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Wireless Sensor Network for Electric System Automation

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Abstract - ***In today's competitive electric utility marketplace, reliable and real-time information become the key factor for reliable delivery of power to the end-users, profitability of the electric utility and customer satisfaction. The operational and commercial demands of electric utilities require a high-performance data communication network that supports both existing functionalities and future operational requirements In this paper we explain the opportunities and challenges of wireless sensor networks (WSNs) and present design objectives and requirements of WSNs for electric system automation applications.***

Keyword: - Wireless sensor Network (WSN), Wireless automatic meter reading (WAMR), quality of service (QoS), High-performance data communication network, Dynamic topologies

I. INTRODUCTION

Electric system automation, which is the creation of a reliable and self-healing electric system that rapidly responds to real-time events with appropriate actions, aims to maintain uninterrupted power service. The operational and commercial demands of electric utilities require a high-performance data communication network that supports both existing functionalities and future operational requirements. Therefore, the design of the network architecture is crucial to the performance of the system. In this section, we explain the opportunities and challenges of wireless sensor networks (WSNs) and present short distances. A wireless sensor network (WSN) consists of spatially distributed autonomous sensors to cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants. In addition to one or more sensors, each node in a sensor network is typically equipped with a radio transceiver or other wireless communications device, a small microcontroller, and an energy source, usually a battery. The ever-increasing capabilities of these tiny sensor nodes enable capturing various physical information, e.g., noise level, temperature, vibration, radiation etc., as well as mapping such physical characteristics of the environment to quantitative measurements. In the area of electric utility measurement systems, WSNs are used in wireless automatic meter reading (WAMR) systems, which can determine real-time energy consumption of the customers accurately. WAMR systems are important for electric utilities, since they can reduce operational costs and enable remotely controlled flexible management systems based on real-time energy consumption statistics. Therefore, WSNs provide an alternative real-time monitoring system for electric utilities with the potential to improve business performance and technical reliability of various electric utility operations. In WSNs, the architecture of the network depends on the purpose of the application. Based on the application requirements, the sensor nodes are scattered in a sensor field as shown in Fig. 1. Each of these scattered sensor nodes has the capability to collect data and route data back to the sink node in a multi-hop manner. In this architecture, the role of the sink node is to monitor the overall network and to communicate with the task manager, e.g., control center in the power utility, in order to decide the appropriate actions. The sink node can communicate with the task manager via Internet or satellite.

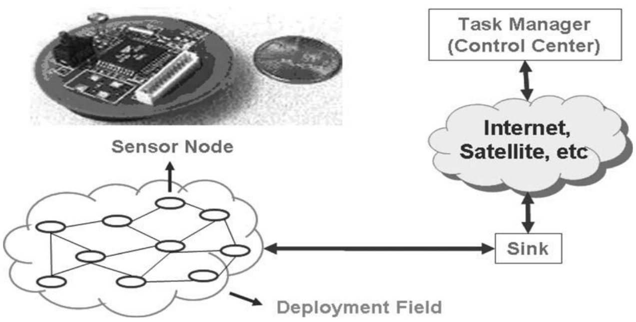

Fig. 1. An illustrated architecture of wireless sensor networks

II. Design Considerations of Wireless Sensor Network

When wireless sensor network technology for electric system automation applications is considered, there exist two key design elements which are critical to develop cost-effective wireless sensor network to support both existing functionalities and new operational requirements of the future electric systems. These key elements are described in the following.

A. Network Topology and Architecture

The topology of a sensor network has significant implications on several network aspects, including network lifetime, routing algorithms, communication range of the sensor nodes and etc. The network architecture requirements contain the physical and logical organization of the network as well as the density of the sensor nodes. In general, the objective of sensor networks is to efficiently cover the deployment area. The logical and hierarchical organization of the network also impacts energy consumption and the selection of communication protocols. In addition, based on topology requirements, sensor networks can have a distributed organization or a clustered organization, where selected nodes can handle data forwarding. The network topology and architecture requirements for electric utilities can be determined by answering the following questions:

• What type of network topology best fits the application? (Is it one to one, one to many, many to one or many to many?)

