Sensors Lifetime Enhancement Techniques in Wireless Sensor Networks - A Critical Review

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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 dies, 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 of different techniques to enhance the lifetime of the sensors in WSN and identifies future trends in designing energy efficient WSN protocols.

Keywords

Wireless Sensor Networks.Life time of sensor.Neural Network.Transmission power control.Automata.Dynamic duty cycle control. Limited energy capacity

I. Introduction

Advances in wireless communication made it possible to develop wireless sensor networks (WSN) consisting of small devices, which collect information by cooperating with each other. These small sensing devices are called nodes and consist of CPU (for data processing), memory (for data storage), battery (for energy) and transceiver (for receiving and sending signals or data from one node to another). The size of each sensor node varies with applications. For example, in some military or surveillance applications it might be microscopically small. Its cost depends on its parameters like memory size, processing speed and battery [1].Today, wireless sensor networks are widely used in the commercial and industrial areas such as for e.g. environmental monitoring, habitat monitoring, healthcare, process monitoring and surveillance. For example, in a military area, we can use wireless sensor networks to monitor an activity. If an event is triggered, these sensor nodes sense it and send the information to the base station (called sink) by communicating with other nodes.

The use of wireless sensor networks is increasing day by day and at the same time it faces the problem of energy constraints in terms of limited battery lifetime. As each node depends on energy for its activities, this has become a major issue in wireless sensor networks. The failure of one node can interrupt the entire system or application. Every sensing node can be in active (for receiving and transmission activities), idle and sleep modes. In active mode nodes consume energy when receiving or transmitting data. In idle mode, the nodes consume almost the same amount of energy as in active mode, while in sleep mode, the nodes shutdown the radio to save the energy.
The following steps can be taken to save energy caused by communication in wireless sensor networks [2].

- To schedule the state of the nodes (i.e. transmitting, receiving, idle or sleep).
- Changing the transmission range between the sensing nodes.
- Using efficient routing and data collecting methods.
- Avoiding the handling of unwanted data as in the case of overhearing.

In WSNs the only source of life for the nodes is the battery. Communicating with other nodes or sensing activities consumes a lot of energy in processing the data and transmitting the collected data to the sink. In many cases (e.g. surveillance applications), it is undesirable to replace the batteries that are depleted or drained of energy. Many researchers are thereforetrying to find power-aware protocols for wireless sensor networks in order to overcome such energy efficiency problems as those stated above.All the protocols that are designed and implemented in WSNs should provide some real-time support as they are applied in areas where data is sensed, processed and transmitted based on an event that leads to an immediate action. A protocol is said to have real-time support if and only if it is fast and reliable in its reactions to the changes prevailing in the network. It should provide redundant data to the base station or sink using the data that is collected among all the sensing nodes in the network. The delay in transmission of data to the sink from the sensing nodes should be short, which leads to a fast response.

II. Network Design Challenges and Routing Issues

The design of routing protocols for WSNs is challenging because of several network constraints. WSNs suffer from the limitations of several network resources, for example, energy, bandwidth, central processing unit, and storage [4,5]. The design challenges in sensor networks involve the following main aspects [3,4,5]:

Limited energy capacity: Since sensor nodes are battery powered, they have limited energy capacity. Energy poses a big challenge for network designers in hostile environments, for example, a battlefield, where it is impossible to access the sensors and recharge their batteries. Furthermore, when the energy of a sensor reaches a certain threshold, the sensor will become faulty and will not be able to function properly, which will have a major impact on the network performance. Thus, routing protocols designed for sensors should be as energy efficient as possible to extend their lifetime, and hence prolong the network lifetime while guaranteeing good performance overall.

Sensor locations: Another challenge that faces the design of routing protocols is to manage the locations of the sensors. Most of the proposed protocols assume that the sensors either are equipped with global positioning system (GPS) receivers or use some localization technique [6] to learn about their locations.

Data Aggregation:Since sensor nodes may generate significant redundant data, similar packets from multiple nodes can be aggregated so that the number of transmissions is reduced. Data aggregation technique has been used to achieve energy efficiency and data transfer optimization in a number of routing protocols.

Diverse sensing application requirements:Sensor networks have a wide range of diverse applications. No network protocol can meet the requirements of all applications. Therefore, the routing protocols should guarantee data delivery and its accuracy so that the sink can gather the required knowledge about the physical phenomenon on time.

Scalability: Routing protocols should be able to scale with the network size. Also, sensors may not necessarily have the same capabilities in terms of energy, processing, sensing, and particularly communication. Hence, communication links between sensors may not be symmetric, that is, a pair of sensors may not be able to have communication in both directions. This should be taken care of in the routing protocols.

