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Unleash Narrowband Technologies for Industrial Internet of Things Services

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***Abstract*—As the industrial market grows, it is becoming noticeable that there are many industrial Internet of things (IIoT) use cases for which existing technology can not meet the huge demand of machine connectivity. For example, in the utility market, there is a strong trend to adopt new technology that can support positive business use case scenarios for the efficient system operation and elaborate the dramatic increase of the services demand. Apart from this, most of utility grid applications required long-range, low-power, secure, and reliable communications, which is narrowband (NB) technology can be the dominant choice. To address these challenges, this article provides a new framework architecture to enable technical decision-makers to plan for NB-IIoT. Moreover, we highlight the key aspects of narrowband technology by focusing on the challenges, standardization, and requirements to facilitate the IIoT connectivity for industry revolutions. The motivation behind employing NB is to provide high level of reliability, better quality of service (QoS), and coverage. In particular, the article addresses the main applications of utility use cases under the NB umbrella, which can perform as a good bridge between utility services and the fundamental of communication infrastructure. The utility use cases based on emerging technology can support the full array of smart grid services that are required for both central and distributed operation systems. Finally, the article provides connectivity solutions for potential IIoT deployment aiming to define a new roadmap for the NB technology on specific industrial use cases.**

Introduction

UTILITIES are belligerently chasing wireless communication opportunities to formulate the industry of smart grid distribution in order to improve the operational system and to increase productivity. At the same time, narrowband (NB) is a new wave of technology that can support the grid reliability and accelerate the digital transformation. In fact, the opportunity of accessing the NB spectrum can open the door for new integration platforms, which are the key factors of industrial revolution [1]. The narrowband-Internet of things (NB-IoT) [2] and low power wide area network (LPWAN) are new wave of wireless communication technology, which can support both utility services and the market fragmentation challenges in terms of interoperability. The NB technology is anticipated to facilitate fast communication connectivity that is going to allow achieving higher levels of productivity and sustainability. The tremendous deployment of machines (e.g. sensors, actuators, etc.) may disclose various technical challenges and opportunities, which need to be overcome to meet the complex utility requirements [3]. Adopting NB-IoT schemes can facilitate the utility grid system to monitor and control their field devices remotely, resulting in promoting the power system to operate efficiently and economically. The new technology can act as a bridge interconnecting distributed energy resources (DERs) and control centers to provide real cooperation advanced utility markets. Thus, the utility providers need to develop their DERs, energy storage, electric vehicle (EV) and use interoperability standards through practical implementation, especially by considering industrial IIoT connectivity [4]. The main advantage of adopting low power technology is to enable the utility operators and consumers for real-time data flow monitoring [5]. Apart from this, modern grid [6] required communication systems that can support interoperability to handle high demands and improve the distributed grid behavior. In parallel, the evolution of emerging technology has continued to grow significantly through the past few years. The NB IoT utility market is connected with smart distribution systems including advanced smart metering and distribution management system (DMS) to enable power operators to maximize their energy efficiency. Given the wide-range of applications and services required by the smart grid environment, the utility industries are looking to modify their old-style communications infrastructure by focusing on specific applications when they selected their network technology. This approach can be crucial to shape up the prosperity of utility business, disclosing opportunities around new radio technologies, but it also raise several questions and concerns about the modern grid system design. The main motivation of industrial market is to adopt new technology by considering millions of different machines connected with each others causing a significant needs for additional bandwidth resources. Thus, employing NB will provide better coverage and additional bandwidth resources to connect a huge numbers of machines. Particularly, NB will add a value of enhancing the data delivery by overcome the problem of signal fluctuation when connected the machines remotely. Therefore, it is necessary to plan for new architecture for NB deployments. Where the new wave of communications technology will reinforce industrial-grade internet of things deployments to facilitate the system reliability and increased the capacity. To this end, utility operators adopting NB IIoT technology can maintain the interaction of general functionalities and improve the industrial productivity.

The main contributions of this article are:

1) NB-IIoT technology is introduced aiming to fulfill the high demand of industry services and applications. Adopting NB IIoT can bring various opportunities and solutions to the modernization market.

2) A new framework architecture is proposed to match the industry needs, where the IIoT can add contributions.
3) This article presents different use case scenarios to identify the advantages of the proposed architect. The key benefits of adopting NB IIoT use cases for utility market is to achieve cost-efficiency, to increase the coverage, to improve the battery life and system reliability.
4) Last, but not least, this article can be a roadmap guidance for potential NB technology deployment for specific industry use cases that may need more flexible infrastructure and higher bandwidth.

