ELECTRIC POWER RESEARCH INSTITUTE

IP-Addressable Smart Appliances for Demand Response Applications

Legislation and environmental concerns are making traditional generation capacity more difficult to bring online. Faced with this difficulty, and rising demand, utilities are increasingly interested in demand-side management.

The residential sector, while more challenging to control because of the sheer number of devices, cannot be ignored due to its significant on-peak contribution. Connecting household appliances, including HVAC and water heaters, to the utility with a communication system is a necessity if these loads are to be made to respond in real-time to the varying supply of energy.

Many technologies and system architectures have been considered for these communication systems. Some, particularly one-way devices, have been in use for 20 to 30 years. The communication protocols involved are as numerous as the technologies themselves. Some are proprietary, kept by a vendor whose strategy involves both ends of the communication chain while others are open and standardized.

This technical brief considers the internet protocol as it might apply to connecting residential appliances. System architectures for reaching the devices are discussed, and network types that are IP compatible are described. A sample list of companies who purported to have internet protocol appliances is also tabulated.

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Introduction to Smart Appliances

The term "smart appliance" has been used to refer to those with embedded microprocessors and the advanced functionality that processors bring. Often, the intelligence of a smart appliance is accompanied by the ability to communicate with other devices both inside and outside the home. Such devices have also been called "networked appliances." This paper researches the state of the industry regarding smart, networked appliances, and in particular the potential for using the internet protocol to accomplish this networking.

During the internet (or dot-com) bubble of the late 1990s and early 2000s, the idea of a smart home filled with networked appliances was popular and appliance manufacturers showcased many proof-of-concept devices. These appliances attempted to bring homeowners added value by offering new and extended functionality.

TMIO, LLC introduced what was called "the world's first internet oven" in 1996. This device could be fully controlled from remote locations. It evolved over time and in its maturity could refrigerate food throughout the day, cook, and then maintain serving temperature until the family arrived home for dinner. It could follow voice prompts via telephone, or be controlled over the internet by a simple graphical user interface that duplicated the actual oven controls.

At least six different companies have offered internet connected microwave ovens. As if the microwave itself had not made things convenient enough, these devices allowed recipes to be downloaded from the internet and could communicate with the user audibly to determine proper power levels and cooking times.

The refrigerator was probably the most common networked appliance, with at least ten models introduced in the 1998 to 2002 timeframe. At Home Tech 2002 in Berlin, Germany, LG electronics released their Internet DIOS refrigerator to the European market. This device had a complete pen-based computer with a 15" monitor in the door. It allowed internet browsing and TV viewing, and took digital still images inside the refrigerator for checking stock remotely.

After several years of trying, however, a market for these products had not materialized. A microwave's customer-perceived value was limited to its ability to cook food and a refrigerator to its ability to chill. For the masses, talking appliances were found more annoying than convenient, like automated voice answering services. High-tech additions didn't generate enough customer-interest to justify the price tag and these products spent more time on tradeshow floors than on department store shelves. In the words of one manufacturer who struggled through this time, "homemakers would rather curl up in a chair with a good cookbook than stand at a terminal in front of their refrigerator."

Continuing forward, some appliance manufacturers began to emphasize that "smart" in the context of an appliance, does not mean that it communicates, but that it does its job intelligently. Panasonic, having once commercialized networked refrigerators, washing machines, microwaves, and air conditioners, now reports having stopped that business altogether. The internet connected appliances of this early period may have been smart in many ways, but energy consumption appears to have been low on the priority list and demand response not considered at all.

The Value Proposition for Networked Appliances – Reduced Electricity Bills

Several appliance manufacturers interviewed during this research used the phrase "no killer-app" in describing the situation earlier in the decade. They didn't find a compelling application for smart appliances or an application that would motivate the masses to pay even a little more for all the high-tech features. Now, only a few years later, it appears that a compelling application has been found: reducing electricity bills.

Through demand side management (DSM) programs, electric utilities are creating incentive for networked appliances. The appliances of interest during the internet bubble were those in front of which people spent the most time, and the goals of the added intelligence were front-side features. This made sense, given the vision of enticing buyers with futuristic capabilities. But when the vision becomes managing peak energy consumption, the appliances of interest shift to those

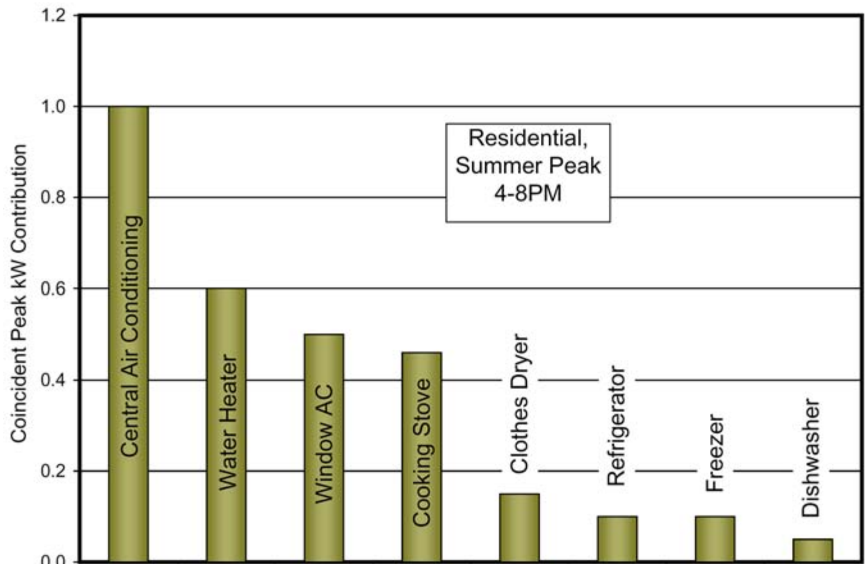

Figure 1. Top Residential Coincident Peak Contributors

that consume the most peak energy as listed in Figure 1,[1] and the functionality can be largely transparent.

The business case for energy-smart appliances, from the home owner's point of view, is simple. You pay a little more upfront for an energy-smart or demand-responsive appliance, enroll in a utility program, and receive a reduced electricity bill. In some programs, utilities communicate time-differentiated energy prices and smart-appliance owners save money because the appliances minimize consumption when prices are high. In other programs, utilities communicate direct load control signals, and owners save money by receiving a fixed credit on their monthly bill.

For example, Great Lakes Energy offers $6.00 per month, 12 months a year, for direct control of a 50 gallon water heater.[2] Over a 10 year product life that is $720 in incentives, double the cost of many water heaters. Compared to early smart-appliances, where the perceived value of new features didn't support their cost, energy smart appliances make clear sense. The success in the marketplace of compact fluorescent bulbs, which cost many times that of their incandescent equivalents, is an example of how consumers can learn to consider total cost of ownership when buying appliances.

