UNITED STATES OF AMERICA
BEFORE THE
DEPARTMENT OF ENERGY

Implementing the National Broadband	)	
Plan by Studying the Communications	)	Request for Information
Requirements of Electric Utilities to	)	
Inform Federal Smart Grid Policy	)	

COMMENTS OF ON-RAMP WIRELESS, INC.

Joaquin Silva, Chief Executive Officer
Dr. Theodore Myers, Chief Technology Officer
ON-RAMP WIRELESS, INC.
10920 Via Frontera
Suite 200
San Diego, CA 92127
(858) 592-6008

Kenneth G. Hurwitz
HAYNES AND BOONE, LLP
1615 L Street – Suite 800
Washington, D.C. 20036
(202) 654-4521

Paul Dickerson
HAYNES AND BOONE, LLP
One Houston Center
1221 McKinney Street
Suite 2100
Houston, Texas 77010
(713) 547-2506

Their Attorneys

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I.
GENERAL INTRODUCTION

On-Ramp Wireless, Inc. ("On-Ramp") hereby submits comments in response to the Department of Energy's ("DOE") May 11, 2010 *Request for Information* as to the communications needs of electric utilities to inform federal Smart Grid policy.

In these comments, On-Ramp addresses two vital aspects of the need for wireless communications in connection with Smart Grid—more specifically, for customer smart meters and devices and for certain types of distribution grid system monitoring. First, On-Ramp discusses the need to reliably link millions of customer meters and home area networks with each other and with utility access points.[1] Second, On-Ramp discusses the importance of *efficiently* addressing the foregoing wireless communications needs, from equipment, economic and spectral efficiency perspectives. Simply stated, *efficiency* is vital because it drives down the cost to utility customers of implementing Smart Grid.

[1] In this context, On-Ramp uses the term "reliability" to refer to the ability of the wireless system to close communications links, and to do so without causing undue interference with other devices or being unduly susceptible to interference from other devices.

On-Ramp believes that an optimized star topology system,[2] using central access points and sensitive, interference-resistant signal processing capability able to collect data from and distribute data to the monitoring and metering devices in a spectrally efficient manner, is a tailored solution that would efficiently address these needs. At the same time, other wireless solutions, which as of today seem to be the typical utility choice, fail to satisfy these basic reliability and efficiency criteria.

In these comments On-Ramp also argues that, especially in light of certain recent experiences with Smart Grid deployment, it is vital to incorporate minimum quality and efficiency standards as part of the inter-operability standards under development by the National Institute of Standards and Technology ("NIST"). And, to give these standards "teeth," On-Ramp recommends that they should be immediately employed in pilot programs to measure the robustness of utility wireless system proposals.

To put the foregoing summary in context, it is important at the outset to identify, in slightly more detail, three discrete subsets of Smart Grid functions: (1) the collection of temporal usage data from residential and commercial customer meters and energy consuming devices, the transmission of those data to the utility, and the communication of price and other electric system information back to customers; (2) those aspects of digital monitoring of the distribution system, by use of sensors placed on distribution lines and substations, that do not require instantaneous communications, such as distribution grid sensors, transformer monitors and Fault Circuit Indicators (hereinafter, "Medium-Latency Distribution-System Monitoring");

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[2] For the remainder of these comments, On-Ramp will refer to an "optimized star topology system" as one optimized for certain Smart Grid applications. As more fully discussed below, these Smart Grid applications, such as distribution grid monitoring and Advanced Metering Infrastructure, (i) are characterized by numerous users that send and receive infrequent, small packet-size transmissions and utilize battery operated devices, and thus (ii) require a star topology system that addresses these requirements and has high receive sensitivity, a large link budget, capacity efficiency and low power requirements.

and (3) other Smart Grid functions that do require low latency, real-time communications to maintain critical system control of the distribution, transmission and generation systems.

On-Ramp exclusively focuses on functional subsets (1) and (2). The central theme of these comments is that that the dual criteria of system reliability and efficiency *demand* that utilities adopt a tailored solution for these functions. Function (3), on the other hand, poses an entirely different set of wireless communications issues and challenges that cry out for wholly different solutions.

II.
INTRODUCTION TO ON-RAMP

Located in San Diego and managed by a team of professionals from the wireless, digital, defense and utility automation industries, On-Ramp has developed the first wireless system that is specifically designed to connect millions of hard-to-reach meters and sensors in challenging utility and industrial environments. Today, On-Ramp is working with several utilities and automation companies on a global basis to implement its system, including (1) a public utility in the U.S. and several public utilities in Asia; (2) a company that is a global leader in utility automation systems with thousands of systems deployed for energy efficiency, smart metering and water grid automation across Europe, the Middle East, North America and Asia; and (3) a company that is a global leader in broadband radio development and manufacturing with industry-leading market share. Because On-Ramp's system is purpose-built to cost effectively and reliably connect millions of hard-to-reach meters and sensors in challenging environments in free spectrum, it will work seamlessly with the end-user and distribution system segments of Smart Grid.

On-Ramp's technology employs Central Access Points in a star configuration to transmit and receive low-power signals directly communicating with nodes embedded in the myriad of sensors and customer meters in an urban, suburban, ex-urban or rural environment. The Central Access Points, in turn, communicate bi-directionally with a variety of third-party product platforms, including utility data collection and management systems.[3] The same Central Access Point-to-node configuration can be used and has been successfully tested for distribution system tasks such as substation monitoring, metering systems and below ground and above ground Fault Circuit Indicators.

The Central Access Points and nodes use Ultra-Link Processing™ technology ("ULP"), a high-receptivity signal processing innovation developed by On-Ramp that is capable of wide-area coverage and is immune from all but high levels of interference, at a significantly lower cost and with far greater capacity, efficiency and system security than existing and proposed wireless mesh systems, and with coverage and reliability far superior to that offered by the commercial cellular network. Equipped with Ultra-Link Processing™ technology, a single Central Access Point can cover an entire industrial site, a 50-story office building or an entire small metropolitan area. On-Ramp's website, www.onrampwireless.com, sets forth additional background on the company and its announced projects.

III.
COMMENTS

A. Smart Grid is a Pivotal Element of National Energy Policy

The focus of national energy policy as declared by Congress and the Obama Administration is to promote energy efficiency, reduce greenhouse gas emissions and encourage energy independence. Smart Grid is a cornerstone of that policy and can contribute greatly to meeting all three of those goals.

[3] The backhaul communications by the Central Access Points can be made via a variety of media, including for example the commercial cellular network, T1 lines and satellite communications.

