Accelerating Change in the Power Grid Infrastructure

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ABSTRACT

There are a multitude of initiatives working towards the upgrade and improvement of the North American power grid, in essence creating a "Smart Grid". Central to this is the need for advanced technologies and standards to integrate intelligent equipment across not just the network, but across multiple affected industries. These standards must include the networking protocols as well as the "language" that will be used by the equipment. Fundamental to the networking protocols are the following: the underlying technology will undoubtedly be wireless, the use of IP addressing and routing is inevitable, and the solutions must work reliably. The basic time synchronized approach using wireless channel hopping with intelligent network management being adopted in several industries is key to a more reliable, integrated and interoperable grid.

1 SMART METERING AND AMI ARCHITECTURE

In the past, electromechanical meters served as the cash register for our utilities. These meters simply recorded the total energy consumed by the customer over a period of time – typically a month–and this information was collected manually. Smart meters are solid state programmable devices that can store and communicate consumption data to both the user and the utility. The information is collected via a network, an Advanced Metering Infrastructure (AMI), which serves as a building block of the Smart Grid. Once this bi-directional communication is established, users and producers are capable of performing many more consumption-related functions, including:

- Time-correlated pricing and consumption data for the utility and their customers
- Net metering (taking into consideration reverse power flow for facilities generating power)
- Power quality monitoring
- Loss of power (and restoration) notification
- Communications with other intelligent devices
- Demand response programs

Utilities implement demand response programs to help limit energy use at specific peak times, when demand strains the electric grid and they are forced to provide incremental power at what is typically a higher cost for them. One way to reduce that peak demand relies on the installation of smart thermostats and other load control devices. These devices allow the utilities to cycle equipment like air conditioners on and off for short periods of time.

However, demand response programs are not typically designed to meet the needs of industrial facilities where energy efficiency improvements are intertwined with complex industrial processes and the facility's often unique operational characteristics. Nor are they designed to respect the needs of the multitude of businesses where HVAC requirements may be critical to maintaining optimum operations.

Therefore the AMI infrastructure must support the needs of both consumers as well as the industrial consumers of electric power. Fortunately, the architectures and the need for continuous communications between the utility, the consumer and the electrical load controls are fairly similar for both constituents. Possible options include:

- Power Line Carrier (PLC)
- Copper or optical fiber
- Wireless, either centralized or distributed mesh
- Some combination of the three

More importantly, the network architecture must be highly scalable, and the communication protocols and standards that ride over these different media must bi-directional, and highly secure. The Electric Power Research Institute defined an IntelliGrid Architecture and lists the following elements as critical to implementing the Smart Grid:

- Proven, Internet derived communication technologies
- Service based architecture at the enterprise level
- Self healing technology
- Well defined interfaces and points of interoperability
- Application of industry and international standards
- Built in security and network management

This paper proposes that Smart meters using an IPv6-based protocol stack running over IEEE 802.15.4 wireless mesh networks is a rapidly deployable solution that will meet these requirements. It additionally proposes that this same network technology, already being integrated into industrial processes and applications, can provide utilities with the underlying communications network required to collect detailed information concerning demand requirements that can be used to reduce over-provisioning and create a more efficient, demand-driven, "Smart" power generation model.

2 THE STANDARDS

2.1 IEEE 802.15.4

IEEE 802.15.4 is a standard which specifies the physical layer (PHY) and media access control (MAC) for low-rate wireless personal area networks. It is an established standard utilized by alliances and standards groups such as Zigbee and WirelessHART. It is a low data rate solution with multi-month to multi-year battery life (some cases a decade or more) as well as offering low complexity. Operating in an unlicensed, international frequency band 802.15.4 is the basis of a broad group of Wireless Sensor Networking products enjoying rapid adoption in the Industrial space.

Key features include:

- Data rates of 250 kbps, 40 kbps, and 20 kbps.
- Two addressing modes; 16-bit short and 64-bit IEEE addressing.
- Support for critical latency devices
- Automatic network establishment
- 16 channels in the 2.4GHz ISM band, 10 channels in the 915MHz I and one channel in the 868MHz band.

2.2 IEEE 802.15.4e

IEEE 802.15.4e will define a MAC amendment to the existing standard 802.15.4-2006. The intent of this amendment is to enhance and add functionality to the 802.15.4-2006 MAC to better support the industrial markets and provide for the low power, and high reliability demanded by the users in these markets.

At this time the task group has defined the application spaces that it will address along with the MAC behavior changes that are required to enable those application spaces. These application spaces include: Industrial Automation, Asset Tracking, and General Sensor Control (Industrial/Commercial, including Building Automation).

