WHITE
PAPER

The Home Area Network: Architectural Considerations for Rapid Innovation

Deciding whether to locate the HAN gateway in the meter or in a separate device has important long-term implications

Introduction

Two recent reports published by ON World, a research firm providing business intelligence on smart technology markets, predict that 100 million smart meters will be deployed in the next five years and that half of these will have a built-in Home-Area Network (HAN) gateway for in-home energy management programs and services. ON World's survey of 77 utilities in the United States also found that 21% are planning to integrate a HAN gateway into every smart meter deployed.[1]

The question addressed in this white paper is whether or not this integration of the HAN gateway function into the smart meter is a smart architecture for the Smart Grid? Before examining the architectural alternatives for the HAN gateway, some background information is provided in the next two sections on The HAN's Value in the Smart Grid and HAN Architectures in Existing Standards. The two viable HAN gateway architectures (integration into the smart meter and the dedicated in-home gateway device) are then evaluated in detail using four criteria. A brief conclusion summarizes the discussion.

Note that the exclusive focus of this white paper is the residential customer. Businesses, universities, government agencies and other large commercial and industrial organizations also have a need for networking to implement demand response or demand-side management (DSM) programs. Many of the same technologies are likely to be employed in both residential and commercial and industrial applications. However, home networking poses different financial considerations compared to commercial and industrial customers owing to the sheer number of homes involved. In aggregate, home-based energy efficiency programs have the potential to materially reduce overall load requirements so the cost/benefit analysis must factor in both total savings and the summation of per-home costs. And this cost sensitivity applies whether the consumer or the utility pays for the home-based DSM equipment required.

In addition, it is important to note that the term "home-area network" is also used with home-based multimedia applications that integrate voice, video and data communications to support media centers for viewing television and movies, voice over IP (VoIP), broadband Internet access and other forms of entertainment. It is possible there may be some convergence between the two different HANs someday, but they are expected to coexist as separate networks for the foreseeable future. This paper focuses exclusively on the HAN as used for demand-side management applications.

The HAN's Value in the Smart Grid

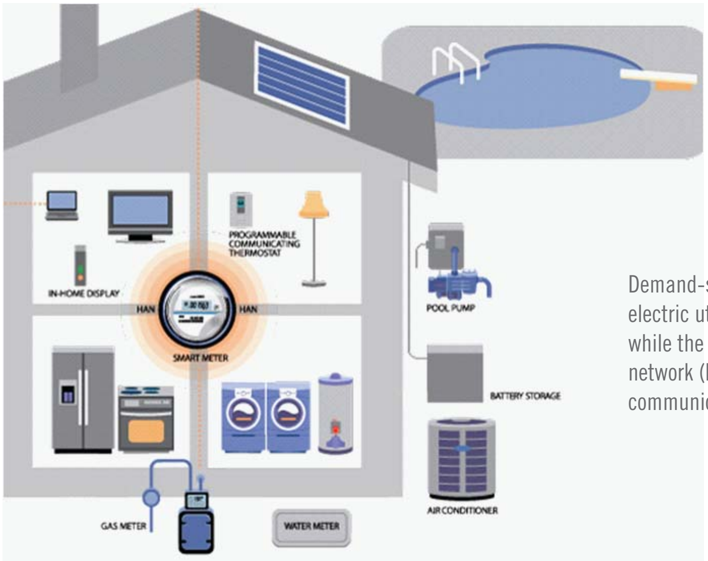
Energy efficiency, demand response, and direct load control are key components in realizing value in a Smart Grid deployment. Behavioral energy efficiency utilizing real-time meter data, technology-enabled dynamic pricing, and deterministic direct load control are examples of demand-side management applications that are enabled by high bandwidth, two-way, end-to-end communications in the Smart Grid. A Smart Grid that incorporates energy efficiency and demand response increases its value as a long-term infrastructure investment and reduces the time required to achieve a satisfactory return on investment in the short-term.