Two key pieces of legislation enacted in the last three years confirm Smart Grid's central role. The Energy Independence and Security Act of 2007[4] ("EISA") declared that it is the policy of the United States to support the development of Smart Grid—the modernization of the Nation's electricity transmission and distribution system to maintain a reliable and secure electricity infrastructure that can meet future demand growth. The American Recovery and Reinvestment Act of 2009 ("ARRA")[5] reaffirmed the importance and supported the development of Smart Grid in several important ways. First, it appropriated substantial funds to the DOE to implement the Smart Grid program established by EISA.[6] Second, ARRA made available to companies employing "smart grid technologies" a qualifying advanced energy project tax credit equal to 30 percent of the qualified investment in the smart grid technology.[7] Third, ARRA directed the Federal Communications Commission ("FCC") to develop a National Broadband Plan, to include "a plan for the use of broadband infrastructure and services in advancing … energy independence and efficiency."[8] In the National Broadband Plan issued pursuant to ARRA, the FCC recognizes that Smart Grid technology is a promising way to meet those goals and makes specific recommendations as to how to advance the implementation of Smart Grid.[9]

A review of how Smart Grid is intended to work makes abundantly clear that Smart Grid is vital to meeting the goals of national energy policy. Smart Grid advancements will apply digital technologies to the electric grid, enabling real-time coordination of information from

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4 Public Law No. 110-140, 121 Stat. 1492 (2007).

5 Public Law No. 111-5, 123 Stat. 115 (2009).

6 ARRA, Title IV, at Department of Energy, Energy Programs, Energy Efficiency and Renewable Energy. To date, the DOE has issued Funding Opportunity Announcements ("FOA") under which it will distribute at least $4 billion in ARRA grants to support development of Smart Grid.

7 ARRA § 1302(b), codified at 26 U.S.C. § 48C.

8 ARRA § 6001(k)(2)(D).

9 *Connecting America: The National Broadband Plan* at Chapter 12.1.

traditional generation supply sources, demand resources and distributed energy resources. Specifically, Smart Grid will possess the following functionalities:

- The ability to develop, store, send and receive digital information concerning electricity use, costs, prices, time of use, nature of use, and storage, to and from the electric utility system.

- The ability to program any end use device such as appliances and HVAC systems to respond to communications automatically.

- The ability to sense and localize disruptions or changes in power flows on the grid and communicate such information instantaneously and automatically for purposes of enabling automatic protective responses to sustain reliability and security of grid operations.

- The ability to detect, prevent, respond to, and recover from system security threats such as cyber-security threats and terrorism, using digital technology.

- The ability to use digital controls to manage and modify electricity demand, enable congestion management, assist in voltage control, provide operating reserves, and provide frequency regulation.[10]

Once Smart Grid is fully implemented for the electricity system, consumers, faced with the real-time costs of their electricity consumption and armed with sophisticated methods to adjust their consumption patterns, will consume less electricity overall and, importantly, at peak times. Intermittent resources such as wind, and distributed generation resources such as residential solar, will be more easily integrated into the grid. Electric vehicles will be able to charge their batteries during off-peak hours and will even be able to act as sources of electricity to help offset fluctuations in the output of intermittent resources. Transmission and distribution systems will become far more reliable. In short, the implementation of Smart Grid will foster the nation's ability to become more energy efficient, reduce emissions of greenhouse gases, and increase our energy independence.

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[10] *See also* the definitions of "smart grid functions" at EISA § 1306(d).

B. It is Axiomatic that Smart Grid Cannot Work Without Robust Communications Capabilities

While Smart Grid's capabilities will ultimately reach upstream to coordinate all elements of the utility system, including generation, transmission and distribution functions, one of the very basic components of Smart Grid is Advanced Metering Infrastructure ("AMI"). Under AMI, data will be sent by customer meters to the utility and the utility will convey price information to "smart" commercial and residential controllers or end-use consumer devices such as thermostats, washer/dryers and refrigerators. In order for AMI to work to its full potential, it is essential that robust, secure two-way communications be established between each residence and commercial establishment and the utility. Only with such communications will customers be able to see and respond to price and system conditions, and will the utility to be able to cost-effectively and reliably coordinate its operations to provide its customers far more efficient services at far lower cost.

Another key component of Smart Grid is Distribution Automation, under which sensors will be placed in numerous locations throughout the distribution system—on distribution lines, transformers and in substations—to tell the utility when equipment is about to fail, to sense frequency or voltage fluctuations that suggest a problem is about to occur, and to transmit information to control devices on the distribution system to fix or prevent the problem. As noted above, Distribution Automation falls into two categories: applications requiring real-time, low latency communications, and Medium-Latency Distribution-System Monitoring. As with AMI, Medium-Latency Distribution-System Monitoring cannot work properly without robust, secure two-way communications.

Moreover, anything less than 100 percent coverage of end-user and distribution system meters and devices would be unacceptable. Millions of meters and sensors will be deployed throughout the utility's service territory. Often, the devices will be located in remote areas, or areas rendered hard to reach by trees, topography or man-made structures. Even if 80 percent of the meters are readily accessible for communications purposes, the other 20 percent consisting of "worst cases" must also be kept in the communications fold. In other words, Smart Grid communications systems must be designed on a worst-case basis to enable a data dialogue with *all* customers, even those in the most compromised areas of the electric utility service territory. For a utility to fail in this respect would severely hamper the effectiveness of Smart Grid, and would invite customer claims of undue discrimination under state law.[11]

Finally, for Smart Grid to function, customer and distribution system meters and devices must not *cause* undue interference to, and must not be unduly *susceptible* to interference from other devices. This is true whether the point of reference is unlicensed spectrum or licensed spectrum. The problem, and hence the challenge, is especially pronounced for communications protocols that operate in the crowded unlicensed ISM band. This band is heavily populated with devices such as Wi-Fi, baby monitors, audio and video transmitters, garage door openers and other radiators. While under the FCC's Part 15 regulations their power output must be maintained within strict limits to prevent interference with other spectrum users,[12] it is well known that interference in these bands is rife and quickly growing worse.

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[11] *See*, *e.g.*, the statement by Pacific Gas and Electric Company ("PG&E"), one of the nation's largest utilities, that its choice of wireless technology for Smart Grid must ensure that the meter "coverage probability" will be 100 percent. The PG&E statement goes on to note that its "technology choice must be robust in the dense areas and still be flexible enough to cover the rural areas." *PG&E Smart Grid Discussion* before the IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs) (May 9, 2008), available at https://mentor.ieee.org/802.15/dcn/08/15-08-0297-00-0000-pg-e-smart-grid-discussion.ppt.

