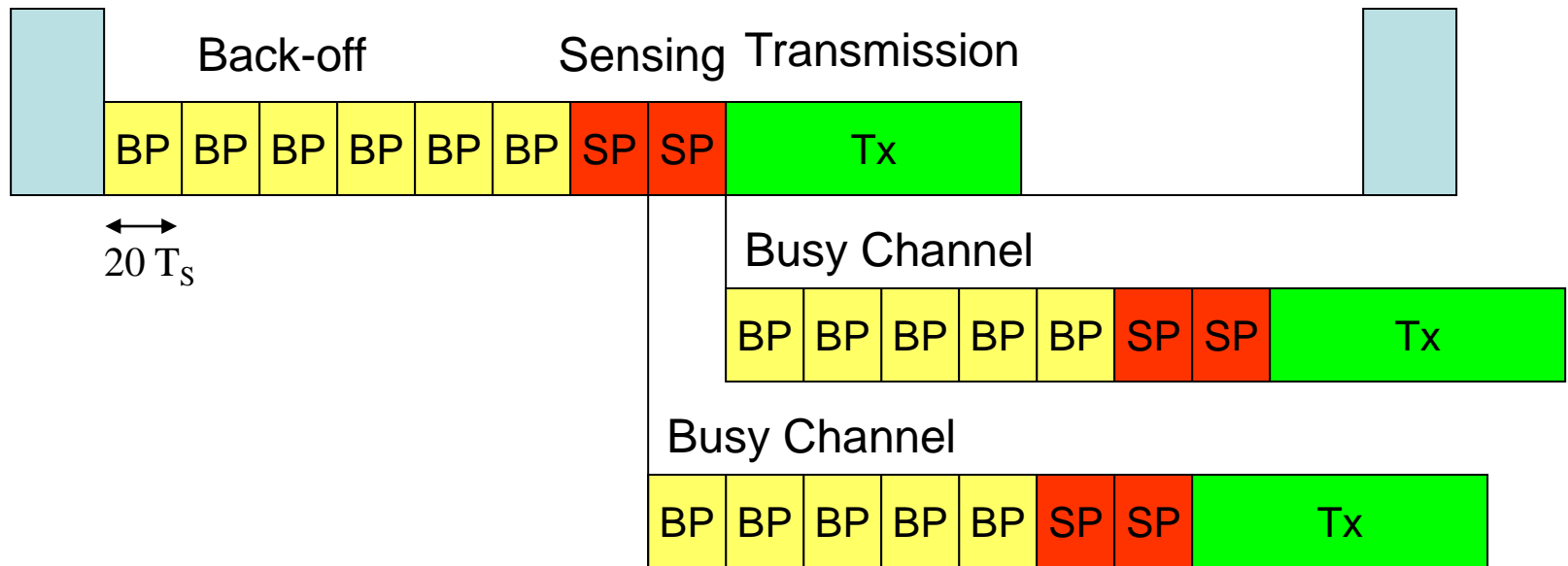
- NB counts the number of times the node tries to access the channel
- BE used to derive the backoff time
- CW used so that two sensing phased are performed before the transmission





# Beacon-Enabled Mode: slotted CSMA/CA

Beacon

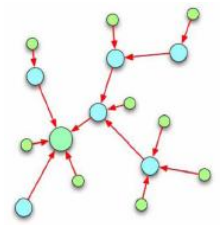


Back-off Time = random  $[0, 2^{BE}-1]$ \* Back-off Period

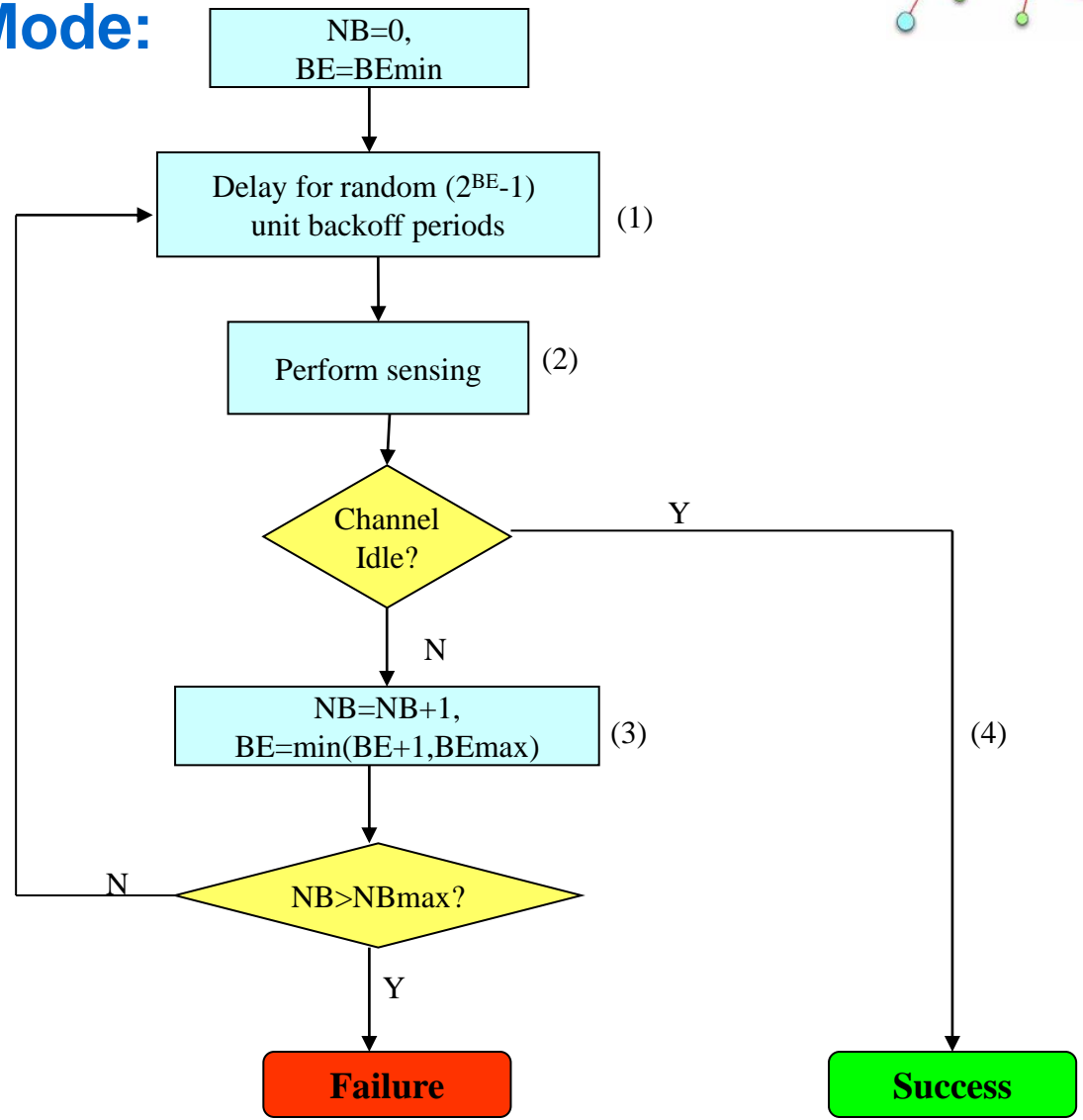
Back-off Period =  $20 T_s$

Sensing Period =  $20 T_s$

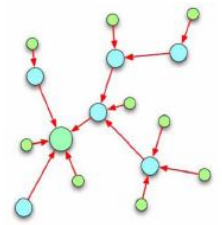
$T_s$  (symbol period)= $16\mu s$ .