III. Energy Optimization Methods

The methods [25] in which energy savings can be affected or can be classified under two heads:

Device Level: Hardware component selection and their configuration to achieve low energy consumption in a wireless sensor node.

Network Level: Choice of communication methods and protocols to minimize energy consumption.

In a sensor node [26-28] there are four essential parts: processing unit, sensing unit, transceiver unit and power unit. Processing unit is a part of microcontroller unit which can read sensor data, perform some minimal computations and make a packet ready to transfer in the wireless communication channel. Figure 1 reflects power consumption of WSN in various states.

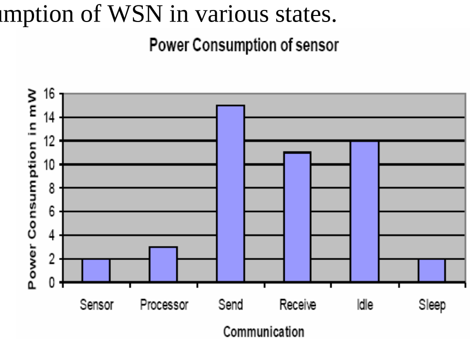

Fig 1: Power Consumption of WSN in Various States Sensor

In reality sensor unit [29] is the medium to communicate between the physical world and the conceptual world of processing unit. The sensor unit is the one of the vital part of wireless sensor mode, it sense and detect the physical state of environment and sends the data to processor. Processor manipulates data and decides where it has to promote or else transmit the data to base station. Sensor converts energy from one form to another form. In reality sensor acts as the transducer where energy is convert into analog signal or digital signal. Sensor can be distinguished based on what kind of energy they detect or transfer to the system. A wireless sensor node [30] can be built with different type of sensor, and different types of sensors use different amount of energy. Some of them require a significant large amount of energy than others. For example, gas sensor requires a comparatively higher amount of energy than temperature sensors, pressure or image sensor because it requires active heating elements. Table 1 shows power requirement of different sensors. Image sensors also require a higher amount of energy because thousands of conversions (analog to digital) are require for producing images.

Table 1: Power Consumption of different types of sensor

Sensor Type	Power Consumption
Gas sensor	500mW-800mW
Pressure sensor	150mW
Image sensor	10mW-15mW
Acceleration sensor	3mW
Temperature sensor	0.5mW-5mW

IV. General Approaches to Energy Saving

A. Time Synchronization in Wireless Sensor Networks

Time synchronization is of primary importance for the operation of wireless sensor networks (WSN). Time measurements, coordinated actions and event ordering require common time on WSN nodes. Due to intrinsic energy limitations of wireless networks, there is a need for new energy-efficient time synchronization solutions, different from the ones that have been developed for wired networks [11]. The trade-off between time synchronization accuracy and energy saving in WSN has been investigated and on this basis we have developed a power-efficient adaptive time synchronization strategy, that achieves a target synchronization accuracy at the expense of a negligible overhead. Also, we studied the energy benefits of periodic time synchronization in WSN employing synchronous wakeup schemes, and developed an algorithm that finds the optimal synchronization period to save energy while assuring high flexibility and reliable operation of WSN [12].

B. Neural Network Approach in Wireless Sensor Networks

The performance of Wireless Sensor Networks strongly depends on their lifetime, i.e., how their energy resources are being handled. As a result, Dynamic Power Management approaches with the purpose of reduction of energy consumption in sensor nodes, after deployment and designing of the network, have drawn attentions of many research studies. Recently, there have been a strong interest to use intelligent tools especially Neural Networks in energy efficient approaches of Wireless Sensor Networks [14], due to their simple parallel distributed computation, distributed storage, data robustness, auto-classification of sensor nodes and sensor reading. The most important application of neural networks in WSNs can be summarized to sensor data prediction, sensor fusion, path discovery, sensor data classification and nodes clustering which all lead to less communication cost and energy conservation in WSNs [13].

