IEEE 802.15.4 LR-WPAN

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Talk Outline

- Introduction to IEEE 802.15.4
- Technical aspects
  - MAC
  - PHY
- Miscellaneous
- Conclusion

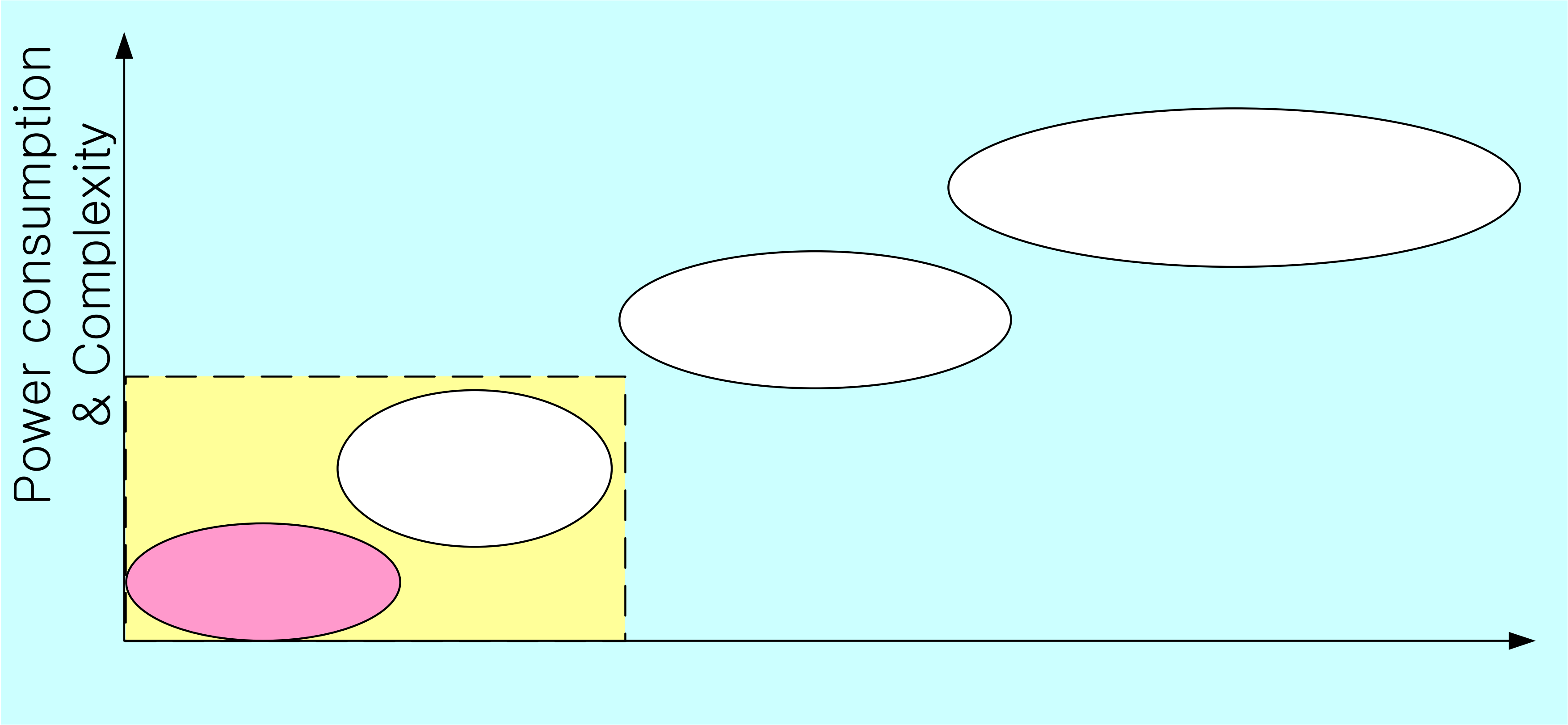
802.15.4 with Five Key Words

- Very low cost
- Very low power consumption
- Low complexity
- Low rate
- Short range

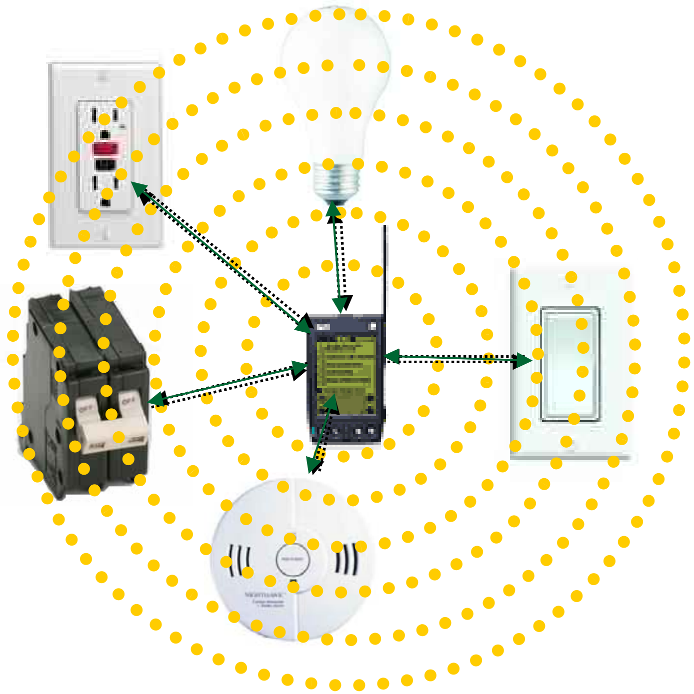
Why Not Other Wireless Solutions?

