Assessment of Communication Standards for Smart Appliances:

The Home Appliance Industry's Technical Evaluation of Communication Protocols

October 2010

AHAM
ASSOCIATION OF HOME APPLIANCE MANUFACTURERS

Leadership ➤ Knowledge ➤ Innovation

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ABSTRACT

THIS IS A FOLLOW-UP REPORT TO AHAM'S SMART APPLIANCE WHITE PAPER AND IS THE INDUSTRY'S TECHNICAL EVALUATION OF THE MULTITUDE OF EXISTING COMMUNICATIONS PROTOCOLS DESIGNED FOR THE SMART GRID.

As the trade association that represents the home appliance industry, the members of the Association of Home Appliance Manufacturers (AHAM) are committed to providing innovative and sustainable products that improve the lives of consumers. Because home appliances are an integral part of the Smart Grid, AHAM drafted a White Paper titled, The Home Appliance Industry's Principles & Requirements for Achieving a Widely Accepted Smart Grid in December 2009 (found at www.aham.org/smartgrid) to communicate essential requirements for the development and implementation of a successful Smart Grid, including open, flexible secure Communication Standards that are limited in number.

ABOUT THE ASSOCIATION OF HOME APPLIANCE MANUFACTURERS

AHAM represents manufacturers of major, portable and floor care home appliances, and suppliers to the industry. AHAM's membership includes over 150 companies throughout the world. In the United States, AHAM members employ tens of thousands of people in the United States and produce more than 95% of the household appliances shipped for sale within the United States. The factory shipment value of these products is more than $30 billion annually. The home appliance industry, through its products and innovation, is essential to U.S. consumer lifestyle, health, safety and convenience. Through its technology, employees and productivity, the industry contributes significantly to the U.S. job market and the nation's economic security. Home appliances also are a success story in terms of energy efficiency and environmental protection. The purchase of new appliances often represents the most effective choice a consumer can make to reduce home energy use and costs.

AHAM is also a standards development organization, accredited by the American National Standards Institute (ANSI). The Association authors numerous appliance performance testing standards used by manufacturers, consumer organizations and governmental bodies to rate and compare appliances. AHAM's consumer safety education program has educated millions of consumers on ways to properly and safely use appliances such as portable heaters, clothes dryers, and cooking products.

EXECUTIVE SUMMARY

The Association of Home Appliance Manufacturers (AHAM) is interested and involved in the development of the Smart Grid and the policies surrounding a Smart Grid in the United States. The objective of the Smart Grid is to provide technology and systems (integrated into appliances and consumer devices used in everyday activities) that will allow consumers to automatically control their energy use and costs. The development of standardized and interoperable communications and application protocols for smart appliances will benefit consumers and utilities, allowing customers to manage their energy use and demand, thus reducing peak loads on the electric grid as well as enabling consumers to save money on their electric bills. A smart appliance is a product which has the capability to receive, interpret and act on a signal received from a home energy management system, utility, or third party energy service provider, and automatically adjust its operation depending on the signal's contents and settings from the owner.

The growth of Smart Grid infrastructure in the U.S. (60 million smart meters, or 47% of U.S. households, are planned by 2019[1]), will provide the hardware and rate structure incentives to enable consumers and utilities to manage the use and demand for electric energy. The resulting Smart Grid system will produce energy and financial savings to both the grid and individual consumers. It is critical, however, that the implementation costs of the grid infrastructure and smart appliances themselves results in benefits that far outweigh the costs. To assure that the implementation costs are minimized for smart appliances, national communication standards are needed to allow manufactures to develop mass produced products suitable for nation-wide distribution. AHAM does not presently intend to develop these communication standards, but has undertaken a technical evaluation of existing communication standards, and an assessment based on their application with home appliances, for standards bodies and government agencies to consider.

National standards are needed to ensure an appliance has the capability to function anywhere in the U.S. where the Smart Grid infrastructure is available. These national standards also will promote interoperability between appliances and enhance consumer choice. National standard communications and application protocols will make it possible for consumers to move from one area of the country to another while continuing to benefit from Smart Grid technologies without having to replace, modify, or upgrade their appliances.

The members of AHAM currently produce or represent production of over 95 percent of the household appliances sold within the U.S. The AHAM membership is focused on understanding the consumer appliance marketplace. AHAM members are best suited to understand the needs and requirements of consumers and the types of products that will meet those consumer expectations. This report presents AHAM's methodology and technical analysis of smart

[1] *Institute for Electric Efficiency, February 2010,* *http://www.edisonfoundation.net/iee/issuebriefs/IEE_SmartMeterRollouts_update.pdf*

appliance communications protocols. It does not represent an industry agreement or proposal. It also does not represent every possible evaluation criterion. It does not evaluate affected intellectual property rights (IPR) or regulatory concerns that may be associated with a particular technology. IPR is a recurring and an important consideration for standards bodies and market participants. Safety issues in particular are critical to every product design and must be separately evaluated.

HIGHEST SCORING PROTOCOLS

Application Layer: SEP 2.0 and OpenADR.

Media/Network Layers: Wi-Fi, ZigBee, and HomePlug Green PHY

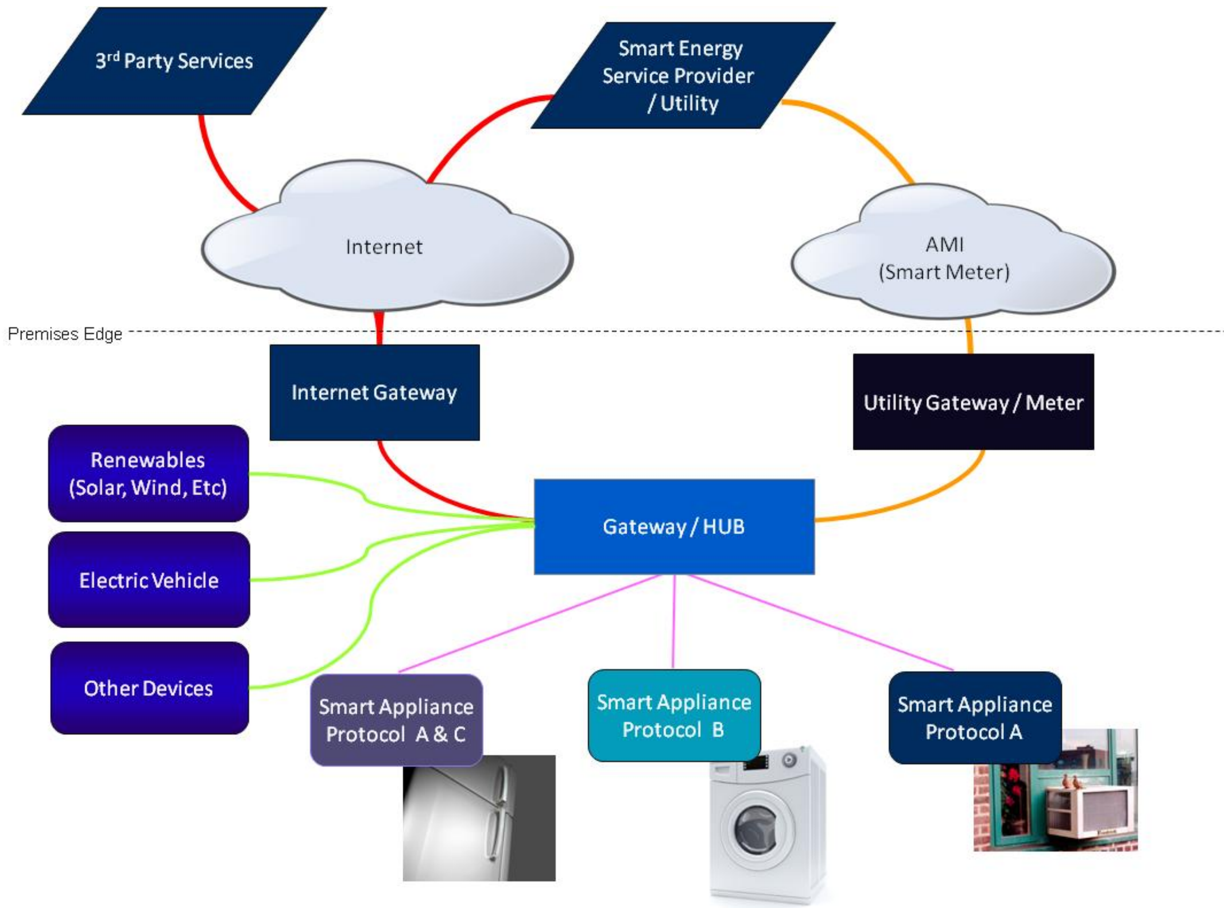
This assessment evaluated issues across numerous existing communications technologies with respect to the following key communications layers: Application (APP), Network (NET), and Media Layers (MAC, PHY). It was often impossible to separate a technology's value statement from an associated networking technology—thus, these were often combined for evaluation purposes. Each communications technology was evaluated against a set of clear, consumer-driven requirements, as identified by participating AHAM members based on their expertise and knowledge of the industry. Each technology was evaluated through a requirements driven scoring system, by an independent consultant to rank the ability of the studied communications technologies to meet the unique needs of appliance consumers. According to the assessment's results, the most relevant communications technologies were clearly separated from their peers for use in Smart Grid appliance applications. For the Application layer, SEP 2.0 and OpenADR scored the highest. Across the media and network layers evaluated, Wi-Fi, ZigBee, and HomePlug Green PHY, scored the highest.

Although there could be other viable architectures, the Assessment reflects a clear preference by the home appliance industry that the best communications architecture at this time features a hub or gateway (see Figure below) that can communicate using common protocols and serve as the adapter or bridge to other devices on the Home Area Network (HAN). This type of architecture is consistent with the OpenHAN architectures and provides simplicity for the consumer, and the flexibility needed for future development needs. Additionally, this type of architecture supports a more robust, comprehensive "home networking" system approach compatible with consumer electronics devices.

This technical assessment finds that these application protocols, and the media capable of delivering them, are the best performing protocols for Smart Grid targeted applications for a consumer audience. Appliance manufacturers may voluntarily use these results to increase the energy management capabilities of their appliances, recognizing that other considerations may apply. Incentives for consumers and appliance manufacturers need to be pursued in all applicable areas to promote active and rapid growth of the role of appliances in the Smart Grid ecosystem.

AHAM encourages constructive comments and feedback regarding this study from organizations related to or involved in Smart Grid communications technology.

AHAM consensus architecture with one possible configuration of connectivity and information pathways in the Smart Grid



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Objective and Scope

OBJECTIVE

AHAM's previous Smart Grid White Paper, "The Home Appliance Industry's Principles & Requirements for Achieving a Widely Accepted Smart Grid," dated December 2009, identified three essential requirements for the implementation of a successful Smart Grid, which were that **pricing** must provide incentives to manage energy use more efficiently and enable consumers to save money; **communication standards** must be open, flexible, secure, and limited in number; and **consumer choice & privacy** must be respected; the consumer is the decision maker.

This assessment was framed and executed to address the communication standards requirement and the four communication parameters: open, flexible, secure, and limited in number. To address these parameters, AHAM undertook the task of identifying protocols that meet the four identified parameters through a technical, transparent and objective methodology. To best enable the smart grid, relevant standards should meet the needs of consumers first, then the needs of utilities, and then the needs of those involved with integrating smart appliances into the Smart Grid. Some issues limiting advancement of communications technology for smart appliances, such as intellectual property rights, cost, regulatory affairs, and particularly safety (beyond the scope of what was considered in this assessment), also must be considered and were beyond the scope of this assessment.

Currently various industries are considering many different communications protocols for use in Smart Grid, but little has been done to establish or isolate any clear or emerging preferred protocols for use in smart appliances. This situation has created confusion in the Home Area Network (HAN) device space for utilities, consumers, and device manufacturers. It is the objective of this assessment to identify potential best technologies for use in smart appliances based on stated, explicit, consumer focused requirements. These consumer requirements were used to evaluate protocols, drive requirements, and determine approaches to the HAN having scalability and longevity in the market. Primary needs such as consumer security, privacy, consumer choice, simplicity, flexibility, and factors impacting cost are main areas of focus used in this evaluation. Furthermore, various consumer demographics, including low-income households, were considered.

Several needs that are specific and unique to the appliance industry must be addressed. Appliances have relatively long useful lives and tend to move with their owners. These factors create complications not present in some devices such as the home electric meter. Thus, an appliance needs to be compatible with many utility service providers across the country. An appliance must withstand changes in connection and technology throughout its average useful life, which can extend beyond ten years. This assessment addresses these issues in the context of the consumer need to narrow the field of protocols relative to these points.

Consumers want the Smart Grid to manage home energy use more efficiently, thereby saving the consumer money on electricity. Utilities want the Smart Grid to decrease energy use during high price periods, thus reducing peak demands on the utility grid. Manufacturers must provide energy saving technology and processes that are integrated into the appliances and devices consumers use in their everyday lives – all without causing significant disruption in a person's daily life. A successful Smart Grid will allow consumers to receive valuable and understandable information that enables them to make informed choices about how and when they use energy; all while minimizing consumer cost and out-of pocket expenses that could arise with the implementation of the Smart Grid. If the cost of the Smart Grid outweighs its benefits, consumers' willingness to participate in the Smart Grid will be severely impaired, and the Smart Grid concept will suffer.

SCOPE

This assessment is focused on identifying protocols that–based on explicit, clear, and technical criteria—are best suited for residential customers and appliance operations. AHAM's previous White Paper recommended the need to focus on a limited number of protocols to support development of a robust national market for smart appliances, capable of functioning anywhere Smart Grid infrastructure exists. This report provides the scope and results of a commissioned technical evaluation that provides valuable information to help identify appropriate protocols for smart appliances and narrow the field by clarifying what protocols are performing well relative to explicitly stated and evaluated appliance customer needs at this point in time.

AHAM recognizes that each manufacturer must make an independent and voluntary decision as to which communications protocol to incorporate into its products, and what level of external interoperability will be supported. The assessment AHAM commissioned provides appliance manufacturers with additional information as they develop products for use on the Smart Grid. Technologies will change and evolve over time for various economic and competitive reasons. An initial assessment of the many communication protocols that exist can help to ensure future interoperability within the appliance industry and the Home Area Network (HAN) at-large so that the consumer is protected from constant upgrade concerns over the lifespan of their appliances.

This assessment focuses on communication protocols identified in "NIST Framework and Roadmap for Smart Grid Interoperability Standard, Release 1.0," as well as candidate protocols recommended by the AHAM commissioned consultant and AHAM members. The AHAM communications assessment surveyed and assessed protocols for Physical Layer/Media Access Control/Network layers (PHY/MAC/NET) and Application layers in terms of consumer smart appliance requirements.

LIMITATIONS AND ASSUMPTIONS

To facilitate this assessment, certain assumptions and limitations had to be applied. These limitations were considered necessary to present a realistic picture of the Smart Grid as best can be predicted at this time. Furthermore, some assumptions were put in place to create as fair and objective evaluation of candidate technologies as possible. AHAM contracted with EnerNex to provide expert and impartial management and input to this assessment. AHAM and EnerNex jointly developed the list of requirements and criteria that should be evaluated. EnerNex did the actual evaluation of the requirements and criteria based on their technical expertise and AHAM member input.

Regulatory and Intellectual Property (IP) issues were initially considered for inclusion as a measure in the assessment as they are a major concern for any manufacture of appliances. However, it was determined that such discussion is out of scope for this technical assessment. Nevertheless, openness of a protocol, i.e., a protocol that is not proprietary, or is from a standards development organization or an Alliance, was considered and measured in the assessment.

The consumer inputs in this assessment are based on AHAM members' knowledge of consumer preferences and represent a consensus list of items and criteria within the scope of that knowledge. Marketing research has not been performed as part of this work. But AHAM members are uniquely qualified to make these judgments because understanding consumer expectations, needs, and wants, can be the difference between a successful product launch and a failure in the competitive appliance industry. Thus, the considerable experience of the AHAM member manufacturers regarding the major appliance market was employed to ensure the quality and value of this work.

The technical requirements of OpenHAN were considered during this assessment. At this time, OpenHAN appears to be the only source of HAN requirements with support from multiple industries and Smart Grid stakeholders. These requirements were used as general guidelines during assessment evaluations to help frame consumer requirements within this model of the HAN.

AHAM made the decision to perform the evaluations under the assumption that HomePlug Green PHY, SEP 2.0, OpenADR, Bluetooth 4.0, and LON 2.0 were complete. While not in official release at the time of this assessment, it was recognized that these protocols have mature developments that are well supported and will see maturity in the near term, and as such are best evaluated by being assumed complete. That assumption was further supported by the fact that the NIST Framework and Roadmap document recognized those protocols as viable standards. The draft revision of SEP 2.0, dated May 7, 2010, was used in the analysis, and for HomePlug Green PHY, it was assumed that the final certification was approved.

These protocols that are not yet fully completed were then evaluated based on research and the experience of the EnerNex consultant. For example, some chips that support the current released version of the protocols will be forward compatible with the new version of the protocol, and as such can help establish and frame various aspects of performance and use. Additionally, industry experts were queried to get the best information available at the time of this assessment to approximate accurate performance and requirements for unreleased protocols. These efforts should allow for a fair and accurate assessment of such protocols as they will eventually be released.

Background

SMART APPLIANCES ENABLE DEMAND RESPONSE

The growth and development of smart appliances represents a significant component of the potential residential demand response capability to the Smart Grid. Several early utility programs established the capability for consumers to assist in grid control through "opt-in" programs controlling items such as home air conditioning and electric water heating units. Smart appliances built upon these earlier programs, including Direct Load Control, can extend these concepts to far more widespread demand reduction opportunities if they are properly enabled and incentivized for consumers.

> ***". . . it is the residential class that represents most [sic] untapped potential for demand response. . . While residential customers provide only roughly 17 percent of today's demand response potential, in the AP [Achievable Participation] scenario they provide over 45 percent of the potential impacts."***
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> *Federal Energy Regulatory Commission, A National Assessment of Demand Response Potential (June 2009), p.29*

As FERC has identified, the participation and integration of the residential sector to the Smart Grid could be a significant factor in national or regional demand reduction programs. Appliances represent a portion of the residential sector that can be controlled to support this opportunity. Potential savings from demand reduction programs and the resulting incentives to consumers represent the best chance to engage the general public in making residential appliances available to utilities and to help increase efficiency and energy savings of the grid overall.

Integration of smart appliances into the future Smart Grid offers consumers the opportunity to save money while providing utilities a mechanism to more efficiently operate the grid. Kitchen appliances consume about 300 billion kilowatt hours (kWhs) of electricity annually and laundry appliances use another 76 billion kWhs of electricity in the U.S.[2] If just 5 percent of this energy usage could be shifted to off-peak hours with a 40 percent savings for off-peak Time of Use (TOU) rates, consumers would save almost $900 million annually.[3] Further, integration of smart appliances would help reduce the need for the additional cost and infrastructure of "peaker plants," plants that are called upon to generate electricity only at peak demand instances. The

[2] DOE Electricity Consumption by End Use in U.S. households, 2001, Table U.S.-1, http://www.eia.doe.gov/emeu/reps/enduse/er01_us_tab1.html

[3] Based on 11.92 cent per kWh, Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State, 2010, http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_a.html

cost of reserving peaker plants for only a few hundred hours of service per year is estimated at more $1 billion dollars annually in California alone.[4]

The appliance industry is an important part of the Smart Grid. Enabling communications with appliances is critical to the success of the Smart Grid. Recognizing the importance of work of the various organizations including NIST and OpenSG Home Area Network (OpenHAN), the work contained within this assessment is consistent with the general requirements and architectures presented in OpenHAN, which provides the necessary information for devices and appliances to participate in demand response behaviors in the form of Home Area Network (HAN) requirements. Once appliances can participate in the HAN, innovation will follow. Having a limited number of protocols to select from, ideally one interoperable protocol, is a critical enabler to appliance participation. This assessment evaluates possible communication protocols based on specified needs of appliance consumers as seen by the members of AHAM.

> This assessment is aimed at evaluating possible communication protocols based on the needs of appliance consumers as seen by the members of AHAM.

HURDLES FOR THE SMART GRID

Numerous factors exist that contribute to the overall complexity of the Smart Grid. Many aspects of the complexity stem from the extension of the concepts of the Smart Grid beyond the typical energy management demarcation point of the meter to within the home area network and environment. And a national communications protocol will help simplify many of these complications. These include:

- There are over 3200 utilities in the United States most of which have long histories spanning more than 100 years. Utilities serve their customers with a mix of new and legacy systems which in many cases were developed prior to standardization. Further, utilities must operate safely and reliably while meeting regulations from multiple sources including federal, state and regional groups such as Public Utility Commissions (PUCs), OSHA, FERC, state legislations, and regional air quality management agencies. In addition to utilities, FERC mandated that third parties must also be allowed to participate in demand response markets. Thus, smart appliances would have to integrate with many different entities creating significant complication without a single or limited number of standards.

