Alcatel·Lucent

TECHNOLOGY WHITE PAPER

Smart Choices for the Smart Grid

Using wireless broadband for power grid network transformation

Evolving traditional electric grids into smart grids will improve delivery, enable automated demand response, reduce operating costs and cut carbon emissions. As is often the case with any emerging platform, for many utilities the technological pathway to realizing the smart grid vision is not perfectly clear. With extensive experience designing and deploying wireless broadband solutions, Alcatel-Lucent can provide critical insight into the strategic and tactical decisions facing transmission distribution and system operators (TDSOs) — accelerating the deployment of smart grids around the world.

Table of contents

Addressing the challenges of smart grid implementation

Technological advancements have radically altered the world's telecommunications networks over the past decade. Yet another important network in our day-to-day lives — the energy distribution grid — has been slower to evolve. That is about to change, however, with the proliferation of smart grid technology.

The smart grid is generally characterized as the merger of communications-intensive IT applications with the electric power systems managed by transmission and distribution system operators (TDSOs) — outfitting 20th century electric grids with 21st century telecommunications technology. The smart grid's purpose? To create near-real-time control mechanisms that improve the quality of electricity delivery, reduce carbon emissions, incorporate distributed energy resources, provide automated demand response and reduce the cost of electricity to consumers.

A mature smart grid will comprise a number of integrated yet distinct applications that require varying degrees of reliability, latency, availability, throughput, security and economic justification (not only for the TDSO itself, but also in the eyes of public service commissions and municipal councils). As such, TDSOs face many difficult choices with regard to smart grid implementation — in particular, which specific technologies should be used to create the reliable, two-way communications paths required for the operation of the smart grid infrastructure and for the data, video, voice and security needs of the associated applications.

There are few easy answers. Different technologies are better suited than others for specific smart grid applications, network geographies and customer demographics. The significant experience of Alcatel-Lucent in designing and deploying mission-critical wired and wireless broadband solutions provides unique insight into the challenges and choices faced by TDSOs. This paper explores some of the more critical choices — both strategic (how to meet shareholder, regulatory and economic objectives) and tactical (how the transformation translates into the procurement of specific products and services) — that TDSOs face in weighing the merits of implementing wireless broadband services and transforming the energy distribution infrastructure into a modern smart grid.

Network ownership vs. leasing of commercial services

TDSOs considering smart grid network improvements must first consider the advantages and disadvantages associated with either owning their own network or leasing a network from a commercial service provider. To maintain control, most TDSOs prefer exclusive ownership of the communications and IT infrastructure supporting their operational networks. As well, owning the network is often perceived as simpler: embedding commercial services — whether wireless or leased line — within an integrated communications network complicates the physical and logical connectivity of the architecture as well as functions associated with routing, reliability, security, regulatory compliance and supply chain management.

Owning a private communications network, however, may not be an option for all TDSOs for reasons of cost, lack of in-house network design and maintenance skills, or capacity to deploy applications expeditiously. Moreover, owning such a network can extend technology refresh cycles. Commercial service providers have extensive experience managing complex technology infusions according to strict audit and regulatory standards, which allows them to regularly update and integrate new technologies for consumer use. TDSOs can find this difficult to replicate. And while commercial service providers can share the costs of such upgrades among many customers, network-owning TDSOs must shoulder them alone.

Ultimately, the choice of whether to use commercially available services or to build and maintain an independent network will be based on each TDSO's network requirements and the associated costs and business risks.

Network requirements for smart grid applications

Network requirements associated with smart grid applications play a considerable role in determining how TDSOs implement the technology into their energy distribution infrastructures. The following table lists some of the most important smart grid applications, as well as other utility applications typically carried over the communications network, and their qualitative network requirements.

