IEEE 802.15.4

ZigBee PHY and DLL layers

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ELEC3227/6255: Networks

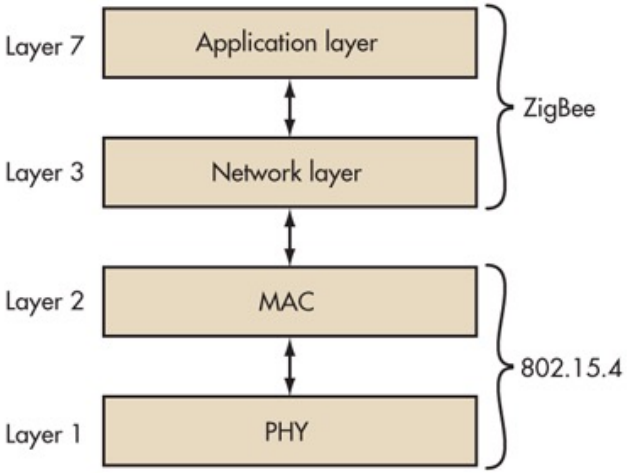
Image: https://cdn.sparkfun.com/assets/home_page_posts/1/9/5/1/20278278029_d61fd1424d_k__1_.jpg

Outline

- Introduction
- The IEEE 802.15.4 PHYsical layer
- The IEEE 802.15.4 DLL/MAC layer

Introduction

- Standard for low-data-rate WPANs (>700 pgs)
  - https://ieeexplore.ieee.org/document/7460875
- 802.15 standard: only PHY + DLL/MAC



- Numerous revisions
  - 802.15.4a/b
  - 802.15.4c for China
  - 802.15.4d for Japan
  - 802.15.4e for industrial applications
  - 802.15.4f for active (battery powered) radio-frequency identification (RFID)
  - 802.15.4g for smart utility networks (SUNs) for monitoring the Smart Grid

Image: https://www.electronicdesign.com/what-s-difference-between/what-s-difference-between-ieee-802154-and-zigbee-wireless

Introduction

*"A low-rate wireless personal area network (LR-WPAN) is a **simple**, **low-cost** communication network that allows wireless connectivity in applications with **limited power** and **relaxed throughput** requirements.*

*The main objectives of an LR-WPAN are **ease of installation**, **reliable data transfer**, **extremely low cost**, and a **reasonable battery life**, while maintaining a **simple and flexible protocol**."*

802.15.4 Frame Structure

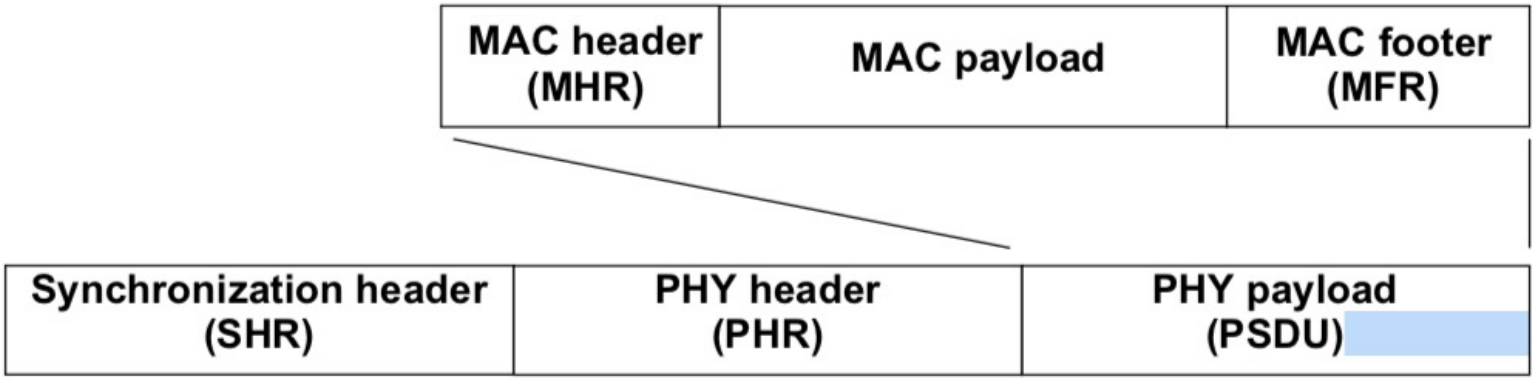


Figure 5-9—Schematic view of the PPDU

- **PPDU:** PHY Protocol Data Unit: the data transmitted/received on the channel
- **PSDU:** PHY Service Data Unit: the PHY payload
- **MPDU:** MAC Protocol Data Unit: the entire MAC frame, i.e. same as PSDU
- **MSDU:** MAC Service Data Unit: the MAC payload (i.e. the NPDU, etc)

