A Review of Wireless and Satellite-based M2M Services in Support of Smart Grids

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Abstract. The Smart Grid (SG) is an evolution of the electricity network that integrates the activities of power consumers, power generators, distribution grid, and devices connected to the grid (e.g., substations, transformers.) Machine-to-Machine (M2M) technology is designed for automated data exchange between devices, and thus has applicability to SGs. With M2M technology, organizations track and manage assets; inventories; transportation fleets; oil and gas pipelines; mines; wide-spread infrastructure; natural phenomena such as weather conditions, farm production, forestry condition, and water flows; and, as noted, SGs. Wireless communication is a staple of M2M. These wireless technologies range from unlicensed local (so called 'fog') connectivity, to licensed 3G/4G/5G cellular, to Low Earth Orbit (LEO) satellites. All of these technologies are relevant to the SG. Utilities have started to gradually support M2M and Supervisory Control And Data Acquisition (SCADA) systems over satellite links. This article focuses on wireless and satellite-based M2M services, as applicable to the Smart Grid, including the use of Internet of Things (IoT), particularly for the transmission and distribution space (T&D) sector; some comparisons to wireline solutions are also discussed.

***Keywords*: Smart Grid, Wireless, Low Earth Orbit**

1. INTRODUCTION

The intelligent integration of information from actions of users connected to the electricity grid – consumers, generators, and the distribution grid -- are performed by the SG. Efficient, sustainable, economical and secure delivery of electricity supplies is the main goal of SG, as described by the European Technology Platform for Electricity Networks for the Future. Thus, a SG encompasses the various stages of power generation, distribution, and consumption. SGs are an evolution of a traditional power system; their goal is to exploit the power of automation to better control distribution, green efficiency and consumption. Looking at a traditional power system, the initial step entails converting power from a generation source, such as steam-, hydroelectric-, or renewable-based generation systems, into a high voltage electrical signal that can be transported utilizing the power grid. Often, but not always, the power is generated at some distance from the consumption point; this is particularly the case for hydroelectric and wind-generated power. The next stage occurs where the high-voltage power is "stepped-down" utilizing switchgear and transformers; the power flow is then controlled downstream using circuit breakers and arresters. At that juncture, the resulting medium-voltage electrical power is distributed to the users after additional step-down transformers. It should be noted that, due to long distance transmission loss, even with high voltage lines, about 40% of the generated power is lost; thus any technology that, in some way, can reduce these losses is highly desired, especially as there is a societal drive to affect a greening of the environment. Systems in countries with large or remote regions (e.g., Canada, Brazil, China, Philippines, Australia) can greatly benefit from wireless and satellite based systems for grid control.

It is the case that the transmission and distribution systems are currently facing a multiplicity of change drivers, including the emergence of distributed renewable energy generation and the increasing electrical energy demand of businesses and consumers. SG management technologies are needed to address these and related issues. The power industry is increasingly seeking to incorporate Information and Communication Technologies (ICT) into its operations, including at the edges. The thus-enhanced grids are known as SGs.

An extensive body of literature and research on the topic of SG is available, e.g., see [1, 2]. SGs typically entail the following disciplines: Advanced Distribution Network Architectures, Smart Metering, Demand Response, Integration of Renewable Sources, Smart Cities, Home Intelligence, Market Integration, Storage, Privacy and Data Security. SG control requires wide-area network coverage that spans the generation, the transmission, the distribution, and the consumer portions. For this purpose, cost-optimized communications networks are needed. Attempts at controlling parts of the grid, for example, using Automated Meter Readers (AMRs), go back several decades; one application of Integrated Services Digital Networks (ISDN) developed in the mid-1980s was intended to be for AMR and for telemetry; unfortunately, ISDN turned out to be too expensive and with limited penetration. Although wireline-based solutions have evolved and are now available, wireless communication technologies will become increasingly important in the broad-based deployment of SGs. Specifically, a power line carrier-based communications have been deployed, however, currently few of these technologies have been broadly adopted in terms of level of practicality, scalability, and cost-effectiveness. These attributes are critical to enable the industry to institutionalize them as a viable final solution, particularly in rural environments, supporting the long-distance portion of the transmission grid. Wireless automatic meter reading (WAMR) is of particular interest to utilities for both urban and suburban environments.

