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Energy Efficient Protocol Design Issues in Wireless Sensor Networks

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ABSTRACT

Sensor networks consist of a large number of small, inexpensive sensor nodes. These nodes have small batteries with limited power and also have limited computational power and storage space. When the battery of a node is exhausted, it is not replaced and the node dies. When sufficient number of nodes die, the network may not be able to perform its designated task. Thus the life time of a network is an important characteristic of a sensor network and it is tied up with the life time of a node. This paper presents a survey for designing energy efficient Wireless Sensor Network (WSN) Protocols and identifies future trends in designing energy efficient WSN protocols.

Keywords : WSN, Energy efficient protocol, WSN design issues

1. OVERVIEW OF WIRELESS SENSOR NETWORKS

The recent development of small wireless sensing devices has opened the door for several new applications. These applications have the potential in changing the way we perceive, monitor, and interact with the physical world. Many application domains have already been mentioned in the literature [1, 2, 3, 4, 5, 6]. For example, sensor nodes can be deployed in the battlefield to monitor and track the enemy's troop movement (i.e., military applications). Sensor nodes can also provide attractive solutions for challenging medical problems; for example, small bio-sensors can function as an artificial retina that replaces a damaged one [3] when deployed inside the human body. Environmental monitoring is another promising application domain for wireless sensor networks. For example, wireless sensor networks can be used to monitor pollution levels in water resources and soil. Also, wireless sensor networks can be used to track and monitor volcanic and earthquake activities, this allows for the early detection of any activities, which helps in avoiding or at least mitigating disasters. Like in out-door applications, WSNs have many promising in-door applications. For example, WSNs can be deployed in the apartments of elderly people providing an innovative non-obtrusive tool to better monitor the activities of elders living in their apartments. In this capacity, WSNs facilitate connecting seniors to their caregivers and the communication of any emergency conditions such as falling of the elder.

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Environmental monitoring is one of the earliest envisioned applications of wireless sensor networks. Therefore, research challenges of this particular application caught the attention of many researchers, which resulted in a large body of work. In this application, researchers envision large scale deployment, where a large number of sensor nodes are scattered in the sensor field. After deployment, these nodes should organize among themselves and form a multi-hop network and should remain functional for long time periods, several years in some applications [1, 4]. By functional, we mean that the network should be able to perform the original job the network is supposed to do, e.g., sensing the environment and sending the results back to some base station. Since the lifetime of individual sensor nodes is usually on the order of a few months, and that it is infeasible to re-power individual nodes by simply changing their battery, techniques to save the power consumption and so extend the lifetime of wireless sensor networks is vital in real life applications and have been extensively studied in the literature.

Researchers have considered several techniques to decrease power consumption at the different layers. At the application level, aggregation [7, 8, 9], where multiple data messages are diffused and integrated into a single data message, is one of the techniques used to lower the power consumption spent on transmitting redundant data messages from the data sources back to the sink. Several energy-aware routing protocols [10, 11, 12, 13, 14] have been discussed in the literature. In these protocols the current power level of the sensor node is considered by the routing protocol as a criteria in choosing routes between sources and destinations. Trading off network delay to power consumption was leveraged by MAC protocols to introduce low duty cycle operation modes, where nodes turn their radios off if not actively transmitting or receiving [15, 16, 17, 18].

Like other network protocols, topology control was used as yet another attempt to extend the network lifetime and reduce power consumption. The term "topology control" has been used in the literature in two contexts, some people [19, 20, 21, 22, 23, 24, 25] use the term to refer to the problem of adjusting the transmission power of the sensor nodes and so adjusting the network topology, while others [2, 26, 27, 28, 29, 16, 30, 31, 32, 33] use the term to describe the process of turning the sensor nodes radio on and off consequently controlling the network topology and decrease total power consumption. We refer to the latter as the node scheduling technique.

In node scheduling protocols [2, 26, 27, 28, 29, 16, 30, 31, 32, 33], node redundancy was exploited to extend the network lifetime. The key idea in this class of protocols is to identify node redundancy in terms of some functionality (usually communication), cluster redundant nodes together, and finally schedule nodes in the clusters for active or sleep modes in such a way the network is able to perform the original function adequately. Although all topology control protocols that fall in this category share the basic idea, the exact node redundancy definition and criteria for a node to stay active or switch to sleep are still the property of a specific node scheduling protocol.

2. ENERGY EFFICIENCY DESIGN OF WSN

Energy efficiency is always one of the major goals in the design of WSN. Energy efficient protocols have been explored for a long time. Previous work expects to achieve the goal of energy efficiency by designing energy efficient query protocols [44], routing protocols, such as [10, 11,12,13,29,32], energy efficient MAC protocols like [10, 17], energy efficient clustering and duty cycle management [7,14], sensor network topology management [30], and other energy efficient approaches [11, 12, 13, 15, 16, 17]. However, these approaches mainly focus on finding some energy efficient path, designing better turn on/off schedules, forming energy efficient clusters, and so on, but none of them has examined the energy efficiency from the view of the data itself, i.e., to adapt the data sampling rate to the data dynamics and keep lazy when data consistency is maintained.

