A Review of Energy Conservation in Wireless Sensor Networks

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Abstract

In wireless sensor networks, energy efficiency plays a major role to determine the lifetime of the network. The network is usually powered by a battery which is hard to recharge. Hence, one major challenge in wireless sensor networks is the issue of how to extend the lifetime of sensors to improve the efficiency. In order to reduce the rate at which the network consumes energy, researchers have come up with energy conservation techniques, schemes and protocols to solve the problem. This paper presents a brief overview of wireless sensor networks, outlines some causes of its energy loss and some energy conservation schemes based on existing techniques used in solving the problem of power management.

Keywords: Wireless sensor network, Energy conservation, Duty cycling and Energy efficiency.

1. Introduction

A wireless sensor network (WSN) comprises of sensor nodes capable of sensing the environment, process, store and transmits the sensed data through wireless channels (Akyildiz & Kasimoglu, 2004). It can be used as a system with static sensors or a system with mobile nodes. When deployed over an area, sensor nodes computes locally the information gathered from the environment. They also have the ability to detect information such as temperature, vibration, humidity and other physical environmental conditions. Information is then processed locally and the result is sent to the sinks.

Each node in the network is equipped with a battery with limited capacity which is very difficult to change or recharge due to the kind of environment in which they are deployed (Papadinitrion & Georgiadis, 2006). Wireless sensor network is likely to become significant enabling technology in many areas such as scientific, logistic, environmental monitoring, agriculture, production and delivery, military, structural health monitoring or healthcare applications.

The structure of a typical wireless sensor node has four main parts:

(i) Sensors to sense data to be acquired;

(ii) Processor for local data processing with memory;

(iii) Communication hardware used for wireless data communication; and

(iv) Power supply unit.

In addition to the basic components, sensor nodes may also include a location finding system to obtain the location and a mobilizer to change the location.

The combination of different techniques is needed to prolong the lifetime of a sensor network. During network activities, energy efficient protocols are used to reduce energy consumption to the minimal. It is important to note that a large percentage of energy is consumed by other components such as central processing unit and radio even in the idle state (Dimirkol, et al, 2006). Hence, power management schemes are used to switch off components that are not yet needed.

In this paper, a review of energy conservation schemes is carried out. Emphasis is laid on the three major approaches: duty cycling, data reduction and mobility. The rest of the paper is organized thus: section 2 highlights some major causes of energy loss in wireless sensor network while section 3 discusses the energy conservation schemes. The conclusion is contained in section 4.

2. Energy Waste in Wireless Sensor Networks (WSN)

There are several challenges in wireless sensor networks, most of which leads to energy waste (Ye & Heidemann, 2003). This section highlights the major causes of energy waste in wireless sensor nodes communication.

- Idle listening: occurs when nodes wake up and listen for incoming frames even when no data is being transmitted. This depletes the lifetime of wireless sensor networks.
- Collision: results when two or more close stations want to transmit packets at the same time. When this happens, all packets involved in the collision have to be discarded and retransmitted which results in energy loss.
- Over-hearing: when the wireless channel broadcast a message, many nodes around the sender may overhear the packet transmission even when they are not the intended recipients of these transmissions. Overhearing unnecessary traffic can result in energy waste.
- Control packet overhead: control packets consumes a lot of energy in sending receiving and listening, therefore it is advisable that a fewer number of control packets should be employed for data transmission in order to reduce the overhead.

3. Energy Conservation Techniques

Energy is one of the most critical resources for wireless sensor networks but one problem common to most of these WSNs is lack of reliable power for each sensor node in the network. The breakdown of the energy consumed in the network depends on the specific sensor node. Results from several experiments show that the cost of transmitting a single bit of information is equivalent to the one required to process a thousand operations (Raghunathan et al, 2002). In essence, data transmission consumes much more energy than data processing. However the energy consumed by the sensing subsystem varies depending on each node. In some cases, sensing consumes less energy than the one required for data processing while in other cases, it even consumes more than the energy needed for data transmission.

In view of the above, several research works has been carried out to solve the energy problem which results in different schemes and protocols. Most energy conservation techniques target the networking subsystem and sensing subsystem thus, both energy efficient protocols to minimize energy consumption during network activities and power management schemes for switching off idle node components are necessary for maximum energy conservation in wireless sensor networks (Pottie and Kaiser, 2002).

These schemes and protocols can be grouped into three; duty-cycling, data reduction, and mobility, each of the schemes is further broken into several parts as shown in figure 3.