The article is organized as follows. Firstly, we present the main challenges and opportunities for the industry market. Then, we elaborate and highlight the standardization activities of NB technology, the market requirements and provide a feature comparison of communications technologies with respect to the market benefits. Finally, we demonstrate the prospective utility use cases.

Challenges and Opportunities

The telecommunications industry is expected to reach [7] massive connectivity growth from billion in the existing topology to around 50 billion by 2020 (Cisco, 2011) and beyond. The utility market predictions are relaying on the visible challenges and barriers for each power system operator and IIoT sector. Apart from this, modern utility grid is suffering from critical issues such as system uncertainty, especially in the big cities where disturbance events and loss of power energy often occur. A dramatic expansion of the new wave of technologies may require flexible connectivity to trigger critical communication infrastructures, which cannot be satisfied by the old-style power grid networks. To mitigate these challenges, for example in the utility sector the grid topology shape needs to be shifted from centralized to distributed style in order to facilitate a flexible network with dynamic data path. Many industrial utilities have fear from the digital revolution (e.g. IIoT), as they believe that this development can have a detrimental impact on their existing business style. In reality, this evolution will offer more opportunities to the power industrial sector to push their business ahead of the traditional model. In this framework, utility may need to consider smarter equipment integrated through IIoT technology to enable global vision of real-time monitoring. Focusing on the current opportunity of the smart grid communications market, most of the modernizers are working hardly to adopt NB technology scenarios, in the assumption that this technology can be implemented in their particular system model. The new area of NB is becoming increasingly valuable and easier to interconnect with the existing old-style power system. For example, sensors and other field equipments, which are responsible of capturing the critical information and deliver them via IIoT platform, are going to allow to create new great ”visions” and way of interoperability. These ”visions”, are result of independent decision-making and things connections through various industry sectors and market trends. Smart grid services (e.g. fault management) require an efficient use of advanced communication infrastructure and allowed new services to facilitate extra data exchange within control centre for better system analysis. The adoption of IIoT (see Fig.1) for utility industries will most probably offer new trends in the utility market [8] by connecting things, platforms, energy resources and other in a seamless and professional way.

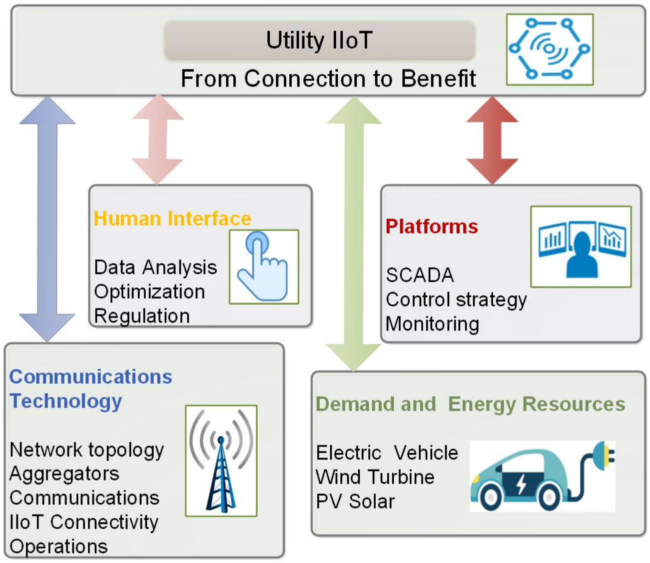

Fig. 1. Opportunities of utility industrial Internet of things.