• How will the monitoring network work? (Is it master–slave, point-to-point, point-to multipoint or peer to peer?)

• What are the worst case ambient conditions in the coverage area?

• How many substations should be controlled and monitored including both current and future requirements of the electric system?

• Are there any known potential interference problems due to physical obstructions, RF interference from power lines or large induction motors?

B. Application Requirements

The required information that is to be relayed through the sensor network for electric utilities should be classified and quantified. These requirements can be achieved by a comprehensive analysis of the electric system automation applications. Based on the application requirements, the properties of individual sensor nodes can also be identified which impact network modeling and communication protocol choices. The following questions can help electric utilities to determine these requirements: • what are the Quality of Service (QoS) requirements of the application? (Does it require real-time monitoring or delay tolerant monitoring?)

• Does the system continuously poll for the information (periodic monitoring) or is it generated by exception (event-based monitoring)?

• What is the type of the sensor data, i.e., video, voice, data?

As a result, electric utilities should determine the network topology, architecture and application requirements comprehensively in order to establish the best fit wireless sensor network for their applications. Full consideration of the different sensor network options and how will they fit the electric utility application is critical for a successful implementation.

C. BENEFITS OF WSN FOR AUTOMATION

1. Monitoring in harsh environments: The sensors in WSNs are rugged, reliable, self-configurable and unaffected by extreme ambient conditions, e.g., temperature, pressure, etc. Thus, WSNs can operate even in harsh environments and eliminate the cabling requirement in electric systems.

2. Large coverage: WSNs can contain a large number of physically separated sensor nodes that do not require human intervention. Although the coverage of a single sensor node is small, densely distributed sensor nodes can work simultaneously and collaboratively so that the coverage of the whole network is extended. Therefore, the coverage limitations of traditional sensing systems can be addressed efficiently.

3. Greater fault tolerance: The dense deployment of sensor nodes leads to high correlation in the sensed data. The correlated data from neighboring sensor nodes in a given deployment area makes WSNs more fault tolerant than conventional sensor systems. Due to data redundancy and the distributed nature of WSNs, adequate monitoring information can be transported to the remote control center even in the case of sensor and route failures.

4. Improved accuracy: The collective effort of sensor nodes enables accurate observation of the physical phenomenon compared to traditional monitoring systems. In addition, multiple sensor types in WSNs provide the capability of monitoring various physical phenomena in the electric system.

5. Efficient data processing: Instead of sending the raw data to the remote control center directly, sensor nodes can locally filter the sensed data according to the application requirements and transmit only the processed data. Thus, only necessary information is transported to the remote control center and communication overhead can be significantly reduced.

6. Self configuration and organization: The sensor nodes in WSNs can be rapidly deployed and dynamically reconfigured because of the self-configuration capability of the sensor nodes. The ad hoc architecture of WSNs also overcomes the difficulties raised from the predetermined infrastructure requirements of traditional communication networks. More specifically, new sensor nodes can be added to replace failed sensor nodes in the deployment field and existing nodes can also be removed from the system without affecting the general objective of the monitoring system of the electric utility.

7. Lower cost: WSNs are expected to be less expensive than conventional monitoring systems, because of their small size and lower price as well as the ease of their deployment.

III. Applications of WSN in Electric System Automation

WSN technology can enhance the performance of electric utility operations by enabling wireless automatic meter reading and real-time and reliable monitoring systems for electric utilities. In the following, WSN applications for electric system automation are described in detail.

