Chapter 2
Smart Grid Communications Network (SGCN)

This chapter provides a top-level system description as well as technical details for the SGCN so as to help readers grasp system and network requirements and challenges when designing and implementing the SGCN. Specifically, this chapter elaborates on the overall architecture of the SGCN by decomposing it into three representative network segments. For each segment, details regarding required communication delay, bandwidth, network coverage and potential applications are addressed. Since inter-operability is one of the most vital concerns in the SGSN, this chapter then gives an overview on the standards for the SGCN developed by various organizations such as the Institute of Electrical and Electronics Engineers (IEEE) and the National Institute and Technology (NIST). Finally, this chapter discusses QoS attributes and requirements of the various elements in the SGCN.

2.1 Overall Architecture of the SGCN

The SGCN is typically composed of various segments, each of which is responsible for information and control message exchanges within a specific region of the power grid as sketched in Fig. 1.2b. Communications characteristics of these segments will be discussed in the following subsections.

2.1.1 Premises Network

The premises network gathers sensor information from a variety of smart appliances and devices within the customer premises and delivers control information to them for better energy consumption management. The coverage areas of this network could be apartments, homes, residential/commercial buildings, and factories.

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2.1.1.1 Home Area Network (HAN)

A HAN is deployed in an apartment or a residential dwelling. It can support functions such as cycling heaters, washers/dryers, or turning air conditioners off during peak load conditions and controlling the charging/discharging procedure for PEVs. An important component of a HAN is the home energy management system (HEMS) that allows consumers to see how much power their household is consuming at any moment in time as well as over a period of time. In order to facilitate applications related to TOU-based energy management, demand response, etc., the HEMS communicates with a smart meter (SM) installed in consumer site and works as a communications gateway relaying information related to real-time energy price, home energy usage information, and control signals between the HAN and the utility. HEMS allows the consumer to customize their power usage profile in order to minimize their electricity bill. Typically, HANs need to cover areas of up to 200 m^2 and support from 10 to 100 kilobits per second (kbps).

2.1.1.2 Building Area Network (BAN)

Similar to HAN, a BAN is responsible for monitoring and controlling consumer smart devices and exchanging information with the utilities. However, it needs to cover an entire building which consists of multiple apartments and offices. A BAN can be a collection of HANs connected with a building SM which is typically installed at the building's power feeder. Especially, the BAN may incorporate a microgrid that generates electricity by harvesting heat wastes or renewable resources such as solar or wind energy. Due to a higher number of network elements and energy management applications, it requires higher data rates, compared to HAN.

2.1.1.3 Industrial Area Network (IAN)

An IAN is a communications network deployed in factory floors. It incorporates connected sensors, controllers, and specialized building management software. The IAN handles building or multi-building applications, such as building automation systems and energy management, for optimizing energy, economic and environmental performance of all connected devices. Similar to BAN, a microgrid is also an important element of IAN. However, a microgrid of this network has a larger scale, higher capacity and complexity than that of BAN. Additionally, as industrial customers run more sophisticated applications, their SMs should possess the ability to record additional data such as power quality, voltage sags/surges, and phasor measurements.

Despite the fact that there are a number of differences between HAN, BAN, and IAN as just mentioned, these networks share many common characteristics and design disciplines. They are mostly deployed in indoor environments and need to support short-range communications between network elements for monitoring and control applications. Also, they use a SM as a gateway to connect them with other network segments and the utilities. As a result, thereafter, the HAN is used to represent the premises network.

2.1.2 Neighbor Area Network (NAN)

The NAN is responsible for smart metering communications that enables information exchange between customer premises and utility company's WANs. NAN endpoints are SMs that are considered to be at the heart of SG revolution. SMs support energy consumption recording and real-time or near real-time data acquisition and control for various SG applications including distribution automation, power outage management, power quality monitoring, etc. A NAN cluster usually covers an area of several square kilometers. The number of SMs in each cluster varies from a few hundreds to a few thousands depending on the power grid topology and the employed communications technology and protocol. The data rate required by each SM may widely vary depending on deployed applications. For example, for interval and on-demand meter reading, only around a few bps per meter is required. However, in order to support future applications, such as advanced distribution automation, fault detection and restoration and so on, higher data rates, e.g., a few tens of kbps per meter, may be required. It is noted that the NAN is a critical segment of the SGCN since it is responsible for transporting a huge volume of different types of data and distributing control signals between utility companies and a large number of devices installed at customer premises.