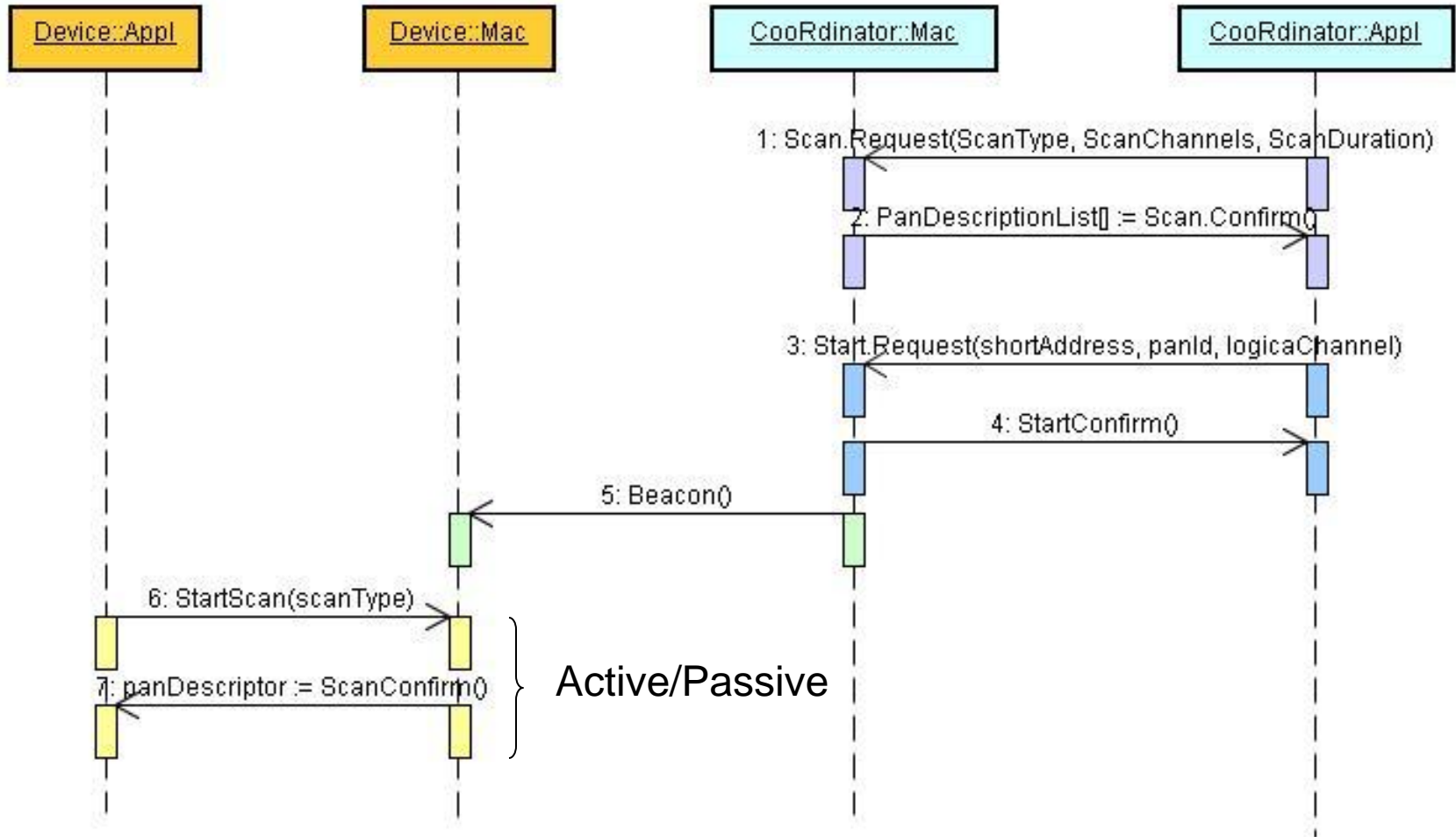
# Non Beacon-Enabled Mode: unslotted CSMA/CA

