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A Novel Utilization of Wireless Sensor Networks as Data Acquisition System in Smart Grids

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Abstract. In this paper, after studying the demands and requirements of a perfect smart grid and specifications of network topology and sensor nodes utilized in a Wireless Sensor Network [WSN], a manipulated version of them is proposed to be combined with smart grid in order to improve the data acquisition step, increase the security and facilitate the process of information and desired commands from users. We will take the advantage of computer simulations to illustrate improved capacity and speed of this method. Finally, we will analyze the advantages of employing this proposed structure in a smart grid.

Introduction

Since last decade, principal improvements have occurred in the structure of power networks in the entire world. Rise of energy consumption, increased energy costs, reduction of oil sources and the demand of applying a reliable electrical system, makes us try to use smart grid instead of classical power distribution systems [1]. Development of such systems has established links with ICT field [2]. It is essential to have communication infrastructures, in order to simplify the process of control and distribution of power in various network nodes; in addition, wireless control is a principal demand to be fulfilled. Most significantly, there is a need to analyze, log and report the statistics of energy consumption and failure reports [3]. In a modern network, we should be able to set the power for each device in a smart manner, according to the information that automatically could be achieved by devices from the smart grid.

Generally, the operation of smart grids could be summarized in three steps:

Data Acquisition. Initially, the purpose of smart grids is to automatically attain the required information including the current or power of nodes, specifications of transmission lines, power distribution throughout network and information achieved from nodes about power production or consumption. Other information, such as instant state of nodes and transmission lines are essential to control and improve the physical security of the network as well. For instance, when an unexpected temperature increase in a particular node is observed, appropriate decisions should be made in order to prevent damages. WSNs are networks comprised of sensor nodes and data centers and an appropriate communication mean for data transmission; as it is presented in this paper, these networks are viable to be implemented as smart grids, because of their benefits in the data acquisition stage.

Data Processing. After through data acquisition, the next step is to process it; because of the diversity in the attained information, this stage should perform a real-time process. Since the network requires abrupt and fast commands due to emergent situations, delay times should be extremely reduced to increase the data rate [4]. These networks are referred to ‘complex networks’ because of variety and large amounts of data acquired which complicates the stage of processing [5]. Since it’s difficult to store and perform such huge computations on one data center, these calculations are done on various layers and distributed over many data centers. In this method, an initial and local process is performed; subsequently, if needed, for special nodes additional information are sent to main processing centers for further processing; obviously, effective real-time process is obtained just for critical nodes, while all of the nodes are locally real-time processed.

Command and Control. The purpose of establishing a smart grid is to optimally control a power system, improve the security, reduce energy dissipation, facilitate the commercial steps of power trade and let users select their desired service [6]. There are two kinds of commands: first, commands by different parts of the network, including the coordinator, and second, commands by users in order to manipulate their settings and consumption. Both kinds of commands are principal and require specific controllers to change the specifications and properties in order to perform the desired command. Implementing smart networks and exploiting automatic algorithms will tremendously increase the data rate and security in this part [7].

Introduced steps are all important in establishing a reliable power network; however, in this paper we will focus on the first step and propose a new method to solve discussed problems in data acquisition. The rest of this paper is organized as follows: in Section II, we will introduce WSNs comprised of several sensor nodes and communication link between them, and their applications in smart grids. Section III will explain the structure of sensor nodes and propose a manipulated version to be implemented in smart grids. Next, in Section IV we will study different communication links between nodes and network structures and propose an appropriate one. In Section V, benefits of implementing wireless sensor networks in data acquisition stage are expressed; finally, will conclude this paper with an overview of proposals, results and advantages.

Wireless Sensor Networks in Smart Grid

WSN is a network of numerous sensor nodes consisting of data centers to obtain and process information from sensor nodes and communication links to establish connections among sensor nodes and data centers. These networks are mostly employed to monitor a specific natural environment, traffic control and disaster situations awareness; for instance, earthquake, fire, flood and etc. Recently, these networks are improved with 'E-Learning' capability. In the next section, a proper network structure and sensor node architecture for WSN is introduced to be utilized in smart grids.