[4] California Flex Your Power website, http://www.fypower.org/news/?cat=24

- There are physical and electrical variations within the homes of consumers (i.e. 200 unit apartment buildings, older homes, etc.) that impact the deployment of communication technologies.
- Consumers are continuing to purchase products and services that utilize a diverse set of communications technologies within the home. With no current dominant communications protocol standard, it may become difficult to interoperate multiple devices with many different technologies in place.
- Appliances move with consumers. When they move, they often change utilities. If the new utility does not use the same protocols and information models, the appliance would be rendered useless or require modifications to work with the new utility.
- Appliances are part of consumer's lives for more than 10 years. This longevity requires protocols to adapted or function across many years of growth and change in the Smart Grid
- Appliances can be located in homes or buildings in manners that interfere with some methods of signal transmission (e.g. basements). It is necessary for protocols to be capable of adapting to these different environments.

The AHAM assessment focuses on various implementation needs and how some of the hurdles presented by the Smart Grid are addressed by the protocols considered.

Communications Architecture

AHAM COMMUNICATIONS ARCHITECTURE

AHAM worked to identify general architectures to address many of the hurdles present in common residential installations. From various architecture models a general model was developed. Three general architecture models developed here were combined with the consumer requirements to complete this assessment.

An architecture that is flexible and adaptable to the consumer's changing needs and environment is necessary to successfully enable the promise presented by the Smart Grid. Taking a longer term view of the Smart Grid and home environment, consumers will be living in a world of many changing technologies and standards for years. AHAM strives to meet this challenge by supporting a communications architecture within the home that enables the consumer to easily and economically adapt to changes. This architecture must provide for communications with utility devices as well as third party services and the adaptations that will be required as the Smart Grid grows and develops, all while minimizing the impact on the consumer.

Several possible communications scenarios were considered when pursuing an architecture model that would be most beneficial to both the manufacturers and the consumers. The simple interoperable scenario (see Figure 2) would suggest that all devices on the HAN use compatible protocols at all OSI layers for the ideal level of interoperability, reliability, and security. AHAM recognizes, however, that this is extremely challenging due to the lack of coordination or agreement between state regulators, utilities, and the variety of deployed AMI systems.

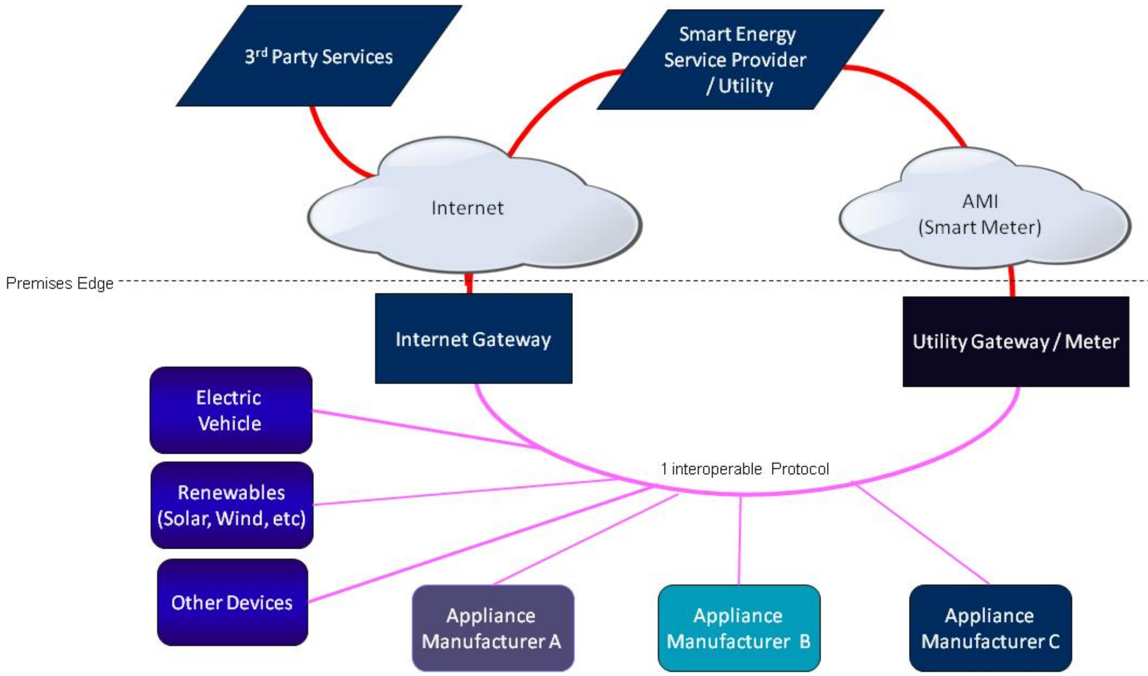

Figure 2: Simple interoperable scenario with one single protocol in use between all devices

In a worst case interoperability situation (see Figure 3) each appliance or device may be using its own protocol (PHY/MAC/NET and APP) as well as multiple different potential protocols across the country for the meter and other interfaces. This can lead to a considerable number of combinations. This situation may be resolved by having a converter at each device, but this approach adds complexity, overall expense to the system, and major problems for consumers to install and maintain

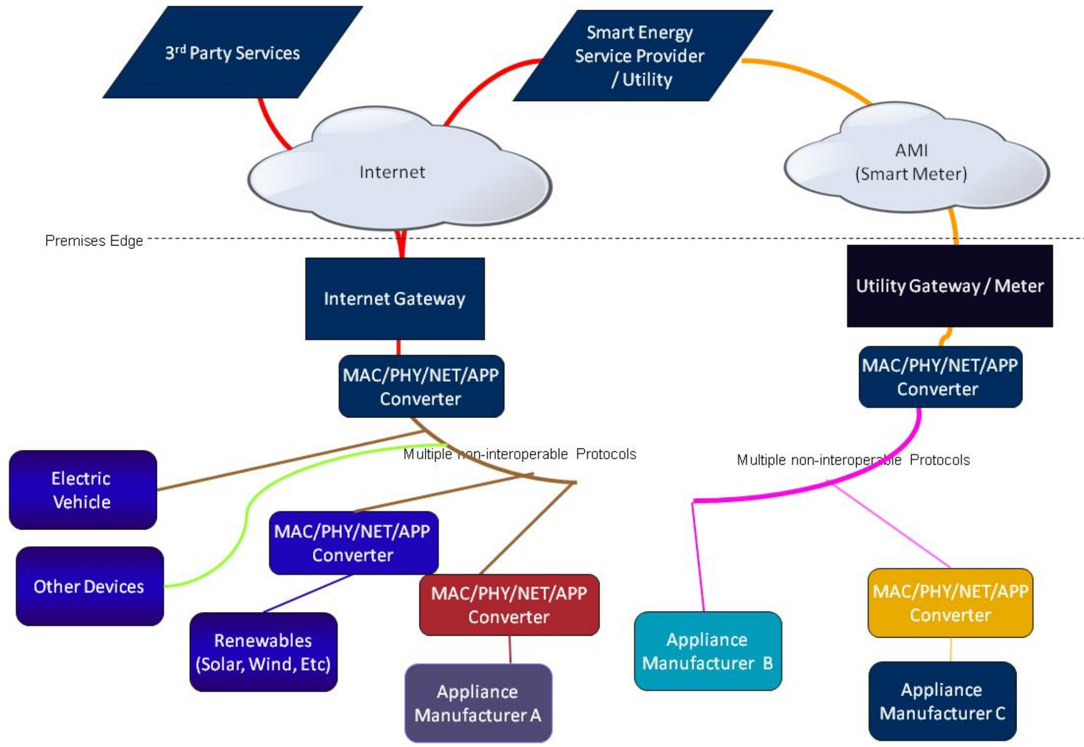

Figure 3: Worst case interoperability situation with many different protocols at each portion of architecture

Although there could be other viable architectures, the Assessment reflects a clear preference by the home appliance industry that the best communications architecture at this time features a hub or gateway (see Figure 4) that can communicate using common protocols and serve as the adapter or bridge to other devices on the Home Area Network (HAN). This type of architecture is consistent with the OpenHAN architectures and provides simplicity for the consumer, and the flexibility needed for future development needs. Additionally, this type of architecture supports a more robust, comprehensive "home networking" system approach compatible with consumer electronics devices.

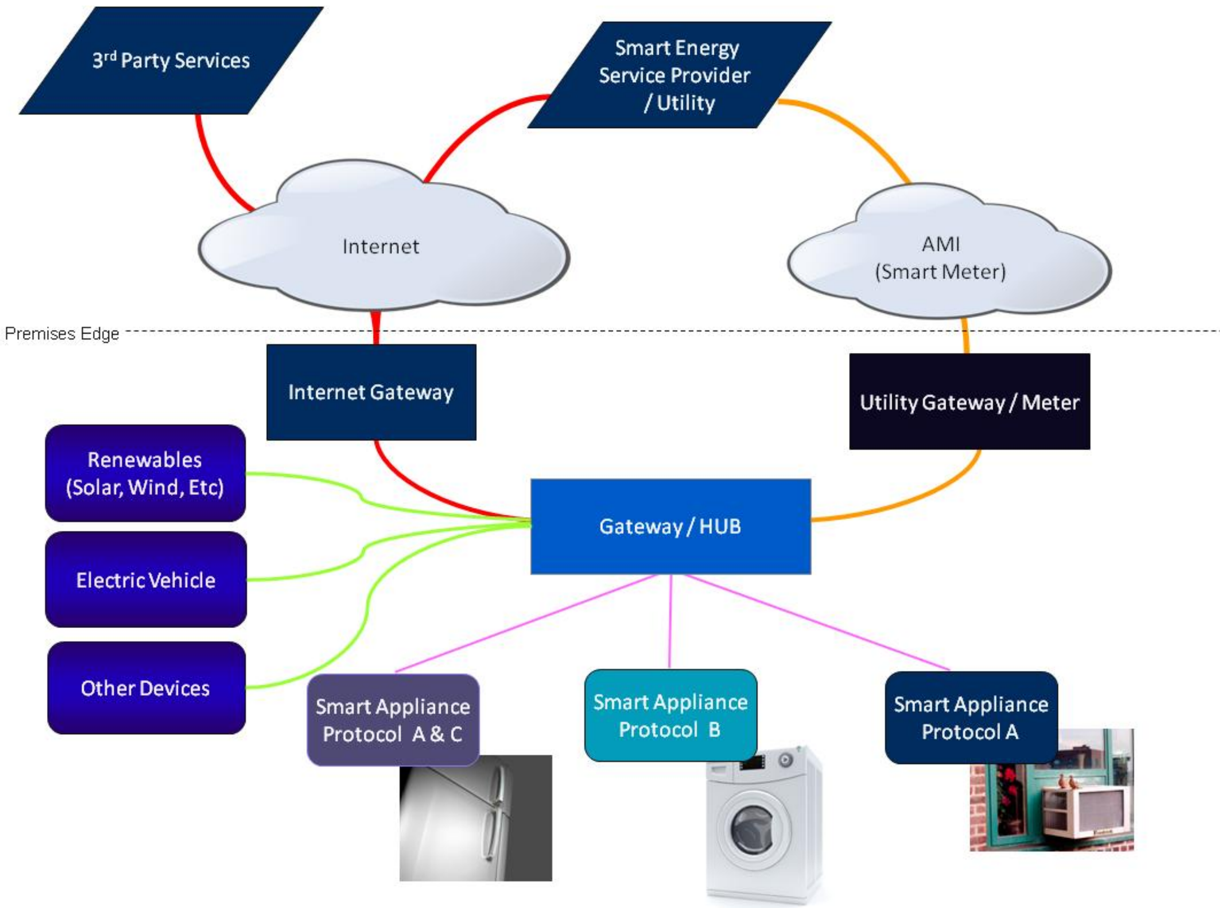

Figure 4: AHAM consensus architecture for connectivity and information pathways

The hub based architecture allows for coordination of the various appliances in the system and also allows for different connectivity and security implementations, thus allowing the various appliances to adapt to the many different possible installation scenarios. The hub also provides a ready conversion point at which a switch in protocols and physical layers can be executed without affecting or causing the smart appliance to become obsolete due to the use of a protocol not implemented in the meter or elsewhere. The hub can also provide a line of demarcation between the utility and the HAN. Furthermore, the hub can provide additional intelligence and adaptability to the entire system as the state-of-the-art advances, while also minimizing the need for device upgrades. The ability of this architecture to facilitate high level functions on the hub, including support of the identified protocols, communications diagnostics, security features, online reprogramming, and other functions, allows for more flexibility of requirements within various applications.

The hub architecture allows for the role of the hub to be accomplished by any device with suitable access and capabilities. The hub may reside within an AMI, an energy management system (EMS), or other possible devices and does not need to be an additional or standalone device. Simply put, the function of the hub is to provide a means by which Physical, Data Link, Network layer and Application layer protocol conversion can easily and economically occur.

AHAM believes the hub architecture represents the best optimization of utility and consumer needs, as well as overall implementation flexibility and simplicity.

Significant Technical Considerations

STRESS SCENARIOS

As AHAM and the EnerNex experts discussed and reviewed the different protocols, a few difficult cases were identified as stress scenarios that describe challenges that any protocol must be able to address. These stress scenarios are addressed for the protocols that were identified in the evaluation as those that best met the identified evaluation criteria. In some cases boundaries of responsibility are identified between the consumer, the property owner, and the utility or service provider.

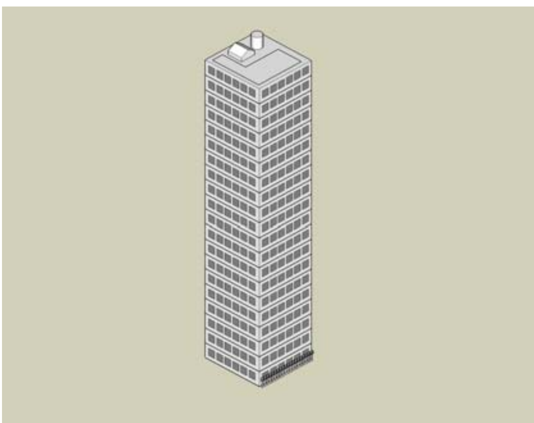

Figure 5: Multi-Story apartment buildings present unique challenges for getting signal to individual HAN

The first stress scenario is the multi-story apartment building (see Figure 5). The concern is for the consumer on the top floor to receive an AMI signal from a meter in the basement. The signal must reach each apartment and may require various technologies and stakeholders to support the signal transmission. The hub architecture helps to facilitate this situation as the hub becomes the single point at the residence that must be reached rather than multiple individual devices. Diagnostics within the hub would help both the utility and the consumer identify communication problems that might arise.

Similarly, for the stress scenario where the density of meters and signals create problems (see Figure 6), the hub is the single point to which the utility must be able to get the signal. Once the signal reaches the hub, propagation is within the consumer domain.

Once assurance of the signal to the hub has been achieved, by visual indicator or other means, the consumer is responsible. OpenHAN 2.0 recommends that HAN devices have communications diagnostics built-in in order to help the consumer ensure communication is occurring. In best-case scenarios, the establishing of communications will be achieved in a plug-and-play manner. Consumers may, however, need to be involved in the commissioning/registering and enrolling process, at least in some cases.

In some stress scenarios, the signal will not reach the appliance. This may be due to the structure of the building, installation of the appliance, or other factors that significantly limit or totally block incoming signals. Considerations were made within this assessment for mechanisms to support scaling into most stress scenarios such as robust signaling, coexistence mechanisms, high single station home coverage, bridging, repeating, and routing. For example, if a wireless signal is having trouble reaching one room of the home, coexistence and bridging mechanisms will allow for a hard-wired communication to be used to reach through the walls or other wireless impediments. Similarly, a repeater could be deployed within closer proximity to the room under consideration in less extreme situations.

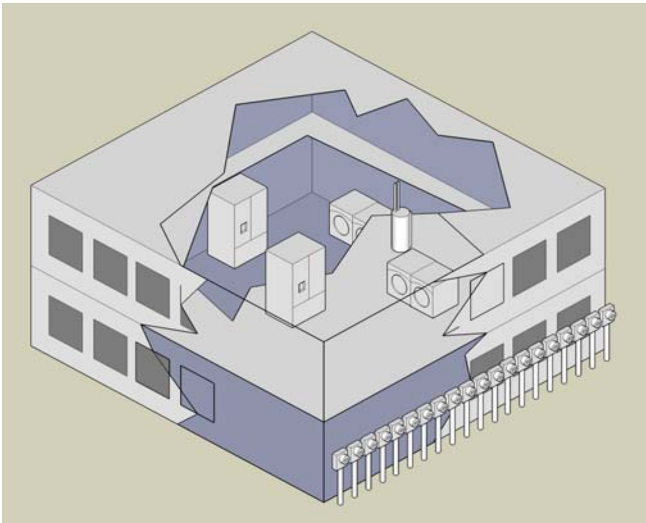

Figure 6: High meter density represents a unique stress scenario for the Smart Grid

LOW INCOME CONSUMERS

Low-income consumers are more vulnerable to rising energy costs than other sectors of society because a larger proportion of their disposable income is used to pay for energy. Extra effort should be taken to ensure that the low-income segment is not "left behind" by the Smart Grid. Consumers should be offered options such as time-of-use rates, critical peak prices, or peak-time rebates in order to have, if they want, more control over their bills and the ability to save money. Initially, a lower-cost Smart Grid solution is unlikely for smart appliances, legacy demand response devices such as air conditioners, or other new devices such as electric vehicles. Intermediary steps are, therefore, necessary for low-income consumers. A possible analogy could be the conversion from the analog to digital TV signals where a small public subsidy was used to rollout inexpensive digital converter boxes so that those least able to afford it were not left behind. The hub architecture described above takes the low-income consumer into account because it allows for a single node, rather than requiring access points for each enabled appliance, thereby providing a reduced-cost option for adoption of Smart Grid technology.

SECURITY AND PRIVACY

Privacy and Security are extremely important in the consumer environment. In a societal environment where identity theft is rampant, consumers are sensitive to the issue of devices in their home that could compromise their personal safety or privacy. The appliance industry must do its part to protect the consumer. For that reason, this assessment weighted the requirements related to privacy and security the heaviest by giving them a weighting of five out of five. Furthermore, protocols make use of encryption at different layers. NIST has established standards for encryption techniques and the handling of the keys used within those techniques.

This assessment gives preference to the protocols that follow the NIST recommended techniques.

The task of providing security services for the Smart Grid is not trivial due to its large scale deployment, legacy devices, scattered field devices, and its heterogeneous architecture[5]. An attacker may launch a wide range of attacks including man-in-the-middle (MITM), impersonation, eavesdropping, message forgery, packet dropping, message storms, and noise injection. Impacts of these attacks can be as serious as blackouts.

Thus, there are many crucial security requirements for the Smart Grid such as device authentication, privacy, message authentication, data integrity and data availability. All these requirements rely upon securely authenticated devices as a basis. Further, the HAN is the only part of the grid for which the utility has no direct control. It may, therefore, be the most vulnerable part of the Smart Grid. For this reason utilities have put in place the Energy Service Interface (ESI) in AMI HAN systems. Third parties will also implement an ESI to protect their systems from possible attacks to the HAN.

Appliance applications should use appropriate security measures to ensure that consumers have control of their appliances, and that unauthorized persons do not. Different security measures can be used to accomplish that goal. Encryption is used to ensure that consumer information is not visible to unauthorized persons. Authorization logic is used to grant privileges to consumers using access controls. Authentication is used to verify that users are who they represent themselves to be. Authentication logic is typically implemented with passwords. Various combinations of these security measures may be necessary to meet the security needs of smart appliances.

Despite advances in the security area, there is still work ongoing in this area for the HAN due to identified flaws in current schemes. These flaws include the need for user intervention or effort in establishing the security association, Man-in-the-Middle (MITM) attack vulnerabilities, and risk of compromise through other means. Thus, the ongoing work in the NIST Cyber Security Working Group on key management and cryptography is of fundamental importance as the Smart Grid evolves. Allowing for adaptation as advances occur in the security area was also considered within the hub architecture and addressed by the ability of the architecture to facilitate updating and improving of security at the hub.

[5] Cisco, "Securing the Smart Grid", available online: http://www.ciscosystemsnetwork.net/web/strategy/docs/energy/SmartGridSecurity_wp.pdf, 2009.

