

IoT Access Technologies -IEEE802.15.4

IEEE 802.15.4 is a wireless access technology for low-cost and low-data-rate devices that are powered or run on batteries. In addition to being low cost and offering a reasonable battery life, this access technology enables easy installation using a compact protocol stack while remaining both simple and flexible. Several network communication stacks, including deterministic ones, and profiles leverage this technology to address a wide range of IoT use cases in both the consumer and business markets. IEEE 802.15.4 is commonly found in the following types of deployments:

- Home and building automation
- Automotive networks
- Industrial wireless sensor networks
- Interactive toys and remote controls

Physical Layer

The 802.15.4 standard supports an extensive number of PHY options that range from 2.4 GHz to sub-GHz frequencies in ISM bands. (ISM bands are discussed earlier in this chapter.) The original IEEE 802.15.4-2003 standard specified only three PHY options based on direct sequence spread spectrum (DSSS) modulation. DSSS is a modulation technique in which a signal is intentionally spread in the frequency domain, resulting in greater bandwidth. The original physical layer transmission options were as follows:

- 2.4 GHz, 16 channels, with a data rate of 250 kbps
- 915 MHz, 10 channels, with a data rate of 40 kbps
- 868 MHz, 1 channel, with a data rate of 20 kbps

You should note that only the 2.4 GHz band operates worldwide. The 915 MHz band operates mainly in North and South America, and the 868 MHz frequencies are used in Europe, the Middle East, and Africa. IEEE 802.15.4-2006, 802.15.4-2011, and IEEE 802.15.4-2015 introduced additional PHY communication options, including the following:

- **OQPSK PHY:** This is DSSS PHY, employing offset quadrature phase-shift keying (OQPSK) modulation. OQPSK is a modulation technique that uses four unique bit values that are signalled by phase changes. An offset function that is present during phase shifts allows data to be transmitted more reliably.

- **BPSK PHY:** This is DSSS PHY, employing binary phase-shift keying (BPSK) modulation. BPSK specifies two unique phase shifts as its data encoding scheme.

- **ASK PHY:** This is parallel sequence spread spectrum (PSSS) PHY, employing amplitude shift keying (ASK) and BPSK modulation. PSSS is an advanced encoding scheme that offers increased range, throughput, data rates, and signal integrity compared to DSSS. ASK uses amplitude shifts instead of phase shifts to signal different bit values. These improvements increase the maximum data rate for both 868 MHz and 915 MHz to 100 kbps and 250 kbps, respectively. The 868 MHz support was enhanced to 3 channels, while other IEEE 802.15.4 study groups produced addendums for new frequency bands. For example, the IEEE 802.15.4c study group created the bands 314–316 MHz, 430–434 MHz, and 779–787 MHz for use in China.

Figure 4.1 shows the frame for the 802.15.4 physical layer. The synchronization header for this frame is composed of the Preamble and the Start of Frame Delimiter fields. The Preamble field is a 32-bit 4-byte (for parallel construction) pattern that identifies the start of the frame and is used to synchronize the data transmission. The Start of Frame Delimiter field informs the receiver that frame contents start immediately after this byte.

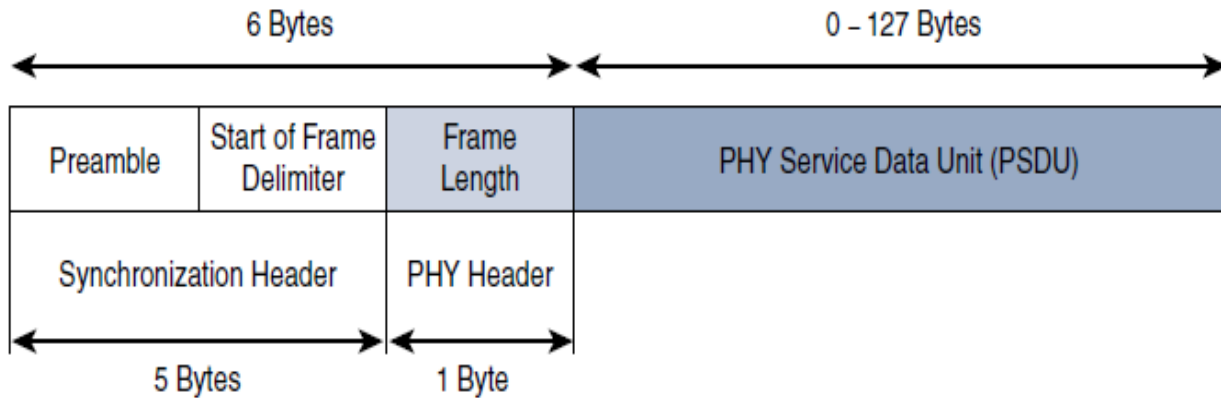


Fig. 4.1 IEEE 802.15.4-PHY Format

Ref: David Hanes, Gonzalo Salgueiro, Patrick Grossetete, Robert Barton, Jerome Henry, "IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Things", 1st Edition, Pearson Education (Cisco Press Indian Reprint).