The shift in industry interest toward energy smart appliances is evident in both the types of appliances offered and the organizations involved in the work. In Japan, where much innovation in the smart appliance area has originated, an organization called the ECHONET Forum[3] was

1 Data from Table 1, Eustice, Horst, and Hammerstrom, Appliance Interface for Grid Responses, Grid-Interop Forum 2007

2 http://www.gtlakes.com/waterheaterload.aspx

3 http://www.echonet.gr.jp/english/1_echo/index.htm

formed to study and promote appliance networking specifically for energy-oriented applications. ECHONET stands for Energy Conservation HOme NETwork and was formed in 1998.

Overview of Demand Response

Demand response, in a broad sense, is a system that enables a utility to influence the load as opposed to simply letting it run wild and serving its requirements. Demand response programs take on many forms. The example above from Great Lakes Energy is a direct load control program. In these programs, incentives are often flat (independent of load-shed operations) or calculated on a per-event basis. With direct load control, bill settlement depends on verification of participation. Verification is difficult when one-way communication systems are used to deliver events to the loads. Statistical verification through random polling is sometimes used when two-way acknowledgement is not possible.

An alternative and, in many ways, preferred approach to load management is for the utility to communicate time-differentiated energy prices to the premises and allow the devices there to independently determine when and how to manage consumption. In this way, provision is made for consumer choice, either through a user interface on the end device, an energy management console, or a remote web portal. Settlement is simpler using this approach, because measurement and verification is replaced with common time-of-use or interval metering.

Today's evolving energy markets require multiple demand response technologies that can achieve different load shaping and load shifting objectives. Successfully employed technologies accomplish this by automating processes in the home, and by teaching new, energy-aware, behavior. Utilities and energy service providers need systems that aggregate load resources and integrate their management with system operations.

Demand response is recognized as a vital resource to ensure reasonable wholesale market prices and reliable grid operations.[4] Advances in semiconductors, communications, and end-use technologies are providing a growing array of options for keeping up with the changing market. This new capability allows for the design of customer-centric demand response programs that can redefine the way customers interact with their energy providers to benefit both parties. New demand response programs will provide flexibility, choice, and accountability on both sides of the meter.

History of Demand Response

Rapidly rising energy costs in the 1970's and associated regulatory changes provided utilities and their customers with an incentive to conserve energy and reduce peak demands. Utilities implemented ad-hoc direct load control (DLC) programs to address immediate and pressing needs. In the 1980's, utilities took a more structured approach and grouped DLC and energy efficiency programs that required customer participation into an area called Demand Side Management (DSM). With deregulation, DSM received little funding and attention and many programs were pushed to the sidelines. As the end of first decade of the 21st century approaches, the industry is coming back to the environment of the 1970's where the incentive to conserve energy and

4 http://www.ferc.gov/legal/staff-reports/12-08-demand-response.pdf

reduce peak demand is high. This time, more enabling technologies are available to utilities and customers.

Getting Connected

Although demand responsiveness is providing a value proposition for smart appliances that is more plausible than the superfluous features of the internet bubble, other challenges remain unchanged. One of the most significant challenges is establishing connectivity from the utility to end devices. The most common communication architecture currently employed for demand-side management is direct wide-area communication using either wireless (FM, VHF, pager) or power-line carrier communications. This architecture works well for broadcast messaging where large groups of devices are informed simultaneously of a common price or event message. However, many of these technologies communicate effectively only one-way and cannot perform verification of the load response on a per-device or per-event basis. Though attractive because they exist and work today, none of the direct wide-area communication systems identified were found to be based on internet protocol[5] and so all fell outside the scope of this investigation.

As an alternative to directly communicating with each appliance, the home automation market has long favored a separate network within the premises that can, as an option, communicate outside the home through a variety of interface or gateway devices. X.10, Z-Wave, and Insteon systems are examples of such traditional networks.

As utilities have studied connecting to devices within homes, the model of a separate home network has been favored by some. This approach provides a simpler way for devices within the premise to exchange data with one another. For example, an in-home display might read consumption data from a meter, then share this same information with another appliance. In addition, communication devices for a home area network can be designed to consume less power and utilize spectrum less efficiently as a result of their limited range. The UCA International Users Group released a system requirements specification for home-area networks in August, 2008 that describes multiple architectures and use cases for separate home networks.[6] Given the utility industry's potential interest in a home network that is separate from the network outside the home, it is appropriate to discuss each separately. Decisions about the network outside the home can influence the case for IP inside the home.

Reaching the Home Via Internet

One method for utilities to reach home networks is to share existing internet infrastructure as shown in Figure 2. This is simplest when the homeowner independently subscribes to an internet service and is responsible for the internet interface equipment and local network management. A less common approach to this same architecture is for the utility to provide and own the necessary broadband equipment.

5 Some commercial and industrial solutions used GPRS modems

6 UtilityAMI 2008 Home Area Network System Requirements Specification, Version 1.04, UCA International Users Group, August 19,2008

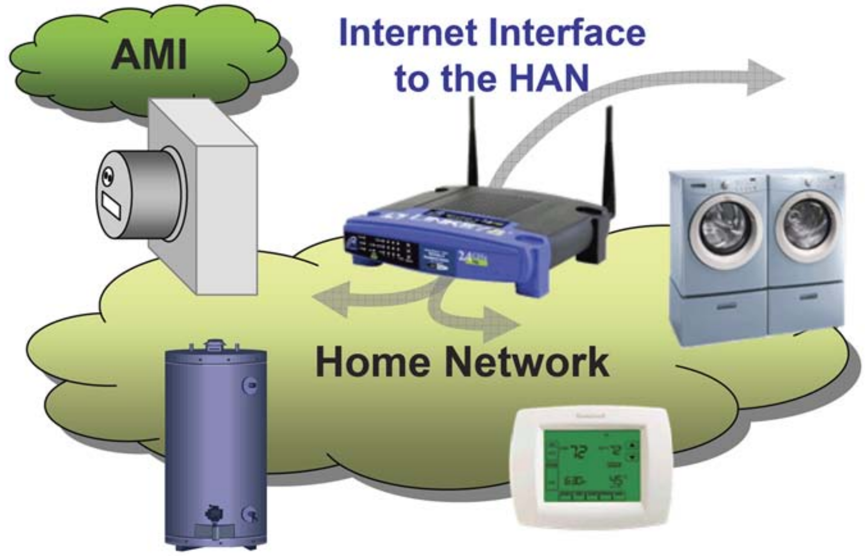

Figure 2. Reaching the Home Via Internet

In mid 2000, when smart home advocates were promoting interconnecting everything, less than 5% of U.S. residences subscribed to broadband internet, or any continuously-on connection. For the vast majority of homeowners who bought home automation products at that time, devices within the home could talk to each other, but could not be controlled from outside the home.

