Wi-Fi® for the Smart Grid:

Mature, Interoperable, Security-Protected Technology for Advanced Utility Management Communications

Wi-Fi Alliance®
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1.0 Executive Summary

This paper describes the suitability of Wi-Fi technology for use in the Smart Grid infrastructure.

Smart Grid solutions are being driven by the desire for more efficient energy usage worldwide. The Smart Grid communications network will be a heterogeneous network based on many different standards. Wireless technology will certainly be part of any future Smart Grid. Wi-Fi is cost effective, scales to cover large geographies and many endpoints, and requires no new cabling within the home.

Wi-Fi is mature, proven technology that implements many of the Smart Grid application scenarios today. Wi-Fi networks can be deployed to meet the Smart Grid requirements for robustness, manageability, performance and security. Moreover, Wi-Fi technology has an ongoing roadmap of innovation and established mechanisms for collaboration (via the Wi-Fi Alliance and IEEE) to meet the evolving needs of Smart Grid applications well into the future.

The Wi-Fi CERTIFIED program tests devices based on the 802.11 family of standards for interoperability and quality. The Wi-Fi CERTIFIED program provides a widely-recognized designation of interoperability and quality and has contributed to the success of Wi-Fi technology. Key attributes of Wi-Fi include:

- Mature technology with more than a billion nodes already deployed[1]
- Mechanisms to deliver robust performance in shared-spectrum and noisy RF environments including Listen-before-talk protocol, RF noise awareness and reporting, and received signal strength
- Transports all IPv4 and IPv6-based protocols, thereby supporting all IP-based applications
- Extensive radio performance and network management mechanisms to provide radio link quality, history reports and channel selection optimization
- Low costs due to economies of scale: Wi-Fi chipset shipments now exceed one million units per day and will grow past one billion units per year by 2011[2]
- One standard that allows implementation of several interoperable performance/power dissipation profiles
- Rates ranging from 1 Mbps (802.11b) to 600 Mbps (802.11n)
- Networks can scale from a single pair of devices to thousands of access points and clients

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[1] ABI Research, Wi-Fi IC Market Data, 3Q 2009.

[2] ABI Research, Wi-Fi IC Market Data, 3Q 2009.

- Security protections: Link-, network-, and application-level security based on international standards which meet FIPS 140-2 certification[3]
- Rogue device and intrusion detection tools

2.0 Background

The need for Smart Grid solutions is being driven by the emergence of distributed power generation and management/monitoring of consumption, and the desire for more efficient energy usage worldwide. Smart Grid advancements will apply digital technologies to the grid, enabling two-way communications and real-time coordination of information from generating plants, distribution resources and demand-side end points.

Government and Regulatory Forces

The U.S. Department of Energy is accelerating the development of a smart electric grid system targeting long-term savings for consumers by improving the efficiency and operation of the grid. The Smart Grid Policy Statement sets priorities for work on development of standards crucial to a reliable Smart Grid.[4]

As defined by the Department of Energy, the Smart Grid Standards must:

- Provide two-way communication among grid users, e.g. regional market operators, utilities, service providers and consumers
- Allow power system operators to monitor their own systems as well as neighboring systems that affect them so as to facilitate more reliable energy distribution and delivery
- Coordinate the integration into the power system of emerging technologies such as renewable resources, demand response resources, electricity storage facilities and electric transportation systems
- Ensure the cyber security of the grid

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[3] Sheila Frankel et al., "Establishing Wireless Robust Security Networks: A Guide to IEEE 802.11i," February 2007, NIST Special Publication 800-97, http://csrc.nist.gov/publications/nistpubs/800-97/SP800-97.pdf (8 September 2009).

[4] Federal Energy Regulatory Commission, "Smart Grid Policy of the Federal Energy Regulatory Commission," 16 July 2009, www.ferc.gov/whats-new/comm-meet/2009/071609/E-3.pdf/ (8 September 2009).

Standards are critical to enabling interoperable systems and components. Mature international standards are the foundation of markets for the millions of components that will have a role in the future Smart Grid.