2.1.3 Field Area Network (FAN)

A FAN provides connectivity for smart devices in transmission and distribution grids and substations. These devices include power line monitors, breaker controllers, voltage regulators, capacitor bank controllers, recloser controllers, smart transformers, data collectors, etc. They are used to quickly detect anomalies and failures and to automate responses to improve reliability and quality of power services. Besides, the FAN enables mobile workers to access field devices using their laptops, tablets or hand-held equipment in order to collect and analyze data for failure/fault detection, troubleshouting and service restoration. Similar to NAN, this network segment incorporates a large number of devices and covers wide areas. NAN and FAN may also have overlapped coverage since numerous smart devices are tied to both of them for successful implementations of various emerging applications. As an illustrative example, SMs need to be accessible by both of these network segments to ensure that the distribution grid can obtain vital information from customer premises in real-time to enable efficient vol/VAR control.

Therefore, NAN and FAN share many design principles and communications technologies. It is sufficient to only focus on the NAN that can be considered as a representation of these two segments.

2.1.4 Wide Area Network (WAN)

A WAN aggregates data from multiple NANs and conveys it to utility company's private networks. It also enables long-haul communications among different data aggregation points (DAPs) of power generation plants, distributed energy resource stations, substations, transmission and distribution grids, control centers, etc. Additionally, the utility company's WAN is responsible for providing the two-way network, needed for substation communications, distribution automation, power quality monitoring, etc., while also supporting data aggregation and back-haul for NANs. The WAN may cover a very large area, i.e., thousands of square kilometers and could aggregate a large number of supported devices and thus require hundreds of megabits per second (Mbps) of data transmission.

2.1.5 Interconnection of Network Segments

In order to form the SGCN, the network segments that have been just presented in the above subsections are interconnected through gateways: a SM between HAN and NAN and a DAP between NAN and WAN. A SM collects the power-usage data of a home or building by communicating with the home network gateway or functioning as the gateway itself. The DAP aggregates data from a cluster of SMs and relays it to the grid operator's control centers. Instructions for optimizing the power grid and user energy consumption can be sent from control centers to intelligent electronic devices (IEDs) and consumer devices through WAN, NAN and HAN in the opposite direction. These segments may employ different communications technologies and protocols to meet their own requirements in terms of data rates, communications latencies, deployment/maintenance costs. Therefore, in addition to data aggregation/filtering and traffic routing, the gateways also perform network address translation, protocol translation/mapping, etc., as necessary to provide system inter-operability.

2.2 Standards in the SGCN

It has been observed that inter-operability is at the heart of technological revolutions in telecommunications, transportation, industrial manufacturing, and many other industries. As presented in the preceding section, the SGCN is the integration of multiple segments, each of which is required to provide network connectivity for a vast number of devices of different types. Therefore, inter-operability in this network is also a vital concern.

By definition, inter-operability is "the ability of two or more systems or components to exchange information and to use the information that has been exchanged" [1]. The lack of widely accepted standards limits the inter-operability between SMs, smart monitoring and controlling devices, renewable energy sources and emerging advanced applications, and thus prevents their integration. As a result, many regional, national, and international Standards Development Organizations (SDOs) have been working towards a variety of standards for the SG, e.g., Institute of Electrical and Electronics Engineers (IEEE) [2], National Institute of Standards and Technology (NIST) [3], American National Standards Institute (ANSI) [4], International Electrotechnical Commission (IEC) [4], International Organization for Standardization (ISO) [5], International Telecommunication Union (ITU) [6], etc. In addition to SDOs, there are a number of alliances that recognize the value of a particular technology and attempt to promote specifications as standards for that technology. For example, some well-known alliances related to the utility industry in the HAN market are ZigBee Alliance [7], WiFi Alliance [8], HomePlug Powerline Alliance [9], Z-Wave Alliance [10]. The following subsections provide an overview of the key roles and activities of the IEEE and the NIST in developing standards for inter-operability of the SG.

