

An analysis of communications and networking technologies for the smart grid

Joaquín García Hernández

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Resumen

El concepto de red eléctrica inteligente (REI) ha sido conceptualizado como la integración de la red eléctrica (generación, transmisión y distribución) y la red de comunicaciones, esta última es considerada como la tecnología habilitadora fundamental para el desarrollo e integración de la futura REI.

Las tecnologías modernas de comunicaciones, arquitecturas de protocolos y estándares pueden ayudar a construir una infraestructura común de comunicaciones para el transporte de datos entre las instalaciones del cliente, subestaciones eléctricas, sistemas de distribución de energía y centros de control de las empresas eléctricas.

Para hacer esto posible, la red eléctrica inteligente requiere una infraestructura de comunicaciones bidireccional entre las diferentes áreas, desde los sitios de generación hasta los sitios de consumo (usuarios).

Este trabajo presenta el análisis de las tecnologías de redes y comunicaciones más relevantes aplicables a la REI.



Summary

The Smart Grid concept has been foreseen as the integration of the electrical generation, transmission and distribution network and the data communications network. Although, traditional communications interfaces, protocols and standards has been used in the electrical grid in an isolated manner, modern communications network is considered as the fundamental enabling technology within the future Smart Grid. Modern communications technologies, protocol architectures and standards can help to build a common communications network infrastructure for data transport between customer premises, power substations, power distribution systems, utility control centres and utility data centres.

The Smart Grid will support traditional applications such as SCADA, distribution automation (DA), energy management systems (EMS), demand site management (DSM) and automatic meter reading (AMR), etc., as well as new applications like advanced metering infrastructure (AMI), substation automation (SA), microgrids, distributed generation, grid monitoring and control, data storage and analysis, among others. To make this possible, the Smart Grid requires a two-way wide area communications network between different dispersed areas, from generation, to distribution to consumer premises. In fact, it will consist of many different types of communications networks such as wide area networks, local area network, home area networks, etc. This requires a new architectural approach to implement a common communications infrastructure that provides the reliability, scalability, security and interoperability to support multiple applications. In addition, open standards addressing interoperability, are key for the development and deployment of the Smart Grid as a true integrated network. A communications backbone is necessary to provide interoperability.

To achieve the level of networking, interoperability and security that meets the technical requirements of the Smart Grid, its data communications network architecture must be built using standard, open protocols. Internet Protocol (IP) and broadband networks could form the backbone of this infrastructure, as they are flexible and resilient enough to meet the demand of the grid. The benefits of using IP-based networks include the matu-

urity of a large number of IP standards, the availability of tools and applications that can be applied to multiple smart grid areas, and the widespread use of IP technologies in both private and public networks. In addition, IP technologies are the link between applications and the underlying communication physical medium. They allow applications to be developed independent of both the communications infrastructure and the various communications technologies to be used, either wired or wireless. From a general point of view, the main role of communication and networking technologies is to make the current electrical grid, smart. The Smart Grid will use many types of communications technologies such as public and private, wired and wireless, licensed and unlicensed, and standard and proprietary technologies. There exist a great number of communications and networking technologies that can be used to support smart grid applications, including fiber optics systems, cellular, satellite, trunked radio, WiMAX, power line carrier, broadband over power lines (BPL), and IP, as well as in-home technologies such as Ethernet, Wi-Fi, HomePlug, ZigBee, RF Mesh, etc. In this work, an analysis of the most relevant communications and networking technologies applicable to the Smart Grid is presented.

Introduction

Communications systems play an important role in the electrical environment, such as the transmission of telecontrol data from the power system to a remote control centre, voice and data communication between substations and the power generation plant, monitoring signals, alarms, remote surveillance, to mention a few. The communication requirements of electric utilities and other entities involved in the generation, transmission, and distribution of electricity are very important to dimension the required communications infrastructure and to support the applications of electric utilities and their consumers.

One of the key technology areas of the Smart Grid is two-way communications, which allows for dynamic monitoring of electricity use as well as for the automated electricity use scheduling. The Smart Grid is based on the concept that all components of the power grid are capable of communicating and supporting smart grid applications such as real-time energy consumption status, and remote controlling of appliances. To achieve this, the different subsystems that constitute the power grid have to be able to communicate with each other through a communications network.