A. Wireless automatic meter reading (WAMR)

Currently, traditional manual electricity meter reading is the most common method for the electric utilities. These systems require visual inspection of the utility meters and do not allow flexible management systems for the electric utilities. In addition, network connections between traditional meters and data collection points are basically non-existent; thus, it is impossible to implement a remotely controlled flexible management system based on energy consumption statistics by using traditional measurement systems. With the recent advances in Micro Electro- Mechanical Systems (MEMS) technology, wireless communications and digital electronics; the development of low cost smart sensor networks, that enable wireless automatic meter reading (WAMR) systems, has become feasible. As the de-regulation and competition in the electric utility marketplace increase, so does the importance of WAMR systems. Wireless collection of electric utility meter data is a very cost-effective way of gathering energy consumption data for the billing system and it adds value in terms of new services such as remote deactivation of a customer's service, real-time price signals and control of customers' applications. The present demand for more data in order to make cost-effective decisions and to provide improved customer service has played a major role in the move towards WAMR systems. WAMR systems offer several advantages to electric utilities including reduced electric utility operational costs by eliminating the need for human readers and real-time pricing models based on real-time energy consumption of the customers. Real-time pricing capability of WAMR systems can also be beneficial for the customers. For example, using the real-time pricing model, the electric utility can reward the customers shifting their demand to off-peak times. Therefore, the electric utility can work with customers to shift loads and manage prices efficiently by utilizing WAMR systems instead of once a month on-site traditional meter reading. However, the real-time pricing model of electric utilities requires reliable two-way communication between the electric utility and customer's metering equipment. WSN technology addresses this requirement efficiently by providing low cost and low power wireless communication.

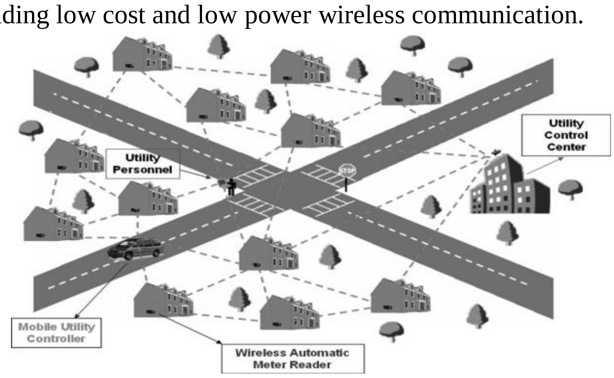

Fig. 2. WMAR system using WSN technology

In Fig. 2, a wireless automatic meter reading system using sensor network technology is illustrated.

As shown in Fig. 2 the sensed data from the meter is collected by the utility control center through multi-hop wireless communication. This monitoring system can also provide flexibility to the electric utility so that utility personnel or mobile utility controller can monitor the system locally when it is required, e.g., in case of alarm situations. Therefore wireless automatic meter reading systems can provide the following functionalities for electric systems.

B. AUTOMATIC METER READING FUNCTIONALITIES

WSNs enable real-time automatic measurement of energy consumption of the customers. The automatic meter measurements can also be classified as individual meter measurements, cluster meter measurements and global meter measurements. Here, the objective is to provide flexible management policies with different real-time monitoring choices for electric utilities.

C. TELEMETRY FUNCTIONALITIES

The electric utility control centers can obtain real-time data from smart sensor nodes and control some elements located at selected points of the distribution network, e.g. control of the status of the switches. Thus, distributed sensing and automation enhance electric utility services by reducing failure and restoration times.

1. Dynamic configuration functionality: In electric system automation applications, reliability of the measurements should be ensured even in case of route failures in the network. Thus, it is extremely significant to dynamically adjust the configuration of the network, e.g., dynamic routing, in order to provide reliability requirements of the applications. In this respect, the self-configuration capability of WSNs enables dynamic reconfiguration of the network.

2. Status monitoring functionality: Monitoring the status of the metering devices, which are embedded by smart sensors, is another functionality of WAMR systems. This functionality can be very helpful to determine sensor node failures in the network accurately and timely. In addition, status monitoring functionality can be utilized in case of tampering with metering devices. For example, if someone tries to vandalize a metering device, the system can notify the police automatically. This reduces the considerable costs of sending service crews out to repair vandalized metering devices. As advances in WAMR technologies continue, these systems will become less expensive and more reliable.