2.2.1 IEEE Standards

IEEE has more than 100 approved standards and many under-development standards relevant to the SG. This organization is also working closely with the NIST and other standards bodies in developing a standard roadmap and conformance testing and certification framework for the SG [11]. The IEEE P2030 [12] is a standard guide for SG inter-operability. It provides understanding, definitions, and guidance for design and implementation of SG components and end-user applications for both legacy and future infrastructures. The knowledge base addresses terminology, characteristics, functional performance and evaluation criteria, and the application of engineering principles for SG inter-operability of electric power system (EPS) with end-use applications and loads. Besides, the reference model, namely Smart Grid Inter-operability Reference Model (SGIRM), presents three different architectural perspectives with inter-operability tables and charts. The IEEE 2030 series of standards will address more specific technologies and implementation of SG systems (e.g., P2030.1 Electric Vehicle, P2030.2 Storage Energy Systems).

The SGIRM is the central part of the IEEE P2030 standard. It is intended to present inter-operable design and implementation alternatives for systems that facilitate data exchange between SG elements, loads, and end-use applications. The IEEE P2030 SGIRM encompasses conceptual architectures of SG from power systems, communications, and information technology perspectives and characteristics of the data that flows between the entities within these perspectives. Each conceptual architecture presents a set of labeled diagrams that offer standards-based architectural direction for the integration of energy systems with information and communications technology (ICT) infrastructures of the evolving SG. It aims to establish a common language and classification for SG community to communicate effectively. The interfaces between entities in each architecture will typically contain a wide variety of data. The IEEE SGIRM data classification reference table provides guidance in identifying a set of characteristics for the data at those interfaces. It is a starting point in determining appropriate classifications for the data.

The Inter-operability Architectural Perspectives (IAPs) primarily relate to logical, functional considerations of power systems, communications, and information technology interfaces for SG inter-operability. The Power Systems IAP (PS-IAP) mostly represents a traditional view of the EPS, while Communications Technology IAP (CT-IAP) provides a means to getting the data from place to place and the Information Technology IAP (IT-IAP) provides a means to manipulate data to provide useful information. A summary of the three perspectives is as follows:

- *PS-IAP*: The emphasis of the power system perspective is the production, delivery, and consumption of electric energy including apparatus, applications, and operational concepts. This perspective defines seven domains common to all three perspectives: bulk generation, transmission, distribution, service providers, markets, control/operations, and customers.
- *CT-IAP*: The emphasis of the communications technology perspective is communication connectivity among systems, devices, and applications in the context of SG. The perspective includes communications networks, media, performance, and protocols.
- *IT-IAP*: The emphasis of the information technology perspective is the control of processes and data management flow. The perspective includes technologies that store, process, manage, and control the secure information data flow.

The IEEE SGIRM data classification reference table presents various data characteristics (e.g., reach, information transfer time, latency, etc.) and their corresponding value ranges (representative of values that are typically used). The user of the table may need to identify more appropriate data characteristics and values for their specific circumstances.

Besides, the IEEE P2030 SGIRM methodology provides understanding, definitions, and guidance for design and implementation of SG components and end-use applications for both legacy and future infrastructures. The key to using the IEEE P2030 SGIRM is to determine the relevant interfaces, data flows, and data characteristics based on the intended SG application requirements and goals. Once the data requirements of the goals have been defined, the users, based on SGIRM, select a set of interfaces on each IAP of the model that meet the data needs. These interfaces and data flow characteristics are key elements for subsequent SG architectural design and design of implementation operations. The determination of these interfaces is the first step toward determining the implementation of the intended SG application requirements and goals. To assist in this step, the PS-IAP interface tables are provided to identify logical information to be conveyed, the CT-IAP interface tables identify the general communication options of the interface, and the IT-IAP data flow tables identify the general data types.

2.2.2 NIST Standards

NIST has been assigned the "primary responsibility to coordinate development of a framework that includes protocols and model standards for information management to achieve inter-operability of smart grid devices and systems ..." (Energy Independence and Security Act of 2007, Title XIII, Section 1305). Its primary responsibilities include (i) identifying existing applicable standards, (ii) addressing and solving gaps where a standard extension or new standard is needed and (iii) identifying overlaps where multiple standards address some common information. NIST has developed a three-phase plan to accelerate the identification of an initial set of standards and to establish a robust framework for the sustaining development of the many additional standards that will be needed and for setting up a conformity testing and certification infrastructure.

