第四章

无线个域网—IEEE 802.15.4

Outline

- Introduction
- WSN Applications
- Topologies
- Architecture
- Physical Layer
- MAC Layer
- Superframe structure

Introduction

- Until recently, the main concern in wireless communication was on high throughput
- Some applications need a different set of requirements
- Example: LR-WPAN applications

-Low cost communication network

-Limited power

-Low throughput

- Require: reasonable battery life, extremely low cost, short range operation, reliable data transfer

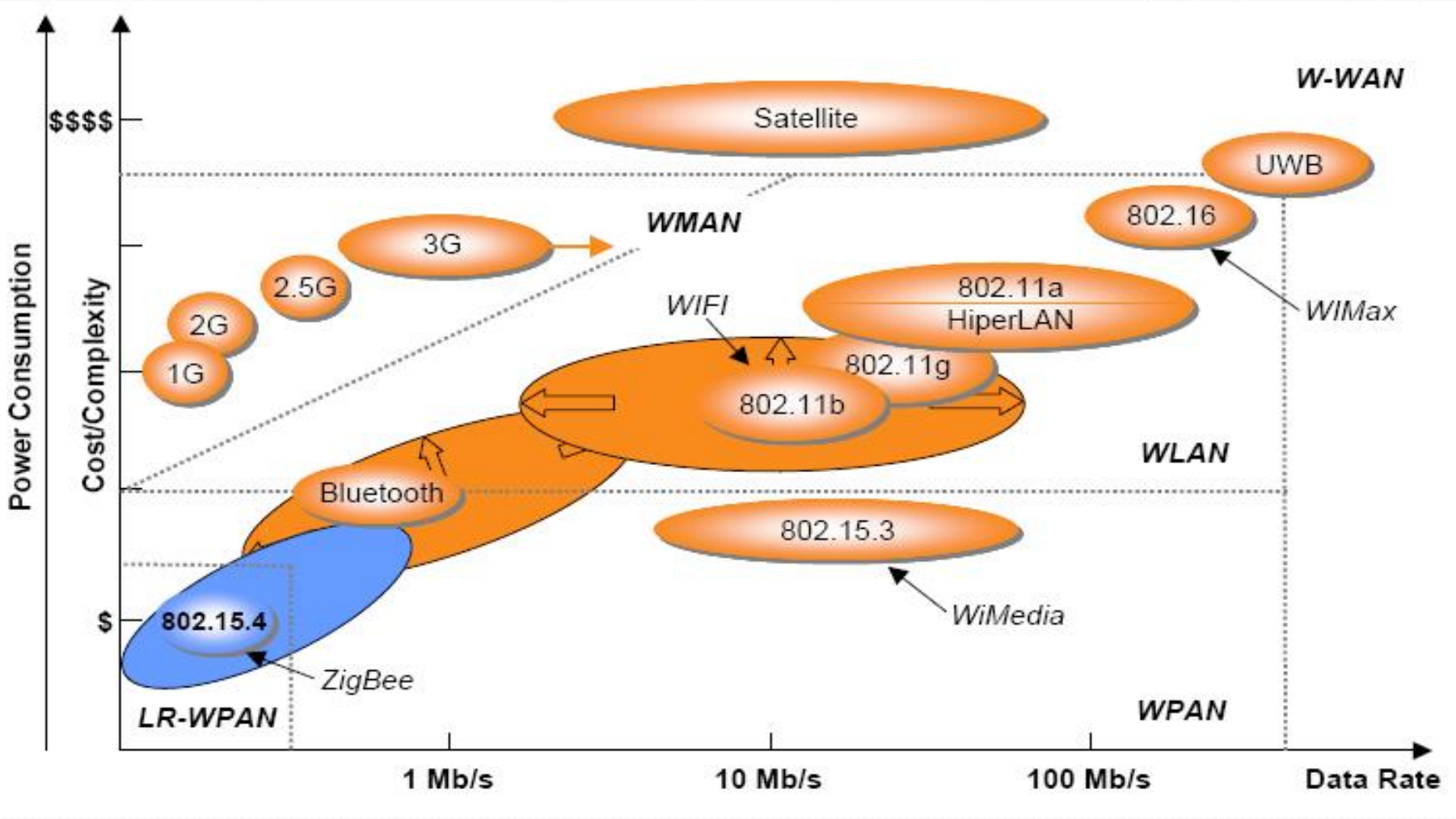
LR-WPAN Applications

Home Automation	Heating, ventilation, air conditioning, security, lighting, control of objects.
Industrial	Detecting emergency situations, monitoring machines.
Automotive	Automotive sensing such as time pressure monitoring.
Agriculture	Sensing of soil moisture, pesticide, herbicide, PH levels.
Others	Controlling consumer electronics, PC peripherals, etc.

Solution?

- Existing standards not suitable for these applications b/c of complexity, power consumption, and high cost.
- Need a simple, flexible protocol
- IEEE 802.15.4 defines protocol via RF for PAN.
- Provide a standard with ultra-low complexity, cost, and power for low-data-rate wireless connectivity among inexpensive fixed, portable, and moving devices.

Wireless Protocols Comparison



Comparison (2)

	LR-WPAN	Bluetooth™	WLAN
Range	10–30 m	~10–100 m	~100 m
Data Throughput	<0.25 MBPS	1 MBPS	~2–11 MBPS
Power Consumption	<BT/10	BT	>BT
Size	Smallest	Smaller	Larger
Nodes/Net	<<BT	BT	>BT
Cost	~$1	~$10–$15	~$40

Device Types

- 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

Modes of Operation

- *Network Device:* An RFD or FFD implementation containing an IEEE 802.15.4 medium access control and physical interface to the wireless medium.
- *PAN Coordinator:* A coordinator that is the principal controller of the PAN. A network has exactly one PAN coordinator. Only an FFD can be a coordinator.

Network Topologies

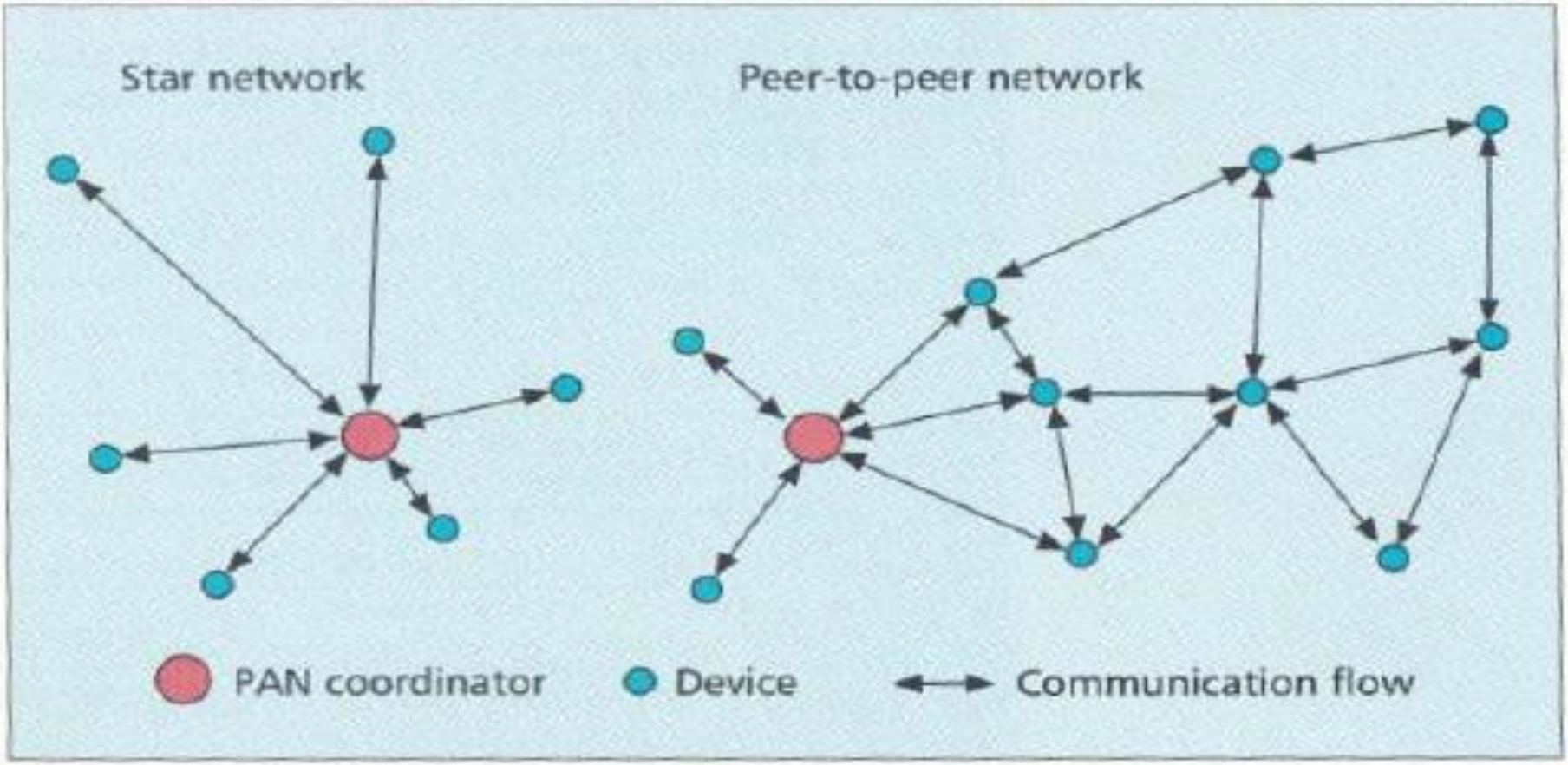
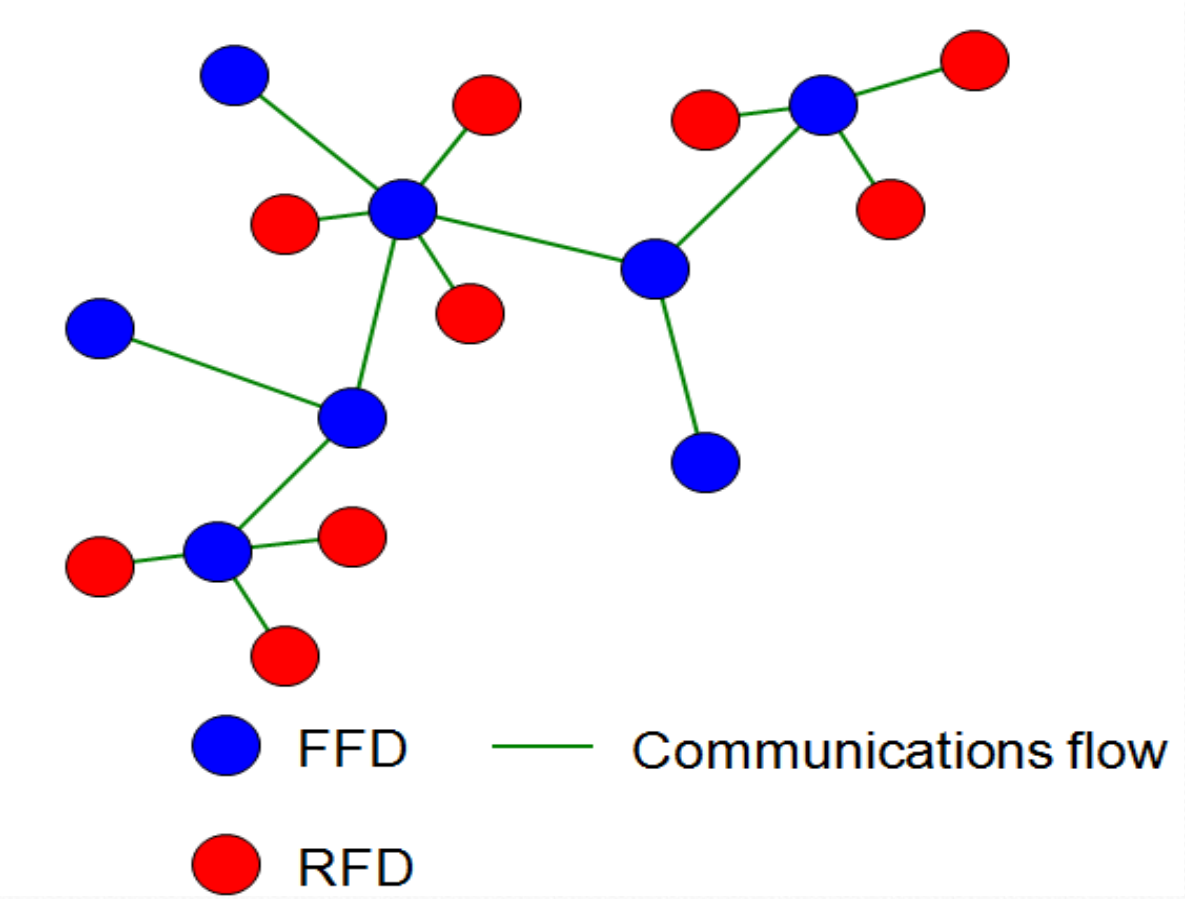


