FUTURE OF
UTILITY COMMUNICATIONS
Private Wireless Networks that Combine Technologies

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Introduction

Increasingly, electric utilities are deploying intelligent electronic devices (IEDs) and other smart apparatus in substations and along distribution feeders as well as equipping field workers with laptop, tablet and handheld computers. Electric utilities are also installing specialized computers and software in substations plus enterprise software applications in their data centers to automate various facets of utility operations.

These technologies are often labeled smart grid. They enable valuable applications such as automated metering infrastructure (AMI), substation automation, distribution automation, outage management, automatic load shedding, and the ability to manage alternative energy sources. These applications enable vast improvements in utility efficiency, security and reliability.

An additional component is required to make this intelligence productive – two-way communication, as shown in Figure 1. Two-way communication enables intelligent devices in the field to provide data to applications running on computers in substations and data centers. A modern wireless communication network is a key element in this overall electric utility communication infrastructure. Private wireless networks built using wireless mesh, broadband point-to-point (PTP), point-to-

multipoint (PTMP) and narrowband PTP/PTMP technologies extend communication from the substation control house to the substation yard and along distribution feeders.

Figure 1 – Two-way Communication

This article describes how a combination of private wireless mesh and broadband PTP/PTMP technologies, coupled with narrowband wireless technologies for specific applications, can meet the requirements for modern wireless utility communication networks. It also compares and contrasts the capabilities of these private wireless networking technologies with data services provided by public cellular network operators.

