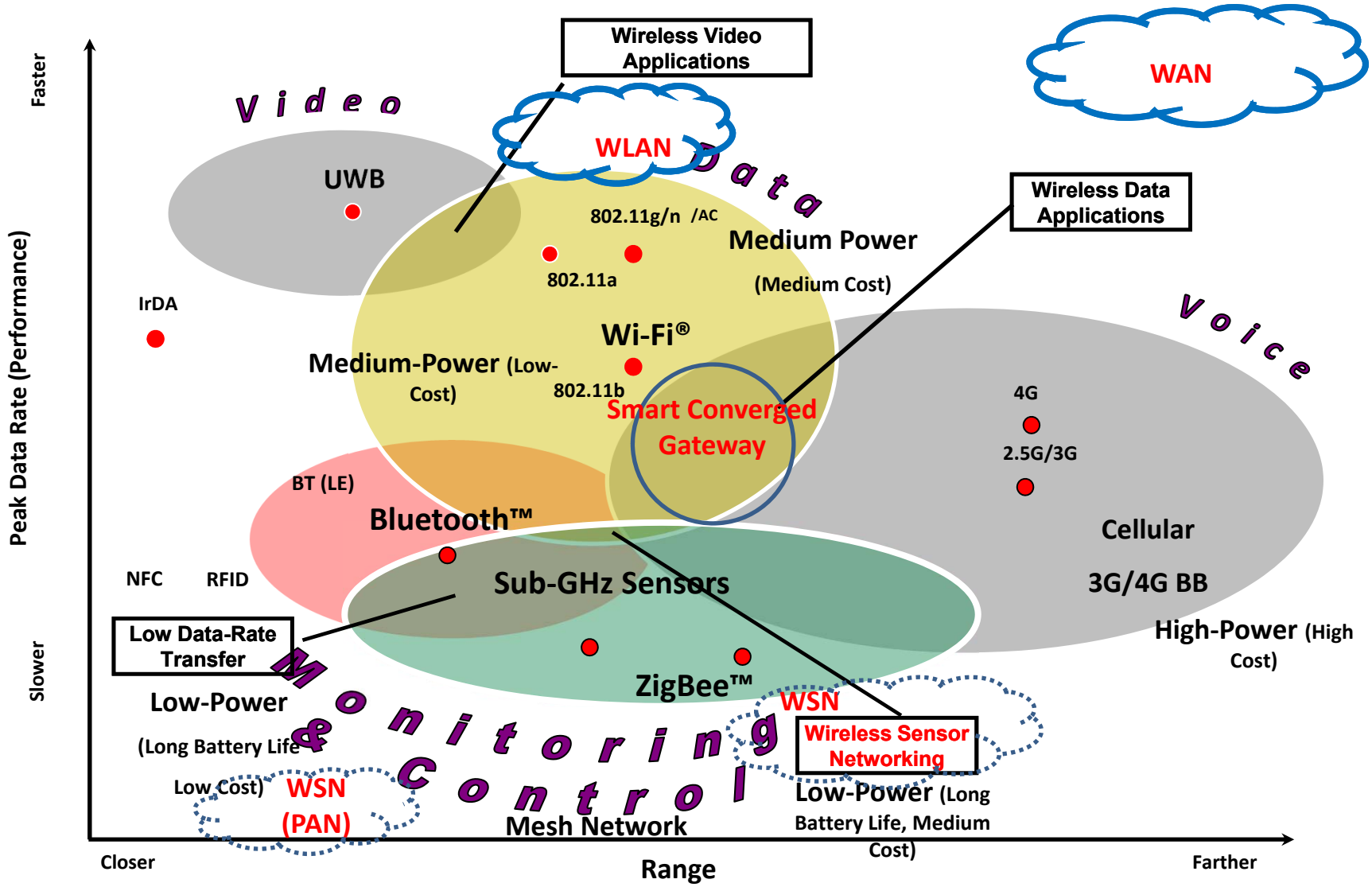
RF Wireless Data Rates & Ranges



RF Radios Communication Technologies

Communication Technologies

	NFC	RFID	Blue-tooth®	Blue-tooth® LE	ANT	Proprietery (Sub-GHz & 2.4 GHz)	Wi-Fi®	ZigBee®	Z-wave	KNX	Wireless HART	6LoWPAN	WiMAX	2.5–3.5 G
Network	PAN	PAN	PAN	PAN	PAN	LAN	LAN	LAN	LAN	LAN	LAN	LAN	MAN	WAN
Topology	P2P	P2P	Star	Star	P2P, Star, Tree Mesh	Star, Mesh	Star	Mesh, Star, Tree	Mesh	Mesh, Star, Tree	Mesh, Star	Mesh, Star	Mesh	Mesh
Power	Very Low	Very Low	Low	Very Low	Very Low	Very Low to Low	Low-High	Very Low	Very Low	Very Low	Very Low	Very Low	High	High
Speed	400 Kbs	400 Kbs	700 kbs	1 Mbs	1 Mbs	250 kbs	11-100 Mbs	250 kbs	40 Kbs	1.2 Kbps	250 kbs	250 Kbs	11-100 Mbs	1.8-7.2 Mbs
Range	<10 cm	<3 m	<30 m	5-10 m	1-30 m	10-70 m	4-20 m	10-300 m	30 m	800 m	200 m	800 m (Sub-GHz)	50 km	Cellular network
Application	Pay, get access, share, initiate service, easy setup	Item tracking	Network for data exchange, headset	Health and fitness	Sports and fitness	Point to point connectivity	Internet, multimedia	Sensor networks, building and industrial automation	Residential lighting and automation	Building automation	Industrial sensing networks	Senor networks, building and industrial automation	Metro area broadband Internet connectivity	Cellular phones and telemetry
Cost Adder	Low	Low	Low	Low	Low	Medium	Medium	Medium	Low	Medium	Medium	Medium	High	High

Networked Smart Gateway (MPC8308NSG)

Converged Architecture

- Wireless media gateway
- Home security & safety surveillance
- Smart energy home automation
- Health monitoring & management

Seamless Wireless Connectivity (TCP/IP, 802.11n, ZigBee)

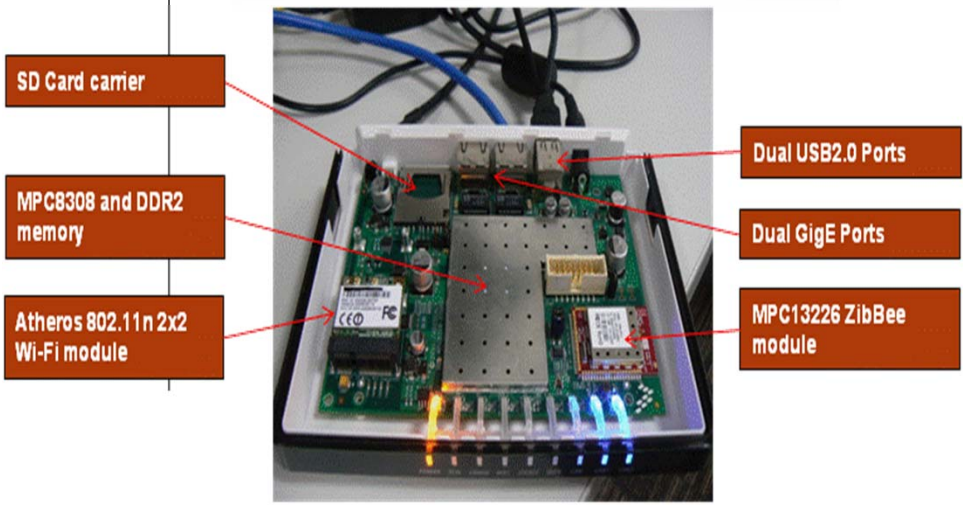
- Smart metering connectivity via SE 1.0 or MBus
- Smart appliance management via ZigBee HA1.0
- Anytime/Anywhere access via internet connected devices

Integration of four essential software stacks

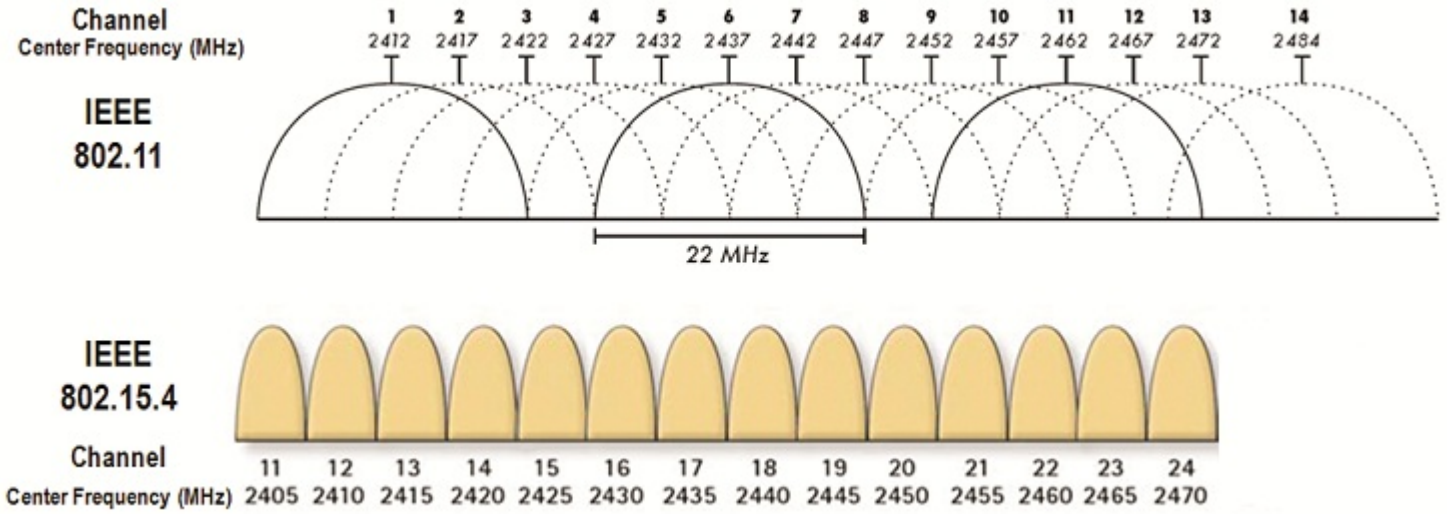
- TCP/IP - Broadband WAN/LAN connectivity
- ZigBee Home Automation 1.0 Profile
- ZigBee Smart Energy 1.0 Profile
- Web-based GUI (Java) for Ease of Use

Fully ready for Mass Production NOW

- Freescale owned hardware & software
- Solid hardware partnerships
- Several ODMs are engaged
- Traction with several consumer & utility OEMs
- Branding, value and eCommerce enabling platform



IEEE 802.15.4


Channel
Center Frequency (MHz)
IEEE
802.11
1 2412
2 2417
3 2422
4 2427
5 2432
6 2437
7 2442
8 2447
9 2452
10 2457
11 2462
12 2467
13 2472
14 2484
22 MHz
IEEE
802.15.4
Channel
Center Frequency (MHz)
11 2405
12 2410
13 2415
14 2420
15 2425
16 2430
17 2435
18 2440
19 2445
20 2450
21 2455
22 2460
23 2465
24 2470

Content

- Overview
- Topologies
- Superframe structure
- Frame formatting
- Data service
- Management service
- Interframe spacing
- CSMA procedure

Introduction

- Until recently the main concentration In wireless was on high throughput.
- Some applications for home automation, security, agriculture, industrial etc. have relaxed throughput requirements with low power consumption and low cost.
- Existing standards are not suitable because of high complexity, power implications and high cost.

