Understanding Wireless Topologies for Smart Grid Applications

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Abstract

As smart grid standards are developed and deployed nationwide, communication technology systems within the grid architecture are continuing to improve, allowing utilities to adequately meet demands for the first time. Many previous communication systems relied on outdated wireless systems with extensive and costly network infrastructure requirements, and were highly susceptible to issues such as interference, unpredictable network planning, limitations in range and capacity.

However, recent technology innovations such as a high capacity, star topology system – which several utilities have already begun implementing, can provide performance several orders of magnitude greater than current spread spectrum implementations – finds a large number of extremely weak incoming signals, and features ultra-low power consumption. This system has the coverage and throughput capacity to enable the vision of a real-time intelligent utility networking across various applications such as in-home energy management, above and below ground distribution automation, and electrical, gas and water meters, thereby maximizing the benefits of the Smart Grid.

Joaquin will present a highly technical, informative perspective on how utilities can plan the right network topology given various physical layer technology options, network management and scaling these networks across a number of dimensions such as node count, bandwidth size, physical geography, etc.

INTRODUCTION

Current wireless systems implementations for the Smart Grid addressing critical applications such as Automated Metering Infrastructure (AMI) use a variety of different wireless technologies to communicate. The most common technologies being employed were not designed at the physical communications layer for the application at hand and therefore introduce severe limitations. These limitations can only be overcome by adding complex network infrastructure, which in turn drives capital cost and leads to an unreliable platform with no ability to scale for the future of the grid.

THE SMART GRID NEEDS A ROBUST COMMUNICATIONS INFRASTRUCTURE

It is a stated goal of the U.S. Congress and the Obama Administration to promote energy efficiency, reduce greenhouse gas emissions and encourage energy independence. Smart Grid is at the center of this effort, and a robust communications system to support the grid is essential to meeting the three goals set forth.

The communication system should provide real-time information throughout the networked grid. The following are examples of applications that should be supported by the chosen communication system:

- Sending and receiving information about electricity use, time and nature of use, and costs.
- The ability to communicate, bi-directionally, with energy consuming end devices, such as commercial HVAC systems.
- The capability to transmit alerts related to unintended events in the transmission and distribution grids, such as voltage spikes, enabling an automated and seamless response.
- The ability to detect and prevent security related threats, such as cyber-security threats or terrorism.
- The integration of digital controls for Demand Response, enabling congestion management, supply operating reserves, and provide frequency regulation.

Additional consideration needs to be given to other utility-related applications, such as distributed power generation assets, e.g. solar, electric vehicle charging systems, and automated gas and water meter applications.

All this requires a communications infrastructure that is extremely scalable, robust, built for utility grade reliability, and based on a network architecture that is efficient and manageable.

Given the national security implications surrounding the grid, robustness, scalability, and security should become the cornerstones of the grid communications infrastructure.

TODAY'S WIRELESS COMMUNICATIONS FOR THE SMART GRID

A secure, two-way, wireless data connection is required to support the vital functions of the Smart Grid. This would serve purposes ranging from distribution and transmission management, and automation to customer premise functions, including meter reading and communication with in-home devices and appliances. The wireless system must also, given its public utility status, provide coverage for 100% of end-user meters and devices, regardless of whether the user is located in an urban, suburban or rural area.

It is also essential that the system is capacity efficient. In the wireless industry, spectrum is limited even if it is free spectrum. A wireless technologies ability to achieve the needed payload throughput given the realities of available spectrum and interference is critical.

Use of Cellular in Smart Grid Applications

Commercial cellular networks cannot effectively and reliably provide adequate communication to and from the millions of nodes that make up the end-points in the envisioned future Smart Grid. The cellular networks were designed to solve a different problem, namely voice communications and high-speed (primarily downlink) data links. The cellular transceivers are also characterized by relatively short battery life, making them unfit for end-points that do not have available grid power, such as distribution and transmission sensors, and water and gas meters.

In addition, cellular coverage, as most users experience on a regular basis, is unreliable. It is unlikely that cellular network operators will make significant improvements to solve this issue for the Smart Grid utility applications, as their network considerations are driven by the demands on the high RPC (Revenue Per Customer) segments (i.e. the $150/month iPhone user). A utility demanding 99.99% reliability on a $5/month data plan just doesn't have the same clout and has different requirements.

Use of Free ISM Mesh Networks with Cellular Backhaul

One of the more popular architectures in the early rollout of wireless Smart Grid infrastructure is the combination of mesh networks, typically 900MHz ISM-band, with cellular backhaul at the gateway (mesh aggregation point).

In a mesh network distributed nodes (e.g. a node in each meter on your neighborhood street) will transmit and receive data by "hopping" from node to node until either the receiving node is reached (downlink data) or transmitted data hops from node to node until the mesh gateway is reached. From the gateway, the data is typically transmitted to the utility data center via a cellular data backhaul link.

Proponents claim these networks offer a reliable, high capacity network. However, this is not mirrored in reality.

