IoT Access Technologies- 802.15.4g and 802.15.4e

IEEE 802.15.4g-2012 is also an amendment to the IEEE 802.15.4-2011 standard, and just like 802.15.4e-2012, it has been fully integrated into the core IEEE 802.15.4-2015 specification. The focus of this specification is the smart grid or, more specifically, smart utility network communication. 802.15.4g seeks to optimize large outdoor wireless mesh networks for field area networks (FANs). New PHY definitions are introduced, as well as some MAC modifications needed to support their implementation. This technology applies to IoT use cases such as the following:

- Distribution automation and industrial supervisory control and data acquisition (SCADA) environments for remote monitoring and control
- Public lighting
- Environmental wireless sensors in smart cities
- Electrical vehicle charging stations
- Smart parking meters
- Microgrids
- Renewable energy

Physical Layer

In IEEE 802.15.4g-2012, the original IEEE 802.15.4 maximum PSDU or payload size of 127 bytes was increased for the SUN PHY to 2047 bytes. This provides a better match for the greater packet sizes found in many upper-layer protocols. For example, the default IPv6 MTU setting is 1280 bytes. Fragmentation is no longer necessary at Layer 2 when IPv6 packets are transmitted over IEEE 802.15.4g MAC frames. Also, the error protection was improved in IEEE 802.15.4g by evolving the CRC from 16 to 32 bits.

The SUN PHY, as described in IEEE 802.15.4g-2012, supports multiple data rates in bands ranging from 169 MHz to 2.4 GHz. These bands are covered in the unlicensed ISM frequency spectrum specified by various countries and regions. Within these bands, data must be modulated onto the frequency using at least one of the following PHY mechanisms to be IEEE 802.15.4g compliant:

■ **Multi-Rate and Multi-Regional Frequency Shift Keying (MR-FSK):** Offers good transmit power efficiency due to the constant envelope of the transmit signal

■ **Multi-Rate and Multi-Regional Orthogonal Frequency Division Multiplexing (MR-OFDM):** Provides higher data rates but may be too complex for low-cost and low-power devices

■ **Multi-Rate and Multi-Regional Offset Quadrature Phase-Shift Keying (MR-OQPSK):** Shares the same characteristics of the IEEE 802.15.4-2006 O-QPSK PHY, making multi-mode systems more cost-effective and easier to design.

Enhanced data rates and a greater number of channels for channel hopping are available, depending on the frequency bands and modulation. For example, for the 902–928 MHz ISM band that is used in the United States, MR-FSK provides 50, 150, or 200 kbps. MR-OFDM at this same frequency allows up to 800 kbps. Other frequencies provide their own settings.

MAC Layer

While the IEEE 802.15.4e-2012 amendment is not applicable to the PHY layer, it is pertinent to the MAC layer. This amendment enhances the MAC layer through various functions, which may be selectively enabled based on various implementations of the standard. In fact, if interoperability is a “must have,” then using profiles defined by organizations such as Wi-SUN is necessary. The following are some of the main enhancements to the MAC layer proposed by IEEE 802.15.4e-2012:

■ **Time-Slotted Channel Hopping (TSCH):** TSCH is an IEEE 802.15.4e-2012 MAC operation mode that works to guarantee media access and channel diversity. Channel hopping, also known as frequency hopping, utilizes different channels for transmission at different times. TSCH divides time into fixed time periods, or “time slots,” which offer guaranteed bandwidth and predictable latency. In a time slot, one packet and its acknowledgement can be transmitted, increasing network capacity because multiple nodes can communicate in the same time slot, using different channels.

A number of time slots are defined as a “slot frame,” which is regularly repeated to provide “guaranteed access.” The transmitter and receiver agree on the channels and the timing for switching between channels through the combination of a global time slot counter and a global channel hopping sequence list, as computed on each node to determine the channel of each time slot. TSCH adds robustness in noisy environments and smoother coexistence with other wireless technologies, especially for industrial use cases.

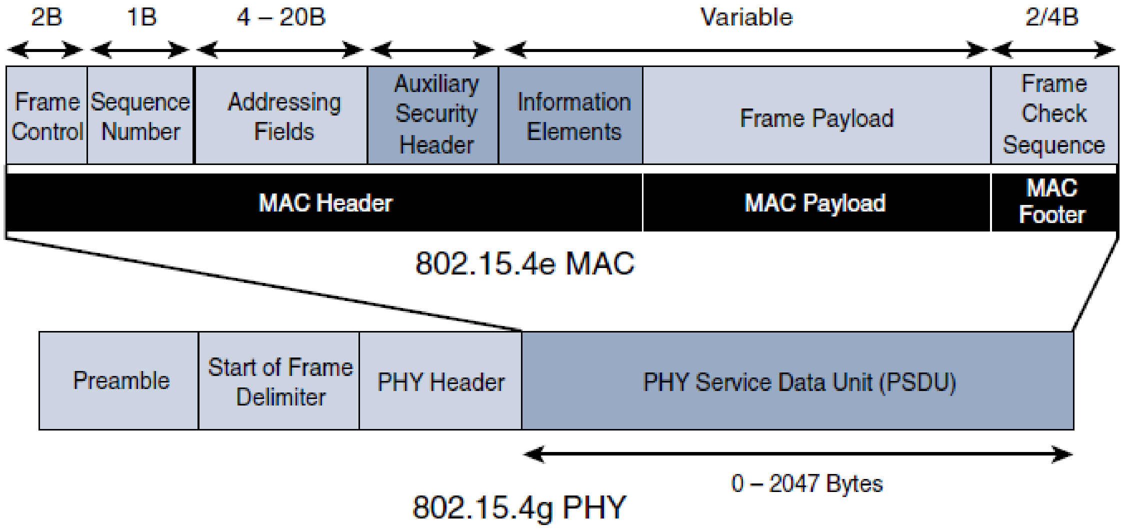
Information elements: Information elements (IEs) allow for the exchange of information at the MAC layer in an extensible manner, either as header IEs (standardized) and/or payload IEs (private). Specified in a tag, length, value (TLV) format, the IE field allows frames to carry additional metadata to support MAC layer services. These services may include IEEE 802.15.9 key management, Wi-SUN 1.0 IEs to broadcast and unicast schedule timing information, and frequency hopping synchronization information for the 6TiSCH architecture.