The HAN is a subsystem within the Smart Grid dedicated to demand-side management (DSM), including energy efficiency and demand response. A number of HAN aspects influence the Smart Grid infrastructure:

- Pace of technology innovation – Emerging standards, such as the ZigBee Smart Energy Profile and UtilityAMI's OpenHAN, are rapidly evolving along with the demand-

1 www.onworld.com/html/newssmartmeter.htm

The Home Area Network



Demand-side management for the home holds significant promise for electric utilities. The HAN communicates among devices in the home while the HAN gateway communicates with the neighborhood-area network (NAN). Meters communicate via the NAN but may or may not communicate with the HAN (the subject of this white paper).

side management applications that leverage these standards.

- Upgradability – Although consumer devices, such as in-home displays and programmable communicating thermostats, deliver demand-side benefits immediately, making them upgradeable over time requires increasing firmware and hardware resources.
- Consumer choice – Choice is a critical component in consumer adoption, and choice requires simultaneous sustained product innovation and attentiveness to existing technologies.
- Device ownership – The increasing variety of products and product types resulting from technology innovation that leverages Smart Grid communication capabilities are redefining the relationship between consumers and utilities.
- Market diversity – Fueled by product innovation, consumers and utilities are facing a mix of retail, direct-to-consumer and services markets that influence and are influenced by device ownership aspects of the HAN.
- Interoperability – The ability of devices and systems to work together is critical for the applications that deliver value to consumers, utilities, retail energy providers, load aggregators, and other stakeholders.
- Total cost – A variety of cost models may apply depending on the HAN gateway architecture chosen, and the Smart Grid business case must account for this.
- Performance – System level performance of applications can be hindered or enhanced by different architectures. This makes it vitally important to assess the risks, objectives, and current state-of-the-art in technology for the Smart Grid.

HAN Architectures in Existing Standards

The ZigBee Smart Energy Profile is an emerging standard to "define device descriptions and standard practices for Demand Response and Load Management 'Smart Energy' applications needed in a Smart Energy based residential or light commercial environment."[2] The Smart Energy Profile (SEP) provides suitable core demand-side management functionality to satisfy many of the needs of utility programs for energy efficiency, demand response, and direct load control. Two versions of the SEP have been released and a third is being drafted:

- Version 1.0 provides a core set of functions that smart energy devices may need, such as programmable communicating thermostats, in-home displays, and direct load controllers. It also specifies the ZigBee 2007 radio communications stack.
- Version 1.5 introduces incremental improvements and functionality for demand-side management, such as additional tariff support for inverted tier rates.
- Version 2.0 will unite efforts by the ZigBee Alliance and the HomePlug Power Alliance and introduce significant radio communications changes, including a transition to an IPv6 stack. For this reason, when version 2.0 is available, it will not be backwards-compatible with either version 1.0 or version 1.5.

2 ZigBee Smart Energy Profile Specification r14, May 29, 2008

The rapid evolution of the underlying HAN radio communications protocols, as well as the HAN applications they support, introduces a need for a system architecture that can evolve with HAN technology. The SEP addresses this need with a device called the Energy Service Portal that "connects the energy supply company communication network to the metering and energy management devices within the home. It routes message to and from the relevant end points. It may be installed within a meter, thermostat, or in-premise display, or may be a standalone device, and it will contain another non-ZigBee communication module."[3] A gateway for connecting different networks is a proven approach and is particularly appropriate for handling rapidly evolving networking technology.

An Energy Service Portal device that connects to both the HAN and the neighborhood-area network (NAN) corresponds to the UtilityAMI OpenHAN Energy Services Interface. In the OpenHAN emerging standard, the Energy Services Interface (ESI) connects the NAN and HAN in a manner that provides a secure, interactive interface, as well as a public broadcast interface for non-interactive information transfer into the HAN. The OpenHAN architecture recommendations state: "the ESI requirements specified in the OpenHAN SRS do not presuppose an architecture in which the interface resides solely within the AMI meter or is owned solely by a distribution Utility. Pricing information, control signals, and messaging may be provided from a third party entity such as a Retail Energy Provider or Demand Response Aggregator. In this model, the AMI meter would continue to provide premise consumption information (e.g., real-time metrology) and would still be part of the HAN."[4]

Alternative HAN Gateway Architectures

"Gateway" is a term employed in the networking industry to describe the means for interfacing two dissimilar networks. The term "HAN gateway" refers specifically here to the function that interfaces the HAN with the NAN, which interconnects meters together. The term "HAN Gateway" can also apply to the physical device dedicated to performing this function. Both ZigBee and OpenHAN recognize the need to support the HAN gateway function, but do not make specific recommendations for where this function should reside, leaving that choice to the utility implementing a Smart Grid for residential DSM applications.

