

HANs lend a hand in Home Energy Management

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Introduction

Growing energy demand, shrinking supplies, increasing costs and climate change are driving demand for more eco-friendly homes. At the same time, utilities are struggling with the “peak energy demand” dilemma, where approximately 10 percent of total electric generating capacity exists only to be used less than one percent of the time. If energy demand can respond dynamically to the available energy supply, huge energy savings and reliability gains can be achieved within the energy grid. Enter home area networks (HANs), which are enabling utilities and homeowners to work together in managing a home’s energy consumption. HANs connect thermostats, load switches, lighting systems and in-home displays to the meters. They also enable utilities to both send and receive data into the home. During periods of peak energy demand, utilities and homeowners can leverage HANs to throttle high-load devices in participating homes, such as changing the thermostat setting of the HVAC system. Utilities save considerably by not having to build new power plants. Homeowners save money through lower bills and attractive rebates. And communities avoid the ravages of rolling blackouts. This paper will focus on the new ZigBee “Smart Energy” profile application that is making this utility-homeowner partnership possible.

Why do we need Home Energy Management?

In the US, capacity margin is declining and the energy generation capacity needed to satisfy demand could not be built in time. For example, Texas (ERCOT) would need to generate another 10,000 MW, while California would require an extra 8,000 MW (US census data and US DOE Energy Consumption). The peak energy consumption can reach as high as 20% more than normal demand and is growing faster than normal demand. This peak demand in the US typically lasts less than 100 hours each year, yet costs billions of dollars in infrastructure, and inevitably means using the most inefficient and dirtiest plants. From 1949 to 2001, annual power consumption per person in the US grew from 500 KWH to over 4,000 KWH, with the highest peak consumption in some states like California coming from Air Conditioning, followed by white goods.

In Europe also, security of energy supply is becoming an issue. According to Professor Ian Fells of Newcastle University in the UK, “There will be a shortfall in UK power generation of 23GW by 2020, rising to between 30GW and 37GW by 2027” (Fells & Whitmill 2008), a problem created largely by the closure of ageing nuclear and coal-fired power stations. This is further exacerbated by fears that gas and oil supplies from the Middle East and Russia will not be enough to sustain the growth in usage until new energy generation strategies in Britain take shape. At the very least there are concerns over the security of supplies from these regions!

In the UK it is anticipated that most carbon savings will come from demand reduction and energy efficiencies. Research in Europe and North America shows that direct feedback through energy displays etc. leads to between 5% and 15% savings on energy usage. It is claimed that people become more energy literate through using feedback and change their habits (Darby 2008).

Where does the HAN fit in?

The Home Area Network (HAN) is one aspect of Advanced Metering Infrastructure (AMI), which includes all two-way communications with a meter, both inside and outside the home. Support for secure two-way communications with the meter within the home is a key capability and guiding principle for the HAN according to the OpenHAN Task Force (2007a), and this capability is what enables all of the other capabilities, including load control integration; direct access to usage data; a platform for future products that leverage HAN and meter data; public price, consumer specific and control signalling; and support for distributed generation and sub-metering (OpenHan Task Force 2007b). As such, the HAN, and therefore the communications technology used by the HAN, is absolutely critical to home energy management.

The first step, however, is the deployment of smart meters with two-way communications capabilities, and in some cases, such as Centrepont Energy and Oncor in Texas (Smith 2008), the utilities are installing smart meters but leaving it up to energy retailers and consumers to provide the in-home equipment for the HAN.

How does a HAN work?

A home area network usually falls into one of two categories; passive or active control of energy usage. In the active model, the home area network is designed to communicate energy usage and pricing information to the consumer, with a view to educating the consumer and influencing behaviour, such as reducing the use of energy in some cases, or using energy at more cost-efficient (off-peak) times. In the passive model, the utility company directly controls the consumer's energy usage under predetermined scenarios and in a predetermined and agreed way, perhaps automatically raising the air conditioning temperature by a degree or two or lowering the temperature of the heating system by a degree or two when there is peak demand on the system.