Study Methodology

EVALUATION PROCESS

The assessment was built with a focus on consumers' needs. To represent those needs accurately, AHAM's approach was to use appliance consumers' requirements to drive identification of the best protocols to use for Smart Grid interfaces. In Six Sigma language, this is called the Voice of the Customer. To represent this voice, AHAM chose to use the Quality Function Deployment (QFD) tool. The definition used in "Design for Six Sigma" by Creveling, Slutshy and Antis says of the QFD, "It is applied to translate, align and quantitatively rank the relationships between the new, unique, and difficult voice of the customer needs and new, unique, and difficult technology requirements." It is AHAM's desire to take the new, unique, and difficult customer needs related to appliances interfacing with the Smart Grid and determine how they correlate to the existing technology requirements in the available protocols.

EnerNex supplied home area networking consulting experts with lifetime expertise in networking media and protocols to conduct the assessment. Common prevalent technologies were identified from each of the three major types of HAN communications technology approaches: special purposed wired technologies, no new wires technologies, and wireless technologies. No technology of interest was intentionally passed over for evaluation. The customer requirements driven framework utilized is appropriate to evaluate any additional communications media that appliance manufacturers should happen to consider. Some technologies were considered for their existing market employment. Some technologies were considered for their emerging market positioning. Some technologies were considered by request of the appliance manufacturers. Most technologies of high relevance are already under consideration by NIST, and many have been identified in the "NIST Framework and Roadmap for Smart Grid Interoperability Standard, Release 1.0" as either vetted for Smart Grid usage or under consideration for vetting.

MAPPING OF REQUIREMENTS TO EVALUATION CRITERIA

According to "The Six Sigma Handbook", by Thomas Pyzdek, "QFD is implemented through the development of a series of matrices. In its simplest form, QFD involves a matrix that presents customer requirements as rows and product or service features as columns. The cell, where the row and column intersect, shows the correlation between the individual customer requirement and the product or service requirement." The product or service requirements under consideration here are the different communication protocols. The result will identify the protocol with highest correlation to the customer requirements.

In the top level matrix, called QFD1, AHAM identified a list of Customer Expectations based on the member companies' experience with their consumers and are listed in Table 1. A relative weighting factor was agreed upon for each of these consumer expectations. AHAM and

EnerNex then identified the System Requirements, which are listed in Table 2, that would be driven by these customer expectations as they relate to the candidate protocols.

Table 1: Consumer Expectation List

Easy to Install	**Consumers want products that are easy to install**
Easy to Use	**Consumers want products that perform well without requiring difficult or extensive inputs from them**
Interoperable	**Consumers want products that work with other brands and devices**
Reliable Operation	**Consumers want products to function consistently without issues**
No Compromise of Privacy	**Consumers expect product to have same level of privacy as current non-communicating products**
Low Security Degradation	**Consumers expect product to have the same level of security as current non-communicating products**
No Compromise of Safety	**Consumers expect products to be as safe as current non-communicating products**

Table 2: System Requirements Driven by Consumer

Proven Interoperable	**Protocol must be proven to interoperate on various types of devices**
Accepted Technology in Marketplace	**The technology must be accepted in various forms in the marketplace and have a commercial history**
Acceptable Cost Trade Offs	**Technology costs should be balanced against the need for meeting the various other requirements**
Easy to Provision/Plug and Play	**The communications need to be able to be established easily with minimal interaction and effort**
Minimize Enabling Infrastructure	**The amount of additional hardware and resources required to enable a system should be minimal.**
Technology Supply Chain Exists	**Various companies and avenues should exist for acquiring the technology and support**
Forward Backward Compatible/Future Proof	**Consumers expect to not have to worry about their products becoming obsolete or being incompatible with other items**
Interference and Noise Handling	**The system should be equipped with mechanisms for dealing with ambient interference and electronic noise issues**
Easy System Operation	**The system should be easy and stable for the consumer to operate**
Easy to Maintain	**The system should have minimal ongoing maintenance requirements**
Easy to Replace	**The system should be easy for the consumer to replace or upgrade when necessary**
Robust Messaging Capability	**Messages should be verified and able to support dynamic content and messaging growth**

Affordable to Install	**The system should be of minimal cost while maximizing performance for the consumer**
Security Mechanisms	**Security mechanisms must exist to address risk in communications**

This evaluation resulted in a ranking of the system requirements that most closely correlate to the customer expectations. The assessment carefully separated the Application level requirements from the Physical and Media Access Control layer requirements. The NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 1.0, however, listed several protocols that combined the Application layer with the PHY/MAC/NET layers. For example, the IEEE 802 family, as well as ZigBee, combine physical requirements with the Application layer. AHAM and EnerNex were careful to ensure the assessment fairly evaluated technology whether the Application layer was combined or not. Accordingly, the QFD lists ZigBee and HomePlug Green PHY in the PHY/MAC/NET evaluation section.

The separate evaluations of the PHY/MAC/NET layers and the Application layer resulted in construction of two second level QFDs (QFD2s). The QFD2s takes the System Requirements from QFD1 and translates them to the "expectations" or Y's in the QFD2s (See solid arrows in Figure 7). These System Requirements are assigned relative weightings according to the ranking from QFD1 (See dotted line arrows in Figure 7). EnerNex and AHAM worked together to develop detailed requirements under those System Requirements in order to provide appropriate differentiation of the protocols. A list of 55 requirements were identified which applied to both the PHY/MAC/NET and Application matrixes. To see the full list of these requirements, the detailed QFD can be found at www.aham.org/smartgrid.

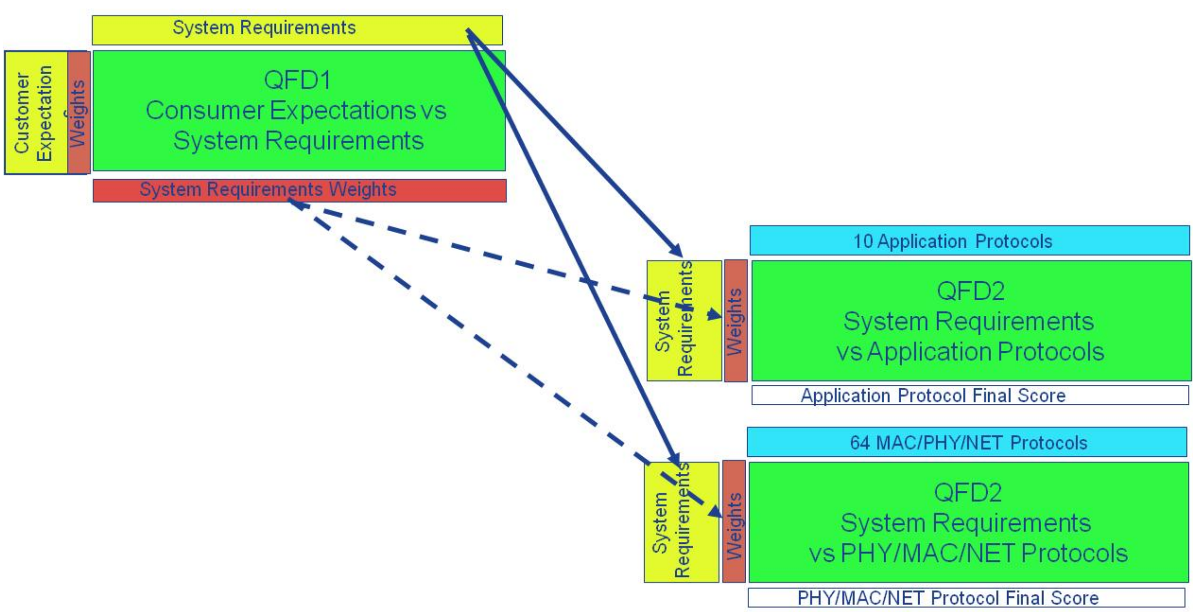

Figure 7: Relationship between QFD's, Consumer Expectation, and Consumer Driven System Requirements

EnerNex then developed evaluation criteria and a corresponding High, Medium, and Low score for each of these requirements. An example of this detailed requirements work is that a "proven protocol" was decomposed into requirements including "Standards Development Organization (SDO) supported" and "Certification Bodies / Test Labs Exist." Each protocol was evaluated to determine if it met the requirement. Values of High, Medium and Low were assigned based on a defined set of criteria. This process is explained in more detail later in this report (see Smart Appliance Communications Technology Study Results).

SURVEYED STANDARDS

This assessment focuses on communication protocols identified in "NIST Framework and Roadmap for Smart Grid Interoperability Standard, Release 1.0," as well as candidate protocols recommended by the AHAM commissioned consultant and AHAM members. The AHAM communications assessment surveyed and assessed protocols for PHY/MAC/NET (see Table 3) and Application layers (see Table 4) in terms of consumer smart appliance requirements.

Table 3: PHY/MAC/NET Protocols Evaluated

IEEE 802.11n	NIST Framework
IEEE 802.11a	NIST Framework
IEEE 802.11g	NIST Framework
IEEE 802.11b	NIST Framework
SEP 2.0 / ZigBee	NIST Framework
SEP 2.0 / HomePlug Green PHY	NIST Framework
IEEE 802.16 WiMAX	NIST Framework
IEEE 802.3	NIST Framework
ISO/IEC 14908-3 LonWorks PLCS	NIST Framework
ISO/IEC LonWorks 14908-2 TPC	NIST Framework
Z-Wave (v4)	NIST Framework
3GPP2 / CDMA2000 1x	NIST Framework
3GPP / GPRS	NIST Framework
3GPP / EDGE	NIST Framework
3GPP / UMTS	NIST Framework
3GPP / HSPA	NIST Framework
3GPP / HSPA+	NIST Framework
ISA 100.11a-2009	NIST Framework
HomePlug AV	NIST Framework
IEEE P1901 / FFT	NIST Framework
IEEE P1901 / Wavelet	NIST Framework
HomePlug C&C	NIST Framework
ITU-T G.hn	NIST Framework
ISO/IEC 12139	NIST Framework
IEEE 802.15.4-2003	NIST Framework
IEEE 802.15.4-2006	NIST Framework
ZigBee Pro	AHAM Member Request
IETF 6LoWPAN	AHAM Member Request
EnOcean	AHAM Member Request
ISO 18000-7 DASH-7	AHAM Member Request
ISO/IEC 14543-3 KNX-RF	AHAM Member Request
ISO/IEC 14543-3 KNX-PL	AHAM Member Request
ISO/IEC 14543-3 KNX-TPC	AHAM Member Request
IEEE 802.15.1 / Bluetooth 1.1	NIST Framework
IEEE 802.15.1-2005 / Bluetooth 1.2	NIST Framework
Bluetooth 2.0 + EDR	AHAM Member Request
Bluetooth 2.1 + EDR	AHAM Member Request
Bluetooth 3.0	AHAM Member Request
Bluetooth 4.0	AHAM Member Request
IEC 62106 Ed. 2 / NSRC RDBS	AHAM Member Request
ITU-R M.584 FLEX Paging	AHAM Member Request

HomePlug AV2	AHAM Member Request
TIA-1113 / HomePlug 1.0	AHAM Member Request
HomePlug 1.0 Turbo	AHAM Member Request
UPA-DHS	AHAM Member Request
PRIME	AHAM Member Request
INSTEON	AHAM Member Request
UPB	AHAM Member Request
X10	AHAM Member Request
A10	AHAM Member Request
G3	NIST Framework
CEBus	AHAM Member Request
IEC 61334	AHAM Member Request
SITRED	AHAM Member Request
MoCA 1.1	AHAM Member Request
HomePNA 1.0	AHAM Member Request
HomePNA 2.0 / G.9951, G.9952 and G.9953	AHAM Member Request
HomePNA 3.0 / G.9954	AHAM Member Request
HomePNA 3.1	AHAM Member Request
EIA-232 / RS-232	AHAM Member Request
U.S.B 1	AHAM Member Request
U.S.B2	AHAM Member Request
U.S.B-OTG	AHAM Member Request
IEEE 1394	AHAM Member Request

Table 4: Application Layer Protocols Evaluated

SEP 2.0	NIST Framework
OpenADR	NIST Framework
BACnet /ISO 16484-5	NIST Framework
BACnet ASHRAE 135-2008	NIST Framework
LON ANSI 709.1-B-2002	NIST Framework
IEC 62056 / DLMS	NIST Framework
ISO/IEC 15067-3	NIST Framework
OPC-UA	NIST Framework
Z-Wave	NIST Framework
ZigBee SEP 1.0	AHAM Member Request

Smart Appliance Communications Technology Study Results

The consumer expectations identified in Table 1 were evaluated for correlation with the system level requirements in Table 2. This resulted in the generation of relative importance scores for each of the System Level requirements. These relative importance scores created three groups of requirements with differing importance scores: privacy and security, reliable operation, and operation.

As discussed above, privacy and security are extremely important in the consumer environment. Similarly, the consumer does not want to be bothered with updates to protocols, whether for security or other reasons. This requires the device to be set up well for compatibility and future proofing in order to meet this customer need. These two systems requirements, Security Mechanisms and Compatibility/Future Proof, are weighted heavier than the others in this assessment. Chart 1 shows these two system level requirements have the maximum weightings of 9.

The next general grouping of system requirements address the reliable operation of the protocol. This assessment broke down reliability into several requirements and sub-requirements and weighted the proven/fielded protocol heavier than the unproven. This grouping had a weight of 3 in Chart 1.

The last requirements group had to do with operation. As stated earlier, consumers expect these products to require no intervention and be functional for up to 10 years. Although this requirements group gets a weight of 1, it does not mean this is not important to the consumer.

Everything on this list is important; these items simply had a lower relative importance compared to other requirements.

Consumer Expectations	Importance	Proven Interoperable Protocol	Accepted Technology in Marketplace	Acceptable Cost trade offs	Easy to provision to HAN / Plug and Play Appliance	Minimize Enabling Infrastructure	Technology Supply Chain Exists	Forward / Backward compatibility / Future proof	Interference and Noise Handling	Easy System Operation	Easy to Maintain	Easy to Replace	Robust messaging capability	Affordable to install	Security Mechanisms	Total
		Consumer Driven System Level Requirements														
Easy to Install	3	h	h	h	h	h	h	h	h	h	m	m	l	h	h	75
Easy to Use	3	h	h	h	h	h	h	m	h	h	h	h	l	l	l	63
Interoperable	3	h	h	h	h	h	h	h	h	h	h	h	l	l	m	69
Reliable Operations	3	h	h	h	m	h	m	l	h	h	l	l	l	l	h	39
No Compromise of Privacy	5	m	m	m	m	l	m	h	l	l	l	l	l	l	h	65
Low Security Degradation	5	m	m	m	m	l	m	h	l	l	l	l	l	h	h	105
No Compromise to Safety	5	m	m	m	m	l	m	h	l	l	l	l	l	l	h	65
TOTALS		153	153	153	135	123	135	201	123	123	81	81	27	91	201	
WEIGHTING TO NEXT LEVEL		3	3	3	3	3	3	9	3	3	1	1	1	1	9	

Chart 1: Top level QFD. Detailed explanations of system level requirements are available in Appendix A. The full spreadsheet is available at www.aham.org/smartgrid.

Charts 2 and 3 show the results of the top 10 protocols when evaluated for correlation to the identified system level requirements. The discussion that follows will address the system level requirements and the resulting scores of the leading protocols. The scores have no absolute meaning other than they provide a relative separation based on the evaluation criteria and expert input provided by EnerNex.

Top PHY/MAC/NET Protocols Scores at Sys Level Req

CONSUMER DRIVEN SYSTEM LEVEL REQUIREMENTS	IEEE 802.11n Wi-Fi	HomePlug Green PHY	ZigBee	IEEE P1901 / FFT	ZigBee Pro	IEEE 802.11g	Bluetooth 4.0	ISA 100.11a-2009	HomePNA 3.0 / G.9954	Bluetooth 2.1 + EDR
Proven Interoperable Protocol	22	18	22	17	16	22	15	12	20	15
Accepted Technology in Marketplace	23	14	19	4	13	22	3	4	13	16
Acceptable cost trade offs	23	27	18	18	23	23	27	23	17	23
Easy to provision to HAN / Plug and Play Appliance	20	27	27	23	20	20	27	27	15	27
Minimizes Enabling Infrastructure	20	20	29	16	29	16	34	29	7	29
Technology Supply Chain Exists	27	27	27	27	27	27	27	17	24	27
Forward / Backward compatibility / Future proof	81	63	63	63	57	57	63	33	57	63
Interference & Noise Handling	17	21	17	21	12	12	21	27	27	17
Easy System Operation	27	27	27	27	21	21	15	21	27	15
Easy to Maintain	9	9	9	9	9	9	9	9	9	9
Easy to Replace	9	9	9	9	9	9	9	9	9	9
Robust messaging capability	9	9	5	9	5	9	9	9	9	9
Affordable to install	3	9	9	3	9	3	9	9	3	9
Security Mechanisms	81	81	81	81	69	69	48	81	69	36
TOTALS	373	368	368	334	325	321	318	317	306	306

Chart 2: Summary of the findings from the second layer QFD called QFD2 for the top 10 scoring PHY/MAC/NET layer protocols. The full spreadsheet is available at www.aham.org/smartgrid

Top Application Protocols Scores at Sys Level Req

CONSUMER DRIVEN SYSTEM LEVEL REQUIREMENTS	SEP 2.0	OpenADR	ISO/IEC 15067-3	OPC-UA	BACnet ASHRAE 135-2008	Zwave	ZigBee SEP 1.0	IEC 62056 / DLMS	BACnet /ISO 16484-5	LON ANSI 709.1-B-2002
Proven Interoperable Protocol	20	16	11	17	11	17	8	20	13	10
Accepted Technology in Marketplace	3	13	3	5	13	27	27	19	13	15
Acceptable cost trade offs	15	19	15	7	13	11	9	19	13	15
Easy to provision to HAN / Plug and Play Appliance	18	4	18	18	18	18	12	4	18	18
Minimizes Enabling Infrastructure	15	6	27	3	27	27	9	6	27	3
Technology Supply Chain Exists										
Forward / Backward compatibility / Future proof	72	69	81	15	39	12	9	15	9	9
Interference & Noise Handling	27	15	3	19	5	13	3	11	5	7
Easy System Operation	23	11	3	18	17	6	18	17	17	23
Easy to Maintain	6	1	1	5	3	5	1	2	3	4
Easy to Replace										
Robust messaging capability	8	5	7	6	4	4	5	3	4	3
Affordable to install										
Security Mechanisms	63	39	7	63	13	21	63	21	13	21
TOTALS	261	194	176	167	161	157	155	133	133	124

Chart 3: Summary of the findings from the second layer QFD called QFD2 Application layer protocols and is available at www.aham.org/smartgrid

CONSUMER DRIVEN SYSTEM LEVEL REQUIREMENTS

This section compares each of the three top technologies with respect to appliance centered communications technology high-level systems criteria. Individual high-level criteria will be described and the top performances will be discussed. The descriptions of the outcomes within this section reflect the decisions and information provided by EnerNex as part of their summary report to AHAM. Some content was edited for continuity and consistency, but the results and language are reflective of the findings of the consultant and the expertise that was relied upon by AHAM members in creation of this assessment.

Proven Interoperable

When a protocol has a track record in the consumer environment, a manufacturer has some level of confidence that the "bugs" have been worked out of the protocol basics. The Proven Interoperable requirement evaluated the overall interoperability potential of protocols based on use of established standards, interoperability with energy protocols, industry backing, and ability to validate interoperability. Several consumer expectations are highly correlated to this "proven track record" (see Chart 1).

Application Layer

The evaluation showed the highest scoring application-level protocols in this category are SEP 2.0 and IEC 62056 DLMS/COSEM (see Chart 3). SEP 2.0 led this category with both loosely coupled independent network layers and IEC CIM (Common Information Model) compliance. DLMS/COSEM placed second with loosely coupled independent network layers and an approved and mature SDO supported specification.

SEP 2.0 performed well in this category because the ZigBee alliance has worked closely with energy experts to develop a protocol which is interoperable in the Smart Grid space. For example, early deployments of SEP 1.0 saw some areas for expansion. The ZigBee team was thus able to leverage their experience to institute improvements in SEP 2.0. A significant improvement of SEP 2.0 is that it is now loosely coupled allowing it to interoperate across other network layers, platforms and media. SEP 2.0 and DLMS/COSEM both score well in this category because they were specifically designed by energy experts to meet the needs of energy load control for devices such as appliances. Thus, these protocols incorporate required interoperability for devices including appliances.

PHY/MAC/NET

Wi-Fi, ZigBee, and HomePlug Green PHY are proven interoperable technologies based on open specifications with a high degree of standards reuse (see Chart 2). These are the top three most suitable communication protocols based on the analysis and have virtually indistinguishable benefits for smart grid applications for appliances interfacing with consumers. Wi-Fi and ZigBee are the most proven technologies of the three. Of the three technologies, only Wi-Fi is holistically standardized under the IEEE 802.11 family of standards. ZigBee's underlying MAC and PHY are fully standardized under IEEE 802.15.4 and current revisions are moving to an IETF RFC based layering of standards for the network and transport layers.