Standardization of Narrowband Technologies

The portfolio of 3rd generation partnership project (3GPP) release 15 new radio technologies, has introduced the machine to machine (M2M) communication service for the utility sector. However, there is still a huge gap between the massive data of IoT devices and the capacity of long term evolution-machine (LTE-M) system. Most recently, the 3GPP started to identify a new item to regulate a new air-interface, known as NB-IoT, to facilitate the power and it is specially efficiency in the bands that are narrower than the LTE-M system, mainly working on the 200-kHz GSM bands, where an LTE-M system fails to work [9]. The new technology can provide interface enhancements for various industry market requirements including massive machine-type communication (mMTC) services to enable large-scale deployment of advanced metering infrastructure (AMI) and measurement devices, such as the phasor measurement unit (PMU). NB-IoT technology provides enhanced machine-type communication (eMTC) that can support supervisory control and data acquisition (SCADA) to facilitate the data aggregation, while still considering the system reliability. These enhancement in the radio access technology is very important to support real-time monitoring and measurement (e.g. PMUs) [10]. Modern eMTC need to cover a certain standard to be able to support distributed energy devices in the grid network infrastructure. For instance, the connectivity of intelligent electrical devices (IED) needs to be supported in such smart grid networks. For what concerns data processing, current measurements, voltage measurements and other electric data readings can be collected in the filed devices or transmitted to the higher layers of the grid communication infrastructure, such as SCADA systems.In order to enable the new technology in the utility grid sector, the architecture of grid services solutions using the communication network layer base on NB-IIoT connectivity is considered, as shown in Fig.2. The smart grid devices including smart metering, PMU, and remote terminal unit (RTU) are anticipated to deliver their aggregated data through IIoT platform using the eLTE infrastructure. By considering the eLTE core network, which involves service the gateways (S-GWs) to enable the data forwarding and packet gateways (P-GWs) to connect the eLTE and provide admission to the external networks (e.g. Internet).

Expanding the use of NB spectrum by introducing new wireless broadband services is obtainable from current communication functionalities that can support critical utility services. Practically, NB-IIoT can be deployed in three different operation modes (See Fig.3): In-band, Guard-band and Stand-alone [2]. Selection of an appropriate operational mode deployment is critical to recognize and react toward other wireless transmissions. The minimum bandwidth requirement is 200 KHz in order to operate the possible modes of the NB-IIoT. NB-IIoT systems will be able to take advantage of radio optimization In-band mode to enable ubiquitous spectrum utilization for a single resource block within a normal LTE carrier, while guaranteeing spectrum co-existence. It can be set up in LTE carrier's Guard-band utilizing unused resource blocks while reducing interference with nearby signals. In Stand-alone mode, NB-IoT can be positioned in to facilitate the reuse of existing second generation (2G) spectrum utilizing standalone 200 kHz carriers. NB-IoT standard allows reducing the interference issues when compared with other NB technologies by using a licensed spectrum. Particularly, there is a number of LPWAN-technologies (e.g. LoRa), considered as non-3GPP LPWA IoT solutions that can provide connectivity and multi-functions under the umbrella of the IIoT paradigm. For example, in Europe, LoRa employs unlicensed band from 863 MHz to 870 MHz, which limits the device transmission power to 14 dBm. Looking into the next future, LTE NB-IoT technology has a strong development potential, including Rel-14 enhancements and the path to NB technology for massive IIoT.

Low Power Wide Area Network Aspects

The new wave of radio emerging technologies is going to play an important role in the power grid domain, a development of enormous MTC can act as a foundational platform that can support a wide range of utility use cases. To make the IIoT real, the utility industry may need to employ a variety of wired/wireless technologies to establish multi-connectivity. The low-power technologies, for example, in the USA have been considered as an appropriate solution for the future power grid integration through a long distance, without absorbing high power energy. Low-power technologies have the functionality from LPWA [11] based on unlicensed band (e.g. LoRa) to licensed band (e.g. NB-IoT). Thus, the selection of the best technology is totally relying on the individual pilot project and market opportunities. LPWA technologies have emerged seems to meet the need of having a long distance network, with long battery life and a very low cost for both the end points and the required infrastructure. LPWAN as a solution has the potential to attract the utility industry by providing seamless market opportunity to support a variety of smart grid services and IIoT applications [12]. Many of the low power unlicensed technologies such as LoRa familiarized the simplification of LPWA connectivity, which can overcome the obstacles in the industry market disintegration and in the ecosystem development. Therefore, the LPWA technologies are highly suitable to the utilities use cases where range, battery life, and end point costs are essential whilst the required data rates are low. To understand why NB is uniquely suited to the specific business of industrial IoT deployments, we compare NB-IoT against IoT against other LPWA alternatives. Table I shows a comparison of well-known NB technologies in order to have a comprehensive overview of the different features and applications.