Fortunately, evolving Machine to Machine (M2M) services under the rubric of Internet of Things (IoT) are seen as increasingly applicable to SG applications [3-9]. M2M communications takes place between two or more mechanistic entities that routinely omits direct human intervention. These devices appear in a large set of operational devices, such as SG controllers, AMRs, surveillance cameras, alarm systems, and automotive equipment, and many more. M2M is defined extensively by ETSI standards. For example, ETSI TD 102 690 V1.1.1 (October 2011) defines a High-Level M2M System Architecture (HLSA). In addition, a number of use cases were published by ETSI for several applications including ETSI TR 102 691: "*M2M: Smart Metering Use Cases*". The expectation is that M2M communication will be an important component for the implementation of the next-generation SG.

A Radio Access Network (RAN) is often used in M2M environments. A RAN can be a cellular network, a satellite network or a number of other evolving wireless "fog"-area networks (FANs) [11]. The RAN can be utilized to support SG applications. Enhancement, modernization, and extension of SCADA functionalities has been supported by the M2M-based solutions. M2M, on the other hand, is not intended to connect directly SCADA-based devices but to provide interoperation with the use of proxies and/or gateways [12]. IPv6 may play an important role in SG systems in the future.

Wireless-based M2M solutions based on a plethora of technologies have been sought in the recent past. As a specific example, cellular telephony solutions may be utilized, but both the modem cost and the service availability outside of major urban centers remain a challenge, especially in developing countries. Hence, satellite-based M2M services may be increasingly applicable to SGs, particularly for rural environments. Satellite-based M2M supports transmission of small data quantities in a wide geographic area. For example, many M2M and SCADA applications are gradually enhanced over satellite links. In addition to SG, satellite-based M2M include applications for connectivity including data collection for monitoring the environment and climate analysis, law enforcement and Coast Guard applications, off-and shore oil drilling. Other wireless technologies may be appropriate for urban environments, where, for example, access to individual meters -- often located in enclosed environments, such as basements -- is needed. Regardless of which wireless link technology is used, cost-effectiveness, appropriate geographic coverage, and security, are key desiderata [3, 13-15].

This review article focuses on wireless and satellite-based M2M services, as applicable to the SG applications, particularly for the transmission and distribution space (T&D) sector. Section II discusses some key SG requirements. Section III discusses relevant wireless technologies that can be employed in the SG/IoT/M2M environment, including satellite-based M2M systems.

2. SMART GRID REQUIREMENTS

Power companies are increasingly injecting ICT technology in general, and M2M principles in particular, into their operations in support of modernization efforts to improve reliability and efficiency, including cybersecurity mandates. SG requirements for wireless and satellite-based M2M services include the following [16]:

- Wireless Channels
  - Two-way channels
  - Good coverage
  - Adequate throughput for a range of applications, including Variable Link Capacity
  - Adequate Quality of Service (QoS), e.g., Packet Loss, Packet Errors, latency, jitter
  - Interoperability,
  - Scalability
  - Scalable internetworking with overlay networks
  - Low cost
  - Flexibility
  - Reliability and self-healing capability, especially for backbone applications
  - Intrinsic security and privacy

- Remote sensing devices
  - Ruggedness
  - Long lasting batteries (if not energized from the line)
  - Ability to support multiple protocols (Multi-Radio Support and Spectrum Efficiency)
  - Self-Configuration and Self-Organization
- Gateways to core networks
  - Ability to support a plethora of physical links and protocol stacks
  - Addressing, Routing, Network address translation (NAT), firewalling/security, authentication, and interworking proxies
  - Resource (channel) management
  - Remote entity management
  - History and data retention, transaction management
  - Compensation brokerage
- Domicile/In-Home devices
  - Ability to support a large number of devices
  - Low power consumption
  - Ability to support a plethora of physical links (e.g., Ethernet, 802.15.4, Wi-Fi, Bluetooth, Power Line Communications, and cellular).

As the SG evolves there is a need to continue to support existing SCADA-based systems and applications. A SCADA collects operational information and transfers the information to a centralized processing center for decision making. The processed and analyzed event data alerts management that an event of interest has occurred, and that some action is needed. Thus, a SCADA system transfers information between a centralized system and a constellation of Remote Terminal Units (RTUs) and/or Programmable Logic Controllers (PLCs) [12]. SCADA systems traditionally used the Public Switched Telephone Network (PSTN) for securing the connectivity needed to support the intended monitoring; wireless technologies are now being increasingly applied to SCADA applications.

