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A Survey on Wireless Sensor Networks for Smart Grid

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Abstract: With the increasing concern for reliability and quality of service, power grid in many countries is undergoing revolution towards a more distribute and flexible "Smart Grid". In the development of envisioned smart grid, situational data awareness takes a fundamental role for a number of crucial advanced operations in the areas of sensing, communication, monitoring and decision making. It is very important that applications of smart grid should always be monitored. The wireless sensors in combination with actuators in the smart grid network would significantly advance the existing networks and could perform more comfortable application preferential control actions. The smart grid needs an efficient medium access approach based on the data prioritization and delay responsiveness. The wireless sensor communication within smart grid system is based on data rate, delay, latency, congestion and so on. The data is collected in a reliable and timely manner from the entire system and based on collected data the entire system is monitored for more advanced controlling schemes. This article surveys a sample of algorithms that can be adaptable for smart grid applications. *Copyright © 2015 IFSA Publishing, S. L.*

Keywords: Sensing, Communication, Smart grid, Data priority, Latency, Congestion, Wireless sensor networks.

1. Introduction

Today many countries are advancing their power sector industry by providing it more intellectual options. The intelligence added to the traditional power grid can make decisions in implementing control actions based on application tasks, by the employment of communications and networking that aims to achieve the stability and reliability in the entire system making it more smarter turning it into "Smart Grid" [1-2]. The sensing can be defined as collection of data from various parameters like voltage-current phasor values, power flow measurements, advanced metering and so on. The data would become meaningful when combined with efficient collection & processing. The smart grid environment requires the support of pioneering applications like wireless sensor networks (WSNs) particularly because it realizes advanced communication networks. The Quality of Service (QoS) indicators for communication within the smart grid measurement system include wide area coverage, monitoring, interoperability, low cost, data-rate, delay and etc. [3-4].

Wireless Sensor and Actuator Network (WSAN) comprises sensors and actuator nodes. It requires a stronger computation and communications. Generally a sensor collects information from applications and an actuator can perform various tasks, such as processing the data and accordingly interacting with the environment. Introduction of a mobile actuator that has ability to change its location timely manner can perform better for an application [5-7]. WSANs are suitable to improve the efficiency, reliability, and security in the smart grid that use advanced information and communication technologies [8].

The impact of priority and delay awareness in medium access techniques is evaluated based on end-to-end delay, delivery ratio and energy consumption of the WSANs. The reduction of delay and prioritizing data is achieved by schemes DRX (a Delay Responsive Transmission layer) and FDRX (Fairness in the Delay Responsive Transmission). These schemes have strengthened the performance of smart grid applications, when sudden changes occur in terms of load or generation [9-12]. In a network it is very important that a reliable event reporting is carried from sensors to actuators. A framework is proposed that works on delay and event reporting which assimilates huge data based on priority based data accumulation that outlines the allocation of actuator [13-14].

EDAL (An Energy-Efficient, Delay-Aware, and Lifetime-Balancing Data Collection Protocol) achieves a significant increase on network lifetime without violating the packet delay constraints [15]. HERO (A Hierarchical, Efficient and Reliable Routing) is a novel hierarchical protocol which is fault-tolerant, energy-efficient and reliable in the context of wireless sensor and actuator networks. This protocol deals with the identifying and organizing the nodes in the network then assembling them to form into cluster [16].

RAP (Real-time communication architecture for large-scale wireless sensor networks), is an efficient communication protocol designed for real time applications in large scale networks which identifies the essential nodes and decreases the length of hop. RAP follows a novel velocity monotonic scheduling (VMS) policy that defines packet scheduling in sensor networks [17]. SPEED (A Stateless Protocol for Real-Time Communication in Sensor Networks) is a well-organized and effective communication protocol when the number of nodes is very high and holds important information that should be transferred with minimum end-to-end delay and decreased hop. This provides good response to congestion [18]. MMSPEED (Multipath Multi-SPEED Protocol) can cater the minimum end-to-end delay requirements that signify the timeliness and consistent performance. MMSPEED deals with very large sensor networks with huge data in an efficient manner [19-20].