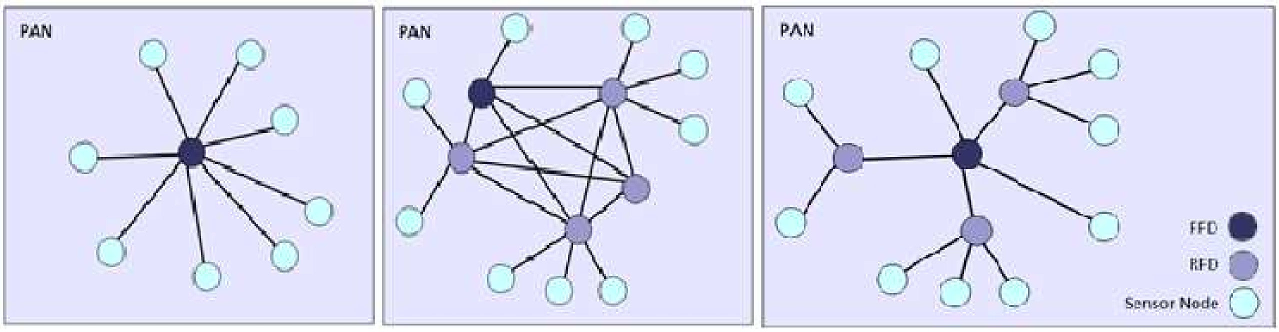
Sensor Nodes

Sensor nodes in a WSN monitor the instant situation and transmit information to data centers using available communication links. Sensors must be selected according to the type of data they are designed to measure [8]. In smart grids, sensors are widely utilized to continuously measure voltage and current (known as 'current sensors' and 'voltage sensors'). By knowing voltage and current, power produced or consumed is determined at each node. Furthermore, other kinds of information are sometimes required; for instance, instantaneous temperature should be derived for particular nodes and power transmission lines that explain the essence of other devices including temperature sensors connected to A/D converters because of their analog output. In addition, wireless transmitter and receivers are vital devices to be included in the structure of sensor nodes. Furthermore, a processor unit should be incorporated in the architecture of sensor nodes, in order to set up the connection among transmitter, receiver and sensor device. According to the application, a simple microprocessor or microcontroller is usually selected to play this role [8]. Since there are occasional disconnections among sensor nodes and the network, this microprocessor should be able to store data on a memory unit, wait for a new connection and transmit the stored data; this is why an external memory unit should be attached to sensor nodes [8]. A challenging issue in implementing sensor nodes is 'power'; because it is mostly hard to perform wired power supply for these sensors, batteries with long life are regularly selected to supply power; however, for sensor nodes in a smart grid, according to electromagnetic induction principle, the energy supplying for the wireless node can be taken from high level voltage line by using a special current transformer (CT) [9]. However, a battery is recommended to be included in the structure of sensor nodes, being charged when power is available and working as an alternative power source when the local network power is off.

Sensor Network

In addition to nodes, another significant part of wireless sensor networks is the communication link between nodes and processing centers. These networks are analyzed according to both the topology and the specific communication system used. In these networks, sensor nodes, referred to RFDs (Reduced Function Devices) are capable of sensing and transmitting data. In the upper stage, FFDs (Full Function Devices) are available to locally process data in addition to sending and receiving; further, they play the role of routers in a network. Above all, the coordinator (Main Processing Station) does the final process on information in order to decide on commands in the smart grid.

In WSN, various topologies are implemented, in which one of the most common used is the Star topology. In this structure, all of the RFDs are directly connected to the coordinator and each Star Network operates independently from other ones [10] – depicted in Figure 1 (a). Another structure, referred to Mesh, differs from Star Network in the connection between RFDs (Sensor Nodes), as presented in Figure 1 (b). In the WSN designed for smart grid, the number of sensors is tremendously high which complicates the processing stage and increases the data traffic in the coordinator. This is why Cluster-tree structure is preferred for our proposed network being used in smart grid. In this structure, FFDs are connected to the coordinator exploiting a Star Network and also RFDs are connected to FFDs with the same structure. This structure is depicted in Figure 1(c) [10].



