

Energy Efficiency Comparisons of Wireless Communication Technology Options for Smart Grid Enabled Devices

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Introduction

The potential growth and impact of the smart grid, particularly with respect to the widespread use of smart appliances and other devices, will have a major impact on the cost and reliability of electric power. The smart grid will enhance the integration of renewable power resources, reduce peak loads on utilities, encourage energy efficiency, and reduce costs for both utilities and consumers. To realize the benefits of the smart grid, it is critical that the underlying communications technology – which is necessary to make the grid “smart” – consume as little power as possible. Because of the widespread use of these communication technologies at the residential level in home area networks (HAN) and in the smart devices, the choice of technologies is very important.

The intent of this paper is to compare the choice of wireless communications network technologies, specifically with respect to the required performance (data rate, range, cost, etc.) and energy consumption to determine which of the existing technologies best minimizes the energy impact of widespread HAN deployment in residential settings.

GE found that the two wireless communications technologies that best meet the overall performance and cost requirements are Wi-Fi (802.11/n) and ZigBee (802.15.4). These technologies were then evaluated under typical HAN/smart-device conditions and in a configuration representative of future mass production to determine which technology makes the most sense for widespread implementation.

Background

Smart Grid Meets the Home Area Network

The explosive growth of the smart grid will change the way consumers think about how and when they use electricity. These changes will impact consumers as electric utilities roll out smart meters over the next few years and as electric markets become actual markets – with prices driven by supply and demand of electricity during the course of a day. By 2012, it is projected that there will be 50 million smart meters installed¹ in homes across the U.S., tracking energy consumption in 15-minute intervals. More importantly, smart meters will allow utilities to change the price of electricity throughout the day based on the actual cost of producing electricity at that time – with higher prices during peak usage periods and lower prices during lower usage, or off-peak, periods.

In this paper, the term smart meter refers to Advanced Meter Infrastructure (AMI) systems, which contain meters capable of two-way communications with a centralized grid control system. These are meters that can receive signals, including the cost of electricity and status of the grid, track electricity usage on a short-term basis, and automatically report the meter readings back to the utility. For some utilities, new pricing structures could take the form of fixed time-of-day pricing, critical peak-period pricing, or even dynamic day-ahead hourly pricing. Regardless

¹ Parks Associates. <http://www.parksassociates.com/events/energysummit/pages/press/pr1.html>. October 2009.

of the rate structure, the widespread availability of smart meters and dynamic rates will change the way that consumers use and pay for electricity.

Connecting the Grid to the Home

A large percentage of smart meters being installed will have the capability to connect the AMI meter to a Home Area Network (HAN), allowing communication of cost, consumption, and other data within the home. The HAN will enable consumers to install products, including real-time displays, home energy managers, and “smart” devices, such as appliances, HVAC thermostats, hot water heaters, pool pumps, and Electric Vehicle (EV) charging stations that are capable of responding to the signals from the smart meter.

Smart Devices Give Consumers Increased Awareness and Control. The combination of the AMI meter and the HAN will enable consumers to be aware of electricity costs on a near real-time basis, monitor their energy usage and, most importantly, manage their usage based upon their preferences and desire to minimize their bills.

To assist consumers in managing their energy use, manufacturers are designing products that contain built-in communication systems that will communicate with the HAN (and the AMI meter). Knowing the cost of electricity and understanding consumer preferences, these smart technologies will manage appliances to either defer operation or adjust the operating condition to reduce peak energy demand.

Smart Products Can Help Reduce Costs. This has the potential to then reduce the consumer’s energy bills and also reduce the peak demand for the utility. Peak reduction can save utilities money by helping avoid construction of new peaking power plants, which exist only to handle peak loads that may occur a few hours per day, or in some cases, only a few hours per year. Utilities will also avoid the cost of upgrading their infrastructure to meet these infrequent peak loads. In addition, the reduction of peak loads will generally result in emission reductions in most areas of the country, thus producing environmental and economic benefits.²

Demand Response-Enabled Products Support Renewable Energy Growth. These smart appliances and devices are often referred to as Demand Response (DR)-enabled. In addition to reducing the consumer’s electric costs, another benefit of DR-enabled products is the ability to support the growth of renewable generation capacity on the grid.