There are a number of SCADA-related protocols; the most common being:

- International Electrotechnical Commission (IEC) 60870-5 series, specifically IEC 60870-5-101 which is commonly referred to as 101. IEC 60870-5-1 specifies the data link and physical layers for application control. Related standards support mapping application data units to transmission frames and rules for defining data and information elements.
- Distributed Network Protocol version 3 (DNP3). This protocol works in serial communications mode for point-to-point data exchange, facilitating inter-device communication for SCADA RTUs. Specifically, the RTU-to-Intelligent Electronic Device (IED) communication protocol and also master-to-RTU/IED communication protocol is included (an IED is an intelligent controller of power system equipment; examples include circuit transformers and breakers.)

In the U.S., responsibilities for coordinating the development and adoption of SG standards and related guidelines due to the Energy Independence and Security Act of 2007 (EISA) is granted to the Federal Energy Regulatory Commission (FERC) and the National Institute of Standards and Technology (NIST). The SG:

- Must be cyber secure;
- Must be a national integrated grid with several command and control centers, not just with local/regional grids;
- Must manage distributed energy from solar and wind and store and manage net metering and the production of renewable sources;
- Must manage loads at the plug level; and,
- Must be resilient and redundant rerouting transmission in real time.

The Advanced Metering Infrastructure (AMI) is one example of this modernization effort. The AMI is the ICT mechanism that is put in place between the consumer and the power utility. In aggregate, it is an integrated assembly of smart meters, networks, and data processing systems that supports two-way communication between the utilities and the consumers [13, 17]. AMI is a significant component of the overall approach for implementing the SG, and the main component for achieving Demand Response (DR). SG devices and smart appliances are increasingly designed to be "Demand Response-enabled". To realize efficiency and load-management goals, utility companies are adopting two-way networking connectivity to enable consumers to monitor and possibly reduce their energy usage [18, 19]. A centralized entity will poll or inform the meter to gather appropriate consumption information. The goal is to improve the efficiency of the distribution of energy by utilizing detailed real time information about the end user's (consumer or business) consumption, especially in conjunction with incentivized billing plans.

As noted, many grid-related functions have been supported utilizing SCADA-based mechanisms, which have traditionally been wireline oriented. The migration to wireless thus entails supporting the SCADA mechanisms along with improved cybersecurity over said media.

As alluded to above, a key element of a SG is a cost-effective communications network (e.g., as supported by the AMI), that enables automated metering capabilities. Specifically, such network collecting power consumption data allows a utility to automatically control customer loads, especially during peak demand periods. Additionally, it enables the utility to remotely and automatically update the grid configuration, and also control supply of power to certain customers. Among other benefits of smart metering are the ease of site access, power usage information, and statement accuracy, and monetary savings associated with DR and management of power demand.

A growing number of utility companies are planning to roll out intelligent metering services by incorporating M2M devices in the meters. A variant application of the smart meter DR capabilities can also be utilized to support a pre-payment arrangement where a consumer purchases a specified amount of the commodity (e.g., electricity, gas, etc.); the data related to the amount purchased is then downloaded to the metering device and stored on the (M2M); when the purchased volume has been consumed, the supply is halted [10].

Home Area Networks (HAN) are also being deployed in support of a Smart Home. Furthermore, vendors have started to design products that integrate built-in-communication systems which interact with the AMI-enabled meter and with the HAN. The combination of the AMI-enabled meter and the HAN allows consumers to remain aware of their electricity usage and associated costs on a quasi-real-time. Codifying information about the cost of power and the consumer's preferences, appliances schedule their operation such as deferring or adjusting the operating parameters to reduce peak energy consumption. Therefore, this method of intelligent management of energy supply potentially reduces expenditures as well as the peak demand. Peak demand reduction helps save money by avoiding the cost of auxiliary power plants construction that is put in place to handle peak loads. To be effective and expedite consumer penetration, a HAN is such that its networking technology (i) supports open standards, (ii) is cost-effective, and (iii) does not require major new infrastructure investments. AMI should utilize a number of communications standards and networking technologies for connecting the domicile device (the meter) to the management applications of the utility. Several industry and standards-organizations are developing physical and upper layer standards, including but not limited to:

- European Commission (EC) M/411 Smart Metering Mandate (2009). Standards for smart meters to facilitate interoperability and consumption awareness;
- EC M/490 Smart Grid Mandate (March 2011). The objective was to build standards for European SGs;
- IEEE P2030/SCC21. Its objective is to address SG interoperability;
- IEEE P1901.2: defines a OFDM-based standard for transmission over power lines;
- ETSI TS/TR 102: describes the M2M services and architecture, including smart metering;
- TIA: TR-50: addresses smart device communications.