The adoption and use of standards-based networking technology brings a wide range of opportunities to the smart grid development. They enable electric utilities to integrate products from different vendors ensuring interoperability across intelligent electronic devices, networking technologies, and backhaul communication links endpoints. In addition, international, regional and national standards will enable the integration of equipment from multiple smart grid technology vendors.

The electric power industry is working on establishing open standards and has been driving the completion of standards in the United States and Europe. The National Institute of Standards and Technology (NIST) has released its smart grid reference architecture along with recommendations for the adoption of 75 existing and developing standards from several organisations.

Several European groups are also working on smart grid standards, including the European Industrial Initiative on electricity grids under the European Technology Platform (ETP) Smart Grid, and the European Utilities Telecom Council (EUTC). The architectures and underlying standards being proposed for the Smart Grid are IP-based. The use of the IP standard supports addressing, security, routing and other attributes that can lead to build an IP-based smart utility network infrastructure. Proprietary technologies, in contrast, depend on the investment by a single vendor and can never provide interoperability in a multivendor environment. According to the NIST (NIST, 2012), the Smart Grid is a network of many systems and subsystems, as well as a network of networks. Within each network, a hierarchical structure consisting of networking technologies, such as home area networks, personal area networks, local area networks, wired/wireless access networks, and wide area networks may be implemented.

In addition, many communications technologies can be used to support smart grid applications, including traditional twisted-copper phone lines, cable lines, fiber optic cable, cellular, satellite, microwave, WiMAX, power line carrier, broadband over power line, as well as short-range in-home technologies such as Wi-Fi and ZigBee. The smart grid applications that might be built on such communications technologies include home area networks (HAN), networks for wide area situational awareness (WASA), substation supervisory control and data acquisition (SCADA) systems, distributed generation monitoring and control, demand response and pricing systems, and charging systems for plug-in electric vehicles, among many others. In the following sections, the most relevant communications and networking technologies applicable to the Smart Grid are analysed.

Wide area networking technologies

A Wide Area Network (WAN) is the core of a utility network. It shall support mission-critical operations, and cyber and physical security measures to protect



the utility's operations. It also often serves as the backhaul infrastructure for substations automation and other advanced network applications. As the network core, it shall serve as the support for mobile data and voice. The WAN needs to be built up of high bandwidth fiber optics-based telecommunication technologies such as SONET/SDH, WDM/DWDM, satellite or microwave technologies, among many others. Next, the main wide area networking technologies that can be used in a smart grid environment are analysed.

Sonet/SDH

SONET (Synchronous Optical Network) and SDH (Synchronous Optical Network) are core transport digital networks that enable the integration of high-speed data services, which facilitate the deployment of large networks with comprehensive network management facilities. Both technologies define a common number of aggregate transmission rates, particularly at the higher rates; however they have significant differences at the lower multiplexing levels. SDH has been widely used in carrier, as well as in electric utility networks to build their backbone transmission networks. It offers carrier-class reliability with short restoration times less than 50 ms, in case of path failures. Modern SDH platforms are pointed to be a universal transport networks for all kind of TDM-based services like voice, data or electric utility specific applications. In addition, newly evolved standards let Ethernet/IP benefit from transport mechanisms SDH can offer, especially in WAN applications. Since its introduction, SDH has been adopted worldwide by many electric utilities for fibre and microwave systems, offering the requested quality of service for demanding real-time applications and mission critical services.

WDM/DWDM

WDM (Wavelength Division Multiplexing) is a technology that permits to exploit the huge capacity of optical fibers by multiplexing a number of high-speed optical data streams onto the same fiber using different optical wavelengths (CIGRE, 2006). In electric utility transmission networks, WDM technology can be used for upgrading the existing SDH infrastructure. Dense WDM (DWDM) technology, allows data transmission at more than one wavelength on each fiber pair of an

optical fiber system. The 16 Synchronous Transport Module level or STM-16 (16 x 155.520 Mbps = 2.5 Gbps) is the transmission speed in the SDH hierarchy which is being most widely used today, can transmit STM-16 signals at four (4 x 2.5 Gbps) or eight different wavelengths (4 or 8 x 2.5 Gbps) to give a total capacity of 10 or 20 Gbps per fiber pair. DWDM-based networks can transmit data in IP, ATM, SONET/SDH, and Ethernet formats. Therefore, DWDM-based networks can carry different types of traffic at different speeds over an optical channel.