By their nature, many of the renewable generation sources, such as wind or solar energy, produce intermittent (or variable) output. Rapid changes in renewable-generation power output can be caused by unpredictable weather conditions, hence the need for the grid to be able to absorb rapid power reductions more frequently and on a relatively large scale.

Currently, the grid is capable of absorbing a limited amount of load variation through the use of spinning reserves (generator plants online and operating at “partial load”) and other load-

²Pacific Northwest National Laboratory. “The Smart Grid: An Estimation of the Energy and CO2 Benefits,” R Pratt, et al. Pacific Northwest National Laboratories, publication number: PNNL-19112, January 2010.

management methods, such as the import and export of power from adjacent systems. However, as renewable resources grow to become a larger portion of the total generation capacity, the need to manage the grid load on a short-term basis will become critical to maintaining grid stability. The management of residential loads as a “buffer” to renewable variation could be an important factor in the widespread integration of renewable power into the grid.

Communications Network – The Smart Home Enabler

The underlying technology that enables these benefits to the consumer and the utility is the availability of an AMI and HAN communication system. To be effective and easily deployed, the HAN communication network must be based on a network technology that utilizes open data architecture, is low-cost, consumes a minimum amount of energy, and does not require extensive new infrastructure.

While various types of power line carrier (PLC)-based communications are technically feasible, none of the current technologies and protocols has reached the level of technical maturity and cost competitiveness to represent a viable solution. While this situation could change in the future, decisions must be made based on current realities due to the rapid deployment of these AMI systems and, for this reason, the comparison in this paper is limited to wireless technologies.

As smart grid technology expands in the U.S., the availability and penetration of these smart appliances will become widespread over time – just as cell phone and wireless communications devices have become ubiquitous, leading to a reduction in the cost of the devices and enabling the growth of unanticipated new products and services.

The choice of communications technology is critical because of the sheer magnitude of products involved, as well as the amount of time these communications systems will be operating – 24 hours per day, seven days per week, and 365 days per year.

Currently, there are approximately 120 million residences in the U.S., including single-family and multi-family homes. Based on the assumption that each residence will likely contain five to six smart products connected to the HAN -- including appliances, thermostats, EV chargers, and home energy managers -- then over 720 million products could be consuming energy to maintain communication at any given time. Factoring in growth of households over the time required to achieve full market penetration of smart products, there could potentially be more than 1 billion smart products in existence by 2025.

Comparing Cost and Efficiency of Wireless HAN Communication Technologies

While it is expected that the use of smart appliances and energy management systems will allow consumers to manage and reduce their energy bills and overall consumption, it is essential that the communication and control hardware designed to perform these management tasks consume the minimum amount of energy possible.

The Impact of Standby Power

Currently, the European Union regulates the stand-by power of all electric devices to one watt or less.³ This requirement is based on the understanding of the large aggregate power requirement needed to support products that consume power continuously – even at the one-watt level. In most U.S. appliances, this standby power is included in the overall Department of Energy (DOE)-mandated energy standards. However, the U.S. DOE has also recently proposed methods to evaluate the standby power in appliances and requested comments from the industry.⁴

Currently, the standby power is included in the overall energy requirement and is not explicitly limited. Nevertheless, manufacturers are acutely aware of the need to minimize the standby power draw of these products. Based on the estimated number of potential smart devices that will be installed, these devices could, in the future, represent nearly a gigawatt of electric generating capacity required to supply them with power. This additional electric load would require a significant investment in power plants and could cost U.S. consumers as much as \$876 million annually in stand-by energy costs (at \$0.10/KWh).

In evaluating the potential wireless communications technologies for smart grid HAN applications, available technologies should be compared for their ability to meet the power consumption, range, data rate, and cost requirements of the HAN.

Three Wireless Technologies under Evaluation: ZigBee, Wi-Fi and Bluetooth

The three logical candidates for HAN/smart-product applications are: Bluetooth (based on IEEE 802.15.1), ZigBee (based on IEEE 802.15.4), and Wi-Fi (based on IEEE 802.11).⁵ While other wireless technologies exist, these are the only technologies that have the technical maturity to deliver the performance and low cost required for the universal incorporation into HANs and associated consumer products (appliances, thermostats, pool pumps, lighting systems, and more).