Advanced Control Systems

Two-way Communications

Smart Devices

Two-way Communications

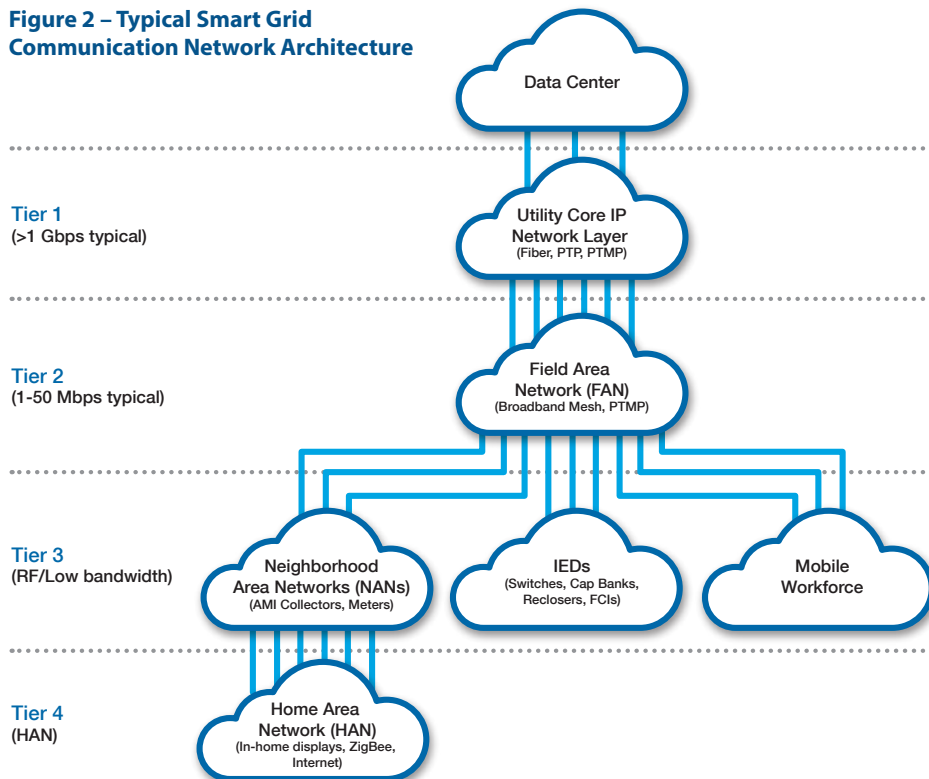Mobile Workforce

Two-way Communications
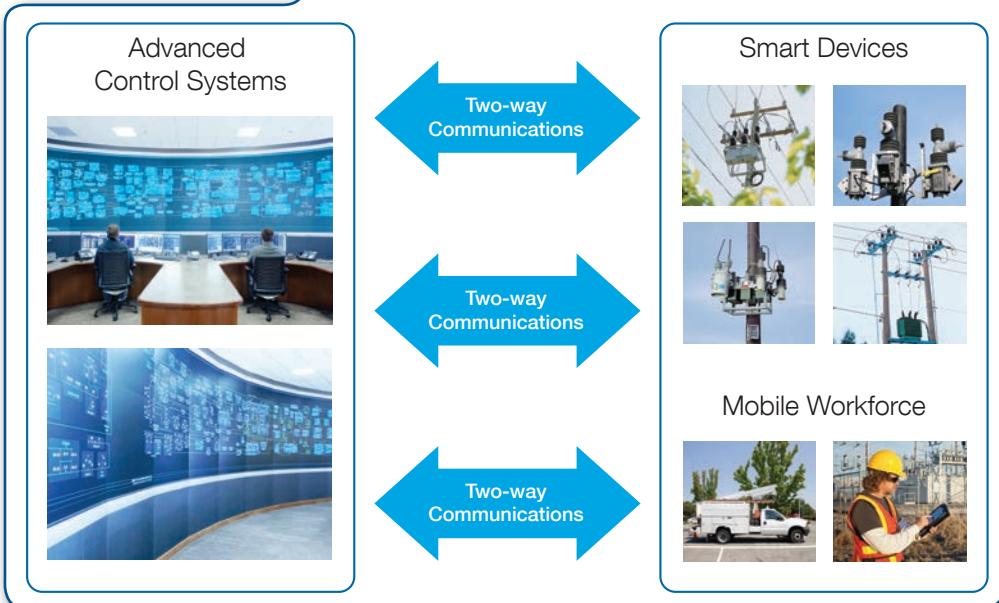
Utility Communication Network Architecture

Most utilities implement a two tier, to a four-tier smart grid communication network architecture, depending on the specific applications they plan to deploy. The tiers are defined as follows and illustrated in Figure 2.

- **Tier 1**: The utility's core IP network, which often connects many of its distribution substations. This tier is generally implemented with fiber-optics. In most cases, the Tier 1 network provides a 10/100/1000BASE-T Ethernet port on a virtual local area network (VLAN)-capable Ethernet switch as the demarcation point for the Tier 2 FAN.
- **Tier 2:** The Field Area Network (FAN) fills the gap between the core Tier 1 networks and devices, as well as personnel, in the field. Substation automation devices (e.g., breaker controllers, voltage regulators, and remote terminal units (RTUs)), distribution automation devices

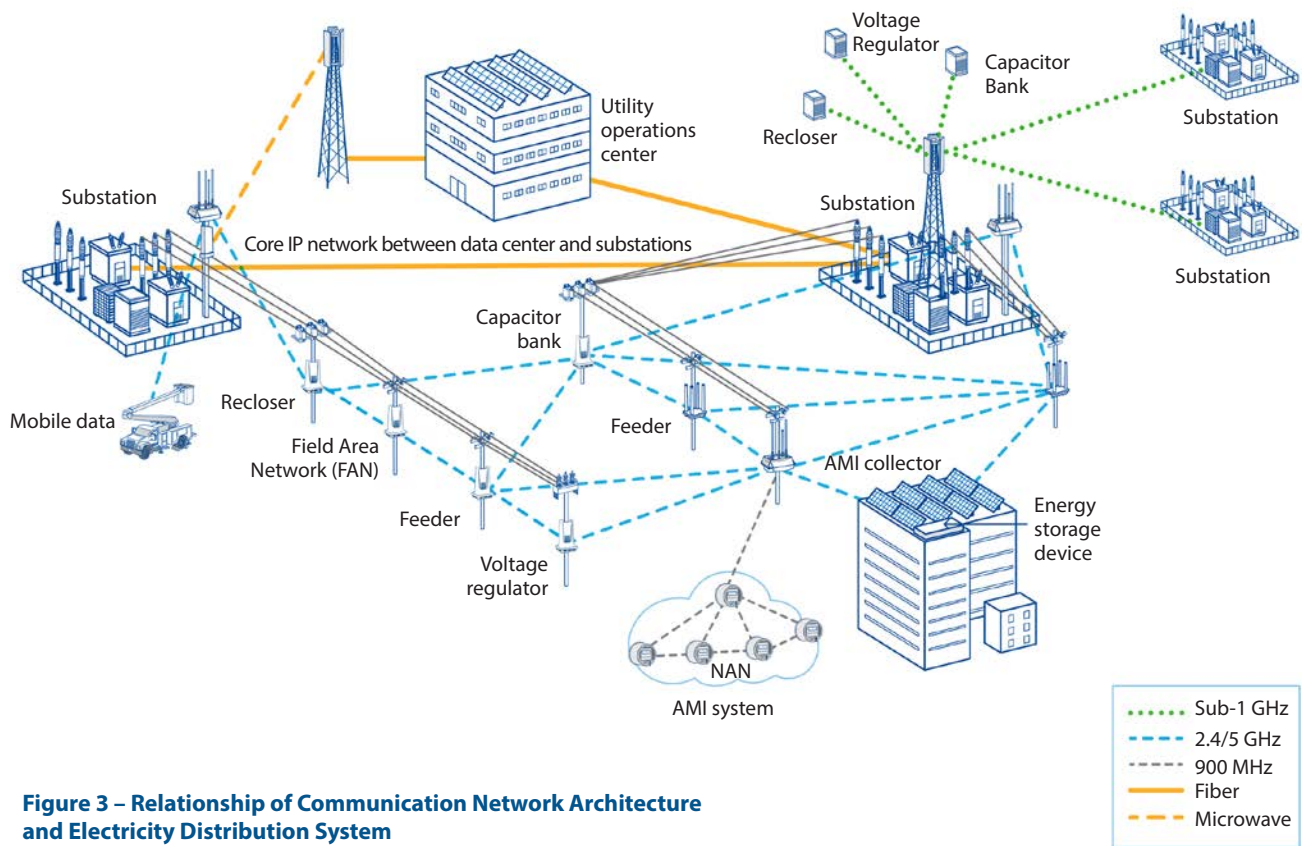**Figure 2 – Typical Smart Grid Communication Network Architecture**