- 802.11 WLAN
  - Too heavy for most 802.15.4 applications
- Bluetooth
  - Originally, for the cable replacement
  - But, too heavy for most 802.15.4 applications too (e.g., synchronous voice support)!
- Both are too expensive and too much power hungry!
  - Would require battery replacement several times per year

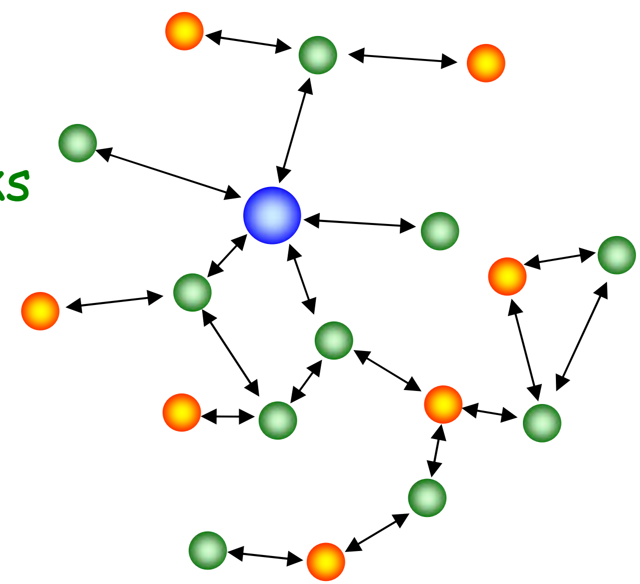
LR-WPAN vs. Other Wireless



802.15.4 Applications Space



- Home Networking
- Automotive Networks
- Industrial Networks
- Interactive Toys
- Remote Metering



Application Examples

- Industrial networks with wireless sensors
  - Emergency situation detection – hazardous chemical levels and fires
- Automotive networks with sensors
  - Tire monitoring system
- Precision farming
  - For environment-adaptive intelligent farming
- Home automation
  - Networking among security system, lighting, AC, and appliances

Common Requirements

- Low power consumption
  - Frequent battery change is not desired and/or not feasible
- Low cost
  - Otherwise, wireline alternative may be preferred
  - An application itself may not be attractive
- High throughput is not required
  - Typically, short-lived sporadic messages
  - Latency or reliability could be more important

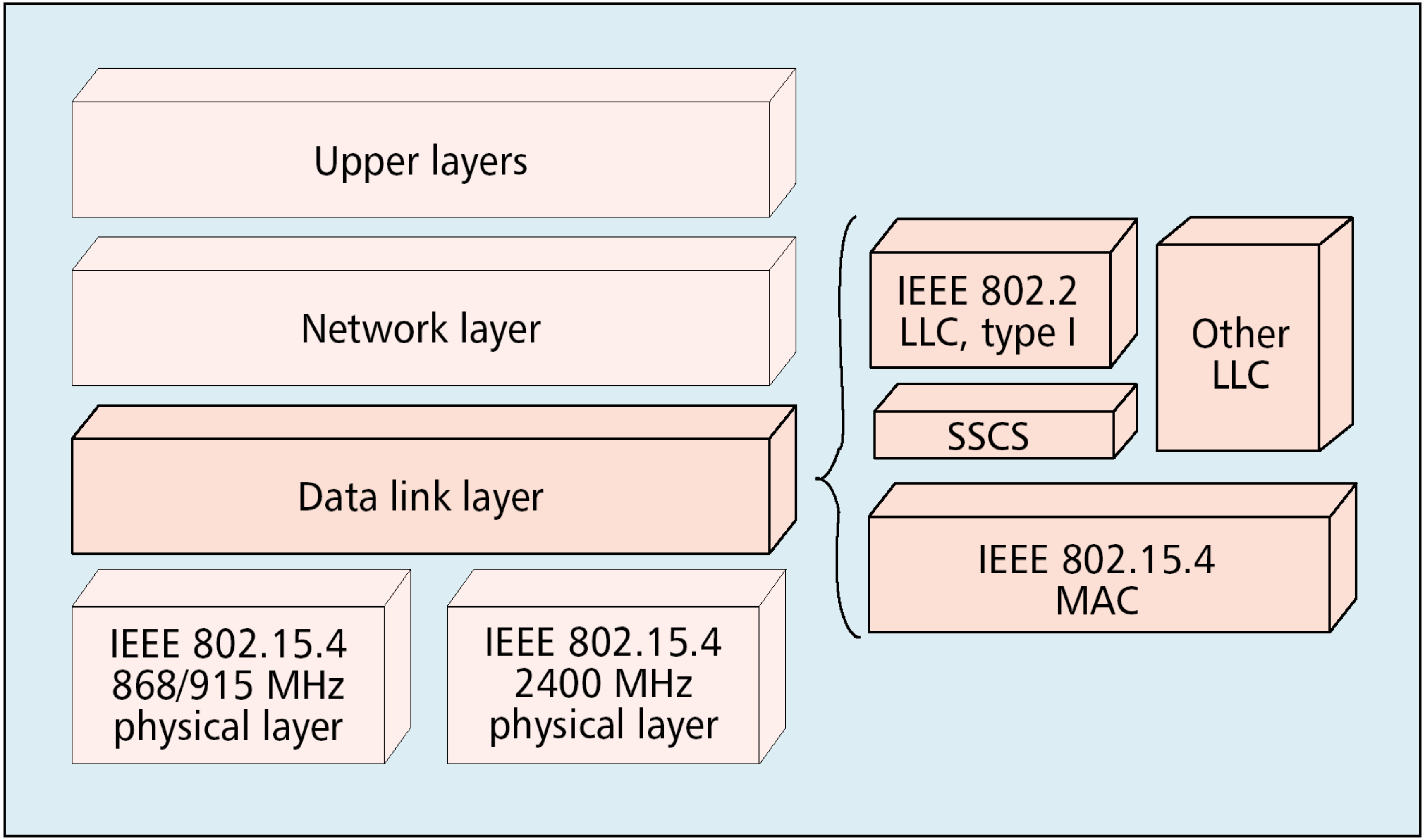
IEEE 802.15.4 for LR-WPAN

Technical Aspects

High-Level Characteristics

Property	Range
Raw data rate	868 MHz: 20 kb/s; 915 MHz: 40 kb/s; 2.4 GHz: 250 kb/s
Range	10–20 m
Latency	Down to 15 ms
Channels	868/915 MHz: 11 channels 2.4 GHz: 16 channels
Frequency band	Two PHYs: 868 MHz/915 MHz and 2.4 GHz
Addressing	Short 8-bit or 64-bit IEEE
Channel access	CSMA-CA and slotted CSMA-CA
Temperature	Industrial temperature range –40 to +85 C

