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Resilient communication for smart grid ubiquitous sensor network: State of the art and prospects for next generation

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ABSTRACT

Smart grid combines a set of functionalities that can only be achieved through ubiquitous sensing and communication across the electrical grid. The communication infrastructure must be able to cope with an increasing number of traffic types which is as a result of increased control and monitoring, penetration of renewable energy sources and adoption of electric vehicles. The communication infrastructure must serve as a substrate that supports different traffic requirements such as QoS (i.e. latency, bandwidth and delay) across an integrated communication system. This engenders the implementation of middleware systems which considers QoS requirements for different types of traffic in order to allow prompt delivery of these traffic in a smart grid system. A heterogeneous communication applied through the adaptation of the Ubiquitous Sensor Network (USN) layered structure to smart grid has been proposed by the International Telecommunication Union (ITU). This paper explores the ITU's USN architecture and presents the communication technologies which can be deployed within the USN schematic layers for a secure and resilient communication together with a study of their pro's and con's, vulnerabilities and challenges. It also discusses the factors that can affect the selection of communication technologies and suggests possible communications technologies at different USN layers. Furthermore, the paper highlights the USN middleware system as an important mechanism to tackle scalability and interoperability problems as well as shield the communication complexities and heterogeneity of smart grid.

1. Introduction

Smart grid deployment is motivated by ambitious goals such as energy savings, efficient and sustainable power supply, reducing greenhouse gas emission and attaining satisfactory levels of security and quality of energy supply [1]. Achieving the smart grid goals will involve a set of functionalities within generation, distribution and consumer premises rather than a set of individual appliances or technologies [1,2]. Self-healing, Demand Side Management (DSM) and seamless integration of renewable energy through distributed generation are desired functionalities that can only be achieved by having a converged and secure communication infrastructure that can intelligently and reliably deliver the aforementioned smart grid functionalities [4]. Converged communications networking, routing and transport protocols and QoS support for smart grid functionalities will enable the system to increase its efficiency to a much greater extent [53]. The electrical grid incorporates different types of systems, devices and communication media with specialised procedures for exchanging data. For example, Supervisory Control and Data Acquisition (SCADA) system with Remote telemetry Unit (RTU) and Programmable Controllers are used on the power grid for monitoring and control purposes using wired or wireless communications with proprietary protocols [54,55]. Expanding the communication network by integrating the existing communication infrastructure with new ones will introduce new complexity and vulnerabilities such as: (i) security, (ii) efficiently aggregating, storing and analysing data, and (iii) coordinating diverse technologies (communications and electricity) which have diverse capabilities and characteristics that are not well defined [3,53]. Neither agreement nor consensus has been reached on which communication technologies should be chosen to achieve a cost effective and reliable smart grid communication, in order to integrate, secure and manage the next-generation smart grid. However in the absence of standardisation for interoperable smart grid protocols, there is an assumption that all smart grid traffic types will use Internet Protocol (IP). IP can provide addresses to numerous communication devices on the grid thus ensuring a flexible communication platform with improved interoperability and also providing support for asset management as compared to bespoke protocols [4]. It has become an increasingly used protocol stack in supervisory and control applications in the energy sector and a document on how best to

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profile the IP suit in smart grid has been presented in [5]. Therefore, it is a boost that existing IP communication technologies will play significant roles in incorporating:

- DSM interaction between customers and suppliers through smart meters
- Self-healing power restoration capability; and
- Distributed Energy Resources (DER) from renewable energy that will be used to supply energy during peak loads.

Deploying existing communication technologies for smart grid functionalities depends on certain properties which may be influenced by a number of requirements from smart grid applications. Several articles have been published, with emphasis on and selecting and optimisation of communication technologies that will meet these requirements. In [6], a number of candidate communications technologies for Home Area Network (HANs) have been compared with emphasis on DSM and dynamic pricing. Factors affecting the choice of communication technologies have also been discussed, which provide a comparison based on different scenarios. In [7], a review of wireless communication technologies for HANs and Neighbourhood area Networks (NANs) together with their smart grid applications is discussed. They highlighted the network issues and challenges and concluded that the choice of communications technology (CT) for smart grid essentially depends on a particular utilities budget and policies. Furthermore, a critical overview of communication systems in smart grids was presented in [53], with a special focus on the role that communication, networking and middleware technologies will have on the transformation of the existing power system in to smart grid.

