Surveying and Enhancing Grid Resilience Sensor Communications:
An Amalgam of Narrowband, Broadband, and Hybridizing Spread Spectrum

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***Abstract*—Distribution utilities engaged in the operationalization of more "resilient, adaptable architectures" have begun to instantiate amalgams of broadband, narrowband, and hybridizing techniques (e.g., spread spectrum, among others) to bridge the gap between broadband and narrowband (e.g., by enhancing the resiliency of narrowband signals) by lowering power requirements while extending coverage so as to develop a more robust communication network; this more resilient communications paradigm better facilitates "expeditious outage response capabilities." This paper presents such an architectural instantiation.**

Keywords—Grid resilience; broadband; narrowband; hybridizing techniques; spread spectrum; communication network; expeditious outage response capabilities.

I. INTRODUCTION

Various splinter lines of efforts (e.g., weather sensors) related to the grid resiliency efforts in the Indo-Asia-Pacific have led to successful instantiations of amalgams of broadband, narrowband, and hybridizing techniques (e.g., spread spectrum, among others) to bridge the gap between broadband and narrowband (e.g., by enhancing the resiliency of narrowband signals) by lowering power requirements while extending coverage. Hyper-locale weather sensors have served as a common thematic for Oceania and Southeast Asia and associated working sessions have increased in cadence. These hyper-locale weather sensors, as just one exemplar, are emblematic of the need for honed communications techniques, so as to fully enable the reliability and economic potential, for ecozones (e.g., Oceania, [Brunei [Darussalam]-Indonesia-Malaysia-Philippines East [Association of Southeast Asian Nations] ASEAN Growth Area] BIMP-EAGA, etc.) that are comprised of geographically disparate and varied characteristics.

Hyper-locale weather information (without resorting to the need for reach-back processing) has served as a fundamental requirement for local fisherman and remote businessmen, alike; accordingly, hyper-locale weather sensors (which only the locals would have) provide incredible insight into the pattern of life for upcoming days and weeks (e.g., it is a good day for fisherman to put out to see, it is a good day for businessfolk to trade/travel, etc.). Contextual awareness is a common thematic (in terms of need) for Oceania and Southeast Asia. As regional cohesion between Oceania and Southeast Asia Increases (e.g., 2022 Asian Games to includes athletes from Oceania), the investment potential in Oceania is at an inflection point; the correct amalgam of Broadband, Narrowband, and Hybridizing Techniques (a.k.a. BNHT) can help facilitate this potential. The purpose of this paper is not to choose singularly among the various IoT devices, but to utilize an appropriate amalgam of existing IoT devices according to the situation and conditions, so that the stability and quality of the involved communications network closely approximates what is desired.

Section I provided an introduction. The remainder of this paper is organized as follows. Section II describes related works regarding narrowband, broadband, and spread spectrum. Section III provides details regarding the Internet of Things (IoT) and non-IoT, and Section IV discusses the Long Power Wide Area (LPWA) technologies such as Narrowband-IoT (NB-IoT), Long Range Wide Area Network (LoRaWAN), LoRaWAN Extended, and SigFox. Section V is explained about smart switch and finally, interim conclusions are summarized in Section VI.

II. NARROWBAND, BROADBAND, AND SPREAD SPECTRUM

Communication sensors that are built according to the theme in this study consist of 3 types, namely narrowband, broadband, and hybridizing techniques (e.g., spread spectrum).

A. Narrowband

Transmission technologies differ according to how much of the wireless spectrum the associated signal utilizes (e.g., whether a wireless service uses narrowband or broadband signalling). For narrowband, a transmitter concentrates the signal energy at a single frequency or in a very small range of frequencies [1]. For a communication system utilizing narrowband transmission technology, the system will keep the bandwidth as narrow as possible to transmit the signal. The disadvantages of narrowband transmission are that it is highly susceptible to jamming and interference. This is due to the limited bandwidth utilized. Jamming relates to network interference caused by a very large power that transports signals that are not needed through the same bandwidth as the signal needed. Consequently, a signal with lower power will be marginalized/blocked. Examples of narrowband technology are the IEEE-802.15.4g standard

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utilizing a 12.5 kHz, T-1 at 1.54 Mbps via fibre optic, infrared, microwave, or two pairs of cables.

