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Challenges in maximizing the life of Wireless Sensor Network

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ABSTRACT

A Wireless Sensor Network is a wireless network that consists of spatially distributed devices called sensor nodes. Each node monitors physical or environmental conditions and communicate with nearby nodes via radio broadcast (network). Research in WSNs has become an extensive explorative area during the last few years, especially due to the challenges offered, energy constraints of the sensors being one of them. Reducing energy consumption of individual sensors in such networks and obtaining the expected standard of quality in the solutions provided by them is a major challenge. The questions how a wireless sensor network's lifetime can be increased and what are the constraints in improving the operational efficiency are motivating. Specifically, we will focus primarily on different protocols which represent the most suitable technique for energy saving. Moreover, we will also survey in-network processing which can guarantee a significant amount of energy saving. Finally, we will make a review on some communication protocols proposed for sensor networks.

Keywords: Wireless Sensor Network, Sensor Node, Energy Consumption of Sensor Node, Energy Conservation,

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1. Introduction

Wireless Sensor Networks (WSNs) have become active research topics recently both in academia and industry. Sensors of various types are deployed ubiquitously and pervasively in varied environments such as office buildings, wildlife reserves, battle fields, mobile networks, etc., to accomplish some high-level tasks [1][2]. One of the most significant benefits of sensor networks is that they extend the computation capability to physical environments where human beings cannot reach. However, energy possessed by sensor nodes is limited, which becomes the most challenging issue in designing sensor networks. The main power consumptions in sensor networks are computation and communication between sensor nodes. In particular, the ratio of energy consumption for communication and computation is typically in the scale of 1000. Therefore it is critical to enable collaborative information processing and data aggregation to prolong the lifetime of sensor networks. In other words, we should carefully select sensor nodes to participate in the task. Akyildiz *et al.* [3] provide a comprehensive overview of different aspects of research in sensor networks. In this paper, we will take a more in-depth look at prolong the lifetime challenges, including more recent techniques in this area. In a typical wireless sensor network, sensors are networked to achieve some specific task, e.g. tracking objects. These nodes are severely constrained in energy and in most case cannot be recharged. Thus minimizing the communication costs between sensor nodes is critical to prolong the lifetime of sensor networks.

Problem statement

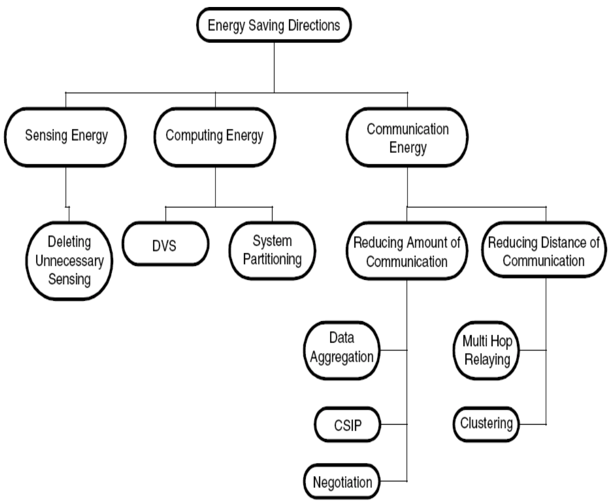
The following issues will be addressed in this paper: Studying network infrastructure, factors influencing energy consumption at network level and things to be look for while making wireless sensor network for more efficiency.

The objective of this paper is to give some preliminary guidance on how to configure the WSN and extend its services in terms of its life time and in order to make it energy efficient based on the criteria discussed above. Finally we make our recommendations, suggest improvements and conclude with a summary.

Maximizing network lifetime is certainly one of the most important design objectives for all the sensor networks that need to run for a long time.

Maximizing Network Lifetime: Network lifetime has been defined in various ways [47], [48], [49], [50], [51] and an energy-efficient mechanism may choose to maximize a certain type of network lifetime. In the simplest case, a network may be considered alive when any of the sensors is alive. Network lifetime can also be calculated as the duration of time when the percentage of sensors that have depleted their energy is below a threshold, e.g., 90% [47], [48].