Figure 1. *Star and peer-to-peer networks.*

Combined Topology

- Ex: hotel where cluster nodes exist between the rooms of a hotel and each room has a star network for control.



Star Network Formation

- After an FFD is activated, it can establish its own network and become the PAN coordinator
- Choose a PAN Identifier different from surrounding networks (within RF sphere of influence)
- The PAN coordinator allows other devices, potentially both FFDs and RFDs, to join its network.

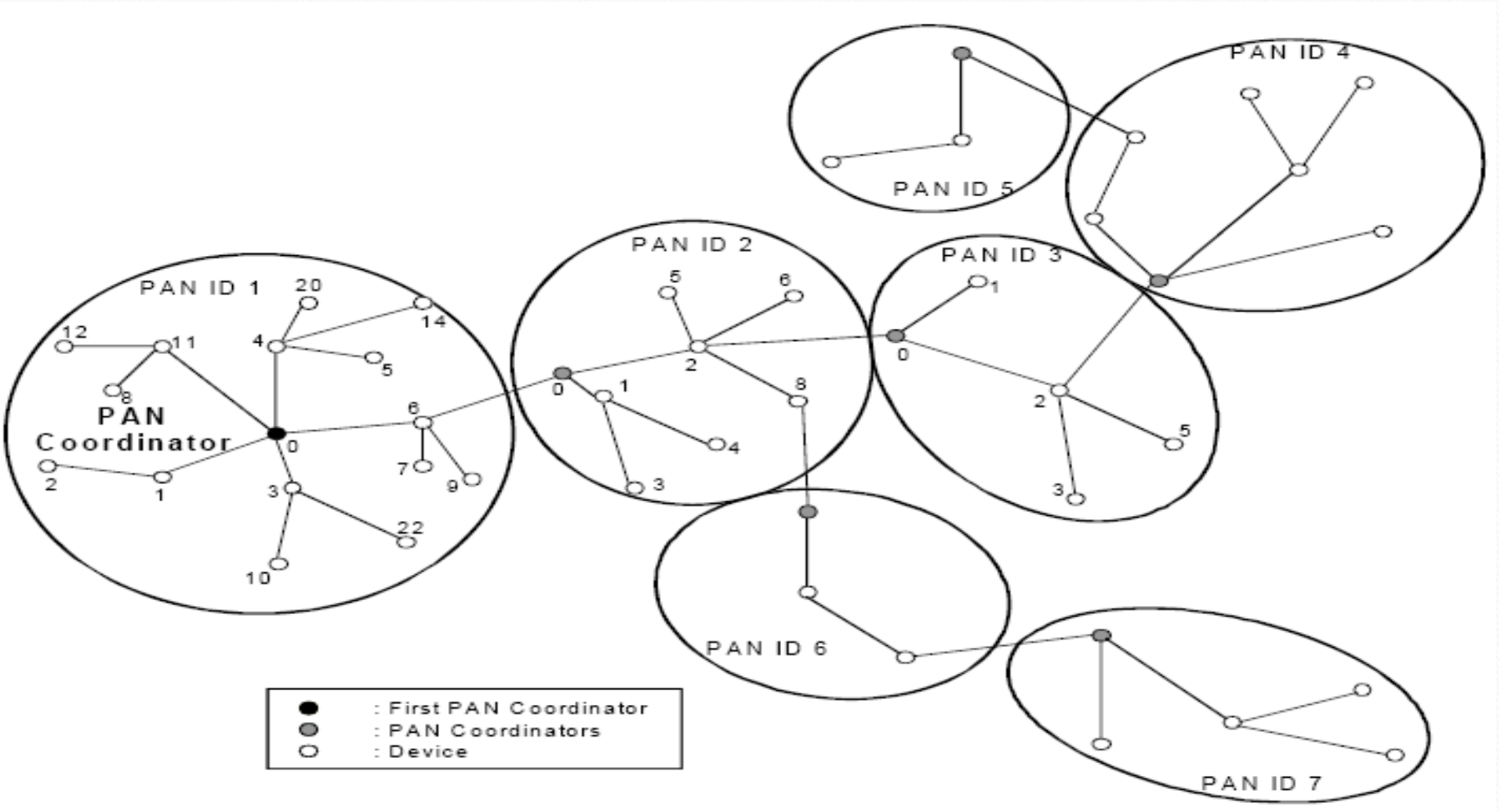
Peer-to-peer Network Formation

- Each device is capable of communicating with any other device within its radio sphere of influence
- One Device is nominated as the PAN coordinator
- Form first cluster by choosing an unused PAN identifier and broadcasting beacon frames to neighboring devices.
- A candidate device receiving a beacon frame may request to join the network at the PAN coordinator.
- If the PAN coordinator permits the device to join, it adds the new device as a child device in its neighbor list.

