Computer Communications 71 (2015) 22–33

Contents lists available at ScienceDirect

Computer Communications

journal homepage: www.elsevier.com/locate/comcom

A survey on wireless sensor networks for smart grid

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ARTICLE INFO

Article history:
Received 15 May 2015
Revised 31 August 2015
Accepted 4 September 2015
Available online 11 September 2015

Keywords:
Smart grid
Wireless sensor networks
Applications
MAC and routing protocols

ABSTRACT

The traditional power grid in many countries suffers from high maintenance costs and scalability issues along with the huge expense of building new power stations, and lack of efficient system monitoring that could increase the overall performance by acting proactively in preventing potential failures. To address these problems, a next-generation electric power system, called the smart grid (SG), has been proposed as an evolutionary system for power generation, transmission, and distribution. To this end, the SGs utilize renewable energy generation, smart meters and modern sensing and communication technologies for effective power system management, and hence, succeeding in addressing many of the requirements of a modern power grid system while significantly increase its performance. Recently, wireless sensor networks (WSNs) have been recognized as a promising technology to achieve seamless, energy efficient, reliable, and low-cost remote monitoring and control in SG applications. In these systems, the required information can be provided to electric utilities by wireless sensor systems to enable them to achieve high system efficiency. The real-time information gathered from these sensors can be analyzed to diagnose problems early and serve as a basis for taking remedial action. In this paper, first WSN-based SG applications have been explored along with their technical challenges. Then, design challenges and protocol objectives have been discussed for WSN-based SG applications. After exploring applications and design challenges, communication protocols for WSN-based SG applications have been explained in detail. Here, our goal is to elaborate on the role of WSNs for smart grid applications and to provide an overview of the most recent advances in MAC and routing protocols for WSNs in this timely and exciting field.

1. Introduction

Electricity, one of the most popular and important forms of energy that impacts human lives, economics and politics, is produced in a very critical infrastructure known as power grid. A power grid is populated by a large number of components that are interconnected, while spreading in various geographic locations. Until recently, a centralized approach was used to develop the existing power grid infrastructure in which a few very high-power AC plants were interconnected with many substations by a large number of distribution lines that supplied (usually after a voltage reduction) uni-directionally the residential loads. In addition, recently, new renewable energy generators (e.g., photovoltaic systems, wind turbines) have been used to provide an alternate way for electricity production. These small-scale electric generators can be located near customer premises and are able to relieve the load from the power grid while helping in balancing the power demand and electricity supply.

The connection of these renewable solutions to the existing power system transformed it in a very large-scale, highly distributed generation system which incorporates a large number of generators, generally characterized by different topologies which combine different technologies with various current, voltage and power levels. With the addition of these new solutions, the existing power grid managed to partially serve the globally increasing demand for electricity, but still had to deal with problems such as: equipment failures, blackouts, poor communication and lack of effective monitoring of the infrastructure. Those challenges, along with production instabilities caused by structural or operational characteristics, can easily lead to huge economic losses, inefficient electricity usage, customer dissatisfaction and pollution from a huge amount of CO_2 emissions. Because of the costly maintenance of the existing aged infrastructures along

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http://dx.doi.org/10.1016/j.comcom.2015.09.006
0140-3664/