3.1 Duty Cycling

There are different modes in sensor nodes radio operation: active and sleep modes. Nodes switches between both modes based on the activities of the network and this behaviour is known as duty cycling (Lai, 2010). During the idle mode, it has been discovered that idle energy is very significant in saving energy in wireless sensor networks. Duty cycle can thus be defined as the percentage of time a node is active during its lifetime.

Duty cycling can be achieved using two different approaches. The first is topology control which reduces the number of nodes involved in forwarding and routing packets generated by the other nodes without reducing network connectivity and coverage. It ensures that nodes not currently needed for connectivity go to sleep and save energy thereby prolonging the network longevity.

Warrier et al (2007), designed and analyzed a topology control scheme whose major components are similar to those of existing protocols but the difference lies in the definition of a rule of thumb that determines the energy gain obtainable in a network of given density. The scheme was implemented on a 42 node mica2 test bed and the result shows that topology control achieves roughly two times energy gain.

The second method is a power management scheme which introduces MAC protocols and a wakeup scheduling scheme in which during idle state, a node sleeps in more slots and still maintains network connectivity. Examples of MAC protocols with low duty cycle are TRAMA, BMAC and ZMAC. TRAMA is a Time Division Multiple Access (TDMA) scheme where nodes communicate only using their assigned slots which greatly reduce energy consumption. In BMAC a contention based protocol, each node have an independent schedule of an awake and a sleep period which utilizes low power listening to achieve low power communication. ZMAC is a hybrid protocol that adopts the behaviors of both TDMA schemes and contention based schemes depending on the level of contention in the network. It employs contention-based protocol when the level of contention is low, and switches to a TDMA scheme when the level of contention is high (Dimirkol et al, 2006).

Lai (2010) identified three categories of neighbor discovery mechanism employ to achieve the wakeup scheduling: on-demand wakeup, scheduled neighbor discovery, and asynchronous neighbor discovery.

- In on-demand wakeup mechanisms, sleeping nodes are woken on demand. This implies that a node should wakeup only when another node is ready to communicate with it. Howbeit, there is the challenge of how to inform the sleeping node that some other node is ready to communicate with it. To solve this problem, the scheme employs multiple radios with different energy tradeoffs and it has been noted that this strategy is very energy efficient.
- In scheduled wakeup mechanisms, sleeping nodes wake up at the same time according to a wake up schedule to communicate with each other then go back to sleep until the next scheduled period. Examples include the S-MAC protocol and the multi-parent schemes protocol.
- The third mechanism, asynchronous wakeup unlike the scheduled wakeup mechanism, does not require clock synchronization. A node can wake up when it likes and still be able to communicate with the other. This scheme has several advantages over others which includes: ease of implementation with low message overhead for communication.

3.2 Data Driven Approach

There are two ways by which data driven approach affects energy consumption (Arunraja & Malatha, 2012): First it sorts out unneeded samples which results in useless energy consumption and stops them from being transmitted to the sink. Secondly, it minimizes the power consumption of the sensing subsystem by keeping the accuracy of the sensor at a reasonable level. Data driven approaches are categorized according to the problem they address into data-reduction schemes and energy-efficient data acquisition schemes (Anastasi et al, 2009). The former solved the problem of unneeded samples while the latter reduces the energy spent on the sensing subsystem.

3.2.1 Data reduction schemes

This scheme employs three different techniques to reduce the amount of data that is transmitted to the sink node. They are in- networking processing, data compression and data prediction.

In-network processing performs data aggregation at intermediate nodes to reduce the amount of data that is transmitted from the source to the sink. It should be noted that, this scheme is good where readings accuracy is not important and the sensors readings are static (Zhang, 2012). Data compression encodes information at the source nodes and decodes it at the sink in order to reduce the amount of data transmitted. Data reduction by prediction scheme uses adaptive filters to predict data both at the source node and the sink nodes.

An aggressive data reduction algorithm based on error inference within sensor segments was proposed by Zhang (2012). The system combined three error control mechanism in order to ensure both energy savings as well as data validity. A performance evaluation was done in an experiment using a readily available soil temperature data. The results proved that the system produces up to a 50% energy savings when compared to several sensing schemes.