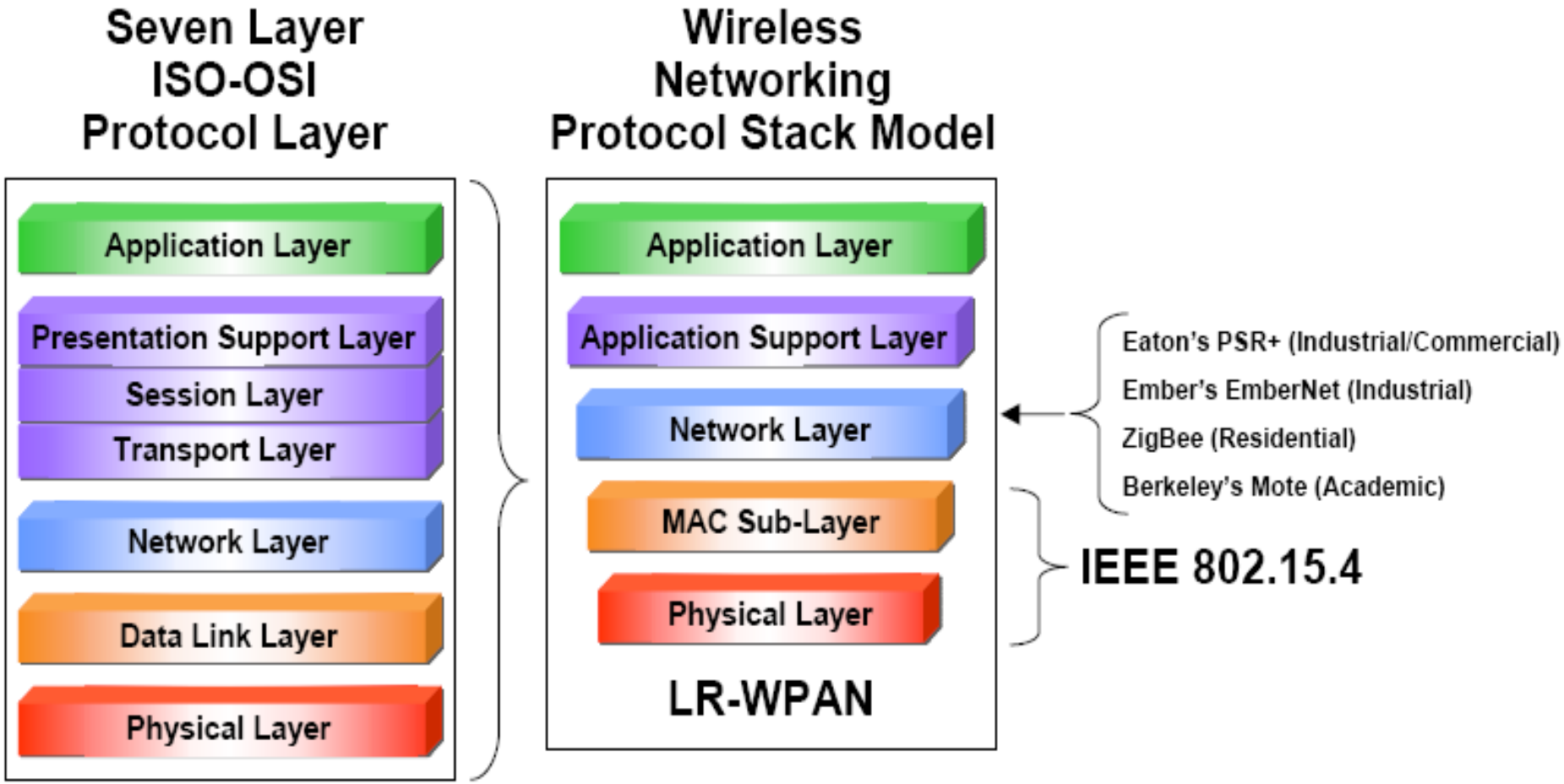
Continued…

- Newly joined device adds the PAN coordinator as its parent in its neighbor list and begins transmitting periodic beacons
- Other candidate devices may then join the network at that device.
- Once predetermined application or network requirements are met, the first PAN coordinator may instruct a device to become the PAN coordinator of a new cluster adjacent to the first one.
- Other devices gradually connect and form a multi-cluster network structure

Cluster Tree Network



Architecture

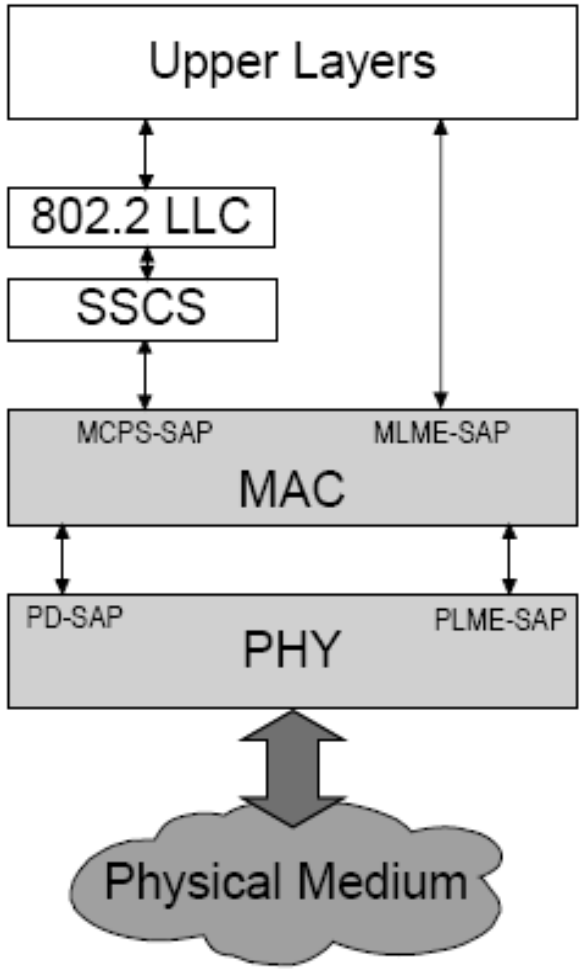


Physical Layer

- Provides two services:

-PD-SAP providing PHY data service

-PLME-SAP providing data and management services to upper layers.



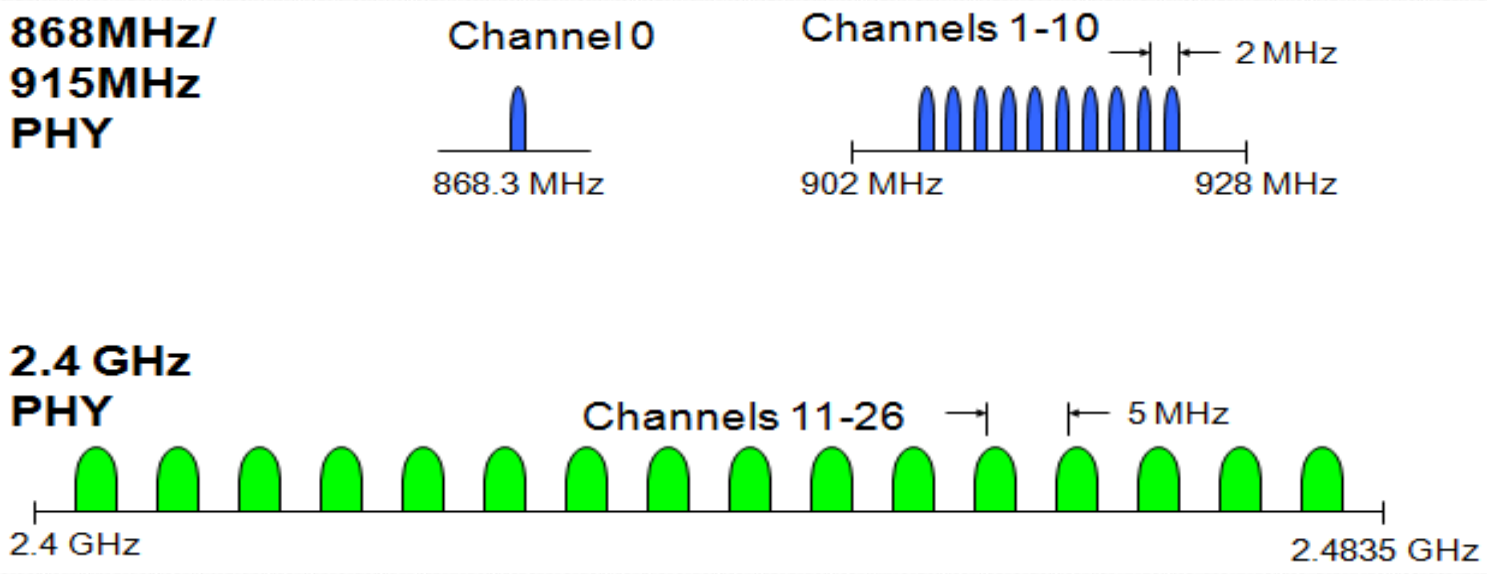
PD-SAP：物理层数据服务访问点
PLME-SAP：物理层管理实体服务访问点

PHY Data Service

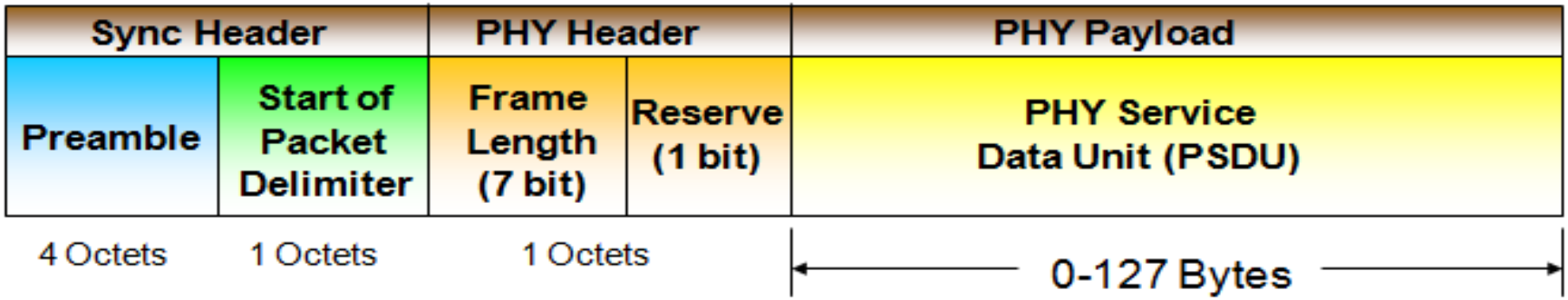
- Enables the transmission and reception of PHY protocol data units (PPDUs) across the physical radio channel
- Activation and deactivation of the radio transceiver
- Energy detection within the current channel
- Link quality indication for received packets
- Clear channel assessment for CSMA-CA
- Channel frequency selection
- Channel switching

Operating Band

- 2.4GHz band operates worldwide- offers 250kb/s
- 868 MHz band operates in Europe- offers 20 kb/s
- 915 MHz band operates in United States- offers 40kb/s



PHY Frame Structure



- The 32-bit preamble is used for synchronization
- “11100101” indicates start of packet
- 7 out of the 8 PHY header bits are used to indicate the length of the PSDU
- The PSDU has a variable length between 0 and 127 bytes

MAC Layer

- The MAC sublayer provides two services:

-MAC data service: enables the transmission and reception of MAC protocol data units (MPDUs) across the PHY data service