The Association of Home Appliance Manufacturers (AHAM) has also performed a screening study of possible communications technologies for use in home appliances.⁶ The AHAM study reached a similar conclusion; based on the current maturity of these technologies, ZigBee, Wi-Fi and Power Line Carrier (HomePlug) best meet the requirements for smart appliances (and other home devices).⁷ As noted previously in this paper, the maturity of PLC technology has not reached the point where it represents a viable solution. In the future, this technology could mature to a level where it is a secondary solution for home networking.

³ EU Commission Regulation No 1275/2008 of 17 December 2008 implementing Directive 2005/32/EC.

⁴ U.S. Department of Energy (DOE) notice of proposed rulemaking (NOPR) dated December 9, 2008.

⁵ Bluetooth, ZigBee and Wi-Fi are trademarks of the Bluetooth Alliance, ZigBee Alliance and Wi-Fi Alliance, which are commercial organizations that certify the interoperability of specific devices designed to the respective IEEE standard.

⁶ AHAM. Assessment of Communication Standards for Smart Appliances.

<http://www.aham.org/ht/a/GetDocumentAction/i/50696%20>. 21 October 2010.

⁷ HomePlug is a registered trademark or service mark of the HomePlug Powerline Alliance.

While the AHAM paper rated these communications technologies at or near the top, the evaluations did not address competitive issues -- such as cost -- and also could not address how each would perform in a specific implementation.

The Distinction between WLANs and WPANs. Wireless Local Area Networks (WLAN) were developed as an extension of the IEEE 802 wired LAN standard designed for high-end data networking. The background and rationale of these protocols are described in the IEEE publication “Low Rate Wireless Personal Area Networks.”⁸ These systems are categorized as WLAN or WPAN (Wireless Personal Area Networks), depending on the data rate, power consumption, and complexity of the technologies.

The 802.11 class of networks are considered WLANs and were designed for high throughput and moderate cost/power consumption and complexity. These devices have become ubiquitous in home area data networks for personal computers (PCs) and other consumer electronics, such as laptops, personal digital assistants (PDAs), mobile communication devices, and entertainment systems, where a high data rate is a key driver. This technology is commonly known as Wi-Fi and is found in every home router, laptop, and many portable personal devices.

By contrast, the 802.15.4 (ZigBee) and 802.15.1 (Bluetooth) networks are WPANs and were designed for lower data rate, low power consumption, and low implementation costs targeted to specific applications.

Bluetooth May Not Be Most Viable Option. Bluetooth has been developed for very short-range and low-cost applications. It is designed primarily as a “cable replacement” for consumer electronic devices, centered on mobile phones and other computer peripherals with a moderate data rate (~ 1 Mb/s) suitable for voice applications.

However, Bluetooth has limited range and, based on this limitation, it is not suitable for home networking of appliances and other products. In addition, Bluetooth is configured as a “star” network, rather than a “mesh” networking technology, and is therefore not well suited to applications like home networking, where meshing can significantly improve network reliability (this is explained in more detail below). Furthermore, Bluetooth is designed for data throughput of up to one Mb/s, which is far greater than the data throughput required to manage home energy loads, which is in the Kb/s range. While Bluetooth has become very inexpensive, it does not represent a viable option for the type of HANs required for energy management within a home.

The lowest power networking technology that is widely available is the 802.15.4 (ZigBee) standard. This standard was developed explicitly for ultralow power applications, including battery-powered applications and low-cost applications, like sensor networks for control. It was designed to fill the operating space of applications that fall below the other 802 standards in terms of lower power usage, lower cost, and lower data rates. It is intended for monitoring and control applications, where data rate and latency is not as critical as in PC network communications. However, ZigBee is optimized to minimize power consumption and cost.

⁸ IEEE. “Low Rate Wireless Personal Area Networks, Enabling Wireless Sensors with IEEE 802.15.4”; Gutierrez, Callaway, Barnett, Published 2004, IEEE Press, Nov 2003, ISBN 0-7381-3557-7.

These characteristics make it well suited to the HAN applications. Although ZigBee can be configured with very low transmit power (Tx), it can be increased by use of a power amplifier (PA) to improve the transmission output to a level such that the ZigBee range can be comparable with Wi-Fi.

Down to Two: A Choice between ZigBee and Wi-Fi

Based on the wireless network options available for HAN and smart appliance applications, the choice of wireless networking technology thus becomes a decision between the 802.11 (Wi-Fi) and 802.15.4 (ZigBee) standards. Given the low data rate requirement of the HAN and smart appliance application, which is in the order of tens of Kb/s, it is clear that both technologies can meet the data performance needs. Both technologies are capable of providing similar transmit power output, thus each should provide adequate range for the application.