HomePlug Green PHY is not yet standardized, but uses and extends a core set of features in P1901-fft for its PHY, MAC PLC layering, as well as IETF RFC layering for its network layer. All the technologies have multiple representative test labs available through their respective commercial technology alliances. Each of the three technologies has been identified by the NIST Smart Grid Interoperability Panel (SGIP) as interoperable and suitable for use in Smart Grid applications. Each technology is currently being actively retooled to support at least one relevant Smart Grid application protocol such as the SEP 2.0.

Accepted Technology in the Marketplace

This systems requirement addresses the maturity of the protocol from the market perspective where Proven Interoperability looks from the technology perspective. It asks the question of how pervasive is the protocol in the marketplaces. These applications will be other than grid related at this time but will provide some indications of the protocols' success in the consumer environment. Chart 1 shows the Consumer Expectations are highly correlated to this system level requirement.

Application Layer

The highest scored application-level protocols in this category are those with commercialized HAN and non-HAN products currently installed in consumers' homes, namely Z-Wave and SEP 1.0 (see Chart 3). Z-Wave and SEP 1.0 products support Smart Grid needs and existing products because both include controllers and devices such as programmable thermostats. Z-Wave and ZigBee SEP 1.0 are well accepted in the marketplace.

PHY/MAC/NET

It is desirable to make appliances integrate with the technology a customer is already likely to have at a premises. Technologies currently appear in several different marketplaces relevant to Smart Grid. ZigBee and HomePlug Green PHY are the furthest along in being retrofitted to work with AMI meter markets. Though several companies have announced support, only initial forays into Wi-Fi for AMI meters have been demonstrated. Premises with Internet connectivity are currently most likely to have Wi-Fi in home internet routers. Initial forays into home internet routers/gateways having HomePlug Green PHY and ZigBee have been made, but they are rare by comparison. Utilities have considered deploying internet connected demand response gateways to help seed the market for demand responsive energy services. In that submarket, ZigBee and Wi-Fi are leading with a strong demonstrated use of ZigBee to communicate with AMI meters and various types of controls. Also, Wi-Fi is more likely implemented in situations requiring it to connect ZigBee to customer owned infrastructure. Finally we looked at what technologies the customer uses in their home. Two major applications exist, connecting consumer end electronics and connecting home automation controls and sensors. Consumer electronics are most likely connected by Wi-Fi, though ZigBee is entering the set top box market. On the horizon is HomePlug Green PHY. This PLC protocol is designed to be highly relevant to the home automation and control market and will have the ability to interact with other HomePlug Green PHY variants that are very likely to appear in the consumer electronics market.

Acceptable Cost Trade-Offs

Cost is a very big issue in the appliance industry. In an attempt to understand the trade-offs between cost and the consumer requirements, this System Level Requirement identified the direct correlation of cost to several protocol parameters that impact consumer expectations.

Application Layer

Top performers in this category were DLMS/COSEM and OpenADR, both of which did well because they did not require additional consumer hardware for configuration, allowed consumers to respond to utility pricing information, and had existing less complex implementations. It is anticipated that these factors will tend to decrease cost to consumers. It should be noted that these protocols are not fully capable of the OpenHAN requirements. The highest performing protocols for this requirement that were OpenHAN compliant as shown in Chart 3 are SEP 2.0, ISO/IEC 15067-3 and LON ANSI 709.1-B-2002.

PHY/MAC/NET

Technology components have various cost trade-offs with respect to appliance requirements. According to EnerNex, who studied the public marketing offerings, determined the reasonable expectation of cost of the top three which ranged from ZigBee having the lowest cost offerings, to HomePlug Green PHY being higher, and then Wi-Fi being even higher, with all three meeting or approaching manufacturer requirements. Wi-Fi solutions offered the highest bandwidth, followed by HomePlug Green PHY, and then ZigBee, with all meeting or exceeding the bandwidth required for appliance smart energy applications. HomePlug Green PHY had the lowest potential latency, followed by Wi-Fi and then ZigBee. All three technologies outperformed single link expectations for appliance Smart Grid application latency requirements. HomePlug Green PHY was clearly designed to mandatorily support energy proportional power consumption while ZigBee and Wi-Fi enabled it in various different forms on different market offerings. In general, the expectation that a Wi-Fi access point (AP) would be required and responsible for being capable of managing its low power mechanisms lowered our energy proportional power consumption. Each of these items -- bandwidth, latency and power consumption -- will need to be balanced during implementation and will directly affect cost of implementation. Manufacturers will have to determine the solutions that provide the best balance and acceptable cost tradeoffs.

Easy To Provision / Plug-And-Play Appliances

This system level requirement is highly correlated to consumer expectation related to installation, use and interoperability (see Chart 1). As stated previously, ideally the Smart Grid enabled product is no more difficult to install than the non-Smart Grid enabled product. The main difficulty with installation will come with the security requirements and the fact that residences are all different (see Minimizes Enabling Infrastructure) due to construction, layout, size, materials, and other factors. The need for security will drive the consumer to, at a minimum, make a phone call or in some other secure manner communicate with the service provider.

The Easy to Provision/Plug-and-Play Appliances requirement is concerned with the ability of the protocol to allow the addition of more appliances/devices onto an existing network and the difficulty related to that activity. For the appliance consumer, this activity should be almost invisible. The Easy to Provision/Plug and Play Appliance requirement evaluated how easily consumers could add a smart appliance to their home. Factors considered within this requirement include the ability to integrate the appliances into the consumers HAN, the ability to authorize users for different capabilities, and the ability to add and modify appliance configurations.

Application Layer

The majority of application protocols did well in this category with 7 of the 10 having the ability to support multiple appliances and to add and modify configurations. Among the top scores, only OpenADR did not score well in this category. OpenADR was originally designed to provide demand response signals to business customers. It lacks explicit support to add and modify device settings.

PHY/MAC/NET

The PHY/MAC/NET evaluation compared the protocols abilities to adapt to the difficult situations. The list of options available and supported by the protocol determined the score for this requirement. Appliance manufacturers want to ensure a very simple and easy process for initial connectivity of the appliance for the customer; this includes joining, security establishment, repeating and routing, bridging, and link state feedback. ZigBee and HomePlug Green PHY have been designed to support all consumer and utility install cases by having common link defaults, 3rd party security management, installer codes, and full support for application layer constructs that enable easy and secure joining in Smart Grid applications. Wi-Fi has the ability to be deployed with many of the features above, but typically requires an involved user configuration process requiring host computers in the current PC type deployment scenarios. It is expected that this situation will change as Wi-Fi grows into a common Smart Grid role, and more refined application and network layer provisioning and binding mechanisms are adopted for the Smart Grid application.

All three technologies provide standard options for signal repeating and individual link extension to support extending appliance connectivity. Wi-Fi has a repeating mode. HomePlug Green PHY has mesh-under repeating and routing. ZigBee has a repeating mode. All three technologies offer standard means for bridging onto other media that may be installed in the customer's home. This enables appliance customers to penetrate walls with one technology, for example wired power line communication, and propagate to areas without wires with another technology such as Wi-Fi. By using multiple technologies a connection to existing infrastructure with any possible combination should such technology mixing be required. ZigBee will have route-over 6LoWPAN gateway support. Wi-Fi and HomePlug Green PHY are 802.2 capable, bridging trivially to other Ethernet-like media, and Wi-Fi supports WDS wireless bridging inherently, as well. Finally, all three technologies have sufficient provisioning feedback support enabled in the technology to enable high detail provisioning error recovery information to customers trying to understand what steps need to be taken to connect their appliances to the Smart Grid.

Minimizes Enabling Infrastructure

The Minimize Enabling Infrastructure category measures the ability of consumers to acquire new smart appliance technology with a minimum of additional extra hardware and software components beyond the appliances and a controller/gateway.

Application Layer

Protocols which scored well in this category include Z-Wave, BACNET and IEC 15067, the Home Electronic System (HES) application model. Among the front runners, Z-Wave performed well in this category because it requires no additional software such as a web server or hardware such as a PC, while other protocols performed less well because they specified web interfaces to perform configuration.

PHY/MAC/NET

To minimize overhead cost to the customer due to additional nodes and to simplify installation and maintenance, it was preferred that individual nodes provide the highest home coverage possible. Wi-Fi and HomePlug Green PHY scored the best in this category as they have been designed to have higher end signal processing, more aggressive coding, and spreading mechanisms for wider pass bands. ZigBee's mesh architecture has resulted in a radio designed for denser station count deployments to achieve high reliability lower power consumption, and reduced interference at a lower cost. A single HomePlug Green PHY station generally covers 200 feet out both legs of 240/120 V wiring schemes without issues up to and including 24 V HVAC segments.

To minimize cost and complexity at installation, technologies that required little additional cabling were preferred. In general, Wi-Fi, ZigBee, and HomePlug Green PHY all require no additional wiring to deploy. Installation topology was considered in how it minimizes additional nodes in the network. While operating at their absolute operating ranges, both Wi-Fi and ZigBee may require repeating devices. Certain modes of Wi-Fi provides better absolute range as compared to ZigBee and HomePlug Green PHY, while ZigBee has the advantage of using a mesh networking topology so each device that joins the network will extend the service and reduce the need to buy a device specifically for range extension. Each additional device in a star networking topology, which Wi-Fi utilizes, will not affect the range of any other devices on the network.

Another important consideration is that appliance communications should require very low amounts of power to help enable other features on the device in various regulated low power modes. EPA ENERGY STAR certifications and other regulatory constraints cause appliance manufacturers to need the lowest possible power consumption in the feature classes considered. In general, both ZigBee and low-powered Embedded Wi-Fi were lowest potential power consumers that met other requirements at tension with power such as cost, data rate, and security. All three technologies had peak power consumptions at or below half a Watt.

Technology Supply Chain Exists

Each technology was evaluated for supply chain maturity. In general, ZigBee, HomePlug Green PHY, and Wi-Fi have well established integration talent, integration tools, and the parts are available for integration into Smart Grid applications. More importantly, each has multiple independent silicon and software stack providers with a projected volume availability of silicon and stacks within an immediate horizon.

Forward/Backward Compatibility/Future Proof

This system level requirement is highly correlated to consumer expectations related to installation, interoperability, privacy, security and safety (see Chart 1). This is an extremely important issue for consumers. Today, consumers have no need to worry about updates to appliances and should not have to worry about this in the future.

Therefore in this category, Easy to Maintain addresses the idea of software upgrades. The criterion for the Application layer places high value on the protocol that implements the known methods for demand response. SDO affiliation is also an indicator of the forward support for a protocol. IEC 15067 and SEP 2.0 performed well in this category because they address the majority of load control and price-related plans currently in use or envisioned in the future. Such load control plans range from direct load control to real-time energy pricing. Many different plans and programs are expected from the more than 3000 utilities, and protocols performed well in this category because they are able to support a wide range of many different types of load control programs as well as independent load control. For this requirement ISO/IEC 15067 (HES) scored the best as it supports all of the current and planned load control programs, while SEP 2.0 supports all current and planned load control programs with the exception of load shifting programs. At the moment, SEP 2.0 is not backward compatible with SEP 1.0 and other earlier releases. There is a pretty significant installed base of SEP1.0 AMI systems. We noticed that there were cases where some of these AMI systems might not be upgraded to SEP 2.0 in the near future. In order to support coexisted SEP1.0 and SEP2.0 AMI systems, the HUB would have to be able to translate the Application layer SEP1.0 to SEP2.0. OpenADR scored third with support for all current and planned load control, except for independent power optimization.

Appliances need to expect that current and future revisions of communications technologies they implement will have longevity in the market, but that if they do not, will have generational compliance features and firmware upgrades to extend the useful window as far as possible. At the PHY/MAC/NET layer Wi-Fi is scores high in future-proof, having demonstrated a long history of backwards compatibility and continued support of an 802.2 bridging point. HomePlug Green PHY has been designed to be fully interoperable at low data rate with other powerline standards such as HomePlug AV and future AV revisions as well as offering an 802.2 compliant bridging point. ZigBee has retained interoperability at the PHY/MAC/NET layers, but has added sufficient architecture to assure future interoperability for the near future through inclusion of IPv6 support and a strong internal standards basis.

Handles Interference and Noise

The Appliance Interference and Noise Handling category measured the ability of applications to operate in typical home environments. The criteria measured included the ability to operate in low power environments with limited resources, auto-recovery from communications errors and a message prioritization method to ensure high priority messages are transmitted before routine ones. Appliances require communications protocols which handle interference and noise because they must operate and coexist in many different home environments ranging from multi-dwelling unit environments to suburban homes. Communication challenges which may exist in homes range from building materials which block signals to homes with a plentitude of competing communications systems.

Application Layer

SEP 2.0 and the OPC Unified Architecture protocols performed well in this category. SEP 2.0 performed top in this category because it provides specific capabilities to overcome common communications issues. Such logic includes specific logic to address loss-of-communications, and the ability to send higher priority messages ahead of lower priority messages. OPC Unified Architecture performed well in this category even though it does not specifically address low power or limited resource environments because it featured auto-recovery from loss-of-communications and quality of service logic to allow high priority messages to be sent ahead of lower priority messages.

PHY/MAC/NET

Appliances require communications technologies which handle interference and noise so that they have features that enable them to scale to multi-dwelling unit environments, coexist with other similar communications technologies, be resilient to direct interference, and attempt to reduce their own emissions where possible. ZigBee scales the best to multi-dwelling environments currently, offering the greatest scalability for band consumed, deployments of size 500 nodes per PAN are easily achievable and installations of up to 8,000 nodes in a multi-dwelling unit have been reported. HomePlug Green PHY came in second and was designed to scale very well across shared transformer to home and endpoint densities of 128 homes per transformers and 32 nodes per home. Wi-Fi came in third. Wi-Fi has overlapping bands and little conflict resolution for interference. In general, Wi-Fi falls back very rapidly to lower data transmission rates when there are unused portions of the spectrum. ZigBee had no coexistence mechanisms for wireless coexistence other than some incidental avoidance strategies and conflicts directly with Wi-Fi for many cases. Wi-Fi coexists with certain other standards such as WiMAX and Bluetooth, but it has no standard mechanism for new technologies to integrate to assure coexistence. HomePlug Green PHY did the best with its use of IEEE P1901-ISP as its coexistence mechanism. All three technologies have means for transmit power control. HomePlug Green PHY and Wi-Fi have explicit coordinated mechanisms for transmit power control and ZigBee implementers could easily implement a mechanism for a given product using the features typically available. HomePlug Green PHY came in second and was designed to scale very well across shared transformer to home and endpoint densities of 128 homes per transformers and 32 nodes per home. Wi-Fi came in third. Wi-Fi has overlapping bands and little conflict resolution for interference. ZigBee has avoidance strategies in the specification and specifies smart energy channels which do not overlap with Wi-Fi channels. Finally, Wi-Fi, HomePlug Green PHY, and ZigBee all had sufficient spectrum spreading mechanisms to reject narrowband interference sources.

Easy System Operation

Application Layer

The Easy System Operation category measures how simple operation of Smart Grid functions of a particular protocol would be for a consumer as would be required in an appliance implementation. Features which enable easy use by consumers include automatic discovery of new appliances, automatic installation, and error messages in human-readable format. Top performers in this category are SEP 2.0 and LON ANSI 709.1-B-2002, which feature capabilities such as auto-discovery of devices which automatically perform common required tasks for consumers. ZigBee and LON performed well because their design addresses consumer usability in addition to technical features.

PHY/MAC/NET

Appliances should not become challenging to use due to communications gear. Communications technologies should offer stable and reliable links, plug and play network interaction, and sufficient link state feedback to the customer. ZigBee, HomePlug Green PHY, and Wi-Fi all offered stable and reliable links. For most modulation means available, the receiver error margin is relatively narrow resulting in links that work well when the link strength is high enough and do not typically behave marginally when they are approaching the edge of their range, eliminating much uncertainty about good coverage. ZigBee, HomePlug Green PHY and Wi-Fi all have demonstrated potential in the market for plug-and-play operation. Finally, all three technologies have sufficient data enabled in the technology to enable high detail link state feedback to customers trying to understand what steps need to be taken to connect their appliances to the Smart Grid.

Easy to Maintain

Application Layer

The Easy to Maintain category measures the ability to update the application software and firmware by consumers and service technicians. SEP 2.0, OPC Unified Architecture and Z-Wave performed well in this category. Protocols which did well in this category were designed to address the need for updates, and thus they provided specific methods to accomplish an update. Protocols which did poorly did not provide an update strategy.

PHY/MAC/NET

Appliance communications technologies should be easy to maintain. Most consumer technologies support this goal, aiming to be maintenance free once installed beyond adding additional customer devices to the network. ZigBee, HomePlug Green PHY, and Wi-Fi all do very well, and are very low maintenance once installed.

Easy to Replace

Appliance communications technologies should be easy to replace. Beyond installing and registering new authentication credentials following a replacement, there is nothing specific that would prevent ZigBee, HomePlug Green PHY, and Wi-Fi from being easy to physically replace. Installation issues are covered in other criteria. Therefore, this remains a manufacturer issue to differentiate the ease of replacement of the physical components implementing the protocol.

Robust Messaging Capability

Application Layer

Robust messaging capability ensures that data messages are verified during transmission, that messages in non-static formats are supported, and that message data queries including appliance-specific queries are supported. Non-static messages allow for more new messages to be used which are not necessarily similar to current messages. Typically non-static message are defined using Extensible Markup Language (XML) or similar methodology. The Robust Messaging Capability was one of the three lower importance requirements and hence it did not influence the survey results as much as more important requirements. The SEP 2.0 and OPC Unified Architecture protocols led this category because they were the only protocols which would allow appliance specific data queries such as queries which applied only to refrigerators.

PHY/MAC/NET

Appliance communications should be robust to changing home area network conditions. To address certain Smart Grid applications, technology features are required to honor quality of service (QoS) and use effective error correcting codes to address changing network conditions. In general, quality of service may be negotiated or designed end-to-end, but must be enforced at individual nodes on a network. Wi-Fi and HomePlug Green PHY both have means to enable quality of service through support of IEEE 802.1Q delivery at the link layer. ZigBee had no such QoS means. All three mechanisms offer sufficient means for error correcting codes. Wi-Fi and HomePlug Green PHY utilized more aggressive coding and forward error correction codes due to the higher data rates they achieve.

Affordable to Install

Appliances need technology that is more affordable for the customer to install. ZigBee and HomePlug Green PHY are peer-to-peer technologies, and therefore only require additional nodes if there are link contact issues. Wi-Fi is a star topology technology and requires that the customer or other entity provide an access point to connect individual appliances. Therefore, cost to install Wi-Fi is very likely higher for the average case than ZigBee or HomePlug Green PHY.

Sufficient Enabling Security Mechanisms

The security mechanisms category evaluated the protocols ability to ensure that consumers have control of their appliances and information, and that unauthorized persons do not.

Application Layer

SEP 2.0, OPC Unified Architecture and ZigBee SEP 1.0 performed well in this category. These protocols did well because they incorporated security mechanisms including both encryption and authorization. The high scoring protocols included encryption and authorization because they viewed consumer privacy and authorization as issues which needed to be addressed.

PHY/MAC/NET

Appliances need security both to allow the customers to protect themselves and to attach appliances directly to utility and third party networks that may have minimum-security expectations. In general, the market expects that network nodes be capable of authenticating themselves using pre-shared keys and certificates, offering link and network encryption options, and enforcing logical network separation. Wi-Fi, ZigBee and HomePlug Green PHY offer means to enable best of breed EAP-TLS based mutual authentication and encryption methods. Each technology has customer-centered features for establishing pre-shared-keys and centralized means for establishing public key infrastructure X.509 certificates. Further, encryption links supporting AES-128-CCM are possible for links, networks, and applications. Finally, all three technologies support one or more forms of logical network separation. Both Wi-Fi and HomePlug Green PHY support 802.1Q style VLAN's, while ZigBee uses 802.15.4 PANs for network separation. All three enable network separation enforcement through encryption.

Conclusions

Smart appliances and the residential consumer represent a significant component of the Smart Grid initiatives—they provide a financial and energy benefit to both consumers and utilities, and as such are an important component in the marketplace.

To facilitate the growth of these devices in the market, it is important that nationwide communications standards are established. These standards are critical to reduce risk and increase the overall simplicity of developing and implementing these devices. Without such standards, risks such as obsolescence, system incompatibility, security faults, and others potentially undermine the vision for the Smart Grid.

