ZigBee 101

Mon, 04/02/2012 - 4:41am   by Jorge Deligiannis, Chief Technology Officer at Energate

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ZigBee has become the dominant utility-requested protocol for home energy management applications, and the growing need for residential demand response programs has increased the level of interest in ZigBee and its outgrowth Smart Energy Profile by electric utilities around the world. This article provides an introductory overview to this important standard for both technical and business decision-makers.

The need for ZigBee

ZigBee fulfills the need for a low-cost, low-power, long-range, modest data rate wireless networking protocol optimized for use in home energy management and home automation applications. Before discussing the particulars of the ZigBee protocol, however, it is useful to understand why other wireless network technologies, such as Wi-Fi and Bluetooth, fail to meet this particular combination of requirements.

Wi-Fi is a very robust and ubiquitous wireless local area network (WLAN) capable of supporting voice, video and data communications in homes, offices and open spaces. To achieve a throughput in excess of 100 megabits per second (Mbps), the latest IEEE (Institute of Electrical and Electronic Engineers) 802.11n standard employs multiple channels and antennas in the unlicensed 2.4 GHz and 5 GHz spectrums (the same used by many cordless phones), while previous versions delivered data rates from 11 to 54 Mbps using only the 2.4 GHz spectrum. Achieving these high data rates at long distances requires a significant amount of power (both transmit power and compute power), which is why battery-operated Wi-Fi devices are normally limited to devices that are recharged regularly and have special features for minimizing power consumption (including disabling Wi-Fi!). This makes Wi-Fi less suitable for home energy management applications where many of the devices are permanently affixed in locations without power nearby, requiring the use of batteries that should not need to be changed often. As a remedy to this restriction, the Wi-Fi alliance is working on a low-powered Wi-Fi standard.

Bluetooth is a wireless personal area network (WPAN) intended to replace all the cables that attach peripheral devices to laptop PCs, tablets, mobile phones, etc. Bluetooth devices, such as mice, keyboards and earbuds, are all powered by batteries. To extend battery life, most Bluetooth devices are limited to about a 10 meter (30 foot) range at a maximum throughput of 720 kilobits per second (Kbps), and employs a "sleep state" that can require multiple seconds for recovery to full operation. The Bluetooth WPAN is also limited to no more than seven devices configured in a star topology (where devices cannot communicate with each other, only with the main device). This combination of features makes Bluetooth wholly unsuitable for monitoring and control applications like home energy management, where numerous devices must communicate with one another over fairly long distances in near-real-time.

There are, of course, many other wireless protocols, such as Z-Wave and the EnOcean radio

Protocol. The former is intended for remote control of home entertainment systems; the latter is designed for commercial and industrial building automation applications. The EnOcean radio protocol could be suitable for home energy management, but its use of ambient energy harvesting to eliminate batteries in all sensors and controls simply makes it too expensive for residential applications.

Protocol primer

Like Bluetooth, ZigBee is a wireless personal area network based on the IEEE 802.15 series of WPAN standards. Unlike Bluetooth, ZigBee can support tens of thousands of devices at clear line-of-site distances of several kilometers. While such distances are far greater than what might be considered a "personal" network, ZigBee's designation as a WPAN derives instead from its use of the IEEE 802.15.4-2003 standard for a Low Rate WPAN. The "Low Rate" categorization can also be misleading, as ZigBee is capable of supporting a raw throughput (without headers, control, error handling and security) of up to 250 Kbps in the multi-channel 2.4 GHz band—more than sufficient for home energy management applications.

The IEEE 802.15.4-2003 standard defines two critical networking protocol layers: the physical layer (Layer 1) and the data link layer (Layer 2). The term "Layer" comes from the 7-Layer Open Systems Interconnection (OSI) protocol model that was created by the International Standards Organization. Atop this foundation at Layers 1 and 2 ZigBee adds a network layer (Layer 3) protocol that provides a self-forming, self-healing mesh internetworking protocol, which makes a ZigBee home area network (HAN) easy to deploy and change. With the ability to have thousands of self-forming devices on a single network, it is highly unlikely that a single premises will ever exceed any limits or experience any configuration problems.