Mesh Technology Offers Energy-Saving and Reliability Advantages. The ZigBee technology is designed for operation in a mesh network topology and is generally used in a mesh network configuration, even though it can be designed in simpler configurations. Mesh topology offers many advantages in HEM networks with multiple devices, including higher data reliability due to multiple transmission paths. Meshing enhances the ability to communicate across the network when one or more nodes are blocked or out of range. Also, ZigBee meshing allows some devices to remain in sleep mode while other parts of the network are active, since the routes are dynamic and do not need to pass through every node. Wi-Fi is not capable of mesh networking, and the underlying network technology is not available for Wi-Fi. Mesh-topology Wi-Fi systems could be developed; however, to bring that technology to maturity would require significant time for the industry to commercialize chipsets, as well as bring costs down to high-volume levels.

Star Network Topology has Energy-Saving Limitations. The dependence of the Wi-Fi network on simple star network topology requires all devices to react to signals from the controller, when in fact only one device is being queried. While Wi-Fi systems can be put to “sleep,” they are limited to sixteen beacon periods. To maintain compatibility with existing home Wi-Fi systems, where the beacon interval is around 100 milliseconds, the Wi-Fi chips could only be in sleep mode for a short time (1.6 seconds) before being required to “wake up,” thus limiting any advantage of the Wi-Fi sleep mode.

The Cost of Chipsets Matters. While a detailed cost comparison is beyond the scope of this paper, chipsets based on both technologies are in, or are approaching, mass-production levels. High-volume cost data for currently available chipsets indicates that the ZigBee chipsets are significantly less expensive than Wi-Fi chipsets by approximately \$2.00 – \$2.20 per device at high quantities (over 100,000 pieces per year).⁹

In addition, the microprocessor required to control the ZigBee chip can be much less complex due to the small size of the ZigBee MTU (Maximum Transmission Unit) compared to Wi-Fi. Based on communications with suppliers, it is estimated that a simple processor for ZigBee is

⁹ Based on prices quoted to GE suppliers in Asia.

\$11.00 less expensive than a simple processor for the Wi-Fi solution. Thus, the cost advantage of the ZigBee chipset extends to the microprocessor, as well.

Based on all of these factors, ZigBee appears to have a significant advantage with respect to first cost. As noted, considering the sheer number of devices that will be smart grid-enabled, the cost savings associated with the choice of the least expensive technology will be significant – in the range of hundreds of millions to several billion dollars over the next 20 years.¹⁰

Power Consumption – A Major Decision Factor. In addition to cost and performance comparisons, power consumption becomes a major decision factor in choosing between the two network technologies. Even at modest power consumption rates (for example, approximately 0.5 watts per device), the cost of energy to power the chip over the lifetime of the product will roughly equal the cost of the chipset. More importantly, the aggregated load of the devices will amass to a large increment of power (and a corresponding amount of energy annually).

Based on existing literature and specifications for the two technologies, it was unclear what the average power consumption would be in actual HAN and smart appliance networks, operating under conditions and data payloads typical of a residential smart-home setting. Technical papers, such as “Towards Energy Efficient Design of Multi-Radio Platforms for Wireless Sensor Networks,”¹¹ indicate that the relative power comparison was a function of data payload size, communication frequency, and processor/wireless interface I/O (input/output) overhead. This reference supported the contention that, for small payloads and a properly matched processor, the ZigBee wireless technology would have a lower power consumption based upon our projected application.

However, this comparison was based upon specific chipsets and, in the case of the Wi-Fi technology, was based on the 802.11/b standard that was widely available when the paper was written in 2007-2008. More recent information on the newer 802.11/n chipsets indicates that these chipsets have been upgraded and designed for improved data rate and signal margin. These improvements have implied that the overall power requirements would be reduced in HAN environments with low data rates, even to the point where power consumption of the Wi-Fi chipsets could be comparable with ZigBee chipsets. Although the specifications for recent sets of 802.11/n chips have claimed¹² that they are “low-power,” as well as higher throughput, there are many factors which impact overall power consumption.

Given the competing claims for the power consumption of the two technologies and the complexity of their operation, the best way to compare them would be to measure the power consumption in a side-by-side test duplicating HAN/smart-appliance communications under identical conditions.