By the end of 2008, approximately 55% of homes subscribed to some form of continuous-on internet service according to research by the Pew Internet and American Life Project.[7] 65 million of these are cable and DSL broadband as indicated in Figure 3.

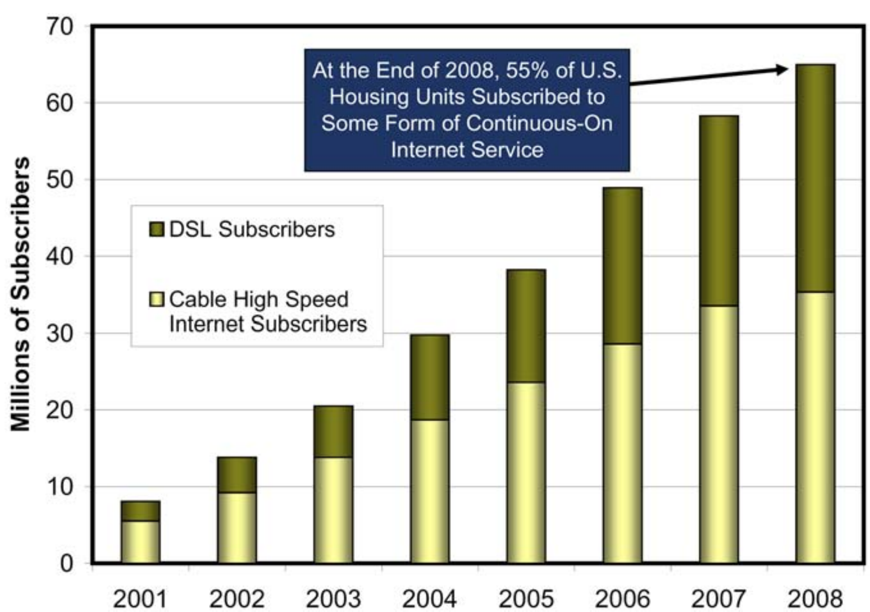

Figure 3. Residential Broadband Subscribers

7 Source: John B. Horrigan, Home Broadband Adoption 2008, Pew Internet and American Life Project, July 2008

Like telephone subscriptions during the 20th century, ultimate penetration levels for internet connectivity will likely be near 100%, but comparing existing data with a common technology-penetration S-curve would indicate that full penetration is still 8-12 years away. Legislative action could significantly reduce the time to 100% saturation for broadband connectivity. The economic and educational value of internet access, as well as its potential use for utility and other critical infrastructure applications is giving rise to action at every level of government. The following proposed language from the Recovery and Reinvestment Bill of 2009 is focused on accelerating infrastructure build-out:

> ***Wireless and Broadband Grants:*** *$6 billion for broadband and wireless services in underserved areas to strengthen the economy and provide business and job opportunities in every section of America with benefits to e-commerce, education, and healthcare. For every dollar invested in broadband the economy sees a ten-fold return on that investment.*[8]

As shown in Figure 4, broadband availability is already high, with 92% of housing units having access to cable-based broadband alone. For those homes reached, but not yet subscribing, utilities could partner with broadband providers, and develop a program whereby interface modems and connectivity are provided, although limited to utility use.

Reaching the Home Via Advanced Metering Infrastructure

To maximize the benefits of demand response programs, utilities will need to make the service available to all customers. If an economic benefit is associated with participation in the program, universal access is required to make it equitable. Faced with such considerations and desiring to

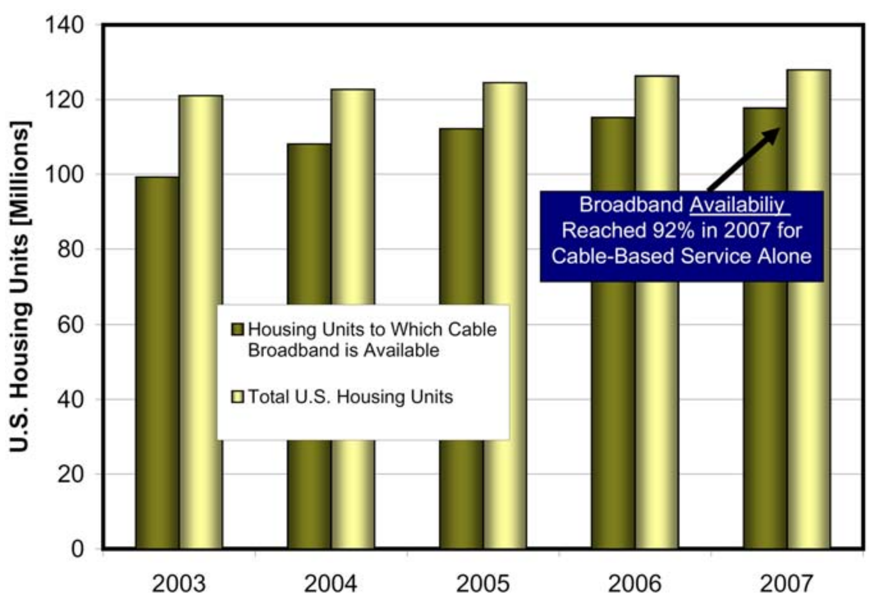

Figure 4. Cable Broadband Availability

8 Summary, American Recovery and Reinvestment Bill of 2009, January 2009

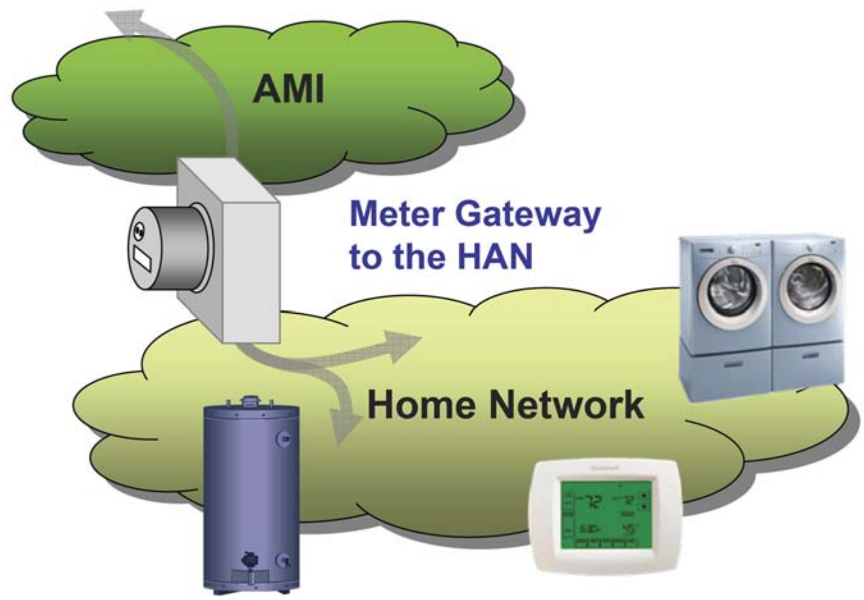

Figure 5. Reaching the Home Via AMI

move forward immediately, some utilities have chosen to reach home networks through utility-managed AMI systems as shown in Figure 5.