Satellite/VSAT

Satellite communication is a technology that has been used in electric utility networks to provide connectivity for SCADA and other applications such as voice, video or data to remote substation sites that cannot be reached by other communications technologies. Currently, satellite communications has evolved in improving performance reliability and reducing costs. Satellite networks provide two-way communications, they are built on IP, and support broadband data rates. In addition, advances in satellite communications and in particular Very Small Aperture Terminal (VSAT) technologies have expanded the range of potential applications within the Smart Grid. These systems use small antennas, IP-compatible terminal equipment, and better performance than traditional satellite systems. VSAT satellite networks provide flexible data rate performance, ranging from 16 kbps suitable for basic SCADA connectivity to speeds of 1 Mbps and above to support voice, video and data applications. VSAT satellite systems can provide new solutions for remote monitoring and control of transmission and distribution substations providing extensive coverage. They also provide location and time synchronization (important for successful use of PMUs) based on a global positioning system (GPS).

Microwave

Microwave is a technology that is used in geographically difficult areas as an alternative transport technology for voice, data, and video applications. It can be used to create complete networks or just to carry out the last mile connections of larger wired or fiber networks. When there is no infrastructure like optical fibers available, a solution is to install point-to-

point microwave links. Microwave technology is a flexible and cost-effective solution for transmission of voice, data, and video services in all parts of a fixed or wireless mobile network, including applications for backhaul or direct access services. Enhancements in wireless technology have also allowed higher order modulation schemes that offer better spectral efficiencies, permitting less bandwidth for the same capacity or higher capacities with the same bandwidth compared to older models. This technology is mainly focused on PDH, meaning bandwidths of 2, 4, 8 or 34 Mbit/s (CIGRE,2006). However, newer microwave systems support SDH standards and will better integrate into modern broadband digital networks for the Smart Grid.

Digital trunked radio

Digital trunked radio is a PMR (Private Mobile Radio) technology that uses unguided electromagnetic waves to propagate information, thus wireless transport of data. A trunked radio system is a complex type of computer-controlled radio system. Trunked (resource sharing) systems use a few channels (the actual frequencies) and can have virtually unlimited talkgroups. The control channel computer sends packets of data to enable one talkgroup to talk together, regardless of frequency. The primary purpose of this type of system is efficiency; many people can carry many conversations over only a few distinct frequencies (Public, 1999). Trunking is used by many government entities to provide two-way communication for fire departments, police and other municipal services, who all share spectrum allocated to a city, county, or other entity. Trunking technology can be used in a smart grid environment to provide electric utilities networks with fleet management and disaster management.

IP Radio

IP Radio, known as Radio over IP (RoIP) is the new next generation technology targeted for data transmission over microwave radio. It is like trunked radio but with IP addressing. As a result the primary traffic interface for IP



radio is Fast Ethernet (Fusion, 2012). IP radio networks can basically use any type of IP infrastructure, whether it is the public Internet, a private network (Intranet), or a local area network using Ethernet (Bouwers, 2002). IP Radio provides a flexible way to extend the reach and improve the efficiency of two-way radio technology, avoiding new investments in IP infrastructure. In addition, IP radio allows two-way radios to communicate with desk and mobile phones, providing interoperability. Electric utilities can improve responsiveness during disaster situations or system failures, by using IP radio technology.

Local area networking technologies

The majority of Local Area Networks (LAN) commercially available products for enterprises, offices and home applications, including industrial applications are based on Ethernet technology. Currently, a vast number of LANs are using in the electric utility enterprise. Ethernet offers many versions such Fast Ethernet (IEEE 802.3u), Gigabit Ethernet, 10 Gigabit Ethernet, including wireless Ethernet.

Ethernet

Ethernet is a LAN technology that offers numerous advantages that make it the communication medium of choice for substation automation systems, including superior versatility, compatibility and speed. As an increased number of intelligent electronic devices (IEDs) are installed in electrical substations, there is a trend to create LANs within the substation. This is the case of IEC 61850 communications standard for the design of substation automation systems, which has adopted Ethernet as the communication network standard inside substations (IEC, 2005). In addition, the NIST (NIST, 2010) has recognized IEC 61850 standard for substation automation and protection applications in a smart grid environment.