Applications

Home automation

- heating, ventilation, and air conditioning, security, lighting, and the control of objects.

Industrial

- detecting emergency situations, monitoring machines

Automotive

- automotive sensing, such as tire pressure monitoring;

Agriculture

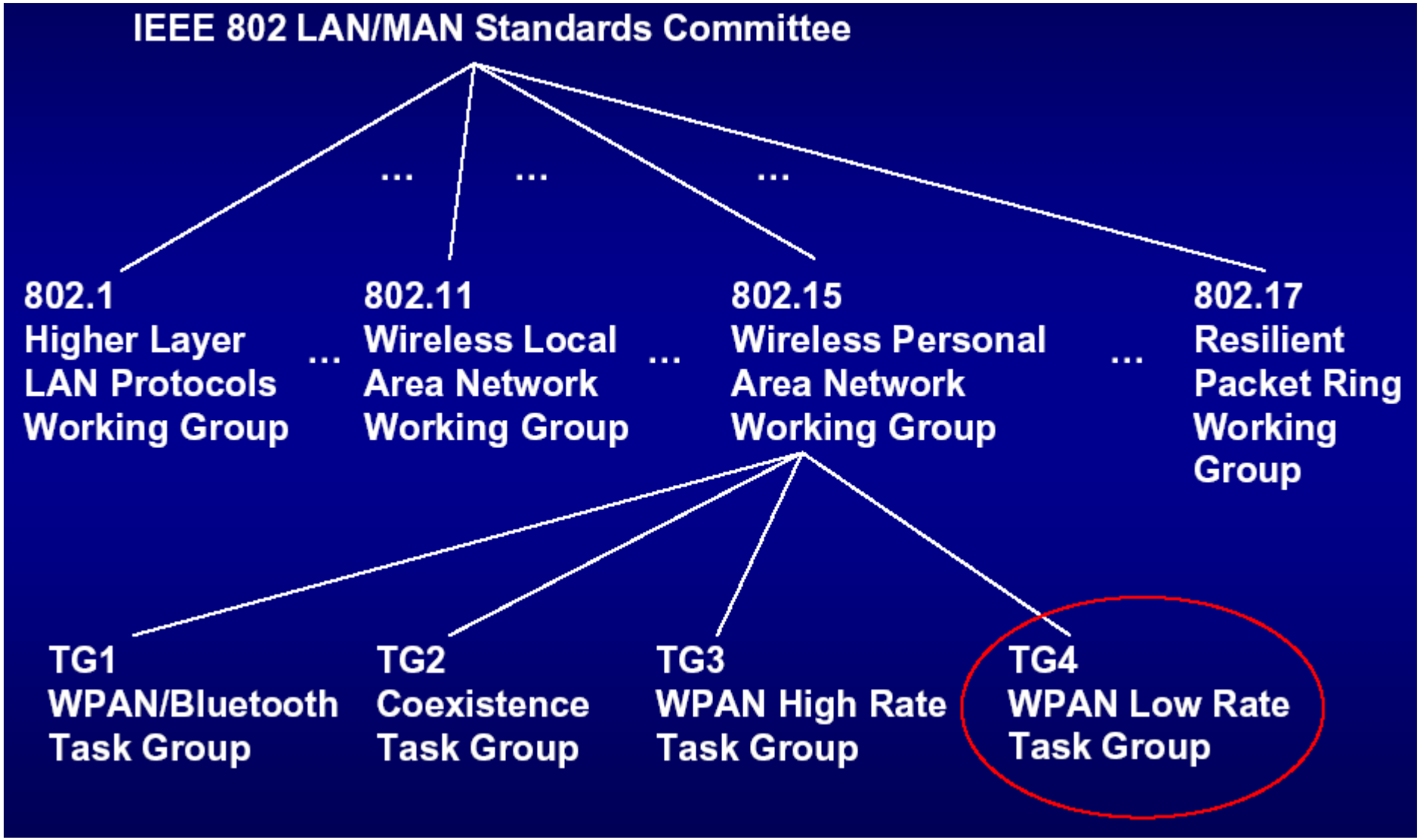
- sensing of soil moisture, pesticide, herbicide, and pH levels.

Others

- Controlling consumer electronics, PC peripherals etc.

Data rate needed ranges from 115.2 kb/s to less than 10 kb/s.

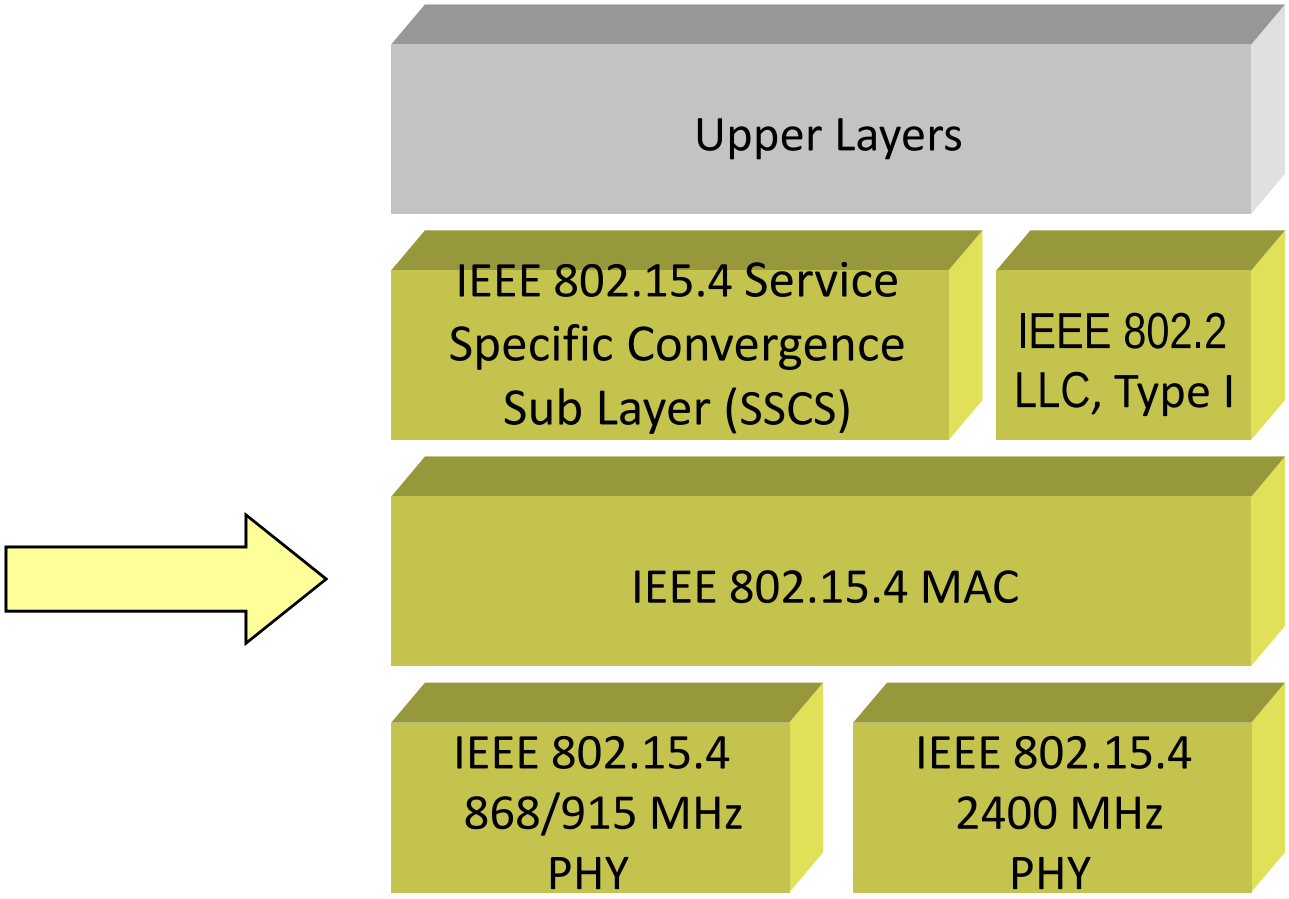
IEEE 802.15 Working Group



Comparison between WPANs

Project	Data Rate	Range	Configuration	Other Features
802.15.1 (Bluetooth)	1 Mbps	10M (class 3) 100M (class 1)	8 active device Piconet/ Scatternet	Authentication, Encryption, Voice
802.15.3 High Rate	22, 33, 44, 55 Mbps	10M	256 active device Piconet/ Scatternet	FCC part 15.249 QoS, Fast Join Multi-Media
802.15.4 Low Rate	up to 250Kbps	10M nominal 1M-100M based on settings	Master/Slave (256 Devices or more) Peer to Peer	Battery Life: multi-month to infinite
802.15.2 Coexistence	Develop a Coexistence Model and Mechanisms Document as a Recommended Practice			

802.15.4 Architecture



Protocol Drivers

- Extremely low cost
- Ease of installation
- Reliable data transfer
- Short range operation
- Reasonable battery life

IEEE 802.15.4 Device Classes

- Full function device (FFD)
  - Any topology
  - PAN coordinator capable
  - Talks to any other device
  - Implements complete protocol set
- Reduced function device (RFD)
  - Limited to star topology or end-device in a peer-to-peer network.
  - Cannot become a PAN coordinator
  - Very simple implementation
  - Reduced protocol set

IEEE 802.15.4 Definitions

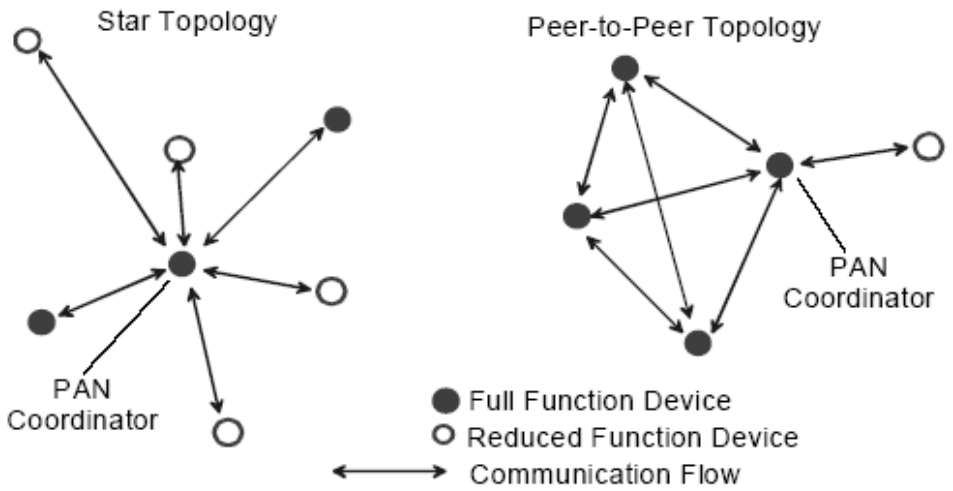
- Network Device: An RFD or FFD implementation containing an IEEE 802.15.4 medium access control and physical interface to the wireless medium.
- Coordinator: An FFD with network device functionality that provides coordination and other services to the network.
- PAN Coordinator: A coordinator that is the principal controller of the PAN. A network has exactly one PAN coordinator.

