Demystifying ZigBee and 802.15.4

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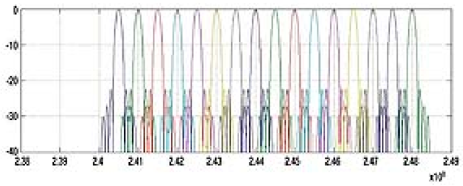
In today's world, wireless networks are becoming more ubiquitous, and they are implemented using a variety of protocols that are specifically designed for radio frequency systems. Some protocols that are in use are proprietary to individual vendors, while others are industry standards. Recently, a lot of attention has been given to 802.15.4 and ZigBee, but there is still some ambiguity as to what is different about 802.15.4 and ZigBee and what kind of networks or systems would benefit from these particular protocols.

What is 802.15.4?

The wireless communication standard 802.15.4 was established by the Institute for Electrical and Electronics Engineers (IEEE). A few examples of wireless IEEE standards include the 802.11 standard which defines communication for wireless local area networks (LANs) and 802.16 that is used for broadband wireless communication in metropolitan area networks.



[1] Figure 1. Communication channels at 802.15.4 specified spacing. (Click image to enlarge)

While both 802.11 and 802.16 standards are concerned with higher bandwidth Internet access applications, 802.15.4 was developed with a lower data rate, simple connectivity and battery applications in mind. The 802.15.4 standard specifies that communication can occur in the 868 MHz to 868.8 MHz, the 902 MHz to 928 MHz or the 2.400 GHz to 2.4835 GHz industrial scientific and medical (ISM) bands. The 868 MHz and the 902 MHz bands offer the least amount of bandwidth under the specification with 20 kHz and 40 kHz available for each band, respectively.
While any of these bands can technically be used by 802.15.4 devices, the 2.4 GHz band seems to have more popularity from a market perspective as it allows for data rates up to 250 kHz, and the 2.4 GHz frequency is allowed by most countries worldwide for data communications. The 868 MHz band is specified primarily for European use, whereas the 902 MHz to 928 MHz band can only be used in the United States, Canada and a few other countries and territories that accept the FCC regulations.

The 902-928 band requires the use of direct sequence spread spectrum, and it uses an offset quadrature phase shift keying (O-QPSK) with half-sine pulse shaping to modulate the RF carrier. The graph in Figure 1 shows the various channels at the spacing specified by 802.15.4.


Figure 2. A central coordinator often acts as a data collector, with multiple remote nodes connecting back to this central host.

At 2.4 GHz, communication occurs in one of sixteen 5 MHz channels ranging from 2.405 GHz to 2.480 GHz, with a maximum over-the-air data rate of 250 kbps and an address space of 65,535 nodes per every 802.15.4 personal area network (PAN). The possible selection of one of sixteen channels helps avoid interference with any other 2.4 GHz networks that may be in the same area. The overhead of the protocol ends up limiting the actual theoretical maximum throughput rate to speeds closer to 125 kHz, and only approximately 2 MHz of the channel is consumed with the specified 5 MHz occupied bandwidth.
If communication in a particular network was infrequent enough, there would be no reason that a single PAN could not support all 65,535 nodes. In many cases, the amount of data that is being sent, and the frequency that the data is required by the system, end up limiting the number of nodes that can be supported to something less than the maximum.

The 802.15.4 standard is designed specifically for communications in a point-to-point or a point-to-multipoint configuration with sleeping and security also being integral parts of the standard. A typical application involves a central coordinator that often acts as a data collector, with multiple remote nodes connecting back to this central host as shown in Figure 2. In essence, 802.15.4 defines a PHY and MAC layer that are ideal for low-data rate, low-power applications.

What is ZigBee?

ZigBee is a protocol that uses the 802.15.4 standard as a baseline and adds additional network layer to the stack to give the system routing and networking functionality. Since the ZigBee protocol uses the 802.15.4 standard to define the PHY and MAC layers, the frequency, signal bandwidth and modulation techniques are identical.