The AHAM commissioned study, through an independent consultant, evaluated each technology via a specified, comprehensive but not complete requirements driven scoring system to rank the various communications technologies' ability to meet the unique needs of appliance consumers. The assessment determined that the most relevant evaluated communications technologies were clearly separated from their peers for use in appliance Smart Grid applications. For the Application layer, that the study found that SEP 2.0 and OpenADR scored the highest. Across the media and network layers evaluated, Wi-Fi, ZigBee, and HomePlug Green PHY, scored the highest. The draft revision of SEP 2.0, dated May 7, 2010, was used in the analysis, and for HomePlug Green PHY, it was assumed that the final certification was approved.

The highest scoring protocols derived from this assessment, with the limits of the criteria applied, have advantages for implementation of consumer appliances into the Smart Grid. Appliance manufacturers can, if they choose, use these results to make individual decisions about producing appliances that will integrate with the Smart Grid.

APPENDIX A
CONSUMER REQUIREMENTS DEFINITIONS

Easy to Install – Consumers want products that are easy to install. A communication protocol must be self-installing and maintaining for the average consumer to make use of it. The consumer should be able to plug in the power cord on the product, indicate they want to be grid connected and after that the communications should just work. Consumers will have to participate in some set up such as reading numbers on the product and communicating them to a third party via telephone or secure web site. Beyond that, the communications install should be invisible to the consumer.

Easy to Use- Consumers want products that perform independently of them. If they do want to intervene in the automatic operations, this must be easy and intuitive to the consumer. The protocol must be invisible to the consumer and require no action accept when they desire to change something. Indicators on the product should provide information related to the current conditions of electricity such as price.

Interoperable – Products must interoperate. When a product is installed it must be able to perform all the assigned tasks through proper and accurate communication with the other products in the network. Again, consumers expect to plug in the product and it just works. This is just expected by the consumer.

Reliable Operation – Appliance consumers expect products to operate worry free for a majority of usable lifetime of the appliance. Communication protocols will have to be able to support this kind of reliable operation for this period of time. A lot consumer intervention for upgrades and changes will not be acceptable to consumers of appliances.

No Compromise of Privacy – Consumers expect no change to their current levels of privacy as a result of adding Smart Grid enable products. This is one of the 3 highest priorities for appliance manufactures of Grid enabled products.

Low Security Degradation – Consumers expect the same level of security to their products as they have on appliances today. This is one of the 3 highest priorities for appliance manufactures of grid enabled products.

No Compromise to Safety – Consumers and the industry expect products to be safe and the addition of communications cannot override existing safety protections and functions. Along with product safety, this is the highest priority for appliance manufacturers of grid enabled products.

APPENDIX B
SYSTEM LEVEL REQUIREMENTS DRIVEN BY CONSUMER REQUIREMENTS

Security Mechanisms - The number one concern of AHAM members is the risk to the consumer that a communications link to the appliances could bring.

Forward / Backward Compatibility / Future Proof - This system level requirement is highly correlated to consumer expectations related to installation, interoperability, privacy, security and safety.

Proven Interoperable Protocol - When a protocol has a track record in the consumer environment, a manufacture has some level of confidence that the "bugs" have been rung out of the basics of the protocol. In this case, all of the consumer expectations are highly correlated to this "proven" track record even if the application of the protocol is somewhat different. Therefore; the systems evaluation looks at these proven protocols and some of the characteristics that come along with this level of experience.

Accepted Technology in the Marketplace - This systems requirement is another attempt to address the maturity of the protocol from the market perspective where Proven Interoperability looks from the technology perspective. It asks the question of how pervasive is the protocol in the marketplaces. This will be in other types of applications and provides some indications of the protocols success in the consumer environment. Again the Consumer Expectations are all seen to be highly correlated to this system level requirement.

Acceptable Cost Tradeoffs - Cost is a very big issue in the appliance industry. In an attempt to understand the trade-offs between cost and the consumer requirements, this System Level Requirement identified the direct correlation of cost to several protocol parameters that impact the consumer expectations, which included the cost of the physical station, sufficient bandwidth, latency measurement, and energy proportionality power consumption.

Easy to Provision to HAN/Plug and Play Appliance and Minimizes Enabling Infrastructure - This system level requirement is highly correlated to consumer expectation related to installation, use and interoperability. Ideally the Smart Grid enabled product is no more difficult to install than the non-grid enabled product. The main difficulty with installation will come with the security requirements and the fact that residences are all different (see Minimizes Enabling Infrastructure).

Minimizes Enabling Infrastructure - Allow consumers to acquire the new technology with a minimum of additional extra components. Ideally users will be able to configure their smart appliance with no additional hardware or software. Consumers are familiar with configuring devices such as programmable thermostats which do not require additional hardware or software. Ideally this implementation model can be used with appliances.

Technology Supply Chain Exists – This system level requirement address the availably of parts, people and tools, which EnerNex researched. Although this is more of a manufacturers concern it is correlated to the consumer's expectation of installation, use and reliability. If parts, people and tools are available to support a protocol the probability of a stable protocol goes up. When engineers are available to support the protocol, that is a strong indicator of stability.

Interference & Noise Handling - The residence is becoming a noisy environment from the prospective of existing sources of RF and Power Line Carriers. A protocol must be able to adapt to these environments. Their own signal must be able to reach the desire destinations without interfering or being interfere with by other protocols. Several techniques exist to accomplish this task.

Easy System Operation - This upper level Systems Requirement is to compare how communications technologies enable easy system operation by building stable and reliable links and enabling appropriate user interfaces to be built around the technology. Easy system operation allows consumers to install and use appliance applications effectively. Features which enable easy use by consumers includes automatic discovery of new appliances, automatic installation and error messages in human-readable format.

Easy to Maintain - Easy system operation allows consumers to install and use appliance applications effectively. Features which enable easy use by consumers includes automatic discovery of new appliances, automatic installation and error messages in human-readable format. Easy system operation allows consumers to install and use appliance applications effectively. Features which enable easy use by consumers includes automatic discovery of new appliances, automatic installation and error messages in human-readable format. This upper level Systems Requirement is to compare how communications technologies are easy to maintain. It is key that day-to-day/month-to-month use of the appliance communications technology by the consumer shall not require attention of the user towards the communications technology itself.

Easy to Replace - This upper level Systems Requirement is to compare how communications technologies are easy to replace. Should elements of the communications capability obviously break, the technology should be designed so consumer should be able to replace them easily, service the device, or find an installer or repair service to service the device. Appliance application should be upgradable by consumers. This set of criteria measures the ability of consumers and field technicians to upgrade application software and firmware

Robust Messaging Capability - Robust messaging capability ensures that data messages are verified during transmission, that messages in non-static formats are supported by the protocol, and that message data queries including appliance-specific queries are supported.

This upper level Systems Requirement is to compare how communications technologies are capable of robust messaging. Energy services potentially provide control stimuli to both the appliance and the consumer. Messages must be delivered correctly and in a timely fashion.

Affordable to Install-This upper level Systems Requirement is to compare how communications technologies minimize cost (e.g. communications technology likely requires no additional monetary cost for consumer to install would be rated high) and maximize performance to the consumer. EnerNex researched the important cost trade-offs in the market available between station element cost, bandwidth, latency, and power consumption. Each of these elements is in tension with the others in its limit. Elements that overlap other areas were not necessarily included here (e.g. single station home coverage).

APPENDIX C
QFD

What is QFD?
From the QFD Institute (www.qfdi.org/what_is_qfd/what_is_qfd.htm)

"Time was when a man could order a pair of shoes directly from the cobbler. By measuring the foot himself and personally handling all aspects of manufacturing, the cobbler could assure the customer would be satisfied," lamented Dr. Yoji Akao, one of the founders of QFD, in his private lectures.

Quality Function Deployment (QFD) was developed to bring this personal interface to modern manufacturing and business. In today's industrial society, where the growing distance between producers and users is a concern, QFD links the needs of the customer (end user) with design, development, engineering, manufacturing, and service functions.

QFD is:

1. Understanding Customer Requirements
2. Quality Systems Thinking + Psychology + Knowledge/Epistemology
3. Maximizing Positive Quality That Adds Value
4. Comprehensive Quality System for Customer Satisfaction
5. Strategy to Stay Ahead of The Game

As a quality system that implements elements of Systems Thinking with elements of Psychology and Epistemology (knowledge), QFD provides a system of comprehensive development process for:

- Understanding 'true' customer needs from the customer's perspective
- What 'value' means to the customer, from the customer's perspective
- Understanding how customers or end users become interested, choose, and are satisfied
- Analyzing how do we know the needs of the customer
- Deciding what features to include
- Determining what level of performance to deliver
- Intelligently linking the needs of the customer with design, development, engineering, manufacturing, and service functions
- Intelligently linking Design for Six Sigma (DFSS) with the front end Voice of Customer analysis and the entire design system

QFD is a comprehensive quality system that systematically links the needs of the customer with various business functions and organizational processes, such as marketing, design, quality, production, manufacturing, sales, etc., aligning the entire company toward achieving a common goal.

It does so by seeking both spoken and unspoken needs, identifying positive quality and business opportunities, and translating these into actions and designs by using transparent analytic and prioritization methods, empowering organizations to exceed normal expectations and provide a level of unanticipated excitement that generates value.

The QFD methodology can be used for both tangible products and non-tangible services, including manufactured goods, service industry, software products, IT projects, business process development, government, healthcare, environmental initiatives, and many other applications.

Consumer Driven System Level Requirements

Consumer Expectations	Importance	Proven Interoperable Protocol	Accepted Technology in Marketplace	Acceptable Cost trade offs	Easy to provision to HAN / Plug and Play Appliance	Minimize Enabling Infrastructure	Technology Supply Chain Exists	Forward / Backward compatibility / Future proof	Interference and Noise Handling	Easy System Operation	Easy to Maintain	Easy to Replace	Robust messaging capability	Affordable to install	Security Mechanisms	Total
Easy to Install	3	h	h	h	h	h	h	h	h	h	m	m	l	h	h	75
Easy to Use	3	h	h	h	h	h	h	m	h	h	h	h	l	l	l	63
Interoperable	3	h	h	h	h	h	h	h	h	h	h	h	l	l	m	69
Reliable Operations	3	h	h	h	m	h	m	l	h	h	l	l	l	l	h	39
No Compromise of Privacy	5	m	m	m	m	l	m	h	l	l	l	l	l	l	h	65
Low Security Degradation	5	m	m	m	m	l	m	h	l	l	l	l	l	h	h	105
No Compromise to Safety	5	m	m	m	m	l	m	h	l	l	l	l	l	l	h	65

Results

Consumer Expectations	Importance	Proven Interoperable Protocol	Accepted Technology in Marketplace	Acceptable Cost trade offs	Easy to provision to HAN / Plug and Play Appliance	Minimize Enabling Infrastructure	Technology Supply Chain Exists	Forward / Backward compatibility / Future proof	Interference and Noise Handling	Easy System Operation	Easy to Maintain	Easy to Replace	Robust messaging capability	Affordable to install	Security Mechanisms	Total
Easy to Install	3	27	27	27	27	27	27	27	27	27	9	9	3	27	27	75
Easy to Use	3	27	27	27	27	27	27	9	27	27	27	27	3	3	3	63
Interoperable	3	27	27	27	27	27	27	27	27	27	27	27	3	3	9	69
Reliable Operations	3	27	27	27	9	27	9	3	27	27	3	3	3	3	27	39
No Compromise of Privacy	5	15	15	15	15	5	15	45	5	5	5	5	5	5	45	65
Low Security Degradation	5	15	15	15	15	5	15	45	5	5	5	5	5	45	45	105
No Compromise to Safety	5	15	15	15	15	5	15	45	5	5	5	5	5	5	45	65
TOTALS		153	153	153	135	123	135	201	123	123	81	81	27	91	201	
WEIGHTING TO NEXT LEVEL		3	3	3	3	3	3	9	3	3	1	1	1	1	9	