[12] 47 C.F.R. Part 15 (2009).

C. An Optimized Star Topology Technology Causes Less Interference and is Immune from All but High Levels of Interference

1. The Characteristics of a Star Topology System

A star topology system—the topology relied upon by the cellular industry—uses central access points (the center of the "star" in the topology) that communicate directly with operating nodes (sensors, meters and other devices) on the system. If the receiver deployed in a star topology system uses a sufficiently sensitive, interference-resistant signal processing capability,[13] it can receive communications from dispersed low data rate applications, such as customer meters, even in the presence of interference that would cripple other communications systems.

A star topology system with this capability can also exert power control of its signals (*i.e.*, the transmitters may be operated below their maximum allowed power level because they can be dynamically adjusted to transmit only at the power level needed). Relatively few central access points are needed, which enables the system to take advantage of antenna elevation to increase its ability to reach in-building energy efficiency monitoring devices as well as below ground distribution grid assets so that a second radio system is not required to connect to these devices.[14] Because the nodes communicate directly with central access points, such

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13 The FCC has recognized the importance of receiver sensitivity. In 2003, the FCC issued a Notice of Inquiry to consider incorporating receiver interference immunity performance specifications into its spectrum policy. The FCC noted that incorporation of receiver performance specifications could serve to promote more efficient utilization of the spectrum and create opportunities for new and additional uses of radio communications. *In the Matter of Interference Immunity Performance Specifications for Radio Receivers*, 18 FCC Rcd 6039 (2003). The FCC terminated this proceeding in 2007, because with the passage of time the *Notice* and record in the proceeding had become outdated. However, in terminating the proceeding, the FCC stated that to the extent receiver interference immunity performance specifications are desirable, they may be addressed in proceedings that are frequency band or service specific. 22 FCC Rcd 8941 (2007).

14 The cellular industry likewise relies upon finding favorable locations for its base stations.

communications are required relatively infrequently. For all of these reasons, a properly configured star topology system causes far less interference than do competing technologies.[15]

2. The On-Ramp System is a Star Topology System that is Optimal for End-User and Medium-Latency Distribution-System Monitoring Smart Grid Functions

Operating in the free ISM bands (*e.g.*, 900 MHz and 2.4 GHz), the On-Ramp system is an example of a star topology system. Nodes embedded in customer meters and devices and distribution system components communicate data to and from central access points that in turn use T-1 links, cellular, satellite and other forms of communications to link up with the utility data processing system. Both the nodes and the central access points use Ultra-Link Processing™ ("ULP") technology—a significant innovation in the well-known and industry-verified technology of Direct Sequence Spread Spectrum ("DSSS") signal processing (used in CDMA systems) that results in very high receiver sensitivity. Employing a new multiple access scheme called Random Phase Multiple Access, the receive sensitivity of the system results in superior interference-resistance and inherent link level security with low transmitter power levels.

According to On-Ramp estimates, by virtue of the high sensitivity of its receivers, only 28 Central Access Point locations employing ULP would be necessary to enable the receipt of AMI data from all electricity customers in the entire City of San Diego. This includes "worst-case scenario" receptivity—receptivity from meters in hard-to-reach locations, as well as devices inside buildings—one of the critical requirements of Smart Grid applications. With only 28 Central Access Point locations necessary to cover such a large area, the On-Ramp System can

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15 Unfortunately, cost-effective high-sensitivity receiver and capacity-efficient multiple access point technology was not available to prior architects of utility networks to address the inherent problems with communications systems for end-user and distribution system Smart Grid applications. Indeed, On-Ramp's system innovation has only recently become commercially available.

also take advantage of favorable antenna locations, such as elevated Central Access Points, which further enhances the robustness of the system by a factor of ten, such that in-building energy efficiency monitoring devices and distribution grid assets located below ground can be reached without a second repeater radio system. Taken together, the On-Ramp star topology configuration confers a 600-times coverage advantage over competing systems at equivalent antenna elevations.

Our nation's Smart Grid must be secure, as the ability to compromise the grid is a National Security issue. In addition to the data encryption standards that all wireless systems may support, On-Ramp's technology offers unique security advantages. On-Ramp's ULP technology operates at a negative signal-to-noise-ratio ("SNR")—below the thermal noise floor.[16] While other technologies require a positive SNR to operate, allowing signals to be easily detected, the On-Ramp ULP technology offers a uniquely low probability of interception and detection that is crucial for a secure national Smart Grid.

Overall, what sets the On-Ramp System apart is its extraordinary range and ability to operate in changing RF propagation environments with varying interference levels. This capability is represented quantitatively in the system's allowable path loss of up to 172 dB. Such a large link budget—the total allowable path loss in a radio system—provides the required level of robustness and enables the system to achieve a very wide range.

16 CDMA cellular systems also operate below the thermal noise floor.

The following table summarizes the functional capabilities of the On-Ramp system:[17]

Required bandwidth	1 MHz
Average power output per meter	0.1 mW
Application throughput normalized by bandwidth	20 kbps/MHz
Interference caused by system	Low
Susceptibility to interference	Low
Susceptibility to jamming	Low
Security	High
Cost	Low
Coverage	100%
Power consumption	Low

D. Neither the Commercial Cellular Network nor Mesh Networks are Sufficiently Robust to Meet Smart Grid Communications Needs

1. The Commercial Cellular Network is an Inadequate Solution

Although it is planned to be used by just a handful of utility systems to communicate meter and other data to central access points, the commercial cellular network cannot effectively and reliably provide adequate communications capability between the millions of customer nodes at issue and utility receipt points. The optimal use of the cellular network is for voice and high-speed data, not the data generated by individual customer meters, which occurs on a low-output basis. Moreover, cellular transmitters and receivers are characterized by short battery life. This phenomenon will exclude a high percentage of the sensors and devices (*e.g.*, gas meters and

17 The primary assumptions used in constructing the table are: the average power in the table is directly correlated with amount of RF interference generated in the ISM bands, and On-Ramp's average power output assumes a 2 kilobyte per day payload data per node and a 100 mW power amplifier.

unpowered monitoring sensors) because they require multi-year battery lives and have no other readily available power sources.