There are really only two viable choices for the utility: should the HAN gateway be integrated into the smart meter that communicates with the NAN, or should the HAN gateway function reside in the home in some other device? The utility may or may not care about the specific in-home device employed, but will certainly care about its effect on the Smart Grid business case.

HAN Integration in the Smart Meter. One obvious way to ensure end-to-end, two-way communications between the utility and the residential subscriber is to have the smart meter become a node on the HAN. In this architecture, referred to here as the Meter Portal, the meter would contain separate NAN and HAN radios—both "under the glass"—with the HAN gateway function interfacing the two. This Meter Portal architecture is well-suited for homogenous and ubiquitous mass deployment of stable HAN technology. The major advantage of this design is that it enables the utility to control exactly how the HAN interfaces with the NAN, the latter being the network used to communicate with all smart meters. A closer examination of the architecture, however, reveals a number of disadvantages that could have adverse implications for the utility.

Separate HAN Gateway or HAN Device Portal. This architecture involves locating the HAN gateway function in the home in a designated device, potentially a standalone unit devoted exclusively to this important function. This design does not require a separate dedicated device if the HAN gateway function is integrated into a required device, such as a programmable thermostat or in-home display. Whether dedicated or integrated, the in-home device would need to contain separate NAN and HAN radios just as with the Meter Portal. This architecture, referred to here as the HAN Device Portal, has numerous advantages and offers a flexible, incrementally-deployable solution that is well-suited to supporting a heterogeneous set of evolving HAN technologies, while continuing to afford the utility control over communications with the NAN.

Note that both the Meter Portal and HAN Device Portal architectures provide equitable access across the utility's service area, meaning that HAN-based applications can reach everyone with a smart meter. The difference, though, is that a HAN gateway must be installed with every smart meter in the Meter Portal architecture while the HAN gateway can be deployed either at the time of the smart meter installation or at another date in the future.

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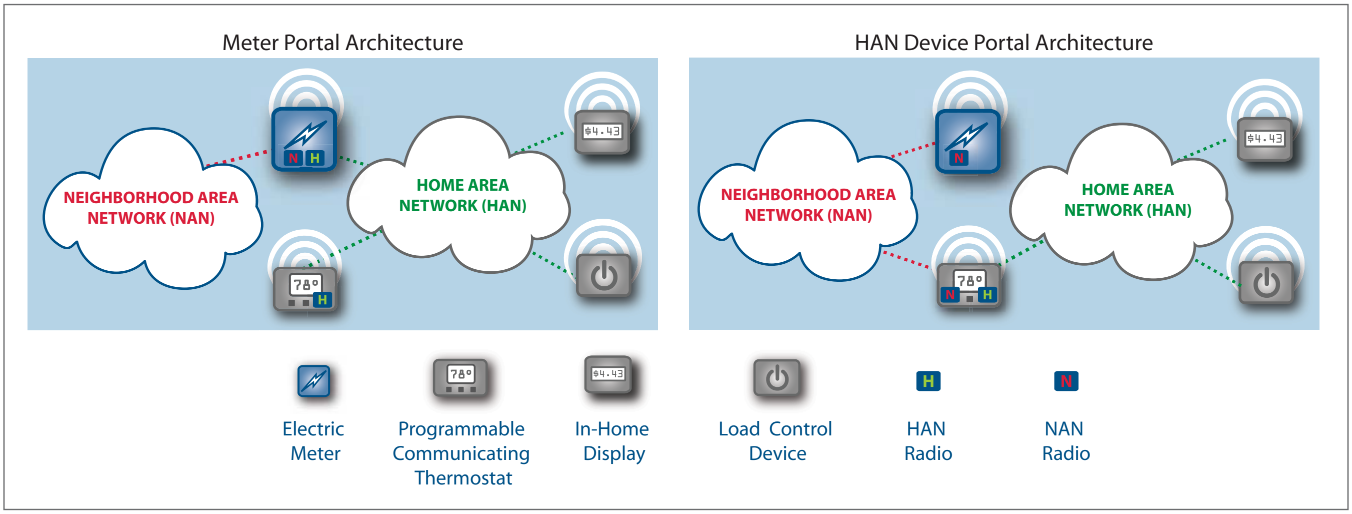
3 ZigBee Smart Energy Profile Specification r14, May 29, 2008