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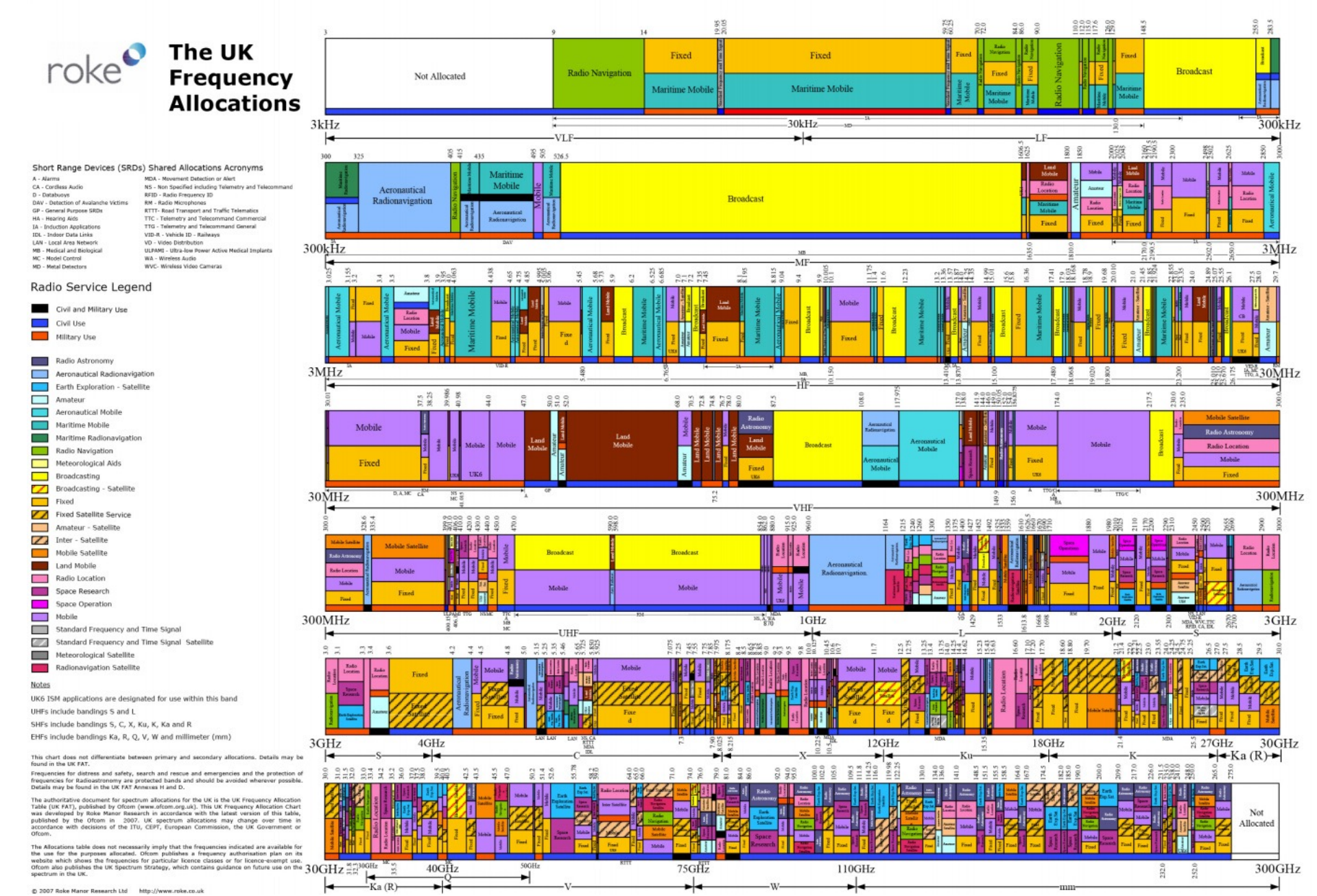
Physical Layer