¹⁰ 720 million - 1 billion devices X \$2/device = \$1.4 billion - \$2 billion in savings.

¹¹ “Towards Energy Efficient Design of Multi-Radio Platforms for Wireless Sensor Networks”; Lymberopoulos, Piryantha, Goraczko, Feng, International Conference on Information Processing in Sensor Networks, 2008. IPSN '08. April 2008.

¹² “LOW POWER WI-FI™ (IEEE 802.11) FOR IP SMART OBJECTS,” Daniel M. Dobkin and Bernard Aboussouan, Gainspan Corporation White Paper, 2009.

Testing the Power Consumption of ZigBee versus Wi-Fi

GE Appliances is currently developing a suite of residential smart appliances, thermostats, and a home energy gateway/home energy manager (HEG) for use in homes that are equipped with a smart meter (AMI) and are under some form of dynamic rate structure (time-of-use billing, critical-peak pricing, day-ahead hourly, etc). These appliances would receive pricing and other signals from the grid and defer or reduce their power consumption during critical periods to lower demand on the utility grid and to potentially reduce consumers' energy costs.

To implement these smart appliances in a practical system, a communications module has been developed to interface the individual appliances either directly with a meter or with the meter via an HEG. In either case, each appliance is equipped with a communication module which contains a wireless radio and dedicated microprocessor. The module communicates with the appliance's embedded control system to manage the mode of operation (deferral or low-energy operation) of the appliance based upon the signals received directly from the meter (AMI) or via the HAN.

GE has designed the modules such that several wireless radio technologies can be used with the same base module. These communication modules have been designed with the intent that once smart appliances move beyond the demonstration phase, the circuitry for the module will be incorporated into the control board of the base appliance, thus greatly reducing the incremental cost of the communications feature.

Due to the complexity of the interactions and the uncertainty regarding the actual power consumption of Wi-Fi and ZigBee in the specific HAN/smart appliance application, GE has performed testing of these two wireless technologies under identical conditions using GE's Appliance Communication Module to determine the power consumption of each wireless technology.

Test conditions. The test was conducted with custom firmware configured to send an application layer packet every five minutes. The data payload size of each packet was the same and based on a typical payload size of Smart Energy Profile 1.0, approximately 50 bytes. Although the data payload packets were identical, each technology attached the MAC level headers and other data overhead structures associated with that technology. The transmit power (Tx) of each radio system was set to the same level (10dBm) to allow a comparison of the systems under identical conditions.

Each system was set up to communicate with a "parent node," and power consumption was monitored over a 24-hour period with five-minute transmission intervals. The power consumption of the module was monitored using a National Instruments A/D data logger. The data acquisition system logged the power consumption (current across a fixed shunt resistor) on one-millisecond intervals to capture the transient details of the transmit and receive events, as well as other power consuming activities associated with the module (I/O, standby, etc.).

The power for the entire module was measured since the power required for standby and tasks, such as microprocessor I/O between the radio and the microprocessor, also impact the overall