Motivations and Directions
A typical sensor node is compact, tiny, and inexpensive, but it integrates the functionalities of sensing, data processing and computation, and communication. It is normally operated by an attached power supply that is usually a non-rechargeable or non-replaceable battery [4].



Energy-conserving directions in WSNs.

RELATED WORK

Energy consumption:
Energy consumption is the most important design factor for sensor networks. Saving power during the operation of the electronic device could be achieved on more than one level. First, on the circuit or VLSI level, power could be saved by using less power for state transition (capacitor charging and discharging) and state maintenance.
On the architecture level, power could be saved by the proper implementation of the processor, the cache, and the instruction set. A study on the Strong ARM110 processor revels that the power dissipation in the instruction cache, data cache, and TLB accounts for almost 60% of the power consumption of the processor that means there is a room for power saving by the proper implementation of the memory system.
Also energy could be saved at the medium access control, and network level protocol. Minimizing the number of collisions or the path length results also in energy saving. Transmission and reception of radio signal is another candidate for power minimization. Short distance transmission and simple circuitry for modulation/demodulation results in power saving.
Sensing Energy
The sensing unit in a sensor node includes the embedded sensor and/or actuator and the analog–digital converter. It is responsible for capturing the physical characteristics of the sensed environment and converts its measurements to digital signals, which can be processed by a computing/processing unit. Energy consumed for sensing includes: (1) physical signal sampling and conversion to electrical signal; (2) signal conditioning; and (3) analog to digital conversion.
Computing Energy
The computing/processing unit is a microcontroller unit (MCU) or microprocessor with memory. It carries out data processing and provides intelligence to the sensor node. A real-time micro-operating system running in the computing unit controls and operates the sensing, computing, and communication units through micro device drivers and decides which parts to turn off and on [5]
Communicating Energy
The communicating unit in a sensing node mainly consists of a short-range RF circuit that performs data transmission and reception. The communicating energy is the major contributor to the total energy expenditure and is determined by the total amount of communication and the transmission distance.
As reported in Pottie and Kaiser [6], processing data locally to reduce the traffic amount may achieve significant energy savings.

Approaches to Conserving energy
Numerous solutions have been proposed for conserving energy in wireless ad hoc (sensor) networks in literature. They can be roughly classified into three approaches, namely topology control, power aware routing and sleep management.

Topology control: Topology control preserves desirable properties of a wireless network (e.g., K-connectivity) through reduced transmission powers. Li et al. proposed a MST-based topology control scheme which preserves the network connectivity and has bounded node degrees [7]. The problem of maximizing network lifetime under topology control is studied in [8].

Sleep management: Recent studies showed that significant energy savings can be achieved by turning wireless radios off when not in use. In this approach, only a small number of nodes remain active to maintain continuous service of a network and all other nodes are scheduled to sleep. SPAN [9], ASCENT [10], AFECA [11] and GAF [12] maintain network connectivity while CCP [13] maintains both network connectivity and sensing coverage. More recently, a sleep schedule algorithm is proposed in [14] to maximize the lifetime of network clustering.

Reasons of Energy Waste in MAC protocol

When a receiver node receives more than one packet at the same time, these packets are called "collided packets" even when they coincide partially. All packets that cause the *collision* have to be discarded and the re-transmissions of these packets are required which increase the energy consumption. Although some packets could be recovered

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by a *capture* effect, a number of requirements have to be achieved for its success. The second reason of energy waste is *overhearing*, meaning that a node receives packets that are destined to other nodes. The third energy waste occurs as a result of *control packet overhead*. Minimal number of control packets should be used to make a data transmission. One of the major sources of energy waste is *idle listening*, i.e., listening to an idle channel to receive possible traffic. The last reason for energy waste is *over emitting*, which is caused by the transmission of a message when the destination node is not ready. Given the facts above, a correctly-designed MAC protocol should prevent these energy wastes. [22]

Power aware routing in Wireless Sensor Networks:
Singh et al. proposed five power-aware routing metrics to reduce energy consumption and extend system lifetime [15]. The implementation of a minimum energy routing protocol based on DSR was discussed in [16, 17]. An online power aware routing scheme is proposed to optimize system lifetime in [18]. Chang and Tassiulas studied the problem of maximizing the lifetime of a network with known data rates [19]. Chang et al. formulated the problem of choosing routes and transmission power of each node to maximize the system lifetime as a linear programming problem and discussed two centralized algorithms [19]. Sankar et al. formulated maximum lifetime routing as a maximum concurrent flow problem and proposed a distributed algorithm [20].