IEEE 802.15.4 Physical Layer

- Provides the following features:
  - Activation and deactivation of the radio transceiver
  - Channel Selection
  - Transmitting and Receiving data
  - Energy detection (ED)
    - A measure of the received signal power within the bandwidth of the selected channel, averaged over 8 symbol periods. No attempt is made to decode the data on the channel.
  - Link Quality Indication (LQI)
    - A measure of the signal strength or quality of a received packet
  - Clear Channel Assessment (CCA), at least one of the following
    - Energy above a threshold
    - Carrier sense
    - Carrier sense + energy above threshold
    - ALOHA (i.e. carrier sense off)

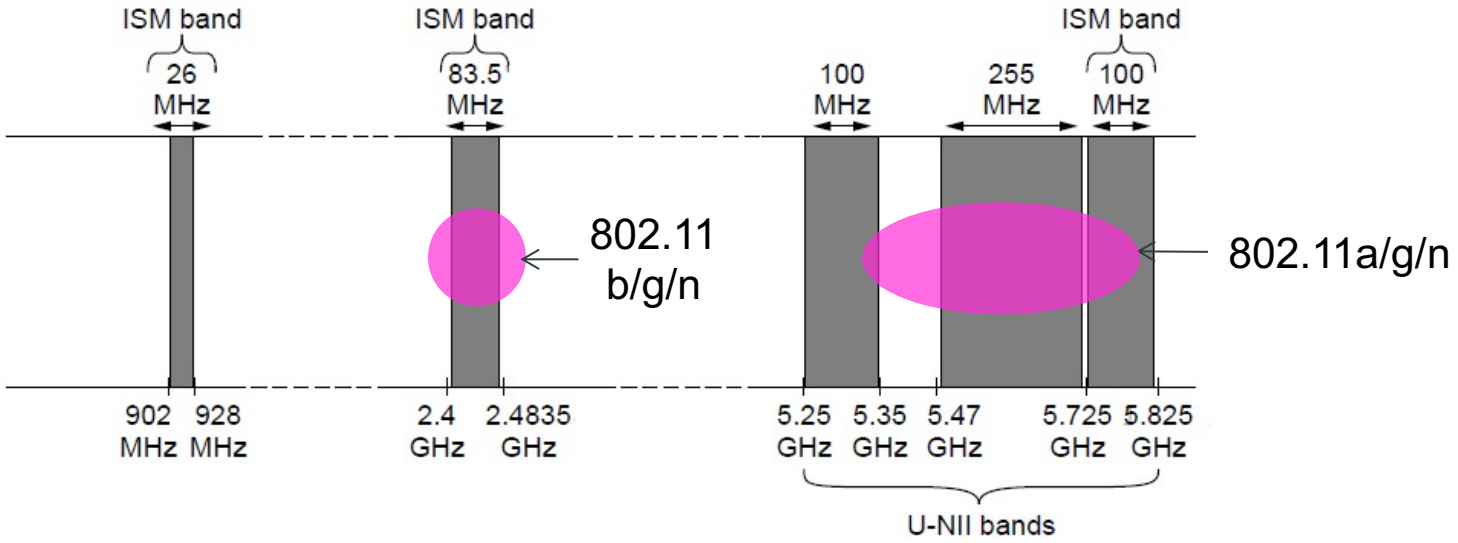


To manage interference, spectrum is carefully divided, and its use regulated and licensed, e.g., sold at auction.

Image: http://www.extremetech.com/wp-content/uploads/2013/01/uk-spectrum-allocation-chart1.jpg

Electromagnetic Spectrum

- Fortunately, there are also unlicensed ("ISM") bands:
  - Free for use at low power; devices manage interference
  - Widely used for networking; WiFi, Bluetooth, Zigbee, etc.



  - Note, some of those shown above are not for the UK (e.g. 868 instead of 915 MHz)
- These are unlicensed, **not** unregulated…

IEEE 802.15.4 Physical Layer

- Originally supported frequency bands:
  - 868 MHz (Europe) @20 kbps, 1 channel, BPSK;
  - 915 MHz (North America) @40 kbps, 10 channels, BPSK;
  - 2.4 GHz (worldwide) @ 250 kbps, 16 channels, O-QPSK + DSSS

- However, standard has been significantly extended, to support other regions (e.g. China, Japan), frequency bands, encoding and modulation schemes, UWB, etc – now supporting data rates of up to 1 Mbps.

