ZigBee

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***Abstract*—ZigBee is a low-power wireless communication standard supporting mesh networks. It is ideal for battery-powered applications as well as geographically distributed installations such as sensor networks and building automation.**

I. Overview

ZigBee is a wireless standard intended for low-power, low-cost, and low-data rate applications. It provides a mesh topology with intelligent routing. ZigBee especially emphases power efficiency, and is ideal for battery-powered applications. According to the ZigBee Alliance, battery life can last several years. ZigBee operates in the 2.4 GHz radio band, or on several other frequencies available for unlicensed use in some countries.

The two topologies supported by ZigBee networks are a star and peer-to-peer, as shown in Figure 1. In the case of a star configuration, all radio traffic is directed through a central node called the personal area network (PAN) coordinator. It is intended that the PAN coordinator be powered from the electricity mains. Conversely, the peer-to-peer topology allows devices to communicate directly with any other device that is within radio range. The ZigBee network layer implements routing across multiple hops of the mesh network, so that devices do not need to be within immediate radio range to communicate.

ZigBee provides data rates of up to 250 kbit/sec and is designed for a range of approximately 10 meters in an indoor environment. The range will vary from device to device. Longer distances are possible through the use of repeater stations in a mesh network.

Two different device types can participate in a ZigBee network. A *full-function device* is able to act as a PAN coordinator and/or route messages on behalf of other nodes. A *reduced-function device* is capable of neither, and connects to a only single node at a time. The reduced-function profile is intended for devices with extreme limits on power consumption and/or computing capability.

II. Physical and Data Link Layers

ZigBee builds upon the physical and data link layers specified by IEEE standard 802.15.4. These standards are freely available from the IEEE[1].

The overall network is synchronised through beacons transmitted by a coordinator. The beacons schedule "contention access periods" (essentially free-for-alls in which any device may attempt to communicate) as well as "contention-free periods" in which bandwidth usage is scheduled ahead of time and is guaranteed to be available. It is also possible to configure the network without beacons, in which case no message scheduling is provided and devices transmit at any time.

[1] http://standards.ieee.org/about/get/802/802.15.html

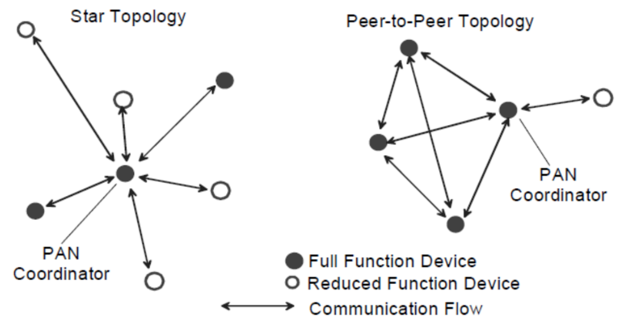

Figure 1. Network topologies supported by ZigBee. In the star configuration, all communication occurs through a central device, whereas the peer-to-peer topology defines a mesh network. (Image from IEEE Standard 802.15.4-2001.)

A key consideration of the physical layer is to optimise for battery-powered devices. This is achieved by allowing a trade-off between message latency and energy consumption. Data can be stored on a coordinating node until a low-power device awakens from sleep. It is intended that reduced-function devices will spend the majority of the time with their radio turned off in order to conserve power. The low-power device needs only to enable its radio when a beacon message is expected, because the beacons will indicate whether a message is pending. A pending message is delivered from the routing node when the reduced-function device wakes up. Conversely, if mains power or a large battery capacity is available, the receiving device can be continuously powered, and therefore messages can be sent immediately.

The radio hardware and physical layer must undergo a validation process to ensure compliance with the specification. Consequently, many embedded systems designers may choose to purchase an existing ZigBee module that has already undergone compliance testing, rather that develop the RF layer from scratch.

III. Network Layer

The ZigBee network layer builds upon the IEEE 802.15.4 standard by providing sophisticated mesh network routing. A single network may support thousands of nodes, potentially spread out over a large range. ZigBee provides routing logic to determine a path between any two nodes, even when those nodes are so distant that they cannot communicate directly.

