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Routing protocol design guidelines for smart grid environments

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ABSTRACT

The evaluation of the current electric power grid with novel communication facilities is one of the most challenging and exciting issues of the 21st century. The modern grid technology is called the smart grid in the sense that it utilizes digital communication technologies to monitor and control the grid environments, which ultimately require novel communication techniques to be adapted to the system. Wireless sensor networks (WSN) have recently been considered as a cost-effective technology for the realization of reliable remote monitoring systems for smart grid. However, problems such as noise, interference and fading in smart grid environments, make reliable and energy-efficient multi-hop routing a difficult task for WSNs in smart grid. Our main goal is to describe advantages and applications of WSNs for smart grid and motivate the research community to further investigate this promising research area. In this study we have investigated and experimented some of the well-known on-demand, table-driven and QoS-aware routing protocols, in terms of packet delivery ratio, end-to-end delay, and energy consumption to show the advantages and disadvantages of each routing protocol type in different smart grid spectrum environments. The environmental characteristics which are based on real-world field tests are injected into ns-2 Network Simulator and the performance of four different multi-hop routing protocols is investigated. Also, we have shown that traditional multi-hop routing protocols cannot deliver adequate performance on smart grid environments. Hence, based on our simulation results, we present some guidelines on how to design routing protocols specifically for smart grid environments.

1. Introduction

The smart grid is the modernization of the existing electric power grid, which mainly has a centralized energy generation and a unidirectional energy distribution. The current power grid suffers from the limited and unreliable communication and monitoring facilities, which cause the existing grid to be unreliable and ineffective [8]. By integrating various digital communication technologies to the power grid, new functionalities and applications for different electricity consumers (industrial, commercial, residential) will be realized.

With the increased use of various digital control and communication techniques for smart grid applications and development of smart grid communications standards, the reliability, security and efficiency of the electric grid will be enhanced. By establishing bi-directional flows of communication and control capabilities, a sustainable and effective electricity generation, transmission, distribution, and utilization for current and future generations is envisioned. Moreover, with the new grid smooth transition to renewable sources, reduced greenhouse gas emissions and resistance to both physical and cyber attacks are also targeted [9].

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There is a tradeoff between the utilization of wired communication and sensor systems and WSNs into the smart grid. Utilization of wired communication systems can be regarded as a more robust infrastructure, however, it would necessitate much more investment and maintenance costs. Also wired sensors would decrease the network scalability which ultimately will cause inflexibility in the new grid. On the other hand, WSNs will be one of the most feasible means to realize embedded electric power grid monitoring and diagnostic systems [35]. In these systems, sensors are deployed on the critical equipment of the smart power grid to measure various system parameters, such as conductor temperature, voltage and dynamic thermal rating line fault detection, outage detection [11–14]. These sensor measurements will then be sent to utility control centers via sink nodes, which may reside in the network gateways. The existing WSNs applications on smart grid vary on a wide range. Some of the applications are: automatic meter reading, equipment diagnostics, automation of distribution, detection of outage, remote monitoring, fraud detection, etc. [23–26]. However, as stated in [6], there exist many problems of deploying WSNs in smart-grid applications. These problems can be summarized as follows:

- ***Harsh environmental conditions:*** In WSN-based smart grid applications, due to the obstructions and the noisy environment, the wireless links show different characteristics over time and space. Thus, wireless link capacity is limited and changes continuously.
- ***QoS provisioning:*** The wide variety of WSN applications has different QoS requirements making QoS provisioning a difficult task. Furthermore, due to the time sensitive nature of the sensor data, it is regarded as a vital subject to transmit the data to controller in time.
- ***Sensor parameters:*** The adaptability of WSNs in smart grid is important, since it enables end-users to cope with dynamic link-quality and topology changes in smart grid environments. In this respect, choosing the appropriate sensor parameters, such as energy scheme, transmission range, and multi-hop routing protocol, is critical to meet application objectives.
- ***Large-scale deployment and ad hoc architecture:*** In most of the smart grid applications, large number of sensor nodes is utilized. Also WSNs are obliged to establish multi-hop network connections because the network infrastructure is not predetermined. Hence, reliable multi-hop routing becomes a vital issue to design a WSN-based smart grid application.

In spite of the recent interest in smart grid applications based on WSNs, wireless multi-hop routing in different smart grid environments is still a vastly unexplored area. To address this need we evaluated and tested different types of routing protocols, such as on-demand (AODV and DYMO), table-driven (DSDV) and QoS-aware (TUQR) routing protocols, in terms of packet delivery ratio, end-to-end delay, and energy consumption to show the advantages and disadvantages of each routing protocol type in different smart grid spectrum environments. In this work, we present and describe the advantages challenges of WSNs for smart grid, specifically on the network layer and motivate the research community to further investigate this research area. Consequently, the main contributions of this study can be summarized as follows:

- Performance evaluations of different types of multi-hop routing protocols, such as on-demand (AODV and DYMO), table-driven (DSDV) and QoS-aware (TUQR) routing protocols, have been conducted specifically under harsh smart grid spectrum environments. Based on these evaluations, important design guidelines on how to develop routing protocols specifically for smart grid environments have been presented.
- The smart grid environmental characteristics (which are taken from real-world field tests using IEEE 802.15.4 compliant wireless sensor nodes [6]) are injected into ns-2 Network Simulator. Upon request, the complete experimental data will be made available. This can help the research community develop novel wireless communication protocols for smart grid applications.

The paper is organized as follows. In Sections 2, WSN-based smart grid characteristics and applications are summarized and the opportunities and challenges of applying WSNs in smart grid are reviewed. In Section 3, the related work on smart grid communications is presented. In Sections 4 and 5, evaluated WSN routing protocols, performance evaluations and an overview of simulation results are explained, respectively. The paper is concluded in Section 6.

2. Smart grid characteristics and applications

The transition to smart grid requires re-establishing and modifying many technologies of the current electric grid. In this sense, smart grid is expected to meet the following principal characteristics towards the demands of the 21st century [17]:

- ***Self-heals:*** The modern grid will be fault tolerant by performing continuous self assessments. To avoid system failures and recover the system timely, it needs to rapidly detect, analyze and respond to system faults. This requires robust and effective communication protocols especially for WSN-based smart grid applications.
- ***Includes consumer:*** In existing power grid, consumers are not informed and non-participative with the power grid. To reduce the cost of delivered electricity, consumers will involve into the decision process of electrical power grid.
- ***Resists to attacks:*** In order to improve public safety, the new grid will be able to protect the system from any cyber and physical attacks.
- ***Accommodates all generation and storage options:*** The modern grid will have very large numbers of diverse distributed power generation (e.g. wind energy, renewable energy) and power storage devices deployed to complement the large generating plants.