Device Addressing

- Two or more devices communicating on the same physical channel constitute a WPAN which includes at least one FFD (PAN coordinator).
- Each independent PAN will select a unique PAN identifier.
- All devices operating on a network shall have unique 64-bit extended address. This address can be used for direct communication in the PAN.
- An associated device can use a 16-bit short address, which is allocated by the PAN coordinator when the device associates.

IEEE 802.15.4 Supported Topologies

- MAC supports 2 topologies: star and peer-to-peer
- Star topology supports beacon and no-beacon structure
  - All communication done through PAN coordinator



Star Topology

- Any FFD may establish its own network by becoming the PAN coordinator
- After formation, star networks operate independently from neighboring networks
- PAN coordinator starts sending beacons
  - Other devices can associate with the network by sending an association request

Peer-to-Peer Topology

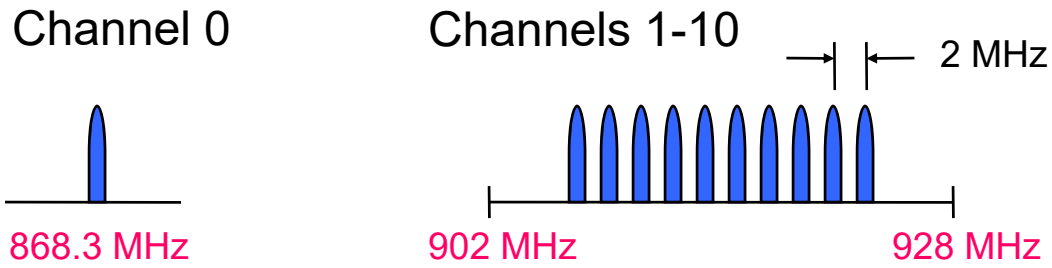
- Any FFD can communicate with any other FFD
  - i.e., this is ad-hoc networking
- RFDs can participate only as peripherals
  - Do not have the capabilities of forwarding packets
- Each device responsible for proactively searching for other devices
  - Once a device is found, then they can exchange information about what devices form the PAN

Technical Characteristics

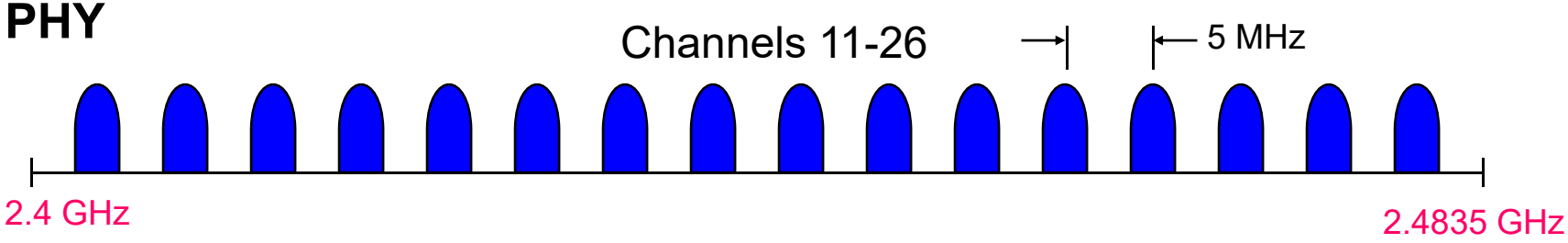
- Physical layer
  - 20 kbps over 1 channel @ 868-868.6 MHz
  - 40 kbps over 10 channels @ 905 – 928 MHz
  - 250 kbps over 16 channels @ 2.4 GHz
- MAC protocol
  - Single channel at any one time
  - Combines contention-based and schedule-based schemes

Physical Frequencies and Channels

868MHz / 915MHz PHY

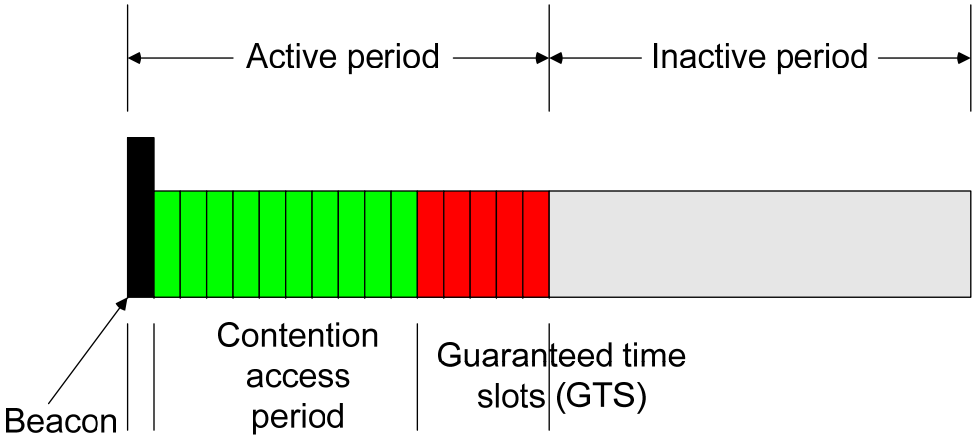


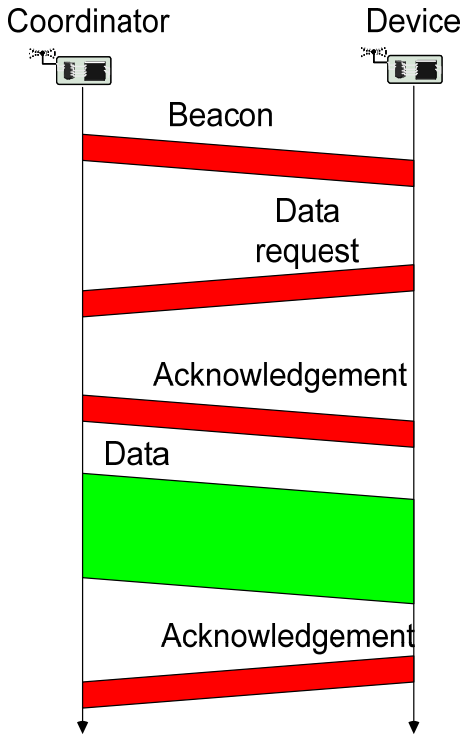
2.4 GHz PHY



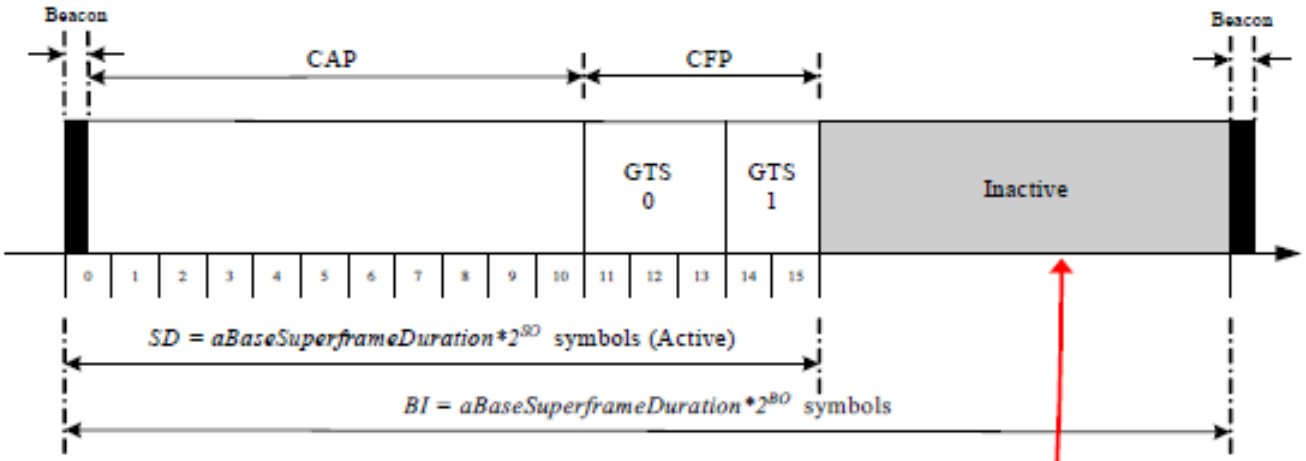
IEEE 802.15.4 MAC overview

- Star networks: ***devices*** are associated with ***coordinators***
  - Forming a PAN, identified by a PAN identifier
- Coordinator
  - Bookkeeping of devices, address assignment, generate beacons
  - Talks to devices and peer coordinators
- Beacon-mode superframe structure
  - GTS assigned to devices upon request b





Superframe



- A superframe is divided into two parts
  - Inactive: all devices sleep
  - Active: Consists of 16 slots; can be further divided into two parts
    - Contention access period (CAP)
    - Contention free period (CFP)