An example network topology is shown in Figure 2. A single node is identified as the ZigBee coordinator. The coordinator is the device that initiates the network. Routers are full-function devices that forward messages through the

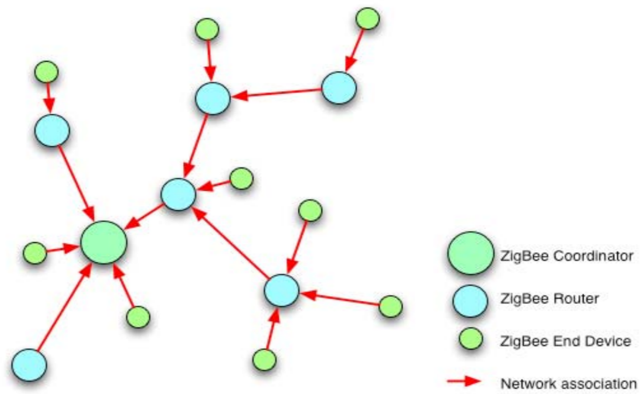

Figure 2. An example network topology for a ZigBee mesh network. (Image from ZigBee Alliance.)

network. Finally, end devices connect only to a single router or coordinator.

ZigBee devices are allocated addresses based on their position within the network tree. The Zigbee protocol determines routes by broadcasting path costs across the network. Additionally, coordinator and router devices maintain a table of neighbouring nodes that are within direct radio range. Messages can be sent directly to a neighbouring node without routing.

IV. Application Layer

The ZigBee Alliance define various application layer protocols that allow devices from different manufacturers to interoperate. Examples of ZigBee standards include home/building automation, remote control, health and fitness monitoring, and light control. For example, the home automation standard supports devices such as lights, switches, occupancy sensors, window shades, heating and cooling, thermostats, intruder alarms, etc. End users can purchase different portions of their home automation system from different suppliers, and ZigBee compliance ensures that these devices will properly interoperate.

Embedded system developers may also implement custom or proprietary application layers on top of ZigBee. An example of this are the XBee modules made by Digi International. XBee modules can provide a "wireless UART" out-of-the-box where serial data is reproduced across the radio link. With configuration, XBee modules also provide line passing where analog signals are reproduced as PWM on the other end of the link.

V. Strengths and Weaknesses

ZigBee's routing layer is incompatible with the Internet Protocol (IP). It would be desirable to connect many ZigBee networks to the Internet, for example for acquiring sensor data or controlling actuators. This is only possible through application-layer proxies that translate between the two standards. There is no network layer mechanism to route between ZigBee networks and the Internet.

The absence of IP support results in a simpler protocol that more easily adapts to situations of extreme energy constraints. The TCP/IP and UDP/IP stacks were never designed for the case of low-power devices with "rarely on" radios. It would have been difficult to get widespread agreement on the best way to adapt decades of Internet technology for low-power mesh networks. This is probably why the original ZigBee designers decided to make their own system.

ZigBee mesh networks can become unreliable when a large number of low-power nodes all wake up at the same time and attempt to transmit. This can occur in practice since reduced-function devices time synchronise their sleep-wake cycle to the beacons transmitted by the coordinator. Consequently, many messages can be transmitted simultaneously during the time immediately after a beacon, degrading the network reliability. An analysis by Anastasi, Conti and Francesco[2] concluded that a large network with a high level of traffic will experience substantial packet loss. According to that paper, it is not possible to simultaneously comply with the standard and achieve a high delivery rate. Additionally, changing network settings to improve the delivery rate caused a substantial increase in message latency. Consequently, ZigBee may not be appropriate for large mesh networks that generate a high network load. Rather, it should be used to mesh networks with sparse traffic patterns or a small number of nodes.

VI. Conclusion

ZigBee is a flexible networking standard that is ideal for battery-powered systems due to its power efficiency. It is also ideal for systems that span a large geographical area such as sensor networks, because of its native support for mesh networks. An embedded systems designer working on small runs or prototype hardware would usually purchase an existing ZigBee implementation in order to avoid the complexities and expense of compliance testing.

[2]Anastasi, Giuseppe, Marco Conti, and Mario Di Francesco. "A comprehensive analysis of the MAC unreliability problem in IEEE 802.15.4 wireless sensor networks." IEEE Transactions on Industrial Informatics, **7**, 52 (2011).