HEED (A Hybrid, Energy-Efficient, Distributed Clustering Approach for Ad-hoc Sensor Networks) identifies the cluster-head among the nodes present in a cluster. HEED incurs low message overhead, and maintains homogeneous relation with all the nodes in a cluster [21-23]. LOFT (A Latency-Oriented Fault Tolerant Transport Protocol for Wireless Sensor-Actuator Networks) selects the best route through which the data has to be sent that has very less packet loss. It estimates the nearest neighbors and then estimates the incoming data rates that can be affordable using priority queue utilization. The preference is given to the prioritized data while transmitting through the data path [24]. A DFT-MSN (The Delay/Fault-Tolerant Mobile Sensor Network for Pervasive Information Gathering) has several distinctive characteristics that deal with sensor deployment, weak connections, admissibility against fault, delayed operations and buffer limit [25-26].

The rest of paper is organized as follows. The Section 2 elaborates different algorithms used in WSNs to improve performance of smart grid and Section 3 includes conclusion followed by references.

2. Algorithms Used to Improve the Performance of WSN

It is very important to note that the traditional power grids are advancing as smart grids by improving greatly in terms of intelligence and by adding communication capabilities that can take effective decisions. Smart grid requires intelligent sensors and actuators for acquiring data and controlling purposes. It is an urgent requirement to recognize the necessary challenges of future scenario of the smart grid which requires the continuous upgradation by adopting the different architectures, frameworks and algorithms. Various algorithms are proposed by many research groups and industry [27-30] to achieve delay estimation, data priority, reliable routing, energy efficient clustering, real-time communications and latency.

2.1. Delay Responsive Algorithms

Irfan S. Albangi, *et al*. [9-12] introduces two layers for data transmission in WSAN's, DRX and FDRX. The delay reduction achieved by DRX and FDRX would enrich the operations of smart grid in circumstances where abrupt alterations arise. The implemented WSAN employed to monitor and control delay critical data in smart grid environment. The data collected by certain sensors have high priority and should be delivered with minimum end to end delay. Both the above mechanisms were based on delay estimation algorithm that has assessment of delay and data prioritizing stages that are implemented by application layer in addition to medium access control (MAC) layer constraints in response to delay requirements of smart grid application and network conditions [13-14]. Prioritizing the data that is adapted from multiple frames of different layers can be done by implementing the adaptive schemes that is defined by DRX. The application layer then evaluates the captured data and takes a decision, based on the priority of the monitored parameter value that is beyond an acceptable threshold (i.e., higher or lower than normal limit values), based on this threshold the algorithm estimates the delay estimation and MAC layer checks if it is above the defined threshold or not. Then DRX changes the clear channel assessment (CCA) duration for entire session. On the other hand FDRX introduces fairness into DRX by preventing few nodes from dominating the communication channel. DRX reduces the end-to-end delay while FDRX has lower collision rate comparison with DRX. Both the above schemes are able to reduce the delay for higher priority data while maintaining packet loss values, FDRX scheme improves the performance of DRX scheme, and achieves the delay reduction that allows rest of nodes to conduct in an appropriate manner within the specified bound. The FDRX will always provide an opportunity to the rest of nodes in the network to transmit the prioritized data. Thus, FDRX are fair enough to the rest of the nodes. In the FDRX scheme, the MAC sub-layer requests the physical layer to reduce the CCA duration. Thus both DRX and FDRX schemes are able to reduce the end-to-end delay.