Requirements and Practices

Industry market when facing the emergence of new business models and utility use cases motivated by the consumers and the operators should develop their requirements. These basic requirements of the industry market will be generated both by the development of existing technologies and merging of new key technologies. Thus, the utility revolution goes step by step with the rapid growth of the demand for advanced communication infrastructure. This is not about the never-ending demand for higher bandwidth, but for new communications requirement to support emerging smart grid services. These may include data management, self-healing, distribution automation, and demand response. For example, NB-IIoT technology is added to the eLTE platform to optimize several power modules and meet the requirements of number of utility use cases in specific market segments. On the other hand, industrial utilities are moving forward to develop their data processing procedure, as shown in Fig. 4. However, most of them still do not consider the basic stages to overcome the practical issues that may affect their system behaviour in the old model. By considering the low power connectivity such as NB-IIoT, the utility provider can establish a reliable link between sensor/actuator and data control centre. All utilities infrastructure required wide area operation for real-time monitoring scenario motivated by less control functionality and low data rates. By addressing these challenges critical solutions of new wave of communication technology can pave the path of the power grid distribution layer and facilitate fast route to collect and monitoring the data. Hence, the effectiveness of a telecommunication system between the physical data layer and a control centre is going to help the current industry segment to monitor the real-time data in an efficient manner. The control system will check frequently an operational power grid over the IEDs in order to maintain the data flow. Database server and data analysis are part of data process delivery to help the practical applications of utility portfolio in several individual programs. From a consumer perspective, the utility grid applications required two-way communications to maintain the data energy flow and to meet the load demands. For example, the smart meeting needs full duplex communication

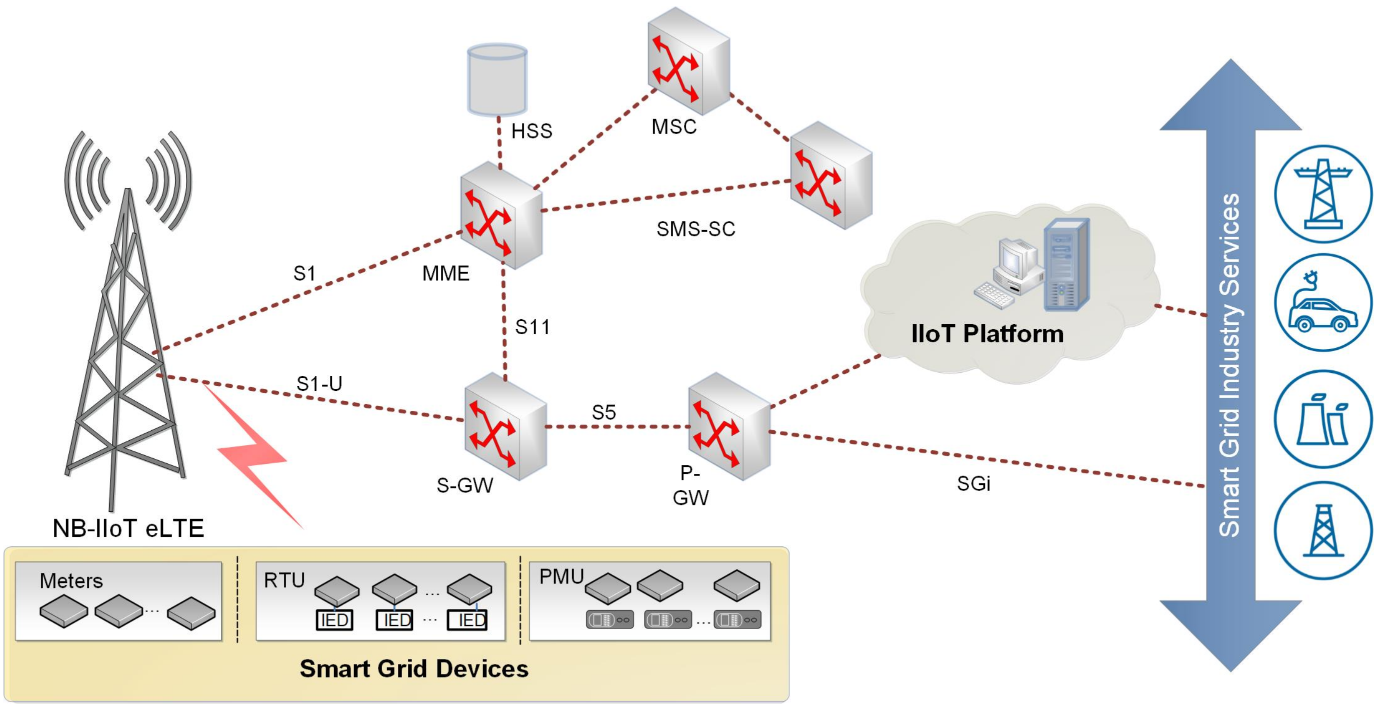

Fig. 2. NB IIoT architecture solution.