4 UtilityAMI 2008 Home Area Network System Requirements Specification

The Home Area Network



Comparing the Architectures

While numerous criteria are often invoked for making architectural comparisons, these four are of particular importance in residential demand-side management applications:

- Cost Implications
- Communications Capability
- Support for Market Innovation
- Risk Mitigation

This section compares and contrasts the two HAN gateway alternative architectures using these four criteria.

Cost Implications

In both architectures, the minimum number of radios needed to interface the HAN with the NAN is three: two in the meter (NAN and HAN) and one in a home device (HAN) for the Meter Portal; or one in meter (NAN) and two in the home device (HAN and NAN) for the HAN Device Portal. With a prudent choice of radio technology for both the NAN and the HAN, the cost for all three radios is comparable. Using the same basic radio technology, such as IEEE 802.15.4, also has the potential for significant cost reductions through volume deployments. And choosing a popular standard, again like IEEE 802.15.4, has the additional advantage of benefiting from even greater economies of scale as these technologies become more widespread globally for other applications.

A major advantage of the HAN Device Portal architecture is that it permits an incremental, pay-as-you-go approach to implementing demand-side management programs for residential customers, even when deployment is expected to be universal over the long term. The cost for initial trials or pilots remains low, while the approach continues to present the opportunity for cost minimization through volume during full-scale deployment. Initially, the HAN Device Portal is deployed only to those consumers opting into the energy efficiency or DSM program, such as demand response or direct load control. Depending on the utility's specific program, the HAN gateway function can be implemented in some device already required, such an in-home display, programmable communicating thermostat or direct load controller. This pay-as-you-go approach is unlike the Meter Portal architecture, where the business case cost-effectiveness is biased toward full deployment to every consumer independently of actual participation in any program.

Although HAN technologies are optimized for low cost, the sheer number of homes involved with relatively few participating in demand side management initially favors deploying the HAN gateway function in a dedicated consumer device. In fact, the percentage of homes actually utilizing a meter's integral HAN gateway may be quite small for many years. ON World, the firm predicting that half of the 100 million smart meters being deployed in the next five years will have integral HAN capabilities, also predicts there will be only 20 million HAN-enabled households worldwide by the end of 2013.[5] An extrapolation of these data reveals there could be upwards of 30 million smart meters with their built-in HAN capabilities going unused for an extended period. By incurring the cost of the HAN gateway only for

5 www.onworld.com/html/newshan.htm

those customers participating, as with the HAN Device Portal, the utility stands to achieve a far better return on investment (ROI) both initially and over time.

Communications Capability

The HAN Device Portal architecture affords superior communications capabilities based on the differences in fundamental operational characteristics for neighborhood-area and home-area networks. NANs are designed to operate over greater distances in outdoor environments, whereas HANs are designed to operate at a much shorter range indoors. Indeed, the basic IEEE 802.15.4 framework for HANs conceives a 10 meter (33 foot) communications area, and ZigBee communications utilize transmit powers ranging from a relatively low 1 mW to 100 mW. The shorter range is not a limitation in the HAN, and this intentional characteristic affords the additional benefits of conserving power consumption and keeping costs low, which are both appropriate in large-scale energy management applications.

Given the fundamental differences in operational characteristics of NANs and HANs, the HAN Device Portal, with its built-in NAN, enjoys a distinct advantage because it can more readily communicate over a considerable distance with the outdoor NAN. For the outdoor Meter Portal to communicate effectively with the indoor HAN, however, it is necessary to overcome some inevitable challenges. For example, consider just these three common scenarios: the rural home, where the meter may be hundreds of feet from the house; the high-rise multi-tenant unit, where the meters are in the basement; and the suburban neighborhood, where meters may be located behind reinforced concrete walls or other obstacles to make them less obtrusive. With its built-in NAN radio, the HAN Device Portal is capable of providing the long-range communications required in all three scenarios. For the Meter Portal to overcome the RF signal loss caused by the distances and/or attenuation involved in each scenario, additional equipment, such as a HAN repeater, may be required, which increases design complexity and cost.