GbE/10GbE

Gigabit Ethernet (GbE) is an extension of the IEEE 802.3 Ethernet standard and builds on the Ethernet and fiber channel technology, but increases speed 100 fold over Fast Ethernet to 10 Gbps. GbE (IEEE 802.3z) was standardized in June 1998 whereas 10 GbE was released in 2003 as the IEEE 802.3ae standard. They can be used in high-speed local area network backbones and server connectivity, respectively as they claim that the total cost of ownership is lower since applications need not change, existing management systems should function, and re-training of technical support people will be unnecessary. With the increasing use of Ethernet in the LAN, there is a growing need to interconnect Ethernet LANs to SDH/SONET wide area networks.

Wireless Ethernet

Wireless LAN technologies are also known as wireless Ethernet. The wireless LAN based on the IEEE 802.11 standard provides robust, high speed point-to-point and point-to-multipoint communication. This standard covers three non-interoperable technologies: Frequency Hopping Spread Spectrum (FHSS), Direct Sequence Spread Spectrum (DSSS), and Infrared (IR) at 1 & 2 Mbps data rates. IEEE 802.11b, also known as Wi-Fi, offers a maximum data rate of 11Mbps. It operates on 2.4GHz frequency band with DSSS modulation technique. Further, currently available technologies based on IEEE 802.11a and IEEE 802.11g can provide data rates up to 54 Mbps. IEEE 802.11a operates on the 5.8 GHz frequency band with Orthogonal Frequency Division Multiplexing (OFDM) modulation; whereas, 802.11g, also known as enhanced Wi-Fi, operates on 2.4 GHz frequency bands with DSSS modulation technique. IEEE 802.11n based on Multiple Input Multiple Output (MIMO) technology is intended to increase data rates up to 600 Mbps. IEEE 802.11i (known as WPA-2) enhances the cyber security in wireless LANs using Advanced Encryption Standard (AES). Deployment of wireless LANs offers various benefits over wired LAN, as it is easy to install, provides mobility of devices, and is less expensive. Wireless LANs can be considered for various smart grid applications, such as distribution substation automation and protection (Rigged, 2012).



Access technologies

The main access network's objective is to connect remote devices. The last mile access networks for a utility enterprise extend from the WAN in order to interconnect utility automation field devices such as reclosers, line switches, capacitor banks, and voltage regulators to the WAN by making use of the utility infrastructure between the electrical substation and the end user, known as the distribution system (Magel, 2009). There are a number of access technologies alternatives for communicating with field devices on the distribution system including wired or wireless solutions. Access networks must reach to grid devices located many kilometres away from the substation. Next, the main access technologies that can be applied to the Smart Grid are analysed.

PSTN

PSTN (public switched telephone network) refers to the international public circuit-switched telephone network based on copper wires carrying analogue voice. It consists of telephone lines, optical fibre

cables, microwave transmission links, cellular networks, communications satellites, and undersea telephone cables all inter-connected by switching centres which allows any telephone in the world to communicate with any other. The PSTN is now digital in its core and includes mobile as well as fixed telephones. Point-to-point circuits are cost effective for high-speed communication between two devices. Digital circuits can carry data at 2.4, 4.8, 9.6, 19.2, 56, and 64Kbps. Digital circuits are not technically voice-grade, but they can be used to carry either voice or data. Low speed leased lines have been used extensively by utilities to provide quick connections to various facilities and devices that cannot be reached in a structured network.

xDSL

DSL (Digital subscriber line) technology is a modem technology using existing twisted-pair telephone lines to carry high-bandwidth applications such as multimedia and video. The term xDSL covers a number of DSL technologies, such as ADSL, SDSL, SHDSL, G.SHDSL, ISDL and VDSL. ADSL (Asymmetric Digital Subscriber Line) has been designed to connect existing residential telephone customers who use the twisted-pair wired telephone infrastructure to the Internet with higher than dial-up data connection speeds. ADSL offers data transfer rates of up to 2 Mbps for download and up to 256 kbps for upload. SDSL (Symmetrical Digital Subscriber Line) even supports a symmetrical 2 Mbps transfer rate. Latest development in DSL modem technology is the SHDSL technique which supports even higher speeds up to 4.6 Mbps over longer distances. G.SHDSL is an international standard for symmetric DSL developed by the ITU which provides for sending and receiving high-speed symmetrical data streams over a single pair of copper wires at rates between 192 kbps and 2.31 Mbps. VDSL (Very high data rate digital subscriber line), transmits high-speed data over short reaches of twisted-pair copper telephone lines, with a range of speeds depending on actual line length. The maximum downstream rate is between 51 and 55 Mbps over lines up to 300 m. Downstream speeds as low as 13 Mbps over lengths beyond 1,500 m. xDSL services are dedicated point-to-point network access over twisted-pair copper wire on the local loop (last mile) between a electric utility and the customer site.