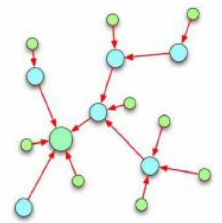




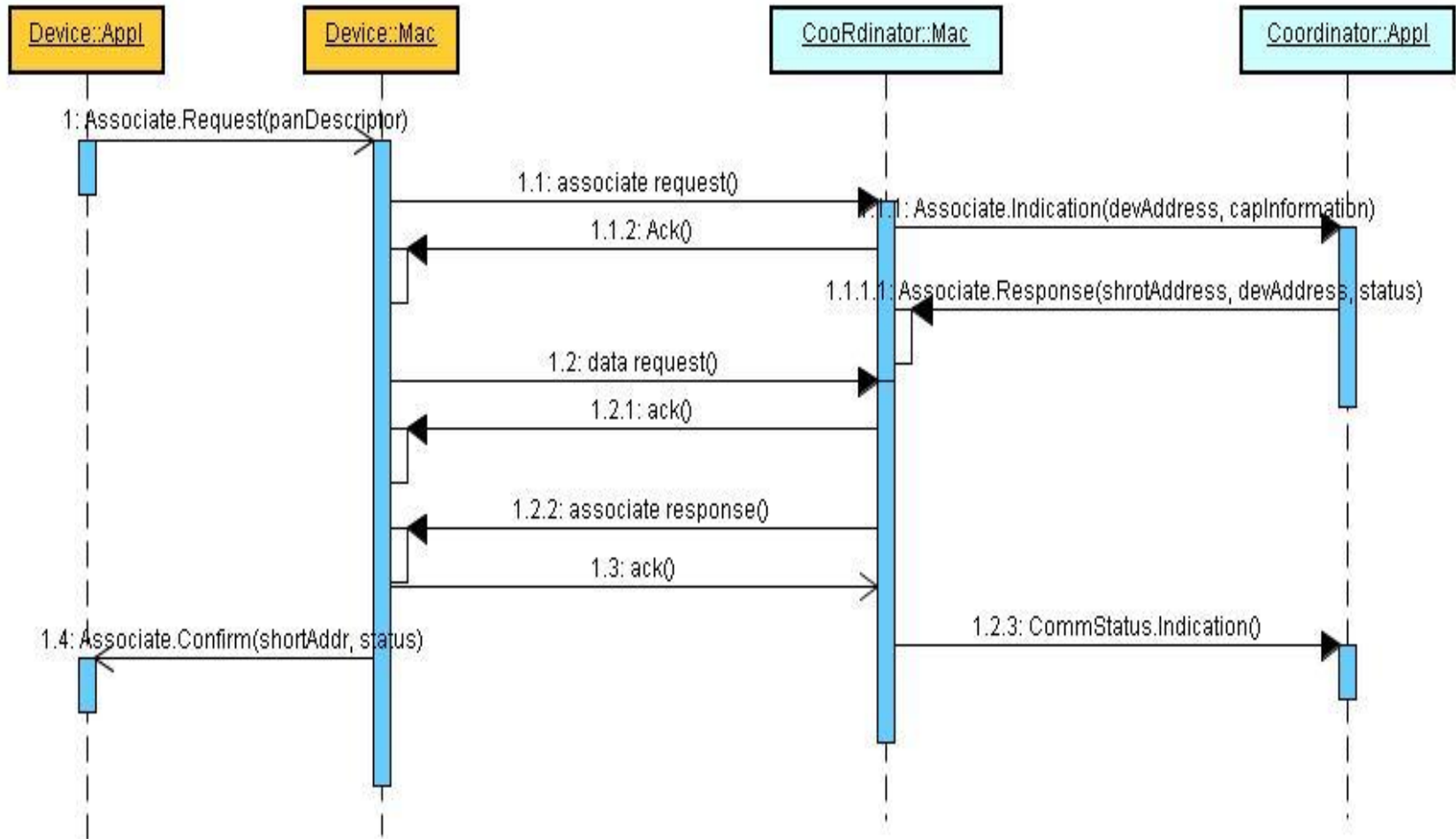


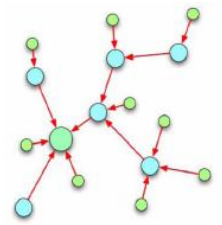
# IEEE 802.15.4 – Node Association





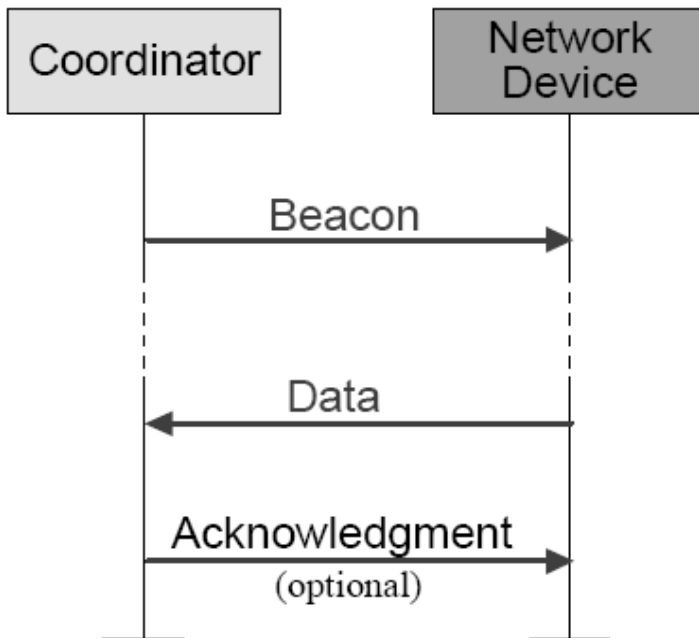
# IEEE 802.15.4 – Node Association



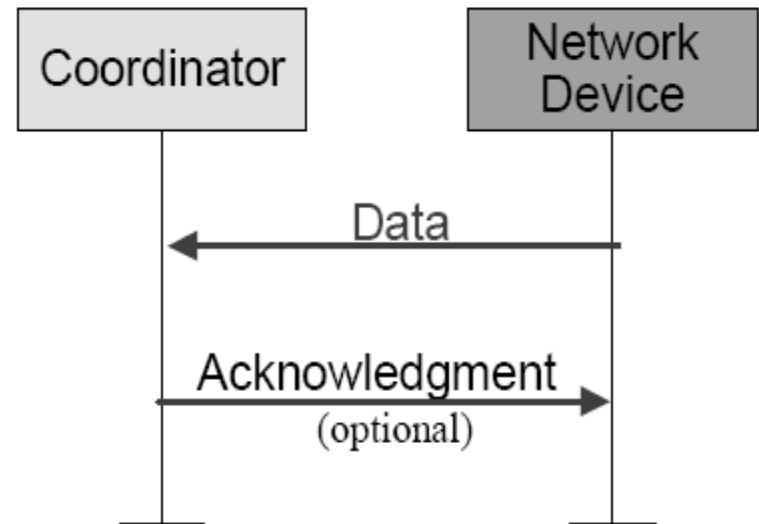


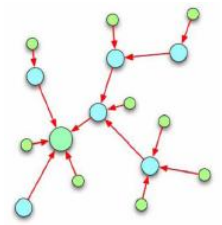
# IEEE 802.15.4 – Data Exchange

## Beacon-Enabled Net



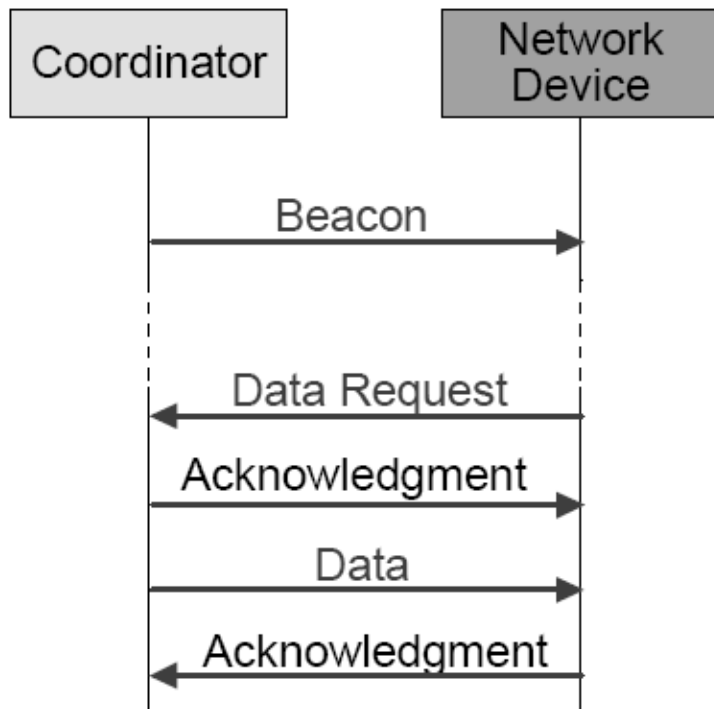