(a) (b) (c)

Figure 1 – (a) Star and (b) Mesh Network Topologies (c) Cluster-tree Topology specialized for Smart Grid

It is assumed that in the wireless sensor network the necessity to command due to information received from each sensor, is of low probability. This probability –defined by the authors as request probability- depends on time and the condition of smart grid; however, mostly this probability is supposed to be less than 0.25 (overestimated). According to this assumption, it is not expected for all of the sensors to send data to the coordinator incessantly. In our proposed network, Sensor Nodes transmit their information to a FFD which locally processes and routes data in the network. If it is effective to decisions made, it will transmit data to the coordinator for final processing.

A simulation of the proposed network is implemented using MATLAB7.5 with 10 FFDs which each is connected to 10 RFDs, request probability set to 0.2 for every single sensor node and compared to the Star Network which has all of the sensors directly connected to the coordinator, in 1000 points in the timeline.

$P_r(s_i)$ - request probability density function of each sensor node - defined to be:

$$P_r(s_i) \sim u[0,1] \tag{1}$$

Obviously probability of s_i being less than P_t – a threshold used for request probability- is equal to P_t. Assuming I to be the number of sensor nodes that their corresponding s_i is less than P_t, which means their data require processing in the coordinator as the main station. Based on the network transmission rate, it will take t_{si} time units for each packet data to be completely sent to the coordinator; this transmission time is selected as:

$$P_{pd}(t_{s_i}) \sim Rayleigh(\sigma) \tag{2}$$

Where σ is mode and in the simulations is properly set to 3, according to packet data size of each sensor node and data rate for wireless communication systems, as shown in Table I.

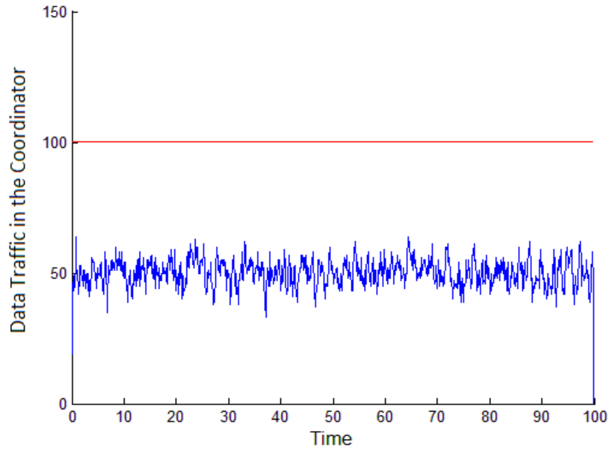


Figure 1 - Result of simulation of data traffic in the coordinator in time domain, where the red curve indicates direct connection of coordinator to sensor nodes, while the blue curve belongs to cluster-tree network with request probablity of 0.2.

The communication system standard utilized in the network is highly significant as well. In the proposed network, there are two connections defined: first, the connection between RFDs and FFDs and second, the connection between FFDs and the coordinator. In smart grids, sensor nodes are not usually fixed at certain locations, hence the connection should be wireless to make the network flexible. Additionally, the distance between FFDs and Sensor Nodes is assumed to be small; therefore, short-distance wireless communication system is appropriate to be adequate. With these assumptions, it is mostly preferred to use WPAN networks, such as Bluetooth, Wi-Fi or ZigBee. The corresponding specifications for each network, is presented on Table I. As it is shown, ZigBee network has the capability to support more Sensor Nodes, while consuming less power. These two advantages of ZigBee network are properties which are beneficial and compatible with the demands of smart grids. Furthermore, this technology is cheap compared to the alternatives and makes WSN economically suitable for being implemented in smart grids.