Edith C. H. Nagai, *et al.* [14] proposes a reliable reporting based on delay sensitivity event in wireless sensor actuator networks. This paper signifies the essence of acting responsively and perfectly for a reporting scheme that is important for sensors to inform the actuators. It estimates the failures of sensor and the delays that occur due to data over-crowding. This paper proposes a general reliability centric framework for event reporting in WSANs. An efficient algorithm is proposed for event data against fault occurrence. The field is coupled by network is divided for event monitoring. The data must be transferred from sensors to actuators by maintaining reliability. The actuator should respond within very short span of time and it should take an accurate decision. The timely delivering not only enables short response time for the actuators but also implies more accurate decisions for the given fresher data. Reliability and time specifications are so important when the network has to deal with the huge data aggregation. Since the events may have different importance, depending on their type of urgency. In a network layer framework, the data sent by a sensor will be in the form of packets that was arranged in a queue, during transmission of this data the most important event data should be scheduled with high priority. This prioritization of the data using queue utilization will serve in selecting optimal hop selection in routing. The routing and transmission protocol for event reporting nodes to the actuator is the core module. The very important point to note is that the number of reports reaching the destination within their latency bound is maximized. Once an actuator receives the event report, it will perform application specific actions.

2.2. Efficient Data Collection Algorithms

Yanjun Yao, *et al.* [15] demonstrates a feasible approach in developing one data collection protocol called EDAL, which is based on two algorithms, the computational overhead is reduced by centralized heuristic and a distributed heuristic makes algorithm scalable for large scale network operations.

The EDAL performs considerable reduction in total traffic for collecting sensor readings under delay bounds. This protocol also focuses on enhancement of data collection efficiency through an emerging technique called compressive sensing, through which data is compressed during transmission to a given destination. It is assumed that all links are directional and are associated with qualitative link. From the sources the data is collected in the form of packets by selected nodes in the network within the deadline. The main objective is that the data is to be delivered with minimum packet loss. It is very important that the number of routes joining in to a node should be the same as the number of routes leaving from it. The time for the packets being transmitted on the routes should not violate delay. This paper integrates compressive sensing with EDAL to achieve a better gain in energy efficiency by exploiting the topological requirements of compressive sensing. Centralized heuristic (C-EDAL) increases overall system lifetime by up to 60 %, Distributed heuristic (D-EDAL) increases system lifetime by up to 52 %. Compared to LRR (Location aware random routing), C-EDAL increases lifetime by 13.79 %, D-EDAL increases system lifetime by up to 8.1 %. Minimum spanning tree is a widely used, conventional routing algorithm for WSNs where it is constructed for collecting data to sink. By implementing compression sensing these values are increased to 81.9 % and 44.9 %. Finally LRR increases the lifetime by 32.9 %.

2.3. Reliable Routing Algorithm

Eduardo Cañete, *et al.* [16] proposed HERO which deals with the formation of novelty multihop that finds the energy efficient path for transmitting the data from sensor nodes to their cluster head. Importantly the operation of HERO protocol mainly consists of three phases: discovering/maintenance phase, joining phase, and routing algorithm. Discovering phase has following advantages like, a node shall find its immediate neighbor and interacts with them, the new nodes were allowed to join the cluster and then new node shall wait for receiving the information for its neighbor then transfers the received information in the efficient path and node shall find immediate alternatives when sudden fault occurs. A node that belongs to same cluster will establish communication for monitoring the task. The node will exchange data as long as it is trustworthy to its cluster head. Depending on the protocol, the cluster constraints were established, and when a node satisfies all the constraints then it joins that cluster. A node while transmitting packets to its neighbor will give more significance to the quality of link and then followed by the node life. To achieve reliability routing for data transmission it is necessary to maintain high packet reception ratio (PRR). This protocol allows in defining the necessary reliability levels between two nodes which are ‘N’ hops far away to each other.

2.4. Real-time Communication Based Algorithms

C. Lu, *et al*. [17] proposed a protocol called RAP designed for large scale sensor network which aims for working with real time applications. This was mainly based on the event based high level complexity services. The working of this protocol was based on communications that work with sensors placed at a novel location. The sensors work with light weight network loads. The network working has advantage of scalability. This protocol presented and evaluated a new policy called velocity monotonic policy that was based on time and distance based constraints. This paper mainly concentrates for scheduling packets that accounts in a sensor network. Sensor network protocols should support real time communications by minimizing the packet deadline miss ratio i.e., percentage of packets meet their end-to-end deadlines. The main design goal includes providing application programming interfaces (API) for micro sensing and control. This maximizes the number of packets meeting their end-to-end deadlines. This protocol scales well to large number of nodes and hops and introduces minimum communication overhead.