Table 1. Network requirements for smart grid applications

APPLICATION	DATA RATE/VOLUME (AT ENDPOINT)	LATENCY ALLOWANCE (ONE-WAY)	RELIABILITY	SECURITY
Smart metering	Low/Very low	High	Medium	High
Inter-site rapid response (for example, Teleprotection)	High/Low	Very low	Very high	Very high
SCADA	Medium/Low	Low	High	High
Operations data	Medium/Low	Low	High	High
Distribution automaton	Low/Low	Low	High	High
Distributed energy management and control (DER, storage, PEV)	Medium/Low	Low	High	High
Video surveillance	High/Medium	Medium	High	High
Mobile workforce (Push to Talk)	Low/Low	Low	High	High
Corporate data	Medium/Low	Medium	Medium	Medium
Corporate voice	Low/Very low	Low	High	Medium

Latency requirements for smart grid and other utility applications vary: less than 10 ms for teleprotection; about 20 ms for some synchrophasor applications; 100 to 200 ms for most smart grid supervisory control and data acquisition (SCADA) and voice-over Internet protocol (VoIP) applications; and up to several seconds for smart metering and other applications. Unlike most other enterprise data networks, support for geographically dispersed utility applications with latency requirements of less than 100 ms represents one of the most challenging aspects of wireless network design. Other than these very low latency applications, many current commercial wireless services can satisfy the requirements of smart grid applications when latency requirements are 150 ms or greater.

It is also important to consider instances when application requirements change due to the operational context. For example, active demand response and emergency load management require higher reliability and lower latency as an integrated system than as part of a stand-alone Automated Metering Infrastructure (AMI) application.

Alcatel-Lucent believes that application-specific, single-purpose networks (such as for SCADA) will be far too expensive and unmanageable in the smart grid scenario, as there will be many different applications penetrating the distribution grid. A better, less costly strategy would be an integrated communications network supporting all applications, with proper implementation of quality of service (QoS), reliability, security and unified network management tools to ensure delivery of critical smart grid application traffic.

An IP-based technology path

Although no single communications technology is best for all smart grid applications, Alcatel-Lucent believes the end-to-end network layer technology of choice will be IP. The IP suite of technologies offers the needed levels of reliability, redundancy and availability, and can leverage an extensive ecosystem of products and services designed for telecommunications.[1] Moreover, IP has been subjected to decades of significant vetting as a network routing protocol, resulting in a robust technology with a mature set of management and security applications to employ.

[1] It must be noted that IP networks do not necessarily imply use of the Internet.

IP-based networks must also continue to support legacy systems and applications by providing the necessary gateways and protocol conversions even as new, IP-based applications are deployed by TDSOs. (IP will be the technology of choice for most applications.) Legacy protocols can be carried through IP using a variety of methods such as tunneling via multiprotocol label switching (MPLS) — a proven technology deployed broadly in large enterprise and carrier networks and already being adopted by the utility industry.

Overview of utility network architectures

A typical utility network consists of the following:

- *A core high-speed network*, which is usually comprised of high-bandwidth optical and microwave links
- *A wide area network (WAN)*, which aggregates traffic from the many different kinds of data, voice and video applications running in the access layer
- *An access network*, which generally includes AMI mesh/PLC and neighborhood area networks (NAN) supporting distribution substations, mobility and feeder applications

Core high-speed network

A TDSO's data and control centers, utility offices, bulk generation sites, metro-area substations and market entities such as independent system operators may all be served directly by the core high-speed network. Overall, the core network should be designed for automatic fail-over and traffic rerouting, preferably at less than 50 ms, to ensure continuity of latency sensitive applications.

The core network is increasingly multi-service IP/MPLS running over carrier-grade optical and microwave transmission equipment that provides SONET and/or Ethernet transport. Fiber (as either privately owned or a mix of private fiber and commercial Ethernet services) is the preferred medium, as even higher aggregate bandwidth rates can be achieved by upgrading existing fiber with wave division multiplexing technologies. However, microwave can also be used in the core network if the economics of laying fiber are not feasible.