## Non Beacon-Enabled Net



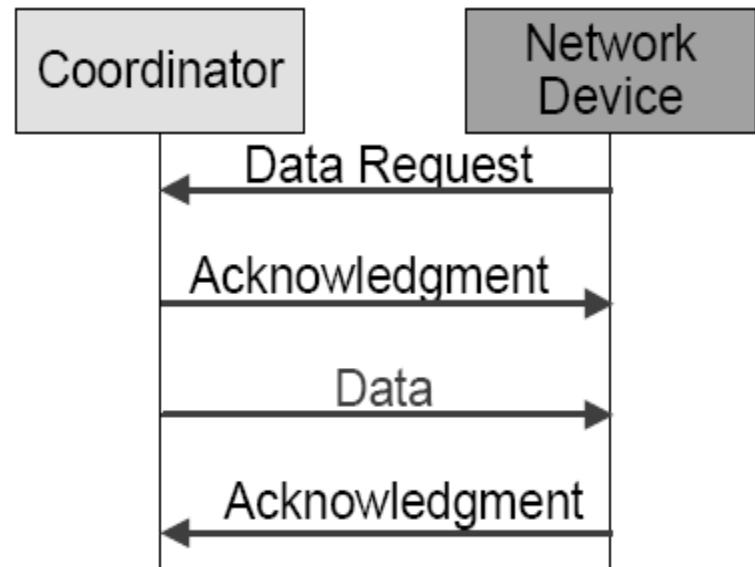


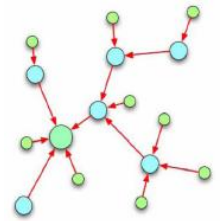
# IEEE 802.15.4 – Data Exchange

## Beacon-Enabled Net



## Non Beacon-Enabled Net





## IEEE 802.15.4 – Addressing and Error Check

### ADDRESSES

Extended, 64 bits

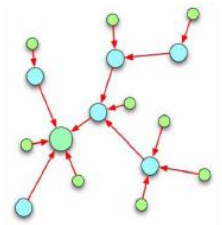
(more than 128 billion devices).

Short, 16 bits

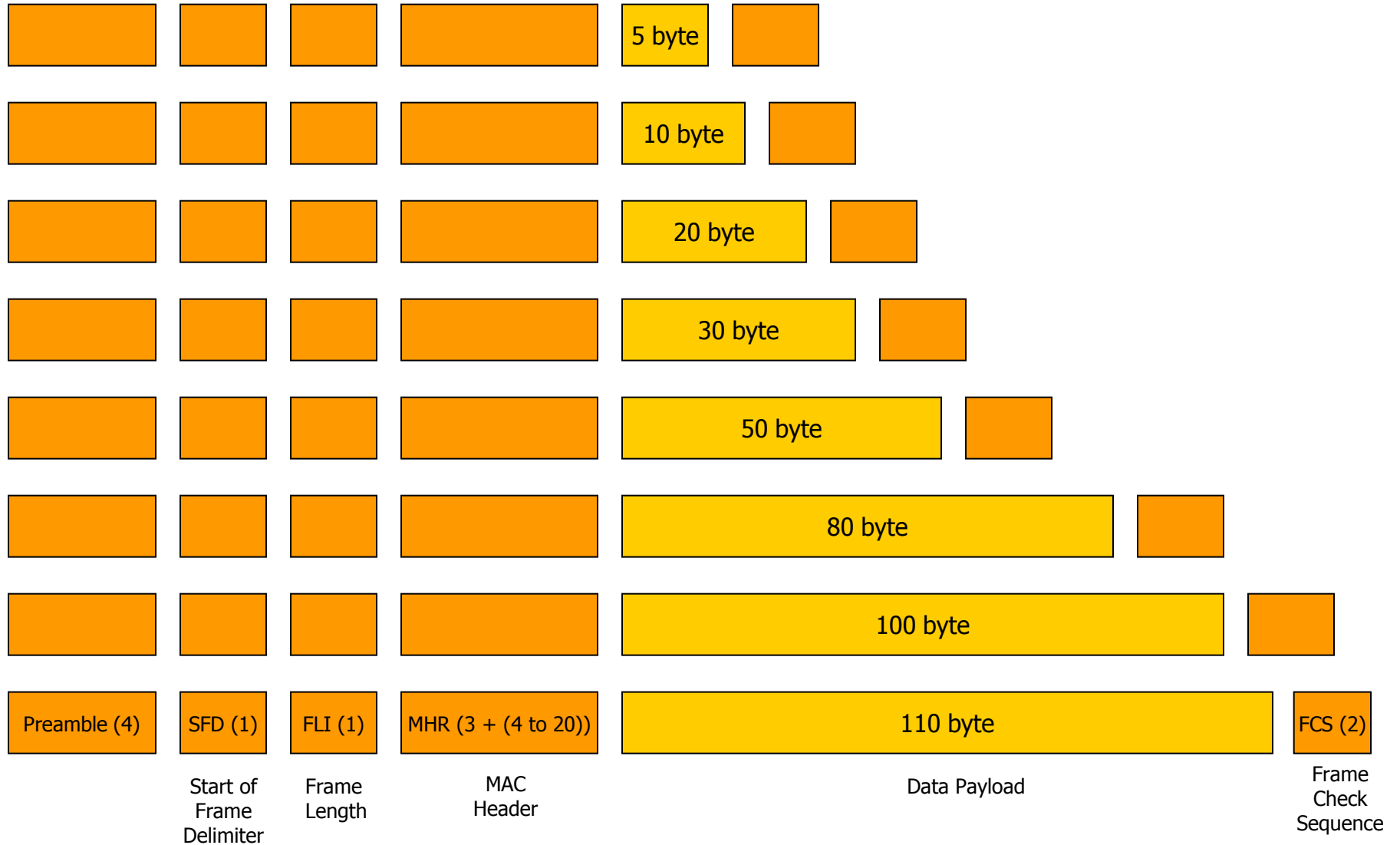
(more than 65000 devices connected to one coordinator)