2.3 IP IS INEVITABLE

The Internet Engineering Task Force (IETF) is the open recognized International Standards Organization (ISO) in charge of standardizing the IP protocol. IP is a proven, stable, and highly scalable communication technology that supports a wide range of applications, devices, and underlying communication technologies.

Over the past 20 years, IP has evolved to support new mechanisms for high availability, enhanced security, support of Quality of Service (QoS), real-time transport, and Virtual Private Networks (VPNs). IP therefore has all the qualities needed to connect billions of communicating devices.

The IP stack is lightweight and runs on tiny, battery operated embedded devices the size of a sugar cube. It has also proven to support a wide variety of Physical and MAC layers and is therefore media-independent, ranging from low-power radios such as 802.15.4 to the more power hungry 802.11 (WiFi), even across long-range radio technology such as GPRS and 3G. On the wired side, it is the dominant standard for high-speed wired Ethernet, multi-gigabit links, and of course, the Internet.

IP is proven across a wide range of applications, on a wide range of devices, and over a wide range of underlying network technologies. This highly scalable and open infrastructure also allows for future innovation as the application space evolves beyond today's vision.

3 RELIABLY CONNECTING USERS AND SUPPLIERS

A demand response system driven by the utility may work in residential applications, but in industrial and business applications, it is the consumer of the electric power that must drive energy efficiencies and share usage information with the utility, which in turn supports the utility's planning and resourcing. A truly Smart Grid demands a solution that delivers the highest performance in all of these areas:

- Standards-based—Compliance to standards such as IEEE 802.15.4 and IETF IPv6 ensure an interoperable solution.
- Reliability—Networks that can deliver greater than 99.99% reliability, even in the toughest RF environments.
- Scalability—The network should be able to support millions of nodes
- Easy-to-deploy—A cable-less solution to minimize cost and maximize flexibility
- Secure—not only with respect to data and communications protection, but also prepared to function during a power outage

Delivering on one or even two of these attributes can arguably be accomplished with a simpler solution such as ZigBee. While this may be sufficient for some applications, such as a thermostat in the home, Smart Wireless Sensor Networks (WSNs) utilizing IP meet all of these criteria and are therefore the key to accelerating change in the power grid infrastructure. The well defined interfaces and points of interoperability ensure that these proven, Internet derived communications technologies easily integrate into the host applications that run the generation and distribution infrastructures day to day.

Clean Technology 2009, www.ct-si.org, ISBN 978-1-4398-1787-2

3.1 MESH TO THE EDGE

Full-mesh networks, sometimes referred to as "mesh-to-the-edge," provide redundant routing to the edge of the network. This has the obvious benefit of reliability but also has dramatic impact on network scalability and long-term predictability. In a full-mesh network, every device has the same routing and transmitting capabilities. As each node is installed, it is able to "decide" where it belongs in the routing structure based on the other nodes it can communicate with, its proximity to the network egress point (for a wireless node), and its traffic load. This allows for true self-forming and self-healing without constraints imposed by device type and architecture.

3.2 CHANNEL HOPPING

Channel hopping and frequency agility are two distinctly different approaches used by 802.15.4 networks to circumvent RF interference. Both approaches use all 16 channels available to 802.15.4 by assigning a different channel for each transmission. However, frequency agility uses a single channel for the entire network. If interference develops on this channel, the entire network moves to a new channel. Frequency agility is only successful if the same channel is available across the entire network, and does nothing to combat multi-path interference.

True channel hopping is only possible for systems that use time-synchronized communication, where nodes share the same sense of time and each communication link is scheduled. In this case each packet transmission can hop to another channel. This proves to offer great resistance to RF interference and adds the benefit of dynamically responding to multi-path interference caused by the chaotic and dynamic world of physical obstacles and multiple WSNs with millions of nodes spread over large areas.

4 CASE STUDY

The average industrial customer is typically an energy intensive consumer of electricity, and this consumption is often a fairly significant cost of doing business. For this reason, energy efficiency is not a new concept. Businesses find it in their best interest to adopt the most cost effective measures. Simply put, low hanging fruit like lighting changes, and motor retrofits are likely to have been done already.

Wireless Sensor Networking is already being used to dramatically reduce the energy consumed in large building complexes and datacenters. One example, the University of California at Santa Barbara (UCSB), highlights the tremendous cost savings possible.