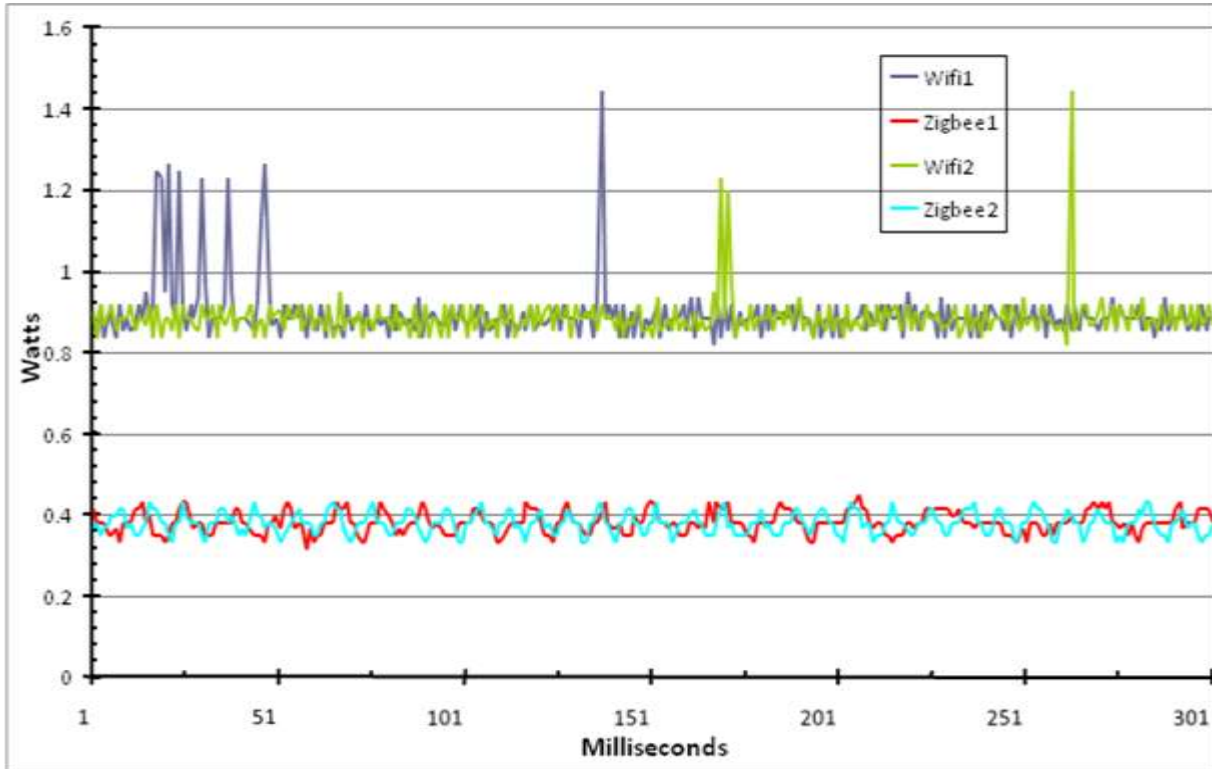
consumption of the module. Although the communication module used for testing was implemented on a stand-alone circuit board, it is representative of the microprocessor and circuitry that will be integrated into the appliance control board when smart appliances reach mass production. Based on the test hardware and conditions, the results of this test will be similar to the power consumption expected in the mature, high-volume smart appliances that will be sold in the future.

The module tested with ZigBee technology contained an Ember EM250 chipset configured as an RFD (Reduced Function Device) with RxIdleWhenON = TRUE enabled (non-router mode and non-sleep mode). The Wi-Fi technology was based on a ZeroG (Microchip) MRF24WBOMA/MB 802.11/n. This Wi-Fi chipset is one of the latest 802.11/n Wi-Fi chipsets. This Wi-Fi chipset is optimized for high-data throughput, as well as low power consumption during the various modes of operation.

Results. Figure 1 demonstrates the power consumption in detail over a selected period of approximately 300 milliseconds to illustrate the differences in the two systems. Two traces for different periods of time are shown for comparison. The data represents the power for the entire communication module using the communication chipset, plus a microprocessor and associated interface circuits, to provide a logic signal to the appliance based on the signal received from the parent device.

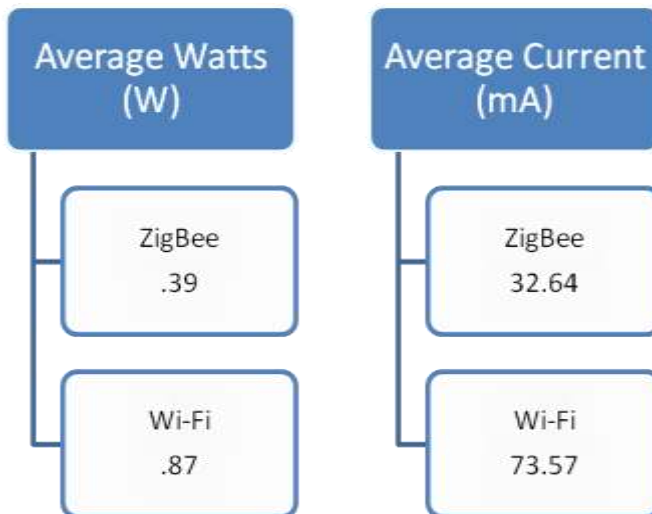
The results of the measurements indicate significant differences in the power consumption over the period. Clearly, the Wi-Fi system has a much larger baseline power consumption, and also indicates spikes associated with the transmit periods. The ZigBee system has a much lower baseline power consumption with much lower variation due to transmit transients.