NIST Framework and Roadmap for Smart Grid Inter-operability Standards, Release 1.0 [13], is the output of the Phase I of NIST plan. It describes a high-level conceptual reference model for SG, identified 25 relevant standards (and additional 50 standards for further review) that are applicable to the ongoing development of SG and described the strategy to establish requirements and standards to help ensure SG cybersecurity. Release 2.0 of NIST Framework and Roadmap for Smart Grid Inter-operability Standards [14] details progress made in Phases II and III. Major deliverables have been produced in the areas of SG architecture, cybersecurity, and testing and certification. Release 2.0 [14] presented 34 reviewed standards (and additional 62 standards for further review). The listed standards have been undergone an extensive vetting process and are expected to stand the "test of time" as useful building blocks for firms producing devices and software for SG. Ongoing standards coordination and harmonization process carried out by NIST will ultimately deliver communications protocols, standard interfaces, and other widely accepted and adopted technical specifications necessary to build an advanced, secure electric power grid with two-way communications and control capabilities [14]. Release 3.0 of NIST Framework and Roadmap for Smart Grid Inter-operability Standards [15] updates NIST's ongoing efforts to facilitate and coordinate smart grid inter-operability standards development and smart grid-related measurement science and technology, including the evolving and continuing NIST relationship with the Smart Grid Inter-operability Panel (SGIP). Lists of standards approved and under-reviewed by NIST can be found in [13–15]. For examples, IEC 61850 protocol suite is for communications within transmission and distribution sectors; ANSI C12.20 is for revenue metering accuracy specification; and IEEE 1588 is for time management and clock synchronization of equipments across the SG.

Table 2.1 PAPs identified by NIST

Supporting	PAPs
Metering	Meter upgradeability standard (PAP 00) Standard meter data profiles (PAP 05) Translate ANSI C12.19 to the common semantic model of common information model (CIM) (PAP 06)
Enhanced customer interactions with the SG	Standards for energy usage information (PAP 10) Standard demand response signals (PAP 09) Develop common specification for price and product definition (PAP 03) Develop common scheduling communication for energy transactions (PAP 04)
Smart grid communications	Guidelines for the use of IP protocol suite in SG (PAP 01) Guidelines for the use of wireless communications (PAP 02) Harmonize power line carrier standards for appliance communications in the home (PAP 15)
Distribution and transmission	Develop CIM for distribution grid management (PAP 08) Transmission and distribution power systems model mapping (PAP 14) IEC 61850 objects/distributed network protocol 3 (DNP3) mapping (PAP 12) Harmonization of IEEE C37.118 with IEC 61850 and precision time synchronization (PAP13)
New smart grid technologies	Energy storage interconnection guidelines (PAP 07) Inter-operability standards to support plug-in electric vehicles (PAP 11)

In addition to reviewing and selecting applicable standards for SG, NIST has another important contribution in identifying a set of Priority Action Plans (PAPs) for developing and improving standards necessary to build an inter-operable SG. Those PAPs arise from the analysis of the applicability of standards to SG use cases and are targeted to resolve specific critical issues. Each PAP addresses one of the following situations: a gap exists, where a standard extension or new standard is needed; an overlap exists, where two complementary standards address some information that is in common but different for the same scope of application [13–15]. A number of representing PAPs is summarized in Table 2.1.

As an illustrative example, PAP 02 deals with wireless communications for SG. It provides key tools and method to assist SG system designers in making informed decisions about wireless technologies. An initial set of quantified requirements has been brought together for AMI and initial DA communications. This work area investigates the strengths, weaknesses, capabilities, and constraints of existing and emerging standards-based physical media for wireless communications. The approach is to work with the appropriate SDOs to determine the characteristics of each technology for SG application areas and types. Results are used to assess the appropriateness of wireless communications technologies for meeting SG applications. A complete list of PAPs addressed by NIST can be found in [13–15].