■ **Enhanced beacons (EBs):** EBs extend the flexibility of IEEE 802.15.4 beacons to allow the construction of application-specific beacon content. This is accomplished by including relevant IEs in EB frames. Some IEs that may be found in EBs include network metrics, frequency hopping broadcast schedule, and PAN information version.

■ **Enhanced beacon requests (EBRs):** Like enhanced beacons, an enhanced beacon request (EBRs) also leverages IEs. The IEs in EBRs allow the sender to selectively specify the request of information. Beacon responses are then limited to what was requested in the EBR. For example, a device can query for a PAN that is allowing new devices to join or a PAN that supports a certain set of MAC/PHY capabilities.

■ **Enhanced Acknowledgement:** The Enhanced Acknowledgement frame allows for the integration of a frame counter for the frame being acknowledged. This feature helps protect against certain attacks that occur when Acknowledgement frames are spoofed.

The 802.15.4e-2012 MAC amendment is quite often paired with the 802.15.4g-2012 PHY. Figure 4.5 details this frame format 802.15.4g-2012 PHY is similar to the 802.15.4 PHY in Figure 4-5. The main difference between the two is the payload size, with 802.15.4g supporting up to 2047 bytes and 802.15.4 supporting only 127 bytes.



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

The 802.15.4e MAC is similar to the 802.15.4 MAC. The main changes shown in the IEEE 802.15.4e header in Figure above are the presence of the Auxiliary Security Header and Information Elements field. The Auxiliary Security header provides for the encryption of the data frame. This field is optionally supported in both 802.15.4e- 2012 and 802.15.4, starting with the 802.15.4-2006 specification.

Topology

Deployments of IEEE 802.15.4g-2012 are mostly based on a mesh topology. This is because a mesh topology is typically the best choice for use cases in the industrial and smart cities areas where 802.15.4g-2012 is applied. A mesh topology allows deployments to be done in urban or rural areas, expanding the distance between nodes that can relay the traffic of other nodes. Considering the use cases addressed by this technology, powered nodes have been the primary targets of implementations. Support for battery powered nodes with a long lifecycle requires optimized Layer 2 forwarding or Layer 3 routing protocol implementations. This provides an extra level of complexity but is necessary in order to cope with sleeping battery-powered nodes.

Security

Both IEEE 802.15.4g and 802.15.4e inherit their security attributes from the IEEE 802.15.4-2006 specification. Therefore, encryption is provided by AES, with a 128-bit key. In addition to the Auxiliary Security Header field initially defined in 802.15.4-2006, a secure acknowledgement and a secure Enhanced Beacon field complete the MAC layer security. Figure 4.5 shows a high-level overview of the security associated with an IEEE 802.15.4e MAC frame.

The full frame in Figure 4.5 gets authenticated through the MIC at the end of frame. The MIC is a unique value that is calculated based on the frame contents. (The MIC is discussed in more detail earlier in this chapter.) The Security Header field denoted in Figure 4.5 is composed of the Auxiliary Security field and one or more Information Elements fields. Integration of the Information Elements fields allows for the adoption of additional security capabilities, such as the IEEE 802.15.9 Key Management Protocol (KMP) specification. KMP provides a means for establishing keys for robust datagram security. Without key management support, weak keys are often the result, leaving the security system open to attack.

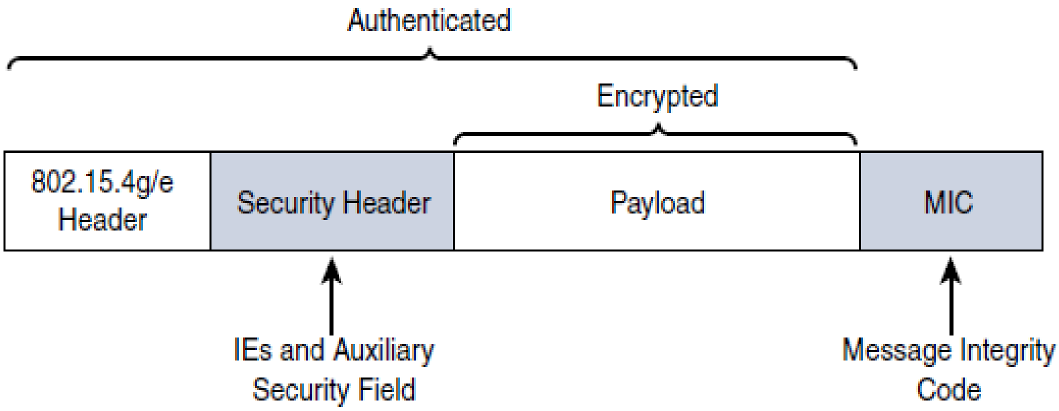


Figure 4.5 IEEE 802.15.4g/e MAC Layer Security