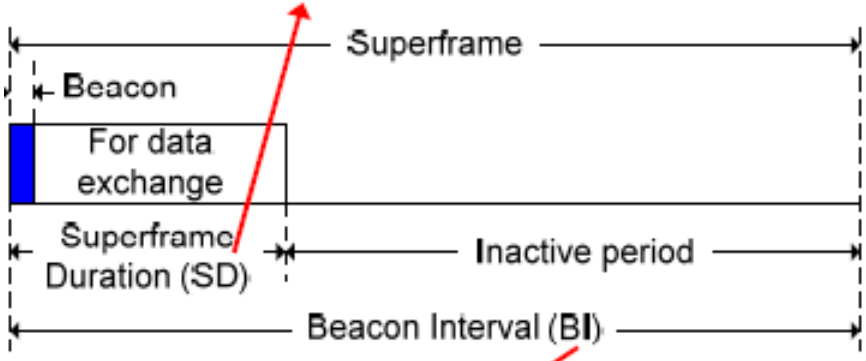
Superframe

- Beacons are used for
  - starting superframes
  - synchronizing with associated devices
  - announcing the existence of a PAN
  - informing pending data in coordinators
- In a beacon-enabled network,
  - Devices use slotted CAMA/CA to contend for the usage of channels
  - FFDs which require fixed rates of transmissions can ask for *guarantee time slots (GTS)* from the coordinator

Beacon Order and Superframe Order

- The structure of superframes is controlled by two parameters: *beacon order (BO)* and *superframe order (SO)*
  - BO decides the length of a superframe
  - SO decides the length of the active potion in a superframe

$$SD = aBaseSuperFrameDuration \times 2^{SO}$$

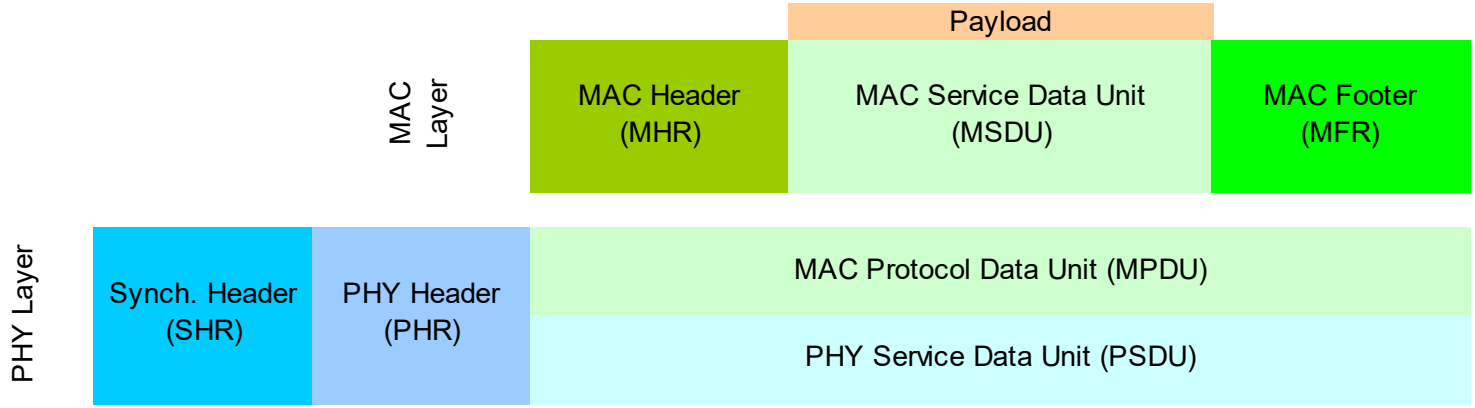


For channels 11 to 26,
aBaseSuperFrameDuration=5.36 ms

$$BI = aBaseSuperFrameDuration \times 2^{BO}$$

IEEE 802.15.4 MAC Overview

General Frame Structure



4 Types of MAC Frames:

- Data Frame
- Beacon Frame
- Acknowledgment Frame
- MAC Command Frame

General MAC Frame Format

Octets:2	1	0/2	0/2/8	0/2	0/2/8	variable	2
Frame control	Sequence number	Destination PAN identifier	Destination address	Source PAN identifier	Source address	Frame payload	Frame check sequence
		Addressing fields					
MAC header						MAC payload	MAC footer

Bits: 0-2	3	4	5	6	7-9	10-11	12-13	14-15
Frame type	Security enabled	Frame pending	Ack. Req.	Intra PAN	Reserved	Dest. addressing mode	Reserved	Source addressing mode

Frame control field

Beacon Frame Format

Octets:2	1	4 or 10	2	variable	variable	variable	2
Frame control	Beacon sequence number	Source address information	Superframe specification	GTS fields	Pending address fields	Beacon payload	Frame check sequence
MAC header			**MAC payload**				**MAC footer**

Bits: 0-3	4-7	8-11	12	13	14	15
Beacon order	Superframe order	Final CAP slot	Battery life extension	Reserved	PAN coordinator	Association permit

MAC Command Frame

Octets:2	1	4 to 20	1	variable	2
Frame control	Data sequence number	Address information	Command type	Command payload	Frame check sequence
MAC header			**MAC payload**		**MAC footer**

- Command Frame Types
  - Association request
  - Association response
  - Disassociation notification
  - Data request
  - PAN ID conflict notification
  - Orphan Notification
  - Beacon request
  - Coordinator realignment
  - GTS request

Data Frame Format

Octets:2	1	4 to 20	variable	2
Frame control	Data sequence number	Address information	Data payload	Frame check sequence
MAC header			**MAC Payload**	**MAC footer**

Acknowledgement Frame Format

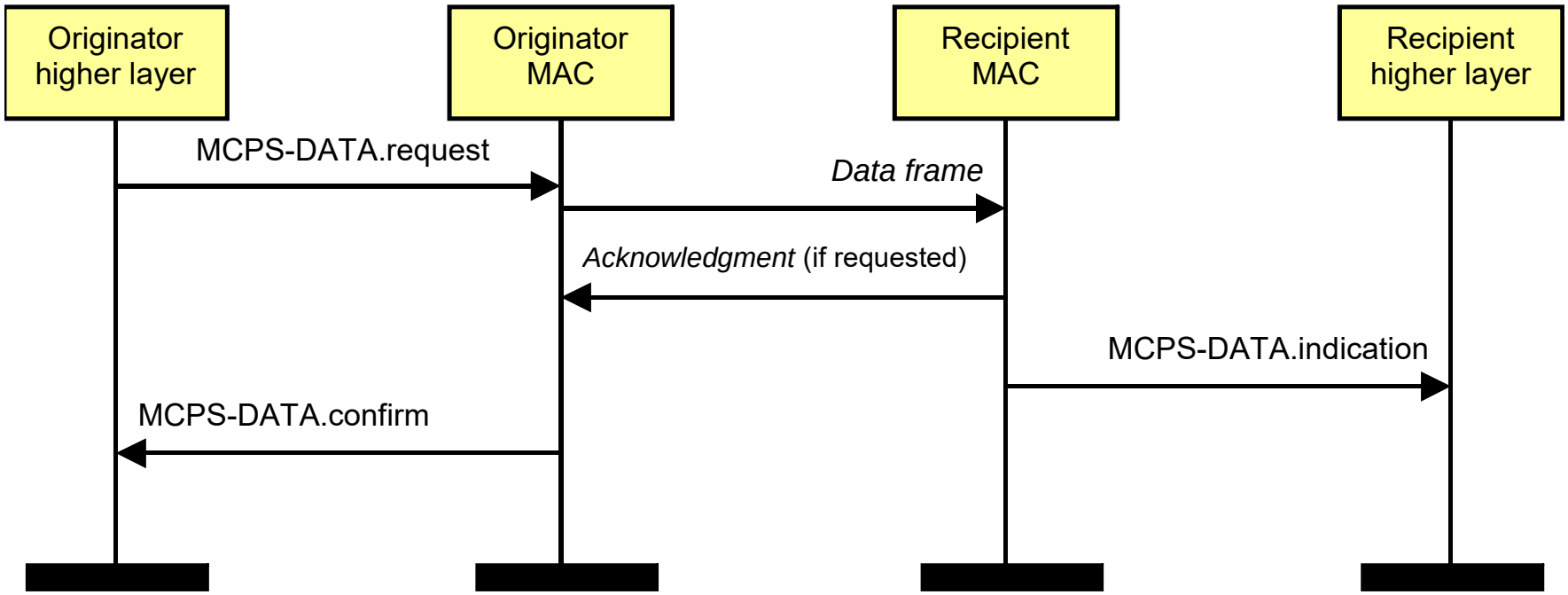
Octets:2	1	2
Frame control	Data sequence number	Frame check sequence
MAC header		**MAC footer**

Data Service

- Data transfer to neighboring devices
  - Acknowledged or unacknowledged
  - Direct or indirect
  - Using GTS service
- Maximum data length (MSDU) *aMaxMACFrameSize* (102 bytes)