B. Broadband

Broadband has been central community networks around the world for over a decade and can be regarded as one of the mainstay technologies amidst the evolution of the internet network. Both the technologies and products of broadband internet networks are developed by Internet Service Providers (ISP). The trending of broadband makes internet access relatively inexpensive and easy (but quality is another issue). Historically, broadband technology has influenced the widespread use of the Internet [2]. There are two kind of broadband technologies: fixed broadband technology and mobile broadband technology. Fixed broadband is a technology wherein the end user must be at the same location to utilize the broadband service, while the mobile broadband technology (e.g., third generation or 3G, fourth generation or 4G, and fifth generation or 5G) can utilize the broadband service from any physical location.

Fixed broadband technology has several ways, namely Digital Subscriber Line (DSL) Fixed Wireline Broadband, Cable Fixed Wireline Broadband, and Fiber Fixed Wireline Broadband. Figure 1 describes the traditional DSL services (e.g., Asymmetric Digital Subscriber Line (ADSL), Very High Bit Rate Digital Subscriber Line (VDSL), etc.) is one way to have fixed wireline broadband services [1]. In DSL access, the traditional copper lines of the telephone network are equipped with digital subscriber line technology. Currently, in many countries in the world, DSL is the most common access network technology and is most commonly used by the public.

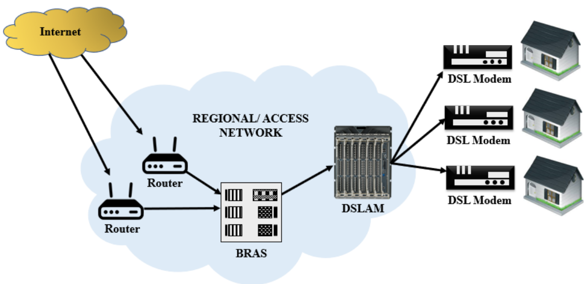

Figure 1. DSL Deployment and the Component [3]

Broadband utilizes wider frequency bands of the wireless spectrum and offers higher throughputs compared to narrowband technologies. A narrowband frequency is 3-500 kHz and a broadband frequency is 1.8-86 MHz.

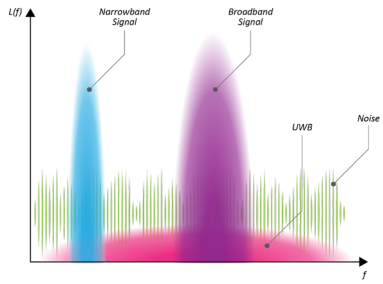

Figure 2. Narrowband and Broadband Signal [4]

Narrowband communication channels have long been used in many applications that depend on achieving reliable links in different operating environments, such as military tactical radios and industrial monitoring requirements. But because more information has to be conveyed between the two points by wireless means, such as for video streaming and sophisticated surveillance systems, broadband communication channels with greater data capacity are becoming more attractive.

Figure 2 explains that narrow band signals occupy much less frequency spectrum and require less transmit power for a given application than wide band signals, while Ultra-Wideband (UWB) signals are short pulses that send information while briefly occupying a large part of the traditional communication frequency spectrum. This is done to send and receive more voice, video, and data over a wider bandwidth frequency channel, which means it costs money, because a wider part of the frequency spectrum also contains more noise sources and higher noise levels [4].

C. Spread Spectrum

Spread spectrum is a form of wireless communication that utilizes multiple frequencies to transmit a signal. Spread spectrum technologies provide robustness to a variety of unintentional forms of interference that are found to impact a communications system, such as interception of signals, jamming, and multipath. One of the advantages of spreading a signal over a wide frequency band is that is requires less power per frequency than narrowband signalling [5].

Spread spectrum techniques were originally utilized by military communications system during World War II. Spread spectrum is more secure than narrowband and broadband signalling because, by way of example, the frequency hopping channel numbers are only known to the authorized receiver and transmitter of the information. The receiver must utilize the exact same hopping sequence to receive information from the transmitter. Consequently, it is extremely difficult for unauthorized receivers to decode and access the information. The two most common forms of spread spectrum are Frequency Hopping Spread Spectrum (FHSS) and Direct Sequence Spread Spectrum (DSSS).