Wide area network

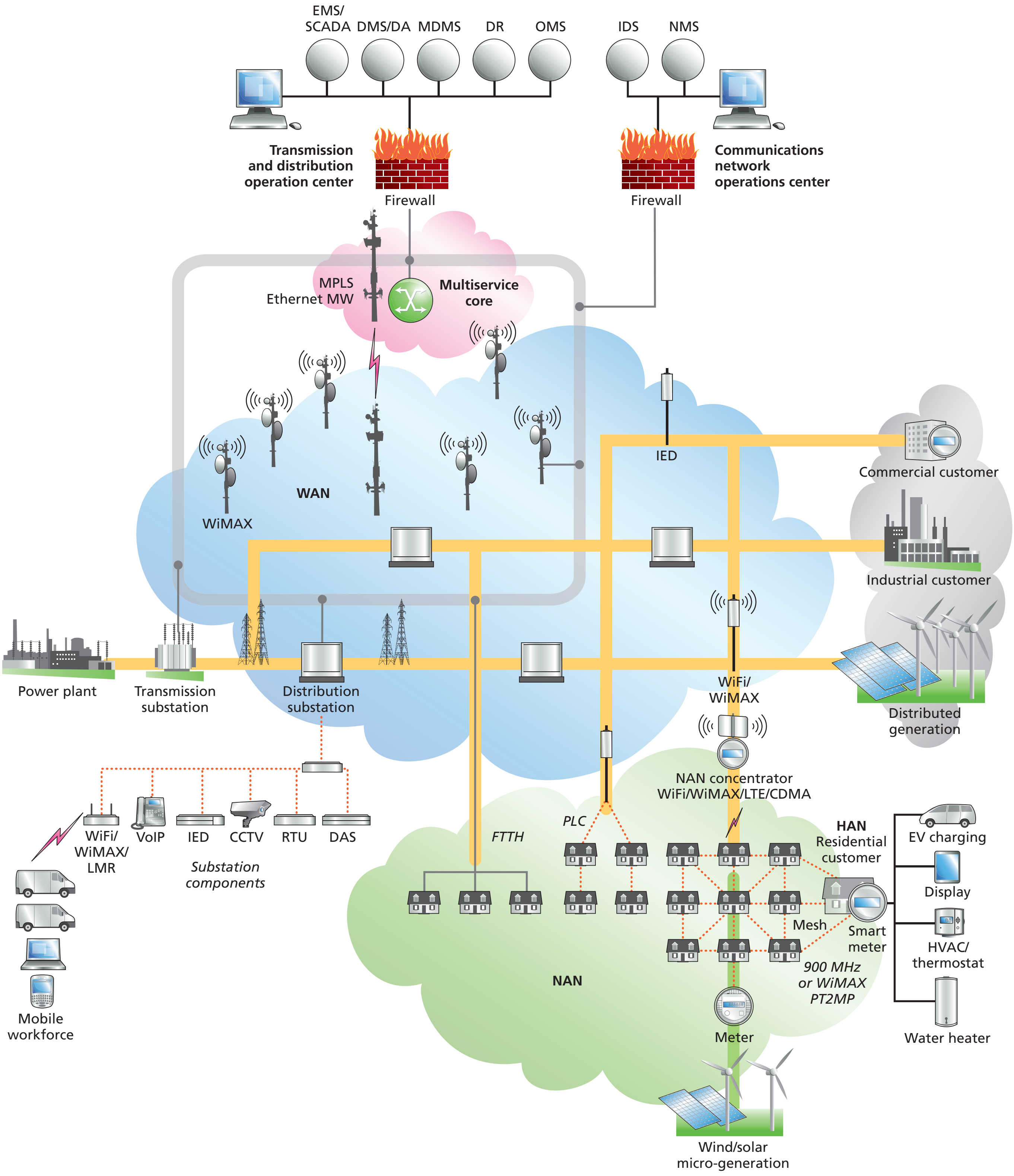
The multi-service capabilities of IP/MPLS may be extended into the TDSO's wide area network to facilitate the aggregation and management of the many different network protocols. For example, implementing MPLS for TDM, DNP3, 4-wire and other applications provides the advantages of streamlined QoS, security implementation, and traffic separation and prioritization due to MPLS virtual private networks (such as virtual LANs).