3.2.2 Energy efficient data acquisition scheme

Energy efficient data acquisition techniques are not focused on reducing the energy consumption of the sensing subsystem but they highly reduce radio energy consumption (Alippi et al, 2009). They aimed at reducing data samples thereby minimizing the number of communication as well. This data acquisition scheme can be divided into three; hierarchical sensing, adaptive sampling and model based sampling

- The hierarchical sampling approach requires that nodes are equipped with different types of sensors. Each sensor is characterized by its own accuracy and its associated energy consumption. This technique dynamically determine which class to activate, in order to get a trade off between accuracy and energy conservation
- Adaptive sampling techniques exploit similarities among the sensed data with respect to the available energy to reduce the amount of data to be acquired from the transducer.

- Model-based active sampling builds a model of the sensed phenomenon on a sample data so that next data can be forecasted. This technique exploits the obtained model to reduce the number of data samples thereby reducing the amount of data to be communicated to the sink.

Chen & Wassell (2012), proposed a data acquisition scheme which employs a compressing sensing theory to minimize the number of samples taken by sensor nodes. The framework adopts new random sampling scheme that takes into consideration the causality of sampling, hardware limitation and the trade-off between the randomization scheme and computational complexity. A scheme for sampling rate is included in the framework to allow the sensor adjust the rate at which it samples data and maintain a reasonable performance.

A performance evaluation of this scheme was done using real data gathered by a WSN. It was observed that the scheme has the ability to reduce greatly the number of samples required to be taken and consequently the energy required for sampling and transmission.

3.3 Mobility Based Approach

Mobility can be used as a means for reducing energy consumption in situations where some of the sensor nodes are mobile. Mobility of sensor nodes can be achieved in different ways: First, a mobilizer can be attached to a sensor which helps to change its location; however this movement is limited to few nodes which are not inhibited by energy (Anastasi et al, 2009). Another method is to put sensors on mobile elements such as animals and cars. This can be achieved either by putting all sensors on mobile elements to make all nodes mobile or placed just a few special nodes on mobile element while the others are static. In any of the techniques mentioned above, it has been shown that there is no energy loss due to mobility. Mobility-based energy conservation schemes can be classified depending on the nature of the mobile element, which is a mobile sink (MS) or a mobile relay (MR).

3.3.1 Mobile Sink

Mobile sinks are needed to notify sensor nodes about their new location information whenever the needs arise. They can be used to balance the consumption of energy in Wireless Sensor Networks (Wang et al, 2008). Most of the approaches proposed by researchers on sensor networks with mobile sinks applied a Linear Programming (LP) formulation to maximize network lifetime and other parameters. Wang et al (2005) employed a linear optimization model to determine the node to be visited and the duration so as to prolong the lifetime of the first node in the network. Using this model, it was demonstrated that deploying a mobile sink has greater improvement over using static sink.

An energy efficient usage of multiple, mobile base stations to increase the lifetime of wireless sensor networks was introduced by Gandham et al,(2003). This technique applies an integer linear program to decide the locations of the base stations and a flow-based routing protocol. A similar technique involves using controlled mobility to increase the lifetime of sensor networks by introducing a Greedy Maximum Residual Energy (GMRE) heuristic (Basagni et al, 2007). It adopts a Mixed Integer Linear Programming (MILP) analytical model to control the sink movement in order to maximize network lifetime.

Another approach was used by Luo & Hubaux, (2005) which employ a combination of mobility and routing algorithms. The paper proposed that the base station should be mobile and shows that the strategy can reduce the traffic of the heavily loaded nodes. This joint mobility and routing strategy achieves a high improvement of the network lifetime.

Yun & Xia (2010) utilized mobile sink to prolong the lifetime of a sensor network. The proposed approach is very good in situation where certain amount of delay in data delivery can be allowed. Each node delays data transmission until the mobile sink is at a location that can enhance its lifetime. The result of an experiment performed on the framework indicates an increase in lifetime of network when compared with sink node that is stationary.

3.3.2 Mobile Relay

There are many approaches to mobile relay, one of the most well-known approaches is the message ferrying (MF) scheme. MF is an approach which deploys a set of special mobile nodes referred to as message ferries to deliver messages for nodes within the deployment area (Zhao et al, 2004). Shah et.al (2010) employs a similar scheme through the data-MULE (Mobile Ubiquitous LAN Extensions (MULES) system. This approach prolong the lifetime of the network by reducing the rate at which sensors communicate. The mobile entity can be animals or even people can be MULEs. The MULE picks up data from the sensors near it, screen it, and drop it off to wired access points. This can lead to substantial power saving at the sensors base stations due to short- distance wireless communication (Jain et al, 2006). The performance of the system was evaluated using a model based on query theory. When compared with adhoc network, data-MULE was able to achieve twice more energy saving.