MAC Layer

The IEEE 802.15.4 MAC layer manages access to the PHY channel by defining how devices in the same area will share the frequencies allocated. At this layer, the scheduling and routing of data frames are also coordinated. The 802.15.4 MAC layer performs the following tasks:

- Network beaconing for devices acting as coordinators (New devices use beacons to join an 802.15.4 network)
- PAN association and disassociation by a device
- Device security
- Reliable link communications between two peer MAC entities

The MAC layer achieves these tasks by using various predefined frame types. In fact, four types of MAC frames are specified in 802.15.4:

- **Data frame:** Handles all transfers of data
- **Beacon frame:** Used in the transmission of beacons from a PAN coordinator

■ **Acknowledgement frame:** Confirms the successful reception of a frame

■ **MAC command frame:** Responsible for control communication between devices. Each of these four 802.15.4 MAC frame types follows the frame format shown in Figure 4-2. In Figure 4-2, notice that the MAC frame is carried as the PHY payload. The 802.15.4 MAC frame can be broken down into the MAC Header, MAC Payload, and MAC Footer fields.

The MAC Header field is composed of the Frame Control, Sequence Number and the Addressing fields. The Frame Control field defines attributes such as frame type, addressing modes, and other control flags. The Sequence Number field indicates the sequence identifier for the frame. The Addressing field specifies the Source and Destination PAN Identifier fields as well as the Source and Destination Address fields.

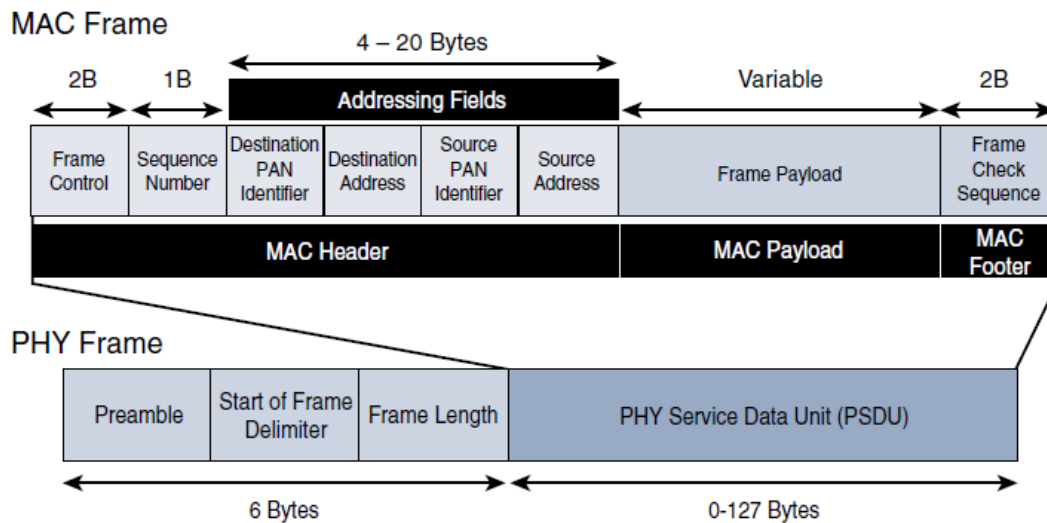


Fig.4.2 IEEE 802.15.4-MAC Format

Ref: David Hanes, Gonzalo Salgueiro, Patrick Grossetete, Robert Barton, Jerome Henry, "IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Things", 1st Edition, Pearson Education (Cisco Press Indian Reprint).

The MAC Payload field varies by individual frame type. For example, beacon frames have specific fields and payloads related to beacons, while MAC command frames have different fields present. The MAC Footer field is nothing more than a frame check sequence (FCS). An FCS is a calculation based on the data in the frame that is used by the receiving side to confirm the integrity of the data in the frame.

IEEE 802.15.4 requires all devices to support a unique 64-bit extended MAC address, based on EUI-64. However, because the maximum payload is 127 bytes, 802.15.4 also defines how a 16-bit “short address” is assigned to devices. This short address is local to the PAN and substantially reduces the frame overhead compared to a 64-bit extended MAC address.

Topology

IEEE 802.15.4-based networks can be built as star, peer-to-peer, or mesh topologies. Mesh networks tie together many nodes. This allows nodes that would be out of range if trying to communicate directly to leverage intermediary nodes to transfer communications. Every 802.15.4 PAN should be set up with a unique ID. All the nodes in the same 802.15.4 network should use the same PAN ID. Figure 4-3 shows an example of an 802.15.4 mesh network with a PAN ID of 1.