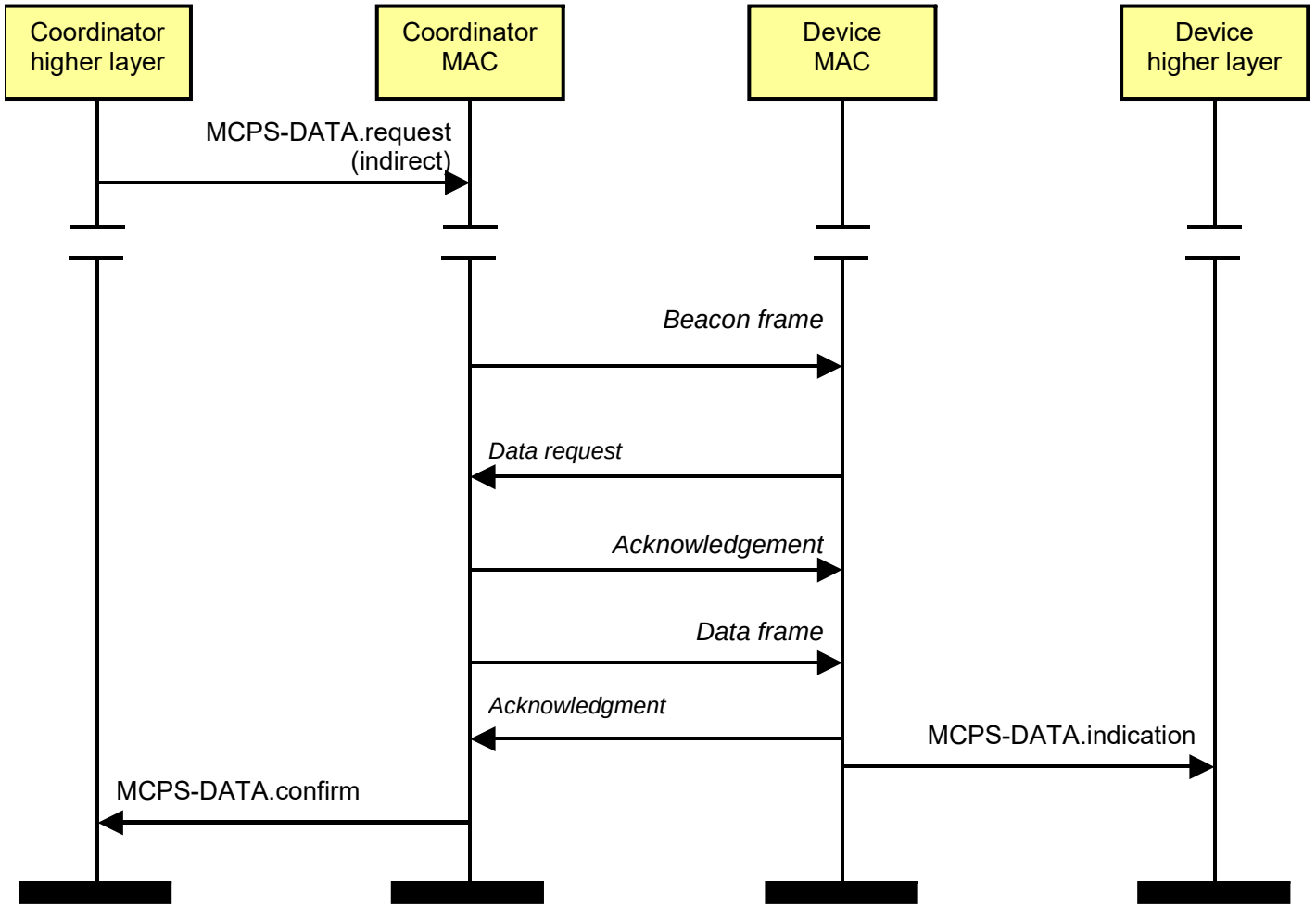
Direct Data Transfer

Message Sequence Diagram



Indirect Data Transfer

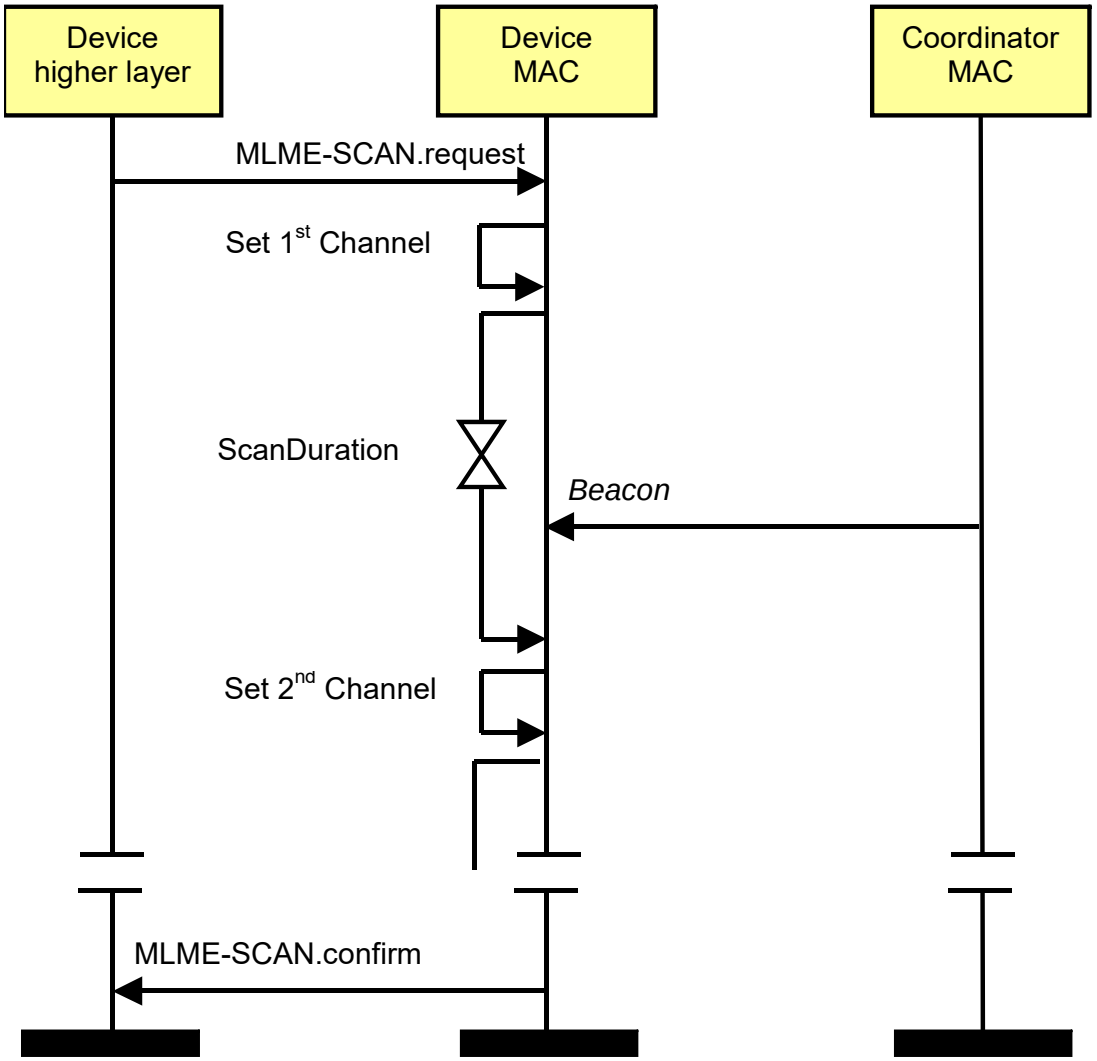
Message Sequence Diagram



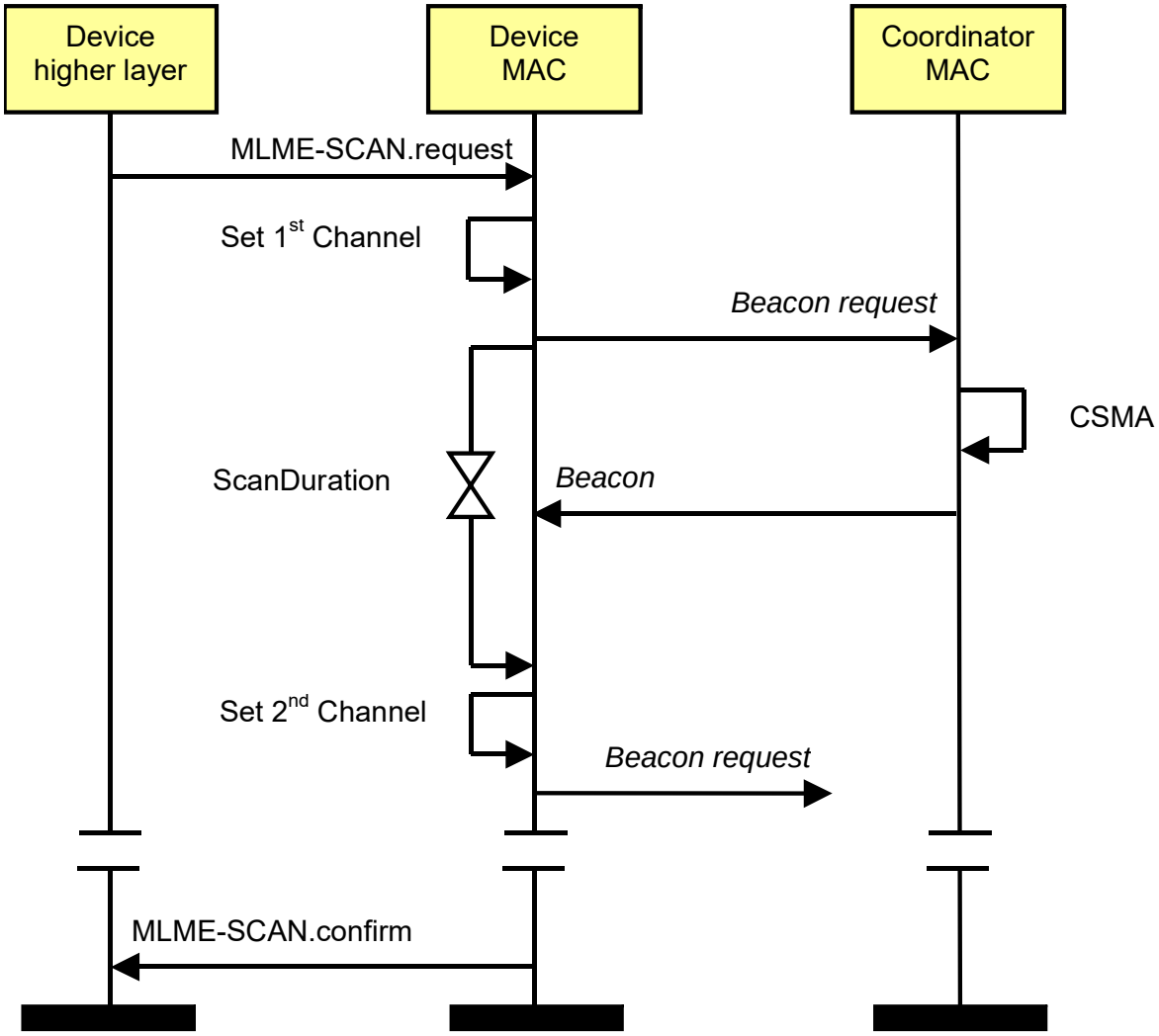
Management Service

- Access to the PIB
- Association / disassociation
- GTS allocation
- Message pending
- Node notification
- Network scanning/start
- Network synchronization/search