In most cases the HAN consists of a smart meter (or meters) communicating to one or more devices in the home, usually an in-home display, but also programmable thermostats, heating and air conditioning systems and perhaps smart plugs or smart appliances.

Where does ZigBee Smart Energy fit in?

As the name implies, a 'home area network' involves communications between various devices. The ability to communicate does not make a device 'smart' per se, but it certainly is one requirement of 'smartness'. In a networked world that is increasingly becoming wireless, ZigBee is the leading open global standard in the area of low power, low data rate wireless mesh networking.

ZigBee defines a networking standard for operating a mesh network using IEEE 802.15.4 compliant radios. ZigBee mesh networking is highly robust, secure and scalable, so it is a perfect match for the rigorous requirements of utilities and meter manufacturers. The level of support and competition among ZigBee chip manufacturers, many of whom are significant top-ten semiconductor companies, ensures that innovation and pricing will continue to be keen well into the future. In addition, at 2.4GHz, ZigBee has the bandwidth to expand beyond very simple sensing and control applications, and the global appeal to encourage product manufacturers to build mass-market products.

ZigBee Smart Energy (ZSE) is more than this however. ZSE is an application profile that sits on top of the ZigBee networking standard, and defines the application level operation of a HAN, in particular its application security, application messaging and network commissioning. Using ZSE ensures that products (devices) from different manufacturers using chipsets from different silicon vendors can communicate with one another (i.e. are interoperable), so that utilities and consumers can be confident that they can source products from a multitude of manufacturers and that the market can be open and competitive. From a tendering point of view, ZSE can be used by utilities or government to specify the products that are required for their HAN, while ensuring strong competition and the possibility of dual sourcing for many devices including meters, in-home displays and programmable thermostats. From a standardisation point of view, the ZigBee certification process that leads to a product obtaining the ZigBee Smart Energy logo, can be used as a prerequisite for utilities when specifying the standard that products must obtain to be included in a smart energy HAN.

Because it is an open global standard and because it sits on top of the ZigBee networking layers, ZigBee Smart Energy does not have to be exclusively used with ZigBee wireless mesh networks, as evidenced by the recent cooperation with the HomePlug Alliance (ZigBee Alliance 2008b), nor does it exclude the use of other industry-standard application protocols such as DLMS or BACNet with ZigBee networks. While much work remains to be done by the ZigBee Alliance and others, a high level of cooperation with other standards and protocols ensures the seamless integration of ZigBee Smart Energy products into the smart metering and home energy management environment.

ZigBee and ZigBee Smart Energy is becoming established as the standard of choice for the HAN because;

- ZigBee chips have the computing power and the bandwidth (at 2.4GHz) to support the level of security that utilities demand for AMI and smart energy;
- ZigBee chips support over the air upgrades;
- ZigBee is an open global standard;
- Utilities and meter manufacturers want multiple competitive suppliers of components to support their projects for 20+ years and with 22 compliant platforms and 300 member companies, ZigBee clearly delivers this;
- ZigBee Smart Energy has been specifically designed for smart energy; and
- ZigBee is designed to handle interference and often coexists with e.g. WiFi.

Non Utility-based Home Energy Management

The HAN is intrinsically linked to smart metering, and usually involves communications with electric, gas, water or heat meters operated by utilities to measure the energy consumed by a given residence or building, however ZigBee and ZSE is also being used to enable home energy management independent of utility meters. Usually this involves the sub-metering of circuits, using energy sensors which are typically either clipped onto the power supply coming from the utility meter, or embedded in a “smart plug” device that is plugged into power outlets and therefore connected to any appliances that use energy.

These home energy management solutions look to provide information about energy usage for the consumer that is independent of the utility’s meter, and with more granularity in terms of which of the users appliances are using energy. Not only that, but they provide the consumer with the ability to automatically and remotely manage the on time of these appliances, effectively filling the gap while the market awaits the first truly smart appliances with built-in communications technology for measuring

and control. When these two worlds come together, the utility's HAN and the consumer's home energy management network, this can be a powerful tool for utilities and consumers alike!

How does ZigBee Smart Energy Work?