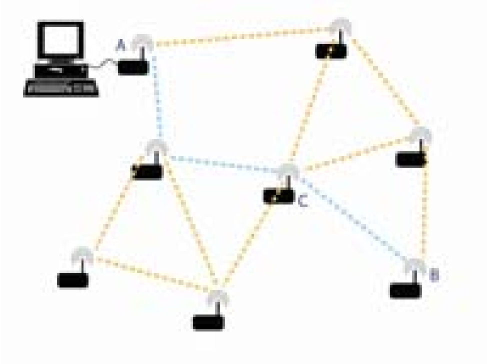


Figure 3. In this typical mesh network, radios transmit data from point A to intermediate radios to relay the messages to their final destination at point C.

The ZigBee protocol was developed by the ZigBee Alliance (www.zigbee.org [2]) as an effort for companies to work in cooperation to develop a mesh network protocol that can be used in a variety of commercial and industrial low data rate applications. Mesh networking is used in applications where the range between two points may be beyond the range of the two radios located at those points, but intermediate radios are in place that could forward on any messages to and from the desired radios.
Figure 3 is an example of a typical mesh network. If in this network it were desired to transmit data from point A to point B, but the distance was too great between the points, the message could be transmitted through point C and a few other radios to reach the destination.

The ZigBee protocol is designed so that if a number of different radios were deployed in a given area, the radios would automatically form a network without user intervention. The ZigBee protocol within the radios will take care of retries, acknowledgements and data message routing. ZigBee also has the ability to self-heal the network: If the radio at point C was removed for some reason, a new path would be used to route messages from A to B.

The real advantages of mesh networks are that they improve data reliability by providing multiple redundant paths in areas where a lot of nodes are deployed. They are not designed, however, for every application. It takes time for paths to form and devices to associate, and additional system delay occurs as messages must be forwarded on through the network. The 250 kHz of over-the-air bandwidth gets used up very quickly with overhead, making video, audio and other high bandwidth applications poor choices for mesh networks.

ZigBee devices can either be used as end devices, routers or coordinators. Routers can also be used as end devices, but the main difference is that end devices are allowed to sleep. The modules and chipsets that are used for ZigBee have sleep currents down to a few mA, so battery life can extend beyond several years.

Because ZigBee was designed for low power applications, it fits well into systems that use small, low-power microcontrollers and those markets where reliability, battery life and versatility are important, but a high bandwidth is not. Some examples of applications for ZigBee networks include home automation, industrial monitoring and control, pressure, temperature, moisture and humidity sensors, commercial and industrial meter reading, home fitness machines and water quality oxygen content monitoring, to name a few. The lower data rate of the ZigBee devices allows for better sensitivity and range, making 802.15.4 and ZigBee one of the longer range technologies that exist at 2.4 GHz.

Figure 4 offers a limited technical comparison of a few features with several other popular wireless technologies.

	Zigbee & 802.15.4	GSM/GPRS CDMA	802.11	Bluetooth
Focus Application	Monitoring and Control	Wide Area voice and data	High-speed Internet	Device connectivity
Battery Life	Years	1 week	1 week	weeks
Bandwidth	150 kbps	up to 128k	11 Mbps	720 kbps
Typical Range (meters)	100+	Several Km	50-100	10-100
Advantages	Low Power, Cost	existing infrastructure	Speed, Ubiquity	Convenience

Figure 4. A comparison of the features of several popular wireless technologies.

Conclusion

Bandwidth, battery requirements, code space, frequency and range are all factors that should be considered if designing a wireless version of a product is on your company’s roadmap. If the application strictly needs to communicate in a point-to-point or a point-to-multipoint fashion, 802.15.4 can handle all the communications between your devices, and it will be simpler to implement than a module or chipset with ZigBee firmware. ZigBee is necessary if you need to use repeating, mesh networking functionality in your system, or if you require the added robustness of a mesh network. In either case, if battery operation is required, then chipsets or modules that use these protocols should be considered.

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