3. IoT-ORIENTED WIRELESS SERVICES

Connectivity of IoT/M2M devices can be achieved by wireline channels, such as PLC[1], however, a number of utility companies have started to use wireless technologies to support AMI/smart meter/SCADA functions. The following wireless technologies are among the major ones applicable to SG applications [21].

3.1 Approaches

- Cellular (large footprint; but high endpoint cost, new cellular technologies coming, LPWA competition);
- Low Power Wide Area (LPWA) (cost-effective buildout, energy efficient, ideal for smart cities & mobility; but low bandwidth);
- Satellite (global; but higher endpoint cost than other solutions; strong regulatory oversight);
- Short range wireless/new technologies (high bandwidth, and use in consumer applications; but interference liabilities); and,
- Wireline (high bandwidth, also in conjunction with Wi-Fi, and used in consumer applications; limited mobility and dependent on Wi-Fi coverage/interference).

[1] *Power Line Communications* (PLC) also called Power Line Telecommunications (or PLT), is a wireline technology that allows data exchange over power lines by using advanced modulation methods. PLC is used to identify technologies, equipment, services and applications over existing "power lines".

3.2 Licensed Spectrum versus Unlicensed Spectrum

Two types of spectrum can be used, according to regulatory regimens: licensed and unlicensed.

Licensed spectrum

- Wireless options: LTE-M Rel-13 (~10 km, licensed spectrum, 1 Mbps, battery ~10 years);
- Narrowband NB-LTE Rel-13 (~15 km, licensed spectrum, 0.1 Mbps, battery ~10 years);
- Narrowband EC-GSM Rel-13 (~15 km, licensed spectrum, 0.01 Mbps, battery ~10 years);
- Next Generation, 5G cellular (~15 km, licensed spectrum, 0.01 Mbps, battery ~10 years, several years out in the 2020s.)

3GPP recently adopted a Low-Power Wide-Area Network (LPWAN) system called Narrow Band IoT (NB-IoT) to define a new radio access for cellular IoT, based mostly on a non-backward-compatible variant of E-UTRAN (Evolved Universal Terrestrial Access Network). NB-IoT aims at improved indoor coverage, large numbers of low throughput devices, low latency sensitivity, low device cost, and low device power consumption. (Note: NB-IoT has replaced the previous NB-LTE and NB-CIoT proposals.)

Unlicensed spectrum

Unlicensed non-3GPP LPWAN IoT wireless technologies (vendor proprietary), including [22]:

- LoRa (15-45 km suburban, 3-8 urban; up to 50 kbps);
- NWave (10 km; up to 100 bps);
- OnRamp (4 km; up to 8 kbps);
- Platanus (<1km; 500 kbps);
- SIGFOX (50 km suburban; 100 bps);
- Telensa (up to 8 km; low);
- Weighless-N (up to 5km; up to 100 kbps unidirectional); and,
- Amber Wireless (up to 20 km; up to 500 kbps).

These wireless services and others support wireless sensor networks in general and smart city, SG, and crowdsensing applications in particular.

3.3 Cellular Services

Cellular networks may be a practical solution for IoT/M2M applications aimed at operating over a large area such as a nation, a region of the country, or even a city [24]. In general, even beyond SG applications, various M2M applications are expected to be a major contributor of traffic (and also revenues) for cellular networks in the near future. Analysis shows that there are cost, reliability and deployment schedules, as well as performance, tradeoffs in choosing 3G, 4G or 5G, and/or the M2M-specific cellular services for SG. It is well-known that IoT/M2M traffic has specific characteristics, including data priority, transaction size, the real-time streaming QoS requirements, and the higher delay tolerance of the AMI/SCADA data. In order to cost effectively employ cellular technologies, these characteristics have to be taken into account as design criteria [25]. Initially on the 3GPP front, efforts have focused on the ability to differentiate Machine Type Communications (MTC), and to enable operators to selectively support MTC devices in case of network congestion. Thus, a priority indicator was added to enable support of congestion control in both core and radio access networks [26]. Among them, reliability, security and confidentiality are key considerations. For that purpose, endpoints need to provide and support virtual private network (VPN) constructs, embedded firewall, and other capabilities.