ZigBee Smart Energy is a public application profile defined on top of the ZigBee standard specification to define the application protocols, device behaviour and network configuration of a Smart Energy HAN. A number of devices are already defined in ZSE (ZigBee Alliance 2008c);

Energy Services Portal (ESP)

The ESP is a gateway provided by the utility for the sole purpose of providing information into the HAN. It may be controlling a smart appliance or providing information for an in home display. In some implementations this is a separate device, but in other cases this will be built into the electricity meter, thermostat or in-premise (in-home) display. The ESP is also the coordinator and trust centre for the HAN.

Metering Device

This is a meter (electric, gas, water, heat, etc.) that is fitted with a ZigBee device. It may be capable of being read immediately by another device, or it may autonomously send readings and other status indicators periodically.

In-Premise (In-home) Display

This device will relay energy consumption information to the user by graphical or text display. The display may or may not be interactive and of course it does not have to be a dedicated device only for this purpose. As a minimum, a display will show current usage, some usage history, pricing information and perhaps text messages from the utility. It may also be used to advise the customer about peak periods to help them plan their energy usage.

Programmable Communicating Thermostat (PCT)

A PCT is a thermostat that has the capability to control the home heating or cooling systems and can communicate using ZigBee with other devices in the HAN.

Load Control Device

This is a device that can receive demand response and load control events to manage the consumption. It will typically exist in devices such as exterior lights, heating pumps, water heaters, pool pumps or air conditioning systems.

Smart Appliance Device

These are devices that can participate in energy management activities when for instance a utility initiates a demand response event or a pricing event, or the appliance provides information about energy usage through an in-home display. These might include for example washer/dryers reporting cycle status or washers switching to using cold or hot water input depending on what is available or whether it is a peak or off-peak usage period.

Prepayment Terminal Device

This device allows utility customers or sub-metering tenants to pay for consumption in increments rather than through a periodic billing agreement. It will accept payment via credit card or code entry, can display remaining unit balances, and raise alarms when the balance approaches zero. In some cases this functionality may be included in the in-home display. Work has not yet been completed on the specification of this type of device, as it was not required for the first wave of products to be deployed by ZigBee manufacturers in the US.

Range Extender

This is a device that acts as a router in the ZigBee mesh network to enhance propagation where necessary. A range extender device does not have any other function in the HAN and does not support any Smart Energy protocols, it just supports mandatory common ZigBee clusters.

New types of devices and messages can be added to the ZigBee Smart Energy profile through a process initiated within the Smart Energy Profile Task Group, which is made up of interested ZigBee Alliance members with voting rights established through attendance on weekly conference calls and more extensive meetings approximately 3 times per year.

Security in the Smart Energy HAN

In a Smart Energy HAN there are typically numerous types of communications that could be regarded as sensitive and thus required to be secure. Apart from usage and pricing data, some control information could be turning on or off supply either in a prepayment scenario, a safety scenario (e.g. with gas meters) or if the home owner is delinquent in paying bills and is to be cut off. In a future scenario, identification information may need to be communicated from a vehicle to the electric meter so that a visiting friend's electric powered vehicle can be charged by the homeowner's supply and that usage can be billed back to the vehicle owner. It is also important for new smart metering initiatives to gain the confidence of consumers who may be sceptical or fearful of the utility controlling or monitoring their home without their permission, or of fraudulent activity by neighbours, for instance.

Energy utilities therefore recognise the need for a strong security mechanism in the Smart Energy HAN.

There are a number of layers of security in the standard ZigBee specification.

- First, ZigBee encrypts all packets sent at a network level using AES-128 bit encryption and a 128-bit Network Key, which is established by the trust centre when the network is being formed, and is rolled over periodically. Some ZigBee chips implement a hardware engine for AES-128 bit security to make the encryption/decryption process faster, more efficient to minimise latency.
- ZigBee also specifies a Trust Centre Link Key, which is used to encrypt communications with the trust centre. This is different from the network key and again is established during network formation and can be rolled.
- Application (APS) link keys are an optional feature of the ZigBee specification, but a mandatory feature of the ZigBee Smart Energy application profile. Any two nodes in a ZigBee network may request from the trust centre a link key, which they can then use to encrypt packets at an application level. Using this mechanism, two nodes can send encrypted data through the mesh network without intermediate nodes being able to read the payload.