802.15.4 Architecture



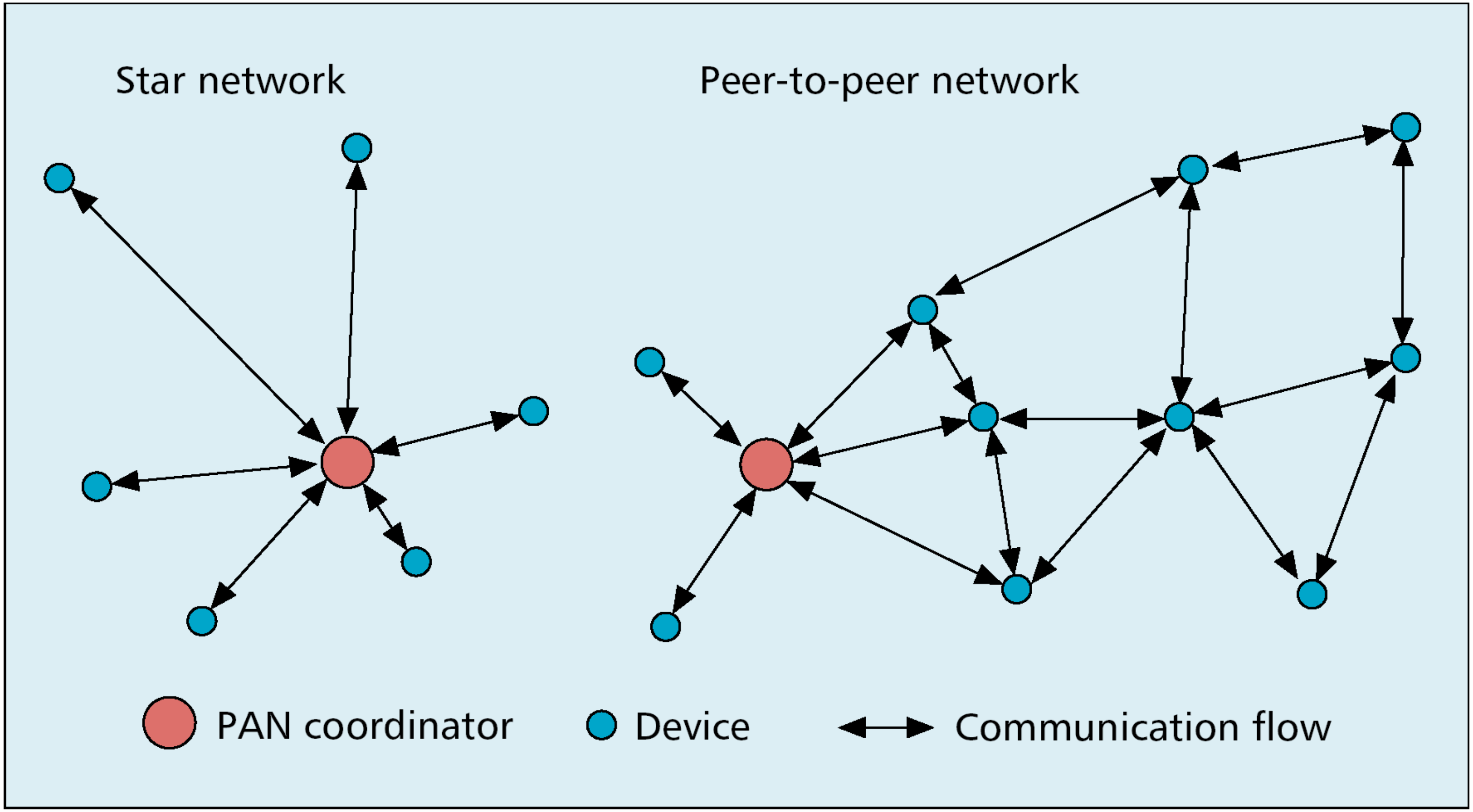
MAC Overview

Design Drivers

- Extremely low cost
- Ease of implementation
- Reliable data transfer
- Short range operation
- Very low power consumption

- Simple, but flexible protocol

Typical Network Topologies



MAC Features

- Association, disassociation
- Optional acknowledged frame delivery
- Channel access mechanism
- Frame validation
- Guaranteed time slot management
- Beacon management

- MAC management has 35 primitives
  - RFD has 24 primitives
  - cf. 131 primitives of 802.15.1 / Bluetooth

Device Classes

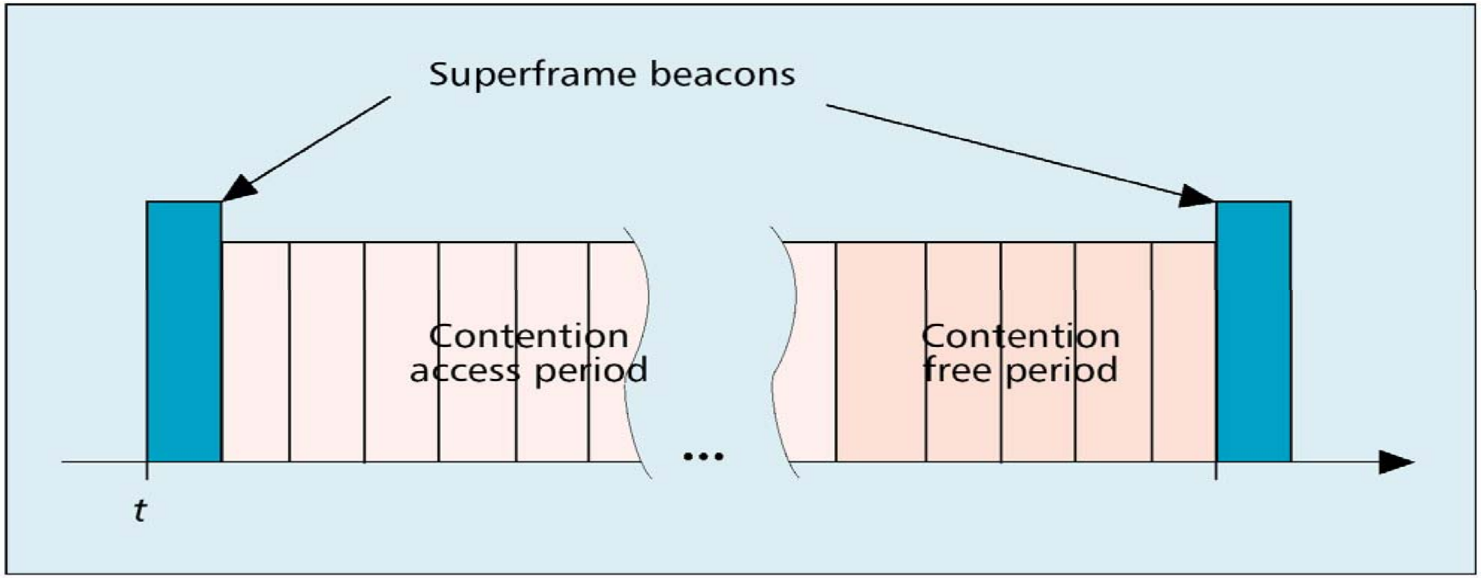
- Full function device (FFD)
  - Any topology
  - Network coordinator capable
  - Talks to any other device
- Reduced function device (RFD)
  - Limited to star topology
  - Cannot become a network coordinator
  - Talks only to a network coordinator
  - Very simple implementation