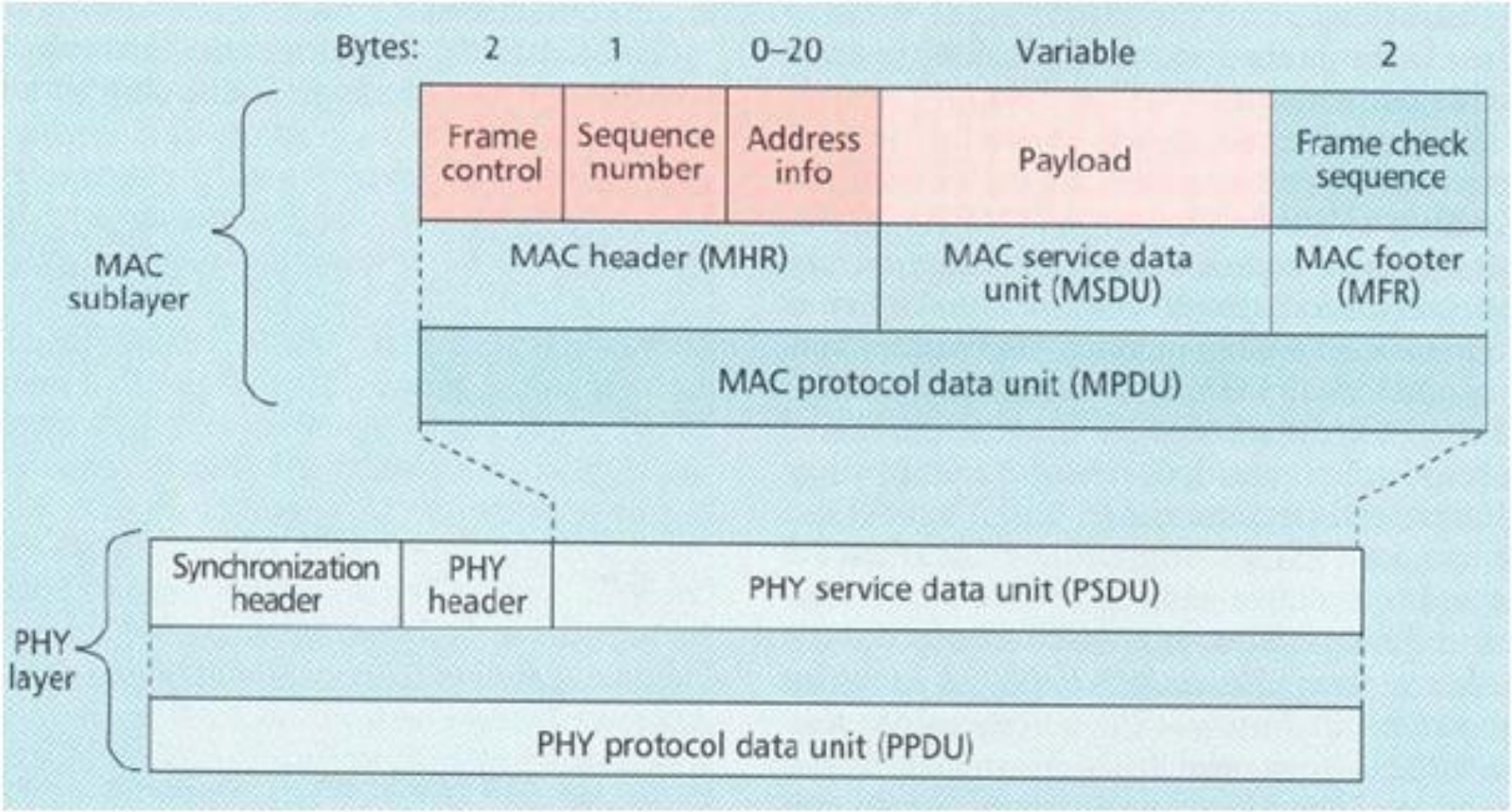
-MLME-SAP: provides data and management services to upper layers

MLME-SAP：MAC层管理实体服务访问点

MAC Sublayer Features

- Beacon management
- Channel access
- Guaranteed Time Slot (GTS) management
- Frame validation
- Acknowledged frame delivery
- Association
- Disassociation
- Provides means for implementing application-appropriate security mechanisms

MAC Frame Format



Frame Control Field

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

地址格式：16位短地址和64位扩展地址
帧控制字段的内容指示地址类型

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

Frame control field

MAC Frame Types

IEEE 802.15.4 defines 4 types of MAC frames:

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

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

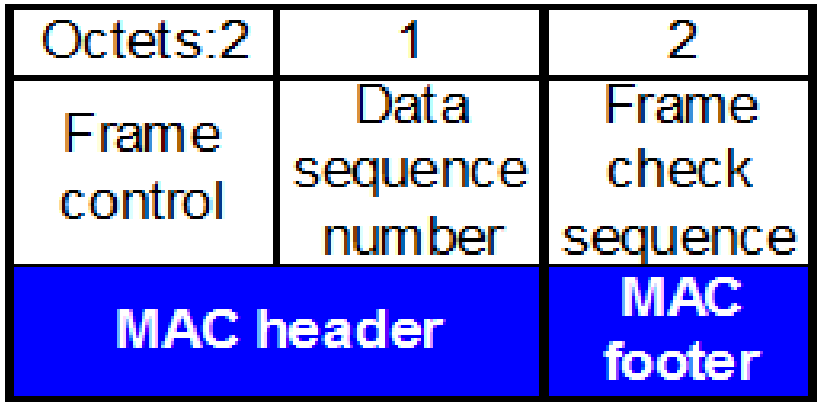
Bits: 0-3	4-7	8-11	12	13	14	15
Beacon order	Superframe order	Final CAP slot	Battery life extension	Reserved	PAN coordinator	Association permit

超帧字段：持续时间，活跃部分持续时间，竞争访问时断持续时间
GTS字段：将无竞争时断划分为若干个GTS，并具体分配给某个设备
Pending Address字段：列出了协调器保存数据相对应的设备地址
Beacon Payload：为上层协议提供数据传输接口，例如安全机制信息

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**

Acknowledgment Frame Format



- 如果设备收到目的地址为其自身的数据帧或MAC命令帧，并且帧的确认请求位设置为1，设备需要回应一个确认帧。
- 确认帧的序列号应该与被确认帧的序列号相同，并且负载长度为0。
- 确认帧紧接着被确认帧发送，不需要使用CSMA-CA机制竞争信道。

Command Frame Format

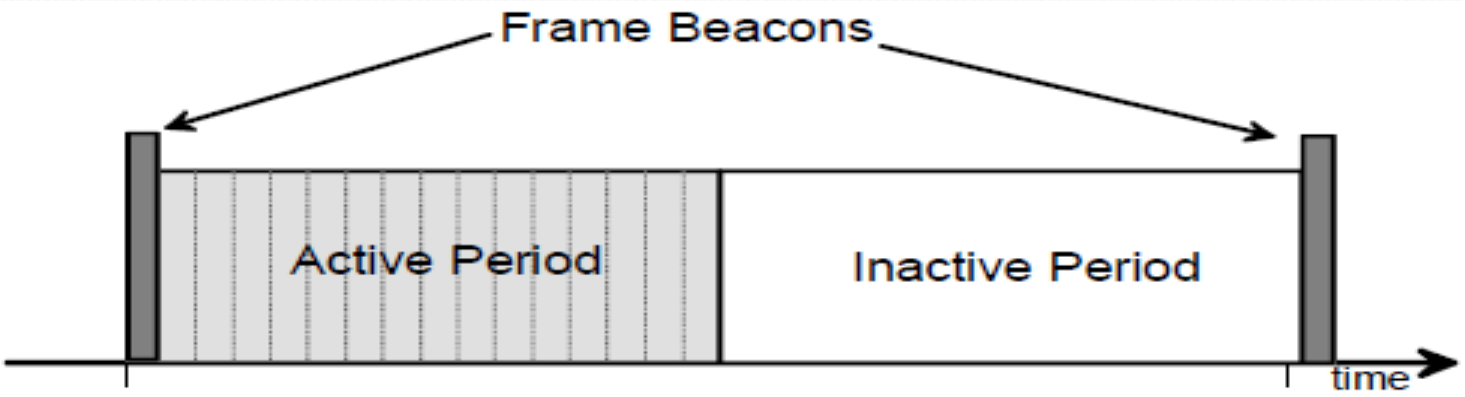
Octets:2	1	4 to 20	1	variable	2
Frame control	Data sequence number	Address information	Command type	Command payload	Frame check sequence
MAC header			MAC payload		MAC footer

- 命令帧用于组建PAN，传输同步数据等。
- 命令帧有9种类型。
- 命令帧的功能：把设备关联到PAN，与协调器交换数据，分配GTS。
- 命令帧的具体功能由帧的负载数据表示。

Command Frame Types

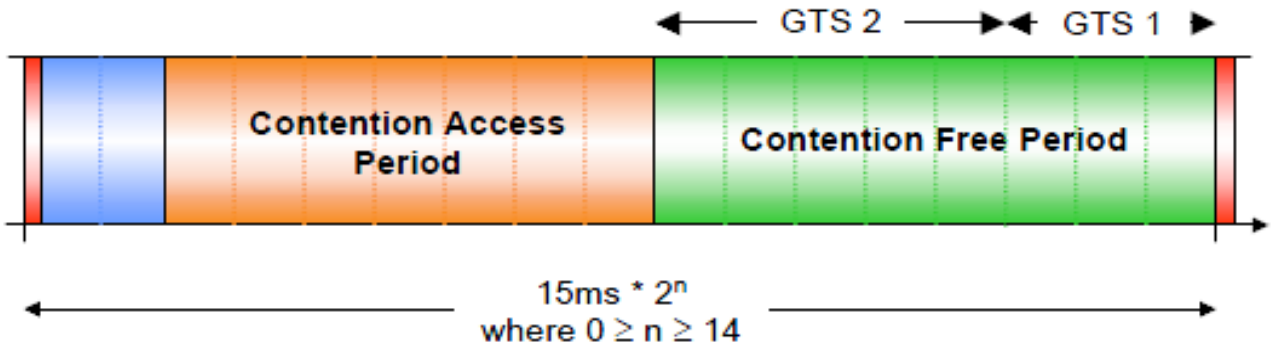
- Association request
- Association response
- Disassociation notification
- Data request
- PAN ID conflict notification
- Orphan Notification
- Beacon request
- Coordinator realignment
- GTS request

Superframe Structure



- The active portion is divided into 16 equally sized slots
- During the inactive portion, the coordinator may enter a low-power mode
- The beacons are used to synchronize the attached devices, to identify the PAN, and to describe the structure of the superframes

Superframe Structure



Network Beacon—Transmitted by network coordinator. Contains network information, frame structure and notification of pending node messages.