TABLE I
NARROWBAND TECHNOLOGIES COMPARISONS.

	Technology			
Features	**LTE-M**	**NB-IoT**	**eLTE**	**LoRa**
Range	<11 km	<15 Km	<15Km	<15Km
Specturm	Licensed	Licensed	Licensed	Unlicensed
Bandwidth	1.4 MHz	200 KHz	Shard	125 kHz
Data Rate	Medium-Low	Low	Very High	Low
Modulation	OFDM	GFSK/BPSK	OFDM	Chirp Spread Spectrum
Max Power Outage	30 dBm	20 dBm	20 dBm	20 dBm
Spectrum Efficiency	High	High	High	Very Low
Power Efficiency	Medium	Medium-High	Medium-High	Very High
Gateway Technique	Two-way communication	Two-way communication	Two-way communication	Two-way communication
Interference Immunity	Medium	Medium	Medium	Very High
Battery Life	>5 Years	>10 Years	>10 Years	>10 Years
Commercial Deployment Cost	Low	Low	Medium	Low
Scalability	High	High	High	Very Low
Security	Yes	Yes	Yes	Yes
Standard	3GPP Release 12	3GPP Release 13	3GPP Release 14	LoRaWAN2
Smart Grid Applications	SCADA, DER, DRM, WAMS, DA	AMI, DRM, DA	SCADA, WAMS, DER	AMI, Home automation, DA

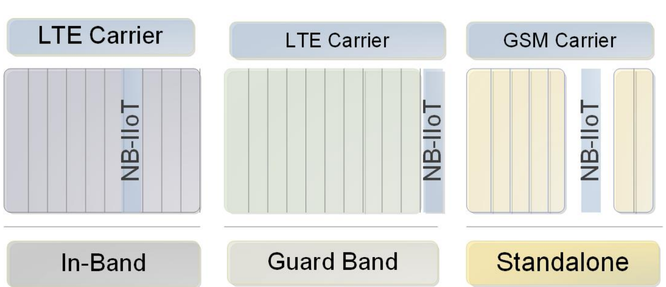

Fig. 3. Narrowband operation modes.

mode to guarantee the data exchange between the consumer and the utility grid applications (e.g. management). Therefore, the wide range options of communication technology solutions are really based on the consumers requirements. The NB technology could be the best option if the data metering and signals for price are to be delivered. For other application services such as the EV connectivity when in a charging station need to be managed and the full range of communication technologies need to be considered (e.g. NB, LTE, Fibre, etc.). Summarising, in order to overcome these requirements, utilities must consider the numbers of an emerging implementation of the industrial IoT when they aim to deploy a practical power grid scenario. These utility market requirements should cover all the concerns and include information about consumers, market segmentation, functionality of the new technology, privacy and security approach, business model, use cases scenarios, and standardization.