These standard ZigBee security mechanisms are deemed appropriate for home automation applications, however for very sensitive data or vulnerable control mechanisms there are some holes in the security related to key establishment and the joining process.

In a Smart Energy HAN, a joining device associates using one of two association methods, each requiring the use of a key establishment cluster.

Joining with a Preinstalled Trust Centre Link Key

One option available to Smart Energy devices joining the HAN is to have the trust centre link key installed prior to joining, probably using some out of band programming mechanism. The device joins the network and is sent the network key encrypted with a key-transport key derived for the preinstalled trust centre link key. After the device has joined, the trust centre updates the pre-configured trust centre link key in the joining device using the key establishment cluster, and may update this key for all devices in the network later.

For Smart Energy networks, the underlying security is assumed to be ZigBee Standard security using pre-configured link keys. A temporary link key for a joining device is produced, by performing a cryptographic hash function on a random number (e.g. serial number) and a device identifier (i.e. the IEEE address / EUI64 of the device). The random number for the device is communicated to the utility via an out-of-band mechanism (maybe via a secure web site), and the utility can then commission the ESP at the premises with the temporary link key for that device using a back channel. Now that both the joining device and the ESP in the HAN has the same temporary link key, there is a secure mechanism for communicating the network key to the joining device at join time.

Certificate-based key establishment

The certificate-based key establishment (CBKE) solution uses public-key technology with digital certificates and root keys, with each device having a private key and a digital certificate, which is signed by a Certificate Authority (CA). This digital certificate includes reconstruction date for the device's public key, the device's IEEE address (EUI64) and some profile-specific information. The certificates provide a mechanism for cryptographically binding a public key to a device's identity and characteristics.

Trust is established by provisioning a digital certificate and a CA root key (public key paired with the CA's private key, used to verify the signature) for each device. Digital certificates can be issued by the device distributor, the device manufacturer, or the end customer. In the end, both the joining device and ESP/trust centre share a secret link key; both devices know with whom they share the link key; each device knows that the other device has correctly calculated the key; no device has complete control over the shared link key; compromising the public key cannot expose any future or past communication; and each shared link key is unique.

Where is ZigBee Smart Energy used?

In the US, ZigBee Smart Energy is becoming the standard for HAN communications among utilities. In California, Southern California Edison (SCE) has chosen to roll out ZigBee enabled smart meters to 5.3 million homes between 2009 and 2012 (Itron 2007), while San Diego Gas and Electric (SG&E) will replace its 2.3 million gas and electric meters with ZigBee-enabled smart meters (Itron 2008a) and Pacific Gas and Electric (PG&E) has initiated trials of ZigBee-enabled meters with a view to doing the same. In Texas a similar trend is emerging, with Oncor planning to deploy 7 million ZigBee-enabled meters (Korzeniowski 2008), Centrepont plans to trial ZSE with 250,000 homes (Itron 2008c) and TXU and Reliant energy both planning to roll out ZSE products to their customers. Elsewhere in the US, Detroit Edison plans to roll out 2.9 million electric and 700,000 gas meters using ZSE starting in 2009 (Itron 2008b) and in Virginia, Dominion is putting out a 200,000 home trial of ZSE. Utilipoint estimates about one third of meters ordered from 2008 will be ZigBee-enabled (Harper-Slaboszewicz 2007).

In Australia, the state of Victoria has specified ZSE for use in HAN communications for its smart meters (Department of Primary Industries 2007) to be rolled out starting in 2009 and New South Wales looks like following suit.