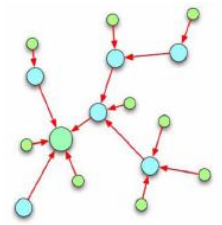
### FCS

CRC with  $G(x) = x^{16} + x^{12} + x^5 + 1$  .

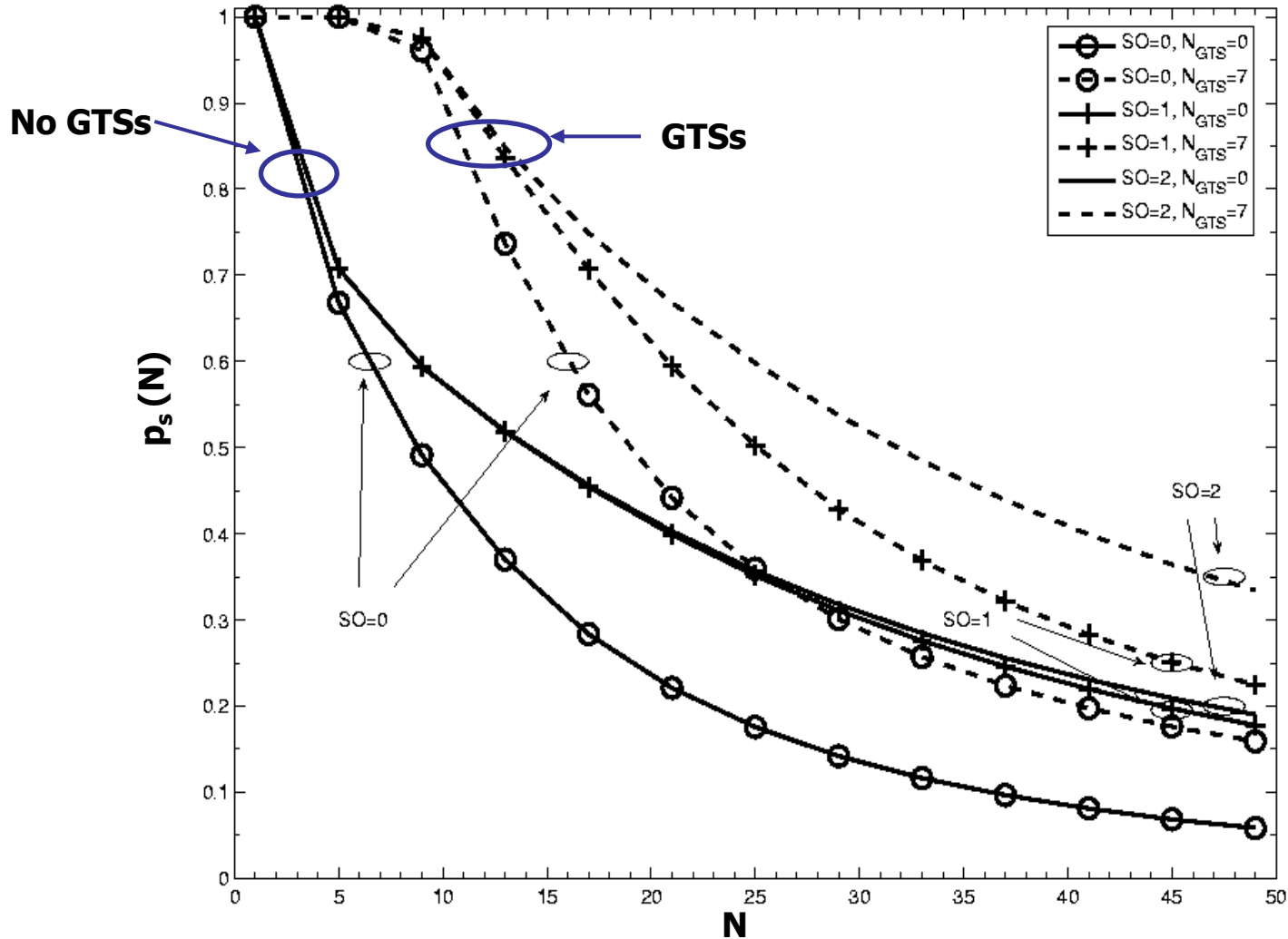


# IEEE 802.15.4 – Headers



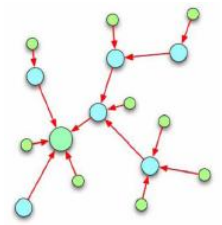


# Beacon-Enabled Mode: $p_s$

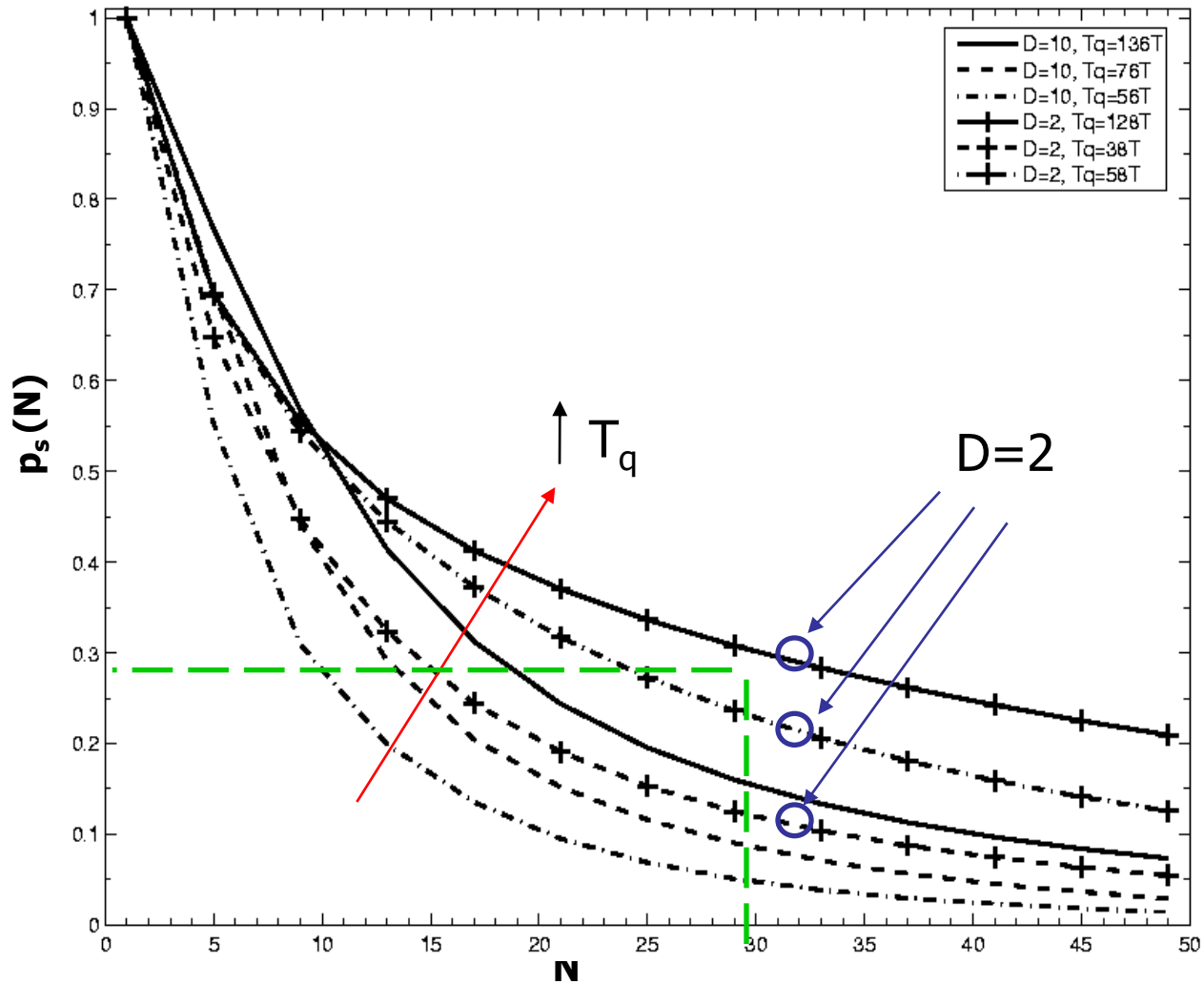


N= number of nodes in the network

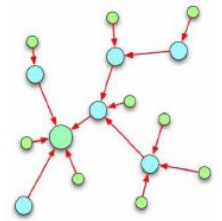
D=2



# Non Beacon-Enabled Mode: $p_s$







## IEEE 802.15.4 – Network Topologies

A Network (PAN) is managed by a coordinator

### RFD

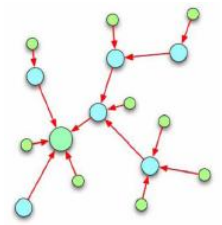
Reduced function device

- Reduced functionalities
- Battery – powered
- No forwarding

### FFD

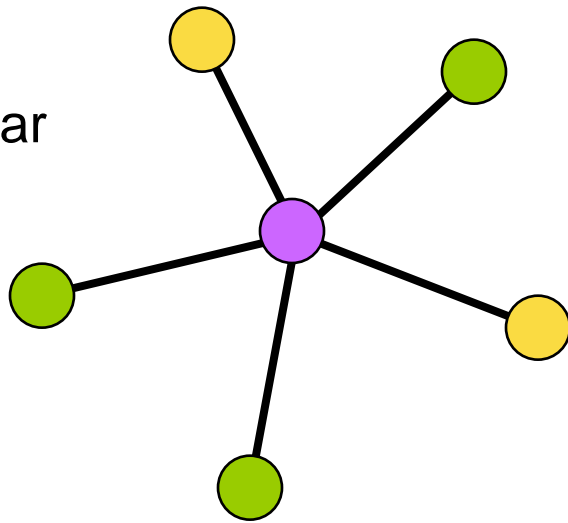
Full function device

- All functionalities implemented
- Forwarding
- Can play the role of coordinators