3.4 Satellite Services

Satellite-based M2M provides connectivity over large areas. Since terrestrial networks may not service all locations on earth, satellite operators, such as Iridium, Inmarsat, and Orbcomm offer global connectivity services that can extend M2M communication to almost 100% of the earth. Hence, delivery of relatively small quantities of data in almost all cases is supported by the satellite-based M2M. Some M2M services support simplex communications; others services support bidirectional communications; the latter is more flexible allowing data exchange. Table 1 defines some key satellite technologies usable in the M2M/SCADA/Grid applications [27, 28].

M2M satellite applications have been extended to Mobile Satellite Services (MSS) and to the L-band; these services support low data rate applications. Many of these applications are considered mainstream M2M applications (e.g., logistics, engine telemetry, environmental sensing), while other applications exist in the context of the IoT rubric, such as SGs, crowdsensing, smart cities, and so on. In SG systems SCADA information can be exchanged between end points on the grid and the operations systems from any points in the footprint of the satellite, including remote areas; this is particularly useful in geographic areas outside the U.S. and Europe [3].

Table 1: Key Satellite Technologies Usable for Grid Applications (from [3] and various industry sources)

Concept	Definition
Geostationary Orbit (GEO)	The satellite orbits the equator. The satellite appears stationary with respect to an antenna on earth. Therefore, a tracking antenna is not required for the satellite.
Fixed-satellite service	This is a satellite service between earth stations at fixed defined positions, when GEO satellites are
High Throughput Satellite (HTS)	When a service area is covered by a large number of distributed satellite spot beams, they provide contiguous service covering. HTS satellites offer covering a large service area contiguously, and therefore supports high user throughput at a low cost per bit. HTS provide broadband data services typically using Ka-band frequencies. HTSs can be GEO or LEO systems. Spot beams cover only a portion of the earth, such as a nation or subcontinent. Shaped narrow beams point to different portions of the geographical area. This method supports higher satellite antenna gain, and therefore requires a small aperture antenna at the user device. Frequency reuse for different beams also increases the system capacity.
Ka-band	This band utilizes spectrum from 18 GHz to 30 GHz and, therefore, is the most susceptible to rain.
Ku-band	This band utilizes spectrum from 10 GHz to 14.5 GHz spectrum and therefore more susceptible to rain fade than the C-band.
L-Band	An Intermediate Frequency (IF, 950-1450 MHz) which is typically employed at earth stations for routing traffic over coaxial/waveguide. Regulatory agencies define a (slightly) different over-the-air L band range. Typically, only a small portion (1.3-1.7 GHz) of L-Band is used in wireless satellite communications, such as for M2M applications.
Low Earth Orbits (LEO)	Elliptical or (more often) circular orbits at 5,000 km above earth or less. The duration of the orbit cycle is generally in the vicinity of 2 hours. The time duration a specific LEO satellite is above the horizon is about 20 minutes.
Mobile Satellite Service (MSS)	A satellite service providing wireless communication to nearly any point on the globe, typically operating at the L-band.

Antennas for M2M Satellite Communication

Small antennas are used in M2M applications. Major M2M antenna technologies are as follows:

- Embedded Antennas: Most M2M devices use internal multi band antennas. These antennas are designed to match the radiating properties of the device itself.
- Stubby Antennas: these M2M products have antennas that are located external to the M2M device; they are optimized to the electromagnetic requirements of the product.
- Very Small Aperture Terminal (VSAT) (Mini) Antennas: these M2M products use Ku and Ka tracking antennas (especially for broadband applications); typically, these antennas are $\leq$1 m.

Comparison of Satellite Services

As it is well known in the satellite industry, there are pros and cons between GEO- and LEO-based solutions. First, the GEO satellites in service are more well-established and are available from a large number of suppliers (SES and Intelsat being the largest providers); LEO constellations are relatively newer and are available from a smaller set of providers. GEO generally provide more bandwidth, especially with the new-generation High Throughput Satellites (HTS); however, they also generally require higher power on the ground. LEO require less on-the-ground power and are available in 98% of the global surface; they are also ideal for mobile, aeronautical, and maritime applications (although this is less relevant for grid applications.) GEO require larger antennas (usually in the sub-meter range), while LEO services require smaller antennas (and often, no tracking for the endsystems.)