2.3 QoS Requirements in the SGCN

The SGCN is designed for large-scale emerging SG industrial applications. Therefore, its anticipated traffic is likely to be quite different from that generated by commercial and enterprise communications networks in use today. Specifically, the SGCN has to be robust and secure. High network availability is critical along with predictable sub-second convergence for any failures. The network should possess a degree of fault tolerance for increased resiliency and have the ability to self-recover. Additionally, the network should support a secure end-to-end transport layer ensuring confidentiality, integrity and privacy of the data for meeting North American Electric Reliability Corporation-Critical Infrastructure Protection (NERC-CIP) regulatory requirements [16, 17].

However, specific requirements vary based on the nature and objectives of the deployed SG application. For example, critical information required for stable and reliable grid operation will be time sensitive and thus have stringent latency requirements. Furthermore, even specific SG applications may require multiple priority settings based on the context of the grid operation. For instance, the desired QoS differentiation for periodic meter reads will vary based on whether the grid is operating in a conventional manner, during an outage or with other active applications that need real-time information (e.g., demand response). Therefore, the SGCN is faced with two important QoS factors: a wide range of latency, bandwidth, security and reliability requirements and the need for dynamic flow priority associations based on grid condition and operation [19].

With that in mind, an in-depth description of anticipated SG applications, extracted from various technical documents including [16–23], is presented below where the applications are classified based on their network association. Specifically, the three main groups are (i) home and AMI, (ii) substation networks and (iii) distribution networks. Further, Table 2.2 gives a summary of the various types of SGCN traffic and their respective bandwidth and latency requirements.

2.3.1 *Home and AMI Networks*

Home and AMI network applications handle the two-way communication between the consumer and the SG. In the uplink direction, from consumer to control center, application communications can range from periodic meter reads to failure notifications. In the downlink direction, from control center to consumer, applications can allow for optimization of electricity usage. In particular, three main classifications can be presented: (i) electricity usage applications, (ii) electric grid state applications, and (iii) demand optimization applications.

Table 2.2 SGCN traffic types and their required QoSs

Traffic type	Traffic regularity and data rate	Latency
Home and AMI networks		
In-home communications	Regular/on-demand A few kbps per device	$2 \sim 15$ s
Meter reads	regular/on-demand A few bps $\sim$ kbps per meter	$2 \sim 15$ s; 100's of ms (for advanced applications)
Connects and disconnections	Occasional Very low rate	Long (customer moving); 100's ms (fast responses to grid conditions)
Outage management	Occasional Low rate	Near real-time (10's of ms)
Demand response (DR)	Occasional/on-demand 10's of kbps	500 ms (mission-critical) up to several minutes (load balancing)
Power trading information	Periodical Low rate	10's of seconds
Substation networks		
Synchrophasor	Occasional/on-demand $600 \sim 1{,}500$ kbps	$20 \sim 200$ ms (monitoring and control); Long (historical data)
SCADA	Polling $10 \sim 30$ kbps	$2 \sim 4$ s
Inter-substation	Regular Variable rate	$12 \sim 20$ ms
Site surveillance	Periodical/event-triggered A few Mbps	A few seconds
Distribution network		
FLIR	Event-triggered $10 \sim 30$ kbps	Real-time
Distribution automation	Periodical A few Mbps	$25 \sim 100$ ms
Event notification signals	Occasional/event-triggered Burst of data	Near real-time
Asset management	Periodical/on-demand Variable rates	Variable latencies
Workforce access	Occasional 250 kbps or higher	150 ms or lower

2.3.1.1 Electricity Usage Applications

At the home level, usage monitoring applications can be used to transfer instantaneous electricity usage for each device to the SM. The transmitted data is typically only a few kbps per device and the latency is not critical and could be between 2 and 15 s [18, 22, 23]. With this information, HAN applications can then optimize home electricity usage and thereby reduce overall home power consumption.

At the neighbor level, aggregate energy consumption information is transmitted by SMs (for each home) on a periodical basis. The associated traffic is predictable and has long latency requirements. For conventional meter readings, only basic power use information is considered and thus the required data rate is very low, i.e., only a few bits per second (bps) per meter, and the latency is in the range of 2–15 s. As they are done on a periodic basis, only medium reliability is required but high security is still necessary to ensure a safe and secure SG [19]. However, for advanced applications (e.g., power quality monitoring, advanced distribution automation, etc.), many other parameters (e.g., active and reactive power, phase and frequency) need to be collected at much higher frequencies. Each meter may therefore need higher data transmission rate and require more stringent latency [16, 18]. For instance, for critical and priority AMI data, based on grid operating conditions, the delay allowance drops to 250 and 300 ms, respectively [21–23].