PHY Format

12.1 PPDU format

The PPDU shall be formatted as illustrated in Figure 12-1.

Figure 12-1—Format of the PPDU

- The PHR indicates the length of the PHY payload (i.e. the PSDU), which can be 0-127 octets

12.1.1 SHR field format

The SHR field shall be formatted as illustrated in Figure 12-2.

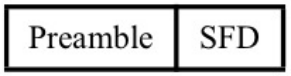


Figure 12-2—Format of the SHR

- Preamble = 32 bits (4 octets, 8 symbols)
- SFD indicates the end of the preamble, and is 11100101_2

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Link/MAC Layer

IEEE 802.15.4 DLL/MAC Layer

- Provides the following features:
  - Association and disassociation
  - Beacon management
  - GTS management
  - Channel Access
  - Acknowledged frame delivery
  - Frame validation

Topologies

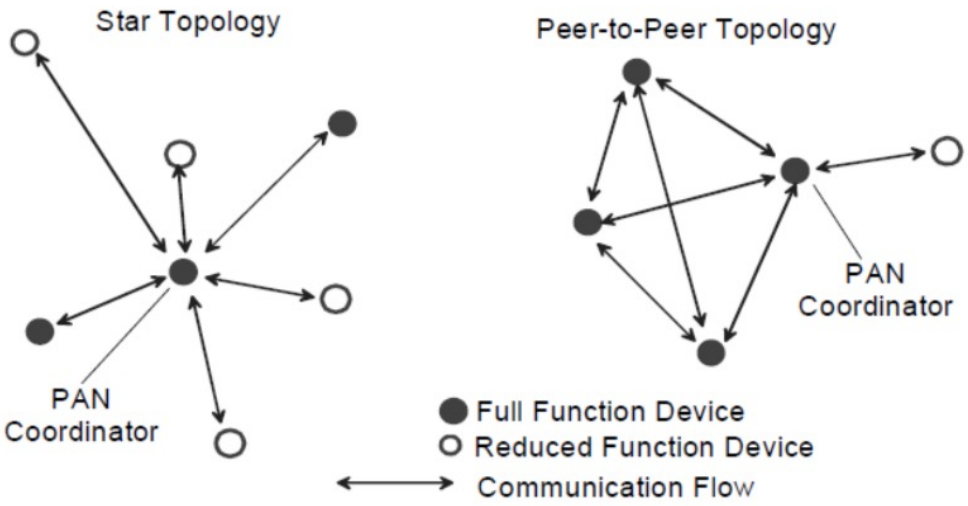


Figure 5-1—Star and peer-to-peer topology examples

- **FFD: Full-Function Device**, a "device capable of serving as a personal area network (PAN) coordinator or a coordinator"
- **RFD: Reduced-Function Device**, "intended for applications that are extremely simple, such as a light switch or PIR sensor; it does not need to send large amounts of data and only associates with a single FFD at a time. Consequently, can be implemented using minimal resources/memory capacity"

Beacons

- IEEE 802.15.4 supports *beacon enabled* and *non-beacon enabled* models
- Beacons are used to:
  - Synchronise devices
  - Identify the PAN
  - Delimit superframes and describe structure (including GTS)
  - Synchronises slotted channel access

- In *non-beacon enabled* networks, devices have to request a beacon from the PAN coordinator (using an *active scan*) in order to identify the PAN and associate with it

PAN Formation and Device Discovery

- A FFD can start a PAN by performing an ED scan and active scan (to identify any existing PANs), and then selecting a unique PAN ID.
- The PAN coordinator indicates its presence to other devices by transmitting Beacon frames; devices can use this to discover the PAN using a passive scan.