Figure 1: Detailed Power Consumption over Period of 300 Milliseconds



Each of the radio technologies was operated for a 24-hour period; power consumption data was collected and integrated over that 24-hour period. The results are shown in Table 1.

Table 1: Power Consumption Data over 24-Hour Period



ZigBee Found to be More Efficient. As Table 1 indicates, the ZigBee chipset/module consumed an average of 0.39 watts over the period, and the Wi-Fi consumed an average of 0.87 watts over the same period. While both of these technologies demonstrated power consumption of less than a single watt, it should be noted that the difference is significant; the Wi-Fi system consumed an additional 0.48 watts. This difference represents a 2.2-time increase in power consumption for Wi-Fi versus the ZigBee over the test period.

Although the two systems had similar transmit power and identical data payloads, the Wi-Fi system had a much higher average power consumption. While the Wi-Fi transmit periods were much shorter than the ZigBee, the non-transmit power consumption was higher for the Wi-Fi, resulting in a much higher overall average power usage.

If the test conditions were to include higher data throughput conditions, then the average ZigBee power would increase due to the longer transmit periods required, and under increased data throughput conditions, the Wi-Fi would have the lowest power consumption. This situation is due to the fact that the 802.11 technology is designed and optimized for high data rate and high data throughput conditions (downloading graphics and video, streaming data, etc.), while the 802.15.4 technology is optimized for low data rate and low data throughput systems (such as sensor and industrial control systems) and is well-suited to the environment of the HAN/smart appliance network.

Given the potential application of smart technology to millions of appliances and devices that will be connected to the smart grid, the difference in continuous power consumption will result in a significant change at the aggregated national level. As noted earlier, with the widespread growth of the smart grid infrastructure, the potential market size for smart, connected devices could range from approximately 750 million to 1 billion. At these levels of widespread deployment, the power and energy savings of adopting the lowest power-consuming technology will be important. Based on the testing of the current chipsets for each technology, it appears that ZigBee offers a significant advantage over Wi-Fi.

ZigBee Could Save Millions Annually. Projecting the difference in power consumption for each device and assuming the potential for 750 million devices, the use of ZigBee versus Wi-Fi would save 4.2 KWh per device each year. This difference in power consumption, aggregated over the potential of 750 million devices, represents the output of a 370 megawatt (MW) power plant. The yearly value of the energy required for a Wi-Fi solution compared to a ZigBee solution would be an aggregate cost savings of approximately \$315 million per year (at \$0.10/kWh). It is apparent that the potential impact of adopting ZigBee as the wireless technology for smart devices in the home will offer substantial savings in terms of power reduction and energy savings.

Conclusion

Wi-Fi (802.11/n) and ZigBee (802.15.4) were evaluated under typical HAN/smart-device conditions and in a configuration representative of future mass-production implementation to evaluate the cost and efficiency of each technology with respect to the other. The testing under

identical conditions in a smart appliance communications module revealed that a ZigBee system consumed an average of 0.39 watts over a 24 hour period, while the Wi-Fi system consumed more than twice (2.2 times) the power of the ZigBee solution, a total of 0.87 watts over the same period. Projecting this difference in device-level power consumption to the projected installed base in the future, results in significant aggregate power (370 MW) and yearly energy cost (\$315 million) savings for choosing ZigBee communication technology over Wi-Fi technology. Based on this experimental data, it is clear that the ZigBee wireless communication technology operating in the HAN/smart device environment, results in the lowest energy consumption, while meeting the communication performance requirements for smart devices within the HAN.

About GE Appliances & Lighting

GE Appliances & Lighting spans the globe as an industry leader in major appliances, lighting, systems and services for commercial, industrial and residential use. Technology innovation and the company's ecomagination(SM) initiative enable GE Appliances & Lighting to aggressively bring to market products and solutions that help customers meet pressing environmental challenges. General Electric (NYSE: GE), imagination at work, sells products under the Monogram®, Profile™, GE®, Hotpoint®, Reveal® and Energy Smart® consumer brands, and Tetra®, Vio™ and Immersion® commercial brands. For more information, consumers may visit www.ge.com.

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Will Watts is a Systems Software Architect for General Electric with over six years of experience in applications of 802.15.4 devices to residential DRLLC, and building energy efficiency. He participates in the OpenSG subcommittee on the OpenADR task force. He holds a BA in Physics and MS in Mechanical Engineering, both from the University of California, Berkeley.