The Wi-Fi Alliance

The Wi-Fi Alliance is a global non-profit industry association comprised of hundreds of leading companies devoted to the proliferation of Wi-Fi technology across devices and market segments. The Wi-Fi Alliance develops rigorous tests, conducts Wi-Fi certification of wireless devices that implement the IEEE 802.11 standard for wireless LANs, and develops additional specifications that enhance Wi-Fi for particular market applications. With technology development, market building, and regulatory programs, the Wi-Fi Alliance has enabled widespread adoption of Wi-Fi worldwide.

The Wi-Fi CERTIFIED™ program was launched in March 2000. It provides a widely-recognized designation of interoperability and quality, and it helps to ensure that Wi-Fi enabled products deliver the best user experience. The Wi-Fi Alliance has completed more than 6,000 product certifications to date, encouraging the expanded use of Wi-Fi products and services in new and established markets.

In the ten years since its inception, the Wi-Fi Alliance has provided an important forum for innovation. In addition to interoperability testing, the organization is the birthplace of widely-deployed specifications including Wi-Fi Multimedia ™ (WMM®) for Quality of Service on multimedia networks and Wi-Fi Protected Setup™ to ease setup of security-protected home and small office networks. Wi-Fi Alliance task groups address industry opportunities by developing testing programs which address market needs for interoperability, security protection, and performance.

Through its collaboration with other industry organizations, the Wi-Fi Alliance helps deliver Wi-Fi technologies which suit the needs of a wide variety of devices, applications, and use environments. For example, in collaboration with CTIA®, the Wi-Fi Alliance developed an extensive RF performance mapping test for converged Wi-Fi/cellular devices, now widely specified by mobile carriers. Collaborations with other organizations including the Digital Living Network Alliance (DLNA) and Fixed-Mobile Convergence Alliance (FMCA) have resulted in information-sharing and the specification of Wi-Fi CERTIFIED technology by other certification bodies.

3.0 Smart Grid Communications Networks and Wi-Fi

The Smart Grid communications network is typically partitioned into three segments: Home Area Network (HAN), Neighborhood Area Network (NAN), and Wide Area Network (WAN/Backhaul). Wi-Fi technology addresses all three segments.

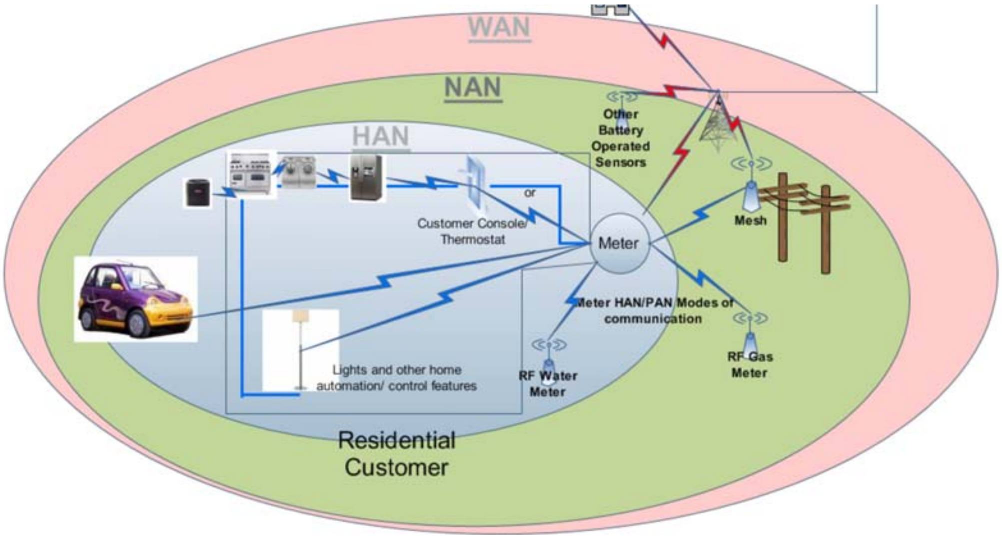

Figure 1: Three Smart Grid Segments

Wi-Fi in the Home Area Network

The Home Area Network for the Smart Grid is used to gather sensor information from a variety of devices within the home, and optionally send control information to these devices to better control energy consumption. The electric meter on each residence is a natural place to aggregate this information and possibly act as a bridge to the Neighborhood Area Network,