Passive Scan

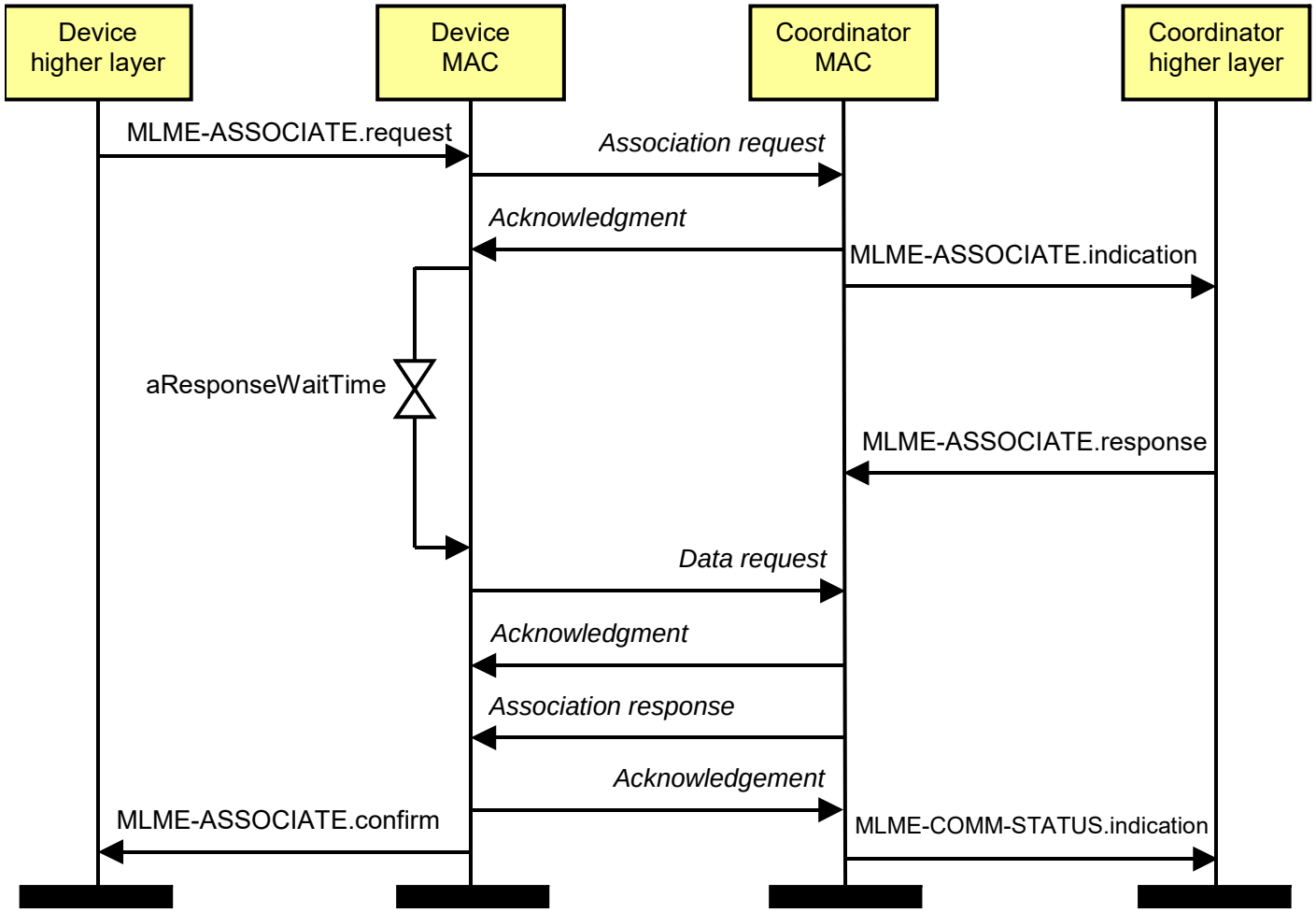


Active Scan


Device higher layer
Device MAC
Coordinator MAC
MLME-SCAN.request
Set 1st Channel
Beacon request
CSMA
ScanDuration
Beacon
Set 2nd Channel
Beacon request
MLME-SCAN.confirm

Association

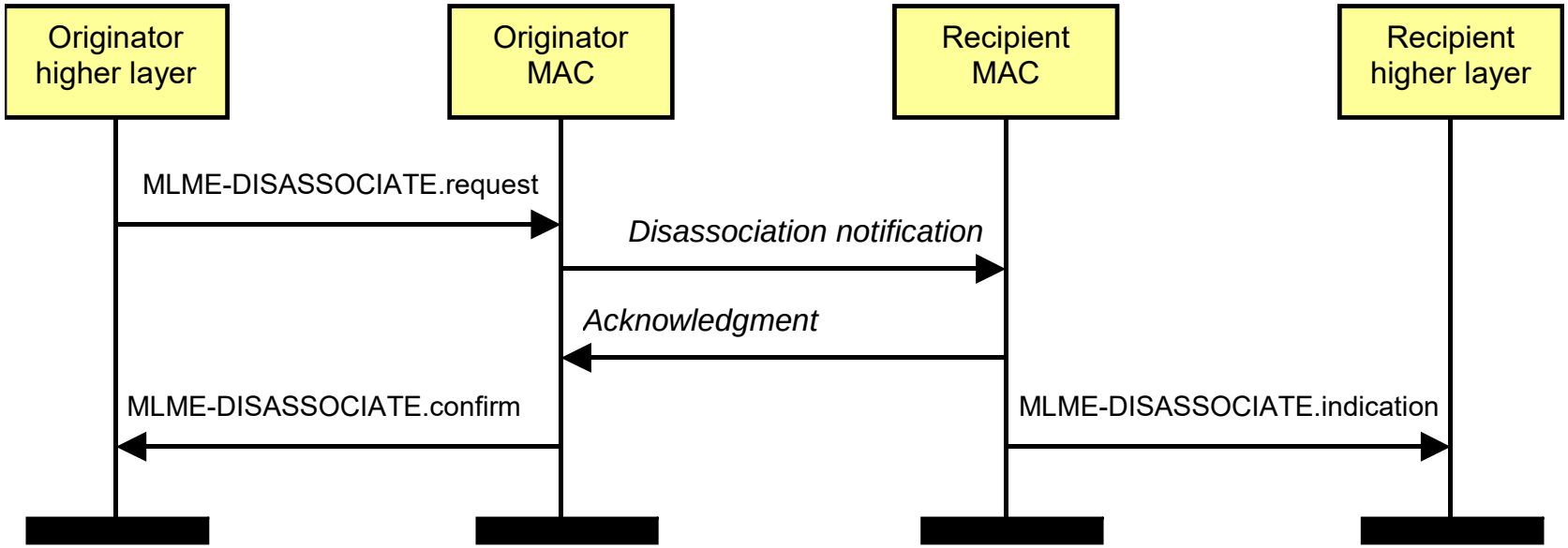
Message Sequence Diagram



In IEEE 802.15.4, association results are announced in an indirect fashion

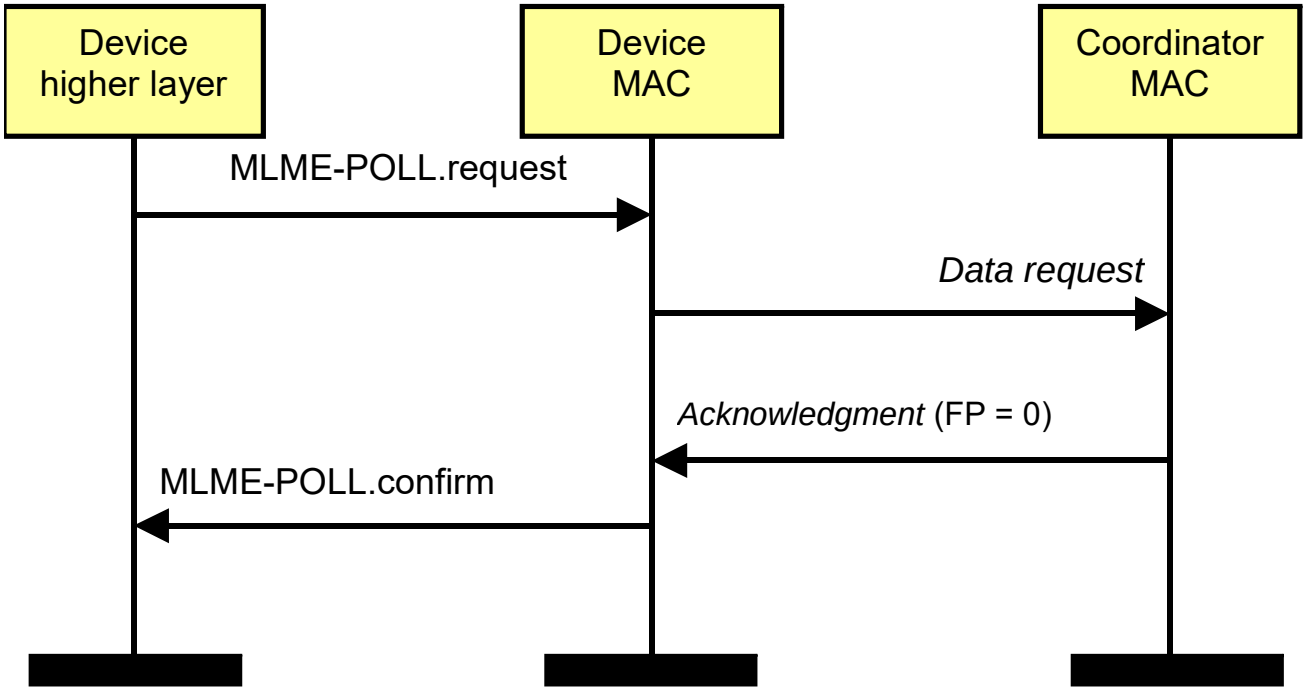
Disassociation

Message Sequence Diagram



Data Polling

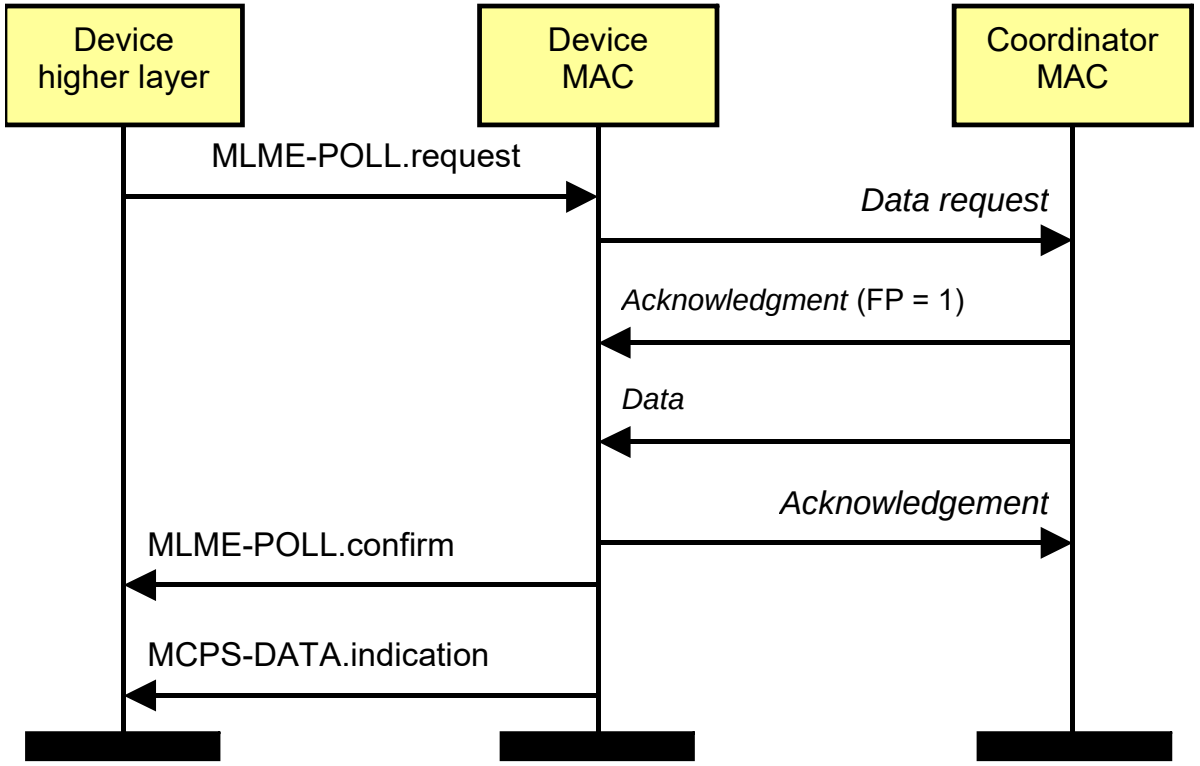
Message Sequence Chart



No data pending at the coordinator

Data Polling

Message Sequence Chart



Data pending at the coordinator

Channel Access Mechanism

In non beacon-enabled networks

- unslotted CSMA/CA channel access mechanism

In beacon-enabled networks

- slotted CSMA/CA channel access mechanism

Based on a basic time unit called Backoff Period (BP)