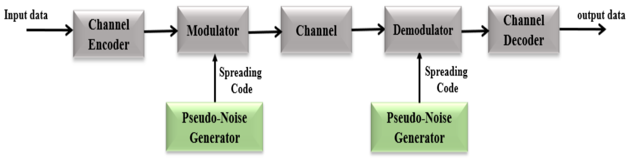

Figure 3. Model of Spread Spectrum Digital Communication System [6]

In FHSS transmission, the existing frequency is divided into multiple parts and then sent across the air in a random pattern of radio frequencies, hopping from frequencies to frequencies at fixed intervals. During that interval, some number of bits is transmitted utilizing some encoding scheme. Both transmitter and receiver channel utilize the same code to tune into a sequence of channels in synchronization.

In DSSS, the original data signal is multiplied with a pseudo random noise spreading code. The spreading code spreads the signal across a wider frequency band in direct proportion to the number of bits used. This spreading code has a higher chip rate, which results in a wideband time continuous scrambled signal. Different variants of spread spectrum techniques are used. Long Rang (LoRa) utilizes Chirp Spread Spectrum (CSS) while IEEE-802.15.4g (a standard for Smart Utility Network or SUN communications, which are an essential part of the smart grid), Ingenu (Low Power Wide Area network or LPWAN implementation), and Weightless-P (ultra-high performance LPWAN) utilize Direct Sequence Spread Spectrum (DSSS).

Figure 3 explains the general model of spread spectrum digital communication system. First, Spread Spectrum input the data into a channel encoder. Then, the data produces analog signal with Narrow Band width. Signal is further modulated using sequence of digits, spreading code, and spreading sequence. Spreading code generated by pseudo-noise or pseudorandom number generator. The effect of this process is demodulation which is used to increase the bandwidth of the signal to be sent and recovered data [6].

III. IoT and non-IoT

An Internet of Things (IoT) platform is a set of technology-enabled entities including physical smart objects, as well as systems and software services that are connected together [7]. There are four main components of an IoT system, namely the “thing” or object (e.g., sensors, actuators, etc.), the local network (e.g., gateway), the Internet, and back-end services (e.g., personal computer [PC] or mobile devices). The communication network for IoT can be construed in two parts: cellular and non-cellular. Cellular IoT hardware is typically equipped with Subscriber Identity Module (SIM) cards and connected to networks via 2G, 3G, and 4G, while non-cellular IoT are connected via wireless network.

The “things” in IoT need Internet Protocol (IP) address, as the “things” are mostly servers, switches, firewalls and routers, laptops, phones, and tablets with IP to IP connectivity. An IP address is an address or numeric identity that is given to a device so that the device is identified and can communicate with other devices. IP addresses can be further sub-divided in two, namely IP static and IP dynamic. IP Static is an IP address that is set or manually set by a network admin so that this IP address will not change automatically, unless it is manually changed by the network admin. The advantages of utilizing IP Static on communication network are that it is easy to remember a host, it is suitable for small-scale networks, and the router is set up with a static IP as well. IP Dynamic is an IP address that is set or set through a router that has been set up as a Dynamic Host Configuration Protocol (DHCP) Server, where the DHCP Server functions to provide an IP address automatically to each host connected to the network so that a computer connected to the network does not need to set the IP address again because it has been given one by the router. The advantages of utilizing IP Dynamic on communication networks are that it is suitable for large-scale networks, it facilitates the networks admin setting IP addresses, and no IP address collision will likely occur.

IV. Low Power Wide Area (LPWA) Technologies

LPWA technologies are a generic term for a group of technologies, which enable wide area communications at lower cost point and improved power consumption. LPWA has become one of the fastest growing area within IoT. Many LPWA technologies have developed in both the licensed and unlicensed bands, such as Narrow Band (NB-IoT), Long Range (LoRa), SigFox, etc. Solutions based upon the LP-WAN paradigm have a long coverage range of about 10 km and high-power efficiency that facilitates lifetimes for end-devices to about 10 years [8].These achievements are attained by making use of the following strategies: transmitting data at very low bitrates, making use of low frequency bands (sub-GHz bands), and limiting the communication capabilities of the end-devices (number of messages per day) [9].