Beacon Extension Period—Space reserved for beacon growth due to pending node messages

Contention Period—Access by any node using CSMA-CA

Guaranteed Time Slot—Reserved for nodes requiring guaranteed bandwidth [n = 0]

Guaranteed Time Slots (GTSs)

- For low-latency applications or applications requiring specific data bandwidth
- PAN coordinator may dedicate portions of the active superframe to that application
- PAN coordinator may allocate up to seven of these GTSs, and a GTS may occupy more than one slot period

Data Transfer not using GTSs

- Three types of data transfer:

-Data transfer to a coordinator in which a device transmits the data

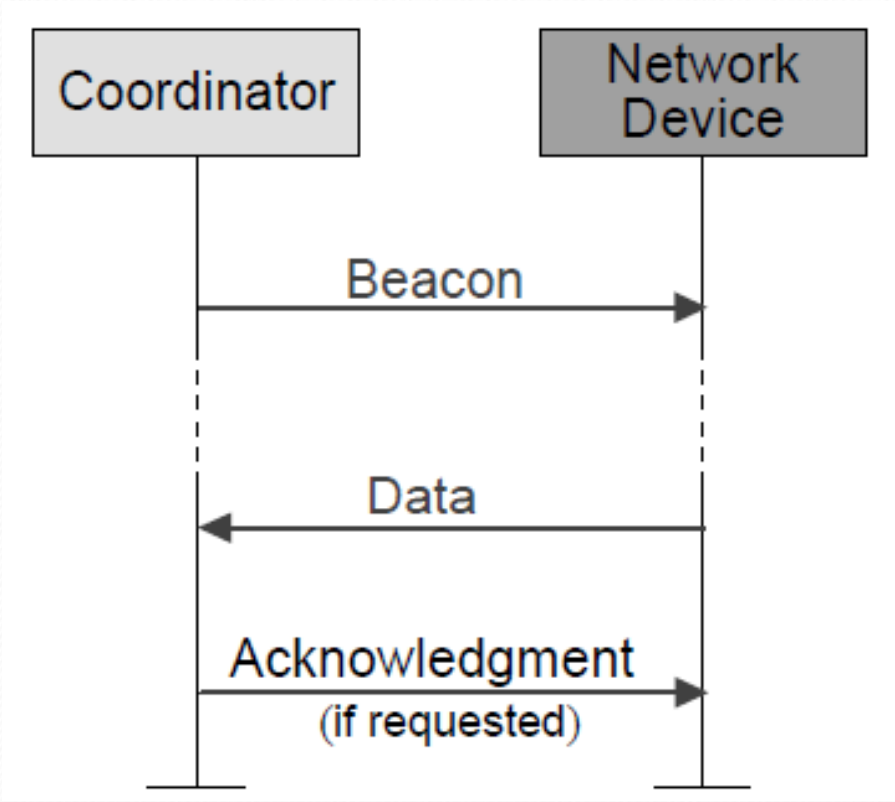
-Data transfer from a coordinator in which the device receives the data

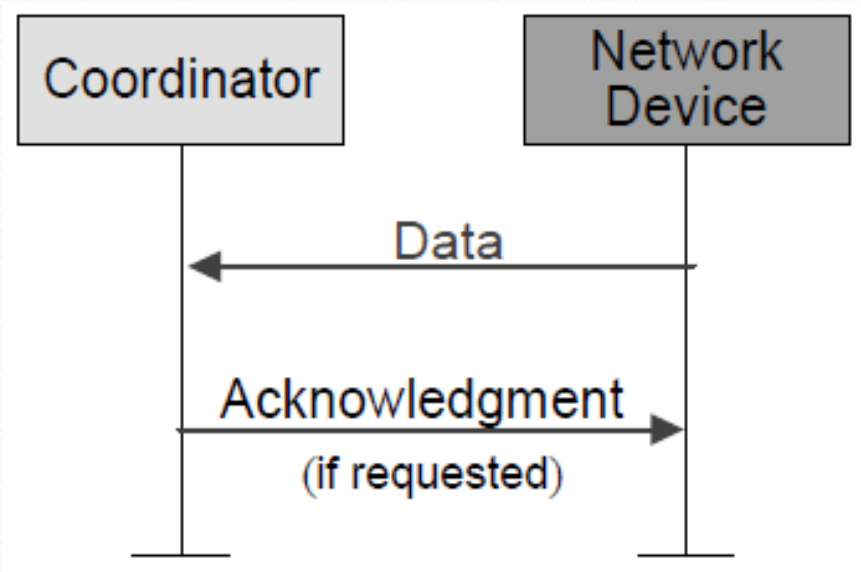
-Data transfer between two peer devices

*In star topology only first two are used

*The mechanisms for each transfer type depend on whether the network supports the transmission of beacons

Data Transfer to a Coordinator

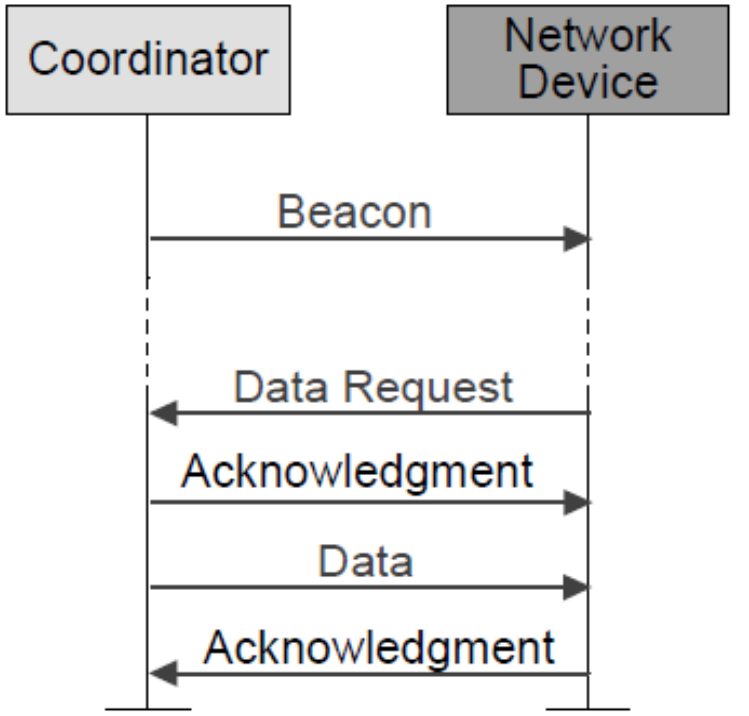


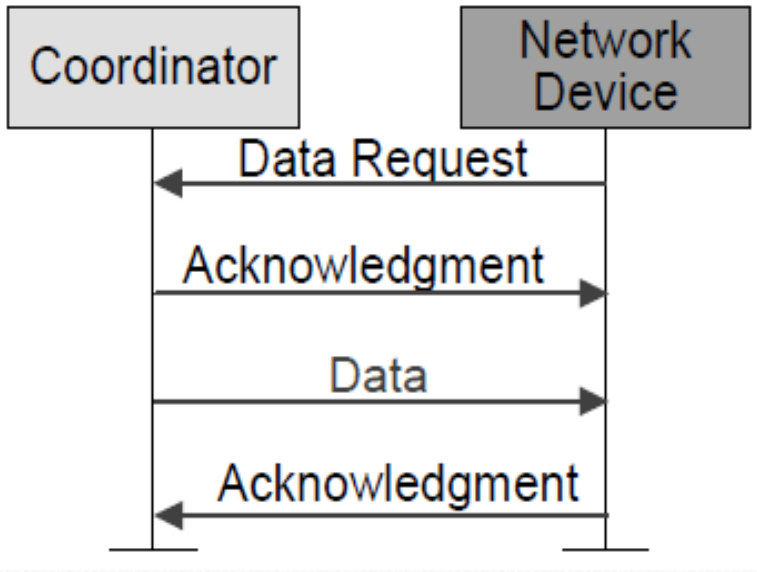


- Beacon-enabled PAN
- Slotted CSMA-CA

- Nonbeacon PAN
- Unslotted CSMA-CA

Data Transfer from a Coordinator





- PAN indicates message is pending in the beacon frame
- Device request data at application-defined rate

Peer-to-peer Data Transfers

- Devices wishing to communicate will need to either receive constantly or synchronize with each other
- In the first case, the device can simply transmit its data using unslotted CSMA-CA
- In the latter case, other measures need to be taken in order to achieve synchronization

Improving Probability of Successful Delivery

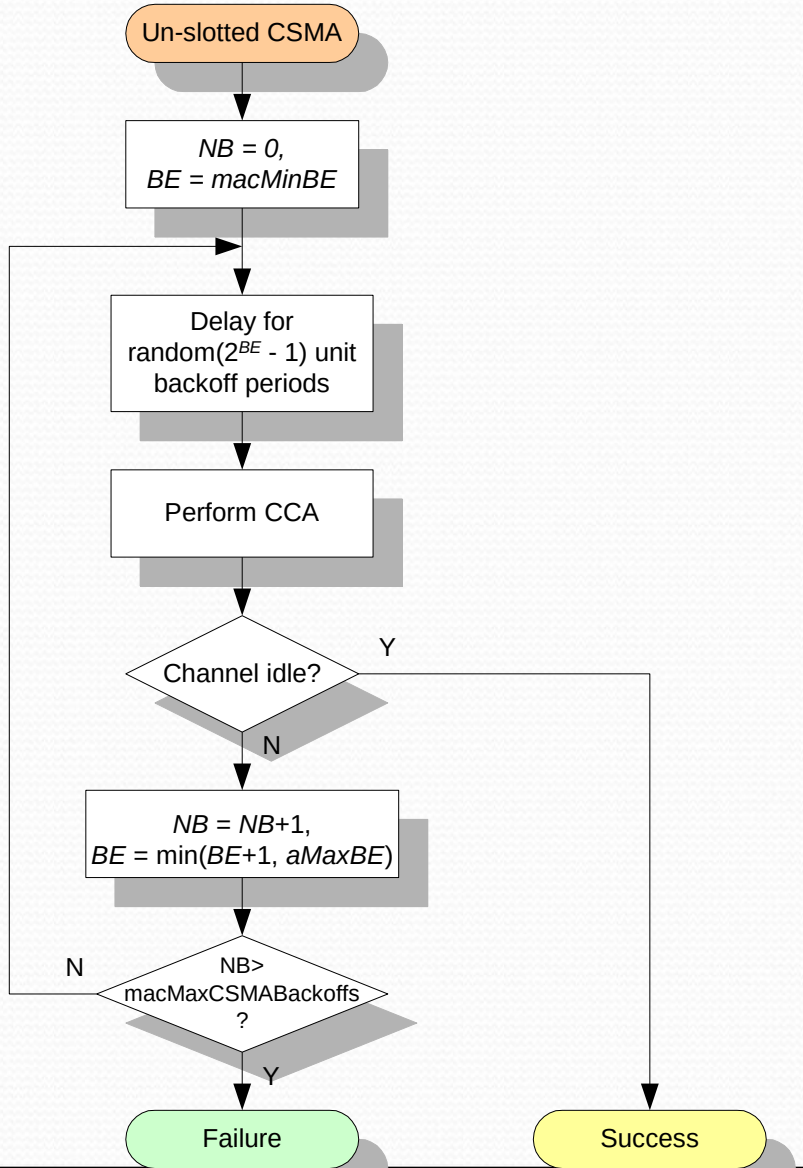
The IEEE 802.15.4 LR-WPAN employs various mechanisms to improve the probability of successful data transmission:

- CSMA-CA mechanism
- Frame acknowledgment
- Data verification

Unslotted CSMA-CA

- Used by nonbeacon-enabled PANs
- Each time a device wishes to transmit data frames or MAC commands, it waits for a random period
- If the channel is found to be idle, following the random backoff, the device transmits its data
- If the channel is found to be busy following the random backoff, the device waits for another random period before trying to access the channel again
- Acknowledgment frames are sent without using a CSMA-CA mechanism

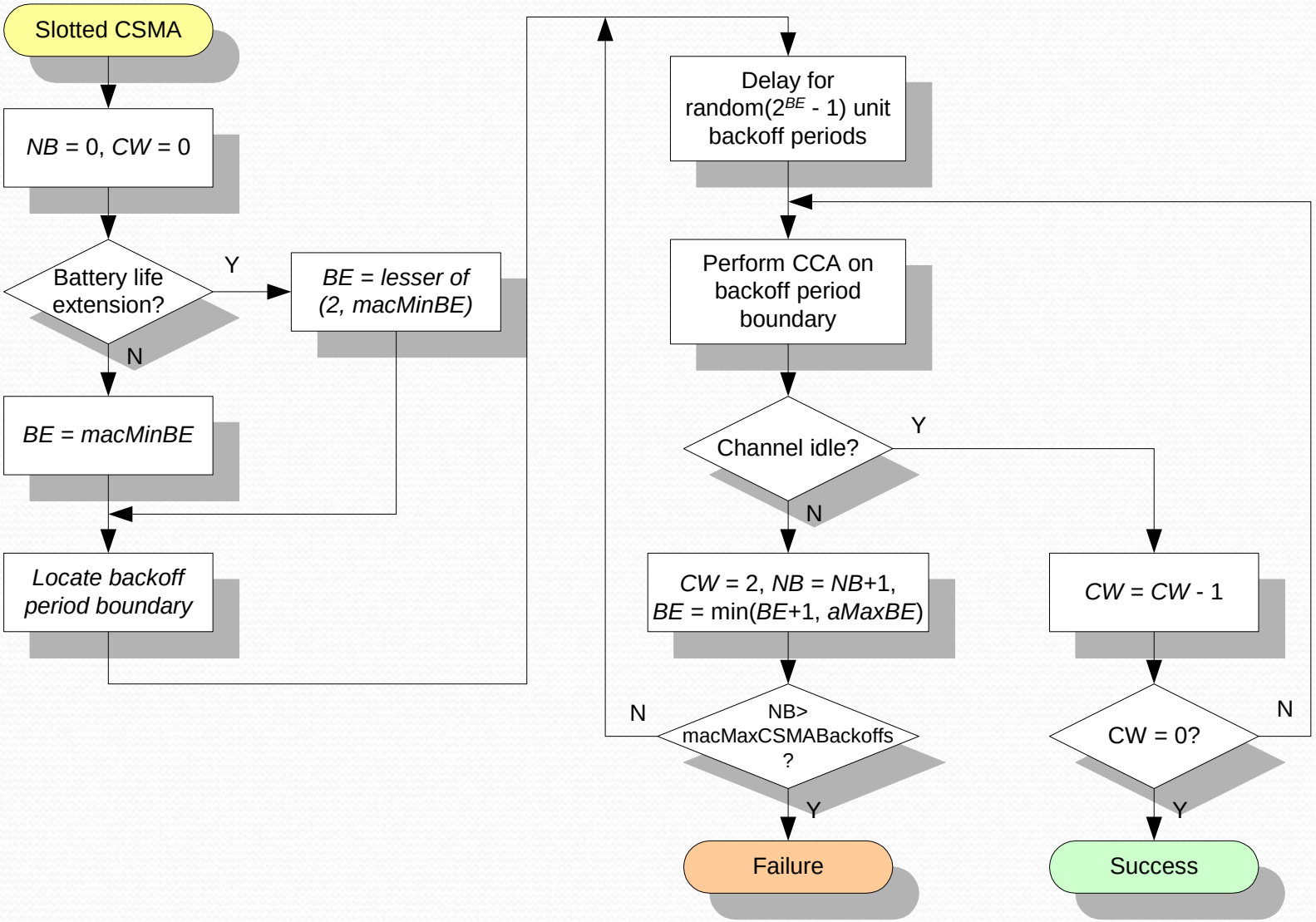
Unslotted CSMA-CA Mechanism



Slotted CSMA-CA

- Used by beacon-enabled PANs
- Backoff slots are aligned with the start of the beacon transmission
- Device locates the boundary of the next backoff slot and then waits for a random number of backoff slots
- If the channel is found busy, following this random backoff, the device waits for another random number of backoff
- If the channel is found idle for two consecutive slots, the device begins transmitting on the next available backoff slot boundary

Slotted CSMA-CA Mechanism



Frame Acknowledgment

- A successful reception and validation of a data or MAC command frame can be optionally confirmed with an acknowledgment
- If the originator does not receive an acknowledgment after a timeout period, it assumes that the transmission was unsuccessful and retries the frame transmission within the retry limit
- When the acknowledgment is not required, the originator assumes the transmission was successful

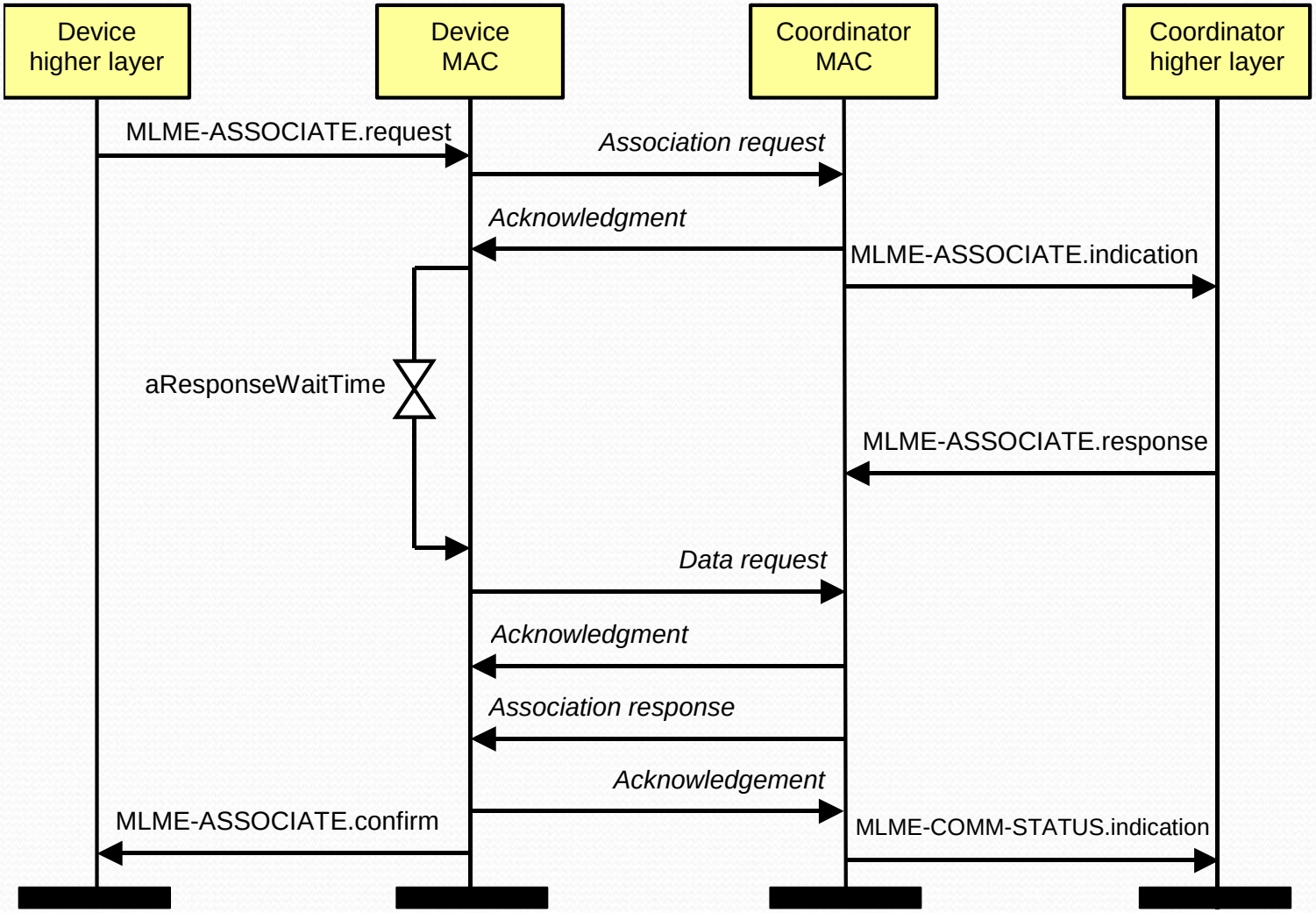
Data Verification-FCS Mechanism

- In order to detect bit errors, an FCS mechanism employing a 16-bit International Telecommunication Union—Telecommunication Standardization Sector (ITU-T) cyclic redundancy check (CRC) is used to detect errors in every frame