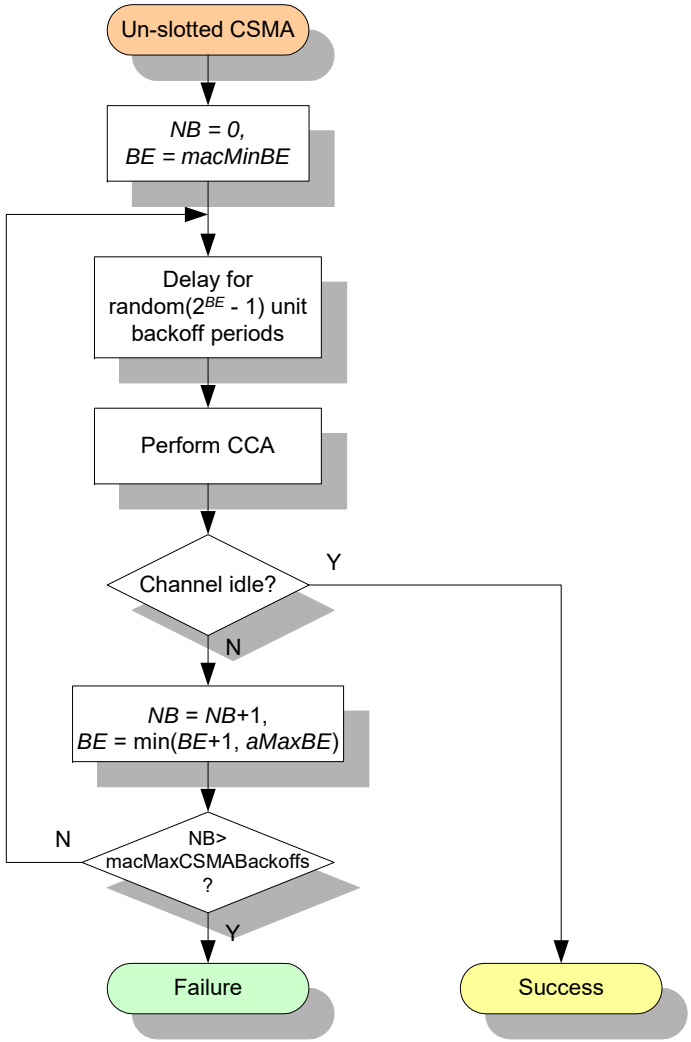
= *aUnitBackoffPeriod* = 80 bits (0.32 ms)

Unslotted/Slotted CSMA/CA Algorithm

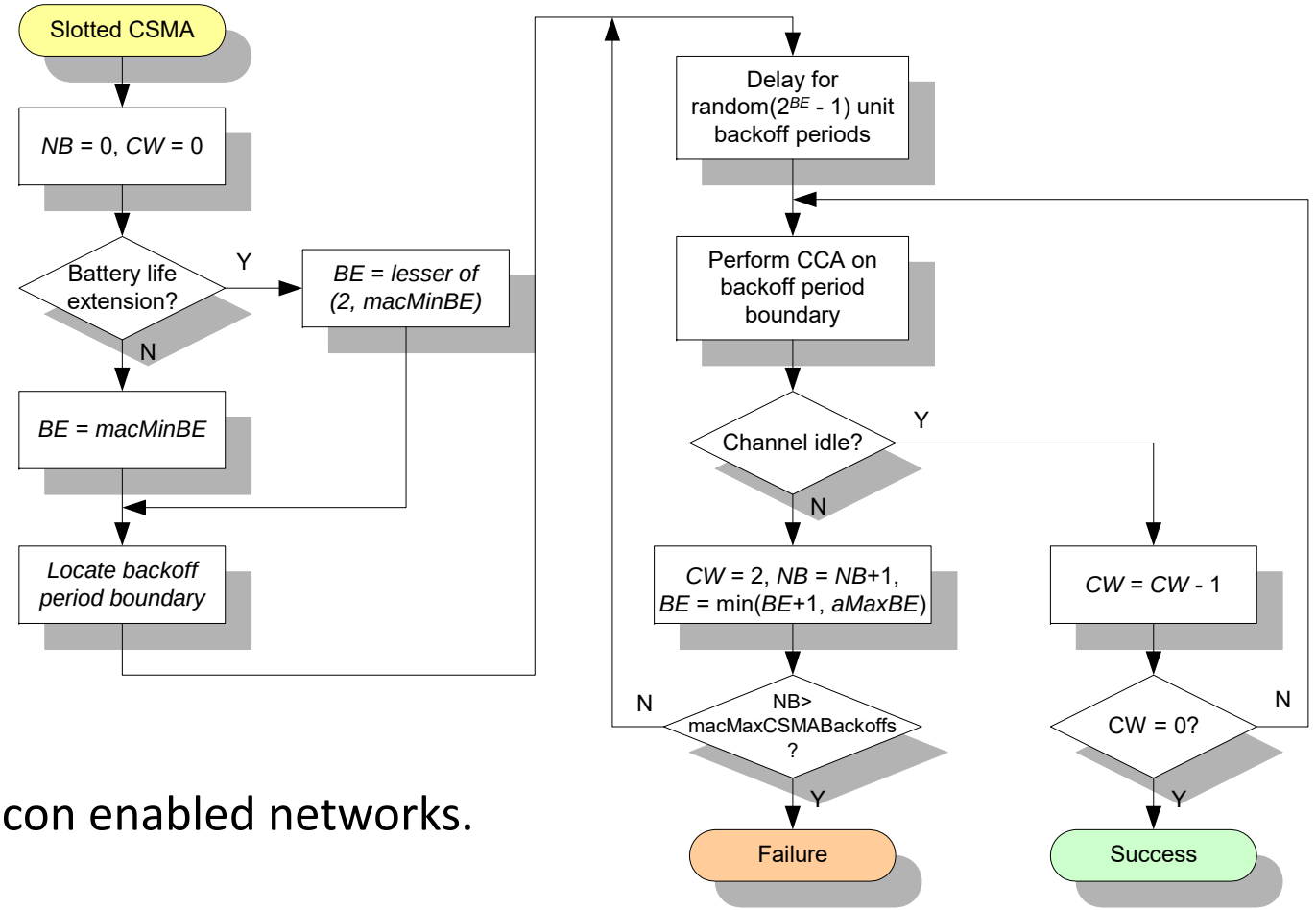
- Each device shall maintain two variables for each transmission attempt
  - BE: the backoff exponent which is related to how many BPs a device shall wait before attempting to assess a channel
  - NB: number of time the CSMA/CA algorithm was required to backoff while attempting the current transmission
- Additional one variable for slotted CSMA/CA
  - CW: contention window length, the number of BPs that needs to be clear of channel activity before transmission can commence (initial to 2 and reset to 2 if sensed channel to be busy)

Un-slotted CSMA Procedure

Used in non-beacon networks.

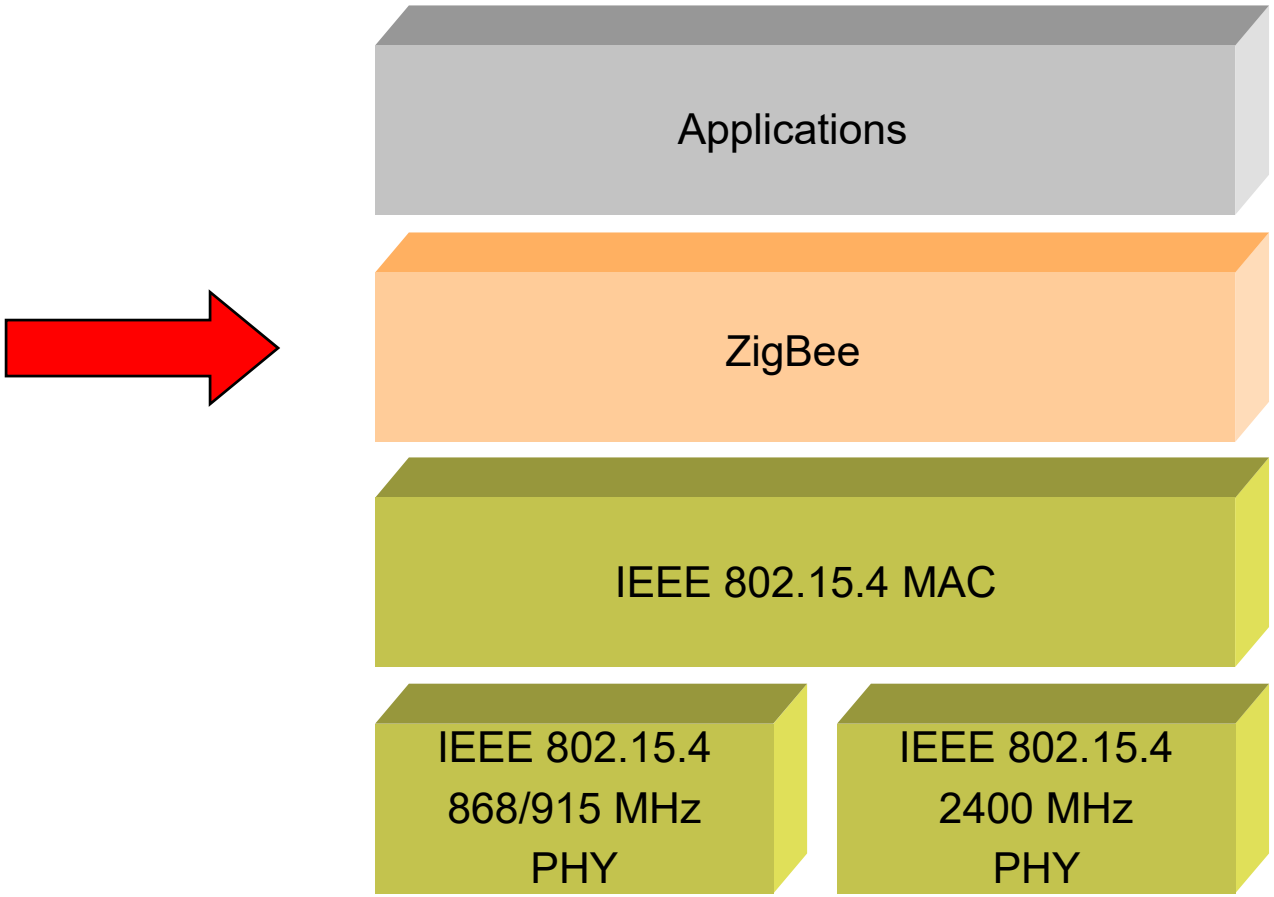


Slotted CSMA Procedure



Used in beacon enabled networks.