Locations such as transmission and distribution substations, or devices like AMI traffic concentrators that are collectively part of the distribution grid, require reliable communications paths back to the high-speed core network. TDSOs have many technology choices for WAN communications other than MPLS, including leased lines, point-to-point and/or point-to-multi-point private microwave, and VPNs running over the Internet. In addition, critical voice services may ride over private, licensed land-mobile radio systems, as may a portion of mobile data traffic. However, TDSOs will try to minimize the number of communications technologies used in the WAN in order to simplify the configuration and operation of these networks, as there may be hundreds, if not thousands, of virtual and real physical connections to manage.

Access network

The access portion of the smart grid network will require the highest level of customization so that TDSOs can cost-effectively meet their unique requirements (for example, differences in geography and demographics). At the access level, both wireless and wireline broadband technologies can be configured to meet most application requirements. (Examples of wireless technologies include WiMAX, LTE, CDMA 2000 EvDO and HSPA. Wireline examples include DSL, DOCSIS, GPON and PLC, including BPL.) In the end, the choice of access technology will mostly depend on the cost-effectiveness and ability of the technology to provide suitable coverage.

Figure 1. The intersection of communications networks and electricity grids



Smart metering solutions

One of the key elements of the smart grid is its capacity to support advanced metering solutions. Where a TDSO is publicly owned and can offer its own revenue-generating services (such as Internet access and IPTV services), fiber can be provided directly to customers at the access level, using technologies such as GPON that enable the installation of Ethernet-capable smart meters. TDSOs that are limited or prohibited from offering additional services may choose to use a customer's existing broadband connection. However, TDSOs wishing to deploy a smart metering solution that relies on third-party broadband access face a number of challenges, including the fact that it is far from certain that every customer will subscribe to, or stay subscribed to, that particular third-party broadband service. As a result, it may be better to invest in wireless access networks (whether narrowband like 900 MHz or broadband like WiMAX) to guarantee access to smart meters.

Other options for carrying low bit rate, high-density smart metering traffic include PLC (wireline) or RF mesh over an unlicensed spectrum at 900 MHz ISM[2] and 2.4 GHz (WiFi). Technologies such as 900 MHz ISM, however, are cost-effective only in high-density urban and suburban environments where signal coverage can take advantage of shorter hops between meters and/or numerous towers. As real-time demand response becomes a reality, these low bit rate, unlicensed network systems will require migration to other technologies that support broadband communications (such as WiMAX and LTE). Also, as latency-sensitive, real-time telemetry control applications are deployed across the distribution grid (such as syncrophasor control and other real-time sensors), spectrum interference in unlicensed bands or across commercial carrier networks will inhibit the deployment and usefulness of unlicensed radio systems.

In addition to smart meters, buildings on the electric grid may also feature local electricity generation facilities (such as photovoltaic cells or uninterruptible power supplies) and storage facilities (for plug-in hybrid electric vehicles, for example). These facilities may be connected, along with the meter, over a local area network (LAN) or a home area network (HAN) to manage the building's energy usage through protocols such as Zigbee and HomePlug. As buildings also gain smarter management capabilities, bandwidth needs will increase — putting pressure on 900 MHz RF and PLC technologies and accelerating the need for broadband connections directly into these high-traffic sites.

Using wireless broadband services in the access layer

Many smart grid applications being deployed today can adequately operate on existing commercial wireless networks. However, out of concerns that the quality and reliability of commercial services create unjustifiable operational risk, most utilities prefer exclusive access arrangements. As an example, priority network access and priority flow management are key requirements for critical smart grid applications. To encourage widespread adoption of commercial services by TDSOs, commercial wireless providers will need to adopt the technologies necessary to permit critical utility traffic to preempt non-critical commercial traffic.

United States industry regulations dictate that acceptable communication network performance, security and reliability requirements must be met during wide-scale power outages and the resulting 'black start' processes for grid restoration. In the event of an extended power outage (often 72 hours or more), wireless networks will need to function independently of commercial electric service to sustain critical voice and data communications. This capability is not prevalent today in commercial wireless networks and would require significant investment in emergency power infrastructure to remediate.

That being said, how should TDSOs expect wireless broadband services in the access layer to be used in order to meet the requirements and challenges associated with network reliability, availability and security?