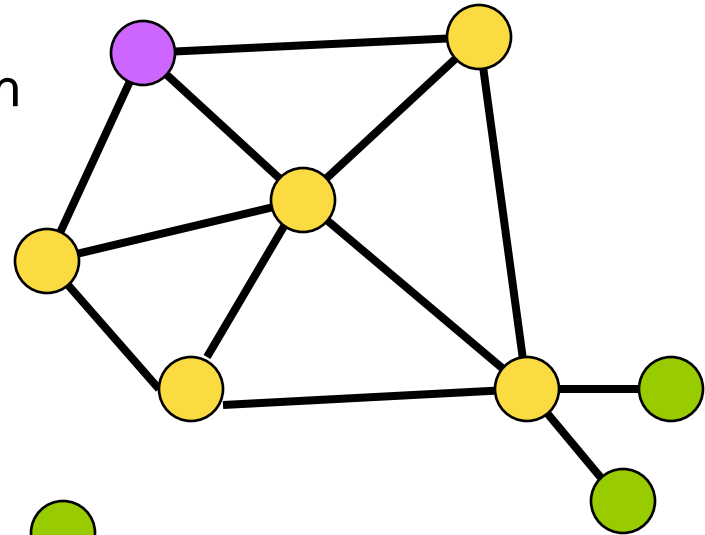


# IEEE 802.15.4 – Network Topologies

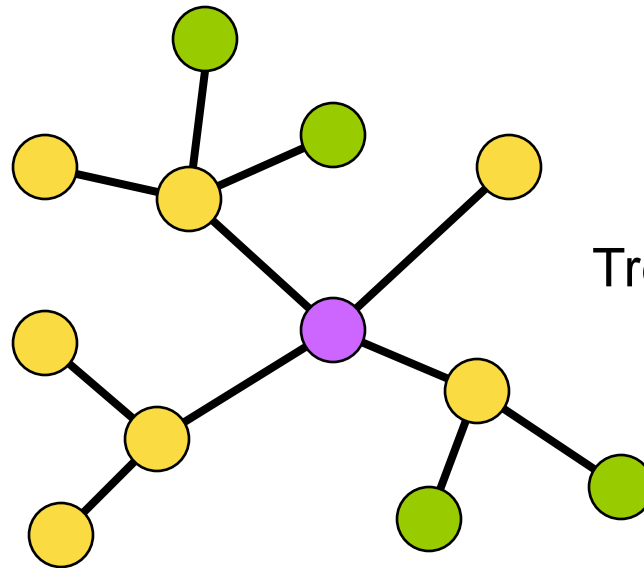
Star






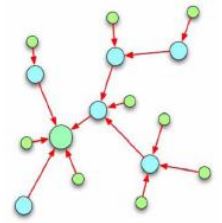
Mesh



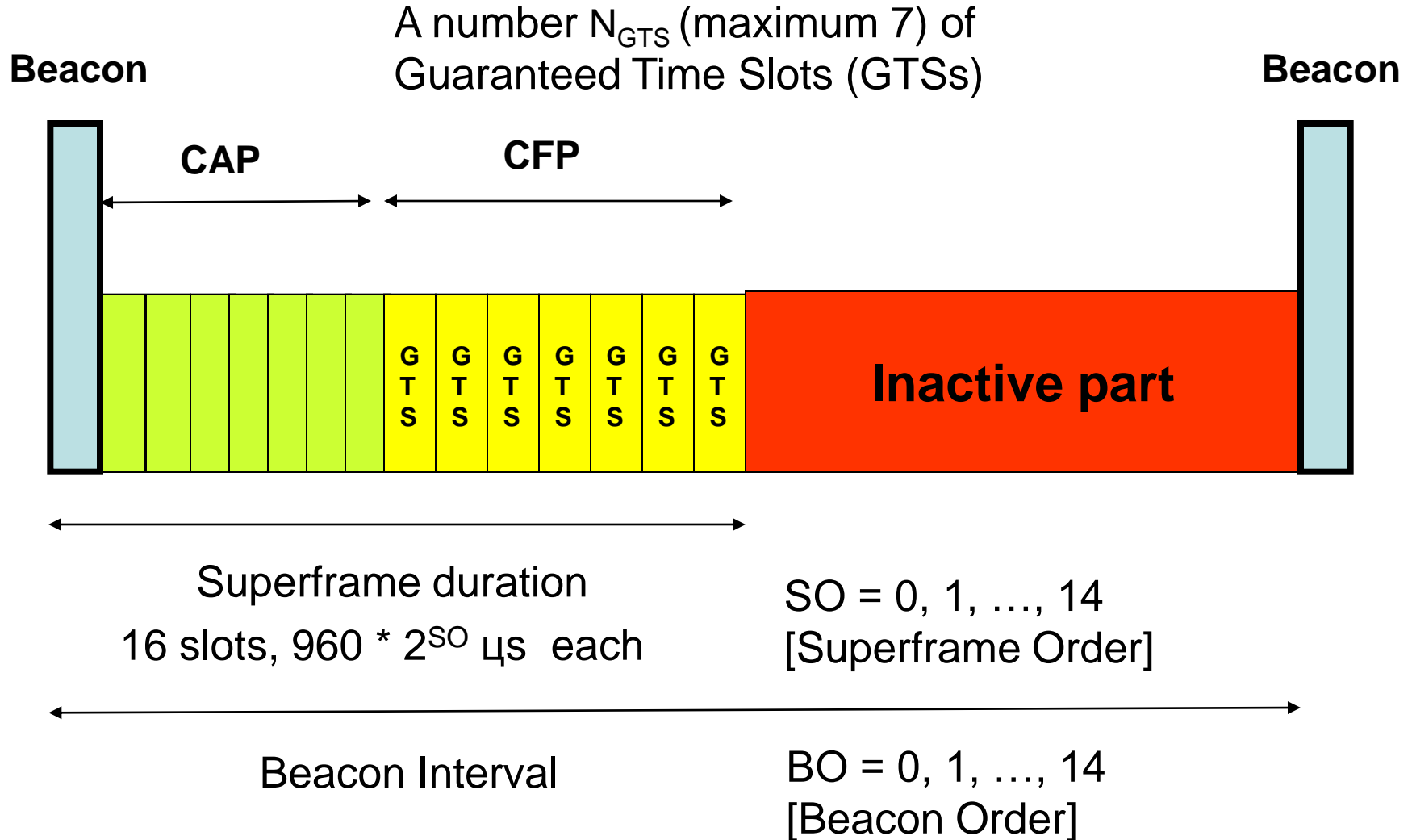
Tree

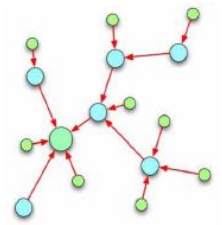


-  PAN Coordinator
-  Full Function Device
-  Reduced Function Device

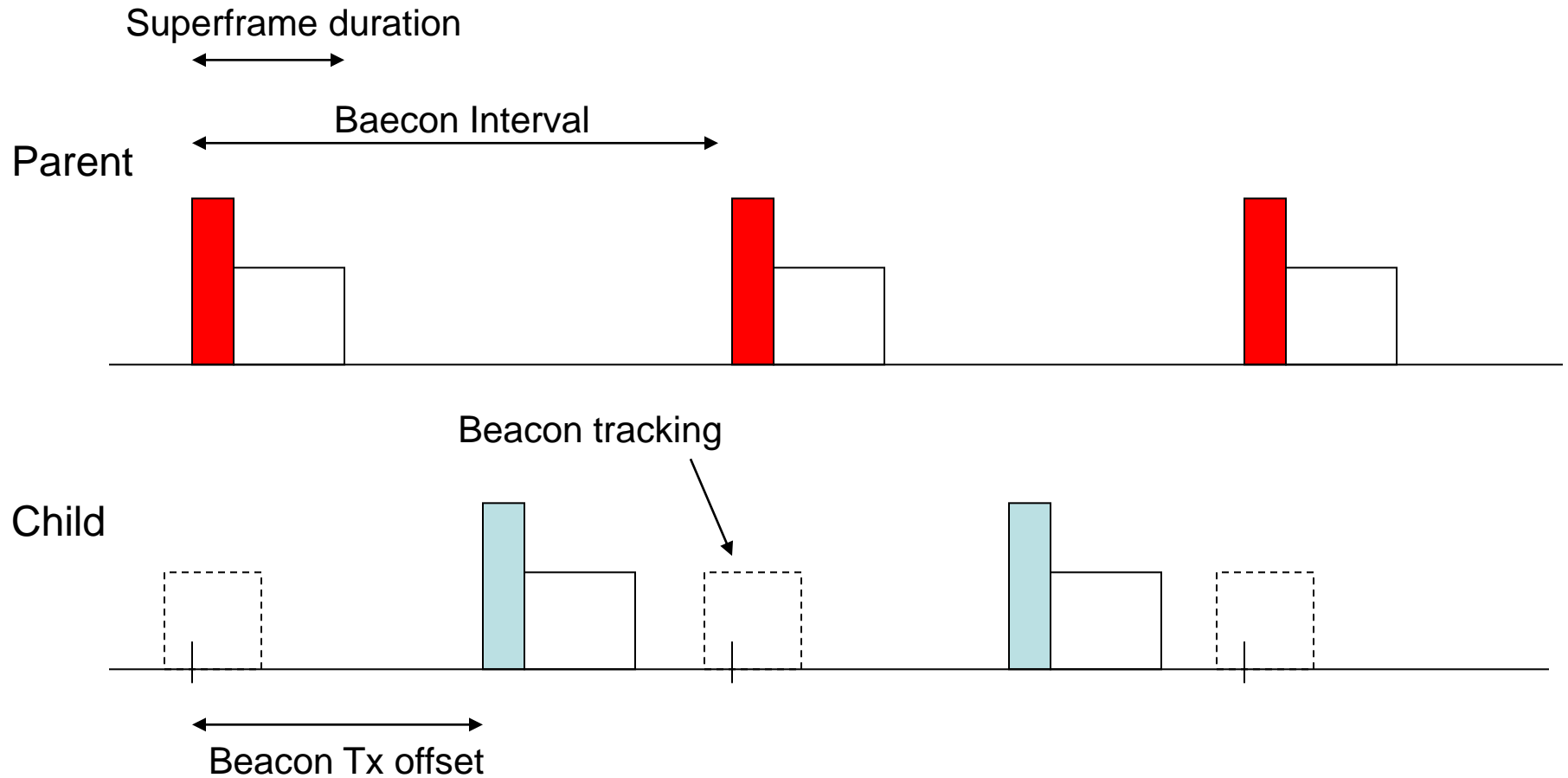


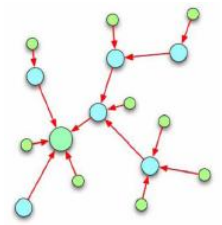
# IEEE 802.15.4 - MAC (Beacon Enabled Mode)





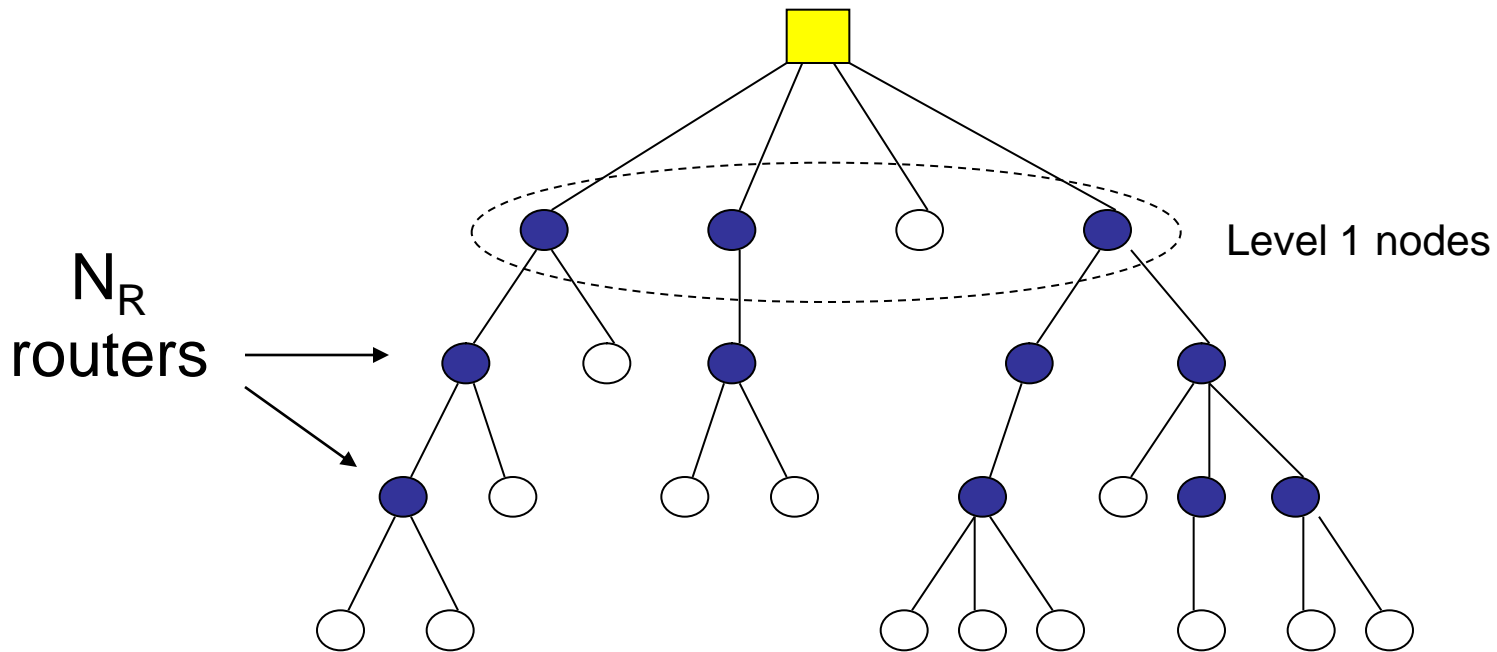
# IEEE 802.15.4 - MAC (Beacon Enabled Mode)