Because utilities generally install and own AMI infrastructure, coverage is under their control, and the need to reach every home is shared by the basic metering application.

The benefit of using internet protocol to network home appliances is influenced by these wide-area communication architectures. Benefits are maximized when unbroken IP connectivity can be established from utility to end device as discussed later.

The Home Area Network

Once wide-area connectivity to the home is achieved, whether by internet, AMI system, or some other means, a local premise network or home-area network (HAN) can be used to reach each device. Both IP-based and non-IP devices are emerging for energy-oriented home area networks. Some small devices, like thermostats and in-home displays are available, but major appliances that are demand-response ready are not commercially available. As a part of this research, several major appliance manufacturers were interviewed and were asked what factors most impede widespread deployment of demand responsive communicating appliances. Three responses stood out:

1. **Consensus in Communication Technology** – Appliance manufacturers are constrained by the lack of consensus in the area of communication device technology. As a group, they are very knowledgeable about energy efficiency and enabling demand response. Many manufacturers have been actively participating with utilities for years, creating prototype products for conceptual testing, but they cannot readily commercialize these products because of differ-

To make economic sense, appliance manufacturers must be able to sell the same appliance coast to coast.

ences in technology preference from region to region. To make economic sense, appliance manufacturers must be able to sell the same appliance coast to coast.

2. **Application Functionality** – Even if there were immediate agreement on the type of communication device used, demand responsive appliances cannot be delivered to the marketplace because of lack of application specifics. If an appliance is delivered a price, what does it do with it? If provision is made for customer preferences, how are they handled, communicated and stored? How does an energy management console, if present, understand the energy-related capabilities of an appliance?

3. **Longevity** – As shown in Figure 6,[9] common residential appliances have long service lives. In contrast, communication technologies are rapidly evolving to keep up with growing market penetration and user performance expectations. To manage this difference, appliance manufacturers must use either a separate network technology that evolves more slowly or modularity in design that allows communication modules to be upgraded.

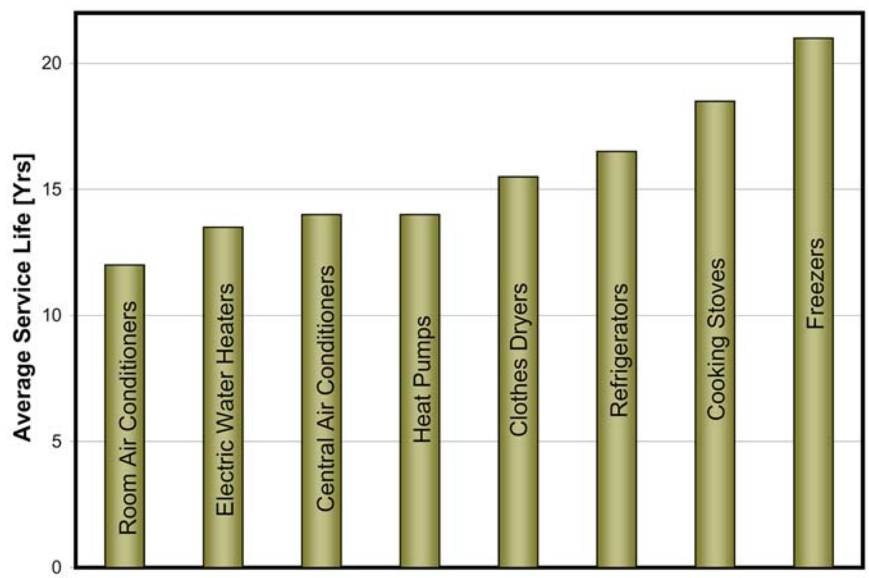

Figure 6. Residential Appliance Life Expectancy

Advantages of Internet Protocol at the Appliance

Internet protocol (IP) is by far the most common data link/network layer protocol in modern computing systems. IP combined with the Transmission Control Protocol (TCP) at the transport layer, are the defining elements of the internet protocol suite, referred to as TCP/IP. Internet protocol utilizes encapsulation in layers, as shown in Figure 7,[10] so that it can run over any physical media and can carry data for any application.

9 Data Source: Report #: DOE/EIA-0554(2008) Table 10. Minimum and Maximum Life Expectancies of Equipment June 2008
10 Adam Dunkels and JP Vasseur, IP for Smart Objects, Whitepaper #1, IPSO Alliance, September 2008

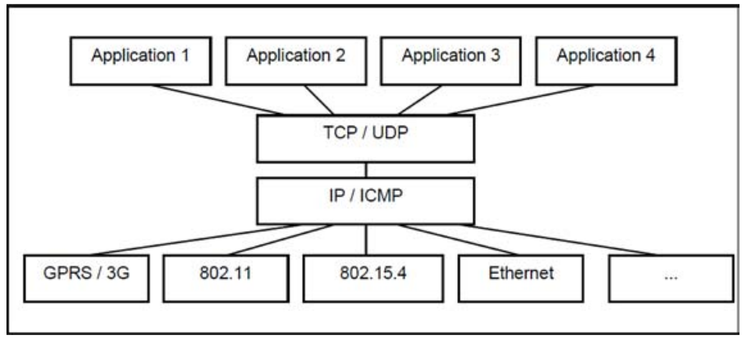

Figure 7. The Layered IP Architecture

Simple Interfacing WAN to HAN

The architecture of Figure 2 supposed an internet connection to a home area network. In such an arrangement, there are clear advantages to an IP based home network. The interface from the WAN to the HAN needs only to pass TCP/IP packets from one network to the other, without having to modify the packet or understand its contents. This interface could be considered a router, like those in home computer networks that interface Wi-Fi and Ethernet LANs to cable, DSL, or fiber WANs.

If the protocol on the home network is not IP, as with Zigbee, Z-wave, and others, the interface device must function as a gateway, translating incoming IP packets into the language of the local network. This requires that the gateway have some level of knowledge of the local protocol and, depending on approach, can include a full understanding of the messages and applications of the home area network. In such a case, firmware upgrades to an end device or introduction of a new appliance could require an upgrade of the gateway device as well. Such interdependence is undesirable.