Data Center

Tier 1 (>1 Gbps typical) — Utility Core IP Network Layer (Fiber, PTP, PTMP)

Tier 2 (1-50 Mbps typical) — Field Area Network (FAN) (Broadband Mesh, PTMP)

Tier 3 (RF/Low bandwidth) — Neighborhood Area Networks (NANs) (AMI Collectors, Meters); IEDs (Switches, Cap Banks, Reclosers, FCIs); Mobile Workforce

Tier 4 (HAN) — Home Area Network (HAN) (In-home displays, ZigBee, Internet)

Figure 3 – Relationship of Communication Network Architecture and Electricity Distribution System

Legend:
- Sub-1 GHz
- 2.4/5 GHz
- 900 MHz
- Fiber
- Microwave

(e.g., capacitor bank controllers, recloser controllers, and smart transformers), AMI collectors, and mobile workers equipped with laptops, tablets or handhelds connect to the FAN. As wireline carriers discontinue analog leased line services, utilities are also turning to FANs to provide connectivity to remote substations and other far-flung assets. FANs are most often implemented with wireless networking technologies, usually a combination of broadband wireless mesh, point-to-point (PTP) and point-to-multipoint (PTMP), and/or cellular data links. Endpoint connections to the FAN can use wireless or wired Ethernet or serial links.

- **Tier 3:** The AMI network, also known as the Neighborhood Area Network (NAN), includes smart meters and AMI collectors. Meters may communicate directly with collectors or via other meters using a meter meshing system. The NAN is generally implemented using narrowband wireless mesh or cellular data. When a broadband wireless mesh network is used to implement the Tier 2 network, the AMI collectors in the Tier 3 networks are generally co-located with the mesh routers that form the Tier 2 network. The collectors attach to a wired Ethernet port on the mesh routers. The AMI network may also provide the communications interface for the Home Area Network.
- **Tier 4:** The Home Area Network (HAN), is usually implemented using ZigBee or Home Plug technology, provide connectivity to smart grid devices, applications and displays inside homes and businesses. If supported by the meters used in the AMI system, HANs can connect to NANs, and, in turn, the rest of the utility communication network, via the smart meters deployed on the customers' premises. Otherwise, the HAN will generally connect to the utility's operations center via the internet.

A different view of the typical utility communication network architecture, showing how the tiers relate to components of the electricity distribution system, is shown in Figure 3.