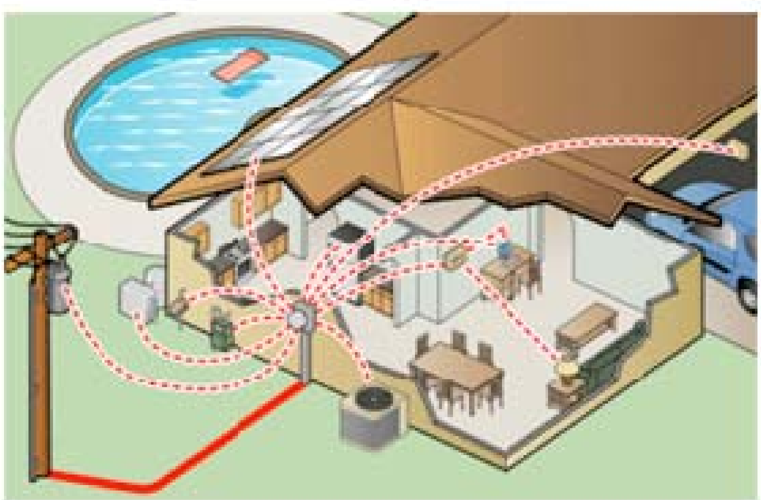

Figure 2: The Home Area Network

Wi-Fi is quite suitable for the Home Area Network of the Smart Grid. Wi-Fi is based on very mature technology and has a large installed base in home networking (estimated at more than 100 million households worldwide[5]). The latest generation, 802.11n, is capable of distributing high definition video throughout the home, but Wi-Fi devices are also capable of supporting low data rate/low power applications as well. Wi-Fi is being included in a very wide range of portable and stationary consumer electronics devices, and its home market share will only increase.

Wi-Fi operates in unlicensed spectrum and so is subject to interference. However, Wi-Fi is designed to operate in this uncontrolled spectrum and is resilient to many types of interference. Wi-Fi coexists very well with other technologies that share these bands.

Wi-Fi has a mature ecosystem, with widely-demonstrated interoperability, more than one billion devices shipped to date, and a continued growth rate expected to continue in double-digits for the foreseeable future.[6] The Wi-Fi Alliance's certification program is the benchmark for all other wireless technologies. Hundreds of vendors deploy the technology in a wide range of devices. Ongoing innovations in power management are bringing tremendous improvements to Wi-Fi power dissipation profiles. Already the network of choice in millions of homes, Wi-Fi is ready to be the Home Area Network standard for Smart Grid.

[5] Kurt Scherf, Parks Associates, April 2008, "Networks in the Home: Global Growth; A Report for the Wi-Fi Alliance".

[6] ABI Research, 3Q 2009, "Wi-Fi IC Market Data".

Wi-Fi in the Neighborhood Area Network

The Neighborhood Area Network of the Smart Grid will collect information from many households in a neighborhood and connect them to a wide area network. NAN endpoints will typically be utility meters mounted on the outside of single family houses or on the roof of multiple dwelling units. The transmission range should be at least 500 meters and can potentially incorporate a multi-hop mesh approach.