The architecture of Figure 5 supposes a separate advanced metering communication system, such as an RF mesh or 2-way powerline carrier that is used to reach the home. In this scenario, interfacing to the home network is not necessarily simplified by an IP-based protocol. The AMI industry is dominated by proprietary hardware and protocols, having come into existence in an area devoid of applicable standards. Recently, ANSI approved the C12.22 standard for communication over AMI systems, but it too is not IP based. If the AMI system does not use internet protocol, then a language-translating gateway function is required even if the home network uses internet protocol.

End to End Security

Security can be applied at several layers, from the physical to the application. If the home network and the communication to the home are both based on IP, there is inherent end-to-end integrity – utility to appliance. This allows end-to-end security of the internet protocols to be used and interface or gateway devices can be uninvolved.

If the home network is not IP based, it must have its own security and this security can end at the WAN interface. In the worst case, communication from an end device would pass securely over the home network to a gateway device, be decrypted using the local security mechanism, then re-encrypted for transmission over the wide-area IP network. This process would create a point of vulnerability that is avoided if the same protocol is used and data packets are secured from the point of origin through to the destination.

Leveraging the Existing Home Network

If existing infrastructure can be utilized to serve utility interests, it is, at a minimum, worth investigating. A gateway device that interfaces a utility-specific home network to the internet might need to be utility owned and funded, whereas Wi-Fi or G.hn interfaces will increasingly be found to pre-exist as a part of user owned home networks.

In addition to possibly sharing hardware, utility use of common IP based networks aligns the utility industry with other industries that have home networking interests. This alignment allows the utility industry to benefit from the efforts of others.

For example, in the 1999-2002 timeframe, the internet community worked aggressively on networking home appliances, and in particular in standardizing the methods and protocols involved. Significant research was conducted at Telecordia Technologies to identify ways to simply and securely connect to appliances in the home, even when they are behind a firewall or Network Address Translator (NAT). The proposal,[11] developed in conjunction with the IETF, was based on the Session Initiation Protocol with certain extensions and new methods. This work was intended to address some of the same problems that the utility industry is working separately to solve today.

Application Flexibility

As indicated in Figure 7, the internet protocol suite is layered and encapsulated so that it is application independent. One can easily identify a large number of examples, within the power distribution industry, of software applications that communicate over IP.

In the past two years, Zigbee has gained significant utility interest as a wireless home network protocol. While not IP based, Zigbee runs on IEEE 802.15.4 RF mesh radios and allows each industry segment to define its own application layer functionality called "profiles." For the utility industry, that application specification is the "Smart Energy Profile" which was released in January 2008.[12] This specification identified basic messages for several home devices of utility interest, including thermostats, load shedding devices, and electricity meters. Currently, this application interface specification is being studied by a joint committee of both Zigbee and HomePlug members and could become a network-independent industry standard, through the IEC.

In a demonstration of the flexibility of the internet protocol, systems and software provider Arch Rock developed an open framework for running the Smart Energy Profile, and any

11 S. Moyer, D. Marples, et.al., Telecordia Technologies, Inc., Framework Draft for Networked Appliances Using the Session Initiation Protocol, Internet Engineering Task Force, June 2001

12 Zigbee Smart Energy Profile Specification, Zigbee Alliance, January 22, 2008, Free download from http://www.zigbee.org/

Zigbee application profile for that matter, over IP.[13] Called the Compact Application Protocol (CAP), the proposed architecture extends the Smart Energy Profile's usability to the broader range of IP based networks including Ethernet, Wi-Fi, HomePlug, and many others.

The compatibility of TCP/IP with almost any application is a strength. But the complete lack of IP-oriented application layer standards for use in utility type home networks has been a weakness. Credit must be given here to the Zigbee organization which, while avoiding IP, recognized the need for a solution covering every layer. The IETF, in contrast, has historically avoided application-layer involvement and remained focused on providing only the middle-layer fabric for communication. In this regard, the efforts by Arch Rock to bring the Smart Energy Profile to IP is a great service to the industry.

Utility Industry Benefit from Other Industry Efforts

Internet protocol has been used by a large number of industries. Many of these have contributed to the standard by investing in the protocol itself, its management, and its applications. Additionally, several forums, user groups, and other organizations have been formed to study particular problem areas and to find solutions. To whatever extent the utility industry utilizes IP, it takes advantage of these prior investments.

One example of a beneficial effort, particularly in regards to IP for utility networking of home appliances, is that of the UPnP Forum.[14] This organization, formed in 1999, now includes 874 member companies, and is self-described as follows:

> *…an industry initiative designed to enable simple and robust connectivity among consumer electronics, intelligent appliances and mobile devices from many different vendors. As a group, we are dedicated to making the connected home and lifestyle mainstream experiences for consumers - and great opportunities for the industry.*

UPnP stands for "Universal Plug and Play" and, as the name suggests, works to automate the process for a device joining and participating on a network. Some would debate the usability of current UPnP protocols for utility networking of demand responsive appliances, perhaps citing the need for security improvements. However, the Forum goal of simplifying the networking process, even to the point of simply plugging a device in, takes-on one of the utility industry's central needs. Perfect or not, the enormity of the effort that has been applied in this area and the technology it has produced is freely available to those who would consider IP based networking of home appliances.

IPV6

Internet Protocol Version 4 (IPV4) was the first publicly used version of the internet protocol. Since its inception in 1981, IPV4 has generated concern regarding address space. Internet protocol version 6 (IPV6) is the assumed successor to IPV4. IPV6 uses 16 byte addressing as opposed

13 New Arch Rock Framework Moves Zigbee Application Profiles onto IP, Arch Rock Press Release, October 21, 2008

14 http://www.upnp.org/

to 4 bytes in IPV4. The resulting 3.4x1038 addresses are enough to allow for 6.7x1019 addresses for every square centimeter of the earth's surface. While some argue that the V6 address space is excessive, others argue that it is still not enough because of the extreme inefficiency of address space division required for commercial and political reasons. Regardless of the detail, a significant increase was needed to allow for unique addressability of smart sensors and appliances.

Although Internet Protocol version 6 was approved as a standard in 1998 by the IETF, it is not interoperable with IPV4 and adoption has been slow. A recent study indicates that IPV6 penetration is less than 1% in any country.[15] Nonetheless, rapid adoption is now expected due to exhaustion of IPV4 space[16] and government mandate.[17]

Networks Using Internet Protocol

Ethernet

Ethernet needs no introduction. For many engineers and business people, it has been a part of life for as long as can be remembered. Ethernet, which is actually a family of specifications covering twisted pair and fiber optic backbones, was first standardized by the IEEE as 802.3 in 1983. Improving in speed over time, Ethernet specifications now extend to 10Gbits per second. Ethernet exists most commonly as a wired local network for computers running at 10/100Mbits per second.