TABLE I. Comparison of Zig-Bee, Wi-Fi and Bluetooth Standards

Feature	Standard		
	Zig-Bee ® 802.15.4	***Wi-Fi ™ 802.11b***	***Bluetooth ™ 802.15.1***
Transmission Range (m)	1-100	1-100	1-10
Battery Life (days)	100-1000	0.5-5	1-7
Network Size (# of nodes)	> 64000	32	7
Application	Monitoring and Control	Web, Video, E-mail	Cable Replacement
Stack Size (KB)	4-32	1000	250
Throughput (kbps)	20-250	11000	720

Conclusion

According to simulations and discussed benefits of wireless sensor networks, they definitely satisfy nearly all of the demands of a desired smart grid. With high data process capability, secure transmissions, flexibility, simple request analysis and information computation in various layers and data centers, WSNs with a cluster-tree topology are one of the proper choices for the design of smart grids [11]. With cheap prices, they are further economically preferred to other data acquisition systems. As simulations of the proposed structure prove, data traffic is remarkably reduced in the main processing station which overcomes one of the most concerns in the smart grid – the network capacity. Furthermore, with utilization of WSN with suggested specifications, it's possible to perform real-time processing and increase the speed of decision making for command and control stage of smart grid function [12]. Finally, as a result of ease of implementation it could be utilized fast which portrays a bright perspective and remarkable achievements for smart grids in the future exploiting wireless sensor networks.

References

[1] Vehbi C. Gungor, Bin Lu, and Gerhard P. Hancke, "Opportunities and Challenges of Wireless SensorNetworks in Smart Grid", IEEE Transactions On Industrial Electronics, Vol. 57, No. 10, October 2010.

[2] O. Asad, M. Erol-Kantarci, H. T. Mouftah, "Sensor Network Web Services for Demand-Side Energy Management Applications in the Smart Grid," IEEE Consumer Communications and Networking Conference (CCNC'11), Las Vegas, USA, January 2011.

[3] I. S. Jacobs and C. P. Bean, "Fine particles, thin films and exchange anisotropy," in Magnetism, vol. III, G. T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271–350.

[4] V. C. Gungor, O. B. Akan, and I. F. Akyildiz, "A real-time and reliable transport protocol for wireless sensor and actor networks," IEEE/ACM Trans. Netw., Vol. 16, no. 2, pp. 359–370, Apr. 2008.

[5] Elie Fute Tagne, Fabrice Lauri, Abder Koukam and Emmanuel Tonye. The Coverage Problem in Wireless Sensor Networks by Holonic Multi-agent Approach. International Journal of Computing and ICT Research, ISSN 1818-1139 (Print), ISSN 1996-1065 (Online), Vol.3, No.1, pp. 32-41.

[6] U.S. Department of Energy, Grid 2030: A National Vision for Electricities Second 100 years, Offince of Transmission and Distribution, July 2003.

[7] Sai-Yi Wang; Yi-Nong Li, "Annual replacement decision-making of electrical equipments in distribution network", Electricity Distribution, CICED 2008.

[8] Verdone, R., D. Dardari, G. Mazzini and A. Conti “Wireless Sensor and Actuator Networks” Elsevier, London.2002.

[9] Zhai Zi-Nan, Gui Wei-feng, “Research on Monitoring Power System Faults by Wireless Sensor Network”, Proceedings of the Third International Symposium on Electronic Commerce and Security Workshops(ISECS ’10) Guangzhou, P. R. China, 29-31,July 2010, pp. 354-357.

[10] Shahin Farahani, “ZigBee Wireless Networks and Transceivers”, Elsevier,2008

[11] V. Pothamsetty, S. Malik, “Leveraging Intelligent Communications to Transform the Power Infrastructure”, Cisco Systems, February 2009.

[12] Reetu, Shabana Mehfuz, Mini S. Thomas, “Development Of Wireless Sensor Network For Distribution System Management”, Proc. of Int. Conf. on Control, Communication and Power Engineering 2010.