System Requirements Mapped to Technology Requirements PHY / MAC / NET

System Requirements	Importance	Relative Weight	IEEE 802.11				SEP 2.0				CEA LonWorks				3GPP							IEEE P1901																																															
			IEEE 802.11n (SE 2.0 capable)	IEEE 802.11a	IEEE 802.11g	IEEE 802.11b	ZigBee (SEP 2.0 capable)	HomePlug Green PHY (SEP 2.0 capable)	IEEE 802.16 WiMAX	IEEE 802.3	ISO/IEC 14908-3 LonWorks PLCS	ISO/IEC LonWorks 14908-2 TPC	Z-Wave (v4)	3GPP2 / CDMA2000 1x	3GPP / GPRS	3GPP / EDGE	3GPP / UMTS	3GPP / HSPA	3GPP / HSPA+	ISA 100.11a-2009	HomePlug AV	IEEE P1901 / FFT	IEEE P1901 / Wavelet	HomePlug C&C	ITU-T G.hn	ISO/IEC 12139	IEEE 802.15.4-2003	IEEE 802.15.4-2006	ZigBee Pro	IETF 6LoWPAN	EnOcean	ISO 18000-7 DASH-7	ISO/IEC 14543-3 KNX-RF	ISO/IEC 14543-3 KNX-PL	ISO/IEC 14543-3 KNX-TPC	IEEE 802.15.1 / Bluetooth 1.1	IEEE 802.15.1-2005 / Bluetooth 1.2	Bluetooth 2.0 + EDR	Bluetooth 2.1 + EDR	Bluetooth 3.0	Bluetooth 4.0	IEC 62106 Ed. 2 / NSRC RDBS	ITU-R M.584 FLEX Paging	HomePlug AV2	TIA-1113 / HomePlug 1.0	HomePlug 1.0 Turbo	UPA-DHS	PRIME	INSTEON	UPB	X10	A10	G3	CEBus	IEC 61334	SITRED	MoCA 1.1	HomePNA 1.0	HomePNA 2.0 / G.9951, G.9952 and G.9953	HomePNA 3.0 / G.9954	HomePNA 3.1	EIA-232 / RS-232	USB 1	USB2	USB-OTG	IEEE 1394	Total
Proven Interoperable Protocol																																																																				1030
Standards Basis Re-Use	3	0.10	h	h	h	h	h	h	h	h	h	h	l	h	h	h	h	h	h	m	h	h	h	m	h		m	m	m	h	l		h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	m	l	l	l	l	h	h	h	l	h	h	h	h	h	h	h	h	h	h	139.8
Open Specification	3	0.10	h	h	h	h	h	h	h	h	h	h	m	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	l	h	h	h	h	h	h	l	l	h	h	h	l	h	h	h	h	h	h	h	h	h	h	163.8
Proven, Testable Technology	3	0.10	h	h	h	h	h	m	h	h	h	h	h	h	h	h	h	h	h	m	h	h	h	h	h	l	h	h	h	h	h	m	h	h	h	h	h	h	h	m	l	h	h	l	h	h	l	h	h	h	h	h	l	l	m	m	m	h	h	h	h	h	h	h	h	h	143.4
Certification Bodies / Test Labs Exist	3	0.10	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	l	h	m	m	h	l	l	h	h	h	l	l	l	h	h	h	h	h	h	h	h	h	h	m	h	h	h	l	l	m	l	l	l	l	l	h	l	h	h	h	h	h	h	h	h	h	h	134.4
On the NIST Interoperability Roadmap	3	0.10	h	h	h	h	h	h	h	h	h	h	m	m	m	m	m	m	m	m	m	m	m	m	m	m	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	51.6
SDO supported / vetted	3	0.10	h	h	h	h	h	l	h	h	h	h	l	h	h	h	h	h	h	h	m	m	h	l	h	h	h	h	l	h	l	h	h	h	h	h	h	l	l	l	l	h	h	l	h	h	l	l	l	l	l	l	l	h	h	l	l	h	l	h	l	h	l	l	l	l	114
Commercial Alliance Supported / Vetted	3	0.10	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	l	h	h	h	h	l	l	l	l	h	l	h	h	h	h	h	h	h	h	h	h	h	h	l	h	h	h	h	h	h	l	l	l	l	h	l	l	h	h	h	h	h	l	h	l	h	h	139.2
DLMS/COSEM Delivery Support	3	0.10	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	h	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	h	h	l	l	l	l	l	l	l	l	l	l	l	l	24
SEP 1.0 Delivery Support	3	0.10	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	h	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	21.6
SEP 2.0 DeliverySupport	3	0.10	h	h	h	h	h	h	h	h	l	l	m	h	h	h	h	h	h	h	h	h	h	h	l	l	l	l	l	m	l	h	l	l	l	l	l	l	l	m	h	l	l	h	h	h	h	h	l	l	l	l	h	l	l	l	h	h	h	h	h	l	l	l	l	l	97.8
																																																																				0
Accepted Technology in Marketplace																																																																				663.6
AMI / Electric Meter Vendor Use	3	0.20	m	l	l	m	h	h	h	l	m	l	l	m	m	m	l	l	l	l	m	m	l	l	l	l	h	h	m	m	l	l	l	l	l	l	l	l	m	l	l	l	m	l	h	l	l	m	l	l	l	l	m	m	h	m	l	l	l	l	l	h	l	l	l	l	96
Home Internet Gateway Use	3	0.20	h	h	h	h	l	l	l	h	l	l	l	m	m	m	l	l	l	l	m	l	l	l	l	l	m	m	m	l	l	l	l	l	l	l	l	l	m	l	l	l	l	l	m	m	m	l	m	m	m	m	l	l	l	l	h	h	h	h	h	m	h	h	m	m	117.6
Other HAN Installed Base Vendor Use (e.g. CE)	3	0.20	h	h	h	h	m	l	m	h	m	l	m	m	m	m	l	l	l	l	m	l	l	l	l	l	m	m	m	l	m	l	h	h	h	h	h	h	h	l	l	l	m	l	l	l	l	l	l	l	l	l	l	l	l	l	h	m	h	h	m	h	h	h	m	h	148.8
DR Gateway Use	3	0.20	h	l	h	l	h	h	l	h	m	l	m	m	m	m	l	l	l	l	m	l	l	l	l	l	m	m	m	m	l	l	h	h	h	l	l	l	m	l	l	l	m	l	l	l	l	l	m	l	l	l	l	l	m	l	l	l	l	l	l	m	m	m	l	l	97.2
Protocol Operational with non appliance devices (e.g. HA)	3	0.20	h	m	h	h	h	m	l	h	h	h	h	m	m	m	l	l	l	m	m	l	l	m	l	l	h	h	h	m	m	h	m	m	m	h	h	h	h	m	l	h	h	l	h	h	h	m	h	h	h	h	m	m	h	h	l	l	l	l	l	h	h	h	l	m	204
																																																																				0
Acceptable cost trade offs																																																																				1077
Low Cost Per Physical Station	3	0.25	h	m	h	m	h	h	l	h	m	l	h	l	l	l	l	l	l	h	m	m	m	m	m	l	h	h	h	h	h	h	h	h	l	h	h	h	h	h	h	l	h	l	m	m	m	m	h	l	h	l	m	l	m	l	l	l	l	l	l	h	h	h	h	h	247.5
Sufficient Station Data Bandwidth	3	0.25	h	h	h	h	h	h	h	h	l	h	h	h	h	h	h	h	h	h	h	h	h	l	h	h	h	h	h	h	l	m	m	m	h	h	h	h	h	h	h	l	m	l	h	h	h	h	h	m	l	l	l	m	l	m	l	h	h	h	h	h	h	h	h	h	346.5
Sufficient Station Data Latency	3	0.25	h	h	h	h	m	h	m	h	m	h	m	m	m	m	m	m	m	h	h	h	h	h	h	h	h	h	h	h	l	m	m	m	h	h	h	h	h	h	h	l	l	h	h	h	h	h	h	m	m	m	m	m	m	l	h	h	h	h	h	h	h	h	h	h	322.5
Energy Proportional Power Consumption	3	0.25	m	m	m	l	m	h	h	l	l	l	m	m	m	m	m	m	h	m	m	m	m	h	h	l	m	m	m	m	h	h	l	l	l	m	m	m	m	m	h	l	h	h	l	l	h	l	l	l	l	l	l	l	l	l	l	l	m	m	m	l	l	m	h		160.5
																																																																				0
Easy to provision to HAN / Plug and Play Appliance																																																																					1136
Endpoints Easy to Join to a Network	3	0.20	m	m	m	m	h	h	h	h	m	m	l	h	h	h	h	h	h	h	h	h	h	m	h		m	m	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	303
Secure Joining to Network Easy	3	0.20	m	m	m	m	h	h	h	h	l	l	m	m	m	m	m	m	m	h	m	m	m	m	m		m	m	m	m	h	m	l	l	l	h	h	h	h	h	h	m	m	m	m	m	m	m	l	l	l	l	m	l	l	l	m	m	m	m	m	l	l	l	l	l	136.2
Intgrated Support for PHY Extenders / Repeaters	3	0.20	h	h	h	h	h	h	m	h	h	h	h	h	h	h	h	h	h	h	m	h	h	l	m	l	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	m	m	l	l	l	h	h	m	m	m	m	m	l	l	l	l	l	l	l	l	h	h	h	h	247.2
Change of PHY / Bridging Supported	3	0.20	h	h	h	h	h	h	m	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h		l	l	h	h	m	m	h	h	h	h	h	h	h	h	h	l	l	h	h	h	h	h	h	l	l	l	h	m	m	l	h	h	h	h	h	h	m	m	m	h	273
Support Provisioning User Feedback	3	0.20	h	h	h	h	h	h	h	m	m	m	m	m	m	m	m	m	m	h	h	h	h	l	l	l	m	m	m	m	l	m	m	m	m	h	h	h	h	h	h	l	l	h	m	m	m	m	h	m	l	l	h	m	m	m	m	m	m	m	m	l	m	m	m	h	176.4
																																																																				0
Minimizes Enabling Infrastructure																																																																					1094
Enables Low Power Consumption	9	0.25	m	m	m	m	h	m	l	l	l	l	h	l	l	l	l	l	l	h	l	l	l	m	l	l	h	h	h	h	h	h	m	m	l	h	h	h	h	h	h	h	m	l	l	l	l	m	m	m	m	m	m	l	m	m	l	m	l	l	l	h	m	l	m	m	544.5
High Single Station Home Coverage	3	0.25	h	m	m	m	m	h	h	l	l	l	m	h	h	h	h	h	h	m	h	h	h	m	h		m	m	m	m	h	h	m	m	l	l	l	m	m	m	h	h	h	h	h	h	h	m	m	m	m	m	m	m	m	m	m	m	m	m	m	l	l	l	l	l	228.8
Requires minimal additional cabling	3	0.25	h	h	h	h	h	h	h	l	h	l	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	l	h	h	h	h	h	h	h	h	h	h	h	h	m	m	m	m	m	m	m	m	m	m	m	m	m	m	l	l	l	l	l	321
Topology minimizes additional stations	3	0.25	m	m	m	m	h	h	l	l	h	h	h	l	l	l	l	l	l	h	m	h	h	m	m		l	l	h	h	h	h	h	h	h	l	m	m	m	m	m	m	l	l	m	m	m	m	m	h	h	m	m	m	m	m	m	l	l	l	l	l	l	l	l	l	179.3
																																																																				0
Technology Supply Chain Exists																																																																					1565
Integration Talent Exists	3	0.33	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	l	h	h	h	m	l	l	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	m	h	h	h	m	h	h	h	h	m	h	h	m	h	h	h	h	h	h	h	h	h	h	522
Integration Tools Exists	3	0.33	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	l	l	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	l	h	h	h	m	h	h	h	h	m	h	h	l	h	h	h	h	h	h	h	h	h	h	532
Part availability																																																																				0
Multiple Silicon Implementers Identified	3	0.11	h	h	h	h	h	h	h	h	l	l	l	h	h	h	h	h	h	h	h	h	h	l	m	m	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	l	h	h	h	h	h	h	h	h	l	h	l	l	l	l	h	h	h	h	h	161.3
Silicon Availability Now / 6-12 mo	3	0.11	h	h	h	h	h	h	h	h	h	h	m	h	h	h	h	h	h	h	h	h	h	h	l	l	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	m	h	h	h	m	h	h	h	h	m	h	h	l	h	h	h	h	h	h	h	h	h	h	176
Software availability	3	0.11	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	h	m	h	h	h	h	l	l	h	h	h	h	h	m	h	h	h	h	h	h	h	h	h	h	h	l	h	h	h	m	h	h	h	h	m	h	h	l	h	h	h	h	h	h	h	h	h	h	173.3
																																																																				0
Forward / Backward compatibility / Future proof																																																																					1947
Backward Compatibility	9	0.33	h	l	h	l	m	m	l	h	h	h	h	h	h	h	l	h	h	l	m	m	l	l	l	l	l	h	h	h	l	l	l	l	l	l	h	h	h	h	h	l	l	h	l	h	l	l	l	l	l	l	l	l	l	l	l	l	h	h	h	l	l	h	h	h	864
Forward Compatibility	9	0.33	h	l	l	l	h	h	l	l	m	m	h	l	l	l	l	l	l	l	h	h	l	m	l		l	l	l	l	l	l	l	l	l	l	l	h	h	h	h	l	l	h	h	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	495
Firmware Upgrade Exists	9	0.33	h	h	h	h	h	h	h	l	l	l	l	l	l	l	l	l	l	h	l	h	l	l	l	l	l	l	h	l	l	l	l	l	l	m	m	m	m	m	m	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	h	h	l	h	h	h	l		588
																																																																				0
Interference & Noise Handling																																																																					835.5
Scales to Multiple Dwelling Unit Environments	3	0.25	m	m	m	l	h	h	m	h	l	m	l	h	h	h	h	h	h	h	l	h	h	m	l		m	m	m	m	h	h	h	m	h	l	l	l	l	l	l	h	h	h	l	l	l	m	m	l	l	l	m	l	l	l	h	h	h	h	h	l	l	l	l	l	212.3
Coexistence Mechanism Use	3	0.25	l	l	l	l	l	l	m	l	l	l	l	l	l	l	l	l	m	h	h	h	h	m	l	l	l	l	l	l	m	l	l	m	l	h	h	h	h	h	h	l	l	m	m	l	l	m	m	l	l	l	m	l	m	m	h	h	h	h	h	l	l	l	l	l	156
Supports Transmit Power Control	3	0.25	h	h	m	l	m	h	h	l	l	l	l	h	l	l	h	h	h	h	l	l	l	l	l	l	m	m	m	m	l	l	m	l	l	m	m	m	m	h	h	l	l	h	l	l	l	l	l	l	l	l	m	h	l	l	h	h	h	h	h	l	l	l	l	l	174
Supports Spectrum Spreading	3	0.25	h	h	h	h	h	h	h	l	l	l	l	h	h	h	h	h	h	h	h	h	h	h	h		h	h	h	h	l	l	l	l	l	h	h	h	h	h	h	l	l	h	h	h	h	h	l	l	l	l	h	h	l	l	h	h	h	h	h	l	l	l	l	l	293.3
																																																																				0
Easy System Operation																																																																					1156
Stable and Reliable Links	3	0.33	h	h	m	m	h	h	h	h	m	h	h	m	m	m	m	m	m	h	h	h	h	m	h	m	m	m	h	h	l	h	h	m	h	m	m	m	m	m	m	m	m	h	h	h	h	h	m	l	l	l	h	h	m	m	h	h	h	h	h	h	h	h	h	h	394
Plug and Play	3	0.33	h	h	h	h	h	h	h	m	m	m	h	m	m	m	m	m	m	m	h	h	h	h	h	m	m	m	h	h	h	h	l	l	l	h	h	h	h	h	h	h	h	h	h	h	h	m	h	h	h	h	m	l	l	l	h	h	h	h	h	h	h	h	h	h	438
Link State Feedback	3	0.33	h	h	h	h	h	h	h	h	m	m	h	h	h	h	h	h	h	h	m	h	h	m	m	m	m	m	m	m	l	m	m	m	m	m	m	m	m	m	m	m	m	h	m	m	m	m	l	l	l	l	m	m	m	m	h	h	h	h	h	l	m	m	m	m	324
																																																																				0
Easy to Maintain	1	1.00	h	h	h	h	h	h	h	h	m	m	h	m	m	m	m	m	m	h	h	h	h	h	h	h	h	h	h	h	h	h	m	m	m	h	h	h	h	h	h	h	m	h	h	h	h	h	h	h	h	h	h	m	m	m	h	h	h	h	h	h	h	h	h	h	486
Easy to Replace	1	1.00	h	h	h	h	h	h	h	h	m	m	h	m	m	m	m	m	m	h	h	h	h	h	h	m	m	m	h	h	h	h	m	m	m	h	h	h	h	h	h	h	m	h	h	h	h	h	h	h	h	h	h	l	l	l	h	h	h	h	h	h	h	h	h	h	462
Robust messaging capability																																																																				396
Supports and Enforces Quality of Service (QoS) Delivery	1	0.50	h	h	h	h	l	h	h	h	l	l	l	l	l	l	l	l	l	h	h	h	h	l	h	l	l	l	l	l	l	l	l	l	l	h	h	h	h	h	h	l	h	h	h	h	h	h	l	l	l	l	h	l	l	l	h	h	h	h	h	l	h	h	h	h	168
Offers Error Correcting Codes	1	0.50	h	h	h	h	h	h	h	h	h	h	l	l	l	l	l	l	l	h	h	h	h	h	h	h	h	h	h	h	l	l	h	h	h	h	h	h	h	h	h	l	h	h	h	h	h	h	h	l	l	l	h	h	l	l	h	h	h	h	h	l	h	h	h	h	228
Affordable to install	1	1.00	m	m	m	m	h	h	m	l	m	l	h	l	l	l	l	l	l	h	m	m	m	h	m	l	h	h	h	h	h	h	l	l	l	h	h	h	h	h	h	h	h	m	m	m	m	h	h	h	h	h	h	l	l	l	m	m	m	m	m	l	l	l	l	l	302
																																																																				0
Security Mechanisms																																																																					2688
Link Encrypted (AES-128-CCM or better)	9	0.17	h	h	h	h	h	h	h	m	l	l	l	h	h	h	h	h	h	h	h	h	h	h	h		h	h	h	h	m	h	l	l	l	l	l	l	l	l	h	l	l	h	l	l	l	h	l	l	l	l	h	l	l	l	h	l	l	h	h	l	l	l	l	l	472.5
Network Encrypted (AES-128-CCM or better)	9	0.17	h	l	l	l	h	h	h	l	l	l	h	l	l	l	l	l	l	h	h	h	h	h	h		l	l	h	l	l	h	l	l	l	l	l	l	l	l	l	l	l	h	l	l	l	h	l	l	l	l	h	l	l	l	l	l	l	h	h	l	l	l	l	l	310.5
Endpoints Mutually Authenticatable	9	0.17	h	h	h	h	h	h	h	m	m	m	l	h	h	h	h	h	h	h	l	h	h	l	h		l	l	l	l	m	h	l	l	l	m	m	m	m	m	m	l	l	h	l	l	l	l	l	l	l	l	h	l	l	l	l	l	l	h	h	l	l	l	l	l	388.5
Supports PKI	9	0.17	h	h	h	h	h	h	h	m	l	l	l	h	h	h	h	h	h	h	l	h	h	l	h		l	l	h	l	l	h	l	l	l	l	l	l	l	l	l	l	l	h	l	l	l	l	l	l	l	l	h	l	l	l	l	l	l	l	l	l	l	l	l	l	349.5
Supports PSK	9	0.17	h	h	h	h	h	h	h	m	l	l	h	h	h	h	h	h	h	h	h	h	h	h	h		h	h	h	h	m	h	l	l	l	h	h	h	h	h	h	l	l	h	h	h	h	h	l	l	l	l	h	l	l	l	h	l	l	h	h	l	l	l	l	l	580.5
Supports Logical Separation	9	0.17	h	h	h	h	h	h	h	h	l	l	h	h	h	h	h	h	h	h	h	h	h	h	h		h	h	h	h	l	h	l	l	l	h	h	h	h	h	h	l	l	h	h	h	h	h	l	l	l	l	h	l	l	l	h	l	l	h	h	l	l	l	l	l	586.5
																																																																				0