A. Narrowband Internet of Things (NB-IoT)

NB-IoT is a new 3rd Generation Partnership Project (3GPP) technology released in June 2016. NB-IoT is designed to achieve excellent co-existence performance with General Packet Radio Service (GPRS), Global System for Mobile (GSM), and Long-Term Evaluation (LTE). NB-IoT can provide 50-100 times access to the existing wireless technology. NB-IoT has a 200 kHz wide carrier, which contains 12 Orthogonal Frequency-Division Multiplexing (OFDM) (a method of digital signal modulation in which a single data stream is split across several separate narrowband channels at different frequencies to reduce interference and crosstalk) subcarriers and unlicensed frequencies in the 700, 800, or 900 Mhz bands to assist with signal penetration in-building. NB-IoT increases the gain of 20dB and expects to cover the inaccessible places, such as underground pipelines, basements, etc [10]. NB-IoT supports three different operational modes: stand-alone operation, guard-band operation, and in-band operation.

The NB-IoT communication protocol is considered to be a new air interface for LTE. NB-IoT reduces LTE protocol functionalities to the minimum and enhances them as

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required for IoT applications [11]. For example, the LTE backend system is used to broadcast information that is valid for all end devices within a cell. As the broadcasting back-end system obtains resources and consumes battery power from each end device, it is kept to a minimum in size, as well as in its occurrence. It was optimized to small and infrequent data messages and avoids the features not required for IoT purposes, e.g., measurements to monitor the channel quality, carrier aggregation, and dual connectivity. Therefore, the end devices require only a small amount of battery, thus making it cost-efficient [11].

B. LoRaWAN

LoRa is a network technology solution for wireless battery-operated devices. LoRa uses unlicensed Industrial, Scientific, and Medical (ISM) bands, i.e., 868 MHz in Europe, 915 MHz in North America, and 433 MHz in Asia. LoRa allows long range communication (between 2-8 km in urban areas and 15-20 km in rural areas) with low power consumption. LoRa has the goal of providing secure bidirectional communication [12]. LoRa utilizes a chirp spread spectrum spreading modulation technology (can use one or more channels), which enables low energy consumption, end-to-end secure communication with low data rates [13]. The spread spectrum provides orthogonal separation between signals by using unique spreading factor individual signal. This method provided an advantage in managing data rate [14]. The resulting signal has low noise levels, enabling high interference resilience, and is difficult to detect or jam [15]. LoRa does not deploy a LBT (Listen-Before-Talk) feature; instead, it utilizes the duty cycle restrictions required by regulation and the maximum dwell time [16].

The technology is presented in two parts: Lora (the physical layer) and LoRaWAN (the communication layer), which an open source communication protocol defined by the LoRa Alliance. One of the most interesting features of LoRaWAN is the possibility of configuring certain transmission configuration parameters, enabling longer coverage ranges, greater transmission bit rates, and enhanced communication robustness [17]. LoRaWAN defines three classes for end point devices to address the different needs reflected in the wide range of possible application: Bi-directional end devices (Class A), Bi-directional end devices with scheduled receive slots (Class B), and Bi-directional end devices with maximal receive slots (Class C). LoRa and LoRaWAN layers can be seen in Figure 4 below.

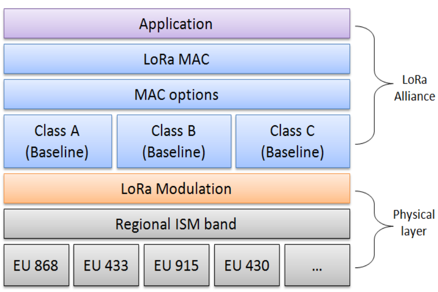

Figure 4. LoRa and LoRaWAN layer [18]

The system architecture comprises end devices, gateways, and a network server. End devices transmit directly to all the gateways within range utilizing LoRaWAN. LoRaWAN gateways correspond to base station in a cellular network, as well as communications between the end devices and the network server based upon Internet Protocol (IP). The end devices typically have sensors, LoRa transponders to transmit signal, and a micro-controller. Figure 5 presents the LoRaWAN architecture.