As a candidate for networking home appliances, Ethernet has ample performance, but is not accessible in the necessary locations. Even modern homes pre-wired with Ethernet, have access jacks in just a few rooms. It is unreasonable to expect Ethernet, or any wired (non powerline) communication standard, to be available at water heaters in garages, in laundry rooms, and behind every kitchen appliance. Even when pulling new wires through old homes is possible, the cost is generally prohibitive.

The most appealing aspects of a separately-wired home communication network, like Ethernet, are network formation and security. Wireless and powerline-carrier based communication propagates outside the premises, providing an opportunity for unapproved direct network access and potential confusion as to which network an appliance belongs.

Wi-Fi

In 2001, chip maker Intel cast the decisive vote for Wi-Fi when it abandoned support for HomeRF, a wireless standard supported by Proxim, Siemens, Motorola, and Compaq. Intel at that time began shipping systems supporting the IEEE 802.11b standard, or Wi-Fi, joining Apple, Dell, Cisco, and a long list of others.

In the years following, Wi-Fi became the clear networking technology of choice, claiming almost 100% of the worldwide market for wireless inter-networking of laptop PCs and other portable

15 Global IPv6 Statistics - Measuring the current state of IPv6 for ordinary users, S.H. Gunderson (Google), RIPE 57 (Dubai, Oct 2008)

16 http://en.wikipedia.org/wiki/IPv4_address_exhaustion

17 http://www.whitehouse.gov/omb/memoranda/fy2005/m05-22.pdf

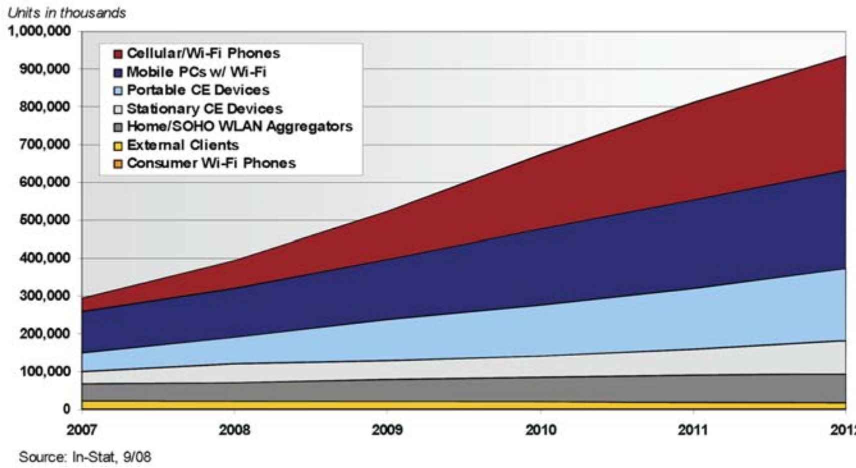

Figure 8. Forecast for Total CE Devices with Wi-Fi, Source: In-Stat 9/08

computing devices. Additional growth in Wi-Fi chipset shipments began in 2008 as it gained popularity as a second technology in dual-mode cellular phones. As indicated in Figure 8,[18] total sales of Wi-Fi enabled consumer electronic devices are expected near 1 billion by 2012, with no signs of slowing.

Wireless networking of home appliances solves the ubiquity problem, providing connectivity everywhere in the premises without the installation of new infrastructure, but introduces some new challenges:

- **Network Formation** – The boundaries of wired networks are clearly defined by the wires themselves. When a homeowner plugs an appliance into an Ethernet LAN, it is part of that network and no other. With any wireless LAN, there will be situations where multiple networks overlap. A process is then required to determine which network an appliance should join. The common process for portable computers joining a network involves an application running on the device and associated user input. Simplicity for the end-user means complexity underneath.
- **Security** – Whether or not a homeowner is concerned about the security of their appliance network, there is likely security (WPA, WEP, etc.) on their Wi-Fi network to protect personal data on their computers. Security further complicates the process of joining a network, particularly if the appliances involved have no display or keyboard for pass key entry.

6LoWPAN

In spite of the growing market volume and associated cost reductions of Wi-Fi, some believe that its complexity and power consumption are too high and that, as a result, the technology will never be the most cost effective for embedding in residential appliances. 6LoWPAN offers a wireless alternative to Wi-Fi by running internet protocol over the simpler IEEE 802.15.4 radio.

18 Used by permission, Wi-Fi in Consumer Electronics: The Swiss Army Knife Technology, In-Stat, September 2008

These direct sequence spread spectrum radios are available as single chip transceivers and are the same as those upon which the non-IP Zigbee platform is built.

6LoWPAN stands for IPV6 over Low power Wireless Personal Area Networks. It is a standard codified by the Internet Engineering Task Force (IETF) as RFC 4944. The specific intent of 6LoWPAN is to define optimizations and compressions for IPV6 headers so that it can be efficiently used over IEEE 802.15.4 radios.

Lacking a promotional or marketing organization early-on, 6LoWPAN received little attention in spite of its IP foundation and technical merits. In 2008, the IPSO Alliance[19] was formed to establish internet protocol as the network layer for the connection of smart objects. IPSO stands for 'Internet Protocol for Smart Objects', and Smart Objects are defined by IPSO as:

> *…small computers with a sensor or actuator and a communication device, embedded in objects such as thermometers, car engines, light switches, and industry machinery.*[20]

While this definition is certainly much broader than the appliances of interest to the utility industry, smart grid and energy management are listed as two of the application areas these objects are intended to enable. Founding members of the IPSO Alliance include Electricité de France R&D, Duke Energy, ekaSystems, Silver Spring Networks, and others with utility interests.

HomePlug 1.0

The HomePlug Powerline Alliance, founded in 2000, is on open-standards based organization that develops powerline communication specifications and certifies products against those standards. Currently, the alliance has four powerline communication focus areas: HomePlug 1.0, HomePlug A/V, HomePlug BPL, and HomePlug Command and Control (HomePlug C&C).

The 1.0 specification was finalized in 2001 and is the most mature. Many products are commercially available for home computer networking that use the 1.0 specification. HomePlug AV was approved in August 2005 and has throughput near 100 Mbps to support video streams. HomePlug BPL is for outside powerline communication to the residence. HomePlug C&C is still in development. Although HomePlug 1.0 is well known as an IP-based computer networking specification, it is not generally considered as a candidate for networking energy-smart appliances for utility programs due to complexity and cost.