Access Mechanisms

- Carrier-Sense Multiple Access with Collision Avoidance (CSMA-CA)
- Either slotted or unslotted version used
  - Slotted CSMA-CA in a beacon-enabled network
  - Unslotted or standard CSMA-CA in networks without beacons
- Optionally, contention-free access using Guaranteed Time Slots (GTSs) in beacon-enabled mode

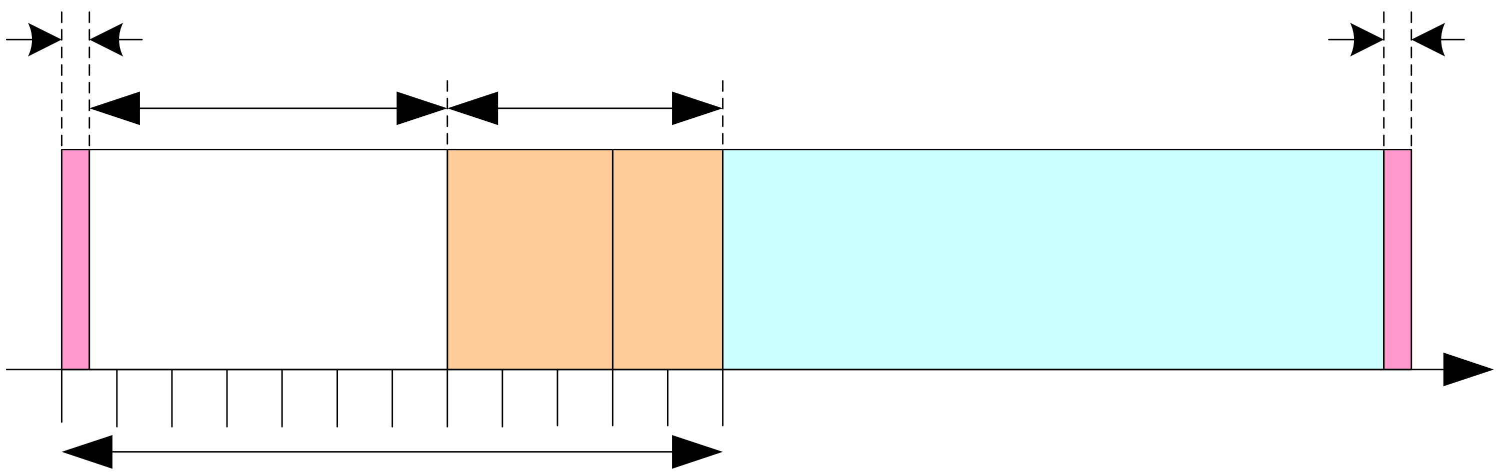
Optional Contention Free Period

- For some applications requiring dedicated bandwidth to achieve low latencies
  - Beacon transmitted every 15 msec~245 sec
  - Each superframe comprises 16 equal superframe slots



Superframe Structure

- Inactive portion can exist for the power save
- Guaranteed Time Slots (GTSs) allocated within CFP
  - Up to 7 GTSs can be allocated in a superframe



MAC-Related Parameters

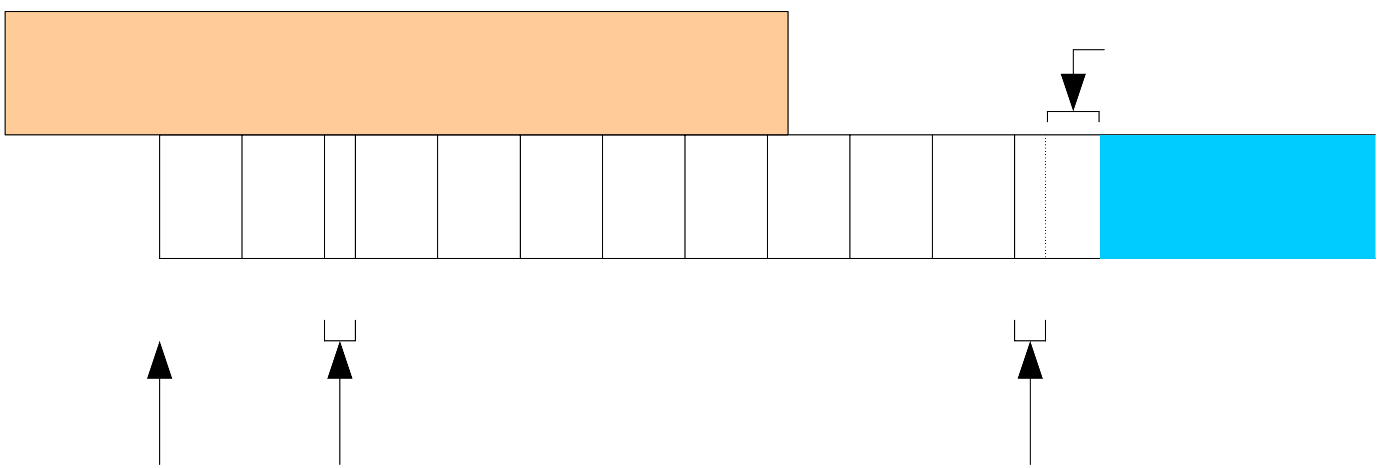
- One symbol = 16 usec (@2.4GHz)
- UnitBackoffPeriod = 20 symbols
- BaseSlotDuration = 60 symbols
- CCA detection time = 8 symbols