C. Real-Time Support in Wireless Sensor Networks

The sensor nodes majorly depend on batteries for energy, which get depleted at a faster rate because of the computation and communication operations they have to perform. Communication protocols can be designed to make efficient utilization of energy resources of a sensor node and to obtain real time functionality [15]. All existing routing protocols and MAC (Medium Access Control) layer protocols have abilities to achieve energy efficiency and supports real-time functionality. The design trade-off between energy conserving and quality of service support, results when protocols are tested on the assumption factors like latency, scalability, energy awareness, synchronization, etc. have been discussed. Contention-based protocols like SMAC, TMAC and TEEM use a single radio and change the radio state periodically in order to make the nodes energy efficient. STEM is also a contention-based protocol, but uses two radios (data and wake-up radio) to make the nodes energy efficient. It allows the nodes to wake up the data radio when there is a need to process data; otherwise it stays in sleep state. In contention based protocols transmission suffers from collision and delay because each node is allowed to access the shared medium. Contention-free protocols like DEMAC, PACT and LMAC provide collision-free communication. Each node has pre-assigned time slots to transmit the data but each node has to listen to the time slots of its neighbors in order to synchronize [16]. This may increase the energy consumption. Contention-free protocols suffer with clock drift problems and require tight synchronization. There are still many more challenges that need to be solved in the sensor networks like in MAC protocols to find out the suitable solution for real time support and energy efficiency because contention based protocols are energy efficient but they don’t guarantee the real time support while contention free protocols give real time support but lack in energy efficiency. Hence in routing protocols both real time support and energy efficiency need to be achieved.

D. Transmission Power Control in Wireless Sensor Networks

The operation which consumes most power is data communication. Transmission power adaptation for a particular transmitter-receiver pair based on several environmental conditions is an approach for power optimization. Two main factors including distance and wireless link quality affect the transmission power required to reach the receiver. The link quality depends upon several factors such as physical barriers and climatic conditions. At a given link quality, transmission power is adjusted in order to maintain a good link which supports data delivery success and power optimization [7]. The major drawback of a sensor is resource constraint. Transmitting data at a full power capacity may guarantee successful data delivery but it may cause a rapid decrease in battery power level. WSNs are application-specific as a different set of requirements is required by a different application category. Controlling transmission power according to link quality is an efficient approach as it provides the minimum power required to maintain a good link at a specific link quality. Most of the existing research works focus on multi-hop communication as they believe that intermediate nodes are required for data forwarding. Moreover, they do not support some applications which require single-hop communication. Data communication in WSNs can be conducted in a single-hop fashion. The existing Transmission Power Control (TPC) approaches only measure a current link quality between a pair of sensors at a specific time [8]. To overcome this, multiple base stations (sinks), with each base station having more power and higher computation capacity than an ordinary sensor, are scattered over an area for more frequent link quality measurements. The power is then repetitively decreased to discover the minimum power which provides successful data delivery. However, additional control data delivery and communication amongst base stations to exchange link measurements are required. Hence the cost required for such implementations are dramatically high and have to be minimal in order to achieve the power optimization goal.

E. Encryption Schemes Applied To Wireless Sensor Networks

In this approach, we focus on the energy efficiency of secure communication in wireless sensor networks (WSNs). It considers link layer security of WSNs, investigating both the ciphers and the cryptographic implementation schemes, including aspects such as the cipher mode of operation and the establishment of initialization vectors. We evaluate the computational energy efficiency of different symmetric key ciphers considering both the algorithm characteristics and the effect of channel quality on cipher synchronization [9]. The computational energy cost of block ciphers is less than that of stream ciphers when data is encrypted and transmitted through a noisy channel. We further investigate different factors affecting the communication energy cost of link layer cryptographic schemes, such as the size of payload, the mode of operation applied to a cipher, the distribution of the initialization vector, and the quality of the communication channel. A comprehensive performance comparison of different cryptographic schemes is undertaken by developing an energy analysis model of secure data transmission at the link layer. This model is constructed considering various factors affecting both the computational cost and communication cost and its appropriateness is verified by simulation results which shows that using a *block cipher* instead of a stream cipher to encrypt data for wireless sensor network applications, achieves energy efficiency without compromising the security in WSNs [10].

F. Data Management in Wireless Sensor Networks

In this dissertation, we address three key issues of data management in WSNs [19]. For *data collection*, a scheme of making some nodes sleep and estimating their values according to the other active nodes' readings has been proved energy-efficient. For the purpose of improving the *precision of estimation*, we propose two powerful estimation models, Data Estimation using a Physical Model (DEPM) and Data Estimation using a Statistical Model (DESM). Most of existing data processing approaches of WSNs are real-time. However, historical data of WSNs are also significant for various applications. No previous study has specifically addressed distributed historical *data query processing*. In this approach, an Index based Historical Data Query Processing scheme which stores historical data locally and processes queries energy-efficiently by using a distributed index tree is used. Area query processing is significant for various applications of WSNs [20]. Hence an energy-efficient in-network area query processing scheme is proposed. In this scheme, an intelligent method (Grid lists) is used to describe an area, thus reducing the communication cost and dropping useless data as early as possible, hence energy efficient.