Cellular system dead spots, which plainly cannot be ruled out in many utility service areas, are also a serious concern. While electric utilities, electric cooperatives and municipal systems long ago achieved universal electric service within their service territories, the same cannot be said for the commercial cellular networks of existing carriers. Rather, cellular system dead spots, which occur because of geography (a road between two ridgelines in a rural area), building or infrastructure design (tunnels and shopping malls), or distance from cell towers, are common; on an individual level, every reader of these comments is fully familiar with the phenomena of dropped phone calls and calls that fail to reach their destination. Utilities cannot tolerate such gaps if they are to successfully offer Smart Grid capabilities to their customers on a non-discriminatory basis and integrate customer information into utility operations.

Gaps in system coverage, however, are not the only problem with using the commercial cellular network for Smart Grid applications. Rather, the reliability of the network is also being threatened by the steady penetration of advanced cell phones with high-speed data capabilities used for web browsing, music download and video services, and by ubiquitous laptop computers with the same capabilities. The cost of building out the cellular network to eliminate such gaps in coverage and performance would be prohibitive.[18]

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[18] For example, On-Ramp estimates that such a build-out for San Diego area would cost approximately $150 million and require very substantial bandwidth.

2. Free ISM Mesh Networks with Cellular Backhaul are Also Inadequate for Large-Scale Smart Grid Application

a. General Description of Mesh Networks

Many utilities are contemplating the use of unlicensed ISM-based mesh networks with cellular system backhaul to collect and transmit data to utility data collection and processing systems. Joint mesh network/cellular systems combine two sets of technologies, each with its own limitations for Smart Grid applications. Moreover, the *combination* of the two technologies poses serious problems. On-Ramp will explain these limitations below after a brief explanation of how mesh systems are configured.

A mesh network is a wireless network consisting of spatially distributed autonomous devices called radio nodes. Each node is typically equipped with a radio transceiver or other wireless communications device, a microcontroller and often a battery when no power source is available. The nodes in a mesh network "hop" their signals through neighboring nodes in the network via peer-to-peer links. In effect, nodes act as router/repeaters for neighboring nodes, which means that the users themselves constitute the network. In addition, numerous repeaters have to be installed in addition to the radios on the meters. The mesh network arranges itself on an *ad hoc* basis, and several nodes may forward data packets to a base station or central collection point. The base station typically relies on cellular backhaul to communicate the collected data to the utility.

Supporters of mesh networks combined with cellular backhaul often claim that the combination offers highly reliable, large capacity communications capabilities. But the reality, in relation to their utility for Smart Grid applications, is otherwise. The reality is that mesh systems both suffer from and cause high levels of interference as to other devices in the crowded ISM bands. Mesh systems are also highly susceptible to intentional and unintentional jamming.

Furthermore, the frequent and predictable traffic patterns required for inter-node mesh communications leave these systems vulnerable to security breaches.

b. Mesh Systems do not Work in the Home Area Network ("HAN")

In a mesh system, one radio connected to the meter will operate as a node in the mesh network, while a second radio connected to the meter will communicate with devices, such as the thermostat or the dishwasher, in the HAN. The receiver for the second radio currently planned for use is a poor sensitivity receiver (-95dBm) with limited signal processing capability to deter jamming or interference. For a significant portion of homes, meters will be located outside or in the basement, and signals from the radio will not be capable of piercing walls to reach energy consuming appliances located on the first floor and above. In the 900 MHz and 2.4 GHz ISM bands, in particular, where baby monitors, cordless phones, Wi-Fi and Bluetooth are deployed in many homes, the result will be an unreliable networking system incapable of communicating in the home between the customer meter and HVAC systems and thermostats for demand-side management purposes.[19]

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[19] It is not just On-Ramp that has raised the issue of interference. Commenters responding to the FCC's notice requesting comments on the implementation of Smart Grid technology, in GN Docket Nos. 09-137 *et al*., raised the same issue. For example, Honeywell, which provides energy management technologies such as switches to cycle air conditioning and communicating thermostats, filed comments in the FCC's Smart Grid proceeding, in which it requested that "[t]he customer premises network (*e.g.*, HAN or network for commercial building) should explore the potential use of dedicated spectrum [because] Honeywell has experienced interference and signal quality problems with unlicensed ISM bands, especially in 2.4 GHz." *Comments of Honeywell International Inc. on NBP Public Notice #2*, at p. 5, filed Oct. 2, 2009.

In addition, American Electric Power Company ("AEP") commented that it "is concerned that future demands on the 902 – 928 MHz spectrum will raise the noise floor in some areas to the point where metro-area mesh networks will no longer be viable." *Comments–NBP Public Notice #2–American Electric Power Company, Inc.*, at p. 10, filed Oct. 2, 2009. Noting that in some metropolitan areas of AEP's service territory there has been "a higher noise floor, *i.e.* an overall increase in background noise due to a large number of industrial, commercial, and consumer devices in operation," AEP commented that "while 900 MHz mesh networks are suitable for today's relatively modest data requirements in the Smart Grid, increasing needs for throughput may push mesh networks beyond their capabilities." *Id.* at pp. 24-25.

c. Mesh Systems Cause Massive Interference

Mesh systems are not technologically scalable.[20] In other words, they cannot be successfully adapted to serve a typical utility's entire customer base without causing severe interference to other devices in the already crowded unlicensed ISM band. This interference results from the combination of numerous devices operating at full power, in a narrowband behavior, with numerous hops to communicate data to the central collection points, and concentrated use of meters close to collection points.[21] All this interference likely will be exacerbated by degrading positive feedback loops. It is useful to break this problem into its constituent parts.

First, it is planned that each home's electric meter will be equipped with a one-watt power amplifier. In order to achieve the necessary range to hop to the next mesh point, eighty such amplifiers per square mile will be required in exurban and five-hundred in urban environments. As noted above, the mesh system will require the installation of numerous repeaters in addition to the radios on the meters. The network will not be functional unless the radios operate at their maximum power.

Second, the mesh networks will use up to 20 channels, throughout the entire 900 MHz ISM band. Using this many channels increases the likelihood that communications between

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20 Nor are mesh systems scalable from a *cost* perspective. The per-unit infrastructure costs and operations costs for each radio node and repeater in the mesh system are very high, such that the cost for an entire utility customer base would have a significant impact on customer rates. We will discuss mesh systems' lack of economic scalability in more detail in a later section of these comments.