2.3.1.2 Electric Grid State Applications

The state of the electric grid can change with either scheduled modifications in consumer connects/disconnects or with failures. In the case where customers move, the change to the grid state is in response to a planned event and thus long latencies are tolerated and the triggered connect/disconnect does not affect overall grid performance. However, when connect/disconnect operations are used as responses to grid conditions, in order to ensure grid stability and reliability, the required latency may drop to only a few hundred milliseconds [24].

Further, in the event of a power outage, i.e., short circuits, failures at power stations and damage in transmission and/or distribution lines [25], fast response is necessary. Traditionally, outages are reported via phone calls from customers. However, to enable fast outage detection and recovery, the SG allows for outage management systems (OMSs) that are used to predict outage location, provide outage analysis and allow for service restoration. Moreover, the OMS can be enhanced with the inclusion of near real-time data exchanged between SMs and control centers. With this integration, SMs can act as a trip wire to indicate the loss of power at an end-point. They can be programmed to automatically give a “last gasp” message to indicate that they have lost power, thereby providing the utility company with valuable information for pin-pointing the origins of the outage [26]. Additionally, with this notification system, utilities can forego the extra manpower required for accurate outage reports and analysis. As outage management is a critical function of the SG, this type of message falls under the critical AMI setting and requires latency within the 250-ms range to ensure grid reliability.

2.3.1.3 Demand Optimization Applications

As the SG allows for near real-time electricity consumption information, it includes the ability to optimize electricity usage. For example, the Demand Response (DR) application allows utilities to communicate with home devices such as load controllers, smart thermostats and home energy consoles in an attempt to reduce or shift power use during peak demand periods and thereby mitigate the need for rolling blackouts. In particular, with direct load control, this power usage shift can be triggered by a simple switch-off command to an appliance and thus its bandwidth requirement is quite low, i.e., few tens of kbps [18]. Estimates of the latency requirements of DR fall into a wide range, from as little as 500 ms (e.g., for mission-critical control messages) up to several minutes (e.g., for load balancing management) [16, 18].

Furthermore, customers can participate through demand pricing. Specifically, the nodal market price for power will vary every 5 min and customers opting for dynamic power pricing can buy their power under current market conditions. This means that a water heater, for example, would receive the information and could use it to decide when to run and when to remain idle. All nodal pricing will need to be available in a centralized manner in one place for some market traders. Others will just want selective data. The exact format of this information is unknown at this time, but it is expected that individual nodal price updates will be small, perhaps 1,400 bytes in size.

2.3.2 Substation Networks

At the substation level, substation automation systems (SAS) are designed for monitoring, control and protection of substation devices. These applications perform actions based on collected real time data. To that effect, communications in this setting is critical and should be highly reliable, scalable, secure and cost-effective [25]. As for communications between substations, emerging applications such as distributed energy resources and distribution automation rely on communications with strict latency requirements from 12 to 20 ms [16, 22, 23]. Specifically, most substation SG applications can be categorized as either monitoring or control applications, some examples are presented below.

2.3.2.1 Monitoring Applications

Wide area situational awareness (WASA) refers to the implementation of a set of technologies designed to improve the monitoring of the power system across large geographic areas and thus respond to power system disturbances and cascading blackouts in an efficient manner. One of its primary measurement technologies is synchrophasor.

Synchrophasor traffic has varying levels of latency requirements. For real-time monitoring and control, latency requirements are very stringent, i.e., from 20 to 200 ms. Specifically, latency requirements are in the range of 60 ms for measurements, 100 ms for phasor measurement units (PMUs) clock synchronization and 500 ms for PMU data. For post-event, historical data, low latency is less imperative [18, 22, 23, 27]. The required bandwidth is between 600 and 1,500 kbps and its main factors are the number of PMUs, word length, number of samples and frequency [16, 18, 22, 23]. Additionally, synchrophasors require a more stringent reliability of approximately 99.99995 % which equates to being out of service for 16 s year^{-1} [18].