T. He, *et al.* [18] proposes SPEED which is specifically designed for real time applications based on sensor networks. When a node is deployed in network, it starts collecting information about immediate neighbor nodes that are deployed in the network. The SPEED works well when the number of nodes deployed in a network is of high density. SPEED works with high efficiency that can be scalable. The designing of SPEED mainly depends on three types of communications, real time unicast, real-time area multicast and real-time area any cast. The knowledge on the immediate neighbors would provide uniform data rate delivery across the network. The design goal of SPEED mainly includes balancing of traffic load, maintenance of confined behavior of network, void avoidance. SPEED is the only one routing protocol especially designed for sensor networks to satisfy real-time requirements. SPEED has an important factor for real time applications that mainly concentrates on localized feedback control approach. According to SPEED, the node which is considered should maintain the information of all the neighboring nodes and their performance. The data is transferred in the form of packets in a network. The SPEED would guarantee a certain data-rate delivery for every packet transferred in the network. When network is busy SPEED would avoid the data congestion. The beacon exchange mechanism collects information about the nodes and their location. Delay estimation at each node is basically made by calculating the elapsed time when an ACK (acknowledgement) is received from a neighbor as a response to a transmitted data packet which is based on "Back Pressure Routing". The neighborhood feedback loop module is responsible for providing the delay ratio which is calculated by looking at the miss ratios of the neighbors of a node. The backpressure-rerouting module is used to prevent voids, when a node fails to find a next hop node, and to eliminates congestion by sending messages back to the source nodes so that they finds new routes.

Emad Felemban, *et al*. [20] described MMSPEED protocol designed for real time applications based on sensor networks. It performs packet delivery mechanism that avoids the data traffic in wireless sensor networks. The performance quality is relative to appropriateness and consistency. MMSPEED performance depends on the timeliness of the delivered data in the form of packets that has to be transmitted from source node to destination node deployed in a large scale sensor networks. The routing protocol has designed with two important goals, the first was a priori path setup that provides differentiated QOS options in isolated timeliness and the other one is based on reliability domains. The localized packet delivery can be achieved without considering the knowledge of network topology which defines procedural model for overcoming a smaller amount of consistent and boundless transmissions over wireless links. Localized packet routing decisions were taken without knowledge of global network topology or prearranged path setup. Each node knows its physical, geographic location absolute via GPS or relative to other nodes via distributed location services. Packet destinations were specified by these physical locations rather than node locations. Node location information exchanged via periodic location update packets. Therefore, each node knows where is it deployed and where are its neighbors placed in a network. Knowing the final geographic destination of a packet, a node could determine the best neighbor node to communicate. Not taking into account congestion characteristics etc., this would normally be the neighbor which is closest to the final node. In this manner, a packet would eventually reach its final destination. In extreme cases a node would simply drop packets so that it can keep at least one neighbor within delay estimate which satisfies the "Set Speed" requirement.

In addition, in the cases of congestion nodes may issue back-pressure packets to neighbors to reduce incoming traffic. When a packet arrived at the node, it must classify the message based on the urgency of its contents. When data packets of higher layers are arrived, it should not cause any delay the packets in the lower layers. Once processing is done and the packet is ready to be sent the MAC layer that has knowledge on the current clock time as well as the packet length and transmission output rate of the node. The MAC layer updates elapsed time in the packets header and makes its first attempt to send the packet on the first layer. Each successive resend attempt delay the packet a little bit more so the MAC layer would be update each time to ensure an accurate value. The results show that MMSPEED can significantly improve the effective capacity of a sensor network in terms of number of flows meeting both reliability and timeliness requirements.

2.5. Efficient Clustering Algorithm

Ossama Younis, *et al.* [21-23] proposes a design for the formation of clusters in an energy efficient way using HEED protocol. After a cluster formation takes place, the protocol performs following activities, it determines about the deployment of nodes, the distance between nodes is assessed, the cluster head for every certain period of the time is decided and it obtains the information about the energy level of nodes. It estimates the distance between the cluster head and a node which is necessary to make the network active for longer period of time. Thus HEED plays a major role in distributing the load in a uniform manner. The important constraints for HEED include battery life, processing, memory and communication capabilities. HEED makes a decision on the needful or wasteful energy.