3. Electric system monitoring

Equipment failures, lightning strikes, accidents, and natural catastrophes all causes power disturbances and outages and often result in long service interruptions. Thus, the electric systems should be properly controlled and monitored in order to take the necessary precautions in a timely manner . In this respect, wireless sensor networks (WSNs) can provide a cost-effective reliable monitoring system for the electric utilities. An efficient monitoring system constructed with smart sensor nodes can reduce the time for detection of the faults and resumption of electric supply service in distribution networks. In addition, electricity regulators monitor the performance of the electricity distribution network operators utilizing a range of indices relating to customer service. Distribution network operators have targets and incur penalties based on the length of time of service interruptions, i.e. both outage frequency and duration. Continuity of electricity service is also crucial in today's competitive electric utility marketplace from the perspective of customer satisfaction. In order to evaluate the performance of the electric system, several Quality of Service (QoS) indices can be obtained utilizing WSN technology. For example, average duration of service interruption and average repair time can be computed. Typically, for densely deployed urban areas, these performance indices are correlated with the time for remote or manual switching of supply circuits. In this context, smart sensor nodes deployed in the electric utility can provide rapid identification of service interruptions and timely restoration of the electric utility services. Therefore, WSNs can help electric utilities maintain regulatory targets for the performance indices.

IV. Design Challenges in Wireless Sensor Networks

Although WSNs bring significant advantages over traditional communication networks, the properties of WSNs also impose unique communication challenges. These challenges can be described as follows:

A. Limited resources: The design and implementation of WSNs are constrained by three types of resources: (i) energy, (ii) memory and (iii) processing. Constrained by the limited physical size, sensor nodes have limited battery energy supply . For this reason, communication protocols or WSNs are mainly tailored to provide high energy efficiency. It is also important to note that in electric systems, the batteries of the sensors can be charged by the appropriate energy supplies. In addition, the collaborative effort of sensor nodes can handle the problems of limited memory and processing capabilities of the sensor nodes.

B. Dynamic topologies and environment: The topology and connectivity of the network may vary due to route and sensor node failures. Furthermore, the environment, that sensor nodes monitor, can change dramatically, which may cause a portion of sensor nodes to malfunction or render the information they gather obsolete. Thus, the developed communication protocols for WSNs should accurately capture the dynamics of the network.

C. Quality of service concerns: The quality of service (QoS) provided by WSNs refers to the accuracy between the data reported to the control center and what is actually occurring in the environment. In addition, since sensor data are typically time sensitive, e.g., alarm notifications for the electric utilities, it is important to receive the data at the control center in a timely manner. Data with long latency due to processing or communication may be outdated and lead to wrong decisions in the monitoring system. Therefore, the developed communication protocols for WSNs should address both real-time and reliable communication simultaneously.

V. Conclusion

Electric utilities, especially in urban areas, continuously encounter the challenge of providing reliable power to the end-users at competitive prices. Equipment failures, lightning strikes, accidents, and natural catastrophes all causes power disturbances and outages and often result in long service interruptions. In this regard, electric system automation, which is the creation of a highly reliable, self-healing electric system that rapidly responds to real-time events with appropriate actions, aims to maintain uninterrupted power services to the end-users. However, the operational and commercial demands of electric utilities require a high performance data communication network that supports both existing functionalities and future operational requirements. Therefore, the design of cost-effective and reliable network architecture is crucial. Our aim is to present a structured framework for electric utilities who plan to utilize new communication technologies for automation and hence, to make the decision-making process more effective and direct. The motivation of this paper is to provide a better understanding of the hybrid network architecture that can provide heterogeneous electric system automation application requirements. Consequently, our aim is to present a structured framework for electric utilities who plan to utilize new communication technologies for automation and hence, to make the decision-making process more effective and direct.

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