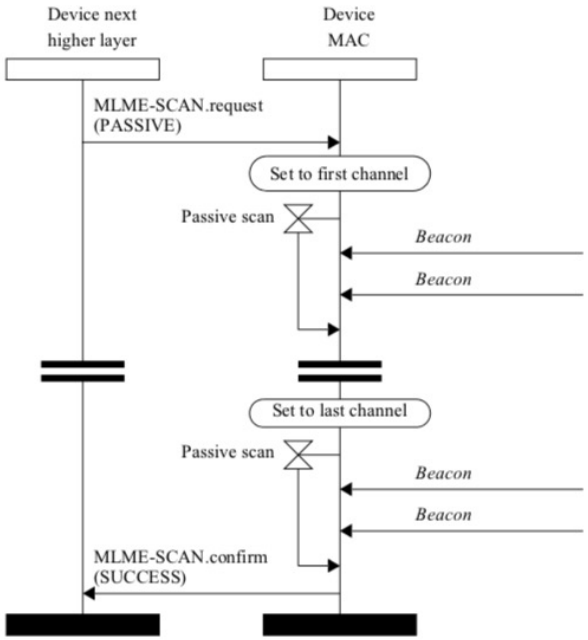


Figure 6-15—Passive scan message sequence chart

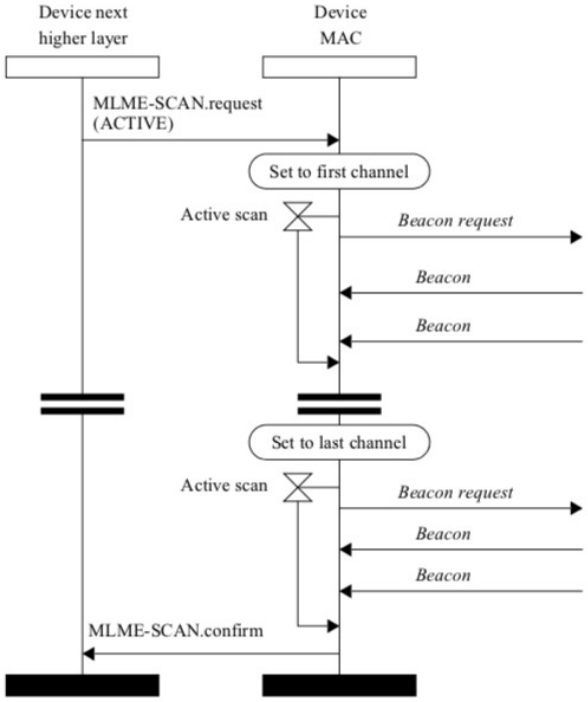


Figure 6-14—Active scan message sequence chart

Superframe Structure

- Active/Inactive Periods

Inactive period trades latency for energy efficiency

SD = Superframe Duration

BI = Beacon Interval

- Guaranteed Timeslots (GTS)

A Contention Free Period (CFP) suited for low-latency applications, or those requiring specific data bandwidth. CSMA not used.

The PAN coordinator can allocate up to 7 GTSs; however, a Contention Access Period (CAP) always remains.