- Random backoff [0,2^BE-1]
  - Backoff exponent BE increases by one whenever CCA busy
- Contention window length CW
  - For slotted CSMA-CA, it is initially 2 and decreases by one after a CCA idle assessment
  - For unslotted CSMA-CA, initial value is one THK1

THK1 CW is used in both mode
Tae Hyun Kim, 2006-04-13

Unslotted CSMA-CA

- Backoff periods of a device not related to that of any other device
  - Therefore, synchronization is not required THK2
- CCA – Clear Channel Assessment to check if channel is busy or idle



THK3

THK2 To clarify the previous sentence.
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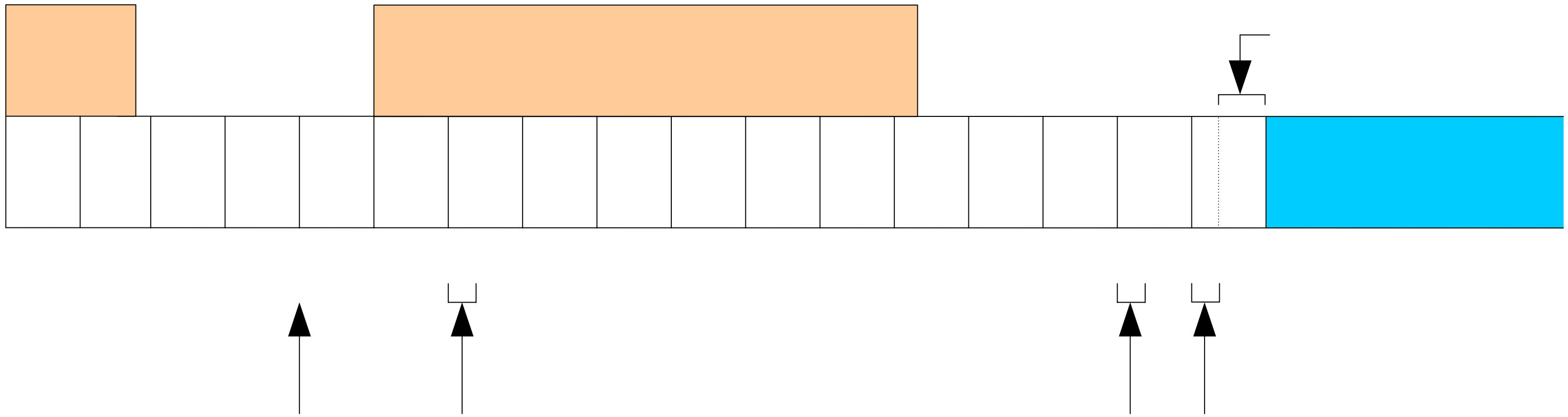
THK3 irrespective of csma-ca type, aTurnaroundTime should be secured between any Rx-Tx radio switching. This is PHY-constant.

Tae Hyun Kim, 2006-04-13

Slotted CSMA-CA

- Backoff period boundaries aligned by the periodic beacon transmission
- It also implies that they are aligned with superframe slot boundaries (for GTS) as Slot = n * aUnitBackoffPeriod



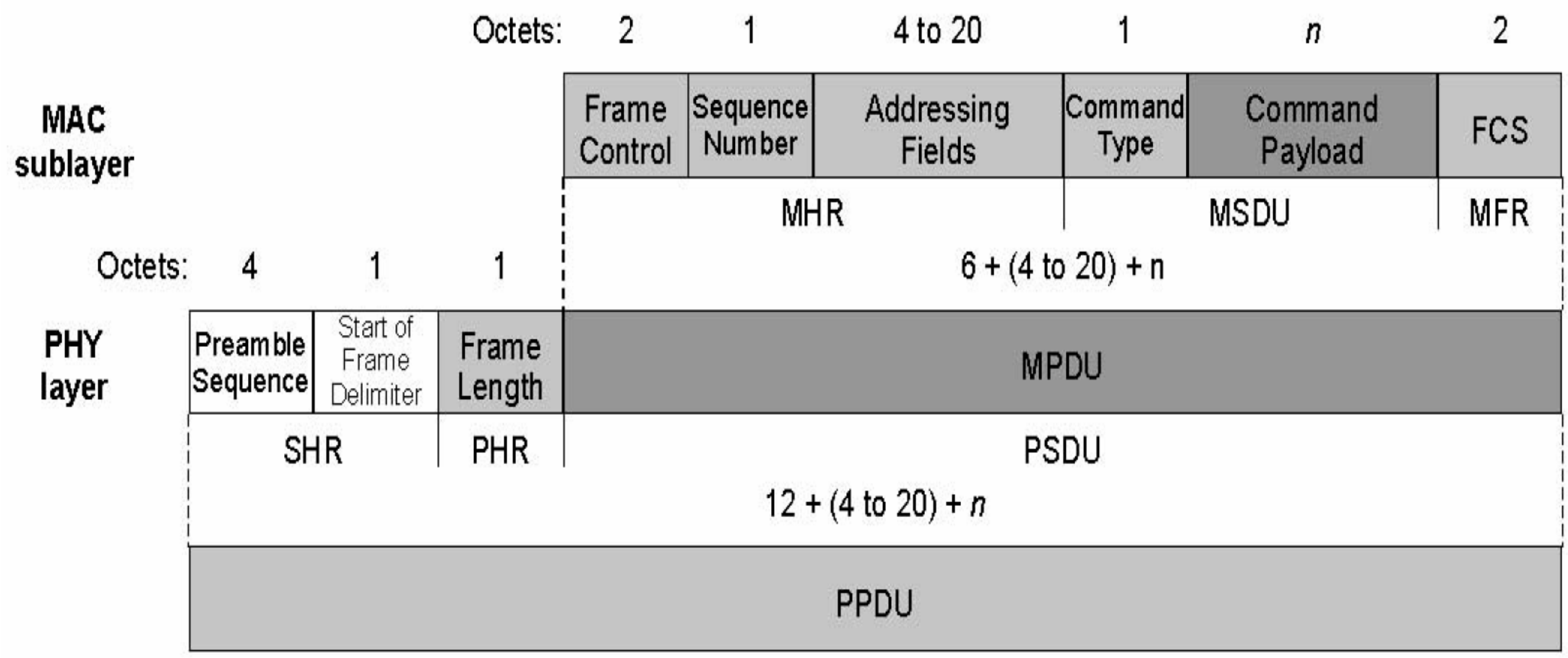
Power Save Mechanisms

- Going to sleep state as often as possible by utilizing:
  - Inactive mode in superframes
  - Backoff periods when macRxOnWhenIdle is reset.
  - GTS for other devices
- Extracting pending messages from coordinator
  - Using data request command
  - Message pending indicated in beacon frames