Indeed, if the meter is unable to communicate effectively and consistently with the HAN, the very purpose of the energy efficiency or DSM application is undermined. A viable Smart Grid architecture must include, at a minimum, a dependable method for communicating alerts and information to all consumers, including notifications that their HAN network is not operating properly. These problems are readily avoided with the HAN Device Portal architecture, which provides reliable messaging through its direct communications with the outdoor NAN.

Support for Market Innovation

The market for home-area networks involves a growing variety of applications and vendor solutions. This market is also global and affords tremendous opportunity for

Utility Smart Network Access Port

The Utility Smart Network Access Port (U-SNAP) was conceived in 2007 when the California Energy Commission (CEC) was considering the concept of programmable communicating thermostats (PCTs) as part of its Title 24 energy efficiency program. PCTs were deemed to be necessary for a statewide demand response application controlled by the CEC through a Radio Data System (RDS) installed in every PCT.

The idea is simple and market-proven: rather than force manufacturers to build separate devices for different communications protocols, why not offer a standardized circuit card that can be "plugged" or "snapped" into any HAN device? That way, each basic device, such as a PCT, in-home display, load controller, and appliance, can be offered in multiple markets that utilize different HAN technologies.

The U-SNAP specification defines the hardware interface, physical dimensions, data transfer, message contents and protocol(s) for the HAN devices. The root of the specification relies on the Serial Peripheral Interface (SPI) port found on most communication chips as the basic transport layer. The card itself is only 1.5 inches (3.8 cm) square, making it small enough to fit into virtually any energy-consuming product. U-SNAP cards are already available through traditional channels supporting ZigBee, Z-Wave, RDS, Wi-Fi and FlexNet. Future versions are expected for Bluetooth, HomePlug, LonWorks and 6LoWPAN.

The compact and inexpensive U-SNAP module is installed during the manufacturing process and can be changed in the field by the consumer. Utilities can, therefore, continue deployment of their smart meters using their NAN of choice, knowing that HAN devices will be compatible today, tomorrow and well into the future. Utilities will enjoy cost-saving flexibility, while consumers will benefit from standardized products available from multiple suppliers, including traditional retail and do-it-yourself channels.

Additional information about U-SNAP is available from the U-SNAP Alliance on the Web at www.usnap.org.

innovation, and utilities will want to be in a position to leverage this innovation as much as possible. Consumers (and utilities) have a choice of home networks, including (in alphabetical order): 6LoWPAN, FlexNet, HomePlug, LonWorks, Radio Data System (RDS), Wi-Fi, Z-Wave and ZigBee.

The choices now available for both home networking and power supply combine to have an impact on the choice of HAN gateway architecture. Residential consumers are increasingly given a choice of power sources, and these retail suppliers of electricity may have their own demand-side management programs, complete with a recommended or required HAN solution. The permutations and combinations of supplier and technology choices have the potential to create an unwieldy situation in some markets. Home energy management devices, many of which use Z-Wave, are now available through retail channels, and some customers are deploying these in advance of any DSM program from their local utility.

This market dynamic creates a distinct advantage for the HAN Device Portal architecture. This advantage derives from the modular design possible in a consumer device. Such modularity is beneficial during the design and manufacturing stages, and can also be extended to the retail environment or even into the home with special plug-in modules, such as those conforming to the Utility Smart Network Access Port (see sidebar). By having a modular design, HAN Device Portals can be upgraded, replaced, reconfigured or otherwise changed as needed—by either the manufacturer or the consumer, or both—to take full advantage of advances or changes in technology at any time. A U-SNAP module could be used in the meter, of course, but because the radio is under the glass, the only way to support different HANs would be to deploy different versions of the meter. In addition, any changes to the HAN technology would require field replacement of the meter in a Meter Portal architecture.

Risk Mitigation

Any utility enjoys full freedom over the choices for its private neighborhood-area network and private wide-area network (WAN). While these choices are critically important, they remain under the utility's full control. The home-area network is a different matter, however, because the destiny of HAN technologies (both current and future) will be determined by the market in the aggregate.