In this case, Federspiel Controls (a Dust Networks customer), provided a wireless control solution called Discharge Air Regulation Technique (DART), which is designed to convert constant volume Heating, Ventilation and Air Conditioning (HVAC) systems to Variable Air Volume (VAV) operation. Battery-powered wireless temperature sensors were installed in or near the discharge air diffusers. The sensors measured discharge air temperatures and regulated the highest or lowest zone temperature by varying the fan speed. Installation time was very short; no mechanical retrofits, and no need to get above the ceiling.

Three DART applications were installed on five fans at Cheadle Hall and Phelps Hall on the UCSB campus. Energy performance data for the five controlled fans (total 115 hp) was collected for about 90 days. The estimated combined fan energy savings were about 58%, which equates to annual savings of 187,000 kWh.

The overall solution was then expanded to cover four buildings across eight Air Handler Units, with the HVAC system converted to VAV. Extracting another 574,000 kWh/yr savings along with a reduction of 25,000 therms/yr was accomplished in only 10 days of installation work.

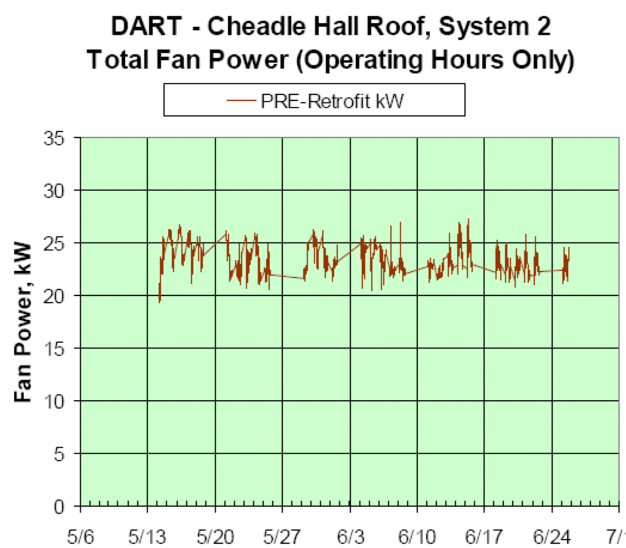

Figure 1 Fan Power Loading Pre-DART

Figures 1 and 2 illustrate just how dramatic the reductions can be, and several days can pass with virtually no loading in Figure 2. This immediate reduction in energy consumed by UCSB creates a startling new reality for their electric power provider, with loads converting from constant loads over time to highly variable loads impacted by changes in the weather or even the start of Spring Break.

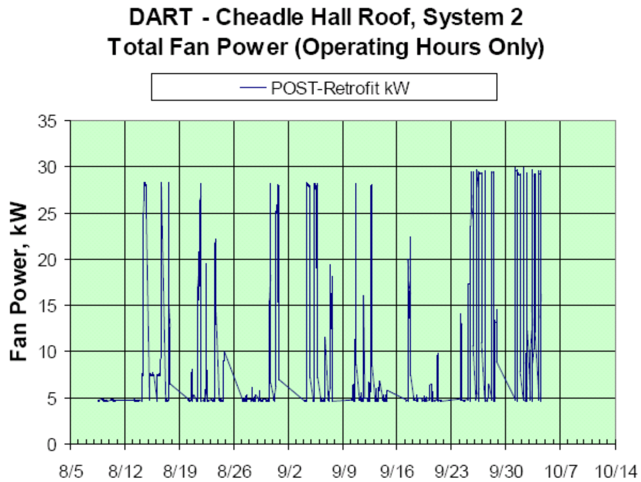

Figure 2 Fan Power Loading Post-DART

If this energy-efficiency solution were to be deployed into tens of thousands of buildings using constant volume systems, the savings for the customers would be spectacular, but perhaps not for the energy supplier. Solutions like the one illustrated are rapidly becoming the norm, and utilities face a very real imperative to gain access to the detailed usage data as well as gain a clear understanding of how these systems will react.

5 SUMMARY

Wireless Sensor Networks are already being deployed in industry for process monitoring and to increase energy efficiency. Closing the data loop between energy consumers and energy suppliers will enable suppliers to react most effectively to the highly variable demand that aggressive energy efficiency techniques will create.

Smart meters using an IPv6-based protocol stack running over IEEE 802.15.4 wireless mesh networks is a rapidly deployable solution that will provide utilities with the underlying bi-directional communications network required. This advanced network can then be used to collect detailed information concerning demand requirements that can be used to reduce over-provisioning and create a more efficient, demand-driven, “Smart” power generation model.

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