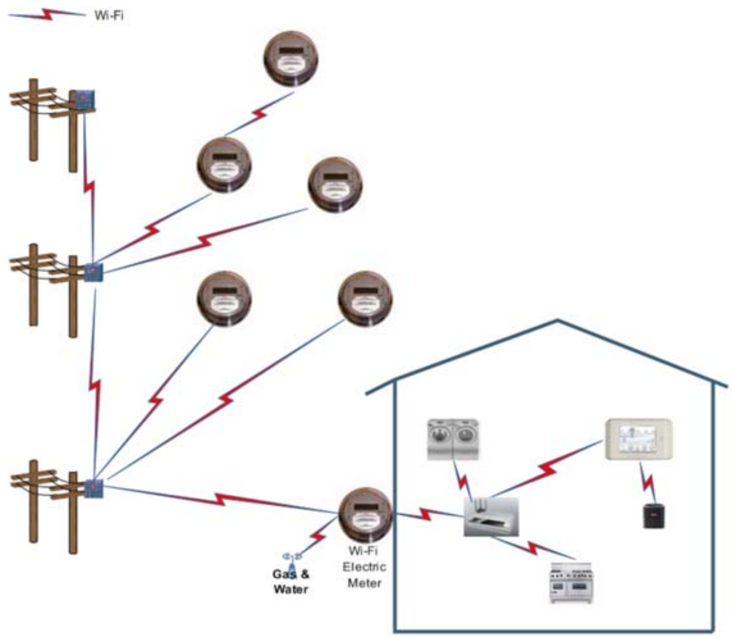

Figure 3: The Smart Grid Neighborhood Area Network

Municipal-scale Wi-Fi network infrastructure has already been deployed using 802.11 technology. This includes systems, for example, that provide access covering up to 500 meters from the AP, interconnected by point-to-point links based on 802.11 technology and using proprietary mesh protocols. Modern municipal Wi-Fi networks typically also support 4.9 GHz access for public safety networks that are also based on 802.11 technology. Newer developments in the 802.11n standard, including support for transmit beam forming, may further enhance the use of Wi-Fi for these outdoor applications.

Existing municipal 802.11-based networks are the appropriate scale for the Smart Grid Neighborhood Area Network. Wi-Fi can connect hundreds of devices on buildings and pole tops in a variety of terrains. The 4.9 GHz public safety application shows that Wi-Fi can be re-banded to support lightly licensed spectrum with different channel sizes. The Smart Grid NAN networks might benefit from operating in lightly licensed spectrum similar to the 4.9 GHz spectrum that has been set aside for public safety applications in the US.

Additional enhancements for the Smart Grid NAN can come from work being done within the IEEE 802.11s Task Group to standardize a mesh networking protocol.

Wi-Fi in the Wide Area Network

The WAN for Smart Grid will aggregate data from multiple Neighborhood Area Networks and convey it to the utility private network. Such "backhaul" can be implemented via point-to-point and/or point-to-multipoint wireless links. Smart Grid WANs may cover a very large area and could aggregate ten thousand supported devices. Multi-megabit capacity will be required, and the links involved may range from sub-kilometer to multi-kilometer distances.

Existing city-wide deployments of Wi-Fi networks demonstrate the clear applicability of Wi-Fi as a Smart Grid WAN technology. Minneapolis[7] is just one example of a metropolitan installation in which Wi-Fi is used not only for neighborhood network access but in the WAN backhaul portion of the system as well. Today such metropolitan area WANs incorporating standard 802.11 Wi-Fi in point-to-point or point-to-multipoint links embody a variety of proprietary network management approaches, demonstrating that Wi-Fi technology could be similarly incorporated into the future standardized Smart Grid management framework for WAN communication.

A key advantage of Wi-Fi for the Wide Area Network Smart Grid is its use of free, unlicensed spectrum. This makes it practical for a city or utility to own and operate a large private wireless network for Smart Grid. WiMAX and cellular data networks can provide the required service, but are usually owned and operated by large carriers who pay for the frequency licenses.

Wi-Fi Network Measurement and Management

All wireless networks require network measurement and management to help optimize RF performance. Wi-Fi has extensive network management capabilities that integrate with existing enterprise network management systems and that make Wi-Fi suitable for very large scale deployments in the Smart Grid. Ensuring that these networks securely and reliably serve the hundreds of thousands of users that rely upon them requires both autonomous and centrally administered problem diagnosis and performance optimization.

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[7] James Farstad, "Wireless Minneapolis a Growing Source of Promising Practices," 13 March 2008, W2i Wireless Government Report, http://w2i.com/resource_center/the_w2i_report__weekly_newsletter/news/p/id_203 (8 September 2009).

Wi-Fi Network Management systems in place today provide:

- Visibility into device performance and usage
- Historical trend reporting
- Threshold-based alerts
- Scheduled events and reports
- Device configuration and reconfiguration, including multi-vendor management when networks are comprised of wireless devices from more than one manufacturer
- Centralized software updates

One major addition to the IEEE 802.11 standard, 802.11k, provides network measurement protocols. A second addition, 802.11v, adding a new suite of network management capabilities, is nearing completion. These two standards extend existing commercial device and management system product capabilities, allowing Wi-Fi devices to measure and report radio link and traffic characteristics. Availability of this information enables optimization in performance and reliability through both local responses (e.g. transmit power control and radio channel change of a wireless Access Point or client device) and centralized management of these extended Wi-Fi networks.