Addressing

- All devices have either 16-bit or 64-bit IEEE addresses
- Short addresses can be allocated by coordinator

General MAC Frame Format



MAC Frame Components

- Frame control
  - MAC frame type, Address field format
  - Controls the ACK – ACK or no ACK
- Address Information
  - Variable number of addresses
  - 16-bit short or 64-bit IEEE device address
- Sequence number
  - Same number use for the subsequent ACK
- Frame check sequence (FCS)
  - CRC-16 for frame integrity check

Four Types of MAC Frames

- Data Frame
- Acknowledgment Frame
  - After some amount of time varying from TurnaroundTime (12 symbols) to UnitBackoffPeriod + TurnaroundTime (32 symbols) THK4
- Beacon Frame
  - Specifies devices with pending messages
- MAC Command Frame
  - Association request/response
  - Data request for pending messages
  - GTS request/allocation and many others

THK4 More exactly speaking, this one sounds better.
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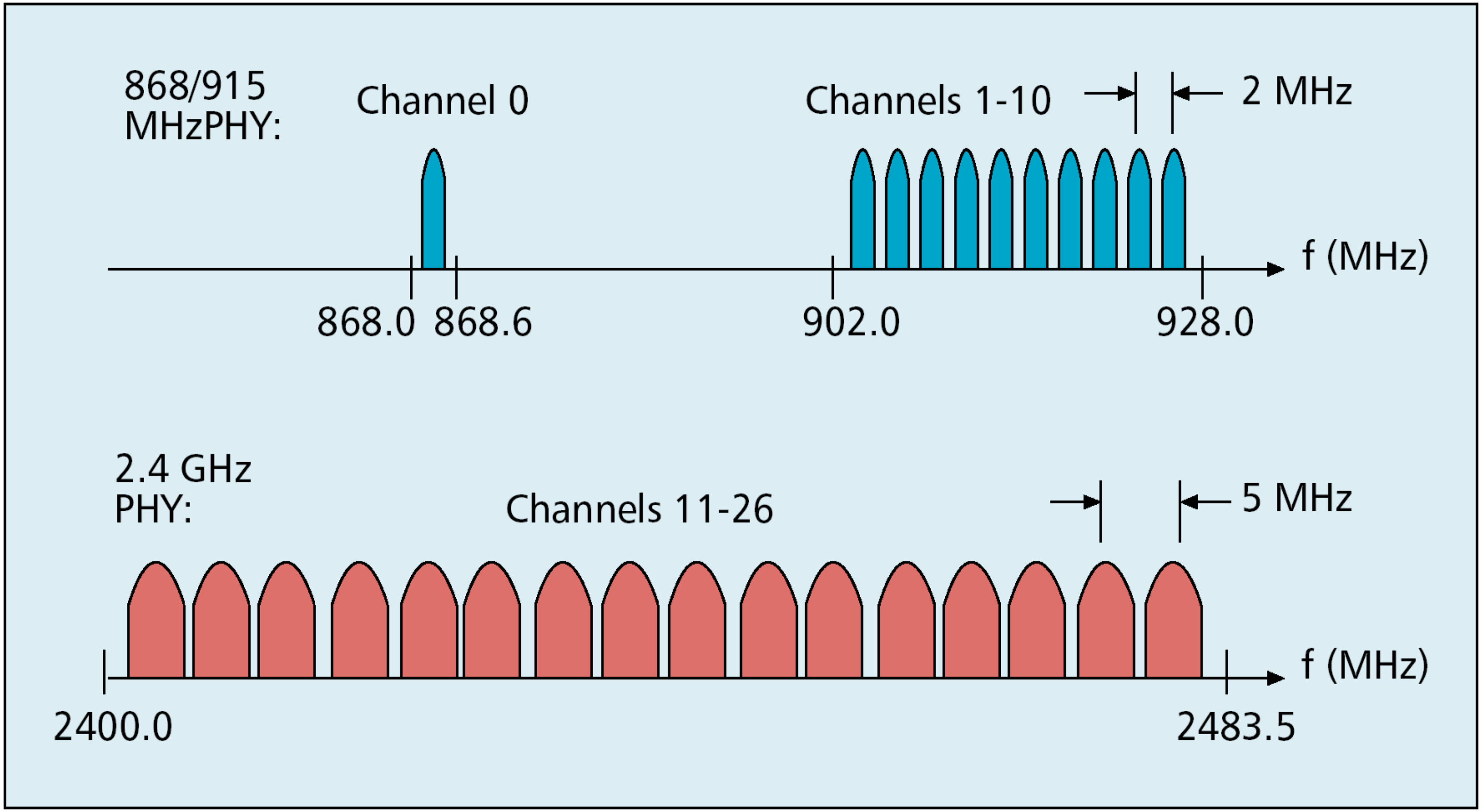
PHY Overview