COMPARISON OF VARIOUS PROTOCOL AND CURRENT ISSUES:
Unlike the wired network, there are lot of challenges and attraction in the routing for sensor network. The data routing in the sensor network are classified into three categories: data centric, location based, and hierarchical routing.
In the cluster based approach, the nodes are grouped and one with least energy is chosen as head. In this case we will be able to achieve efficient energy distribution and not even energy distribution. As we see, only a particular node gets focused on major operation and that node gets more consumed with energy than other. [21.]

Node Clustering in Wireless Sensor Networks:
In order to support data aggregation through efficient network organization, nodes can be partitioned into a number of small groups called *clusters*. Each cluster has a coordinator, referred to as a *cluster head*, and a number of *member* nodes. Clustering results in a two-tier hierarchy in which cluster heads (CHs) form the higher tier while member nodes form the lower tier. Figure 1 illustrates data flow in a clustered network. The member nodes report their data to the respective CHs. The CHs aggregate the data and send them to the central base through other CHs. Because CHs often transmit data over longer distances, they lose more energy compared to member nodes. The network may be reclustered periodically in order to select energy-abundant nodes to serve as CHs thus distributing the load uniformly on all the nodes. Besides achieving energy efficiency, clustering reduces channel contention and packet collisions, resulting in better network throughput under high load. [23]

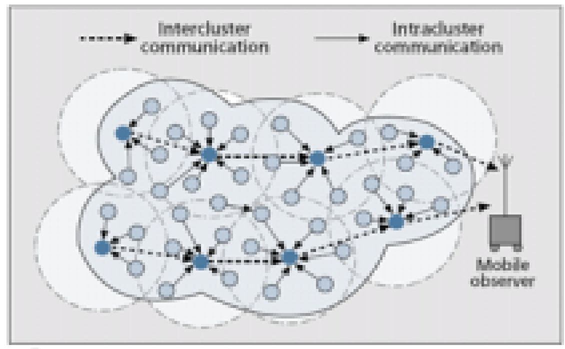

Figure *Illustration of data flow in a clustered network.*

The LEACH protocol [24] is an application-specific clustering protocol, which has been shown to significantly improve the network lifetime. It assumes that every node is reachable in a single hop and that load distribution is uniform among all nodes. LEACH assigns a fixed probability to every node so as to elect itself as a CH. The clustering process involves only one iteration, after which a node decides whether to become a CH or not. Nodes take turns in carrying the role of a CH.
Lindsey and Raghavendra [25] proposed an enhancement over LEACH protocol. The protocol, called Power-Efficient Gathering in Sensor Information Systems (PEGASIS), is a near optimal chain-based protocol. The basic idea of the protocol is that in order to extend network lifetime, nodes need only communicate with their closest neighbours and they take turns in communicating with the base station. When the round of all nodes communicating with the base station ends, a new round will start and so on. This reduces the power required to transmit data per round as the power draining is spread uniformly over all nodes. Hence, PEGASIS has two main objectives. First, increase the lifetime of each node by using collaborative techniques and as a result the network lifetime will be increased. Second, allow only local coordination between nodes that are close together so that the bandwidth consumed in communication is reduced. Unlike LEACH, PEGASIS avoids cluster formation and uses only one node in a chain to transmit to the base station instead of using multiple nodes.
The HEED protocol [26] considers a multihop network and assumes that all nodes are equally important. A node uses its residual energy as the primary parameter to probabilistically elect itself to become a CH. In case of a tie between two CHs, say *u* and *v*, *u* concedes to *v* (i.e., gives up its CH candidacy) according to a secondary parameter, such as node degree or average distance to neighbours. This results in the uniformly distribution of the elected set of CHs across the network. In HEED, each node executes a constant number of iterations. An implementation of HEED in Tiny OS (the operating

system for Berkeley motes) showed that clustering and data aggregation at least double the network lifetime.