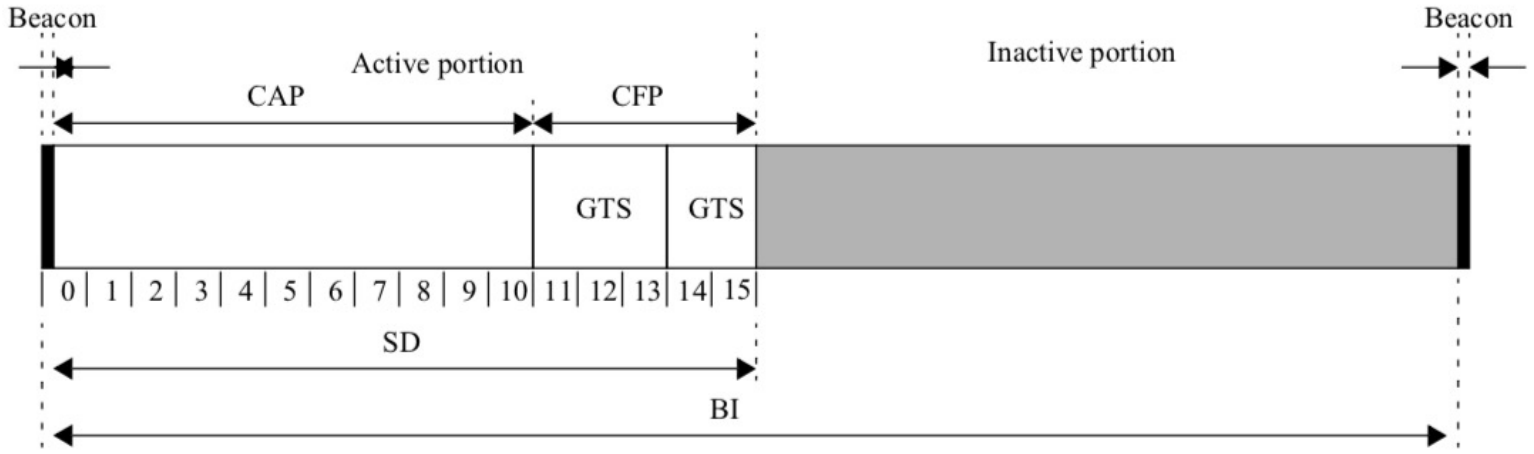


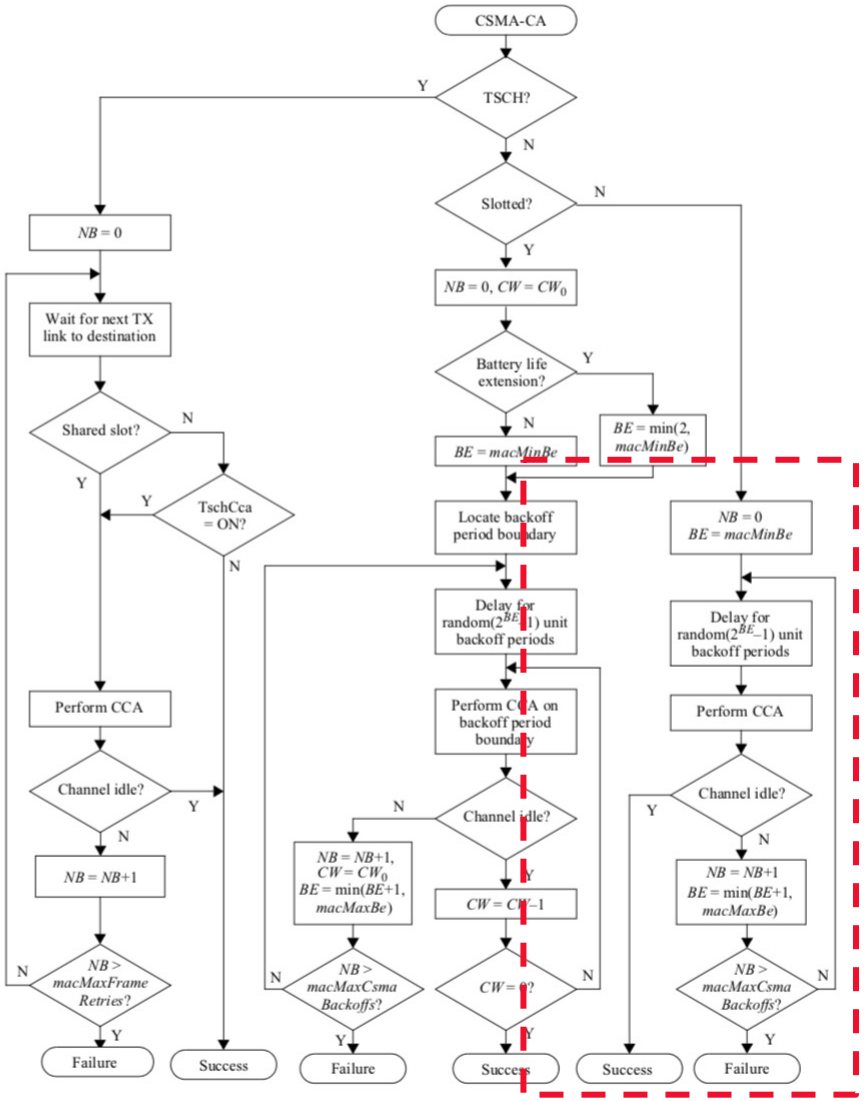
Figure 6-1—An example of the superframe structure

CSMA-CA

- Backs off for a period of random(2^{BE} -1) * *aUnitBackoffPeriod*

- Slotted CSMA-CA (Beacon-enabled)
  - Backoff aligned with superframe slots
- Unslotted CSMA-CA
  - Backoff periods are not slotted

- *NB*: number of times backed-off; stops when reaches predefined value
- *BE*: backoff exponent; increments by 1 each time
- *CW*: contention window length, defines how long the channel needs to be clear before transmitting



Acknowledgements

- The layer supports
  - **Unacknowledged**: an acknowledgement is not requested from the receiver, and the sender assumes that it was successfully received.

Figure 6-34—Successful data transmission without an acknowledgment

Acknowledgements

- The layer supports
  - **Acknowledged**: if the AR (acknowledgement request) field is set, an acknowledgement is requested from the receiver.