Cable modem

Cable modem, also known as Data Over Cable Service Interface Specification (DOCSIS) is a technology that defines standard interface requirements for cable modems providing high-speed data distribution over cable television networks. A cable modem is a type of network bridge and modem that provides bi-directional data communication via radio frequency channels on a HFC (Hybrid fibre-coaxial) and RFOG (Radio Frequency over Glass) infrastructure. Cable modems are primarily used to deliver broadband Internet access in the form of cable Internet, taking advantage of the high bandwidth of a HFC and RFOG network.

FTTH

FTTH (Fiber to the Home) is a technology that provides a broadband optical fiber connection to consumer sites. FTTH has been the preferred solution of the telecommunications industry for decades now, promising nearly unlimited

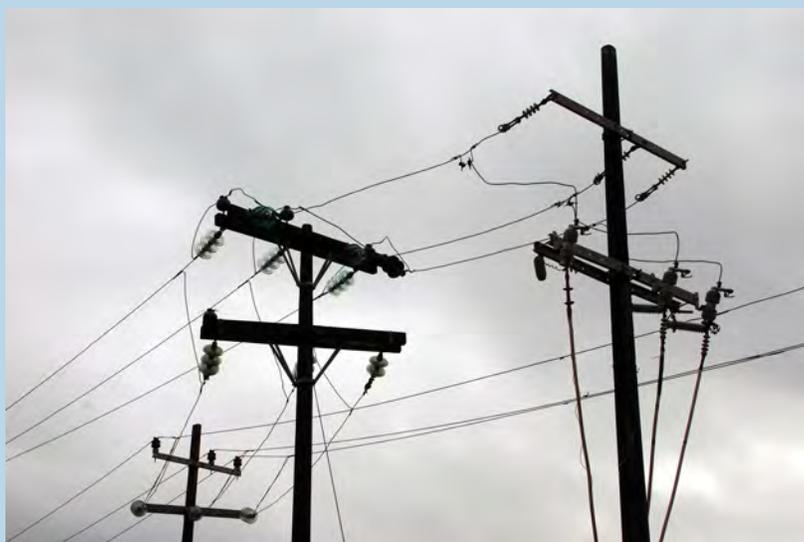
bandwidth to the home user. The key enabler of FTTH is the Passive Optical Network (PON). PON technology permits a single optical fiber to be split up to 128 times without active electronic repeaters. This creates a point-to-multi-point network that does not require any electronics between the consumer premises and the central office.

Paging networks

Paging networks are radio systems for delivering short messages from the telephone system or Internet to/from small, remote, mobile terminals. Paging systems use a variety of technologies, including microwave and satellite. Like cellular systems, virtually all of the paging networks use more than one transmitter to send a message over the entire paging service area to all base stations at a time. Paging systems typically provide one or two-way communications over a variety of open standard gateways that have the ability to send and receive email, numeric pages, and SMS messages.

Access BPL

Access BPL (Broadband over Power Lines) is a technology that carries broadband Internet traffic over medium voltage power lines. Access BPL systems carry high-speed data and voice signals over the medium voltage power lines from a point where there is a connection to a telecommunications network (García, 2008). This point of connection may be at a power substation or at an intermediate point between substations, depending on the network topology. Access BPL systems can be used to provide high-speed Internet access and other broadband services to homes as well as providing electric utility companies with a means to more effectively manage their electric power distribution operations. Given that Access BPL can be made available in conjunction with the delivery of electric power, it may provide an effective means for last mile delivery of broadband services and may offer a competitive alternative to DSL, cable modem services and other high-speed Internet technologies.