Kuhn *et al.* [27] proposed a probabilistic technique to elect CHs, in which the probability is dependent on the node degree. The convergence of their proposed technique, which depends on the number of nodes in the network and the node degree, is much faster than iterative techniques. In addition, this approach elects a dominating set of CHs that is asymptotically optimal (minimal).

In this paper, [28] proposed the MiSense hierarchical Cluster based Routing Algorithm (MiCRA) to extend the lifetime of sensor networks and to maintain a balanced energy consumption of nodes. MiCRA are an extension of the HEED algorithm with two levels of cluster heads. The performance of the proposed protocol has been examined and evaluated through a simulation study. The simulation results clearly show that MiCRA has a better performance in terms of lifetime than HEED. Indeed, MiCRA our proposed protocol can effectively extend the network lifetime without other critical overheads and performance degradation. It has been noted that there is about 35% of energy saving for MiCRA during the clustering process and 65% energy savings during the routing process compared to the HEED algorithm.

Energy-aware Routing for Cluster-based Sensor Networks [29]: Sensors are grouped into clusters. Cluster heads namely gateways are less energy constrained nodes. Gateways maintain the states of the nodes and sets up multi hop routes. Sink only communicates with the gateway. Gateway informs other nodes about in which slot they should listen others' transmission in which slot they can use for transmission. The sensor can be in four states; sensing only, relaying only, sensing-relaying and inactive. A cost function is defined between any two nodes in terms of energy consumption, delay optimization and other performance metrics. Using this cost function, a least-cost path is found between sensor nodes and the gateway.

• Self-organizing Protocol [30]: The protocol can be applied to the heterogeneous networks which consist of mobile, stationary nodes. The sensing nodes send the captured data to predetermined set of nodes, namely routers. This stationary router nodes form the backbone of the network and forward the gathered data to a more powerful node, namely sink. Since such a heterogeneous network requires addressing, the address of the node is identified through the router it connected. There are 4 phases to build a routing table. First phase is Discovery Phase; each node discovers its neighbors. In the Organization Phase groups are formed, each node allocates an address; routing tables are formed for each node. Next phase is Maintenance Phase. Routing tables and energy levels are updated in this phase. The last phase is Self-organization Phase, in case of node failure or partition, group reorganizations are performed.

Two hierarchical routing protocols called TEEN (Threshold-sensitive Energy Efficient sensor Network protocol), and APTEEN (Adaptive Periodic Threshold sensitive Energy Efficient sensor Network protocol) are proposed in [31] and [32], respectively. These protocols were proposed for time-critical applications. In TEEN, sensor nodes sense the medium continuously, but the data transmission is done less frequently. The main drawback of this scheme is that, if the thresholds are not received, the nodes will never communicate, and the user will not get any data from the network at all. TEEN gives the best performance since it decreases the number of transmissions. The main drawbacks of the two approaches are the overhead and complexity associated with forming clusters at multiple levels, the method of implementing threshold-based functions, and how to deal with attribute-based naming of queries

APTEEN, AdaPtive Threshold sensitive Energy Efficient sensor Network Protocol [32]: The protocol is an extension of TEEN aiming to capture both time-critical events and periodic data collections. The network architecture is same as TEEN. After forming clusters the cluster heads broadcast attributes, the threshold values, and the transmission schedule to all nodes. Cluster heads are also responsible for data aggregation in order to decrease the size data transmitted so energy consumed. According to energy dissipation and network lifetime TEEN gives better performance than LEACH and APTEEN because of the decreased number of transmissions. The main drawbacks of TEEN and APTEEN are overhead and complexity of forming clusters in multiple levels, implementing threshold-based functions and dealing with attribute based naming of queries.