4.0 Smart Grid Wireless Use Cases

Wi-Fi can be advantageously employed in a variety of Smart Grid Use Cases -- here are just some examples.

Home Thermostats

A central application of the Smart Grid in a HAN is the thermostat. Between 35 and 60% of a home's energy consumption can be measured and controlled through networked thermostats which control the Heating Ventilating and Air Conditioning. By adding low-power Wi-Fi sensor devices and networking capability to appliances, heating systems, air conditioning systems, water heaters and thermostats, homeowners and utility providers benefit by reducing their energy consumption and supporting conservation initiatives. Homeowners can monitor and control energy consumption with minimal effort and also benefit from incentives provided by their utility providers for energy conservation. Wi-Fi technology represents a massive installed base that already exists in many homes and buildings, and utility providers, by extending a Smart Grid inside the house using Wi-Fi, can better manage peak demand.

Since Wi-Fi devices are designed to operate within an IP networking environment, there is no specific requirement for a gateway element to handle network address translation or custom provisioning.

Advanced Metering Infrastructure (AMI)

AMI provides communications between the consumer end-points of the grid and the backhaul. A major element in the communication networks required to support AMI is the Neighborhood Area Network which couples the consumer premises to the wide area network of the utility company.

As described earlier, Wi-Fi is capable of providing the IP-based NAN capability from a meter to a data collection device in each neighborhood and thus can support the Advanced Metering Infrastructure. By leveraging high gain antennas and other antenna technology such as beam steering, a Wi-Fi radio can provide line-of-sight range to pole-top access points of more than one kilometer.

Grid Intelligence

Efficiency in the transport and delivery of electricity through the grid represents an enormous savings to the utility provider, and ultimately the end consumer of electricity. The current electric grid infrastructure is comprised primarily of legacy, latency-sensitive equipment with one-way or no communication with utility back-end systems.

With the use of Wi-Fi, one can layer a reliable, high-speed, low-latency IP two-way communications network on top of these legacy grid elements. This will allow these elements to respond to conditions in the grid by providing distributed intelligence. Such responsiveness is not possible without a two-way communications network. Incorporating Wi-Fi in the grid intelligence also allows utilities to further reduce operational expenses due to the self-healing, proactive measures possible with a high-speed, IP-based electric grid.

Gas and Water Metering

Many electric utilities are also responsible for natural gas and water delivery to the end customer. Accordingly, there is a need to collect the usage information from gas and water meters in addition to electric meters. The same communications infrastructure being deployed in an electric utilities service territory can be used to collect gas and water usage information. Leveraging Smart Grid assets for these purposes will reduce the capital and operational expense of an integrated utility responsible for gas and electric delivery to the consumer. In cases in which different utilities provide gas, water, and electricity, infrastructure-sharing can improve efficiency and cost of deployment.

Gas and water meters do not typically have access to a power source. Low-power battery-operated endpoints are critical for mass adoption of wireless communications in these meters. Until recently, Wi-Fi enabled devices have not met the 15 to 20 year battery life requirements of such devices as it relates to lower power consumption. However, several new Wi-Fi chip sets have sub uA leakage and are capable of working in systems where the total current in low-power mode is far less than 1 uA.[8] In such a state, battery life can be radically extended. While a low-power host micro-controller maintains the application in the meter, the Wi-Fi radio can be kept in an off position. Information can then be cached and burst through the NAN periodically. Using the latest low-power technology from Wi-Fi solution providers, this can result in 10 or more years of battery life.[9]

Enterprise Mobility for Utility Companies

Utilities will need to have high-speed, reliable communications throughout their service territory for Smart Grid communications. The utility's private Wi-Fi NAN used for AMI could also be used to carry both voice and data to support mobile applications for service technicians and field personnel, complementing existing cellular data and voice networks. Wi-Fi is an obvious choice for this wireless network since low cost interoperable Wi-Fi clients are available and already integrated into mobile phones, laptops, and tablet PCs.