21 Based on an analysis conducted by On-Ramp Wireless, a mesh-based AMI system operating in the 900 MHz ISM bands using a one watt transmit power requires a radio on time of up to 10 percent when performing critical network functions such as software firmware downloads or interactive meter reads, and would occupy the entire 20Mhz of the ISM band in this spectrum area. Due to the density of repeater, gateway and meter transmitters and radio on time, the noise floor would be raised by 15-40 dB, reducing the range of many Part 15 consumer devices by upwards of two to ten times, rendering them useless for long periods of time.

links will collide with wide-band transmissions by in-home devices such as cordless phones, baby monitors, and garage door openers, which require 1 MHz of bandwidth and do not incorporate interference-avoidance mechanisms.

Third, there will be numerous hops from the central collection point to individual meters, and from meters to the central collection points. Frequently, the mesh network will require a radio-on time of up to 10 percent for all nodes in the network due to the substantial communications protocol overhead needed to maintain inter-device networking functions and communicating large file transfers such as firmware downloads. Supporters of mesh systems generally focus on the average number of hops used in a mesh system. But this focus is misleading because it obscures the fact that nodes closer to collection points will transmit far more individual transmissions of data than nodes closer to the periphery of the network. Correspondingly, devices such as garage door openers, baby monitors, and Wi-Fi networks that are located at or near nodes close to collection points will suffer far more interference than devices near peripheral nodes.

Finally, with reference to positive feedback loops, consider a mesh network subject to a jamming source or high data rates (or worse, a combination of the two). Under such conditions, if the network approaches a point at which it fails to receive data, it will respond by repeating transmissions, thus polluting the system even further and leading to yet more transmissions. Ultimately, the system will spiral out of control at the very time the functionality of the system is critical.

The cellular backhaul element of mesh systems presents an additional limitation. The backhaul portion of the data path will originate from thousands, and in some cases tens of thousands, of radio nodes dispersed throughout the utility service area, as contrasted with star topology systems that will originate the backhaul at a limited number of central locations where redundant connections can cost effectively be added. Simply stated, the probability that a dispersed node in a mesh network will be located in a dead spot in the cellular network is significantly greater than the corresponding probability for a central access point in a star topology. The result is that the risk of transmission failure for the backhaul element is a serious concern and that, given the sheer number of required backhaul links, it will be expensive to implement a redundant system to ensure high reliability.

d. Interference Associated with Mesh Systems Would Lead to Complaints

Under § 15.5(c) of the FCC's regulations, the operator of a radio frequency device is required to cease operating the device upon notification by the FCC that the device is causing harmful interference with licensed operations, and may not resume operation of the device until it corrects the condition causing the harmful interference.[22] Operation of mesh network systems for Smart Grid applications will cause unprecedented levels of interference in the bands in which they operate. Put plainly, mesh systems will interfere with licensed operations, and the owners of those licensed operations are likely to complain to the FCC.

As stated above, if planned and implemented properly, Smart Grid will bring numerous profound benefits. It would not be wise public policy to invest in a mesh communications technology that will be plagued by such substantial interference that it may be temporarily or permanently required to cease operations.

Moreover, mesh network systems will interfere greatly with unlicensed operations of Part 15 devices. On-Ramp's propagation analysis (available upon request) shows that an electric meter AMI mesh solution in a sparse suburban environment will reduce the range of a typical 1

[22] 47 C.F.R. § 15.5(c) (2009).

MHz bandwidth, latency-sensitive device by two to ten times. While the owners of such devices will have no legal recourse against the mesh networks, it is equally unwise public policy to allow the widespread implementation of networks that will cause substantial interference with numerous other useful communications devices.

E. The On-Ramp System is Capable of Efficiently Addressing Certain Discrete Smart Grid Functions—Two-Way Data Communications Between Customer and Utility, and Medium-Latency Distribution-System Monitoring—Whereas Other Network Systems are Not

1. The Foregoing Smart Grid Functions Have Unique Communications Characteristics and Needs

A key characteristic of the end-user and medium-latency distribution system monitoring aspects of Smart Grid is that they involve relatively low individual node data rates and small packet-sized transactions[23] for both uplink and downlink, and can tolerate moderate latency. In other words, the amount of data per communication is small, and system latency can be seconds or minutes—compared to other applications, such as transmission grid optimization, where any latency would severely degrade quality of service.[24]

What are the network requirements for these Smart Grid applications? The answer is high capacity (to handle the large cumulative data flows in light of the sheer number of devices and applications), low power demands (to prolong battery life), and, as discussed above, high resilience against interference (because of the ubiquity of other devices and the proximity of other networks) and reliability.

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[23] It is critical to note, however, that cumulative data flows will be extraordinarily large.

[24] To illustrate, On-Ramp has prepared Exhibit No. 1, which is attached hereto. Exhibit No. 1 illustrates the relatively low packet sizes and latency tolerance levels associated with various utility functions, including Smart Grid's AMI and distribution system Fault Circuit Indicator functions. The data packet sizes range from 150 bytes for daily uplink for the latter to 600 kilobytes for firmware upgrades for the former, and latency tolerance is in the seconds or minutes.

Because they have these needs and characteristics in common, it makes eminent good sense to serve these Smart Grid applications with a wireless technology specifically designed to meet their common needs.

2. Existing Technologies are Unable to Efficiently Meet the End-User and Medium-Latency Distribution-System Monitoring Smart Grid Communications Requirements

Existing technologies, such as cellular, WIMAX, mesh and narrowband licensed spectrum solutions, were originally developed to address applications, such as voice and high speed data, with requirements fundamentally different from those set forth above. These technologies' characteristics may make some of them suitable for some low latency, high data rate Smart Grid applications. But they are unable to efficiently meet the requirements of the end-user and medium latency distribution system monitoring Smart Grid applications.

Turning first to cellular, the cellular system was originally optimized for voice and high-speed data applications, which involve very high data rates and use a substantial amount of bandwidth. Accordingly, the spectral efficiency of deploying cellular to serve low packet size transactions is very low. Moreover, the additional base station infrastructure needed to serve each application and customer in the utility's territory and the entire grid would be very costly. Additional equipment in the form of base stations and repeaters would be required to close links with users in dead spots, in light of cellular's lower link budget. Adding infrastructure, however, is not a cure-all, since it cannot offset the inability of cellular to close links with devices located in especially challenging environments, such as underground or beneath manhole covers, and might not even be possible in certain necessary locations because of citizen "not-in-my-back-yard" resistance. When one also considers the short battery life of cellular devices, it becomes readily apparent that employing a cellular network for Smart Grid applications, such as distribution system monitoring and AMI, would present enormous quality of service obstacles.