---

[2] Mesh connections between meters and their concentrator over unlicensed 900 MHz ISM (industrial, scientific and medicine) band in a neighborhood

Reliability

Today, applications such as meter reading can reliably run over commercial wireless networks due to their relatively flexible requirements — dropped ‘calls,’ or even loss of the commercial network for a period of time, are not fatal to these devices or applications. Once traffic from many such devices is aggregated and presented to the network (along with demand response, substation monitoring and control, and other core smart grid applications), the availability requirements laid on commercial wireless networks are significantly increased.

While some commercial carriers are beginning to offer service level agreements (SLAs) to utilities and other customers, commercial wireless networks today were built and continue to operate using a best-effort, one-size-fits-all standard for consumer applications. Satisfying the needs of TDSOs will pressure commercial wireless carriers to offer SLAs — different from those provided to their consumer customers — that guarantee an appropriate level of network performance even under adverse conditions, especially environmental factors (for example, local congestion due to weather or newsworthy events) or security incidents (such as government mandates limiting commercial traffic in the event of a terrorist attack).

Availability

Electric utilities offer nearly universal service, especially in many geographies where no suitable communications networks currently exist. As such, TDSOs may be forced to consider the use of alternative low-bandwidth (but sometimes high-cost) technologies, including PLC, satellite communications and unlicensed RF mesh, to provide themselves with service. However, as new smart grid applications are deployed and radio-enabled grid components become more prevalent, wireless broadband and wireline technologies will be able to provide the most suitable access options.

In addition, it is unlikely that the needs of TDSOs alone will justify the significant investment required of commercial service providers to provide ubiquitous broadband coverage for the utility industry. Instead, co-investment partnerships may present the best way for both commercial providers and TDSOs to meet their goals and requirements.

Security

While commercial wireless services are able to meet the security requirements for smart grid applications, it is unclear whether NERC CIP accountability standards will evolve to a level that will require the TDSO to be accountable for end-to-end security of data, regardless of the network owner. The primary issue today regarding use of commercial carrier networks is ultimately one of availability, not security.

Spectrum requirements

Most TDSOs have access to some licensed spectrum, primarily in narrow-band frequencies intended for land-mobile radio. However, these licensed frequency assignments are not adequate for mobile workforce support, video surveillance or other future real-time grid control applications. In fact, there are very few, if any, TDSOs in the United States that currently have sufficient spectrum to support multiple smart grid applications. A recent study conducted by Alcatel-Lucent for a large TDSO with 20 x 12.5 kHz channels of licensed 900 MHz concluded that 3 Mb/s of constant bit rate wireless throughput per sector (5 Mb/s for peak throughput) will be required for smart grid, mobile workforce and substation security applications — and recent work done by the Utilities Telecom Council[3] quantified the need for up to 8 Mb/s per sector to support peak traffic demand. In the case of the TDSO profiled in the Alcatel-Lucent study, 20 channels of narrowband licensed LMR spectrum will clearly not be sufficient for this level of application data throughput.

---

[3] “Smart Grid Spectrum Requirements.” Klaus Bender, *UTC Journal* 3Q 2009, p. 21-23.

Smart metering applications

In addition to the grid control applications described above, some TDSOs are using 220 MHz and 900 MHz licensed spectrum for smart metering applications. Other manufacturers are building smart meters with 3G radios so that the meter can communicate directly with the commercial wireless provider's network. Although smart metering is the primary application, this solution can also carry smart grid traffic from other distribution grid elements, such as feeder-mounted voltage sensors.

Currently, unlicensed spectrum is the dominant solution for private network communications of wireless meter applications in the United States. Many current smart metering solutions use 900 MHz unlicensed spectrum with channels in the 902 to 928 MHz band with several hundred kilohertz per channel. Zigbee (2.4 GHz) is generally used in home area networks in the United States but has been used for smart metering in other countries. WiFi mesh is another possibility, along with WiMAX in the lightly licensed 3.65 GHz band.