5.0 Wi-Fi for Smart Grid: Gap Analysis

As discussed in the Report to NIST on the Smart Grid Interoperability Standards Roadmap, gap analysis is a critical part of the overall Smart Grid protocol requirements determination.[10] Of particular importance here with respect to the IEEE 802.11/Wi-Fi standard is the identification of any potential gaps with regard to Smart Grid application support. This section provides input towards such a gap analysis.

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[8] Redpine Signals, 18 February 2009, "Redpine Signals Launches Sensifi an Ultra Low-Power 802.11n (Wi-Fi) Wireless Sensor Module," http://www.redpinesignals.com/18feb09.html (8 September 2009).

ZeroG Wireless, 16 February 2008, "ZeroG Wireless Announces Availability of the Industry's First 'Wi-Fi I/O' for Embedded Systems," http://www.zerogwireless.com/company/releases/20090216_dwifi_io.html (8 September 2009).

GainSpan, 3 October 2007, "Gainspan Unveils Wi-Fi Sensor Network Solution with Years of Battery Life," http://www.gainspan.com/news_GS1010_100307.html (8 September 2009).

[9] GainSpan, 3 October 2007, "Gainspan Unveils Wi-Fi Sensor Network Solution with Years of Battery Life," http://www.gainspan.com/news_GS1010_100307.html (8 September 2009).

[10] Electric Power Research Institute, 10 August 2009, "Smart Grid Interoperability Standards Roadmap," http://www.nist.gov/smartgrid/Report%20to%20NISTlAugust10%20(2).pdf (8 September 2009).

IP Protocol Support

All Wi-Fi devices support the Internet Protocol (IP), both IPv4 and IPv6. No new work is needed for full support of IP.

Smart Energy Profile

The Smart Energy Profile helps build a framework for Smart Grid Applications. Version 2.0 of the Smart Energy Profile is PHY independent and thus transportable by Wi-Fi. The only work required for an implementer would be to port SEP 2.0 software to Wi-Fi-based devices.

Substation Automation

The IEC 61850 protocol has been defined for substation automation. There is some work underway to expand the applications for IEC 61850. This is a high level message oriented protocol which can be carried over IP and thus Wi-Fi. The only new work required for an implementer would be porting IEC 61850 to Wi-Fi-based devices.

6.0 Summary

The Smart Grid communications network will be a heterogeneous network based on many different standards. Wi-Fi technology will certainly be part of any future Smart Grid. Wi-Fi is cost effective, scalable to cover large geographies and many endpoints, and requires no new cabling within the home.

Wi-Fi is the dominant home wireless networking standard and thus plays a central role in the Home Area Network for Smart Grid. Wi-Fi is already integrated into home routers, set top boxes, high definition televisions, notebook PCs and smart phones. Wi-Fi enabled thermostats, refrigerators, and washing machines make perfect sense. Whether as a separate network or integrated into existing home networks, Wi-Fi should be the primary Home Area Network for the Smart Grid.

There are many mature products based on 802.11 technology that implement large outdoor networks. These networks have been successfully deployed for years and there is broad expertise available to the industry for deploying and maintaining these types of networks. It is more practical to reuse these existing technologies for the Smart Grid application than to create a new wireless standard or develop a new ecosystem from scratch.

Wi-Fi technology has an ongoing roadmap of innovation and established mechanisms for collaboration (via the Wi-Fi Alliance and IEEE) to meet the evolving needs of Smart Grid applications well into the future. If a need is identified to extend the existing capabilities, the Wi-Fi Alliance provides a well-established forum for further innovation to occur and timely delivery of solutions. Using this expertise and experience, the Wi-Fi Alliance membership is exploring how it might quickly eliminate any real or perceived gaps in Smart Grid deployment phases.

Smart Grid is happening now and provides many opportunities for new solutions based on established Wi-Fi technologies. The Wi-Fi Alliance is committed to help industry leverage these new opportunities in the Smart Grid.

About the Wi-Fi Alliance

The Wi-Fi Alliance is a global non-profit industry association of hundreds of leading companies devoted to the proliferation of Wi-Fi technology across devices and market segments. With technology development, market building, and regulatory programs, the Wi-Fi Alliance has enabled widespread adoption of Wi-Fi worldwide.

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