Cellular (GSM/CDMA)

GSM (Global System for Mobile Communications), is the world's most popular technology for mobile telephone systems. GSM is considered a second generation (2G) mobile phone system. GSM technology offers low-cost implementation of the short message service (SMS), which is supported on other mobile phone standards as well. Using the SMS function of a digital cellular network can be used to provide low-cost substation automation to control and monitor, substation performance when small amounts of control information or monitoring data is needed. Newer versions of the standard are GPRS (General Packet Radio Service) and EDGE (Enhanced Data Rates for GSM Evolution), for higher speed data transmission. CDMA (Code Division Multiple Access) is a cellular technology originally known as IS-95, where data and voice are separated from signals using codes and then transmitted using a wide frequency range. Because of this, there are more space left for data transfer for broadband access and the use of big multimedia messages. For the 3G generation network, CDMA uses 1x EV-DO and EV-DV technologies.

RF Mesh

RF (Radio Frequency) Mesh is a technology that allows meters and other sensing devices to access the network by securely routing data via nearby meters and relay devices. RF-based mesh networks have emerged as the leading NAN (Neighborhood Area Network) technology for smart metering applications (Sonoma, 2009). A mesh network forms a network topology by using mesh or star configurations. Any node not in direct communication range of its target destination will have its data relayed by another node in the mesh (Gohn, 2010). The electric system shall support two-way communication between the meter and the electric utility. New technologies based on RF mesh networking promise an ideal solution with high functionality and low cost. RF mesh networking of multiple sensors in a facility may enable industrial and commercial customers to reduce energy costs through profiling energy usage and developing plans that help to avoid demand charges, reduce energy consumption, and improve business processes such as instantaneous and efficient control of HVAC and lighting systems.

WiMax

WiMax (Worldwide Interoperability for Microwave Access) is a wireless technology that provides high-throughput broadband connections over long distances. It can be used as point-to-point or point-multipoint for providing mainly Ethernet/IP-based data-services as a shared medium to locations where neither copper nor fibre is available or mobility is required. WiMax can provide long distance communications beyond 16 km and in some instances beyond 48 km at data transfer rates of 75 Mbps. WiMax using the IEEE 802.16 standard allows for seamless communication with multiple vendors. Also, WiMax can communicate out of sight via IEEE 802.16e and can communicate with moving trucks or cars. It can serve as the backbone of a transmission and distribution communication system supporting Wi-Fi applications for substation or distribution automation, as well as provide a backhaul infrastructure for AMI systems.

Home area networking technologies

Home area networking technologies are residential local area networks used for monitoring, control and management of devices within the smart home. These technologies are mostly used to interconnect homes, and to connect homes to grid operators and utilities, enabling the information exchange among them. A Home Area Network (HAN) supports those capabilities by using power-line networking and RF standards such as ZigBee, Wi-Fi, and 6LoWPAN, among others. Also, the NIST is promoting interoperability between the different standards. One is the OSHAN initiative (OSHAN, 2012). Next, the main home area network technologies that can be applied to the Smart Grid are analysed.

ZigBee

ZigBee is the only standards-based wireless technology designed to address the unique needs of low-cost, low-power wireless sensor and control networks. ZigBee is a specification for a suite of high-level communication protocols using small, low-power digital radios based on the IEEE 802.15.4 standard for wireless personal area

networks (WPANs), such as wireless headphones connecting with cell phones (ZigBee, 2012). The ZigBee protocol enables communication using multiple network topologies, including star, tree and mesh. The technology defined by the ZigBee specification is intended to be simpler and less expensive than other WPANs, such as Bluetooth. ZigBee is targeted to RF applications that require a low data rate, long battery life, and secure networking. The primary attractiveness of ZigBee is its open standard platform that promises interoperability among multiple products and systems. ZigBee now has a Smart Energy Application Profile that is specifically designed for utility applications within the HAN such as Demand Response, Dynamic Pricing Response, Plug-in Hybrid Electric Vehicle (PHEV) smart charging, etc. The ZigBee Alliance has recently announced a cooperative agreement with HomePlug, which will allow ZigBee-enabled systems to operate seamlessly in a power line carrier or wireless mode. The ZigBee Smart Energy 2.0 has been selected by the U.S. Department of Energy and the NIST as an interoperable standard for HAN devices.