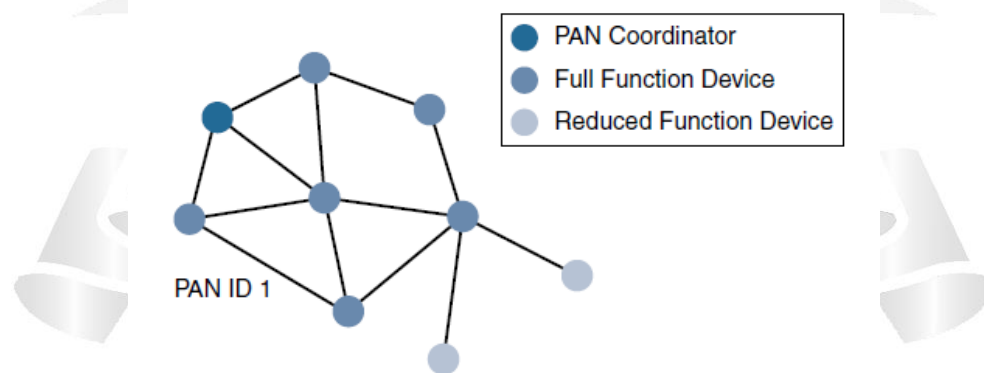
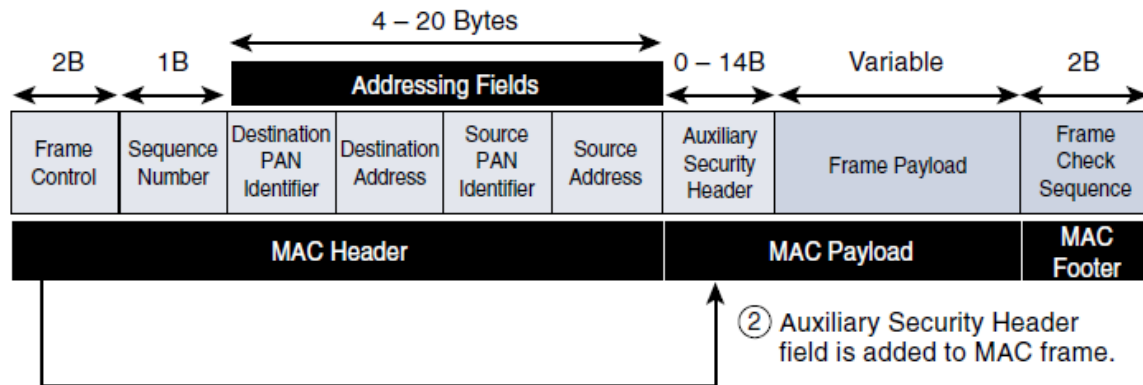


Figure 4-3 802.15.4 Sample Mesh Network Topology

Full-function devices (FFDs) and reduced-function devices (RFDs) are defined in IEEE 802.15.4. A minimum of one FFD acting as a PAN coordinator is required to deliver services that allow other devices to associate and form a cell or PAN. And t a single PAN coordinator is identified for PAN ID 1. FFD devices can communicate with any other devices, whereas RFD devices can communicate only with FFD devices. The IEEE 802.15.4 specification does not define a path selection within the MAC layer for a mesh topology. This function can be done at Layer 2 and is known as *mesh-under*. Generally, this is based on a proprietary solution. Alternatively, the routing function can occur at Layer 3, using a routing protocol, such as the IPv6 Routing Protocol for Low Power and Lossy Networks (RPL). This is referred to as *mesh-over*.

Security

The IEEE 802.15.4 specification uses Advanced Encryption Standard (AES) with a 128-bit key length as the base encryption algorithm for securing its data. In addition to encrypting the data, AES in 802.15.4 also validates the data that is sent. This is accomplished by a message integrity code (MIC), which is calculated for the entire frame using the same AES key that is used for encryption. Enabling these security features for 802.15.4 changes the frame format slightly and consumes some of the payload. Using the Security Enabled field in the Frame Control portion of the 802.15.4 header is the first step to enabling AES encryption. This field is a single bit that is set to 1 for security. Once this bit is set, a field called the Auxiliary Security Header is created after the Source Address field, by stealing some bytes from the Payload field.



- ① Security Enabled bit in Frame Control is set to 1.

Figure 4-4 Frame Format with the Auxiliary Security Header Field for 802.15.4

Ref: David Hanes, Gonzalo Salgueiro, Patrick Grossetete, Robert Barton, Jerome Henry, "IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Things", 1st Edition, Pearson Education (Cisco Press Indian Reprint).

Figure 4-4 shows the IEEE 802.15.4 frame format at a high level, with the Security Enabled bit set and the Auxiliary Security Header field present.