When large numbers of nodes are deployed to study the performance of many applications requires the huge data-acquisition needed for an efficient routing protocol like one-to-many, many-to-one or one-to-all (broadcast) communication. After deployment the node would be left unattended. Every node in the network has limited energy level which allows only specified transmission levels between node-to-node. Every node in a network was at least deployed in one cluster. Using single hop, the node can communicate its cluster head each node independently makes its decisions based on local information. Clustering terminates within a fixed number of iterations. Clustering should be efficient in terms of processing complexity and message exchange. HEED is fast and has low overhead. HEED has advance features such as load-balancing.

2.6. Latency Based Algorithms

Edith C. H. Nagai, *et al.* [24] introduces about a LOFT for WSANs. The group of sensors and actuators collects the data and respond to application. It takes the responsibility that works efficiently for consistent data transport which is essential for reporting the data from sensors to actuators. It considers the importance and freshness of data in a real time system. It provides real time reliable data transport that resists to transmission failures. It estimates the load on the sensors. It evaluates the performance of the actuator that is advancing from one node to other node. It calculates the maximum affordable load to handle data. Coping with transmission failures it estimates the path success rate. It calculates the replication factor for transmission. Each packet should be reported to the actuator within the specific bound of time and fixed data rate.

Yu Wang, *et al*. [25-26] proposes a delay fault tolerant mobile sensor network. DFTMSN mainly focuses on information gathering and efficient data delivery schemes. There are mainly two types of approaches namely data transmission which deals with the decision making about at what time and at what destination data has to be transmitted. The queue management technique decides whether to transmit or to drop the message. DFTMSN focuses communication in high interval environments and the interoperability. This protocol is based on sensor network that is static. Due to a restricted communication range and life of the sensor, each sensor has been roughly connected to each other and may be inaccessible to each other. DFT introduces mobility that improves the network connectivity. Network follows the ZebraNet, based on the past approach for routing. Performance evaluation of DFTMSN proposed on data delivery schemes that achieve the highest message delivery rate with acceptable delay and transmission overhead. The comparative analysis of various protocols used in WSNs is tabulated in Table 1.

Table 1. Comparison of various protocols used for wireless sensor networks.

S. No.	Protocol	Network Simulator	End to End Delay	Data Priority	Energy Efficiency	Packet Loss	Link Failures
1.	DRX and FDRX	QualNet	Less	High	Good	Less	Less
2.	Event Reporting Framework	Ns-2	Less	High	Uniform	Less	Less
3.	EDAL	NS-3	Optimized	Medium	Good	Optimized	Optimized
4.	HERO	COOJA	Less	Very high	Very high	Very less	Very less
5.	RAP	GloMoSim	Less	Depends on the requested velocity	Good	Minimum	Less
6.	SPEED	GloMoSim	Less	Very higher priority	Good	Very Less	Very Less
7.	MMSPEED	J-SIM	Less	Defined by threshold	Good	Application oriented	Less
8.	HEED	Matlab	Optimal	High	High	Very less	Less
9.	LOFT	Ns-2	Optimized	Medium	Good	Optimized	Optimized
10.	DFT-MSN	Ns-2	Tolerable	Depends on buffer	Good	Optimized	Optimized

3. Conclusions

It is true that many countries still rely on the traditional power grids for their power requirements. This situation needs a long term research in the area of power industry in combination with sensing, communication and networking that turns a traditional grid to become smarter and thus making it a "Smart Grid". In this paper, a summary of some important protocols based on the end-to-end delay, data priority, energy efficiency and congestion have been studied. The DRX and FDRX schemes are most efficient and able to reduce the end-to-end delay. This research review would definitely improve the standard in making data centric decisions and signifies the essence to carry-out further research on data prioritization, extending the life of network and should become more application specific in the coming future.

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