Wi-Fi

Wi-Fi (Wireless Fidelity) is a technology intended to be implemented more in enterprises and in industry, including in the Smart Grid. Wi-Fi is commonly used as the abbreviation of 802.11b standard. It supports bandwidth up to 11 Mbps, comparable to traditional Ethernet. The 802.11b standard also uses DSSS as modulation technique in the 2.4 GHz band as the original 802.11 standard, where Wi-Fi devices communicate to each other at data rates up to 11 Mbps. The Wi-Fi Alliance has created a new task group to determine which standards should be modified to take advantage of the Smart Grid. The alliance has issued a report (Wi-Fi, 2012) that looks at areas in the smart grid environment where Wi-Fi can play a role. This includes smart meters, home area networks and the collaboration between Smart Grid and cellular networks. In addition, the Wi-Fi Alliance and the ZigBee Alliance have announced an agreement to collaborate on wireless HAN for smart grid applications. The initial focus will be the ZigBee Smart Energy 2.0, which is expected to operate over Wi-Fi technology.



HomePlug

HomePlug is an industry alliance comprised of industry leaders that work together for the development of industry-standard specifications for home powerline networking products, services and content. The HomePlug alliance provides in-home applications such as sharing high-definition television programming, and other applications such as enabling utility companies to deliver high-speed Internet access to rural areas under the concept plug-and-play (Home Plg, 2012). The majority of HomePlug products are based on the HomePlug 1.0. The HomePlug AV specification is the new type of home networking technology that has been developed to provide high definition digital video and multi-channel audio. The HomePlug applications are based on PLC/BPL technology that generally supports data rates of 200 Mbps for in-home use. PLC/BPL is seeing some new interest as a smart grid technology. In the home, the energy consumer can control plug-in electric vehicle (PEV) charging, smart energy devices such as smart appliances and programmable communicating thermostats (PCT) attached to the HAN.

6LoWPAN

6LoWPAN (IPv6 over LoW Power wireless Area Networks) is the name of the working group in the Internet area of the IETF (Internet Engineering Task Force) 20. 6LoWPAN is an international open standard that enables in-home wireless Internet. It enables using 802.15.4 and the Internet protocol (IP) together and brings IP to devices such as sensors and controllers. As described in the IEEE 802.15.4 standard, 6LoWPAN offers the lower network layers of a type of wireless personal area network (WPAN) which focuses on low-cost, low-speed ubiquitous communication between devices. In addition, IP protocol has proven as a stable and highly scalable technology that supports a wide range of applications, devices and underlying communication technologies (6LoWPAN, 2012).

OpenHAN

OpenHAN (Home Area Network) is a proposed standard to interface with the smart meter in residences and with appliances in the home. OpenHAN can allow for utility control of appliances, customer coordination and timing of appliance activation, and operational states of appliances based on set-points such as price. Upon completion and implementation of this standard, residents will be capable of having appliances automatically run during times when electricity is the cheapest and electric utilities will be able to cease operation of appliances during peak loading times (Utility, 2007). OpenHAN is the fundamental idea behind automated demand response, where there exists a communications link between the smart meter of the customer and the customer's appliances.

OSHAN

OSHAN (Open Source for Home Area Networks) is a technology platform that uses open source hardware and software, that enables interoperability in the home (OSHAN, 2012; ZigBee, 2012; Wi-Fi, 2012; Home Plg, 2012; 6LoWPAN, 2012; Utility, 2007; Open, 2012). OSHAN is an open-source network specification for HANs with an open-source reference implementation available on reliable, low cost, and extremely energy efficient hardware platforms. OSHAN is a wireless kernel based on improved, secured, and reliable foundations: enhanced IEEE 802.15.4, IP addressability (6LoWPAN/IPv6), Smart Energy Profile 2.0, and Routing over Low-power Lossy (ROLL) networks.

Multimedia networking technologies

Multimedia networking technologies are needed to provide QoS (Quality of Service) to related smart grid communications applications such as voice over IP (VoIP) and IP video. Electric utilities are expected to maintain standard voice, data, and video communications networks. These networks have similar requirements to any other enterprise with multiple sites such as customer offices, remote service facilities, etc. The benefits of using IP-based networks include the maturity of a large number of IP standards, the availability of tools and applications that can be applied to multiple smart grid areas, and the widespread use of IP technologies in



both private and public networks. Next, the most representative multimedia networking technologies that can be applied to the Smart Grid are analysed.