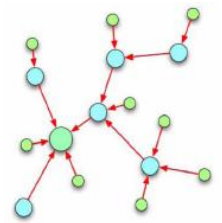


# IEEE 802.15.4 - MAC (Beacon Enabled Mode)

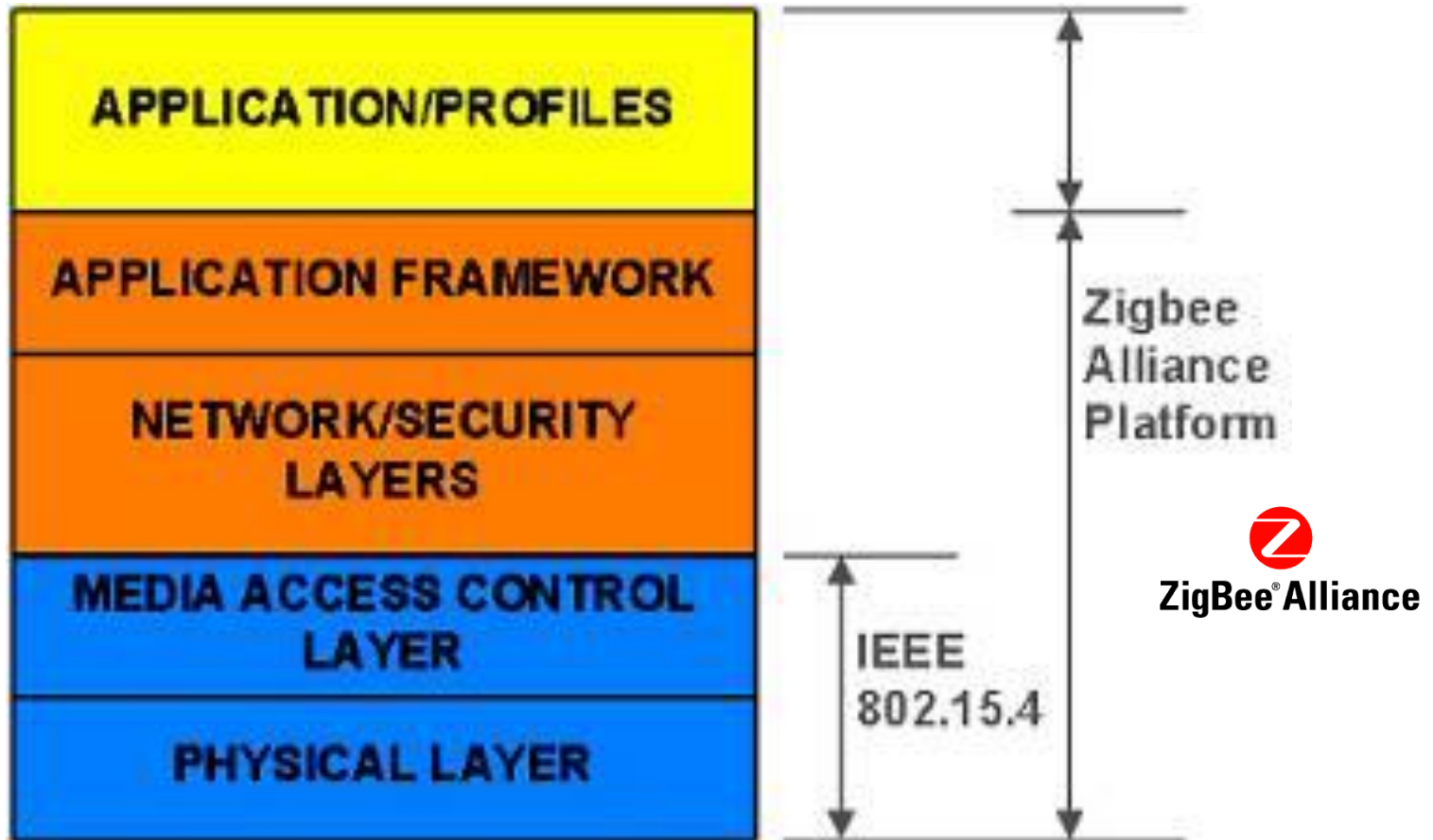
PAN Coordinator

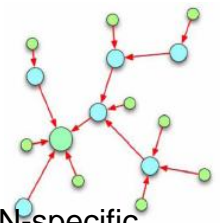


$$2^{BO} \geq (N_R + 1) \cdot 2^{SO}.$$



# IEEE 802.15.4 / Zigbee





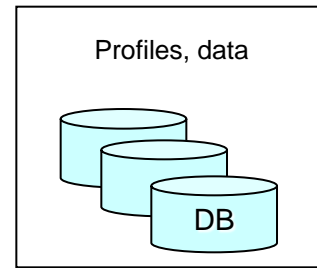
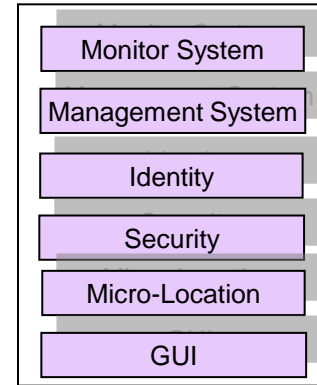
WSN-specific  
Facilities

# Network Architectures

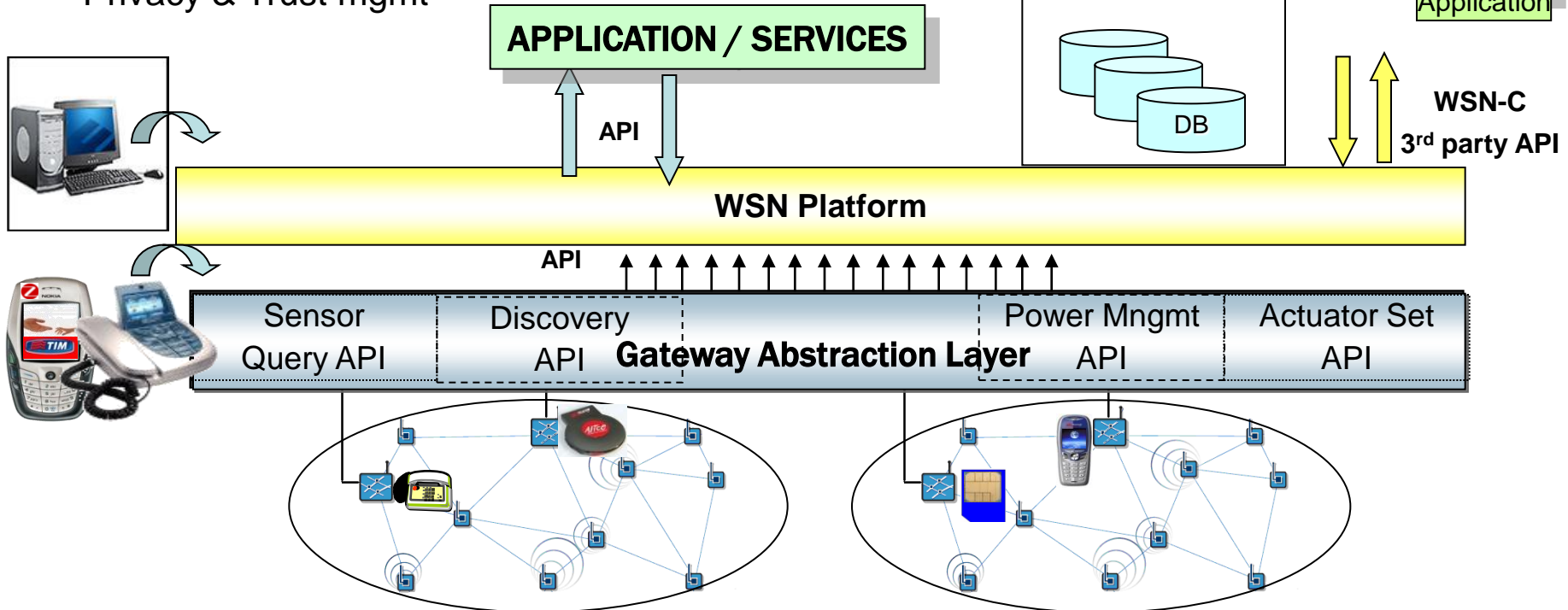
## Network Operator Reference Architecture

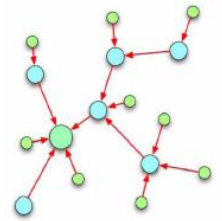
Not just the nodes to build the WSN real applications!