Figure 6-35—Successful data transmission with an acknowledgment

  - If an Ack frame is not received within the expected time or the Ack frame that is received contains a DSN that was not the same as the original transmission, the device shall conclude that the single transmission attempt has failed.

MAC Frame Format

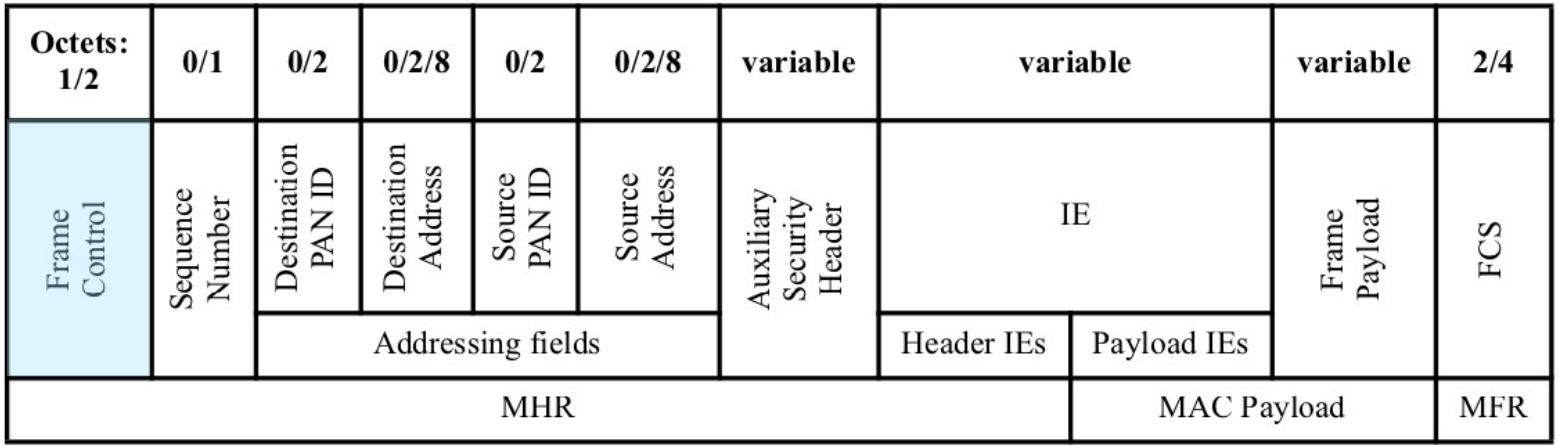


Figure 7-1—General MAC frame format

Frame Control Field

Bits: 0–2	3	4	5	6	7	8	9	10–11	12–13	14–15
Frame Type	Security Enabled	Frame Pending	AR	PAN ID Compression	Reserved	Sequence Number Suppression	IE Present	Destination Addressing Mode	Frame Version	Source Addressing Mode

Figure 7-2—Format of the Frame Control field

Frame type value b2 b1 b0	Description
000	Beacon
001	Data
010	Acknowledgment
011	MAC command
100	Reserved
101	Multipurpose
110	Fragment or Frak[a]
111	Extended