The most significant disadvantage of the Meter Portal architecture is, therefore, the potential for obsolescence

Meter Portal	HAN Device Portal
Every meter burdened with HAN costs regardless of DSM adoption rate and timing ("all-of-nothing")	Meters not burdened with HAN costs; HAN costs incurred with DSM deployment ("pay-as-you-go")
In-home HAN devices must be located close to the meter for connectivity	In-home HAN devices and meter can be considerably far apart
HAN changes or upgrade limited by "under-the-glass"/non-removable hardware	HAN changes or upgrade performed in the field as market/technology evolves
Potential obsolescence of embedded "under-the-glass" technology	No risk of costly "forklift" (with truck roll) upgrade

of the embedded HAN technology. HAN standards and technologies are constantly evolving, and over the lifetime of a meter (measured in decades) the integrated HAN gateway is certain to require upgrades and/or changes. If the design permits these changes via the network (which also increases the meter's cost, perhaps significantly), then the exposure is minimal. But at some point, the design's potential for change may be exceeded. In this situation, the utility has two choices: either replace/upgrade the meter itself (with a truck role) or continue to support the original (now legacy) HAN technology with a special New-HAN-to-Old-HAN gateway in the residence (in a HAN Device Portal!).

The HAN Device Portal architecture, by contrast, can be implemented in such a way that immunizes it against change. With a design that has the radio modules embedded, the device can be replaced at a relatively low cost and without a truck roll. A better design is one with a user-replaceable U-SNAP HAN module. The idea of a replaceable radio module is field-proven with previous technologies, such as Wi-Fi® and Bluetooth®, and allows for more cost-effective evolution to a fully embedded design at a time when the technology becomes sufficiently mature and ubiquitous.

The HAN Device Portal architecture implemented with a user-replaceable HAN radio module mitigates risk from changes in both standards and technology. The ZigBee Smart Energy Profile utilizes an IEEE 802.15.4 standard chipset and presumes that the HAN will evolve around a single homogenous protocol. Which means some or even most changes may not require replacing the module at all, but changing the firmware instead. With the right design, firmware can be upgraded via the network, although the upgradeability of an IEEE 802.15.4 chipset for HAN connectivity is ultimately constrained by the physical memory capacity. Techniques for firmware code size reduction and careful design are likely to allow several generations of HAN evolution in a state-of-the-art chipset before replacement is warranted. It is important to note, however, that HAN technology has and will continue to evolve on a cycle measured in months to years, which is significantly shorter than the anticipated meter lifetime measured in decades.

The HAN Device Portal architecture also lends itself to integration with other networks in the home, including Wi-Fi, dial-up modems, DSL, cable and the "other" HAN for multimedia communications. No one can predict with certainty what home networking and home automation will be like 10 or 20 years from now. In fact, the very flexibility and potential of a design based on an extensible HAN Device Portal may provide the additional incentive some customers need to take the plunge into the 21st century of home management.

This side-by-side comparison summarizes why the in-home HAN Device Portal enjoys a clear architectural advantage over the Meter Portal. The HAN Device Portal affords more flexibility and U-SNAP modules afford additional flexibility by enabling upgrades, replacements, or other changes as needed.

Conclusion

The versatility and extensibility of the HAN Device Portal architecture makes it a superior choice over the Meter Portal architecture in virtually any energy efficiency and demand side management application. Less risk. More market-friendly. Better communications. And lower overall costs, both short- and long-term. Only the HAN Device Portal can scale cost-effectively to mass deployment, while accommodating rapidly evolving HAN standards and technology without expensive "forklift" upgrades, yielding a shorter/higher return on investment and greater value of the investment over time.

Simply put: The HAN Device Portal is the safe choice—one that preserves all of the upside potential of the Smart Grid, while incurring little or no downside exposure. By accommodating the uncertainty that pervades the emerging (and rapidly evolving) home-area networking arena, only the HAN Device Portal architecture provides the attributes that are both necessary and sufficient for a successful residential demand-side management program.

The user-replaceable U-SNAP module shown here measures only 1.5 inches (3.8 cm) square. The plastic enclosure protects the circuitry while providing convenient access from the exterior of the device. A HAN Device Portal designed to use plug-in U-SNAP modules offers the consumer greater flexibility while offering the utility a future-proof approach to the HAN.

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