Additionally, monitoring of transmission lines is crucial for detecting icing, overheating and lightning strikes. In this case, the monitoring scheme includes deploying wireless sensor nodes on some transmission line parts and using relays to gather the transmission line condition information. However, the specifics of communications requirements vary based on the network model, the number of nodes and the preferred communication technology [25].

Furthermore, substation surveillance applications are proposed for enhanced security. These applications require high bandwidths of up to a few Mbps, especially for video surveillance, and the primary factors for bandwidth usage are the number of cameras and the video's resolution. This traffic type can tolerate latencies of a few seconds [16].

2.3.2.2 Control Applications

The standard substation control application is SCADA or Substation Supervisory Control and Data Acquisition. It considers the traffic generated when the master periodically polls IEDs inside the substation. The required bandwidth depends on the number of polled devices and it is forecasted to be around 10–30 kbps. The latency requirement is typically from 2 to 4 s [16, 17]. However, under certain grid conditions, latency requirements are more stringent. For instance, load shedding for underfrequency has a delay allowance of only 10 ms, SCADA critical measurements for poll response require 100 ms, most distribution and SCADA applications require 250 ms. In the second range, SCADA applications include image files, fault recorders, medium speed monitoring and control information, low speed observation and measurement information, text strings, audio and video data streams [21]. Additionally, high security and reliability are required [19].

2.3.3 Distribution Network

At the distribution level, SG applications are mainly employed for two main objectives. First, distribution network communications can be used to detect failure events. Second, communications in this segment can be incorporated to optimize electricity distribution, utility assets and even workforce access.

2.3.3.1 Grid State Applications

When communications are incorporated to detect failures, data will be sent from event/fault recorders whenever an event occurs. An event, for example, might be a lightning strike followed by a set of circuit breakers that trip in response. Sampled waveforms of a number of voltages and currents at 5 kHz for seconds are possible. This data can be quite large when compared to many of the other types of information that are passed around the system. These files will be sent after the fault has occurred, meaning that they normally do not interfere with the current situation. However, if a fault occurs, and it is followed by another fault, then interference could occur. Similarly, if a line is faulted and a device, known as an auto recloser, attempts to reconnect the line, then this could cause a second fault.

When these notifications are sent, the Fault Location, Isolation and Restoration (FLIR) application is used to restore the grid. Since this application is related to grid stability, it has very low latencies requirements in the range of a few milliseconds. Specifically, high speed protection information requires 8–10 ms of delay. Breaker reclosures, lockout functions and many transformer protection and control applications need 16 ms. Finally, some lower priority protection and control applications can tolerate latencies of up to 500 ms and 1 s [21]. The primary factors for its bandwidth usage include the circuit complexity and number of communication steps involved before the fault can be isolated. FLIR typically requires from 10 to 30 kbps [28].

2.3.3.2 Distribution Optimization

Distribution automation (DA) is the service that deals with volt/var and power quality optimization on the distribution grid. In particular, it optimizes the flow of electricity from the utilities to consumers in order to enhance the efficiency and reliability of power delivery. Generally, wide-spread inclusion of DA is expensive but it becomes more important in scenarios with distributed energy resources. This service may generate from 2 to 5 Mbps of traffic and require 25–100 ms of delay bound [29]. Further, high security and reliability are necessary [19, 22, 23].

Asset management is the service for predictively and pro-actively gathering and analyzing non-operational data for potential asset failures. Specifically, it offers management, automation, tracking, and optimization of the work order process, field crew scheduling and field assets [25]. Further, with the introduction of “smart” sensors and monitoring equipment that allow for communications, asset management systems can balance the performance of the system, avert risk of failure and enhance reliability. With that in mind, the primary drivers for bandwidth in this case are the number of assets and the amount of non-operational data that needs to be monitored to predict the health of the asset. As for workforce access, it provides expert video, access to local devices and voice communications with field workers. It typically requires 250 kbps of bandwidth and 150 ms of latency [16, 17, 22, 23]. Specifically, when considering the mobile workforce, latency requirement for enterprise data is around 250 ms, while those for real-time video and push-to-talk Voice over Internet Protocol (VoIP) bearers/signaling are around 200 and 175–200 ms, respectively [21].