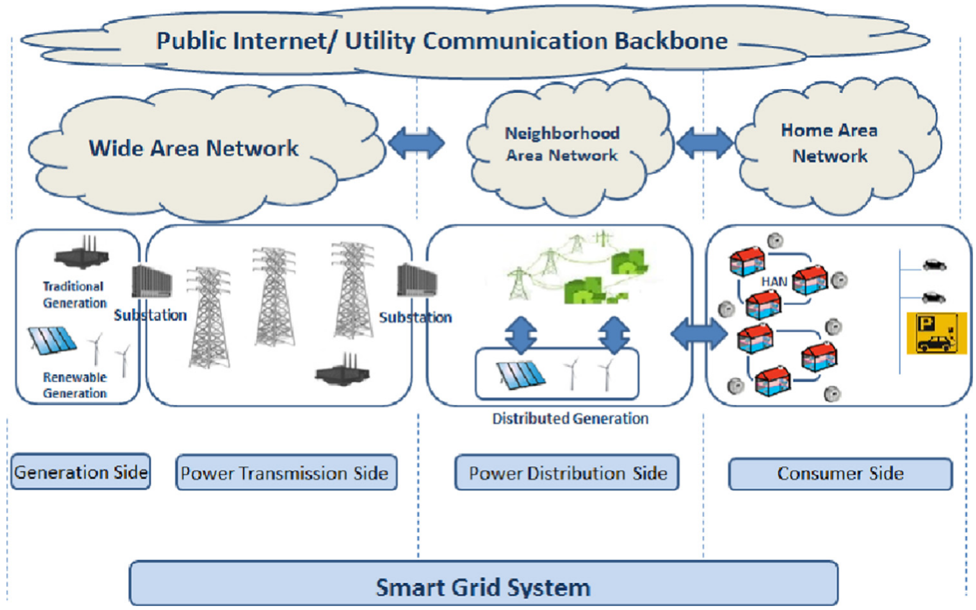

Fig. 1. An illustrative architecture of smart grid from generation to consumer sides.

with the rising costs for building new ones and the declining number of skilled personnel, the need for more dynamic and efficient operation of the system has become inevitable.

To this end, the power grid's efficiency can be improved by the use of various sensors. This approach allows collecting real-time data from various sensor devices in a power grid and communicating the collected data along the infrastructure. In this way, a problem in the system's functionality can be diagnosed proactively and timely generated remedial actions can be taken in order to prevent any failures that might affect the grid's performance. In these monitoring systems, the sensors can be installed on the critical power grid equipment and can be used to monitor essential grid components such as voltage, current, temperature, system frequency and power quality disturbances [1–4]. This way, a next-generation electric power system is created, the *smart grid (SG).*

To this end, the SG is a modernized power transmission and distribution (T&D) network, which uses two-way data communications, distributed computing technologies and smart sensors to improve safety, reliability and efficiency of power delivery and use. Using a sophisticated *information processing* and *communication* technology infrastructure, the SG will be able to fully use and benefit from its *distributed power generation* system, while maximizing the whole system's energy efficiency. Consequently, SG is also considered as a *data communication* network which, by supporting many power management devices, achieves seamless and flexible inter-operational abilities among different advanced system components that leads to an efficient performance [7–11,16]. Basically, the SG network can be divided into three segments; home area networks (HANs), neighborhood area networks (NANs) and wide area networks (WANs) as depicted in Fig. 1:

- ***HAN*** creates a communication path among smart meters, home appliances and plug-in electric vehicles. The HAN enables consumers to collect information about their consumption behaviors and the electricity usage costs via in-home display devices. Due to the low-bandwidth requirements of HAN applications, it needs cost-effective communication technologies, such as HomePlug, Wi-Fi, Bluetooth and ZigBee.
- ***NAN*** is established between data collectors and smart meters in a neighborhood area. To this end, short-range communication technologies, such as Wi-Fi and RF mesh technologies, can be used to collect the measured data from smart meters and transmit them to the data concentrator.
- ***WAN*** creates a communication path between service provider's data center and data concentrators. It is a high bandwidth and robust two-way communication network, which can handle long-distance data transmissions for SG monitoring and control applications. In general, the communication technology providing the best coverage with the lowest cost, such as LTE, cellular networks (2G–3G systems), fiber, power line communication networks, are widely adopted for WAN networks [7–11].

Recently, the *wireless sensor networks* (*WSNs*) have been widely recognized as a technology promising to improve various aspects of SGs, especially those that deal with power generation, bidirectional delivery, utilization and seamless monitoring, providing an energy efficient, reliable and low-cost solution for control management [1,5,6,14]. The existing and potential WSN applications for SG include advanced metering, demand response and dynamic pricing, equipment fault diagnostics, fault detection, load control, distribution automation and remote power system monitoring and control. SG is also considered as a data communications network; therefore the communication capabilities among the elements of an electrical power system will play a huge role on the efficient performance of any WSN-based SG application. However, the selection for the most appropriate communication technology varies depending on the requirements of WSN-based smart grid applications. For example, distributed feeder automation applications require low-latency and high-data-rate communications among substations and intelligent electronic devices in order to timely detect and isolate faults. On the other hand, smart metering applications require latency-tolerant information exchange between the meters and utility management center.

Importantly, Fig. 2 summarizes the evolution from the early automatic meter reading (Phase I), characterized by one-way communication, to the advanced metering infrastructure (AMI) (Phase II), incorporating two-way communications, and to the smart grid (Phase III) with intelligent applications and communication infrastructure via advanced sensor networking technologies. Here, it is crucial to note that the envisioned WSN applications for SG will be realized in the near future with the help of distribution automation, load and outage control, advanced energy management and smart sensors. Therefore,