3.6 Mapping of Requirements

Earlier we listed some key requirements of the communications infrastructure required to support SGs. Table 2 provides a mapping between various SG communications elements and the wireless technologies under discussion.

3.7 Relative Penetration

Market research observers claim that by 2020 short-range technologies such as Bluetooth, ZigBee and Wi-Fi will be the dominant technologies for connecting the majority of IoT devices [23]. Cellular services will remain the largest in terms of revenue (the 2020 worldwide application revenue forecast at about $160B). By revenue ~25% of the deployment will be on 2G/3G cellular, ~50% on LTE trending to 5G, ~15% on LPWA, and ~10% on wireline, short range, and satellite (the latter ~2%.)

Table 2: Ability of Specified Wireless Technology to meet various SG Communications Requirements

SG Comm Element	Requirement	Cellular	Unlicensed spectrum/LPWA	Short range wireless	Satellite	Wireline
Wireless Channels	Two-way channels	Y	Most of them	Y	2-way and 1-way solutions	Y
	Good coverage in various environments	Urban, suburban; issue in rural	Urban	In-building	Y	Urban, suburban; issue in rural/ harsh
	Adequate throughput for a range of applications, including Variable Link Capacity	Y	Most of them	Y	Y	Y
	Adequate Quality of Service (QoS), e.g., Packet Loss, Packet Errors	Y	Most of them	Y	Y	Y
	Interoperability	Y	Most of them	Y	Y	Y
	Scalability	In many instances	Limited; more for urban	Not particularly	Y	Y
	Scalable internetworking with overlay networks	In many instances	Limited; more for urban	Not particularly	Y	Y
	Low cost	Less so	More so	Y, but local	Less so	Usually less so
	Flexibility	In many instances	Limited; more for urban	Not particularly	Y	Y
	Reliability and self-healing capability, especially for backbone applications	Y	Y	NA	Y	Generally; issue in rural or harsh
	Intrinsic Security and privacy	To a degree	To a degree	To a degree	To a degree	To a degree
Remote devices (while using the shown communication link)	Ruggedness	Design dependent	Design dependent	NA	Design dependent	Design dependent
	Long lasting batteries (if not energized from the line)	Design dependent	Design dependent	NA	Generally, more power needed	Design dependent
	Ability to support multiple protocols (Multi-Radio Support and Spectrum Efficiency)	Design dependent	Design dependent	NA	Multi-band (e.g., Ku, Ka) more expensive	NA
	Self-Configuration and Self-Organization	Design dependent	Design dependent	NA	Design dependent	Generally, no
Gateways (while using the shown communication link)	Ability to support a plethora of physical links and protocol stacks	Design dependent	Design dependent	NA	Design dependent	Generally, yes
	Addressing, Routing, Network address translation (NAT), firewalling/security, authentication, interworking proxy	Design dependent	Design dependent	NA	Design dependent	Generally, yes
	Resource (channel) management	Design dependent	Design dependent	NA	Design dependent	Generally, yes
	Remote entity management	Design dependent	Design dependent	NA	Design dependent	Generally, yes
	History and data retention, transaction management	Design dependent	Design dependent	NA	Design dependent	Generally, yes
	Compensation brokerage	Design dependent	Design dependent	NA	Design dependent	Generally, yes
Domicile/In-Home devices (while using the shown communication link)	Ability to support a large number of devices and appliances	Design dependent	Design dependent	Design dependent	(less common use of this link)	Yes
	Low power consumption	Design dependent	Design dependent	Design dependent	(less common use of this link)	Yes
	Ability to support a plethora of physical links (e.g., Ethernet, 802.15.4, Wi-Fi, Bluetooth, PLC, and cellular)	Design dependent	Design dependent	Design dependent	(less common use of this link)	Yes

4. CONCLUSION

With the ever-increasing demand to save energy, many technologies have evolved and are being experimented with for the realization of SGs. Most approaches require access to, and information gathering from, millions of homes.

Stations and control centers for power usage and resource adjustment are the primary points of data aggregation, analysis, and decision making. The sheer number of the end-point devices and otherwise high cost of connectivity using conventional methods, requires new methods of information gathering and dissemination that go beyond traditional approaches. For this reason, all options which could support this difficult task should be called upon. In this article the authors have provided a brief overview of the application of SG in control of power systems with an emphasis on wireless options for their access and connectivity.

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6. BIOS

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