Of most interest to the utility industry is HomePlug C&C.[21] This standard, once completed, is intended to be a simpler, less expensive platform for common household appliances to communicate small amounts of data. In 2007, a C&C version 1.0 specification was completed for the physical/media access control (phy/mac) protocol layers, but the organization intends to continue with development of network, transport, and session layers. One proposal for these upper layers, contributed by Yitran, does not involve internet protocol, so it is not clear that HomePlug connected appliances will use IP at all.

19 http://www.ipso-alliance.org/

20 Adam Dunkels and JP Vasseur, IP for Smart Objects, Whitepaper #1, IPSO Alliance, September 2008

21 http://www.homeplug.org/products/homeplug_cc1/ Four Key Areas of Impact

HomePNA and G.HN

It is worthwhile to include HomePNA in a discussion of IP based home networks. Like HomePlug, HomePNA is a phy/mac standard for exchanging high speed data within premises, but HomePNA utilizes coaxial cable and telephone lines. HomePNA is driven by the entertainment industry and is primarily applied to video and audio distribution. No white goods are known to have yet been produced with integrated HomePNA. As with Ethernet and any separately-wired network approach, it would be difficult to reach appliances throughout the home with HomePNA due to lack of interfaces in the many required locations.

One reason for mentioning HomePNA in this context is the emergence of G.hn. G.hn is the name of a home network standard being developed by the International Telecommunication Union.[22] The phy standard, G.9960, was approved in December 2008 and the mac standard is in process. When complete, G.hn will be a standard phy/mac for all existing-wire home networking, adding powerline support to the coax cable and telephone lines media of HomePNA. Running IP over G.hn is intended to make G.hn the wired complement to Wi-Fi. Mobile devices in the home could use Wi-Fi while those connected to electrical power could use G.hn.

G.hn is a possible converging path forward for HomePNA (cable, phoneline) and HomePlug (powerline). As such, an internet interface device like that depicted in Figure 2 could simultaneously act as a gateway to both wireless and wired devices in the home. G.hn is promoted by the non-profit trade group HomeGrid Forum.

Market Assessment of IP-Addressable Appliances

A sampled survey was conducted to assess the marketplace and to identify IP addressable appliances and devices that existed between 1998 and present. During that timeframe, the home automation industry was focused on lighting, security, and audio/video, but devices of those types were excluded. Of these excluded categories, the audio/video segment was notably IP based whereas the lighting and security segments were dominated by proprietary technologies.

In keeping with an electric power focus, the following high consumption devices were included in the assessment:

- Thermostats / HVAC
- Water Heaters
- Refrigerators
- Clothes Dryers
- Clothes Washers
- Cooking Stoves / Ovens
- Microwave Ovens

22 Press Release, New Global Standard for Fully Networked Home, International Telecommunication Union, December 12, 2008

- Dish Washers

In addition, the following devices, which serve electrical power interests, were included:

- Electric Meters
- Breaker Panels
- Load Switches
- Gateway Devices (IP bridges to non-IP networks)
- Display Devices

Naturally, older data was more difficult to verify. Several appliance manufacturers who were interviewed reported having never designed internet communicating devices, in spite of records from tradeshows indicating otherwise. Further investigation revealed that many of these companies hired outside firms to develop concept prototypes while the company remained internally focused on core business lines. When interest in such devices waned, the relationships with the outside firms were terminated and little or no memory remains of the products that were presented.

Other appliance manufacturers had strategic visions that included advanced appliances, particularly those with internet connectivity, as key elements, and closely guarded the related developments. For example, Korean appliance manufacturer LG Electronics, stated that their DIOS Internet Refrigerator included 75 patented technologies and that their internet washing machine included 107 patents. Ultimately, the devices identified in this research include both real products and tradeshow facades and distinguishing between the two was not possible. Of those that were commercialized, some were limited to particular regions – Asia, Europe, or the U.S.

Figure 9 presents, by type, the total number of IP connected devices that were identified.

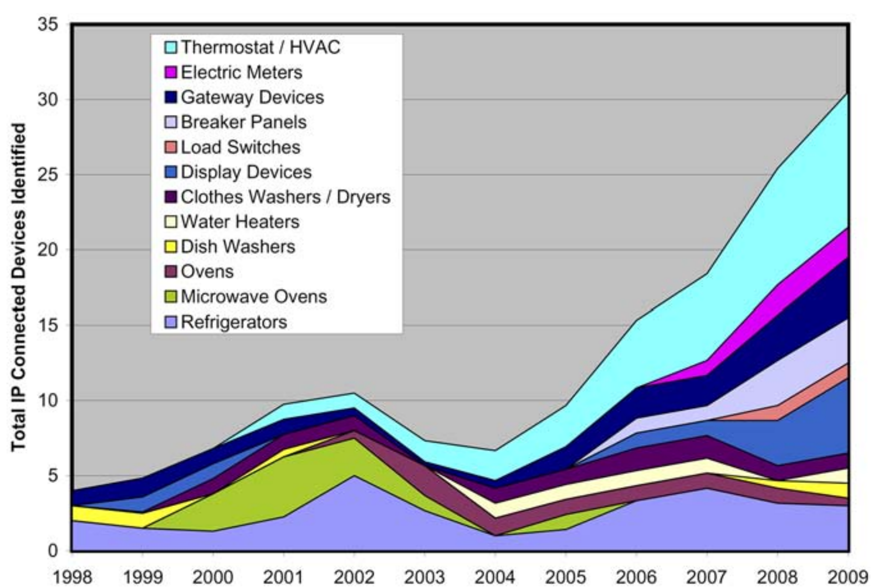

Figure 9. IP Communicating Appliances by Type

There was a clear surge in volume of internet protocol products during the 1998 to 2002 timeframe. The devices of this period were focused on front-side features that offered users a high-tech and futuristic experience. Refrigerators and microwave ovens dominated the field during this time. Energy intelligence, time differentiated pricing, and demand-response were not generally included in the array of features these products offered.

Since about 2005, there has been a steady rise in the availability of energy-focused internet protocol devices, with thermostats and display devices being the most common. During this same timeframe, the availability of the futuristic products of the prior era has declined. Internet connected microwave and traditional ovens of the "downloadable recipe" variety may have disappeared and remaining refrigerators are quickly adding energy smart features.

For further reference, Appendix A lists the companies that were identified in this search.

Usage of IP Network Types

The IP communicating appliances and devices identified in this research used all the network types (phy/mac layers) discussed previously. Ethernet was the most common overall, but Wi-Fi showed the fastest growth in recent years. Figure 10 shows how the IP communicating thermostat market is evolving.