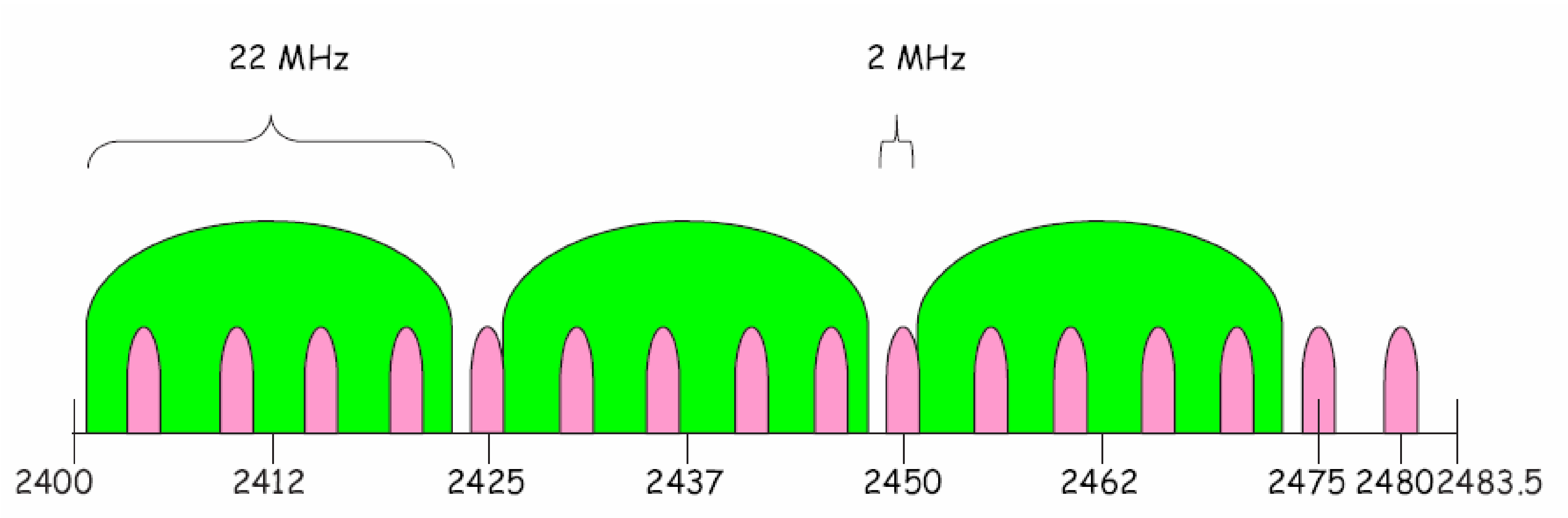
PHY Overview – Operating Frequency Bands

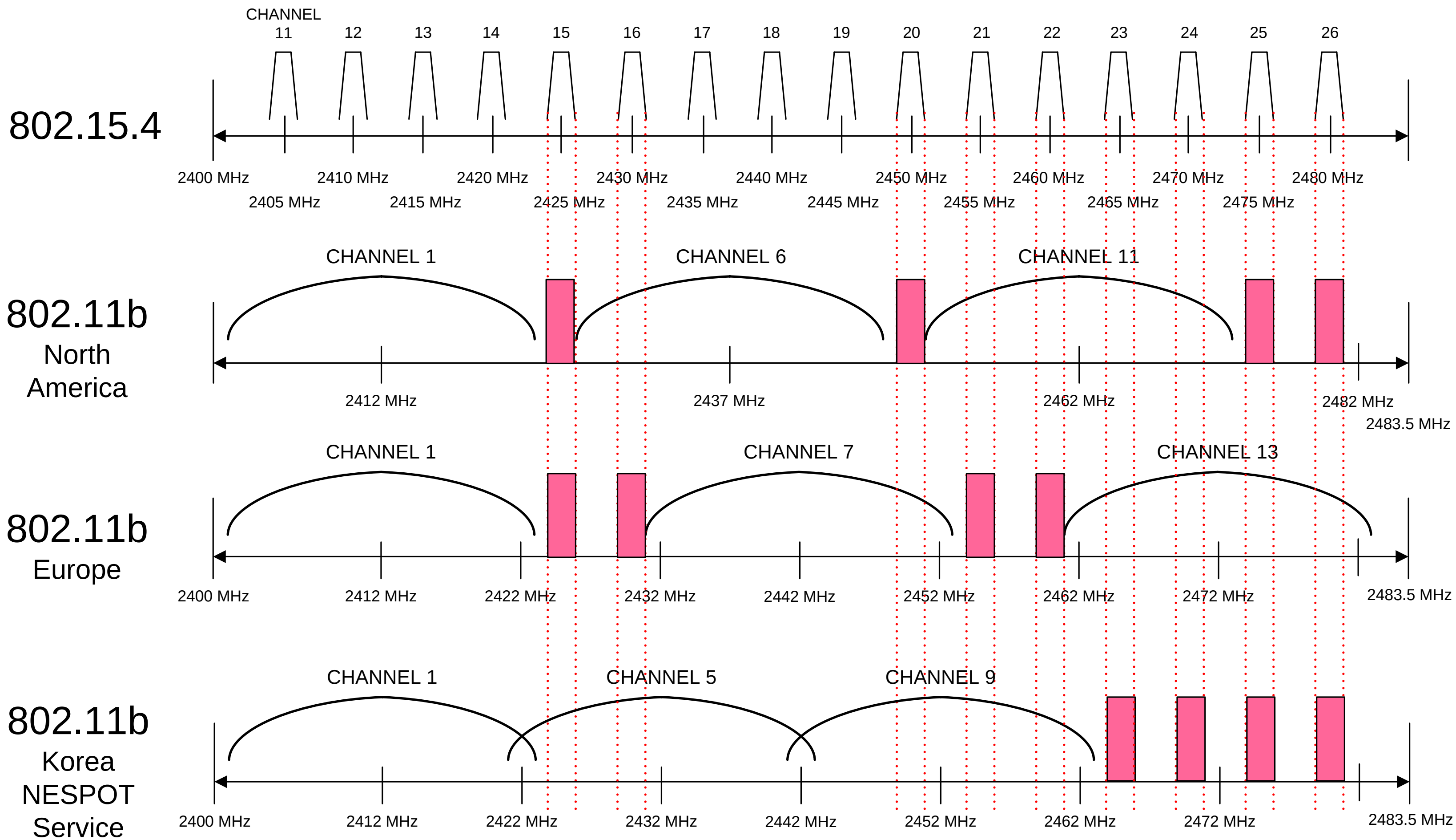


Channel Frequencies

Channel number	Channel center frequency (MHz)
$k = 0$	868.3
$k = 1, 2, \ldots, 10$	$906 + 2(k - 1)$
$k = 11, 12, \ldots, 26$	$2405 + 5(k - 11)$