Overcoming frequency interference

While most vendors of unlicensed spectrum equipment today provide mechanisms to circumvent frequency interference (such as channel hopping or increasing power), and as more businesses use these frequencies for smart meters and other smart grid applications, the problem of interference becomes compounded. This will result in a growing problem with latency — posing a significant threat to grid stability and reliability.

Interference problems in unlicensed bands can be offset by thorough RF studies and planning. However, as the unlicensed RF environment is subject to change as other entities add or remove equipment operating in the same band, network performance can be affected — regardless of the level of planning and optimization — ultimately requiring the TDSO to constantly monitor RF performance and retune systems as conditions change.

The traffic profile challenge

For many smart grid applications, the downlink traffic is less than the uplink traffic — the exact opposite of the typical traffic profile in the consumer world. In this sense, commercial networks using time division duplexing (TDD) are not ideal from a TDSO's perspective. For the TDSO, TDD ratios should be even or biased upstream to reflect the true nature of smart grid application traffic.

Accelerating the deployment of smart grid networks

It is evident that TDSOs face a number of critical choices with regard to smart grid deployment. Overall, Alcatel-Lucent believes that access to contiguous spectrum allocation providing at least 3 to 5 Mb/s (or greater) of wireless throughput per sector would rapidly speed up the adoption of smart grid networks, while overcoming many of the challenges inherent in unlicensed bands and commercial wireless services. This spectrum could be made available through public/private partnerships or by the FCC as a dedicated utility spectrum allocation.

In addition, Alcatel-Lucent recommends that lower spectrum bands should be used for smart grid technology, as they satisfy the requirements of TDSOs operating in both dense urban environments (which require building penetration) as well as rural environments (which need cost-effective coverage). The benefits of this approach are many, principally in the assurance of access to sufficient bandwidth — without the risk of performance degradation that would be unacceptable in the mission critical nature of smart grid communications.

About the authors

Dr. Jayant Deshpande

Jayant Deshpande is a member of the technical team at Alcatel-Lucent Bell Labs, where he has worked for most of the past 26 years. His current focus is smart grid architecture, design and performance; he previously worked on data and voice networking services development, QoS, and network architecture, design, planning and performance analysis. Jayant has also worked at AT&T Labs and held a brief tenure at Cisco Systems. Before joining Bell Labs in 1983, Jayant was a member of the Computer Science and Electrical Engineering faculty at the Indian Institute of Technology in New Delhi, and was a visiting faculty member at Pennsylvania State University.

Arthur Locke

Arthur Locke is Regional Vice President for North American Utility Markets in Alcatel-Lucent Vertical Market Services Division. In his role, he develops services-led turnkey solutions for electric utilities. Arthur has 25 years of experience in the communications sector, the past 10 of which have been spent developing and delivering managed network services for communications-intensive enterprises.

Mark Madden

Mark Madden is Regional Vice President for North American Energy Markets in Alcatel-Lucent Enterprise and Vertical Markets, Solutions and Marketing Division. He sets the company's North American market strategy for the utility, oil and gas sectors, and maintains strategic partnerships with companies in those fields. Mark joined Alcatel-Lucent in 1996 and has worked with leading IT and telecommunications companies for more than 25 years. He has actively consulted electric utility customers on mission-critical telecommunications technologies for the past four years.

Acronyms

AMI	Automated Metering Infrastructure
BPL	Broadband over Power Line
CDMA 2000 EvDO	Code Division Multiple Access 2000 Evolution Data Optimized
DNP3	Distributed Network Protocol 3
DOCSIS	Data Over Cable Service Interface Specifications
DSL	Digital Subscriber Line
GPON	Gigabit Passive Optical Network
HSPA	High-Speed Packet Access
IPTV	Internet Protocol TV
LTE	Long-Term Evolution
MPLS	Multiprotocol Label Switching
PLC	Power Line Carrier
QoS	Quality of Service
SCADA	Supervisory control and data acquisition
TDSO	Transmission Distribution and System Operator
WAN	wide area network
WiMAX	Worldwide Interoperability for Microwave Access

EPG3310091113 (02)

Alcatel·Lucent