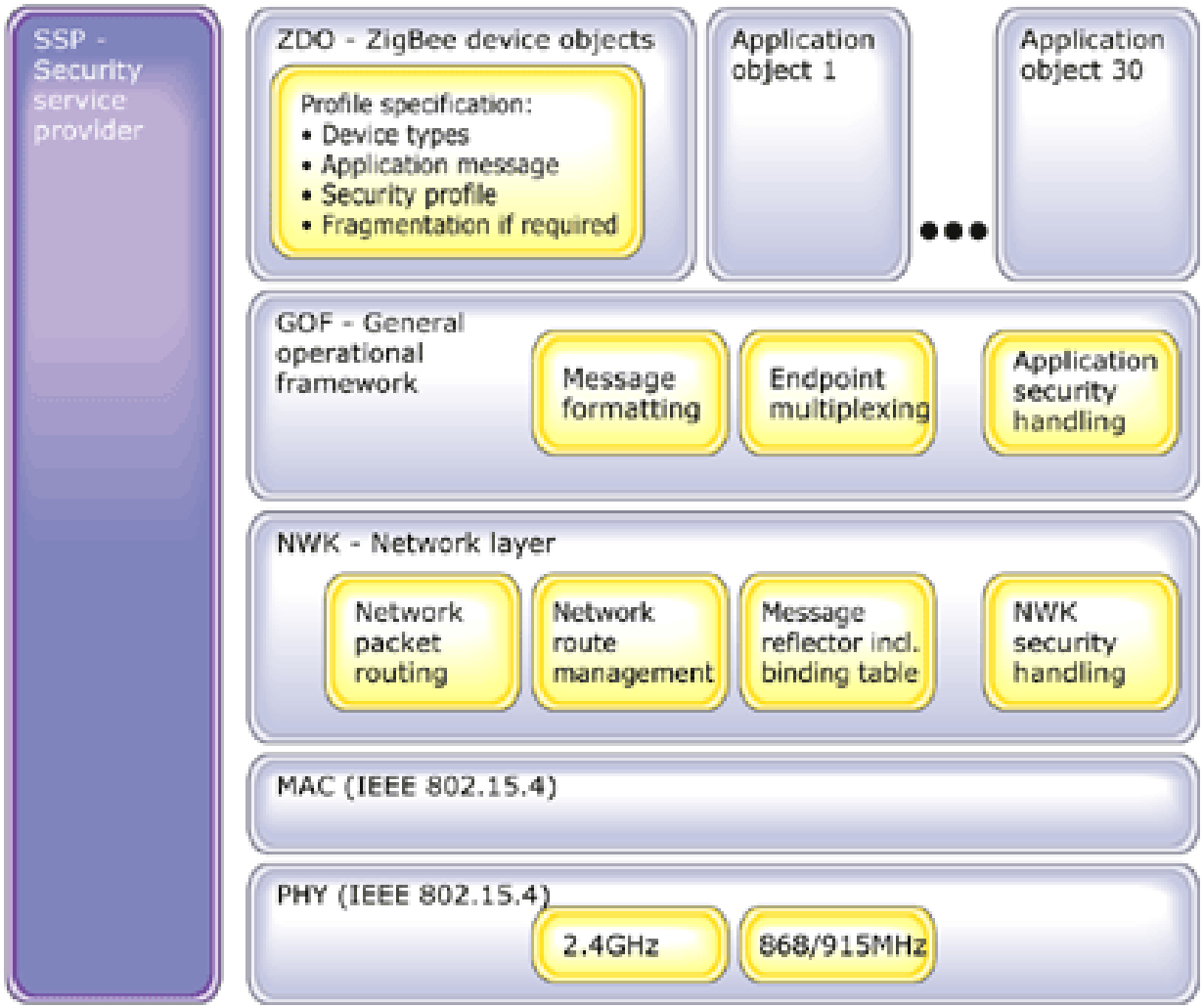
802.15.4 Architecture



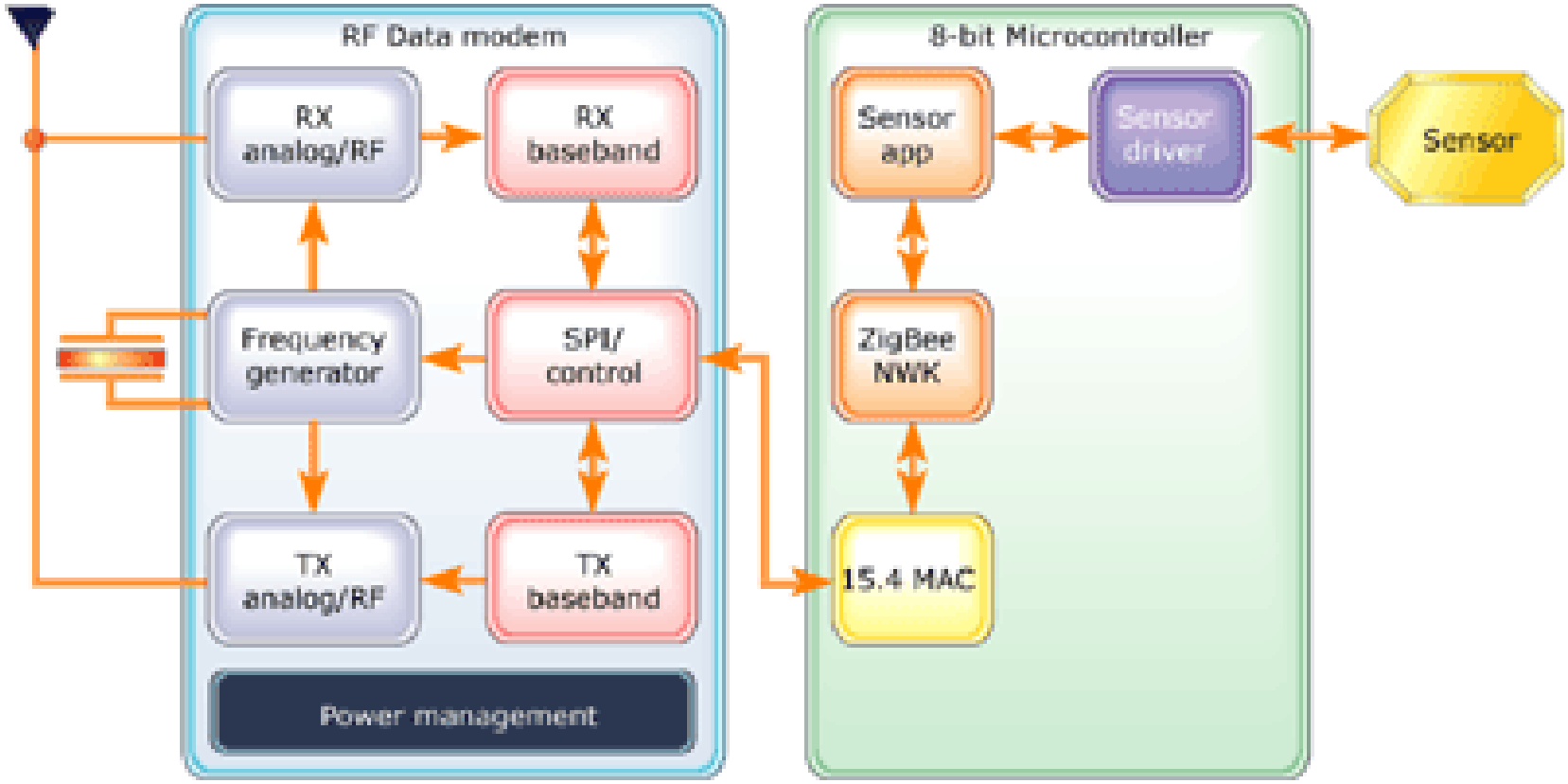
ZigBee

- Pushed by Chipcon (now TI), ember, freescale (Motorola), Honeywell, Mitsubishi, Motorola, Philips, Samsung…
- More than 260 members
  - about 15 promoters, 133 participants, 111 adopters
  - must be member to commercially use ZigBee spec
- ZigBee platforms comprise
  - IEEE 802.15.4 for layers 1 and 2
  - ZigBee protocol stack up to the applications

ZigBee Stack Architecture



Typical ZigBee-Enabled Device Design



Typical design consist of RF IC and 8-bit microprocessor with peripherals connected to an application sensor or actuators

Competing/Similar Technologies

- Bluetooth
  - http://www.bluetooth.org
  - http://www.bluetooth.com
- X10
  - Powerline protocol first introduced in the 1970's.
  - http://www.x10.com/technology1.htm
- Z-wave
  - Proprietary protocol for wireless home control networking.
  - http://www.z-wavealliance.com/
- INSTEON
  - Peer-to-peer mesh networking product that features a hybrid radio/powerline transmission
  - http://www.insteon.net
- nanoNET
  - Proprietary set of wireless sensor protocols, designed to compete with ZigBee.
  - http://www.nanotron.com/

Summary

- 802.15.4: Low-Rate, Very Low-Power
  - Low data rate solution with multi-month to multi-year battery life and very low complexity
  - Potential applications are sensors, interactive toys, smart badges, remote controls, and home automation
  - Data rates of 20-250 kbit/s, latency down to 15 ms
  - Master-Slave or Peer-to-Peer operation
  - Up to 254 devices or 64516 simpler nodes
  - Support for critical latency devices, such as joysticks
  - CSMA/CA channel access (data centric), slotted (beacon) or unslotted
  - Automatic network establishment by the PAN coordinator
  - Dynamic device addressing, flexible addressing format
  - Fully handshaked protocol for transfer reliability
  - Power management to ensure low power consumption
  - 16 channels in the 2.4 GHz ISM band, 10 channels in the 915 MHz US ISM band and one channel in the European 868 MHz band
  - Basis of the ZigBee technology – www.zigbee.org