IPv4

IPv4 (Internet version 4), developed by the IETF is a packet-oriented technology that is the original network layer for the Internet suite of protocols (RFC 791). Its primary characteristics arise from the structure of its four-byte address space that was originally intended to provide some information on how a message should be routed. In IP networks, datagrams (data packets) are delivered to the network without any resource being allocated, and the network makes its “best effort” to serve the packets. To overcome this, different mechanisms at OSI model layer 3 such as DiffServ (differentiated services) has been standardized for maintaining certain QoS functionalities. In IP, the network is responsible for the routing of datagrams, whereas higher entities in the OSI reference model (layer 4) are responsible for the control of the end-to-end communication, such as TCP for connection-oriented communication. These characteristics make IP suitable for applications that can be found in electric utilities networks.

IPv6

IPv6 (Internet v6) is a data networking technology that is a new version of the IPv4. The changes from IPv4 to IPv6 (RFC 2460) fall primarily into the following categories: expanded addressing capabilities (from 32 bits to 128 bits), header format structure, improved support for extensions and options, flow labelling capability, and security mechanisms to support authentication, data integrity, and data confidentiality are specified for IPv6. The support of IPSec is mandatory in IPv6 implementations. IPv6 has increased address space and has many improvements in areas such as routing and network auto-configuration over IPv4.

MPLS

MPLS (Multiprotocol Label Switching) is a data networking technology that combines the flexibility of IP hop-by-hop routing with the QoS and traffic engineering benefits of connection-oriented technologies such as ATM (IETF, 2012). In MPLS, a short fixed length label is used in every hop to determine

the next hop and then replaced for a new label that will determine the next hop in the next MPLS router. An end-to-end path in a MPLS network is defined by a sequence of labels. MPLS technology provides a number of new capabilities and benefits in IP networks such as the support of scalable VPN (virtual private networks), traffic engineering, and the support of IP routing on network switches.

Conclusions

In this work, an analysis of the most relevant communications and networking technologies applicable to the Smart Grid were presented. The basic concept of Smart Grid is to add monitoring, analysis, control, and communication capabilities to the electrical system in order to maximize the throughput of the system while reducing the energy consumption. However, a real intelligent network will not be possible unless each device and the new primary system that is part of the network can communicate with any other network system. This interoperability depends on a coordinated structure of protocols and standards that must be specifically designed to work as an integrated electrical and communications network. The Smart Grid builds on many of the technologies already used by electric utilities but adds communication and control capabilities that will optimize the operation of the entire electrical grid. Many communications technologies are applicable to the Smart Grid, but not all are able to support the Smart Grid new demanding applications. Communications is an essential component for the operation of an electric utility, so establishing an integrated communications backbone is one of the key steps for the implementation of a Smart Grid. Therefore, communications networks must be planned, managed, and designed to meet the mission-critical applications of the Smart Grid.

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JOAQUÍN GARCÍA HERNÁNDEZ

[jgarciah@iie.org.mx]

Doctor de Filosofía (Ph.D.) en Ingeniería Sistemas Electrónicos con especialidad en Redes de Comunicaciones Multimedia de la Universidad de Essex, Inglaterra en 1999. Maestro en Ciencias en Electrónica y Telecomunicaciones por el Centro de Investigación Científica y de Educación Superior de Ensenada, Baja California (CICESE) en 1990. Ingeniero en Comunicaciones y Electrónica por el Instituto Politécnico Nacional (IPN) en 1986. Es investigador de la Gerencia de Control, Electrónica y Comunicaciones del IIE y cuenta con 26 años de experiencia profesional. Ha trabajado en el desarrollo de proyectos relacionados con redes y sistemas de comunicaciones aplicados al sector eléctrico, diseño de sistemas de comunicaciones para la automatización de subestaciones y tecnologías de comunicaciones para la red eléctrica inteligente (*smart grid*). Ha publicado más de 55 artículos en revistas y congresos. Posee dos derechos de autor relacionados con el desarrollo de interfaces de comunicación para redes de computadoras. Es miembro del CIGRE e instructor certificado del programa académico CISCO Networking Academy. Profesor de cátedra del Instituto Tecnológico y de Estudios Superiores de Monterrey (ITESM) campus Cuernavaca.