Results

System Requirements	Importance	Relative Weight	IEEE 802.11n (SE 2.0 capable)	IEEE 802.11a	IEEE 802.11g	IEEE 802.11b	ZigBee (SEP 2.0 capable)	HomePlug Green PHY (SEP 2.0 capable)	IEEE 802.16 WiMAX	IEEE 802.3	ISO/IEC 14908-3 LonWorks PLCS	ISO/IEC LonWorks 14908-2 TPC	Z-Wave (v4)	3GPP2 / CDMA2000 1x	3GPP / GPRS	3GPP / EDGE	3GPP / UMTS	3GPP / HSPA	3GPP / HSPA+	ISA 100.11a-2009	HomePlug AV	IEEE P1901 / FFT	IEEE P1901 / Wavelet	HomePlug C&C	ITU-T G.hn	ISO/IEC 12139	IEEE 802.15.4-2003	IEEE 802.15.4-2006	ZigBee Pro	IETF 6LoWPAN	EnOcean	ISO 18000-7 DASH-7	ISO/IEC 14543-3 KNX-RF	ISO/IEC 14543-3 KNX-PL	ISO/IEC 14543-3 KNX-TPC	IEEE 802.15.1 / Bluetooth 1.1	IEEE 802.15.1-2005 / Bluetooth 1.2	Bluetooth 2.0 + EDR	Bluetooth 2.1 + EDR	Bluetooth 3.0	Bluetooth 4.0	IEC 62106 Ed. 2 / NSRC RDBS	ITU-R M.584 FLEX Paging	HomePlug AV2	TIA-1113 / HomePlug 1.0	HomePlug 1.0 Turbo	UPA-DHS	PRIME	INSTEON	UPB	X10	A10	G3	CEBus	IEC 61334	SITRED	MoCA 1.1	HomePNA 1.0	HomePNA 2.0 / G.9951, G.9952 and G.9953	HomePNA 3.0 / G.9954	HomePNA 3.1	EIA-232 / RS-232	USB 1	USB2	USB-OTG	IEEE 1394	Total
Proven Interoperable Protocol	0	0.00	22.2	22.2	22.2	22.2	22.2	18	22.2	22.2	19.8	19.8	12	20.4	20.4	20.4	20.4	20.4	20.4	12	18.6	16.8	18.6	16.2	13.2	8.1	13.2	13.2	15.6	13.2	10.2	12.9	17.4	17.4	17.4	17.4	17.4	15	15	13.8	15	17.4	13.2	15	19.8	19.8	15	10.8	10.8	7.8	5.4	5.4	10.2	15	15.6	3.6	15.6	19.8	19.8	19.8	17.4	15	15	15	15	17.4	1030
Standards Basis Re-Use	3	0.10	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	0.3	2.7	2.7	2.7	2.7	2.7	2.7	0.9	2.7	2.7	2.7	0.9	2.7		0.9	0.9	0.9	2.7	0.3		2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	0.9	0.3	0.3	0.3	0.3	2.7	2.7	2.7	0.3	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	139.8
Open Specification	3	0.10	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	0.9	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	0.3	2.7	2.7	2.7	2.7	2.7	2.7	0.3	0.3	2.7	2.7	2.7	0.3	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	163.8
Proven, Testable Technology	3	0.10	2.7	2.7	2.7	2.7	2.7	0.9	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	0.9	2.7	2.7	2.7	2.7	2.7	0.3	2.7	2.7	2.7	2.7	2.7	0.9	2.7	2.7	2.7	2.7	2.7	2.7	2.7	0.9	0.3	2.7	2.7	0.3	2.7	2.7	0.3	2.7	2.7	2.7	2.7	2.7	0.3	0.3	0.9	0.9	0.9	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	143.4
Certification Bodies / Test Labs Exist	3	0.10	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	0.3	2.7	0.9	0.9	2.7	0.3	0.3	2.7	2.7	2.7	0.3	0.3	0.3	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	0.9	2.7	2.7	2.7	0.3	0.3	0.9	0.3	0.3	0.3	0.3	0.3	2.7	0.3	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	134.4
On the NIST Interoperability Roadmap	3	0.10	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	51.6
SDO supported / vetted	3	0.10	2.7	2.7	2.7	2.7	2.7	0.3	2.7	2.7	2.7	2.7	0.3	2.7	2.7	2.7	2.7	2.7	2.7	2.7	0.9	0.9	2.7	0.3	2.7	2.7	2.7	2.7	0.3	2.7	0.3	2.7	2.7	2.7	2.7	2.7	2.7	0.3	0.3	0.3	0.3	2.7	2.7	0.3	2.7	2.7	0.3	0.3	0.3	0.3	0.3	0.3	0.3	2.7	2.7	0.3	0.3	2.7	0.3	2.7	0.3	2.7	0.3	0.3	0.3	0.3	114
Commercial Alliance Supported / Vetted	3	0.10	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	0.3	2.7	2.7	2.7	2.7	0.3	0.3	0.3	0.3	2.7	0.3	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	0.3	2.7	2.7	2.7	2.7	2.7	2.7	0.3	0.3	0.3	0.3	2.7	0.3	0.3	2.7	2.7	2.7	2.7	2.7	0.3	2.7	0.3	2.7	2.7	139.2
DLMS/COSEM Delivery Support	3	0.10	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	2.7	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	2.7	2.7	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	24
SEP 1.0 Delivery Support	3	0.10	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	2.7	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	21.6
SEP 2.0 DeliverySupport	3	0.10	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	0.3	0.3	0.9	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	0.3	0.3	0.3	0.3	0.3	0.9	0.3	2.7	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.9	2.7	0.3	0.3	2.7	2.7	2.7	2.7	2.7	0.3	0.3	0.3	0.3	2.7	0.3	0.3	0.3	2.7	2.7	2.7	2.7	2.7	0.3	0.3	0.3	0.3	0.3	97.8
0	0	0.00																																																																	0
Accepted Technology in Marketplace	0	0.00	23.4	13.8	22.2	18.6	18.6	13.8	9	22.2	11.4	7.8	10.2	9	9	9	3	3	3	4.2	9	4.2	3	4.2	3	3	16.2	16.2	12.6	6.6	5.4	7.8	13.8	13.8	13.8	12.6	12.6	12.6	16.2	4.2	3	7.8	11.4	3	13.8	9	9	5.4	10.2	9	9	9	5.4	5.4	13.8	9	12.6	9	12.6	12.6	9	19.8	18.6	18.6	5.4	10.2	663.6
AMI / Electric Meter Vendor Use	3	0.20	1.8	0.6	0.6	1.8	5.4	5.4	5.4	0.6	1.8	0.6	0.6	1.8	1.8	1.8	0.6	0.6	0.6	0.6	1.8	1.8	0.6	0.6	0.6	0.6	5.4	5.4	1.8	1.8	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	1.8	0.6	0.6	0.6	1.8	0.6	5.4	0.6	0.6	1.8	0.6	0.6	0.6	0.6	1.8	1.8	5.4	1.8	0.6	0.6	0.6	0.6	0.6	5.4	0.6	0.6	0.6	0.6	96
Home Internet Gateway Use	3	0.20	5.4	5.4	5.4	5.4	0.6	0.6	0.6	5.4	0.6	0.6	0.6	1.8	1.8	1.8	0.6	0.6	0.6	0.6	1.8	0.6	0.6	0.6	0.6	0.6	1.8	1.8	1.8	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	1.8	0.6	0.6	0.6	0.6	0.6	1.8	1.8	1.8	0.6	1.8	1.8	1.8	1.8	0.6	0.6	0.6	0.6	5.4	5.4	5.4	5.4	5.4	1.8	5.4	5.4	1.8	1.8	117.6
Other HAN Installed Base Vendor Use (e.g. CE)	3	0.20	5.4	5.4	5.4	5.4	1.8	0.6	1.8	5.4	1.8	0.6	1.8	1.8	1.8	1.8	0.6	0.6	0.6	0.6	1.8	0.6	0.6	0.6	0.6	0.6	1.8	1.8	1.8	0.6	1.8	0.6	5.4	5.4	5.4	5.4	5.4	5.4	5.4	0.6	0.6	0.6	1.8	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	5.4	1.8	5.4	5.4	1.8	5.4	5.4	5.4	1.8	5.4	148.8
DR Gateway Use	3	0.20	5.4	0.6	5.4	0.6	5.4	5.4	0.6	5.4	1.8	0.6	1.8	1.8	1.8	1.8	0.6	0.6	0.6	0.6	1.8	0.6	0.6	0.6	0.6	0.6	1.8	1.8	1.8	1.8	0.6	0.6	5.4	5.4	5.4	0.6	0.6	0.6	1.8	0.6	0.6	0.6	1.8	0.6	0.6	0.6	0.6	0.6	1.8	0.6	0.6	0.6	0.6	0.6	1.8	0.6	0.6	0.6	0.6	0.6	0.6	1.8	1.8	1.8	0.6	0.6	97.2
Protocol Operational with non appliance devices (e.g. HA)	3	0.20	5.4	1.8	5.4	5.4	5.4	1.8	0.6	5.4	5.4	5.4	5.4	1.8	1.8	1.8	0.6	0.6	0.6	1.8	1.8	0.6	0.6	1.8	0.6	0.6	5.4	5.4	5.4	1.8	1.8	5.4	1.8	1.8	1.8	5.4	5.4	5.4	5.4	1.8	0.6	5.4	5.4	0.6	5.4	5.4	5.4	1.8	5.4	5.4	5.4	5.4	1.8	1.8	5.4	5.4	0.6	0.6	0.6	0.6	0.6	5.4	5.4	5.4	0.6	1.8	204
0	0	0.00																																																																	0
Acceptable cost trade offs	0	0.00	22.5	18	22.5	16.5	18	27	16.5	21	6	15	18	12	12	12	12	12	16.5	22.5	18	18	18	16.5	22.5	15	22.5	22.5	22.5	22.5	15	18	12	12	15	22.5	22.5	22.5	22.5	22.5	27	9	16.5	21	16.5	16.5	22.5	16.5	16.5	4.5	10.5	4.5	7.5	4.5	6	3	15	15	15	16.5	16.5	22.5	21	21	22.5	27	1077
Low Cost Per Physical Station	3	0.25	6.75	2.25	6.75	2.25	6.75	6.75	0.75	6.75	2.25	0.75	6.75	0.75	0.75	0.75	0.75	0.75	0.75	6.75	2.25	2.25	2.25	2.25	2.25	0.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	0.75	6.75	6.75	6.75	6.75	6.75	6.75	0.75	6.75	0.75	2.25	2.25	2.25	2.25	6.75	0.75	6.75	0.75	2.25	0.75	2.25	0.75	0.75	0.75	0.75	0.75	0.75	6.75	6.75	6.75	6.75	6.75	247.5
Sufficient Station Data Bandwidth	3	0.25	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	0.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	0.75	6.75	6.75	6.75	6.75	6.75	6.75	0.75	2.25	2.25	2.25	6.75	6.75	6.75	6.75	6.75	6.75	6.75	0.75	2.25	0.75	6.75	6.75	6.75	6.75	6.75	2.25	0.75	0.75	0.75	2.25	0.75	2.25	0.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	346.5
Sufficient Station Data Latency	3	0.25	6.75	6.75	6.75	6.75	2.25	6.75	2.25	6.75	2.25	6.75	2.25	2.25	2.25	2.25	2.25	2.25	2.25	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	0.75	2.25	2.25	2.25	6.75	6.75	6.75	6.75	6.75	6.75	6.75	0.75	0.75	6.75	6.75	6.75	6.75	6.75	6.75	2.25	2.25	2.25	2.25	2.25	2.25	0.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	322.5
Energy Proportional Power Consumption	3	0.25	2.25	2.25	2.25	0.75	2.25	6.75	6.75	0.75	0.75	0.75	2.25	2.25	2.25	2.25	2.25	2.25	6.75	2.25	2.25	2.25	2.25	6.75	6.75	0.75	2.25	2.25	2.25	2.25	6.75	6.75	0.75	0.75	0.75	2.25	2.25	2.25	2.25	2.25	6.75	0.75	6.75	6.75	0.75	0.75	6.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	2.25	2.25	2.25	0.75	0.75	2.25	6.75	160.5
0	0	0.00																																																																	0
Easy to provision to HAN / Plug and Play Appliance	0	0.00	19.8	19.8	19.8	19.8	27	27	19.8	23.4	15	15	15	19.8	19.8	19.8	19.8	19.8	19.8	27	19.8	23.4	23.4	10.2	15	1.2	11.4	11.4	19.8	19.8	18.6	16.2	18.6	18.6	18.6	27	27	27	27	27	27	13.8	10.2	19.8	15	15	15	19.8	22.2	10.2	9	9	16.2	11.4	10.2	9	15	15	15	15	15	12.6	15	15	15	22.2	1136
Endpoints Easy to Join to a Network	3	0.20	1.8	1.8	1.8	1.8	5.4	5.4	5.4	5.4	1.8	1.8	0.6	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	1.8	5.4		1.8	1.8	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	303
Secure Joining to Network Easy	3	0.20	1.8	1.8	1.8	1.8	5.4	5.4	5.4	5.4	0.6	0.6	1.8	1.8	1.8	1.8	1.8	1.8	1.8	5.4	1.8	1.8	1.8	1.8	1.8		1.8	1.8	1.8	1.8	5.4	1.8	0.6	0.6	0.6	5.4	5.4	5.4	5.4	5.4	5.4	1.8	1.8	1.8	1.8	1.8	1.8	1.8	0.6	0.6	0.6	0.6	1.8	0.6	0.6	0.6	1.8	1.8	1.8	1.8	1.8	0.6	0.6	0.6	0.6	0.6	136.2
Intgrated Support for PHY Extenders / Repeaters	3	0.20	5.4	5.4	5.4	5.4	5.4	5.4	1.8	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	1.8	5.4	5.4	0.6	1.8	0.6	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	1.8	1.8	0.6	0.6	0.6	5.4	5.4	1.8	1.8	1.8	1.8	1.8	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	5.4	5.4	5.4	5.4	247.2
Change of PHY / Bridging Supported	3	0.20	5.4	5.4	5.4	5.4	5.4	5.4	1.8	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4		0.6	0.6	5.4	5.4	1.8	1.8	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	0.6	0.6	5.4	5.4	5.4	5.4	5.4	5.4	0.6	0.6	0.6	5.4	1.8	1.8	0.6	5.4	5.4	5.4	5.4	5.4	5.4	1.8	1.8	1.8	5.4	273
Support Provisioning User Feedback	3	0.20	5.4	5.4	5.4	5.4	5.4	5.4	5.4	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	5.4	5.4	5.4	5.4	0.6	0.6	0.6	1.8	1.8	1.8	1.8	0.6	1.8	1.8	1.8	1.8	5.4	5.4	5.4	5.4	5.4	5.4	0.6	0.6	5.4	1.8	1.8	1.8	1.8	5.4	1.8	0.6	0.6	5.4	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	0.6	1.8	1.8	1.8	5.4	176.4
0	0	0.00																																																																	0
Minimizes Enabling Infrastructure	0	0.00	20.25	15.75	15.75	15.75	29.25	20.25	15.75	3.75	9.75	3.75	29.25	15.75	15.75	15.75	15.75	15.75	15.75	29.25	15.75	15.75	15.75	15.75	15.75	9	29.25	29.25	29.25	29.25	33.75	33.75	20.25	15.75	3.75	27.75	27.75	29.25	29.25	29.25	33.75	33.75	20.25	15.75	15.75	15.75	15.75	11.25	11.25	11.25	11.25	11.25	11.25	6.75	11.25	11.25	6.75	11.25	6.75	6.75	6.75	21.75	8.25	3.75	8.25	8.25	1094
Enables Low Power Consumption	9	0.25	6.75	6.75	6.75	6.75	20.25	6.75	2.25	2.25	2.25	2.25	20.25	2.25	2.25	2.25	2.25	2.25	2.25	20.25	2.25	2.25	2.25	6.75	2.25	2.25	20.25	20.25	20.25	20.25	20.25	20.25	6.75	6.75	2.25	20.25	20.25	20.25	20.25	20.25	20.25	20.25	6.75	2.25	2.25	2.25	2.25	6.75	6.75	6.75	6.75	6.75	6.75	2.25	6.75	6.75	2.25	6.75	2.25	2.25	2.25	20.25	6.75	2.25	6.75	6.75	544.5
High Single Station Home Coverage	3	0.25	6.75	2.25	2.25	2.25	2.25	6.75	6.75	0.75	0.75	0.75	2.25	6.75	6.75	6.75	6.75	6.75	6.75	2.25	6.75	6.75	6.75	2.25	6.75		2.25	2.25	2.25	2.25	6.75	6.75	2.25	2.25	0.75	0.75	0.75	2.25	2.25	2.25	6.75	6.75	6.75	6.75	6.75	6.75	6.75	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	0.75	0.75	0.75	0.75	0.75	228.8
Requires minimal additional cabling	3	0.25	6.75	6.75	6.75	6.75	6.75	6.75	6.75	0.75	6.75	0.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	0.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	0.75	0.75	0.75	0.75	0.75	321
Topology minimizes additional stations	3	0.25	2.25	2.25	2.25	2.25	6.75	6.75	0.75	0.75	6.75	6.75	6.75	0.75	0.75	0.75	0.75	0.75	0.75	6.75	2.25	6.75	6.75	2.25	2.25		0.75	0.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	0.75	2.25	2.25	2.25	2.25	2.25	2.25	0.75	0.75	2.25	2.25	2.25	2.25	2.25	6.75	6.75	2.25	2.25	2.25	2.25	2.25	2.25	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	179.3
0	0	0.00																																																																0
Technology Supply Chain Exists	0	0.00	27	27	27	27	27	27	27	27	24.333	24.333	22.333	27	27	27	27	27	27	17	27	27	27	18.333	3.6667	3.6667	27	27	27	27	27	25	27	27	27	27	27	27	27	27	27	27	27	8.3333	27	27	24.333	11	27	27	27	27	11	27	27	5	27	24.333	24.333	24.333	24.333	27	27	27	27	27	1565
Integration Talent Exists	3	0.33	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	1	9	9	9	3	1	1	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	3	9	9	9	3	9	9	9	9	3	9	9	3	9	9	9	9	9	9	9	9	9	9	522
Integration Tools Exists	3	0.33	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	1	1	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	1	9	9	9	3	9	9	9	9	3	9	9	1	9	9	9	9	9	9	9	9	9	9	532
Part availability	0	0.00																																																																	0
Multiple Silicon Implementers Identified	3	0.11	3	3	3	3	3	3	3	3	0.3333	0.3333	0.3333	3	3	3	3	3	3	3	3	3	3	0.3333	1	1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	0.3333	3	3	3	3	3	3	3	3	0.333	3	0.3333	0.3333	0.3333	0.3333	3	3	3	3	3	161.3
Silicon Availability Now / 6-12 mo	3	0.11	3	3	3	3	3	3	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	0.3333	0.3333	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	3	3	3	1	3	3	3	3	1	3	3	0.333	3	3	3	3	3	3	3	3	3	3	176
Software availability	3	0.11	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	3	3	3	3	0.3333	0.3333	3	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	0.3333	3	3	3	1	3	3	3	3	1	3	3	0.333	3	3	3	3	3	3	3	3	3	3	173.3
0	0	0.00																																																																	0
Forward / Backward compatibility / Future proof	0	0.00	81	33	57	33	63	63	33	33	39	39	57	33	33	33	9	33	33	33	39	63	9	15	9	6	9	33	57	33	9	9	9	9	9	15	39	63	63	63	63	9	9	57	33	33	9	9	9	9	9	9	9	9	9	9	9	9	33	57	57	9	33	57	57	33	1947
Backward Compatibility	9	0.33	27	3	27	3	9	9	3	27	27	27	27	27	27	27	3	27	27	3	9	9	3	3	3	3	3	27	27	27	3	3	3	3	3	3	27	27	27	27	27	3	3	27	3	27	3	3	3	3	3	3	3	3	3	3	3	3	27	27	27	3	3	27	27	27	864
Forward Compatibility	9	0.33	27	3	3	3	27	27	3	3	9	9	27	3	3	3	3	3	3	3	27	27	3	9	3		3	3	3	3	3	3	3	3	3	3	3	27	27	27	27	3	3	27	27	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	495
Firmware Upgrade Exists	9	0.33	27	27	27	27	27	27	27	3	3	3	3	3	3	3	3	3	3	27	3	27	3	3	3	3	3	3	27	3	3	3	3	3	3	9	9	9	9	9	9	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	27	27	3	27	27	27	3		588
0	0	0.00																																																																0
Interference & Noise Handling	0	0.00	16.5	16.5	12	9	16.5	21	18	9	3	4.5	3	21	15	15	21	21	22.5	27	15	21	21	12	9	1.5	12	12	12	12	10.5	9	10.5	6	9	16.5	16.5	16.5	16.5	21	21	9	9	22.5	10.5	9	9	12	6	3	3	3	13.5	15	4.5	4.5	27	27	27	27	27	3	3	3	3	3	835.5
Scales to Multiple Dwelling Unit Environments	3	0.25	2.25	2.25	2.25	0.75	6.75	6.75	2.25	6.75	0.75	2.25	0.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	0.75	6.75	6.75	2.25	0.75		2.25	2.25	2.25	2.25	6.75	6.75	6.75	2.25	6.75	0.75	0.75	0.75	0.75	0.75	0.75	6.75	6.75	6.75	0.75	0.75	0.75	2.25	2.25	0.75	0.75	0.75	2.25	0.75	0.75	0.75	6.75	6.75	6.75	6.75	6.75	0.75	0.75	0.75	0.75	0.75	212.3
Coexistence Mechanism Use	3	0.25	0.75	0.75	0.75	0.75	0.75	0.75	2.25	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	2.25	6.75	6.75	6.75	6.75	2.25	0.75	0.75	0.75	0.75	0.75	0.75	2.25	0.75	0.75	2.25	0.75	6.75	6.75	6.75	6.75	6.75	6.75	0.75	0.75	2.25	2.25	0.75	0.75	2.25	2.25	0.75	0.75	0.75	2.25	0.75	2.25	2.25	6.75	6.75	6.75	6.75	6.75	0.75	0.75	0.75	0.75	0.75	156
Supports Transmit Power Control	3	0.25	6.75	6.75	2.25	0.75	2.25	6.75	6.75	0.75	0.75	0.75	0.75	6.75	0.75	0.75	6.75	6.75	6.75	6.75	0.75	0.75	0.75	0.75	0.75	0.75	2.25	2.25	2.25	2.25	0.75	0.75	2.25	0.75	0.75	2.25	2.25	2.25	2.25	6.75	6.75	0.75	0.75	6.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	2.25	6.75	0.75	0.75	6.75	6.75	6.75	6.75	6.75	0.75	0.75	0.75	0.75	0.75	174
Supports Spectrum Spreading	3	0.25	6.75	6.75	6.75	6.75	6.75	6.75	6.75	0.75	0.75	0.75	0.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75		6.75	6.75	6.75	6.75	0.75	0.75	0.75	0.75	0.75	6.75	6.75	6.75	6.75	6.75	6.75	0.75	0.75	6.75	6.75	6.75	6.75	6.75	0.75	0.75	0.75	0.75	6.75	6.75	0.75	0.75	6.75	6.75	6.75	6.75	6.75	0.75	0.75	0.75	0.75	0.75	293.3
0	0	0.00																																																																	0
Easy System Operation	0	0.00	27	27	21	21	27	27	27	21	9	15	27	15	15	15	15	15	15	21	21	27	27	15	21	9	9	9	21	21	11	21	13	7	13	15	15	15	15	15	15	15	15	27	21	21	21	15	13	11	11	11	15	13	7	7	27	27	27	27	27	19	21	21	21	21	1156
Stable and Reliable Links	3	0.33	9	9	3	3	9	9	9	9	3	9	9	3	3	3	3	3	3	9	9	9	9	3	9	3	3	3	9	9	1	9	9	3	9	3	3	3	3	3	3	3	3	9	9	9	9	9	3	1	1	1	9	9	3	3	9	9	9	9	9	9	9	9	9	9	394
Plug and Play	3	0.33	9	9	9	9	9	9	9	3	3	3	9	3	3	3	3	3	3	3	9	9	9	9	9	3	3	3	9	9	9	9	1	1	1	9	9	9	9	9	9	9	9	9	9	9	9	3	9	9	9	9	3	1	1	1	9	9	9	9	9	9	9	9	9	9	438
Link State Feedback	3	0.33	9	9	9	9	9	9	9	9	3	3	9	9	9	9	9	9	9	9	3	9	9	3	3	3	3	3	3	3	1	3	3	3	3	3	3	3	3	3	3	3	3	9	3	3	3	3	1	1	1	1	3	3	3	3	9	9	9	9	9	1	3	3	3	3	324
0	0	0.00																																																																0
Easy to Maintain	1	1.00	9	9	9	9	9	9	9	9	3	3	9	3	3	3	3	3	3	9	9	9	9	9	9	9	9	9	9	9	9	9	3	3	3	9	9	9	9	9	9	9	3	9	9	9	9	9	9	9	9	9	9	3	3	3	9	9	9	9	9	9	9	9	9	9	486
Easy to Replace	1	1.00	9	9	9	9	9	9	9	9	3	3	9	3	3	3	3	3	3	9	9	9	9	9	9	3	3	3	9	9	9	9	3	3	3	9	9	9	9	9	9	9	3	9	9	9	9	9	9	9	9	9	9	1	1	1	9	9	9	9	9	9	9	9	9	9	462

Robust messaging capability	0	0.00	9	9	9	9	5	9	9	9	5	5	1	1	1	1	1	1	1	9	9	9	9	5	9	5	5	5	5	5	1	1	5	5	5	9	9	9	9	9	9	5	9	9	9	9	9	9	5	1	1	1	9	5	1	1	9	9	9	9	9	1	9	9	9	9	396
Supports and Enforces Quality of Service (QoS) Delivery	1	0.50	4.5	4.5	4.5	4.5	0.5	4.5	4.5	4.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	4.5	4.5	4.5	4.5	0.5	4.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	4.5	4.5	4.5	4.5	4.5	4.5	0.5	4.5	4.5	4.5	4.5	4.5	4.5	0.5	0.5	0.5	0.5	4.5	0.5	0.5	0.5	4.5	4.5	4.5	4.5	4.5	0.5	4.5	4.5	4.5	4.5	168
Offers Error Correcting Codes	1	0.50	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	0.5	0.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	0.5	0.5	0.5	4.5	4.5	0.5	0.5	4.5	4.5	4.5	4.5	4.5	0.5	4.5	4.5	4.5	4.5	228
Affordable to install	1	1.00	3	3	3	3	9	9	3	1	3	1	9	1	1	1	1	1	1	9	3	3	3	9	3	1	9	9	9	9	9	9	1	1	1	9	9	9	9	9	9	9	9	3	3	3	3	9	9	9	9	9	9	1	1	1	3	3	3	3	3	1	1	1	1	1	302
0	0	0.00																																																																	0
Security Mechanisms	0	0.00	81	69	69	69	81	81	81	33	12	12	45	69	69	69	69	69	69	81	57	81	81	57	81	0	45	45	69	45	18	81	9	9	9	36	36	36	36	36	48	9	9	81	33	33	33	57	9	9	9	9	81	9	9	9	45	9	9	69	69	9	9	9	9	9	2688
Link Encrypted (AES-128-CCM or better)	9	0.17	13.5	13.5	13.5	13.5	13.5	13.5	13.5	4.5	1.5	1.5	1.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5		13.5	13.5	13.5	13.5	4.5	13.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	13.5	1.5	1.5	13.5	1.5	1.5	1.5	13.5	1.5	1.5	1.5	1.5	13.5	1.5	1.5	1.5	13.5	1.5	1.5	13.5	13.5	1.5	1.5	1.5	1.5	1.5	472.5
Network Encrypted (AES-128-CCM or better)	9	0.17	13.5	1.5	1.5	1.5	13.5	13.5	13.5	1.5	1.5	1.5	13.5	1.5	1.5	1.5	1.5	1.5	1.5	13.5	13.5	13.5	13.5	13.5	13.5		1.5	1.5	13.5	1.5	1.5	13.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	13.5	1.5	1.5	1.5	13.5	1.5	1.5	1.5	1.5	13.5	1.5	1.5	1.5	1.5	1.5	1.5	13.5	13.5	1.5	1.5	1.5	1.5	1.5	310.5
Endpoints Mutually Authenticatable	9	0.17	13.5	13.5	13.5	13.5	13.5	13.5	13.5	4.5	4.5	4.5	1.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	1.5	13.5	13.5	1.5	13.5		1.5	1.5	1.5	1.5	4.5	13.5	1.5	1.5	1.5	4.5	4.5	4.5	4.5	4.5	4.5	1.5	1.5	13.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	13.5	1.5	1.5	1.5	1.5	1.5	1.5	13.5	13.5	1.5	1.5	1.5	1.5	1.5	388.5
Supports PKI	9	0.17	13.5	13.5	13.5	13.5	13.5	13.5	13.5	4.5	1.5	1.5	1.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	1.5	13.5	13.5	1.5	13.5		1.5	1.5	13.5	1.5	1.5	13.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	13.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	13.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	349.5
Supports PSK	9	0.17	13.5	13.5	13.5	13.5	13.5	13.5	13.5	4.5	1.5	1.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5		13.5	13.5	13.5	13.5	4.5	13.5	1.5	1.5	1.5	13.5	13.5	13.5	13.5	13.5	13.5	1.5	1.5	13.5	13.5	13.5	13.5	13.5	1.5	1.5	1.5	1.5	13.5	1.5	1.5	1.5	13.5	1.5	1.5	13.5	13.5	1.5	1.5	1.5	1.5	1.5	580.5
Supports Logical Separation	9	0.17	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	1.5	1.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5		13.5	13.5	13.5	13.5	1.5	13.5	1.5	1.5	1.5	13.5	13.5	13.5	13.5	13.5	13.5	1.5	1.5	13.5	13.5	13.5	13.5	13.5	1.5	1.5	1.5	1.5	13.5	1.5	1.5	1.5	13.5	1.5	1.5	13.5	13.5	1.5	1.5	1.5	1.5	1.5	586.5
0	0	0.00																																																																	0
0	0	0.00																																																																	0
																																																																			0
																																																																			0
Total			373	294	321	284	368	368	300	244	170	175	274	251	245	245	221	245	251	317	272	334	281	214	225	74	221	245	325	268	193	268	169	154	148	255	279	302	306	297	318	184	165	303	238	231	206	206	174	137	134	128	218	128	122	79	231	197	220	306	300	179	200	219	212	207	