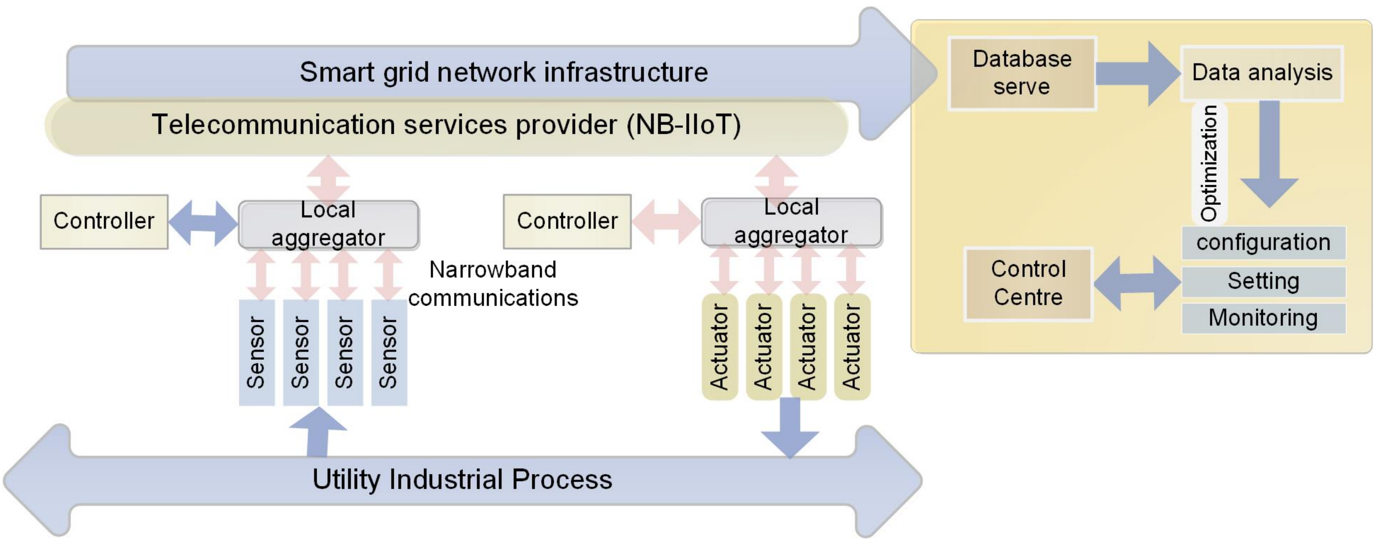

Fig. 4. Industrial process system.

Utility Use Cases

The new era of modern grids is driven by regulatory commands to increase service reliability. Thus, utilities need to consider use cases scenarios under the umbrella of NB technology and IIoT paradigm to mitigate the system requirements. In this article, we address a new NB technology framework architecture aiming to offering a flexible connectivity of ubiquitous smart grid services including teleprotections, self-healing, real-time monitoring, smart metering, and vehicle to grid integration, as shown in Fig.5. The elaboration of each use case scenario is illustrated in the following subsections. The anticipated benefits for these use cases by using narrow band with advanced features, including providing better coverage, increasing the battery life for sensors/meters, cost-efficiency are discussed. Moreover, the NB can provide reliable connectivity, especially when the meters are placed inside a building or in underground utility vaults. For example, adopting NB technologies will enable the utility operator to control the data metering through its existing communications infrastructure, and this will allow the utility provider to take a advantage of cost-effective, standardized design hardware. In conclusion, these utility use cases have been undertaken for both current and future power grid environments and to create an architecture design that can play an essential key in the utility market.

A. Teleprotection

Drawing from utility provider overviews the identification and considerations of potential use cases (e.g. teleprotection) can be presented to move forward to the next stage of industry revolution. There is a tremendous need to track the electric data flow in real-time manner to provide seamless data path, especially when a fault happens in the grid system. This may rely under the umbrella of protection, where the utility needs to consider the deployment of more field devices. For example, to establish a self-healing environment, the utility can employ massive numbers of advanced metering system and PMU equipment to offer precise measurement and monitoring. At substation level, if any damage happens in the system, the response time of restoration must be in the order of milliseconds. Specifically, when a severe alarm take place in the grid and request an urgent protection. By failing to fix the problem, it may cause a big damage to the grid system that will affect the economic status of the utility provider. Thus, a careful implementation of a reliable communication infrastructure can be crucial in the prevention of unwanted events and help to deal with smart grid service application faster. In such a teleprotection scenario, the NB technology can perform as a particular solution that manages the data flow delivery cross substations, which eventually help to avoid failures in a particular power grid.

B. Real-Time Monitoring

In the modern grid design, a tremendous amount of big data, which is associated with monitoring and control system will be delivered through NB communication infrastructures. Thus, the power grid system are anticipated to be divided into different zones or domains that has taken evolutionary steps on both the productivity optimize side of energy generation and increase the level of reliability in the network side. The other major obligation for the sensor/actuators is the requirement to be integrated with a network communication radio in order to transfer the data to the end terminal and to control the grid system. Therefore, monitoring the data needs an alternative solution for optimizing distribution operations. In the context of smart grids, the monitoring and measurement components (e.g. PMU, SCADA, etc.) can capture the system status through the communication infrastructure to inform the control centre with the latest condition. In particular, there is a relevant data flow to be disseminated and stored between utilities, control centres, and consumers in real time. The acquisition data by PMUs, which are collected from different locations in the substation level, will operate through a phasor data concentrator (PDC) and be delivered using NB technology to the control centre through communication network. The adaptation of robust and reliable IIoT system is very important to deal with uncertain behaviours in terms of availability and performance. The IIoT provides essential features to the smart grids by focusing on providing real time monitoring, which can be achieved by considering new NB technology to enable a global view of the smart grid, and to guarantee a high level of protection and control.