WIMAX, like cellular, was designed for high speed data and large downlink file transfers, and has similar performance (or lack of performance) characteristics. Like cellular, it consumes a considerable amount of power, is capacity inefficient for small payload transactions, and is extremely expensive due to the high infrastructure costs associated with the necessity to deliver significant amounts of bandwidth. Also, like cellular, WiMax systems have relatively low receive sensitivity, which results in a small link budget, requiring substantial investment in additional base stations or repeaters to cover gaps, and cannot serve users or devices in underground locations, thus limiting its utility for these Smart Grid applications. Like cellular, it represents a serious mismatch to the needs of these Smart Grid applications.

Mesh systems differ from cellular and WIMAX in their technical characteristics, but they too are seriously inadequate for serving the customer communication and distribution system monitoring Smart Grid functions. First, mesh systems are characterized by an extremely poor data throughput per MHz ratio (low spectral efficiency). This is due to the high capacity overhead they extract for processing and protocol management.[25] Increasing bandwidth for mesh systems is the only practical way to compensate, but doing so would be contrary to sound spectrum allocation policy. Second, mesh systems require costly infrastructure on a per application and per customer basis, which implies prohibitive fixed costs of service as increasing numbers of devices and applications are added to the Smart Grid. Finally, as discussed above, mesh systems cause extensive interference to other devices. Taken together, these factors

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[25] Exhibit No. 2 compares the overhead needs of mesh systems with those of the On-Ramp ULP system. The last row of the exhibit also demonstrates the huge advantage of ULP in terms of spectral efficiency.

militate against the widespread deployment of mesh, because mesh systems cannot be efficiently scaled up to meet the required service levels.[26]

Finally, narrowband license spectrum solutions are also not a viable option for these Smart Grid applications. Narrowband technologies require a positive signal-to-noise ratio and perform poorly with any interference in the system (including co-channel and self-interference). Moreover, they are extremely capacity inefficient, and to operate require scheduled deterministic data flows, which are not possible for inherently *ad hoc* communications such as peak load demand shedding in a building energy management system. In order to achieve sufficient capacity within these types of systems, due to their spectral inefficiency and low throughput, a massive amount of spectrum would need to be allocated. Once again, as in the case of cellular, WIMAX, and mesh, the network solution offered by narrowband would not be adequate for these Smart Grid applications.

In short, the high deployment and maintenance costs these technologies require to overcome their inefficiencies for the target applications, coupled with their poor reliability for critical applications, would foreclose innovation and retard customer acceptance. These problems and gaps in existing technology did not escape the attention of the inventors of On-Ramp's ULP system, who have succeeded in designing, testing and deploying a network technology specifically designed to avoid them. We will now describe the On-Ramp system in some detail to demonstrate that it is ideal for meeting the network requirements to serve these Smart Grid applications.

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26 *See* Exhibit No. 3, which illustrates the huge number of repeaters, dollar investment and additional spectrum that would be required to address meter reading for various utility services.

3. Because of its Scalability and Low Power, the On-Ramp System is Ideal for Meeting the Network Requirements of the End-User and Medium-Latency Distribution-System Monitoring Smart Grid Applications

The On-Ramp system allows data from up to 1,000 Nodes to be simultaneously received at a single Central Access Point and yields superior throughput per MHz of channel allocation. Because the On-Ramp system uses DSSS, it maintains its superior throughput at a fixed uplink aggregate data rate no matter where the Nodes are placed—whether close to a Central Access Point or far away. The system is the only physical layer innovation in many years that has been field-proven to be capable of *efficiently* supporting the large-scale deployment of service applications that require minimal data transactions on a device-by-device basis, are latency tolerant, and must engage in two-way communications with millions of widely dispersed individual Nodes that are often found in hard-to-reach locations.

a. The Efficiency of On-Ramp's Network System in Terms of Investment in Physical Plant—*i.e.*, Central Access Points

On-Ramp estimates that, by virtue of the high sensitivity of its receivers, only 28 Central Access Point locations employing ULP would be necessary to enable the receipt of automatic meter information data from all electricity customers in the entire service territory of San Diego Gas & Electric Company, a 4,100 square mile area about the size of San Diego County, using spectrum in the 2.4 GHz band. This includes "worst-case scenario" receptivity—receptivity from meters in hard-to-reach locations, as well as devices inside buildings—one of the critical requirements of Smart Grid. With only 28 Central Access Point locations necessary to cover such a large area, the On-Ramp system can also take advantage of favorable antenna locations, such as elevated Central Access Points, further enhancing the robustness of the system by a factor of ten. Taken together, the On-Ramp star topology configuration confers a 600-times coverage advantage over competing systems at equivalent antenna elevations and a far greater advantage when able to take advantage of antenna elevation.[27]

As noted above, with the ULP system up to 1,000 transmissions from devices may simultaneously and reliably be received by a single Central Access Point. It is possible to serve such a large number of customers because of two interrelated phenomena associated with the On-Ramp system—high protocol efficiency and low overhead requirements. The attached Chart—*Capacity Efficiency Model* (Exhibit No. 2)—illustrates the high protocol efficiency and low overhead requirements of the ULP system and compares these capabilities with FHSS (mesh) systems. ULP's low overhead requirements imply that the capacity of each Central Access Point is maximized to the point where large numbers of users/end-points can be served simultaneously. In other words, data processing capability is available for performing the Smart Grid functions, and only small amounts will be expended for system "housekeeping." These low overhead requirements mean that the On-Ramp system has been optimized for the task at hand—handling low-data rate, small packet size, and modest latency transactions of seconds to minutes. Attached Exhibit No. 4 illustrates the point. We note that a single ULP Access Point (using 1 MHz of spectrum at 2.4 GHz) can serve 17,280 electric meters. In the event additional capacity is required in a given area, Access Points can be configured to use more than 1 MHz of spectrum or stacked in the same location (though on different channels) to provide this additional capacity. Exhibit No. 4 outlines how this can be done to support dense deployment of electric meters.

The fixed costs per customer associated with Central Access Points is relatively low given the capability of each Central Access Point to serve numerous customers/devices. The only other fixed cost is the cost of network service centers which, by definition, does not vary

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[27] In contrast, mesh systems cannot take advantage of higher antenna elevations because they would be overwhelmed by increased interference at those higher elevation levels.

significantly with the number of customers. Total variable costs of serving customers are small relative to total fixed costs. As customers or devices are added to each Central Access Point, aggregate revenues and operational efficiencies increase relative to total fixed costs, a phenomenon that would enable investment in additional Central Access Points, if required to serve an expanding customer base, and permit utilities and investors to earn a reasonable return on their investment. In other words, the On-Ramp system is scalable, both technically and economically.