A major advantage of a mesh topology (which is why it is also used in the Internet) is its superior resiliency based on the ability of every node to communicate with multiple others. Should any node fail, those upstream and downstream should still be able to communicate on an alternate path. If there are only two devices (which is the case in many home energy management applications today) the mesh becomes a simple point-to-point topology.

In addition to its role in home energy management, ZigBee is also the basis for the RF4CE (Radio Frequency for Consumer Electronics) standard for remote control of home entertainment and other systems. The use of resilient wireless communications is superior to traditional infrared remote controls for today's sophisticated home theaters and media centers.

ZigBee is an international standard that operates globally in the unlicensed industrial, scientific and medical (ISM) bands at 2.4 GHz, as well as in two regional frequency allocations: 915 MHz in the Americas and 868 MHz in Europe. Despite its low power requirements, ZigBee is capable on a theoretical basis of communicating reliably at distances of more than a kilometer. This is important when the utility's outdoor smart meter serves as the gateway to the HAN. One way ZigBee conserves power is with a "sleep state" similar to Bluetooth's, but with a significant difference: the ability for all battery-powered devices to sleep 99% or more of the time based on the guaranteed message delivery afforded by the mesh networking protocol.

The ZigBee protocol was originally created in 2005 and continues to be maintained by the ZigBee Alliance (www.zigbee.org), an open, non-profit association. Membership in the Alliance includes

utilities, system vendors, integrated circuit manufacturers, universities, government agencies, development and testing organizations, and interested individuals. The Alliance is organized by committees, work groups, study groups, task forces and special interest groups that guide the development of specific aspects of the ZigBee protocol suite. In addition to the basic networking protocol, there are several application-specific areas the ZigBee Alliance pursues. One of those areas that has received considerable attention lately is the Smart Energy Profile, or SEP, for home energy management.

SEParate but equal

The Smart Energy Profile extends the ZigBee networking protocol suite to define the four additional layers: the transport; session; presentation; and application layers. This hierarchy is identical to how Web browsers communicate with Web servers atop the Internet protocol (IP).

SEP specifies the way messages are structured and exchanged among the various devices within the ZigBee home area network, and how the utility communicates with the HAN via a smart meter, broadband Internet gateway, or other device at the premises. SEP supports the full spectrum of home energy management needs, including demand response and pricing signals from the utility, load control commands, text messaging for displays, time synchronization, etc. SEP also specifies security provisions to prevent tampering or snooping, including strong encryption and automatic network registration using either pre-installed keys or public key cryptography.

The current version of SEP is 1.1, which includes these notable enhancements over the original version 1.0: over-the-air updates; automatic meter swap-out; block tariffs and prepayment options; tunneling to enable the use of proprietary, manufacturer-specific protocols; enhanced interoperability testing; and full backwards compatibility with the version 1.0. A planned version 1.2 is expected offer some minor enhancements, while in the longer term, the next-generation version 2.0 is expected to offer some significant new capabilities, including: support for charging plug-in electric vehicles (PEVs); firmware download and configuration for HAN devices; extensions for user information and messaging; multiple Energy Service Interfaces in a single premises; interoperability with version 1.X via a gateway function; and the ability to operate over virtually any IP-based network.

This last enhancement with SEP 2.0 is quite significant. ZigBee and SEP were initially inseparable as a full, 7-layer solution for home energy management. Version 2.0 of SEP will instead be network agnostic, enabling the profiles to be used with a wide variety of underlying wired and wireless HANs, including powerline communications, Wi-Fi, and of course, ZigBee. In anticipation of this eventual change, many vendors, including Energate, are designing devices to be upgradable to SEP 2.0, which enables utilities to take advantage of SEP 1.1's substantial feature set now, and upgrade easily later (if desired) to SEP 2.0.

A typical home energy management application

Home energy management is normally part of the local electric utility's efforts to reduce peak demand. As part of a residential demand-side management program utilizing either demand response or direct load control, the utility communicates via the smart meter or a broadband Internet gateway that a peak demand condition exists, potentially accompanied by a temporary rate increase. In response, the programmable communicating thermostat (PCT) raises or lowers the temperature setting (in the summer or winter, respectively) a pre-determined amount to

conserve power. The PCT might also take other actions, such as activating a ZigBee load switch to temporarily turn off an electric water heater or pool pump. Examples of these devices are shown in the figure below.