G. Automata in Wireless Sensor Networks

Low power and limited processing are characteristics of nodes in Wireless sensor networks. Therefore, optimal consumption of energy for WSN protocols seems essential. In a number of WSN applications, sensor nodes sense data periodically from environment and transfer it to the sink [21], [22]. Because of limitation in energy and selection of best route, for the purpose of increasing network remaining energy a node with most energy level will be used for transmission of data. In algorithms introduced for data transmission in WSN up to now, a single route is used for data transmissions that results in decrease in energy of nodes located on this route which in turn results in increasing of remaining energy. Here a new method is proposed for selection of data transmission route which is based on learning automata that selects the route with regard to energy parameters and the distance to sink. In this method, energy of network nodes finishes rather simultaneously preventing break down of network into two separate parts. This will result in increased lifetime of the nodes.

H. Dynamic Duty Cycle Control for End-To-End Delay Guarantees

It is well known that periodically putting nodes into sleep can effectively save energy in wireless sensor networks, at the cost of increased communication delays. However, most existing work [17] mainly focuses on static sleep scheduling, which cannot guarantee the desired delay when the network conditions change dynamically. In many applications with user-specified end-to-end delay requirements, the duty cycle of every node should be tuned individually at runtime based on the network conditions to achieve the desired end-to-end delay guarantees and energy efficiency. Here, 'DutyCon', a control theory-based dynamic duty cycle control approach is proposed [18]. DutyCon decomposes the end-to-end delay guarantee problem into a set of single-hop delay guarantee problems along each data flow in the network. The single-hop delay guarantee problem is formulated as a dynamic feedback control problem and the controller is designed rigorously, based on feedback control theory, for analytic assurance of control accuracy and system stability. DutyCon also features a queuing delay adaptation scheme that adapts the duty cycle of each node to unpredictable packet rates, as well as a novel energy balancing approach that extends the network lifetime by dynamically adjusting the delay requirement for each hop.

I. *Compression Techniques in Wireless Sensor Networks*

Sensor nodes are capable of performing some processing, gathering information and communicating with other connected nodes in the network [23], [24]. Data communication within sensor nodes usually occurs without compression. However, employing data compression optimizes the Data Transfer rate (DTR), because reduction in the effective size of the data to be transferred on the network leads to reduction in the effective file transfer time and hence preserves the network energy.

V. Comparison of Different Techniques

Compared to wired networks and other wireless networks such as cellular networks, WSNs are still at an early stage of development and a lot of work needs to be done in order to take them to the maturity level. In this paper we first describe the energy consumption for components of typical sensor node, and discuss the main directions to energy saving methods in wireless sensor networks. Then we present a methodical and comprehensive taxonomy of the energy optimization methods in wireless sensor networks.

Table 2 represents Classification and Comparison of different life saving methods of WSNs.

Characteristics / ***Techniques***	***Network Power Usage***	***Energy economy***	***QoS***
Time Synchronization	Low	Energy saving is assured due to less Communication Delays.	High
Neural Network Approach	Low	Great compatibility with WSN's characteristics and hence energy conservation is achieved.	Low
Real-Time Support	High	A Routing and MAC protocol is carried in this technique which focused on the energy conserving by their real time support towards application like surveillance.	Low
Transmission Power Control	Low	Controlling transmission power according to link quality is an efficient approach as it provides the minimum power required to maintain a good link at a specific link quality.	Low
Encryption Schemes	High	Cryptographic scheme using a symmetric key block cipher, such as AES, in cipher feedback mode achieves better performance for a wide range of channel qualities and provides significant improvement in energy efficiency.	High
Data Management	Low	The algorithms can reduce the network traffic efficiently hence data management algorithms are energy-efficient.	High
Dynamic Duty Cycle Control	Low	Energy balancing approach that extends the network lifetime by dynamically adjusting the delay requirements allocated to each hop in a data flow.	Low

VI. Conclusion and Future Research

In this paper, we made an attempt to summarize the results of major contributions of various researchers in the field of energy efficiency in wireless sensor networks. These energy saving methods are basically used to increase the life time of sensor nodes in wireless sensor networks. We have also stressed the importance of design issues of Wireless Sensors Networks such as power consumption, hardware constraints, environment, and transmission media. There are still many issues to be resolved around energy management. By solving these issues, we can further, reduce the energy consumption of sensor node in wireless sensor networks. Based on that, there is significant scope of future work, particularly in the design of energy efficient protocol, its implementation and evaluation.

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