	System Requirements	Importance	Relative category weight	SEP 2.0	OpenADR	BACnet /ISO 16484-5	BACnet ASHRAE 135-2008	LON ANSI 709.1-B-2002	IEC 62056 / DLMS	ISO/IEC 15067-3	OPC-UA	Zwave	ZigBee SEP 1.0	Total
1	Proven Interoperable Protocol	3.00												145
	IEC CIM compliant	3.00	0.13	h	l	m	m	l	l	l	l	l	l	8
	Network Interface exists	3.00	0.13	h	h	m	m	l	h	m	h	h	l	21
	Loose coupling	3.00	0.13	h	m	h	h	m	h	m	m	m	l	20
	Certification Bodies / Test Labs Exist	3.00	0.13	h	l	l	l	h	h	l	h	h	h	22
	Commercial Alliance Supported / Vetted	3.00	0.13	m	h	m	m	m	h	l	h	h	m	20
	Open Specification	3.00	0.13	m	l	m	m	m	m	m	m	l	m	10
	On the NIST Interoperability Roadmap	3.00	0.13	h	h	m	m	m	m	h	m	m	l	17
	SDO supported / vetted	3.00	0.13	m	h	h	m	m	h	h	h	h	m	25
2	Accepted Technology in Marketplace	3.00												138
	Current installed base	3.00	0.33	l	h	h	h	h	h	l	l	h	h	66
	Technology currently in use in Non-HAN systems	3.00	0.33	l	m	m	m	m	h	l	m	h	h	44
	Technology currently in use in HAN systems	3.00	0.33	l	l	l	l	m	l	l	l	h	h	28
3	Acceptable Cost trade offs	3.00												136
	User configuration method exists w/o additional hardware	3.00	0.33	m	h	h	h	m	h	h	l	l	m	56
	Pre-configurable	3.00	0.33	h	l	l	l	h	l	m	m	l	m	32
	Standard Implementation Complexity	3.00	0.33	m	h	m	m	m	h	m	m	h	m	48
4	Easy to provision to HAN / Plug and Play Applicance	3.00												146
	Supports adding, deleting, modifying of devices	3.00	0.33	h	l	h	h	h	m	h	h	h	h	76
	Supports multiple appliances	3.00	0.33	h	m	h	h	h	l	h	h	h	m	70
5	Minimize Enabling Infrastructure	3.00												150
	Application requires additional hardware	3.00	0.50	h	m	h	h	l	m	h	l	h	m	84
	Application requires additional software	3.00	0.50	l	l	h	h	l	l	h	l	h	m	66
7	Forward / Backward compatibility / Future proof	9.00												330
	Supports authorized direct load control	9.00	0.17	h	h	l	h	l	m	h	l	m	l	69
	Supports time-based power reduction/consumption	9.00	0.17	h	h	l	h	l	m	h	m	l	l	69
	Supports power reduction to reduce energy costs	9.00	0.17	h	h	l	l	l	l	h	l	l	l	51
	Supports third party load control	9.00	0.17	h	h	l	m	l	l	h	m	l	l	57
	Supports load shifting/optimization	9.00	0.17	m	h	l	l	l	l	h	l	l	l	42
	Supports independent power optimization	9.00	0.17	h	l	l	m	l	l	h	l	l	l	43
8	Interference and Noise Handling	3.00												108
	Auto recovery from Loss of Communication	3.00	0.33	h	m	l	l	m	l	l	h	m	l	32
	Supports Quality of Service (QOS) message prioritization	3.00	0.33	h	h	m	m	l	h	l	h	l	l	46
	Supports Lossy/low power communications	3.00	0.33	h	m	l	l	m	l	l	l	h	l	30
9	Easy System Operation	3.00												150
	Supports auto-discovery of devices	3.00	0.25	h	l	m	m	h	m	l	h	l	h	36
	Auto-installation	3.00	0.25	m	l	l	l	m	l	l	m	l	m	14
	Error Messages/Codes specified	3.00	0.25	h	h	h	h	h	h	l	m	m	h	53
	Protocol specifies error handling	3.00	0.25	h	m	h	h	h	h	l	h	m	m	48
10, 11	Easy to Maintain/Replace	1.00												30
	Software Upgrades can be installed by service technician	1.00	0.25	m	l	h	h	h	m	l	h	h	l	14
	Software Upgrades can be installed by consumer	1.00	0.25	m	l	l	l	l	l	l	h	m	l	6
	Firmware Upgrades can be installed by service technician	1.00	0.25	h	l	l	l	m	m	l	l	m	l	6
	Firmware Upgrades can be installed by consumer	1.00	0.25	h	l	l	l	l	l	l	l	m	l	5
12	Robust messaging capability	1.00												50
	Supports 2 way communications	1.00	0.20	h	h	h	h	h	h	h	h	h	h	18
	Supports general data queries	1.00	0.20	h	m	m	m	l	m	h	h	m	m	9
	Supports appliance specific queries	1.00	0.20	h	l	l	l	l	l	h	l	m	l	6
	Message verified with checksums/CRC algorithm/other	1.00	0.20	m	m	m	m	m	l	l	m	m	l	5
	Supports non-static message formats	1.00	0.20	h	h	m	m	m	m	h	h	m	h	12
14	Security Mechanisms	9.00												324
	Supports session encryption	9.00	0.33	h	m	m	m	m	m	l	h	m	h	138
	Supports user authorization	9.00	0.33	h	h	l	l	m	m	l	h	m	h	144
	Supports authentication	3.00	0.33	h	m	l	l	m	m	l	h	m	h	42

1	Proven Interoperable Protocol	3.00		20	16	13	11	10	20	11	17	17	8	145
	IEC CIM compliant	3.00	0.13	3	0	1	1	0	0	0	0	0	0	8
	Network Interface exists	3.00	0.13	3	3	1	1	0	3	1	3	3	0	21
	Loose coupling	9.00	0.13	3	1	3	3	1	3	1	1	1	0	20
	Certification Bodies / Test Labs Exist	9.00	0.13	3	0	0	0	3	3	0	3	3	3	22
	Commercial Alliance Supported / Vetted	9.00	0.13	1	3	1	1	1	3	0	3	3	1	20
	Open Specification	3.00	0.13	1	0	1	1	1	1	1	1	0	1	10
	On the NIST Interoperability Roadmap	3.00	0.13	3	3	1	1	1	1	3	1	1	0	17
	SDO supported / vetted	3.00	0.25	1	3	3	1	1	3	3	3	3	1	25
2	Accepted Technology in Marketplace	3.00		3	13	13	13	15	19	3	5	27	27	138
	Technology currently in use in Non-HAN systems	3.00	0.50	1	9	9	9	9	9	1	1	9	9	66
	Technology currently in use in HAN systems	3.00	0.50	1	3	3	3	3	9	1	3	9	9	44
	Current installed base	3.00	0.25	1	1	1	1	3	1	1	1	9	9	28
3	Acceptable Cost trade offs	3.00		15	19	13	13	15	19	15	7	11	9	136
	User configuration method exists w/o additional hardware	3.00	0.33	3	9	9	9	3	9	9	1	1	3	56
	Pre-configurable	3.00	0.33	9	1	1	1	9	1	3	3	1	3	32
	Standard Implementation Complexity	3.00	0.33	3	9	3	3	3	9	3	3	9	3	48
4	Easy to provision to HAN / Plug and Play Applicance	3.00		18	4	18	18	18	4	18	18	18	12	146
	Supports adding, deleting, modifying of devices	3.00	0.33	9	1	9	9	9	3	9	9	9	9	76
	Supports multiple appliances	3.00	0.33	9	3	9	9	9	1	9	9	9	3	70
5	Minimize Enabling Infrastructure	3.00		15	6	27	27	3	6	27	3	27	9	150

	Application requires additional hardware	3.00	0.50	14	5	14	14	2	5	14	2	14	5	84
	Application requires additional software	3.00	0.50	2	2	14	14	2	2	14	2	14	5	66
7	Forward / Backward compatibility / Future proof	9.00		72	69	9	39	9	15	81	15	12	9	330
	Supports authorized direct load control	9.00	0.17	13	13	1	13	1	4	13	1	4	1	69
	Supports time-based power reduction/consumption	9.00	0.17	13	13	1	13	1	4	13	4	1	1	69
	Supports power reduction to reduce energy costs	9.00	0.17	13	13	1	1	1	1	13	1	1	1	51
	Supports third party load control	9.00	0.17	13	13	1	4	1	1	13	4	1	1	57
	Supports load shifting/optimization	9.00	0.17	4	13	1	1	1	1	13	1	1	1	42
	Supports independent power optimization	9.00	0.17	14	2	2	5	2	2	14	2	2	2	43
8	Interference and Noise Handling	3.00		27	15	5	5	7	11	3	19	13	3	108
	Auto recovery from Loss of Communication	3.00	0.33	9	3	1	1	3	1	1	9	3	1	32
	Supports Quality of Service (QOS) message prioritization	3.00	0.33	9	9	3	3	1	9	1	9	1	1	46
	Supports Lossy/low power communications	3.00	0.33	9	3	1	1	3	1	1	1	9	1	30
9	Easy System Operation	3.00		23	11	17	17	23	17	3	18	6	18	150
	Supports auto-discovery of devices	3.00	0.25	7	1	2	2	7	2	1	7	1	7	36
	Auto-installation	3.00	0.25	2	1	1	1	2	1	1	2	1	2	14
	Error Messages/Codes specified	3.00	0.25	7	7	7	7	7	7	1	2	2	7	53
	Protocol specifies error handling	3.00	0.25	7	2	7	7	7	7	1	7	2	2	48
10, 11	Easy to Maintain/Replace	1.00		6	1	3	3	4	2	1	5	5	1	30
	Software Upgrades can be installed by service technician	1.00	0.25	1	0	2	2	2	1	0	2	2	0	14
	Software Upgrades can be installed by consumer	1.00	0.25	1	0	0	0	0	0	0	2	1	0	6
	Firmware Upgrades can be installed by service technician	1.00	0.25	2	0	0	0	1	1	0	0	1	0	6
	Firmware Upgrades can be installed by consumer	1.00	0.25	2	0	0	0	0	0	0	0	1	0	5
12	Robust messaging capability	1.00		8	5	4	4	3	3	7	6	4	5	50
	Supports 2 way communications	1.00	0.20	2	2	2	2	2	2	2	2	2	2	18
	Supports general data queries	1.00	0.20	2	1	1	1	0	1	2	2	1	1	9
	Supports appliance specific queries	1.00	0.20	2	0	0	0	0	0	2	0	1	0	6
	Message verified with checksums/CRC algorithm/other	1.00	0.20	1	1	1	1	1	0	0	1	1	0	5
	Supports non-static message formats	1.00	0.20	2	2	1	1	1	1	2	2	1	2	12
14	Security Mechanisms	9.00		63	39	13	13	21	21	7	63	21	63	324
	Supports session encryption	9.00	0.33	27	9	9	9	9	9	3	27	9	27	138
	Supports user authorization	9.00	0.33	27	27	3	3	9	9	3	27	9	27	144
	Supports authentication	3.00	0.33	9	3	1	1	3	3	1	9	3	9	42
														0
	Application Layer Totals			261	194	133	161	124	133	176	167	157	155	1661

	802.11				SEP 2.0	
Feature / Name	IEEE 802.11n LPEW (SE 2.0 capable)	IEEE 802.11a	IEEE 802.11g	IEEE 802.11b	ZigBee (SEP 2.0 capable)	HomePlug Green PHY (SEP 2.0 capable)
Frequency	ISM Band 2.4 GHz - 2.48 GHz U-NII Band 5.8 GHz -	(U-NII Band) f_c=5.1 GHz - 5.8 GHz	(ISM 2.4 GHz Band) f_c=2412 GHz - 2462 GHz	(ISM 2.4 GHz Band) f_c=2412 GHz - 2462 GHz	(ISM 2.4 GHz Band) F_c=2405+5(k-11) k=11..26	1.8 - 30 MHz
Channel Scheme	20 or 40 MHz Blocks	8 non-overlapping 20 - Mhz Channels 52 sub-carriers per Channel	11 overlapping 22 MHz Channels, 5 MHz center separation	11 overlapping 22 MHz Channels, 5 MHz center separation	16 Channels	1155 Subcarriers, 917 For data
Coexistence	CSMA/CA	CSMA/CA	CSMA/CA	CSMA/CA	CSMA/CA	IEEE P1901 ISP
Spreading	OFDM, CCK, DSSS	OFDM	OFDM, CCK, DSSS	CCK, DSSS	DSSS	OFDM
Modulation	Various OFDM Subband	BPSK, QPSK, 16-QAM or 64-QAM	OFDM, CCK, DBPSK/DQPSK+DSSS	CCK, DSSS		QPSK (P1901-FFT: BPSK, QPSK, 8,16,32,256,1024 QAM)
Diversity	Various Diversity up to 4XMIMO Possible	RX Diversity Possible	RX Diversity Possible	RX Diversity Possible	RX Diversity Possible, rarely used	Not currently used
Error Correction	FEC	FEC	FEC	FEC	CRC	FEC, Turbo Codes
Est. Indoor Range	< 70 m	< 35 m	< 38 m	< 38 m	< 30m (0 dB)	> 66 m wire
Estimated Link Latency	>= 4 ms	>= 4ms	>= 4 ms	>= 15 ms	>=24 ms	< 100 ms (P1901-FFT: < 2 ms)
Estimated Link Bandwidth	1 Mb/s, DSSS 2 Mb/s, DSSS 4 Mb/s, OFDM ... See standard covering additional modulator settings used in practice beyond LPEW....	6 Mb/s - 54 Mb/s	1 Mb/s - 54 Mb/s	1 Mb/s - 11 Mb/s	250 kb/s	3.8 Mb/s 4.9 Mb/s 9.8 Mb/s
Scalability Features	Some products can mesh via WDS.	Some products can mesh via WDS.	Some products can mesh via WDS.	Bridges/Repeaters Available	Bridges/Repeaters Available	Bridges/Repeaters Available (P1901-FFT: additionally
Known Scale Limits	Most consumer products default to serving class C subnets, no specific limits. If used, each	Most consumer products default to serving class C subnets, no specific limits. If used, each WDS	Most consumer products default to serving class C subnets, no specific limits. If used, each	Most consumer products default to serving class C subnets, no specific limits.	Typical limits are branch factors of 500 nodes to one ESI, designed	32 nodes to a home, 128 homes sharing a transformer (other
Reliability Features	Pre/post coding, beamforming, etc.	Pre/post coding	Pre/post coding	Pre/post coding	ED, LQI, CCA	Pre/post coding
Link Security	IEEE 802.11i, WPS	IEEE 802.11i, WPS	IEEE 802.11i, WPS	IEEE 802.11i, WPS	AES-128-CCM, PKI, PSK	AES-128-CCM, PKI, PSK
Net Security	IEEE 802.11i	IEEE 802.11i	IEEE 802.11i	IEEE 802.11i	802.11i equivalent mechanisms	802.11i equivalent mechanisms
Generational Compliance	PHY-dependent coverage of 802.11abg	No	Most 802.11g products also offer 802.11b, but are not required to do so.	None	None	Full interop between GP, AV, P1901-fft, forward compatible with future
Link Extension / Repeating	WDS / Repeating Capable	WDS / Repeating Capable	WDS / Repeating Capable	WDS / Repeating Capable	Repeating Supported	Route-under Repeating
PHY Change / Bridging	Enables 802.2 and WDS widely available	Enables 802.2 and WDS widely available	Enables 802.2 and WDS widely available	Enables 802.2 and WDS widely available	Adapted bridging Supported	Enables 802.2 and lower layer bridging
Data-flow Direction	Bi-Directional	Bi-Directional	Bi-Directional	Bi-Directional	Bi-Directional	Bi-Directional
Est. Chip Cost	Special variants <$5	<$10	Special variants <$5	Special variants <$5	<$5	<$5
Est. Idle Power (W)	negligable	negligeable	negligable	negligable	negligable	negligable
Est. TX Power (W)	LPEW variants < .5 W		Special Variants < 1 W	Special Variants < 1 W	< .3 W	< .5W
Est. RX Power (W)	LPEW variants < .5 W		Special Variants < 1 W	Special Variants < 1 W	< .3 W	< .5W
Est. RX Sensitivtiy (dBM)						
TX Power Ranges (dBm)				0 to 20 dBm	-17 to 20 dBm	

			Lon			
Feature / Name	IEEE 802.16 WiMAX	IEEE 802.3	ISO/IEC 14908-3 LonWorks PLCS	ISO/IEC LonWorks 14908-2 TPC	Z-Wave (v4)	3GPP2 / CDMA2000 1x
Frequency	700 MHz, 2.5 GHz, 3.6 GHz, many others	[Special-Purpose Cabling]		[Special-Purpose Cabling]	Locale: F_c for 9.6kbps / F_c for 40kbps EU: 868.42 / 868.40MHz US: 908.42 / 908.40MHz HK: 919.82 / 919.80MHz NZ: 921.42 / 921.40MHz AUS:921.42 / 921.40MHz	
Channel Scheme	Bandwidth dependent : 1.25	[Special-Purpose Cabling]		[Special-Purpose Cabling]	1 channel, 40 kHz wide	
Coexistence	CSMA/CA and TDMA	CSMA/CD	CSMA/CA	CSMA/CD	CSMA/CA	CSMA/CA and TDMA
Spreading	SOFDMA	None		None		
Modulation					FSK + Manchester @ 9.6 kb/s FSK + NRZ @ 40 kb/s	
Diversity	All types including MIMO					
Error Correction	Turbo Code, LDPC					
Est. Indoor Range					> 30 m	
Estimated Link Latency	> 100 ms	negligable			> 100 m	
Estimated Link Bandwidth					9.6 kb/s 40 kb/s	DOWNLINK(2.45 Mb/s 3.1 Mb/s 4.9xN Mb/s) UPLINK(0.15 Mb/s 1.8 Mb/s 1.8xN Mb/s)
Scalability Features						
Known Scale Limits						
Reliability Features						
Link Security			Obfuscation only	Obfuscation only	AES-128	
Net Security					None	
Generational Compliance					Backward Compatible with v3 Z-Wave	
Link Extension / Repeating					yes	
PHY Change / Bridging					yes	
Data-flow Direction	Bi-Directional	Bi-Directional	Bi-Directional	Bi-Directional	Bi-Directional	Bi-Directional
Est. Chip Cost	<$20	<$5	<$10	<$10	< $15	<$20
Est. Idle Power (W)		See LPI variants IEEE 802.3az				
Est. TX Power (W)		See LPI variants IEEE 802.3az				
Est. RX Power (W)		See LPI variants IEEE 802.3az				
Est. RX Sensitivtiy (dBM)					-102 dBm @ 9.6 kb/s -98 dBm @ 40 kb/s	
TX Power Ranges (dBm)					-22 dBm to -2 dBm	

	3GPP							P1901				
Feature / Name	3GPP / GPRS	3GPP / EDGE	3GPP / UMTS	3GPP / HSPA	3GPP / HSPA+	ISA 100.11a-2009	HomePlug AV	IEEE P1901 / FFT	IEEE P1901 / Wavelet	HomePlug C&C	ITU-T G.hn	ISO/IEC 12139
Frequency												
Channel Scheme												
Coexistence	CSMA/CA and TDMA		CSMA/CA and TDMA	CSMA/CA and TDMA	CSMA/CA and TDMA	CSMA/CA	CSMA/CA	CSMA/CA	CSMA/CA	CSMA/CA	CSMA/CA	CSMA/CA
Spreading												
Modulation												
Diversity												
Error Correction												
Est. Indoor Range												
Estimated Link Latency												
Estimated Link Bandwidth												
Scalability Features												
Known Scale Limits												
Reliability Features												
Link Security												
Net Security												
Generational Compliance												
Link Extension / Repeating												
PHY Change / Bridging												
Data-flow Direction	Bi-Directional	Bi-Directional	Bi-Directional	Bi-Directional	Bi-Directional	Bi-Directional	Bi-Directional	Bi-Directional	Bi-Directional	Bi-Directional	Bi-Directional	Bi-Directional
Est. Chip Cost	<$20		<$20	<$20	<$20	<$5	<$25	<$25	<$25	<$10	?	?
Est. Idle Power (W)												
Est. TX Power (W)												
Est. RX Power (W)												
Est. RX Sensitivtiy (dBM)												
TX Power Ranges (dBm)												