In many places in Europe and Asia, focus has not been on the HAN, rather on AMR (Automatic Meter Reading) and AMM (Automatic Meter Management), which involves communications between the meter in the home and the metering system of the utility. Traditionally in Europe, power line communications (PLC) and sub-1GH radio technologies have been preferred for these backhaul networks for what is becoming called the Neighbourhood Area Network (NAN) or "Last Mile Communications", the link between the utility's wide area network (WAN) and the home. Despite the disadvantage (on paper at least) of 2.4GHz radio communications, and perhaps because of its mesh networking capabilities, ZigBee is being considered and used more and more frequently for this type of network as well as for the HAN, especially where the network involves gas meters, which require low power radio communications. For this application, ZigBee can be found already in Gothenburg, Sweden, where a rollout of 270,000 meters is in progress (Arnewid 2008), and is being trialled in Spain and being considered in Italy, France and UK.

In some of these European cases, a natural extension of the NAN to the HAN is being considered, but the UK is one of the few markets in Europe where the HAN is a key component of smart metering. The Energy Retail Association in the UK, representing the 6 largest UK utilities, has just completed its initial investigation into technologies to be used for the HAN (Energy Retail Association 2008), and while at the time of writing the final report was not available (due to be completed at the end of October 2008), and is not intended to deliver a final decision on choice of technology, it could be argued that ZigBee and ZigBee Smart Energy are strong contenders to be chosen for use in UK HAN communications.

Extending ZigBee Smart Energy

ZigBee is an open global wireless mesh networking standard for monitoring and control, supported by almost 300 member companies and 22 certified platforms, with a group of Promoters (ZigBee Board members) that includes two of the worlds largest meter manufacturers, Itron and Landis+Gyr, along with a number of wireless semiconductor manufacturers such as Ember, ST Micro, TI and Freescale. ZigBee Smart Energy provides two things to the HAN; a robust, wireless, mesh network standard to carry HAN communications securely; and a standard messaging protocol

for interoperable communications with smart meters and other home energy management devices.

It is clear that no one standard can hope to provide everything that is needed for 100% of all HANs, either with regard to communications or protocols.

In the US, requirements for ZigBee and HomePlug to operate together are echoed somewhat in Europe with a wish to use DLMS with ZigBee. The ZigBee Alliance, utilities and the HomePlug Alliance have started discussions that will create a smart energy standard for wired communications to compliment the ZSE wireless standard (ZigBee Alliance 2008b) and the ZigBee Alliance has recently reached out to the DLMS user association in Europe, seeking to standardise how DLMS messages could be transported over ZigBee.

Extending the HAN

Currently the devices envisioned by ZigBee Smart Energy and the utility HAN tend to be related somehow to the utility meter. The home automation and monitoring market is also growing with the growth of wireless applications in home security, fire and safety and also energy management. In particular, the monitoring, metering and control of “smart-plug” devices in the home has become a growing business which is somewhat independent of utility-driven smart metering projects.

Wireless mesh networking standards like ZigBee and ZigBee Smart Energy have the capability to bridge the gap between home automation and smart metering, with scalable, flexible, secure networking capabilities. In the not so distant future, the consumer will be able to get overall energy consumption and pricing information from smart meters in the home, while getting a breakdown of how that energy is consumed from the smart appliances and/or smart plugs that appliances are plugged into, and after analysis, will be able to manage and schedule how these appliances are used to minimise energy consumption and ensure that the home is using energy in the most cost effective and energy efficient way. Today, many ZigBee home automation, smart energy and home energy management applications exist in the market. The ZigBee Alliance and ZigBee product manufacturers are working to bring these applications together with interoperable protocols to ensure that the consumer can maximise the information available in the HAN and make use of the connectivity between devices in the home.

Summary

The demand for energy has risen in all markets around the World, while pressure comes on us to reduce usage and manage our limited energy resources. Home energy management is an important mechanism for obtaining energy efficiencies and reduced energy consumption, which is essential if we are to achieve our carbon emissions targets while managing peak demand with existing resources.

The Home Area Network (HAN) is an important element of home energy management, providing the secure, robust networking required to carry information and commands between devices in the home, including smart utility meters, in-home displays and smart appliances.

ZigBee and the ZigBee Smart Energy application profile are becoming established as a well supported, secure, robust open global standard for HAN communications, one which is being adopted in the US, Australia, and it seems, soon in parts of Europe.

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