IP Gateways

There are a large number of non IP protocols and networks presently marketed for home and building automation networks, some based on open standards and others proprietary. Because of the common use of internet protocol outside the premises, there are gateway devices to interface most every other network to IP. In fact, the term "gateway" was found to be almost synonymous with an Ethernet/IP interface, with providers describing the non-IP side of the device, but assum-

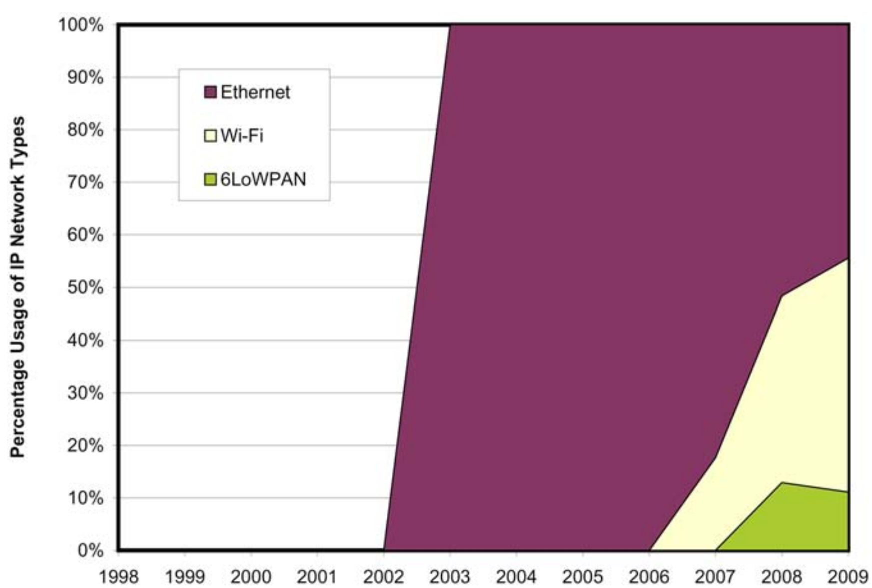

Figure 10. IP Thermostat Breakdown by Network Type

Smart, communicating appliances that automate demand-side response to real time energy pricing and grid events are the primary enabling technology for the residential sector.

ing that buyers knew the other side was EtherNet/IP. The extensive availability of these gateways is a testimony to the prevalence of the internet protocol. Table 1 lists some examples.

Table 1. Example IP Gateway Products

From Internet Protocol to:	Product Manufacturer	Model
Z-Wave	Hawking Technology	Home Remote Pro
Z-Wave	iControl	iHub
Zigbee	Tendril Networks Inc.	Transport Gateway
Zigbee	Digi International	ConnectPort Series
LonWorks (various)	4HomeMedia	EnergyPoint 3200
LonWorks (various)	Adept Systems Inc.	Grouter3A family
BACNet PTP/ARCNET	FieldServer Technologies	FieldServer Gateway
BACNet PTP /ARCNET/MS/TP	Automated Logic Corp.	LGR
Insteon	Universal Devices	ISY-99
Insteon	SimpleHomeNet	EZSrve
X10	SimpleHomeNet	EZBridge
X10	Key Eleven	WebIO
ModBus	Control Solutions, Inc.	Babel Buster Series
ModBus	Moxa, Inc	MGate series
DNP 3	ProSoft Technology	ProLinx Family
DNP 3	Bow Networks	eLAN UDG

Conclusions

The Energy Independence and Security Act of 2007 legislated the "integration of smart appliances and consumer devices" as one of ten policies to modernize the electricity grid.[23] Similarly, DOE-NETL's Modern Grid Initiative identified 'enabling active participation by consumers' as one of seven characteristics of a smart grid.[24] Studies have shown that residential opportunities for energy efficiency and demand response exceed those in the commercial and industrial sectors[25] and that the residential sector's ability to respond to real time grid activity is highly dependent on enabling technologies.[26] Smart, communicating appliances that automate demand-side

23 Energy Independence and Security Act of 2007, Title XIII, Sec. 1301, Effective December 2007

24 A Vision for the Modern Grid v1.0, U.S. Department of Energy, National Energy Technology Laboratory

25 Product 1016987, Assessment of Achievable Potential from EE and DR Programs in the U.S. (2010-2030) Electric Power Research Institute, January 2009

26 Faruqui, A., Sergici, S. The Power of Experimentation: New evidence on Residential Demand Response. Brattle Group. Boston. MA, April 2008

response to real time energy pricing and grid events are the primary enabling technology for the residential sector.

In such an environment, it is likely that communicating appliances will become increasingly common. These communicating appliances will be smart, at least in the sense of enabling interoperability with the electric power systems. Once the cost of intelligence and connectivity are justified by benefits to the electric grid, the value proposition for non-energy applications will become more attractive. It is reasonable to expect that the networks that connect these appliances will be used beyond utility interests and that they will eventually support maintenance, service, and consumer features.

The prevalence and flexibility of internet protocol make it an attractive proposition as a network layer for connecting appliances. Benefits include simplicity of interfacing to existing home networks, opportunity for end-to-end security, and compatibility with many different physical media.

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Appendix A

For reference, Table 2 lists companies identified during this investigation. The search was not exhaustive, so this is a sample group. All those listed here are not equal in the extent of involvement with IP based devices. Some only demonstrated products, others commercialized. Some provide products primarily to commercial and industrial markets, others are residentially focused.

Not all the vendors listed in Table 2 produced products that were included in Figure 10 due to lack of focus on the residential sector or lack of commercial maturity.

Table 2. Companies by Product Category

Appliance Category	Companies Involved With IP-Based Protocols with these Appliances
Thermostats/HVAC	Aprilaire, Carrier, Comtech, eDevice, EcoBee, Fidura Corp., LG Electronics, HeatMiser, Net/X, Proliphix, Radio Thermostat Corporation of America, t-Mac, TXU Energy,
Refrigerators	CSIRO, Electrolux, Haier, LG Electronics, Merloni, Miele, Rltec, Samsung, Toshiba, V-Sync, Whirlpool
Ovens	Merloni, Miele, TMIO, Whirlpool
Microwave Ovens	DeLonghi, LG Electronics, Panasonic, Salton, Samsung, Sharp
Water Heaters	A.O. Smith, Paloma, Whirlpool
Clothes Washers/Dryers	LG Electronics, Merloni, Miele, Whirlpool
Dish Washers	Haier, Merloni, Miele
Display Devices	3Com, Ambient Devices, Control4, Chumby, The Energy Detective, Violet
IP Breaker Panels	Computerized Electricity Systems, Eaton, Square-D
Console Devices	Control4, Merloni, PlugSmart, RTI Corp, Salton, Tendril, Thalia
Load Switches	PlugSmart, Radio Thermostat Corporation of America
Electric Meters	Carina, GridNet, muNet, Silver Spring Networks, SmartSynch
Sub Meters	GreenBox, WattsUp
C&I Products	Akuacom, CalAmp, eMiner

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