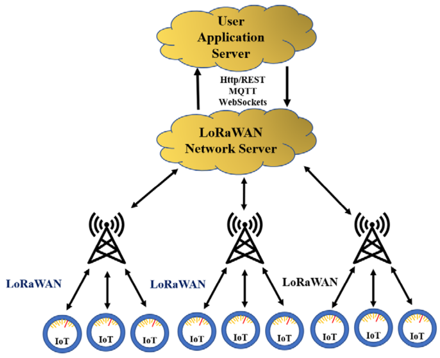

Figure 5. LoRaWAN Architecture [19]

C. LoRaWAN Extended

Low-power wireless networks are a key enabler for the Internet of things (IoT), but familiar options such as Bluetooth, Zigbee, Wireless Fidelity (WiFi), or cellular, lack an acceptable combination of extended range and battery life. To address this, new sub-GHz specifications are being offered, one of which is LoRaWAN.

LoRaWAN can achieve a 15 km range at power consumption levels low enough to enable 10-year battery life. Further, the availability of an off-the-shelf development kit lets designers quickly bring up the complete LoRaWAN network application with minimal effort. All seven layers of the OSI stack have a scope of LoRaWAN certification services with new LoRa Radio Frequency (RF) antenna performance requirements. In order to improve the range in a network with LoRaWAN technologies, the following aspects should be considered [20]:

- Gateway location: utilize outdoor antennas and increase the height of the antennas.
- Antenna selection
- High-quality connectors (N-connectors) and cables (LMR 400 or equivalent)
- Co-localization: avoid strong interference, for example from surrounding Global System for Mobile Communications (GSM) or Universal Mobile Telecommunications System (UMTS) stations.
- Installation of a LoRaWAN gateway should also ensure sufficient surge and lightning protection

D. SigFox

SigFox is a LPWAN network that utilized Binary Phase-Shift Keying (BPSK) modulation in a 100 Hz Ultra-narrow Bandwidth (UNB) sub-GHz band carrier to send small messages. SigFox utilizes unlicensed ISM bands, namely

868 MHz bands in Europe, 915 MHz bands in United States, and 433 MHz in Asia. SigFox utilizes the frequency bandwidth efficiently and experiences very low noise levels, high receiver sensitivity, very low power consumption, and has a low-cost antenna [21]. Initially, SigFox only utilized uplink communications, but eventually advanced by utilizing the bidirectional technology. The Ultra Mobile Broadband (UMB) modulation has limited data rates (100 bits per second), the maximum payload length for every uplink message is 12 bytes, and the maximum payload length for every downlink message is 8 bytes with a protocol overhead of 26 bytes. Despite the limitation, SigFox is suitable for IoT applications that are not time-crucial (e.g., monitoring water meters, air quality sensing, etc.).

Similar to LoRaWAN, the UNB modulation does not utilize LBT but applies duty cycle limitations per transmitter. The SigFox network architecture comprises devices and SigFox servers for an execution process in a cloud schema. Hence, the SigFox system is a cloud-based network system where data is passed to the backend server and customer portal directly [22]. The SigFox cloud system can automatically forward the messages utilizing a callback system. As the base stations can receive messages simultaneously over all the channels and observe the entire system bandwidth to detect and decode uplink data. The end device can randomly choose a frequency channel to transmit their messages. This simplifies the end device design and reduces its cost. Figure 6 presents the architecture of a SigFox network.

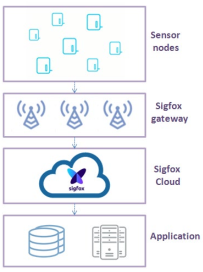

Figure 6. SigFox Architecture

Figure 7 explains the differences in NB-IoT, LoRaWAN, and SigFox technologies from several IoT requirements. Some IoT requirements consist of modulation, standardization, bandwidth, date rate, frequency, typical range, battery life, cost, and bidirectional. In the bandwidth category, LoRaWAN is better than NB-IoT and SigFox, which is 125 kHz and 250 kHz. Another advantage is that the battery life of LoRaWAN is much longer, i.e., up to 18 years and the cost is cheap. Behind the advantages of LoRaWAN, the weakness is in the data rate, which is only 50kbps, less than the NB-IoT 200 kbps and SigFox100 kbps.

Sensor communication can be broken down into 3 types, namely narrowband, broadband, and spread spectrum (hybridized technologies). For narrowband, wideband audio is one of the derivatives that show the development of narrowband technology. While broadband consists of 2 types, namely Fixed Broadband Technology (FBT) and Mobile Broadband Technology (MBT). Spread spectrum is hybridized techniques which can be categorized into IoT (IP address) and Non-IoT (Non-IP address). Figure 8 shows Architectural Instantiation of Sensor Communications, where in the spread spectrum derivative graph, LoRaWAN belongs to the category of IoT non-cellular.