MAC Frame Format

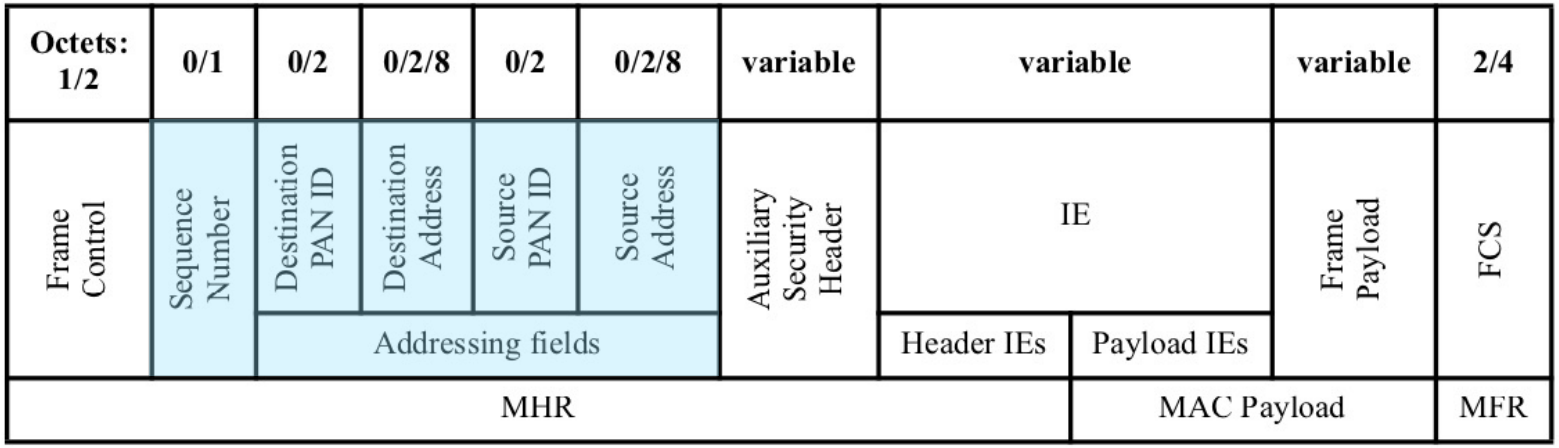


Figure 7-1—General MAC frame format

Addressing

- All devices have a unique 64-bit *extended address* (an extended universal identifier, EUI-64), assigned by a regulatory authority (e.g. the IEEE)
- After a device has associated with a PAN, and been allocated a *short address*, (unique only in the PAN) it uses this wherever possible.

MAC Frame Format

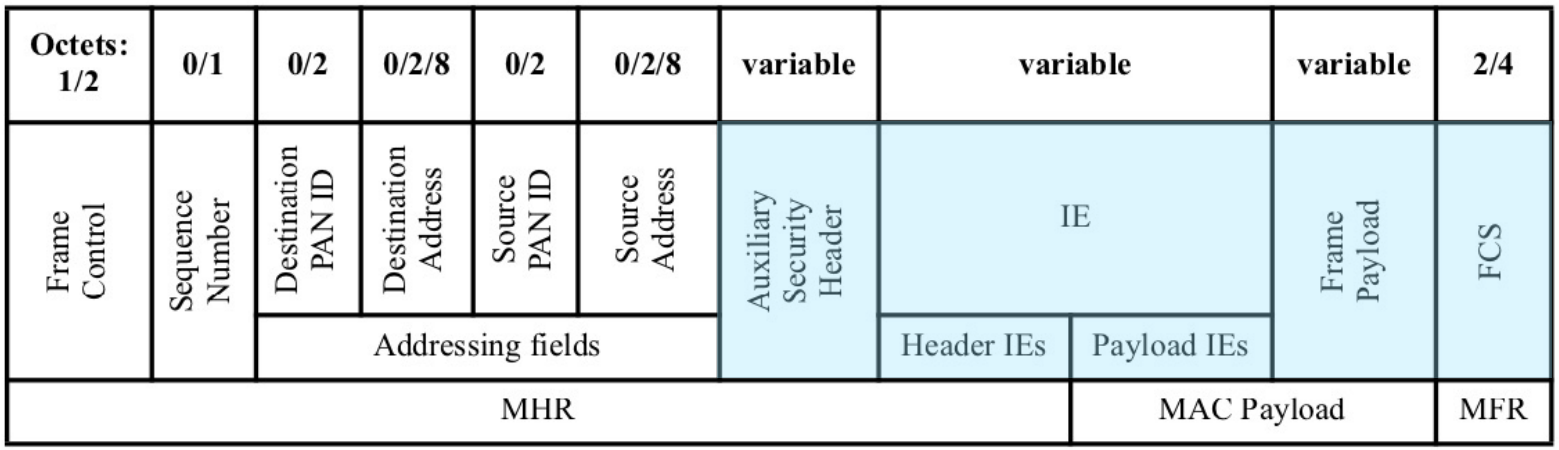


Figure 7-1—General MAC frame format

Checksum (FCS Field)

- One of the following is calculated over the MHR and MAC payload parts of the frame:

- 16-bit ITU-T CRC
  - $G16(x)=x^{16}+x^{12}+x^{5}+1$
- 32-bit CRC equivalent to ANSI X3.66-1979
  - $G32(x) = x^{32}+x^{26}+x^{23}+x^{22}+x^{16}+x^{12}+x^{11}+x^{10}+x^{8}+x^{7}+x^{5}+x^{4}+x^{2}+x+1$

Questions?