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Wireless multimedia sensor and actor networks for the next generation power grid

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ABSTRACT

Electrical power grid is undergoing a major renovation, to meet the power quality and power availability demands of the 21st century. The new power grid, which is also called as the smart grid, aims to integrate the recent technological advancements in the Information and Communication Technology (ICT) field to the power engineering field. The present smart grid implementations focus on smart meter based utility-to-meter and utility-to-customer communications. Although these features provide significant improvements on the customer management side, in the following decades, grid management will be one of the major ICT-dominant fields. Recently, adoption of Wireless Sensor Networks (WSN) for the power grid is gaining wide attention from the industry and the academia. Scalar sensor measurements bring valuable insights, however they can provide limited set of information. In the next generation power grid, limited-sensing, Supervisory Control and Data Acquisition (SCADA) based, centrally controlled operational architecture will be replaced with wireless connected, low-cost, multimedia sensors combined with distributed decision-making and acting systems, working in coordination with a supervisory software tool. In this paper, we discuss the potential applications and the challenges of employing wireless multimedia sensor and actor network (WMSAN) for the smart grid.

1. Introduction

Electrical power grid is among the high priority critical infrastructures of a nation. In last decades, power grid operators have been experiencing problems due to the imbalance between growing demand and diminishing fossil fuels, coupled with aging equipments and workforce. The resilience of the power grid has become questionable especially after the major blackouts in California and Northeast of the United States, in 2001 and 2003, respectively. The lack of pervasive and effective communications, automation, monitoring and diagnostic tools, has resulted in the failure of the power grid. Consequently, the opportunities that become available with the advances in Information and Communications Technology (ICT) have necessitated the modernization of the existing power grid.

Resilience and self-healing combined with distributed renewable energy generation, distributed storage, reduced Green House Gas (GHG) emissions, sophisticated energy management at the demand-side, easy adaptability to future systems, two-way flow of information and electricity are among the desired properties of the smart grid [1]. Recently, smart meters have been installed in the majority of consumer premises in North America to provide communication between utilities and consumers. While this is expected to increase the efficiency of the power grid, the opportunities that rise from the advances in Micro-Electro-Mechanical Systems (MEMS) are not fully exploited yet. Adoption of WSN in the smart grid is an attractive research topic. WSNs can be deployed rapidly and self-organize to form an intelligent monitoring platform [2]. For instance, low-cost sensor nodes that use wireless

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communications, can be spread over the field of operation of a utility and enhance utility asset monitoring capabilities. Although WSNs are decent tools for monitoring, in the following years, the next generation power grid technologies will employ WMSANs to enable distributed and autonomous operation, augmented with fine-grained monitoring capabilities.

WMSAN is a group of distributed sensor and actor platforms that are connected via wireless communications where multimedia sensors record video, capture audio and still images, collect ambient scalar data, and actors are capable of operating the devices. WMSAN have been considered to be used in surveillance, traffic control, health care, elderly assistance, person locator and industrial process control applications previously [3]. In the smart grid, distributed power plants, overhead and underground power lines, transmission towers, substations, industrial consumer premises, commercial/residential buildings and homes, will require low-cost, long-lasting, distributed systems that can sense, communicate and act, i.e. WMSANs.

In the traditional power grid, monitoring equipments such as, power donuts, weather stations, sagometers which generally communicate through wired communications, have been employed at several critical locations. However, wireline communications have high cabling costs especially due to the geographical spread of the utility assets. Moreover, the next generation power grid will need more than a monitoring system since the large-scale and real-time nature of the grid demand quick repose to a large number of incidents occurring at the same time and related with each other. As the decision process and the control algorithms mitigate from human operators and the centralized architecture toward distributed intelligent devices, the capabilities of the power grid will increase. An autonomous grid that can dynamically react to changing ambient conditions, failures and consumer demands can maximize the capacity of energy generation, power transmission and distribution. Furthermore, collecting multimedia content could highly improve the safety and security of the grid. As low-memory image processing algorithms [4] and low-cost hardware that ubiquitously collect multimedia data, such as CMOS cameras and microphones [3,5] become available, the widespread adoption of WMSANs in the smart grid will be possible.

Despite the opportunities that become available with WMSANs, WMSANs have several challenges to be addressed. They suffer from low link quality, high latency, limited bandwidth and limited battery, as well as, lack of established techniques for in-network processing, efficient video streaming, QoS provisioning, distributed decision and control algorithms. Moreover, there are challenges specific to the power grid. Power grid is a large-scale system, in the sense of geographical region and the number of equipments. A single malfunctioning device may cause partial (isolated) outage, or it may cause overall system failure and affect a larger region and higher number of consumers. Similarly, under utilization of resources at a single transmission line or a generation unit may impact the overall system performance. In addition, the operation and maintenance of the grid require strict safety precautions for personnel and public health, therefore WMSANs should not cause hazardous situations.

In this paper, we discuss the potential applications of WMSANs in the next generation power grid. We explore new applications for energy generation facilities, transmission and distribution (T&D) equipments and consumer premises, while discussing the related challenges. In Section 2 we present the state-of-the-art in power grid monitoring tools and introduce possible WMSAN applications. We discuss the challenges of employing WMSANs in the power grid and point out the open issues in Section 3. Finally, we conclude the paper in Section 4.

2. Multimedia sensors for the power grid

In today's power grid, sensing equipments are employed in a limited number of critical assets such as the power transmission lines and substations. Generally, these sensing equipments are not interconnected, i.e., they transmit the collected data to a central location via wireline communications, where a supervisory control system and human operators at the utility headquarters manage grid operations.

The power grid can be conceptually divided into three segments to represent the flow of electricity from a generation facility to the premises where it is consumed. These segments are, energy generation segment (supplier), T&D segment (utility) and consumption segment (demand-side). State-of-the-art sensing equipments are mostly employed in the T&D segment and less frequently in energy generation facilities. In the next generation power grid, it is necessary to have sensors in the generation plants and consumer premises, as well. In this section, we present possible WMSAN applications in the next generation smart grid while briefly summarizing the sensing equipments in use today.

2.1. WMSANs for energy generation facilities

In the traditional grid, energy is generated at power plants which use resources such as nuclear fission, hydro, or fossil fuels (e.g. coal, gas, diesel, natural gas). In several countries, wind tribunes and Photovoltaic (PV) panels also contribute to energy generation. Wind and solar power are called as renewable or green generation methods and they are preferred more than the fossil fuel based energy generation techniques due to their lower cost and lower GHG emissions. However, their availability is limited to the geographical conditions of the grid and the time of the year. For example, solar power is not available at night and wind power varies seasonally. The intermittent nature of these generation techniques makes it hard to employ them as primary power supplies for a grid unless distributed energy storage is available.

In the traditional grid energy storage methods such as pumped hydro, compressed air and flywheel are available however they are not convenient for storing the energy generated at the solar and the wind farms. Energy storage in the smart grid is one the active research topics. The amount of energy to be stored depends on the amount of