Abbasi and Younis in the paper [33] present a taxonomy and general classification of clustering schemes. The survey of energy-efficient clustering based protocols can be found in [34]–[37].

Data Aggregation

The principle of data aggregation or data fusion is to minimize traffic load (in terms of number and/or length of packets) by eliminating redundancy. It applies a novel data- centric approach to replace the traditional address-centric approach in data forwarding. Specially, when an intermediate node receives data from multiples source nodes, instead off forwarding all of them directly; it checks the contents of incoming data and then combines them by eliminating redundant information under the constraints of acceptable accuracy. Several data aggregation algorithms have been reported in literature.

The authors in [38] studied the problem of maximizing the lifetime of the wireless sensor networks. They introduced exact and approximate algorithms for data aggregation. They performed data aggregation on two levels. First, local aggregators are used to aggregate data received from local sensors, then an optimal set of master aggregators are chosen to select the second level of data aggregation. Their results show that substantial saving in energy could be achieved using their technique.

The authors in [39] studied the quality of the aggregated data. They proposed data aggregation algorithms for clustered-based and chain-based aggregation. They showed that their protocol reduces the total energy in the network without sacrificing the quality of the data collected. The problem of how long to delay the messages in every node, to improve aggregation are addressed in [40]. The authors in [41] proposed a heuristic in order to construct and maintain an aggregation tree in wireless sensor networks.

Another technique called TAG is proposed in reference [42]. In this case, the authors propose an SQL like language that is used for generating queries over the sensor network. The TAG approach is one of a general purpose aggregation. That is, it has not been designed with an application specific intent. Its operation is fairly simple; the base station defines a query using the SQL-like language designed for use in TAG. The sensors then route data back to the base station according to a routing tree. At each point in the tree, data is aggregated according to the routing tree and according to the particular aggregation function that is defined in the initial query.

Shrivastava [43], et al proposed a summary structure that is able to support fairly complex aggregate functions, such as median and range queries. It's important to note that typical aggregate functions are capable of performing min/max, sum, and average. The more complex aggregates, such as finding the most frequent data values, are typically not supported. They note that the added aggregate functions are not exact. However, they prove strict guarantees on the approximation quality of the queries.

Wagner et al analysed the resilience of all aggregation techniques in reference [44], and argues that current aggregation schemes were designed without security in mind and that there are easy attacks against them. Wagner proposed a mathematical framework for formally evaluating the security for aggregation, allowing them to quantify the robustness of an aggregation operator against malicious data. This seminal work opened the door to secure data aggregation in sensor networks; however, the one-level homogeneous aggregation model is too simple to represent real sensor network deployments.

Battery

In [45] the authors argue that battery driven design is an important concept for electronic devices that depends on batteries. There are many types of batteries for use in mobile devices. Nickel Cadmium batteries are one of the oldest battery technology. The new Lithium Polymer batteries with their very thin form factor are a promising technology for tomorrow's mobile devices [46]. Also, some batteries may be rechargeable. Rechargeable batteries could substantially increase the lifetime of a network. However it might not be always easy to recharge batteries in sensor networks.

Conclusions& Scope for future work

The field of sensor networks is very recent, and a lot of work needs to be done in it in order to mature and become an acceptable technology. Energy saving in wireless sensor networks has attracted a lot of attention in the recent years and introduced unique challenges compared to traditional wired networks. In this paper, we have summarized some of the research results which have been presented in the literature on energy saving methods in sensor networks. The network lifetime directly proportional to the efficient power consumption and disfunction of any node causes serious damage to the network service considering nodes' dual role of data originator and data router.

Power control and power management are two different types of topology controlling methods. The combination of the two has not yet well studied. We believe by integrating power control and power management, it is possible to provide noticeable improvements on network topology and efficiencies of energy usage. This is another interesting research topic for the researchers in the field.

Instead of using known protocols, that used to work well in Sensor Networks, we should expose new algorithms with energy saving as a prime goal.

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