C. Advanced Smart Metering

Smart metering are anticipated to support grid modernization by facilitating a global view of energy consumption in real-time. Basically, smart meters can help to collect and measure the energy consumption using two-way communication and empowering utility providers to control features of each meter individually. To make this happen, the power system required a reliable and flexible communications infrastructure, which is readily available in NB technology. Power grid applications required high sophisticated integration of connected devices, sensors, and actuators that can be accomplished by intelligent connectivity. The key technology addressed in NB accelerate the time response to this demand of having huge numbers of interconnected meters in modern grid networks. Practically, smart metering can aggregate the data locally in the communication network level and transfer it via local area network (LAN) to eLTE using NB technology. From a smart grid structure perspective, smart meters can be simply reconnected to the NB base station for having a more reliable data exchange between control centres and consumers [13]. In such an advanced metering system, the data transmission can happen every 15 minutes or be occasionally based on the data usage. Monitoring the constancy of a power grid is one of the core duties of the control centre in the industry. With the new wave of radio technology, which supports end-to-end communication, utility providers will be able to capture the best practices information for the energy consumption in real-time manner. As a result, utility will have a global vision about how to enhance power distribution, to reduce the load demand using peak shaving technique and to improve the energy efficiency through critical data analytics.

D. Vehicle to Grid Connections

As a remarkable number of smart vehicles penetrate the market, the practical advantage of using them to support the grid operation system storing electricity and returning it when required. The vehicles to grid (V2G) technology can act as an extra production of power to bridge the gap during the high beak hours and throughout the distribution events, which provide significant benefits to the smart grid. Hence, V2G technology refers to the energy transmission from the smart vehicles to the main power system. In other words, the V2G paradigm is a modern way of using battery storage to provide an electric back to the main power grid and satisfy the grid load demands. Apart form that, the battery storage will be connected to the main distributed energy resources via NB-IIoT, especially when using renewable resources (e.g. solar energy and wind turbine) to be able to access to electricity. All EVs are expected to be activated under the management of the distributed aggregator controller nodes, which acts as facilitator between the EV and the transmission system operator of the energy system. The aggregator node has the ability to gather the critical data information while sighted load demand and the EV status. To make this happen, the utility should consider high level of connectivity to produce an effective interconnection between EV and power system using an advanced communication infrastructure [14]. In practice, the NB spectrum is a promising solution for smart grid applications, where each EV is expected to have a special IP for its identification. When it comes to reliability, the utility should adopt the NB-IIoT scenario to support the grid operators to secure data collection that can be offered to the V2G domain and guarantee an efficient service.

E. Virtual Power Plants

The virtual power plant system can help the utility providers to offer great opportunities to their consumers by intelligently manage and control the power generation system using advanced communication techniques such as NB-IIoT. An advanced communication system will allow the electricity providers to control their growing share of unpredictable energy resources and battery storage. Connecting distributed energy resources with a communication layer can facilitate the integration with the main system operation. Thus, the utility should consider an efficient NB technology solution to improve the capabilities of the power manufacturers. By implementing a new communication system, the utility providers can communicate efficiently with their consumer and monitor the data aggregation efficiently [15].

F. Emergency Self-healing

The management systems can support real-time monitoring of distributed system operations to work in normal mode, emergency response, and grid restoration. The self-healing will be reinforced by fast communication connections and reliable data aggregation methods, supported by respectable decision-making to detect and monitor a wide area of the power system. In an emergency situation, smart metering and actuators will react immediately to recover the grid system by providing fast self-healing. That can happen using features of dynamic and programmable configuration enabled by NB-IIoT connectivity to support the self-healing application program against any cyber-attack or fault events. Some of these field devices will be integrated and coordinated throughout NB communication infrastructure in a peer-to-peer manner. Similarly, adopting a NB scenario will enable new and urgent control signal commands to create alternative electric data path, while providing global visibility for self-healing application to alleviate the attack without harmfully impacting the wide area security policy.