It is instructive to compare the costs of the On-Ramp system with the costs of mesh systems. As shown in the table below, the infrastructure requirements of mesh networks are highly dependent on the deployment environment. And the number of meters deployed in an urban, suburban or rural environment can dramatically impact the number of mesh gateways and repeaters necessary to provide coverage for customer meters and devices. This phenomenon drives costs not only in terms of hardware requirements, but also the planning necessary to lay out the network and the truck rolls necessary to install and test the hardware in the field. In a hypothetical utility system with 300,000 customer meters located in urban, 600,000 customer meters located in suburban and 100,000 customer meters located in rural environments, On-Ramp estimates that the total cost of ownership for a mesh system over a five-year period would be over $110 million.

In stark contrast, the On-Ramp system is insulated from many of these cost drivers due to the ability of the Access Points to provide broad coverage regardless of the deployment environment due to its receive sensitivity, which enables it to provide superior range and penetration into buildings and challenging environments. Furthermore, the simple architecture of an optimized star topology system by itself dramatically decreases the need for repeaters and gateways that a mesh network depends on to connect the endpoints. As a consequence, the total cost of ownership of an optimized star topology system for one million meters deployed in any geographical environment is less than the cost of a mesh system deployed the same geographical area, and for the hypothesized area is about one-tenth the cost of a mesh system.

	900Mhz AMI Mesh System - 1M Endpoints				On-Ramp
	Urban	*Suburban*	*Rural*	**Total**	**Total**
Infrastructure:					
Installed Meters	300,000	600,000	100,000	**1,000,000**	**1,000,000**
Gateways Required	563	335	1,041	**1,939**	**67**
Repeaters Required	8,000	1,000	6,111	**15,111**	**n/a**
Avg. Meters/Gateway	*533*	*1,791*	*96*	***516***	***15,000***
Cost:					
Network Infrastructure (Hardware)				$32,363,426	$1,000,000
Network Plan & Rollout (Services)				$28,868,519	$1,600,000
Annual Operational Cost				$9,769,500	$1,810,000
Total Cost of Ownership (5 Year)				**$110,079,444**	**$11,650,000**

These dramatic cost differences must be taken into account as utilities move forward with Smart Grid-related investments. If state utility commissions ignore them, the result inevitably will be ratepayer hostility and a dramatic slowdown in Smart Grid development.

b. The Efficiency of On-Ramp's Network System in Terms of Spectrum Allocation

On-Ramp's system is not only economically efficient, but it is much more spectrally efficient than mesh systems. Specifically, it is capable of achieving a significantly higher data rate per meter per amount of spectrum than is mesh.

For any given allocation of spectrum, the true measure of spectral efficiency is how many customer installations/devices could be served. The On-Ramp system not only has the ability to serve a large number of customers/devices with a single Central Access Point, it also is able to expand the number of Central Access Points within a given allocation of spectrum. In contrast, mesh systems are characterized by the opposite phenomenon—adding more infrastructure actually lowers performance unless additional spectrum is used. This means that a far greater number of customers and Nodes can be served using the On-Ramp system within a given spectrum band than is the case with competing technologies.

This phenomenon is well-illustrated by Exhibit No. 2. The exhibit demonstrates that a mesh system would be capable of providing a higher data rate than ULP, *i.e*., 100 Kbps as compared to 66 Kbps, if allocated 20 MHz of spectrum (as compared to a 1 MHz spectrum allocation to ULP). However, when their respective overheads and protocol efficiencies are factored in, and the systems compared on a throughput per meter per 1 MHz of spectrum basis, ULP is plainly the "winner" in terms of spectral efficiency (22 bps/meter/MHz as compared to only .05 bps/meter/MHz for mesh). It is important to note that the 22 bps data rate offered by ULP is more than sufficient to meet the needs of the end-user and many distribution-system Smart Grid applications, which require relatively small amounts of data on the order of hundreds of bytes to tens of kilobytes per day per device, and are small packet-size transactions.[28]

c. The Superior Scalability of On-Ramp's Network System

Given that On-Ramp's system is both economically efficient in terms of the fixed infrastructure costs required to serve each customer, and spectrally efficient, the On-Ramp system is *scalable*, meaning that it can be economically deployed within a relatively small amount of spectrum to serve an ever-increasing number of Smart Grid customers.

A Network Deployment Model and Case Study for San Diego County prepared by On-Ramp shows that the system would require lower infrastructure cost and less spectrum than

[28] *See* Exhibit No. 1.

would mesh systems to service Smart Grid applications. On-Ramp has already deployed a network covering 600 square miles (using a single Central Access Point) and conducted a detailed network propagation model proving that 28 Central Access Point locations can reach 97 percent of endpoints in the region. The cost to deploy and operate the network is several orders of magnitude less than existing technologies.

F. Performance Standards for Smart Grid Wireless Network Systems Should be Formulated by the Appropriate Federal Agencies, and Implemented Through Side-by-Side Comparative Pilot Testing Programs Supervised by State Utility Commissions in the Context of Utility Rate Proceedings

The above discussion clearly demonstrates that the ability of the many types of wireless network systems to perform reliably and efficiently in a Smart Grid context is not a foregone conclusion. Rather, there are significant differences among the candidate systems in relation to their reliability, interference implications, and economic and spectral efficiency and scalability. The importance of these factors to successful Smart Grid development and deployment is manifest, because the test of Smart Grid's success or failure ultimately will be, as it is for any utility service or function, whether it can reliably perform its many functions without interruption and at the lowest possible cost to ratepayers. How can the pertinent government agencies work towards the achievement of these goals in the context of wireless system support for Smart Grid? On-Ramp believes that the answer consists of two distinct but related initiatives that need to be taken at the federal and state levels.

As to the first of these initiatives, we note that EISA charges NIST with the responsibility to coordinate the development of a framework to achieve interoperability of smart grid devices and systems, including protocols and model standards for information management. The Federal Energy Regulatory Commission ("FERC"), an independent agency within the Department, is charged by EISA with instituting "a rulemaking proceeding to adopt such standards and protocols as may be necessary to insure smart-grid functionality and interoperability in interstate transmission of electric power, and regional and wholesale electricity markets" once FERC is satisfied that NIST's work has led to "sufficient consensus" on interoperability standards.