IoT Requirements	NB-IoT	LoRaWAN	SigFox
Modulation	DBPSK	CSS	BPSK
Standardization	3GPP	LoRa-Alliance	SigFox company and ETSI
Bandwidth	200 kHz	125 kHz and 250 kHz	100 Hz
Data rate	200 kbps	50 kbps	100 kbps
Frequency	Licensed	Unlicensed ISM bands	Unlicensed ISM bands
Typical Range	1 km (urban), 10 km (rural)	5 km (urban), 20 km (rural)	10 km (urban), 40 km (rural)
Battery life	Up to 6 years	Up to 18 years	Up to 7 years
Cost	Expensive network	Cheap	High subscription cost to pay per devices
Bidirectional	Yes	Yes	No

Figure7. Comparison of NB-IoT, LoRaWAN, and SigFox Technologies

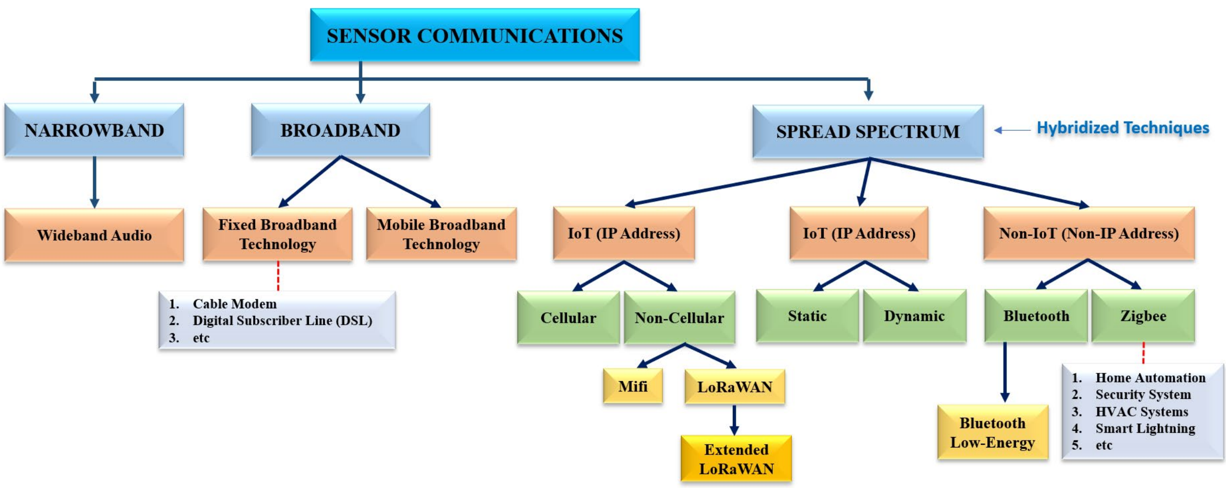

Figure 8. Architectural Instantiation of Sensor Communications

V. SMART SWITCH

Power utility companies utilize communication network so as to conduct real-time monitoring, protection, and optimization of the involved grid components including generation, transmission, and distribution. The planning and implementation of a communications network require the same attention as the installation of the power grid system itself. The communications infrastructure of power grid can be wired (e.g., fiber optic) or wireless. The advantages of the wireless infrastructure compared to the wired infrastructure are low costs and simple connection to distant and unreachable areas [23], whereas fiber optic can be expensive especially when deployed at the distribution level in large scale. Communication standards, such as Bluetooth, ZigBee, Z-wave, IPv6, wired Ethernet, cellular network, and wireless Ethernet (e.g., Wi-Fi) are a few of the standards that can be considered for adding connectivity to a power grid system.

The main challenges for a communications network system are loss of communication, data loss or latency, denial of service, as well as jamming of the Radio Frequency (RF) signal [24]. A smart network switch can be utilized with regards to loss of communications or latency problems. Smart network switching enables the system to automatically switch from an unstable Wi-Fi network (non-cellular) to cellular data or mobile network. This allows the system to preserve a consistent network connection and maintain a high level of connectivity.