Conclusions

The growing demand of machine connectivity and industrial applications is ambitious the market trends for hunting new technologies. At the same time, the industries are racing to

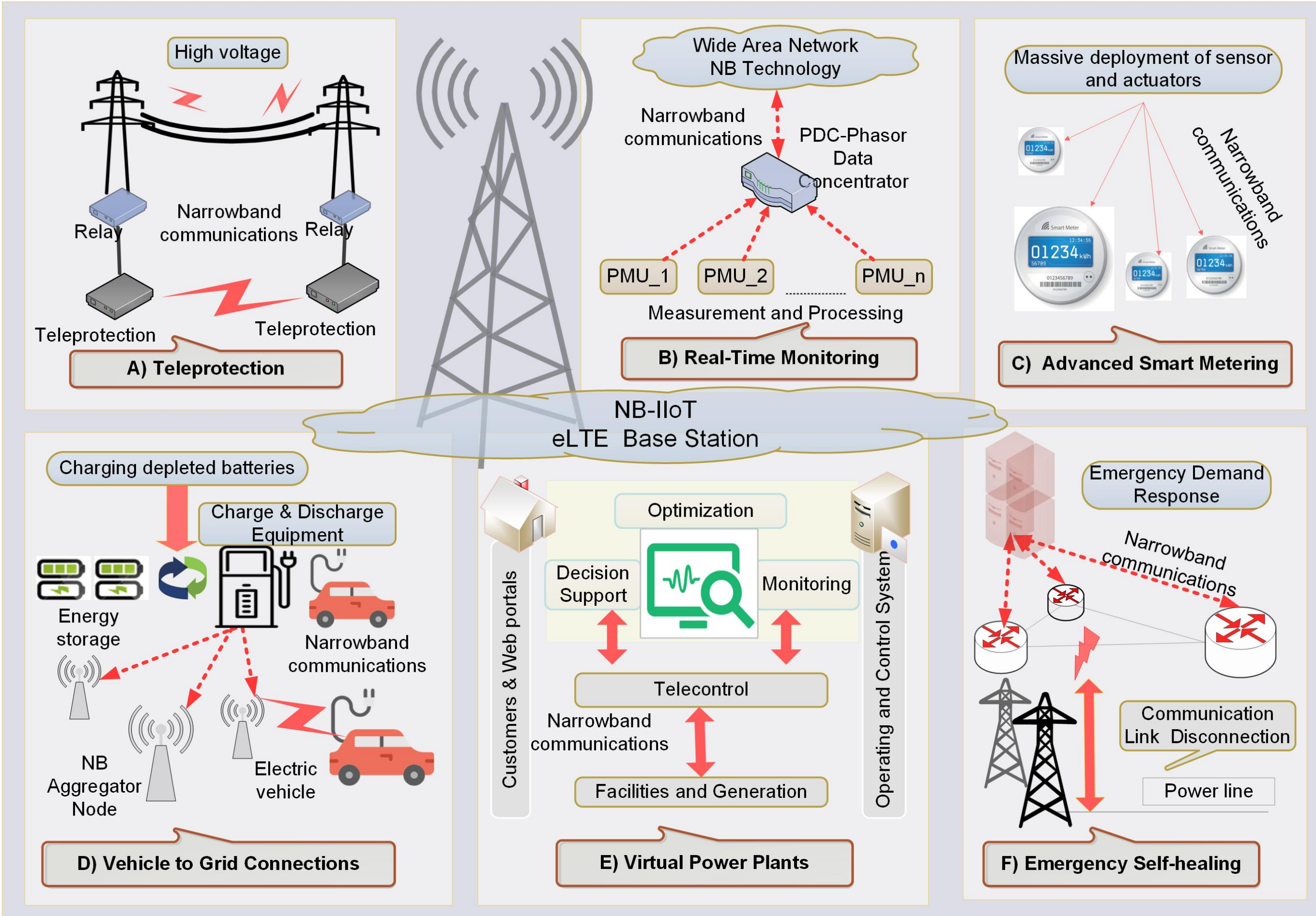

Fig. 5. A proposed architecture for utility use cases.

provide the best solutions to the end user by adopting new wave of NB technology to allow more system reliability and improve the capacity. In order to address these issues in a coherent manner, this article proposed new framework of NB-IIoT architecture towards providing different face of system integration to support high demand services. The new flexible architecture will enable technical decision-makers to open up to the new opportunities and provide high efficiency for all services accommodated on the NB domain. Furthermore, this article highlighted the main features of NB-IIoT with special attention on the smart grid industry and business. Some of the market challenges and opportunities were also presented by introducing utility use cases aligned with NB technology options bonding with IIoT solutions, standardization, and requirements. These use case scenarios can established the best practice solutions to fully satisfy and meet the industry requirements. As the IIoT is anticipated to drive industrial market, the new framework can be long term solutions for integrating within current and future networks to improve the system performance, enhance the coverage and maintain high system reliability in the foreseeable future.

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