While we recognize that DOE is not empowered to issue directives to NIST, or for that matter, to FERC, On-Ramp strongly believes that part of NIST's work on interoperability standards should include the formulation of performance standards and measurement requirements applicable to network systems for specific Smart Grid functions. For example, with respect to Smart Grid's end-user and distribution system functions, NIST should issue performance and measurement criteria for wireless network system reliability, interference, and technical, economic and spectral efficiency and scalability. NIST should also, we strongly believe, formulate measurement protocols in connection with these standards, or as appropriate, issue a guidance document setting forth how cost estimates should be performed.

Second, we believe that state utility commissions should make a practice of using such standards, or on an interim basis, employ standards that they formulate on their own, through consultants or otherwise, in the context of retail rate cases in which utilities seek cost recovery for Smart Grid investments. The importance of these steps cannot be over-emphasized. Spurred on by the economic incentives provided by ARRA,[29] many utilities around the country are now in a scramble to invest in such systems and file rate cases to recover their capital costs and returns on their investment. But unfortunately, many utilities are not, at least outwardly, taking the necessary steps to ensure that the wireless component of their Smart Grid investment programs will meet minimum reliability and efficiency criteria and are relying on vendor-based

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29 *See* note 6, *supra*.

proposals. A recent Maryland Public Service Commission ("MPSC") case seems to be directly on point.

In that case, the MPSC recently rejected the application submitted by Baltimore Gas and Electric Company ("BG&E") for authorization to install smart grid meters and a communications network. The MPSC based its rejection in large part on concerns that BG&E might "adopt new, unproven technology [that] could potentially cause ratepayers to be saddled with infrastructure that will be obsolete before the end of its anticipated useful life or incompatible with AMI technology standards expected to evolve in the near future."[30] In addition, in words that echo one of the central themes of these comments, the MPSC held that "much of the technology BGE intends to rely upon has yet to be tested in an environment comparable to Maryland"[31] referring specifically to the interoperability of meters with related technology that might not work in "a particular sort of physical environment as far as the trees, the rolling hills, the mixture of urban, suburban and rural" found in Maryland.[32] While On-Ramp generally believes that utility investments in Smart Grid should not be discouraged, On-Ramp commends the MPSC for recognizing a critical reliability issue.

Moreover, in this connection, On-Ramp believes that state commissions should explicitly require utilities to conduct side-by-side comparative pilot testing programs, where wireless systems such as On-Ramp's would be field-tested to ensure reliable performance in comparison to other systems across all main utility deployment environments—such as, where applicable, in rural, urban and suburban environments. Such pilots would serve as real word laboratories to

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30 *In the Matter of Baltimore Gas and Electric Company for Authorization to Deploy a Smart Grid Initiative and to Establish a Surcharge Mechanism for the Recovery of Cost*, Case No. 9208, Order No. 9208 (June 21, 2010) at 36.

31 *Id.* at 38.

32 *Id*. at 38-39.

determine whether the pertinent NIST standards, discussed above, have been met, based on NIST measurement protocols, or absent such NIST standards, standards formulated by the state commissions themselves. On-Ramp believes that such real-world, cross-geography side-by-side comparative vendor pilot programs are vital, and that they should be a prerequisite to cost recovery by the utility with respect to the wireless component of its Smart Grid investment.

IV.
CONCLUSION

On-Ramp appreciates the opportunity to submit these comments. For the reasons stated herein, On-Ramp respectfully submits that the Department should recognize the significant differences that have been set forth above as to the performance characteristics of the extant wireless network systems, and use its "bully pulpit" to push for the measures described immediately above—the adoption of performance standards and measurement protocols by NIST, and the institution of side-by-side comparative pilot programs by state commissions.

On-Ramp also commends the Department and its leadership for instituting this proceeding and for the public meetings it has held and will hold in the future.

Respectfully submitted,

/s/ *Kenneth G. Hurwitz*
Kenneth G. Hurwitz
COUNSEL FOR ON-RAMP WIRELESS, INC.

Dated: July 12, 2010

EXHIBIT NO. 1

Utility Network Requirements

	Electric AMI	Gas Meter	Water Meter	Distribution FCI
Daily Uplink Payload Data	5kb +Alarms	500bytes + Alarms	500bytes +Alarms	150 bytes +Alarms
Daily Downlink Payload Data	Network acknowledgement, shut off, rate tables	Network acknowledgment, shut off	Network acknowledgment, shut off	Network acknowledgment, reset
Latency Tolerance	Seconds for alarms; Minutes for payload	Seconds for alarms; Minutes for payload	Seconds for alarms; Minutes for payload	Seconds for alarms; Minutes for payload
Firmware Upgrade	600kb	200kb	200kb	N/A
Battery Requirements	n/a for meter; months to years for HAN devices	15-20 years	15-20 years	10 years

EXHIBIT NO. 2

Capacity Efficiency Model

Application throughput for uplink available for meter data

Uplink Data Rate	Ultra-Link Processing – 1Mhz	FHSS – 20Mhz, 100Khz bandwidth
Uplink Aggregate Data Rate	66 Kbps	100 Kbps
Half-duplex	33 Kbps	Payload dependent (10% - 70% overhead)
Aloha Protocol Max Efficiency	N/A, 33Kbps	18kbps
Engineering Margin/Protocol Efficiency	22Kbps	7 Kbps
After Mesh Inter-device Networking Overhead	N/A, 22 Kbps	1Kbps
1000 meter capacity/1Mhz	22bps/meter/1Mhz	.05bps/meter/1Mhz

EXHIBIT NO. 3

Mesh Does Not Scale Efficiently

Residential Applications

	Electric Meters	Gas Meters	Water Meters	Home Energy	Total
Total Meters	1,400,000	1,300,000	830,000	1,700,000	5,230,000
Required Mesh Repeaters	57,600	205,600			263,200
System Cost Impact	$115M	$113M			$218M
Spectrum	20MHz	5MHz			25Mhz

Plus additional 4.4 million commercial end point devices are not connected

EXHIBIT NO. 4

Network Scaling

Ultra-Link Processing™ Scalability
- Electric AMI Example -

Number of Access Points	1	2	3	4
4	69,120 meters	138,240 meters	207,360 meters	276,480 meters
3	51,840 meters	103,680 meters	155,520 meters	207,360 meters
2	34,560 meters	69,120 meters	103,680 meters	138,240 meters
1	17,280 meters	34,560 meters	51,840 meters	69,120 meters

Available MHz of Spectrum (in 2.4 GHz band)

*Note: Given one application requiring 5KB of uplink data each day; plus downlink control and alarm data with less than 12 second latency for alarms