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References

1. *IEEE Standard computer dictionary: A compilation of IEEE standard computer glossaries*, Institute of Electrical and Electronics Engineers Std., 2003.
2. "Institute of Electrical and Electronics Engineers." [Online]. Available: http://www.ieee.org.
3. "National Institute of Standards and Technology." [Online]. Available: http://www.nist.gov.
4. "American National Standards Institute." [Online]. Available: http://www.ansi.org.
5. "International Organization for Standardization." [Online]. Available: http://www.iso.org.
6. "International Telecommunication Union." [Online]. Available: http://www.itu.int.
7. "ZigBee Alliance." [Online]. Available: https://www.zigbee.org.
8. "WiFi Alliance." [Online]. Available: http://www.wi-fi.org.
9. "Home Plug Poweline Alliance." [Online]. Available: https://www.homeplug.org.
10. "Z-Wave Alliance." [Online]. Available: http://www.z-wavealliance.org.
11. "IEEE Smart Grid." [Online]. Available: http://smartgrid.ieee.org/standards.
12. *Draft Guide for Smart Grid Inter-operability of Energy Technology and Information Technology Operation With the Electric Power System (EPS), and End-Use Applications and Loads*, IEEE P2030 Std., 2011.
13. *NIST framework and roadmap for smart grid inter-operability standards, release 1.0*, Special Publication 1108, National Institude of Standards and Technology Std., 2010.
14. *NIST framework and roadmap for smart grid inter-operability standards, release 1.0*, Special Publication 1108R2, National Institude of Standards and Technology Std., 2012.
15. *Preleminary discussion draft - NIST framework and roadmap for smart grid inter-operability standards, release 3.0*, Special Publication 1108R3, National Institude of Standards and Technology Std., 2014.
16. Y. Gobena *et al.*, "Practical architecture considerations for smart grid WAN network," in *Proc. Power Systems Conference and Exposition (IEEE/PES)*, 2011, pp. 1–6.
17. K. Hopkinson *et al.*, "Quality-of-service considerations in utility communication networks," *IEEE Transactions on Power Delivery*, vol. 24, no. 3, pp. 1465–1474, Jul. 2009.
18. "Communications requirements of smart grid technologies," US's Department of Energy, Tech. Rep., Oct. 2010.
19. E. W. Gunther *et al.*, "Smart grid standards assessment and recommendations for adoption and development," EnerNex Corporation, Tech. Rep., 2009.
20. *IEEE standard communication delivery time performance requirements for electric power substation automation*, IEEE 1646-2004 Std., 2011.
21. G. D. Jayant *et al.*, "Differentiated services QoS in smart grid communication networks," Alcatel-Lucent, Tech. Rep., 2011.
22. Q. D. Ho, Y. Gao, and T. Le-Ngoc, "Challenges and research opportunities in wireless communications networks for smart grid," *IEEE Wireless Communications*, pp. 89–95, Jun. 2013.

23. Q. D. Ho and T. Le-Ngoc. *Smart grid communications networks: Wireless technologies, protocols, issues and standards*, Chapter 5 in Handbook on Green Information and Communication Systems (Editors: S. O. Mohammad, A. Alagan, and W. Isaac), Elsevier, Summer 2012.
24. "Distribution operations curtails customer load for grid management," SCE Internal, Jan. 2010.
25. V. C. Gungor *et al.*, "A survey on smart grid potential applications and communication requirements," *IEEE Trans. on Industrial Informatics*, vol. 9, no. 1, pp. 28–42, Feb. 2013.
26. "Outage management: The electric utilityŠs no.1 headache," TROPOS networks, Tech. Rep., Jul. 2007.
27. "Sychrophasor architectural issues," NASPINET Initiative.
28. G. Hataway, T. Warren, and C. Stephens, "Implementation of a high-speed distribution network reconfiguration scheme," in *Proc. Power Systems Conference: Advanced Metering, Protection, Control, Communication, and Distributed Resources*, Mar. 2006, pp. 440–446.
29. "Voltage regulation and protection issues in distribution feeders with distributed generation," SCE, Jan. 2010.

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