The smart network switch is capable of transmitting and receiving signals to and from other devices (modules). Smart network switch utilizes requirements to support the system, such as multiple transceiver types or speeds including control, flexible low latency data inspection and data path manipulation capabilities, comprehensive and fast configuration and diagnostic interface (e.g., modes, queues), fast start-up including configuration, and powerful switch core. Additional requirements required by a smart network switch are time synchronization, Quality of Service (QoS), and security [25]. Smart switch consists of smart routing controller, open flow hybrid switch, and protocol convert module (see Figure 9) [26]. Smart routing controller executes the packet decision, open flow hybrid switch receive the decision command from open flow controller, and protocol converter module is a device utilized to convert standard or protocol.

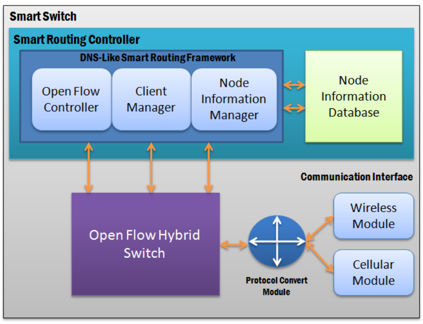

Figure 9. Smart switch architecture

Figure 10 below presents a general communication network and smart switch network embedded into a power grid system.

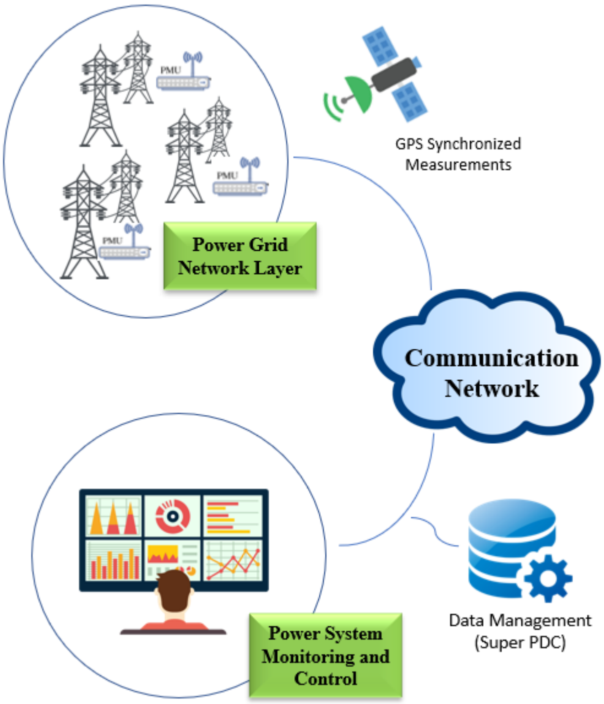

Figure 10. Communication network in power grid system

In Figure 9, the power grid system consists of power transmission infrastructures, communication networks, data management systems, and power grid monitoring and control center [27]. The information collection network is essentially a compound network consisting of satellite communications, Wi-Fi, cellular network, and internet. Smart network switches are embedded into the communication network system. Phasor Measurement Units (PMUs) are deployed over the power grid to monitor the state of the system. PMUs receive a common time reference from the Global Positioning System (GPS) satellites. The measurements from several PMUs are reported to a Phasor Data Concentrator (PDC). All collected data from the PDC are analyzed at a data management center for utilized for decision support. The power grid monitoring and control system receives instructions from the data management center and actuates the power system in real-time.

VI. CONCLUSION

In this paper, we presented a study on communications network technologies and recent trends of network technologies (e.g., Internet of Things [IoT] and Low Power Wide Area [LPWA] technologies, such as LoRaWAN, NB-IoT, and Sigfox) to develop a more robust communications system within a power grid. This paper discusses amalgams of narrowband, broadband, and hybridizing techniques (e.g., spread spectrum) for enhancing grid resilience sensor communications and provides an architectural instantiation for more robust sensor communications. In addition, the smart network switch has also been discussed, so as to resolve the loss of communications and/or latency problems within a power grid system. Overall, this paper presented an amalgam of broadband, narrowband, and hybridizing technique (e.g., spread spectrum) to bridge the gap between broadband and narrowband (e.g., by enhancing the resiliency of narrowband signals) by lowering power requirements while extending coverage so as to develop a more robust communication network; this more resilient communications paradigm better facilitates "expeditious outage response capabilities" for distribution utilities constitutes a more "resilient, adaptable architectures."

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