	On-Ramp System	FH Mesh Systems
Required bandwidth	1 MHz	20 MHz
Average power output per meter	0.1 mW	100 mW
Application throughput normalized by bandwidth	20 kbps/MHz	0.05-0.5 kbps/MHz
Interference caused by system	Low	High
Susceptibility to interference	Low	High
Susceptibility to jamming	Low	High
Security	High	Low
Cost	Low	High
Coverage	100%	< 100%
Power consumption	Low	High

Table 1: Comparison between Ultra-Link Processing and traditional mesh systems

The issues with the mesh/cellular model can be outlined as follows:

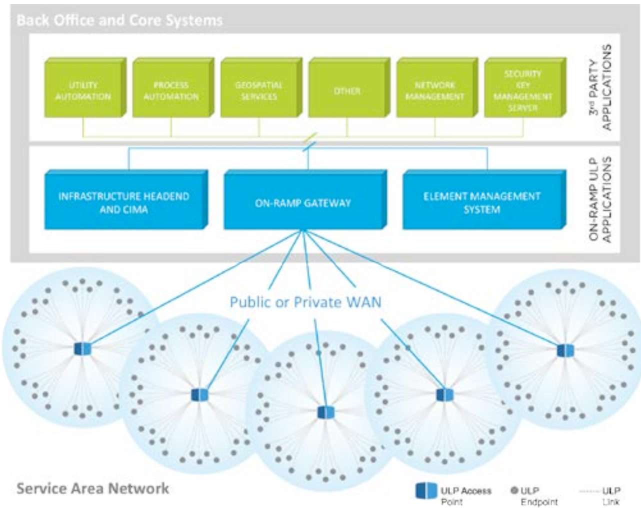
- *Mesh systems are capacity inefficient*: Mesh systems require fine-tuned coordination of the data path. This coordination consumes valuable capacity and significantly lowers the effective data rate of the mesh network. The mesh networks also consume large amounts of bandwidth (20MHz for frequency hopping) compared with a star topology like On-Ramp's (1MHz).

- *Mesh systems cause significant interference*: In order for a mesh node to reach its neighboring node, even in benign conditions, it has to operate at a high power level. This resulting interference will overcrowd the frequency band and eventually produce a degrading feedback loop, which, in turn, causes capacity degradation and failures.

- *Mesh systems require prohibitive amounts of network infrastructure*: The mesh network uses repeaters and gateways to overcome the inherent limitations in transmission range. Early rollouts have already deployed tens of thousands of such infrastructure points, which will ultimately lead to a network management nightmare for the utilities and to reliability problems.

STAR TOPOLOGY: THE RIGHT ARCHITECTURE FOR THE SMART GRID

In a star networking topology – relied upon by the cellular industry – a central access point (the center of the "star), communicates directly with end nodes in its coverage area. End nodes, in the case of the Smart Grid, could be meters (gas, water, power), sensors, appliances, etc.



A star networking topology, on the other hand – which is relied upon by the cellular industry – features a central access point (the center of the "star), which communicates directly with end nodes in its coverage area. End nodes, in the case of the Smart Grid, could be meters (gas, water, power), sensors, assets, etc.

Some star topology systems can demodulate signals at very low energy levels (On-Ramp achieves down to -145 dBm receiver sensitivity), while maintaining high aggregate throughput capacity. Additionally, nodes can operate at significantly lower power levels than the mesh node, which makes this network viable for battery-operated applications. Furthermore, a low receive sensitivity system has far more range than a wireless mesh system and can overcome factors including terrain, clutter type (urban, suburban, rural, etc.), and interference. Regional and national output power regulations also determine the range capabilities of any specific radio.

CONCLUSION

As you can see, it is possible for a star topology system to be designed for low data rate applications, to use highly sensitive transceivers (i.e. transceivers capable of demodulating very low-energy signals), with plenty of capacity, and to be able to provide interference-resistant signal processing. The combination of these factors allows it to far outperform any mesh networking architecture, both in terms of coverage, capacity, reliability and cost.

Biography

Joaquin Silva co-founded On-Ramp Wireless in 2008 to address the large technology gap for pervasive wide-area wireless in the Smart Grid and utility automation markets. Under his leadership, On-Ramp has become an industry pioneer in the Smart Grid space, obtaining a DOE grant for below ground monitoring of distribution grid assets. Based on Joaquin's leadership and direction, On-Ramp Wireless was also selected as a World Economic Forum 2011 Technology Pioneer, a 2011 Bloomberg New Energy Finance Pioneer and a winner of GE's Ecomagination Awards. Prior to founding On-Ramp Wireless, Joaquin was co-founder, President and COO of Ostendo Technologies Inc., where he was instrumental in developing a unique display technology and winning several new customer and government programs. Prior to Ostendo, Joaquin was a Vice President at the investment-banking firm Montgomery & Co., where he led their wireless and semiconductor franchise for 6 years. Earlier in his career, Joaquin was a Captain in the United States Air Force. He has an MBA from University of California, Los Angeles and a BS in Management from the United States Air Force Academy.