Aggregation is one of the most common technologies used in wireless sensor networks to save energy. Aggregation structures such as TAG [7, 8] are designed to aggregate the message. Another work from [11] propose new aggregation scheme that significantly extends the class of queries that can be answered using sensor networks. In [45]also use aggregation scheme used, not only take advantage of the earlier aggregation techniques but also tried to combine several pieces of data together.

Load balanced protocols are designed in different layer of sensor systems to save energy and extend the lifetime of wireless sensor networks. Dai and Han in [31] construct a load balanced tree in the sensor networks to make the load evenly distribute to different branches of the routing tree. Indirectly Query [48] is proposed to balance the load at query layer so that it extends the lifetime of WSN a lot. At the higher level, several researchers have proposed to balance the load of sensors by rotating their functionality, including coordinators in topology management [29], rotation of grid zone headers in GAF routing [32], rotating cluster headers in hierarchical protocols [47], and switching among multi-paths during routing [46].

Energy aware routing is also used to save energy and extend the lifetime of wireless sensor networks. Shah and Rabaey proposed an energy aware protocol [13]. They kept using a set of good paths instead of just finding a single optimal path and used different path at different time with some probability depending on the energy metric. Younis et al. [14] designed an energy-aware routing for cluster-based sensor network. In their approach, the gateway in each cluster applies energy-aware metrics to manage the topology adjustment and routing setup, but the cluster based scheme is argued to be energy inefficient. GEAR [32] and WEAR [44] are both used as energy aware approaches to balance the load to different sensors so that they extend the lifetime of WSN significantly.

Duty cycle management and sensor network topology management are two other approaches to achieve the goal of energy efficiency. In [7,14], the authors tried to design an on/off schedule for sensors so that they can save energy by making sensors sleep as much as possible. Gupta proposed a topology management mechanism in sensor networks to save energy [30]. The basic idea of this approach is to take advantage of the redundant sensors. To be specific, they pick up a set of sensors from the sensor network and make sure that this set of sensors are sufficient to reconstruct data for the entire sensor networks. This approach can save energy but it also introduce load imbalance, and it cannot satisfy some applications that require a certain level of data redundant. In general, data quality management scheme complements this kind of approaches very well by considering both energy efficiency and data quality.

3. NODE SCHEDULING PROTOCOLS

Work on node scheduling protocols is widely diverse; its evolution, over the last five to six years, is divided into three stages. The bulk of the work in the first stage is pure theoretical analysis of the minimum connected dominating set problem. Centralized optimization algorithms are proposed to select the minimum connected dominating set [34, 35, 36], which is known to be an NP-hard problem. This work lacked the practicality which prevented its applicability in real life sensor network deployments. The reported sensor node wireless transceiver module power consumption profile made the node scheduling approach, among others, more appealing in extending the network lifetime, therefore it triggered new interest in the topic. In the second stage, researchers shifted their efforts to address the more practical issues of wireless communication links and investigate localized fully distributed algorithms to select the active node set [2, 26, 27, 28, 29, 16, 30, 31, 32, 33]. The primary goal of the node scheduling protocols in this stage is to select the optimal active node set that most extends the network lifetime, other network properties such as reliability, network capacity, and coverage are ignored. Proposing new node scheduling algorithms was not the primary concern in the third stage. Instead, researchers shifted their efforts again to study and investigate assumptions made in the second stage, such as the assumption that sparse networks improve network capacity. Furthermore, fault tolerance and coverage are considered as important network properties in addition to bare connectivity [19, 37, 38, 39, 40, 41, 42].

4. FUTURE COURSE OF ACTION

Since its conception, Wireless Sensor Networks (WSNs) have been envisioned to operate autonomously for long period of time and without close supervision and human intervention. This key requirement demands that WSNs incorporate features such as self-configuration, self-organization, and dependability. Self-configuration and self-organization requires the development of adequate system-level support that enables the sensor nodes to automatically and continuously discover its surroundings, including its neighbors and topology information, and to organize into a connected network. On the other hand, node failures should not render the WSN non operational. In other words, the WSN should be able to withstand node failures and heal on its own and without external intervention. Further, investigations can be done to develop energy efficient WSN network protocols that move WSNs forward toward implementing this vision (i.e., autonomous dependable WSNs).

This can be planned in two major ways. First, by using analytical models to formalize and quantify WSN dependability characteristics. These models may allow for the systematic integration of WSN dependability as a primary dimension in the design space of the communication stack protocols and algorithms as well as the deployment problem. Perhaps the most prevalent node failures are those caused by harsh environmental conditions. Therefore, focus shall be on WSNs reliability and availability aspects of dependability. Second, WSNs are believed to be application-specific. Different applications impose different requirements and even different research challenges. Furthermore, different WSN application environments yield different sensor node failure models, which imply different WSN reliability behavior and mandate different algorithms from the reliability point of view. Therefore, an application driven approach can be followed in protocol design. Various applications can be targeted such as large-scale environmental applications with irregular and random sensor node placement, in-door mission-critical applications, and environmental application with uniform linear sensor node placement.

5. CONCLUSION

In this paper, we made an attempt to summarize the results of major contributions of various researchers in the field of wireless sensor networks. Based on that, we tried to identify the future areas of work particularly in design of energy efficiency protocols.

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