cycle and therefore affect the consumption of power. Once again, the application areas are such that transmissions will be infrequent, with the devices in a passive mode of operation for most of the time. The Bluetooth 3.0 high-speed specification was adopted on April 21, 2009; that would include the 802.11 high-speed transport protocol, which would continue to consume low power when idle. Each device will have a unique 48-bit address. Such devices are expected to interoperate with earlier devices. A secret shared key can be established between two devices as a link key and can be used for data encryption. Many of the details are yet to be worked out, and the standards committee is working on them. Table 15.6 gives a comprehensive comparison of WPAN solutions.

Table 15.6: ▶
Comparison of WPAN Systems[15.23]
From R.L. Ashok and D.P. Agrawal, "Next Generation Wearable Networks," *IEEE Computer*, Vol. 36, No. 11, pp. 31–39, November 2003.

Technology	Bluetooth (802.15.1)	802.15.3	802.15.4	Bluetooth 3.0 HS
Operational spectrum	2.4 GHz ISM band	2.402–2.480 GHz ISM band	2.4 GHz and 868/915 MHz	2.4–2.4835 GHz or 6–9 GHz
Physical layer details	FHSS, 1600 hops per second	Uncoded QPSK trellis, coded QPSK, or 16/32/64-QAM scheme	DSSS with BPSK or MSK (O–QPSK)	UWB
Channel access	Master slave polling, time division duplex (TDD)	CSMA–CA, and guaranteed time slots (GTS) in a superframe structure	CSMA–CA, and guaranteed time slots (GTS) in a superframe structure	802.11 radio protocol
Maximum data rate	Up to 1 Mbps	11–55 Mbps	868 MHz–20, 915 MHz–40, 2.4GHz–250 kbps	480 Mbps
Coverage	<10 m	<10 m	<20 m	?
Power-level issues	1 mA–60 mA	<80 mA	Very low current drain (20–50 μA)	ultra-low power
Interference	Present	Present	Present	Minimum
Price	Low ($<$\$10)	Medium	Very low	?

15.7 ZigBee

In the field of wireless sensor networks, ZigBee has already established its applicability in various areas. Sensor networks are widely used in agriculture; for example, a vineyard has installed sensors that track climate changes to help predict when certain grapes are ready to be picked. There are environmental applications, such as when scientists install sensors to monitor CO levels in highly populated areas. Ornithologists use sensors to monitor the nesting habits of Leach's storm petrel, a rarely observed seabird. Sensors are installed on bridges and high buildings to monitor their ability to withstand wind and earthquakes. Geologists use sensors to explore underground caves inaccessible to human beings. Both ZigBee and Bluetooth occupy the category of low-data-rate WPAN IEEE 802.14. Because of their similarity, not much study has been made to determine whether they will be competitors.

However, they employ different networking technologies. ZigBee focuses on control and automation with a very low data rate, whereas Bluetooth focuses on connectivity between consumer electronics products such as laptops, PDAs, mice and keyboards with the intent of replacing cable connections. Bluetooth requires a higher data rate and higher power consumption for continuous data forwarding and receiving. The lifetime of Bluetooth applications is short compared with that of ZigBee applications, which must operate for years without the need to replace the power source. In time-critical applications, ZigBee is designed to respond quickly. Bluetooth takes much longer to respond, which could be detrimental in such applications. Still, frequency hopping does provide inherent security in Bluetooth. Thus, users could use both technologies in a PAN to cover all the applications within the network.

ZigBee is a control technology that works by standardizing an existing wireless networking powered by small batteries, requiring low bandwidth and low latency and low energy consumption for the long operational lifetimes of network devices. Due to this low energy constraint, ZigBee reduces energy consumption, while its less complicated implementation maximizes interoperation between many devices at every layer of wireless networking.

For the energy consumption in the Physical layer, the data rate is limited to the 250 Kbps in 2.4 GHz Industrial, Scientific, Medical (ISM) band, 20 kbps in the 868 MHz band in Europe, and 40 kbps in the 915 MHz band in North America and Australia. There are other wireless technologies operating in the ISM band such as IEEE 802.11 and its variants and Bluetooth. Therefore, ZigBee traffic may interfere with these networks. However, ZigBee can employ any of 16 different channels in the 2.4 GHz band as many of these channels do not overlap with the 802.11 band. Moreover, the data transmission is very infrequent in ZigBee, making interference of very little concern. On the other hand, use of the same frequency band could allow access and connection to other wireless technologies, enlarging the effective size of the network.

- MAC layer implementation is based on CSMA-CA. It is ideal for low duty-cycle applications where a channel is not occupied by a single device for long period of time. A smart house system is a good example of such applications. Also ZigBee has active and sleep mode, which allows a device to enter idle mode. When it is in sleep mode, it disables antenna and CPU to conserve energy. The low cost of the ZigBee device is an incentive for large-scale deployment. Therefore, ZigBee handles such high density by using the IEEE 802.15.4 physical and MAC layer standard.

- The network layer is designed to implement topologies such as star, peer to peer, and clustered. All devices must have a short 16-bit, IEEE addressing, which can be allocated to any small packet size. ZigBee networks also require at least one full function device (FFD) as a network coordinator. FFDs can function in any network topology and can communicate with any other devices. Reduced function devices (RFDs) are limited to star topologies; they interact with the network coordinator and are very simple to implement.
- The application layer is responsible for maintaining the table of binding for matching two or more devices based on their service and needs, and it forwards messages between devices. It also handles the discovery of devices operating in the same space. Moreover, it assigns roles to each device and builds a secure network. The manufacturer develops the actual application on top of the ZigBee standard. This extreme energy efficiency of ZigBee enables it to become a global standard for sensors and household devices, where the main objective is to sustain its operation for months or even years.

15.8 Summary

In this chapter we have looked at WLANs, WMANs, and WPANs—all wireless connectivity solutions primarily distinguished by the range they cover and therefore, to some extent, the services they provide. Even though there are several types of protocols within each category, only one from each of these has been able to have a measure of commercial success. The WLAN world is completely dominated by the IEEE 802.11. Most laptops today come with built-in 802.11b cards. The only WPAN standard that has reached the market as a mass consumer technology is Bluetooth. WiMedia^{TM} [15.28] (the IEEE802.15.3) also seems to be promising. Both Zigbee and 802.11-based devices are considered to be useful for sensor networks.

15.9 References

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[15.2] B. P. Crow, I. Wadjaja, J. G. Kim, and P. T. Sakai, "IEEE 802.11 Wireless Local Area Networks," *IEEE Communications Magazine*, pp. 116–126, London, September 1997.