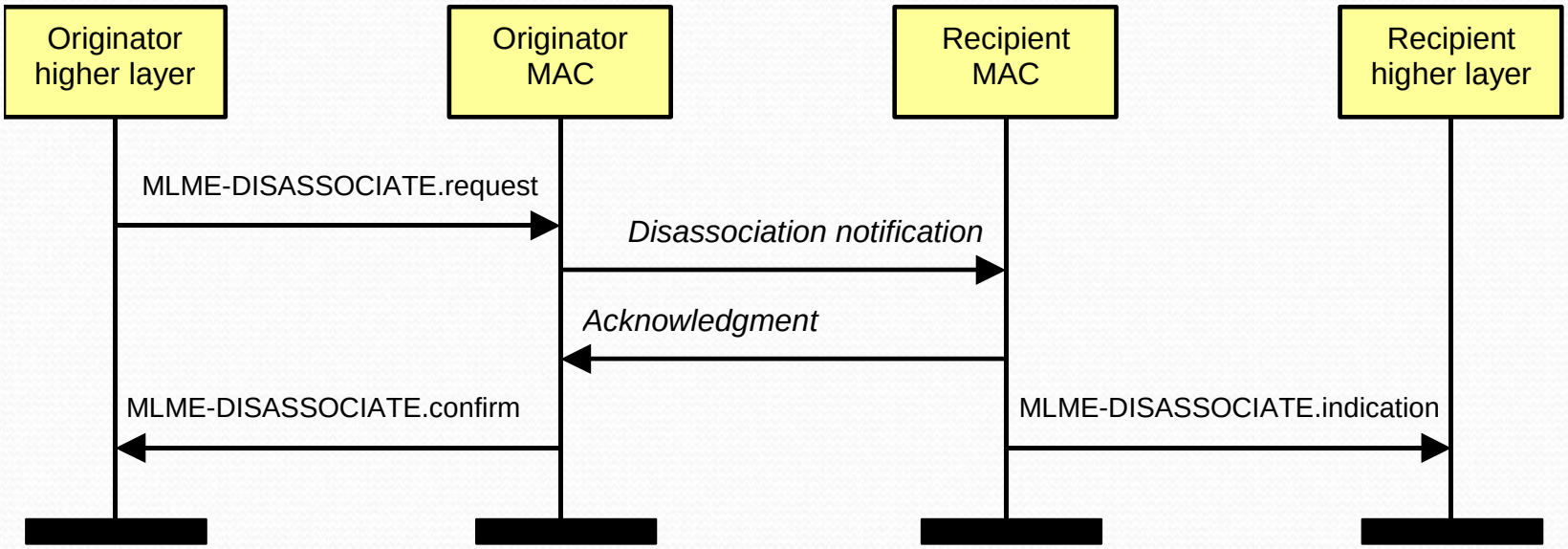
Management Service

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

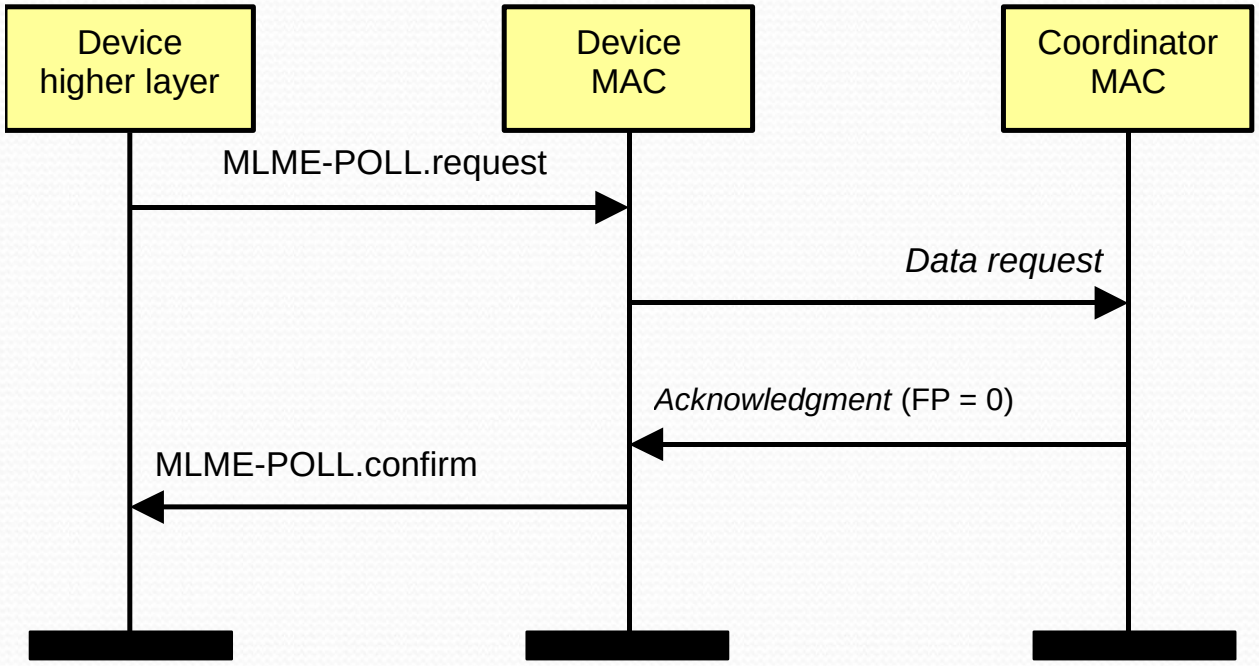
Association



Disassociation

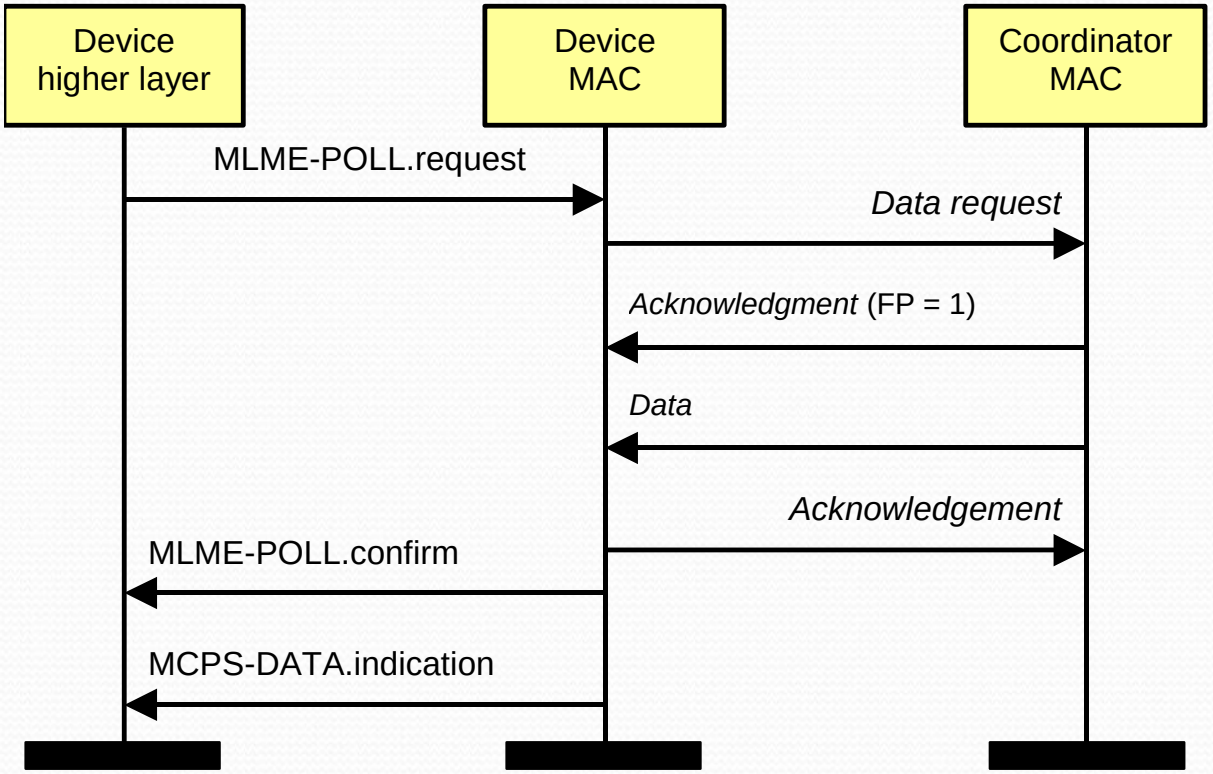


Data Polling



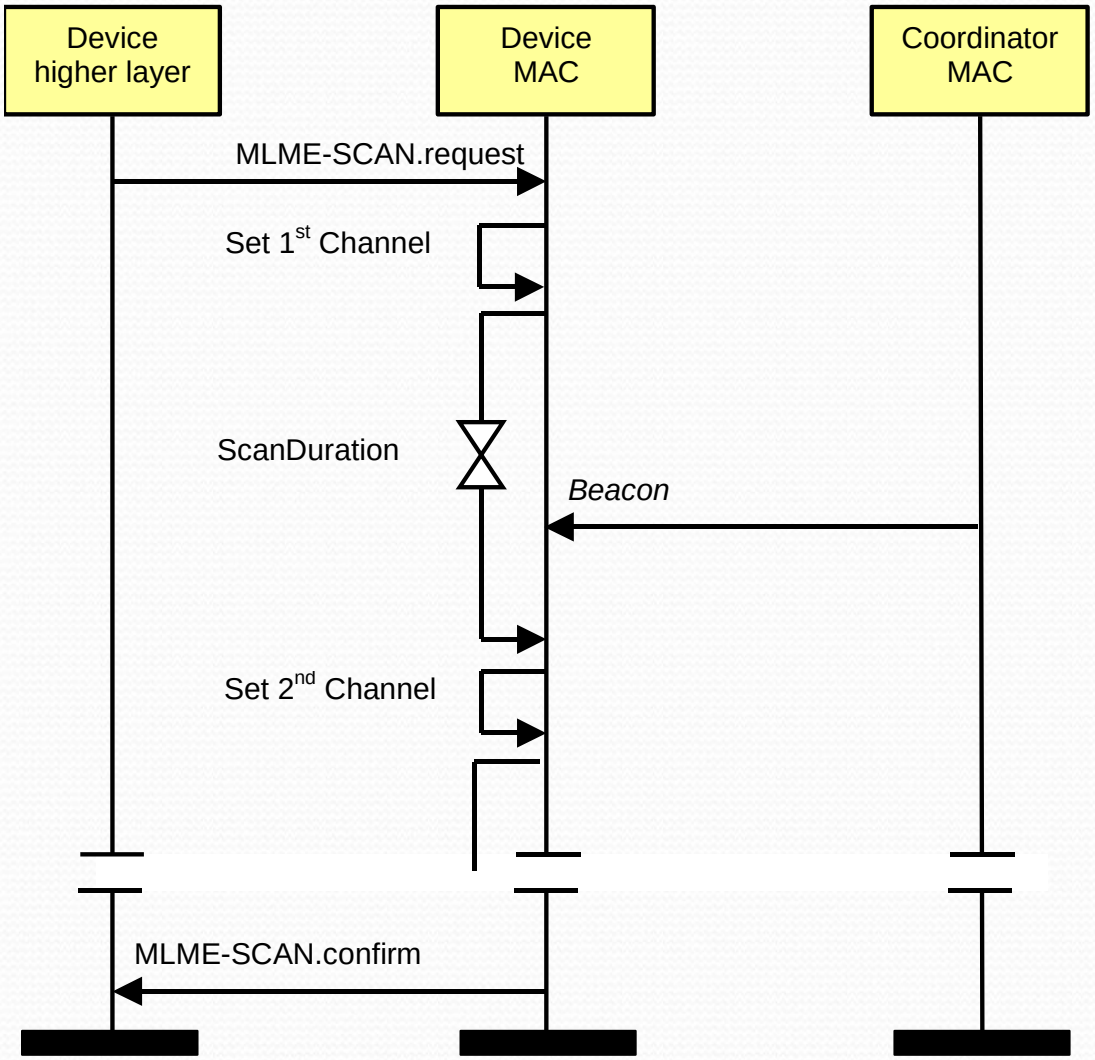
No data pending at the coordinator

Data Polling

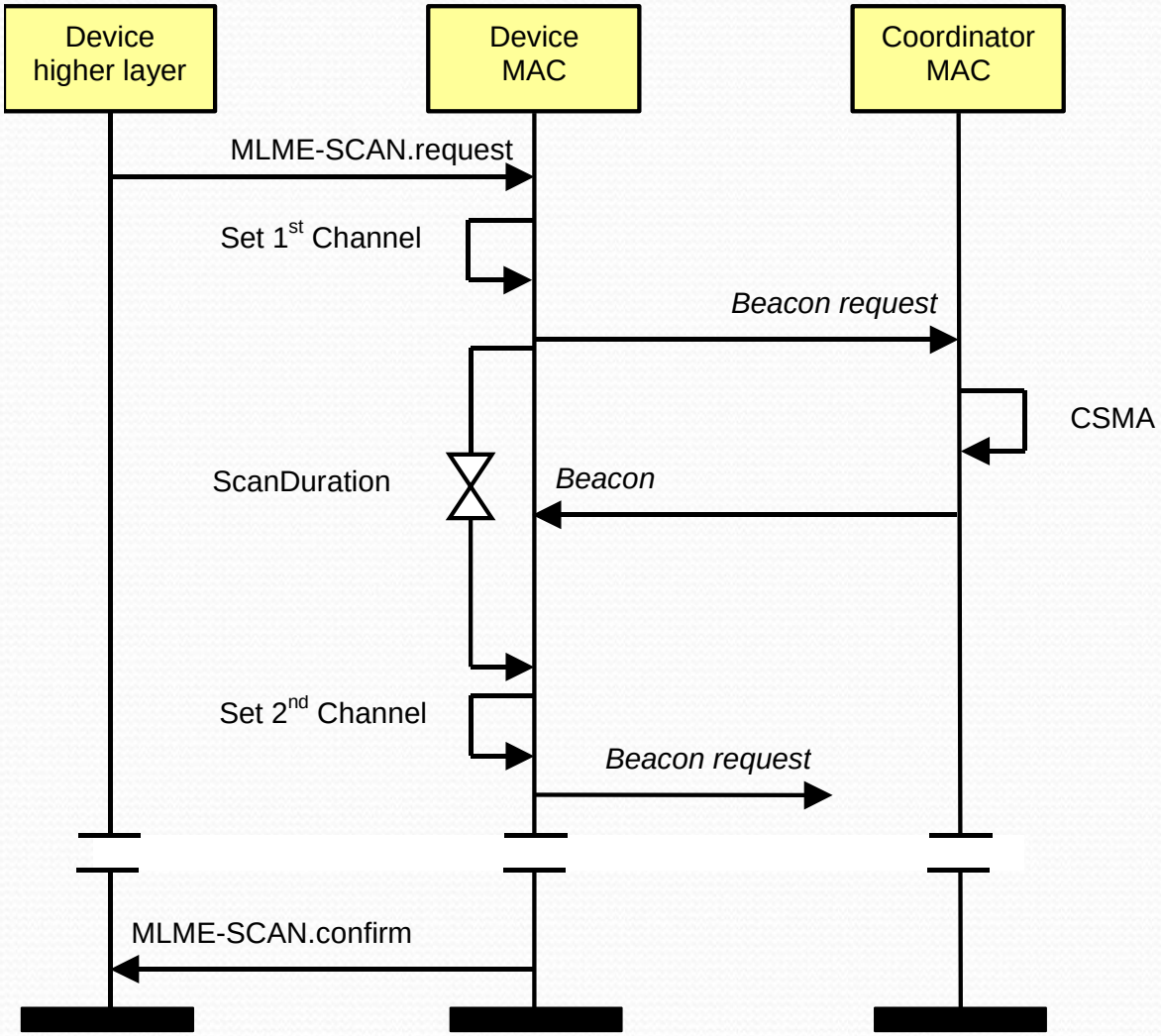


Data pending at the coordinator

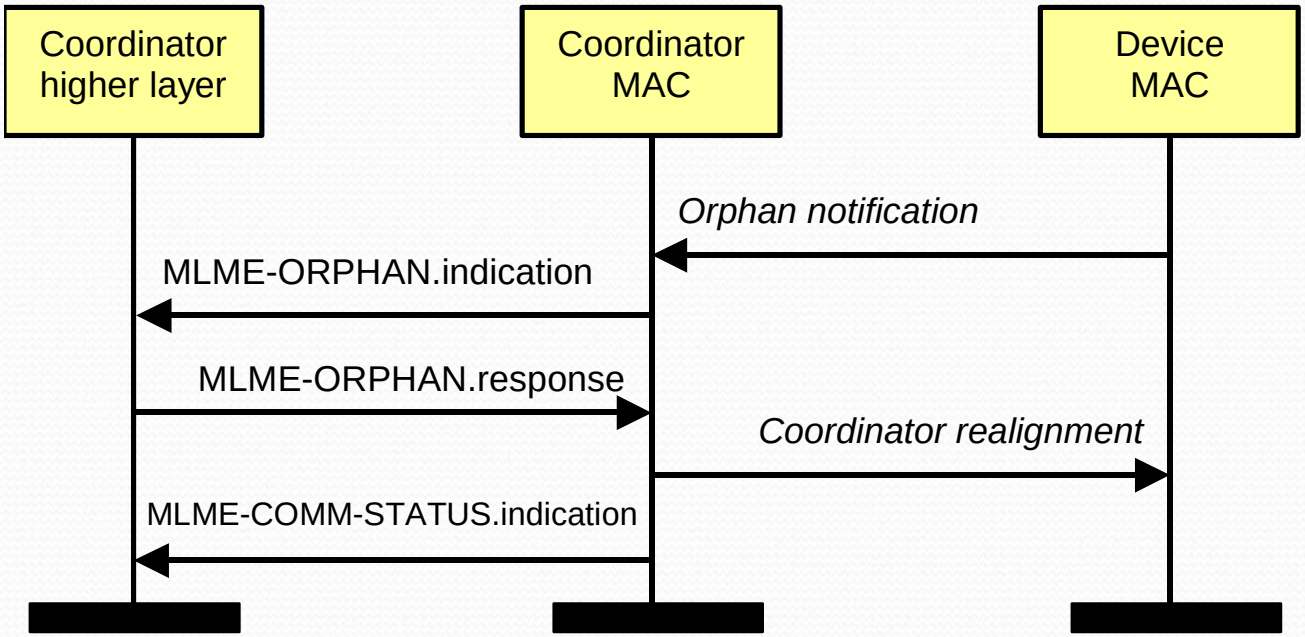
Passive Scan



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

Orphaning


Coordinator higher layer
Coordinator MAC
Device MAC
Orphan notification
MLME-ORPHAN.indication
MLME-ORPHAN.response
Coordinator realignment
MLME-COMM-STATUS.indication

Approaches for Low Power

- The protocol has been developed to favor battery-powered devices
- Battery-powered devices will require duty-cycling to reduce power consumption
- Thus will spend most of their operational life in a sleep state
- Each device periodically listens to the RF channel in order to determine whether a message is pending

第四章作业

1. 简述蓝牙系统的核心规范和概要规范。
2. 简述并比较蓝牙基带规范的两种物理链路。
3. 简述蓝牙设备从待机到连接状态以及低功耗连接状态的建立过程。
4. 简述Zigbee网络对等网络的形成过程。
5. 简述IEEE 802.15.4 信标使能模式下CSMA/CA的接入流程。
6. 简述IEEE 802.15.4 的超帧结构及各部分作用。

End