Co-existence with 11b





802.15.4
CHANNEL
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
2400 MHz
2405 MHz
2410 MHz
2415 MHz
2420 MHz
2425 MHz
2430 MHz
2435 MHz
2440 MHz
2445 MHz
2450 MHz
2455 MHz
2460 MHz
2465 MHz
2470 MHz
2475 MHz
2480 MHz
802.11b
North
America
CHANNEL 1
CHANNEL 6
CHANNEL 11
2412 MHz
2437 MHz
2462 MHz
2482 MHz
2483.5 MHz
802.11b
Europe
CHANNEL 1
CHANNEL 7
CHANNEL 13
2400 MHz
2412 MHz
2422 MHz
2432 MHz
2442 MHz
2452 MHz
2462 MHz
2472 MHz
2483.5 MHz
802.11b
Korea
NESPOT
Service
CHANNEL 1
CHANNEL 5
CHANNEL 9
2400 MHz
2412 MHz
2422 MHz
2432 MHz
2442 MHz
2452 MHz
2462 MHz
2472 MHz
2483.5 MHz

Modulation Parameters

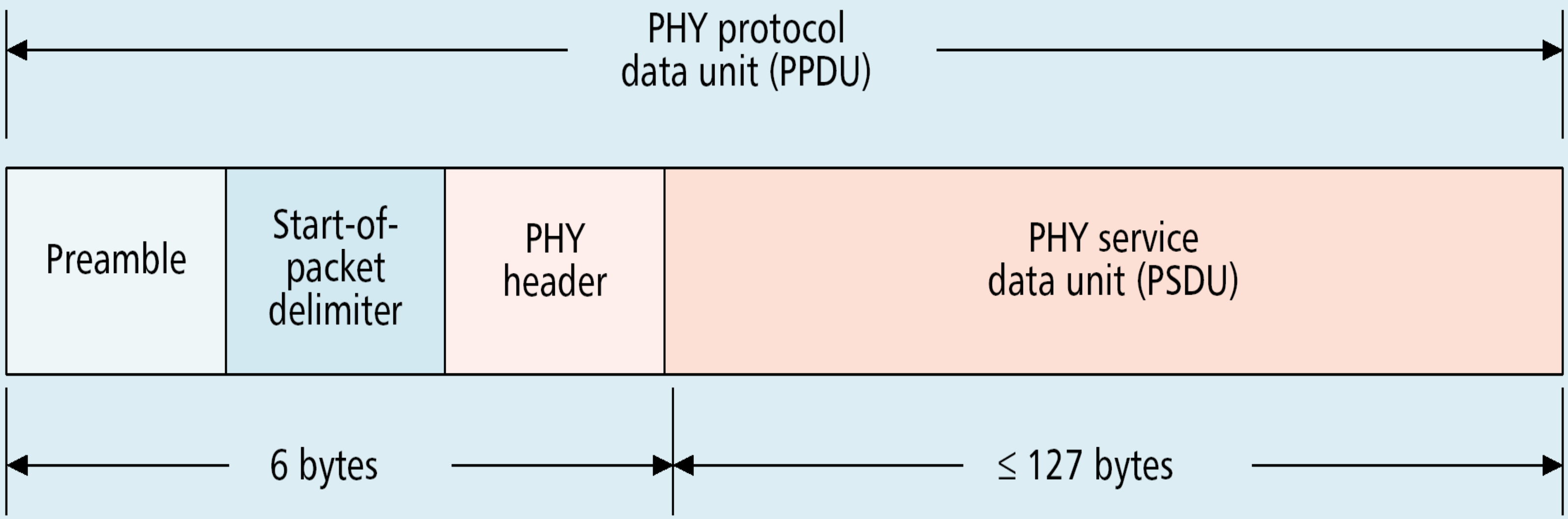
PHY	Frequency band	Data parameters			Spreading parameters	
		Bit rate (kb/s)	Symbol rate (kbaud)	Modulation	Chip rate (Mchips/s)	Modulation
868/915	868.0–868.6 MHz	20	20	BPSK	0.3	BPSK
MHz PHY	902.0–928.0 MHz	40	40	BPSK	0.6	BPSK
2.4 GHz PHY	2.4–2.4835 GHz	250	62.5	16-ary orthogonal	2.0	O-QPSK

- For 868/915 MHz, 15-chip m-sequence used
- For 2.4GHz, each symbol (for 4 bits) = one of 16 nearly orthogonal 32-chip PN sequences

PHY Common Parameters

- Transmit Power
  - Capable of at least 1 mW
- Transmit Center Frequency Tolerance – 40 ppm
- Receiver Sensitivity (Packet Error Rate <1%)
  - −85 dBm @ 2.4 GHz band
  - −92 dBm @ 868/915 MHz band
- RSSI Measurement
  - Packet strength indication
  - Clear channel assessment (CCA)
  - Dynamic channel selection

PHY Overview:
PHY Frame Structure



PHY packet fields:

- Preamble (32 bits) — synchronization
- Start-of-packet delimiter (8 bits) — signify end of preamble
- PHY header (8 bits) — specify length of PSDU
- PSDU (≤ 127 bytes) — PHY layer payload

Miscellaneous

Differences from 802.11 WLAN

- Simpler PHY
  - One Tx rate per channel
  - Low Tx power
- Simpler MAC
  - No virtual carrier-sense
  - No worry about hidden nodes
  - No RTS/CTS & No fragmentation
  - No continuous CCA
  - Relaxed timing requirement
- Extensive power saving features

Zigbee Alliance (http://www.zigbee.org)

- Spinoff from HomeRF
- Defining the higher layers for IEEE 802.15.4
- Different application profiles will be defined there
- IEEE 802.15.4 standardization is done, but the rest is for Zigbee

Conclusion

- Overviewed emerging IEEE 802.15.4 LR-WPAN
  - Based on IEEE 802.15.4-2003
- Expected to be used for many different applications
  - with low-power and low-cost devices

References

- Ed Callaway et al., “Home Networking with IEEE 802.15.4,” IEEE Comm. Magazine, Aug. 2002
- Jose A. Gutierrez et al., “IEEE 802.15.4: A Developing Standard for Low-Power Low-Cost Wireless Personal Area Networks,” IEEE Network Magazine, Sept./Oct. 2001
- IEEE Std 802.15.4-2003 standard specification, Dec. 2003