Let's focus on the Tier 2 'FAN': Field Area Network Requirements
FANs fill the communication gap between the core Tier 1 networks and devices, as well as personnel, in the field. FANs are most often implemented with wireless networking technologies because their large geographic coverage areas, large number of connected devices and the need to support mobile field workers make it technically and economically infeasible to implement them using wired technologies. Wireless networking technologies used in FANs include cellular, narrowband PTP/PTMP, broadband PTP/PTMP and broadband wireless mesh networks.

To support many applications concurrently, FANs must meet the superset requirements of all current and future smart grid applications. Based on more than a decade of experience implementing field area networks for utilities, ABB wireless has determined that following characteristics are required for field area networks to meet current and future smart grid needs.
- High reliability
- Low operating expense
- Secure
- Long single-hop range
- Interoperability
- High capacity
- Low latency
- VLAN and QoS support
- Mobility
- Manageability

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Figure 4 – Wireless FAN Technology Choices

	Cellular	Narrowband PTP/PTMP	Broadband PTP/PTMP	Broadband Mesh
Reliability	¾	¾	½	Excellent
Opex	Poor	¾	¾	¾
Security	½	¾	¾	¾
Single-Hop Range	¼	Excellent	½	¼
Interoperability	¼	¾	¾	Excellent
Capacity	½	¼	¾	¾
Latency	¼	¾	¾	¾
VLANs/QoS	½	¾	¾	Excellent
Mobility	Excellent	Poor	Poor	¾
Manageability	¼	¾	¾	Excellent

Poor ⟷ Excellent

Field Area Communication Network Technology Choices

As shown in Figure 4, numerous wireless technology choices exist for implementing FANs. While some, e.g., broadband wireless mesh networks, score highly across the board, none achieves the highest marks for all FAN requirements. This leads to a natural conclusion – a network that uses a mix of technologies, generally broadband mesh, PTP and PTMP, coupled with narrowband wireless PTP/PTMP for specific applications, will best be able to meet FAN requirements for a utility with a large and varied service territory.

Highly Reliability:

Broadband mesh networks provide high availability by automatically selecting the best route through the network from multiple radio frequency (RF) paths, channels and bands. Using these capabilities, wireless mesh networks can be designed to deliver five 9s system availability. At the other extreme, according to a study by Root Metrics, Verizon Wireless's network has 99.2% reliability while AT&T was 98.3% reliable under normal conditions. This means you can expect 5 hours of downtime on Verizon and 12-14 hours of downtime on AT&T per month. Narrowband and broadband PTP/PTMP fall in the middle, with narrowband perhaps having a bit of a reliability advantage over broadband when operating in lower frequency, licensed bands.

Operating Expenses:

Because utilities' rate structures often link rates to a specified return on assets, many utilities prefer making capital investments (buying infrastructure that they operate) over incurring operating expenses (purchasing a service). As a result, they require field area networking technologies to have low operating expenses. All private wireless network options – mesh, broadband PTP/PTMP and narrowband PTP/PTMP – have low operating expenses. Even some ongoing costs, e.g., extended warranty and maintenance, may be able to be treated as a capital expense if an up-front, multi-year agreement is negotiated. As one would expect when paying for a monthly service, cellular data options are opex intensive.

Secure:

Broadband wireless mesh networks offer the highest levels of security, providing the ability to implement a multi-layer, defense-in-depth security architecture from the network core to the edge. Broadband PTP/PTMP offerings have also generally provided good security capabilities and these are only improving. Narrowband PTP/PTMP products have historically offered poor security, relying on obscurity augmented by frequency-hopping spread spectrum (FHSS) technology. Recently, however, a new generation of narrowband PTP/PTMP products has emerged who security capabilities rival those of wireless mesh and broadband PTP/PTMP. Cellular data services offer limited security capabilities and little transparency as to what happens to data after it exits the customer's network and enters the carrier network.

Single-Hop Range:

Narrowband PTP/PTMP offers the best single-hop range, especially when operating in lower frequency, licensed bands which have excellent non-line-of-sight propagation. This makes narrowband PTP/PTMP an ideal technology for connecting remote endpoints, e.g., substations currently using leased lines. Cellular data services provide similar single-hop range, with two caveats: 1) endpoint-to-tower range may be limited because cellular clients tend to have lower transmit power than narrowband PTP/PTMP subscriber units and 2) because utilities' have no control where cellular base

stations are located relative to utility assets, even the longer single-hop range offered by cellular technology may be insufficient to connect the endpoint to the tower. Broadband PTP/PTMP can offer excellent single-hop range but, because the technology operates in higher frequency bands, it tends to require good line of sight which can involve costly towers, specialized antenna and precise alignment. While, in cases where there is clear line of sight, mesh can offer good single-hop range, more frequently it does not, often by design. Wireless mesh routers are generally mounted at a heights that allows them to use buildings, trees and other obstructions to limit range, creating the opportunity for higher spectral reuse and, hence, higher network capacity.