Shown here (not to scale) are the devices typically used in a home energy management application: broadband Internet-to-ZigBee Gateway (center); programmable communicating thermostat (left); load switch (top); smartphone and tablet apps (right); and a dockable in-home display (bottom).

To make home energy management as simple as possible, the better PCT and IHD systems support "set and forget" programming that enables users to easily make the desired tradeoff between comfort and cost savings, and to change the setting just as easily at any time. For example, Energate's smart thermostat uses a "virtual dial" that lets users specify maximum comfort (no reduction in energy use), maximum savings (temporarily shutting down all major loads), or something in-between. Some solutions also support mobile applications and Web portals to enable users to check settings and make changes while away from home.

The growing pains of a growing ecosystem
As with any set of protocols, the early days of ZigBee and SEP experienced some growing pains. As the protocol suite evolved, the applications evolved even faster, revealing unspecified details in the protocol layers and forcing vendors to be creative with their own interpretations, thereby causing some interoperability problems. The ZigBee Alliance has been quick to respond to these evolving demands, however, and some of the creative problem-solving by vendors has since been incorporated into the standard.

Although Energate is agnostic regarding communications protocols used in the HAN, or any other element of demand response solutions, as an early leader in home energy management the company experienced the evolution of ZigBee first hand. And as a developer of both client and server applications, Energate's experience was both end-to-end and top-to-bottom throughout the protocol suite. This intimate experience in the early days, including actual deployments, enabled Energate to contribute to improving some of the security, routing, packet processing, time synchronization and time zone management provisions of the standard.

One specific Energate contribution involved the Energy Service Interface (ESI), which is normally in the smart meter (the point of demarcation between the utility and the premises). As ZigBee HANs are deployed, the homeowners often, and the utilities sometimes, wish to add devices to the basic system. If the utility and consumer both relied on the advanced metering infrastructure (AMI) communications exclusively, these additional devices might ultimately overwhelm the AMI's available bandwidth. For this reason, Energate developed a broadband Internet-to-ZigBee gateway (which functions as both a client and trusted server) to work with or without a smart meter, and that required authoring an enhancement to support multiple ESIs, as well as the automatic swapping of the trust center between smart meters and gateways.

The most significant contributions, however, have been to the test cases. As with most protocols, these were initially incomplete; products would pass the tests, but fail to interoperate well or at all in practice. Energate's unique insight into client/server interaction has dramatically improved testing, and therefore, interoperability in version 1.1.

SEP is now quite mature—mature enough, in fact, that SEP 2.0 was selected in 2009 by the U.S. National Institute of Standards and Technology (NIST) for residential demand response in the Smart Grid Interoperability Standards Framework. The future of SEP is even more promising based on the network-agnostic version 2.0, which has garnered support from a growing number of other organizations, including the HomePlug Powerline Alliance, HomeGrid Forum, SunSpec Alliance, Wi-Fi Alliance, IPSO Alliance and International Society of Automotive Engineers.

Conclusion

The Smart Energy Profile is now an official standard for home energy management in North America, and even though version 2.0 is network agnostic, ZigBee remains its most popular underlying networking protocol. Version 1.1 is fully mature and, as a result, is now being specified by a growing number of utilities for their residential demand response programs.
The home energy management solutions available have also achieved a robust level of maturity in terms of both their dependability and ease-of-use. These are critically important traits because, without sufficient consumer acceptance and engagement, any utility's demand response program is destined to fall short of its goals.

For proof of this level of maturity, one need look no further than the successful pilots that are transitioning into large-scale roll-outs of residential demand response programs at utilities like Oklahoma Gas & Electric and the Ontario Power Authority. Simply put: SEP over ZigBee works, and works well. So while other impediments may remain for some utilities, at least the infrastructure on the other side of the meter is now ready to go.

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About the author

Jorge Deligiannis is a world-renowned expert in in-home technology, control algorithms, embedded design and communications. After a number of patents developed as a telecom engineer, Jorge joined Enerstat where he became its CTO, leading its team to develop award winning advanced thermostats that were deployed in five continents through leading corporate partners. Jorge continued his development of advanced IP, praised by the top smart grid companies, as he co-founded Energate and inspired a team of very capable developers in software, hardware, firmware, communications, and their effective integration.