- Wireless Sensor Networks nodes
- Gateway
- WSN Platform (configuration, mgmt, data collection)
- Privacy & Trust mgmt



WSN-C  
3rd party API

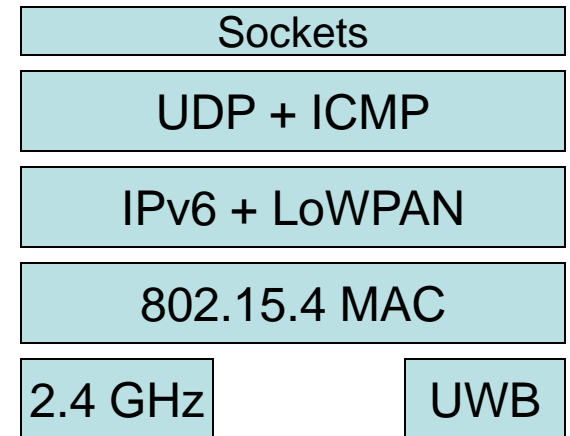
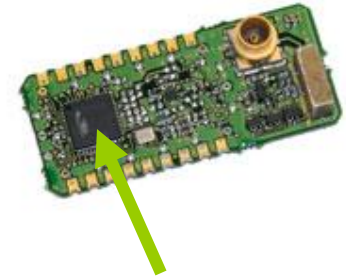




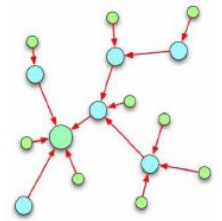
## Network Architectures / 6lowpan

### 6LoWPAN - IP for Low-power Devices

- IETF Standard for IPv6 over IEEE 802.15.4
- 80% compression of headers
- Rich and flexible features
  - Auto-configuration
  - IPv6 fragmentation
  - UDP + ICMP
  - Mesh forwarding
- Common Socket API
- Super compact implementation
- Direct end-to-end Internet integration
- Extremely scalable







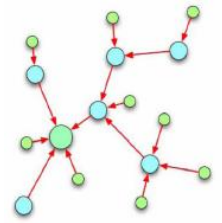
## Summing-Up

**Very different network paradigms  
(operator-centric, independent, ...)**

**Very different types of applications  
(home control, industrial process control, people control,  
emergency, eco-sustainability, info-mobility, ...)**

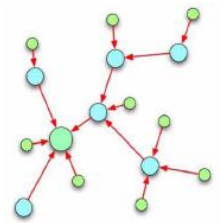
**Very different types of environments  
(BANs, Office, Home, Urban, Rural, ...)**

**Heterogeneity**



# Section 4

## IEEE 802.15.4a (UWB)



## Alternative PHYs

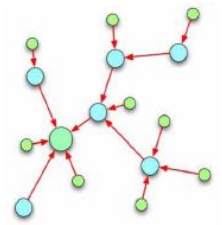
Since 2004, the IEEE 802.15.4a task group has been working on an alternative PHY layer to allow both low-rate data transmission and accurate ranging capability.

Two optional PHY layers have been proposed:

- chirp spread spectrum (CSS) and
- ultra wideband (UWB).

Of those, only the latter unites transmission capacity and acute radar resolution,  
hence it is the main object of this part.

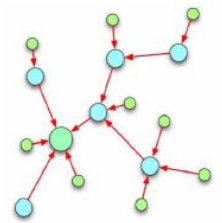
For the former, visit [www.nanotron.com](http://www.nanotron.com)



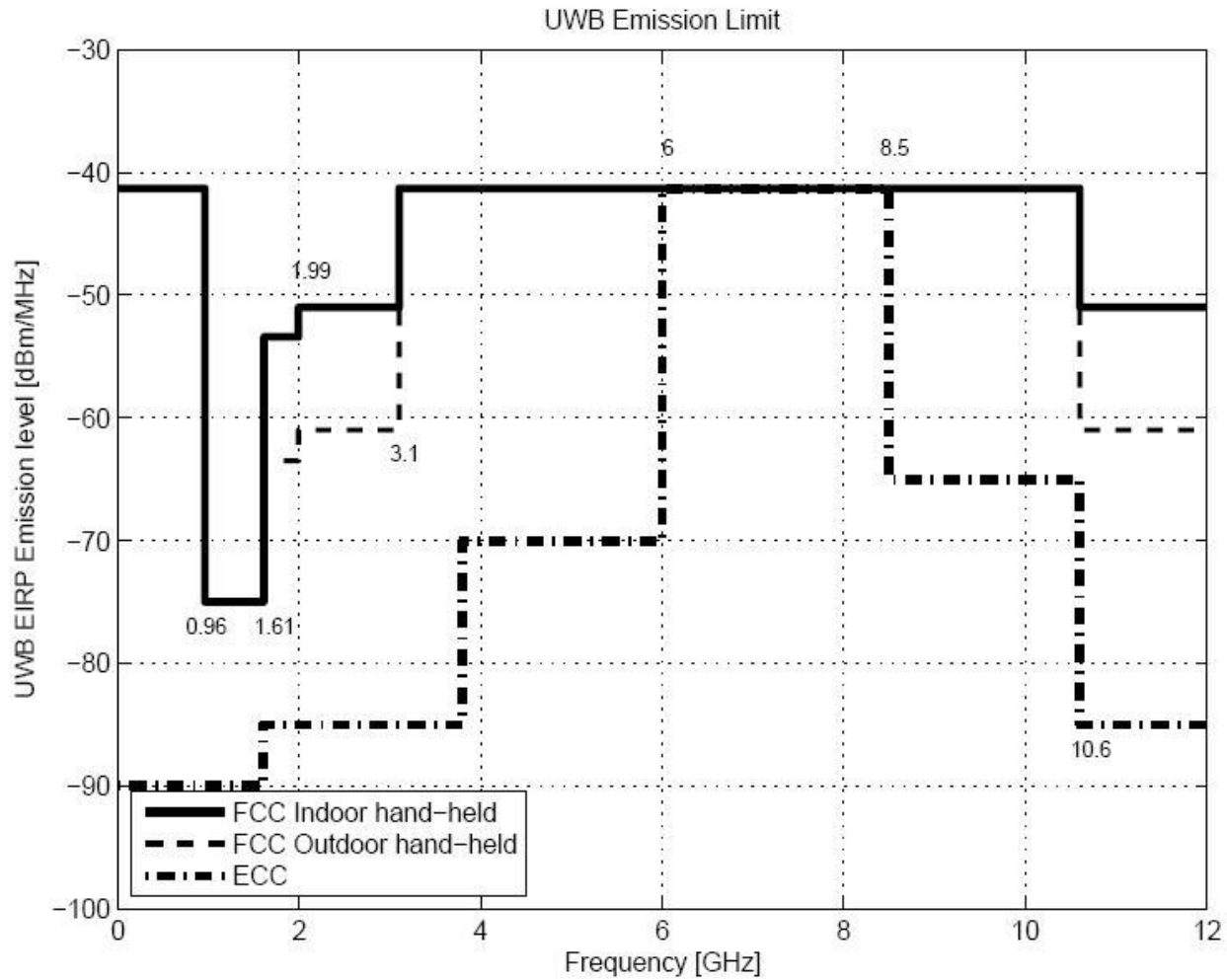
## IR-UWB

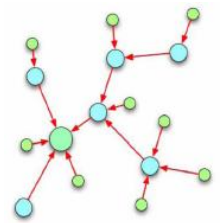
According to Federal Communications Commission (FCC), a UWB system is defined as any radio system that has a fractional bandwidth equal to or greater than 0.20 or has a UWB bandwidth equal to or greater than 500 MHz.

Currently UWB is divided into two main physical layer technology branches: IR-UWB using one very wide band for communications and multi-band (MB) orthogonal frequency division multiplexing (OFDM) ultra wideband (UWB), using several ultra-wide OFDM channels.



# IR-UWB





# IR-UWB