Interoperability:
Broadband wireless mesh networks based on 802.11 provide the best interoperability because they support open standards including TCP/UDP/IP, 802.11 (Wi-Fi) and 802.3 (Ethernet). To integrate legacy field devices and avoid stranded assets, some mesh routers also support secure network connections to devices that use serial RS-232 or RS-485 links and automation protocols such as DNP-3 and IEC 61850. Recently, broadband and narrowband products that also support this range or interfaces and protocols have come to market with the important caveat that none provide integrated Wi-Fi support. Most cellular data modems can interface only to the network of one carrier and support Ethernet as their only additional interface.

High Capacity:
The modern utility's need for information demands a high capacity network that can keep up with amount of data coming in from intelligent field devices and mobile workers. However, a high capacity network is not the same thing as a network in which every link operates at blazingly fast speed. High link throughput is required where the network is aggregating data from a number of applications or support a particularly bandwidth intensive application such as video surveillance. . Broadband wireless mesh networks fit the bill, proven to support in excess of 1 TB per day of transferred data. Broadband PTP/PTMP links also provide high capacity and are useful for, among other purposes, connecting mesh takeout points to the Tier 1 (usually fiber) network in areas where there are no fiber drops close to the desired takeout location. However, for a single, low bandwidth application, narrowband PTP/PTMP links may provide sufficient throughput at lower cost, especially if the connected endpoints are remote. LTE-based cellular services also provide reasonable capacity but may be subject to throttling and overage charges when data caps are exceeded.

Low Latency:
All private wireless network options can provide latency sufficient for most utility applications. Certain particularly delay-sensitive protection applications, which may require dedicated wired connections to operate properly, are an exception. With PTMP technologies, care must be taken to ensure that the scheduling algorithm does not cause latency to grow beyond acceptable limits. Latency for LTE-based cellular services are about an order

of magnitude higher than for private wireless options, in the neighborhood of 90 ms for LTE versus sub-10 ms for private wireless technologies.

VLANs/QoS:
Broadband mesh networks supported and broadband PTP/PTMP systems have long supported VLANs and QoS, enabling traffic from different applications and user groups to be segregated and permitting security, as well as QoS, policies to be tailored to the needs of each application/user group. QoS capability ensures that traffic for latency-sensitive mission-critical applications are prioritized relative to latency-insensitive communications such as metering data. More recently, narrowband PTP/PTMP systems have added these capabilities. While some cellular data systems also support VLANs and QoS capabilities, they are generally less robust and less in the control of the utility than in private wireless network options. For example, the cellular operator may insist that policy changes be implemented during specified maintenance windows and be unable to honor service level agreements (SLAs) during force majeure events.

Mobility:
Cellular data services provide the best high-speed mobility capabilities. Broadband wireless mesh networks can also provide seamless, session-persistent roaming at vehicular speeds. The best mobile network connections can be achieved by using a mobile mesh router. PTP/PTMP technologies do not support mobility.

Manageability:
Broadband mesh networks are, largely out of necessity, usually supported by a network (as opposed to device) management system. PTP/PTMP technologies generally provide device or link-by-link management only. However, as PTP/PTMP technologies become more sophisticated, they are beginning to support some network management functionality as well. Ideally, one network management system would supervise all private wireless network options. While this ideal does not currently exist, the industry is trending in this direction. The manageability of cellular data services suffers not because of lack of tools – carriers have extremely sophisticated network management systems – but because the utilities have little access to those tools and, consequently, little visibility or control over the public carrier networks that provide service to them.

Conclusion
The modern utility needs a modern communication network to be intelligent and efficient. By deploying and operating a modern wireless network – a combination of broadband point-to-point, point-to-multipoint and mesh technologies, coupled with narrowband wireless technologies for specific applications, utilities can meet the communication requirements necessary to run valuable applications that improve the efficiency, reliability and security of electric power distribution.

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