Nonetheless a flexible and scalable communication network architecture is required to tie together the functions of “Home Energy Management (HEM)”, “Distributed Automation (DA)”, “DSM”, “self-healing”, “monitoring” and “control” in smart grid. Consequently, different bodies or groups have been setup to develop interoperability standards for smart grid architectures among which are the IEEE standard P2030 “guide for Smart Grid Interoperability of Energy and Information technology operation with the electrical power system and End-Use Applications and load” and CEN-CENELEC-ETSI Smart Grid Coordination Group were initiated to mention but a few [8,9]. The International Telecommunication Union’s (ITU) Ubiquitous Sensor Network (USN) architecture is an Information and Communication Technologies (ICT) solution initially designed to mitigate effects of climate change by monitoring the environment through pervasive coverage of sensor networks to support context-aware information services through processing collected climate information. A holistic network architecture based on USN to integrate all the communications required by smart grid applications in a single system has been proposed in [19]. They stated that if the five USN schematic layers are applied to smart grid, it can provide a unified and seamless heterogeneous network that is capable of comprehensively supporting stringent communication requirements of smart grid. The schematic layers of the USN architecture and the corresponding smart grid network components is presented in Fig. 1, with the anticipation that this architecture will integrate all the smart grid communication components.

This paper explores the USN architecture for smart grid traffic management and attempts to review candidate communication technologies, to understand which may be best deployed within different parts of the smart grid USN system. The factors that may determine the choice of communication technologies for each USN layer and a use-case to implement the USN architecture for smart grid are also presented in this paper. Also, vulnerabilities and challenges of the USN architecture were discussed and factors that will minimise their effect have been highlighted. The remainder of this paper is organised as follows: Section 2 presents background and overview of related work on smart grid architectures, applications and networks.

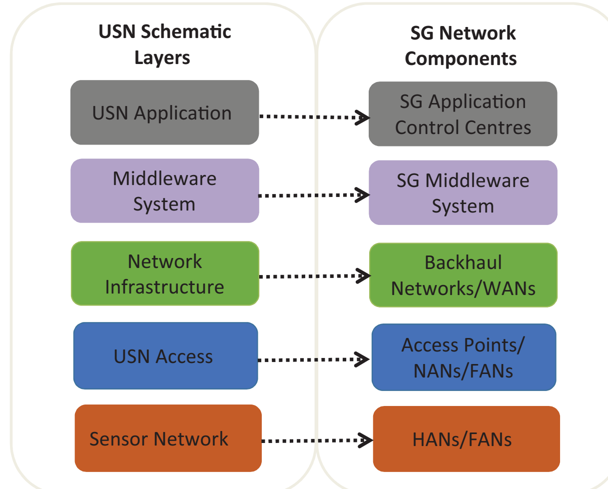

Fig. 1. USN layers with corresponding smart grid network components.

Section 3 describes the adaptation of the USN architecture for smart grid. The factors necessary for the choice of a secure and resilient communication technology in smart grid are discussed in Section 4, while Section 5 presents the benefits and limitation of available communication technologies that can be deployed in smart grid heterogeneous network. Smart grid vulnerabilities are discussed in Section 6 and Section 7 presents a use-case for smart grid heterogeneous communication. Challenges of USN Architecture for smart grid are presented in Section 8 and finally Section 9 outlines the conclusion.

2. Background and related work on smart grid communication

The network infrastructure in smart grid is expected to be a heterogeneous communication in order to successfully achieve smart grid functionalities and meet performance requirements. There has been an increase in research activities and surveys on smart grid communications network [2–4,10,11,53], and [57]. This section presents a background on smart grid architectures and smart grid network components. Also, it highlights the smart grid applications and their requirements.

2.1. Background on smart grid communication architecture

Smart grid definition by several entities has reiterated the relevance of the communication network to the success of smart grid. Cisco defined smart grid as a data communication network integrated with the electrical grid for capturing information on the activity of transmission, distribution and consumption in near real time [12]. The smart grid technology will then analyse the captured data to provide useful information and recommendation to energy suppliers and consumers on the best way to manage power. Other definitions by the US Department of Energy (DOE) and National Institute of Standards and Technology (NIST) have also emphasised on ICT to be the connection between the smart grid applications and the physical energy infrastructures that use and distribute energy [4]. Key motivations of the new and improved communications infrastructures such as: enhanced customer experience; improved energy utilisation; lower fossil fuel dependence and renewable generation, which are related to power grid efficiency, environment and cost, are highlighted in [13]. The existing systems and services on the power grid include SCADA systems [14,54] and Automatic Meter Reading (AMR). AMR is a one-way communication to accomplish meter readings primarily for monthly billing purposes [15]: it may use both wired and wireless communication media with specialised rules for exchanging