Another example of a mobile relay is found in Zebranet (Juang02). Zebranet is a mobile wireless sensor network developed by the joint effort of biologist and computer scientist for wildlife tracking. It employs energy efficient tracking nodes and store and forward communication to improve tracking technology. Though Zebranet was majorly developed to track wildlife in large forest area using communication equipments, it however can be employed for tackling several other communication and management issues in both static and mobile sensors.

The hardware consist of tracking nodes in form of collars with global positioning system (GPS), a simple microcontroller, a radio and a small memory for data retention. The collected data are then transferred from one zebra to another to a base station for processing and analysis. ZebraNet does not require constant access to the base station since it adopts a periodic node discovery as well as a node to node communication to push data towards the base station. Zebranet employs a simple but energy consuming flooding protocol for data exchange. In order to minimize the energy consumed, a data collection and dissemination protocol which makes use of certain hierarchy is adopted. When tested, this protocol proved to be effective in reducing the rate of energy consumption.

4. Conclusion

In this paper we have reviewed the main approaches to energy conservation in wireless sensor networks. This is a very wide topic since energy as one of the most critical resources in WSNs needs to be greatly managed in order to prolong the lifetime of the network. Several research works have been carried out to address this issue which results in different schemes as well as protocols.

Some of these schemes are discussed in section 3 of this paper: duty cycling, data driven and mobility based. However, it should be noted that most of them sacrificed one or more things in order to save energy. One of such is the data reduction algorithm which optimizes the trade-off between energy saving and data validity. Similarly, Appsleep a power management protocol and the mobile relay MULE system traded off latency for energy, this limits their application in real time systems. The topology control approach trades throughput to increase energy saving while mobile sink maximizes the lifetime of wireless sensor network by tolerating a significant level of delay. These limitations need to be further researched and improved upon in order to increase the efficiency of the schemes.

Despite the vast body of research in the field of energy conservation in wireless sensor networks, there are still other areas that need to be fully exploited in order to tackle the energy conservation issue. One of such is energy harvesting from the environment not only as a source of energy but also as a means of conserving energy in wireless sensor networks.

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http://monet.postech.ac.kr/research.html

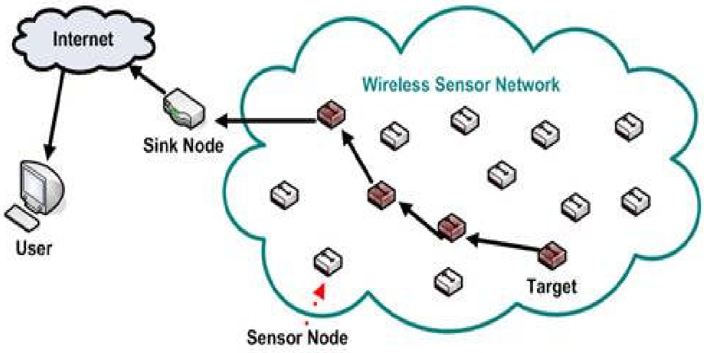

Figure 1. Typical Wireless Sensor Networks Architecture (monet.postech.ac.kr)

Figure 1 shows the sensor nodes and the sink node with a target node sending acquired data to the user through the sink node and the internet.

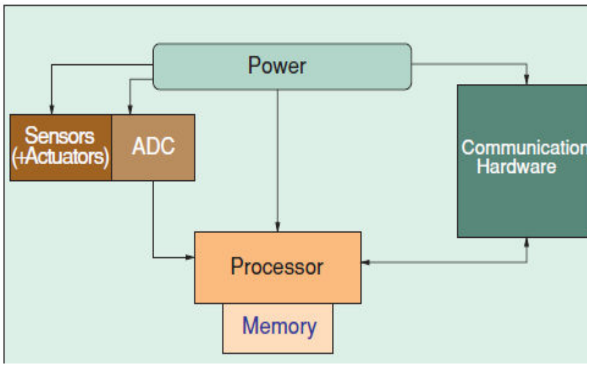

Figure 2. Structure of Wireless Sensor Network (Puccinelli & Haenggi, 2005),

Figure 2 shows the structure of a typical wireless sensor node with the four main parts.

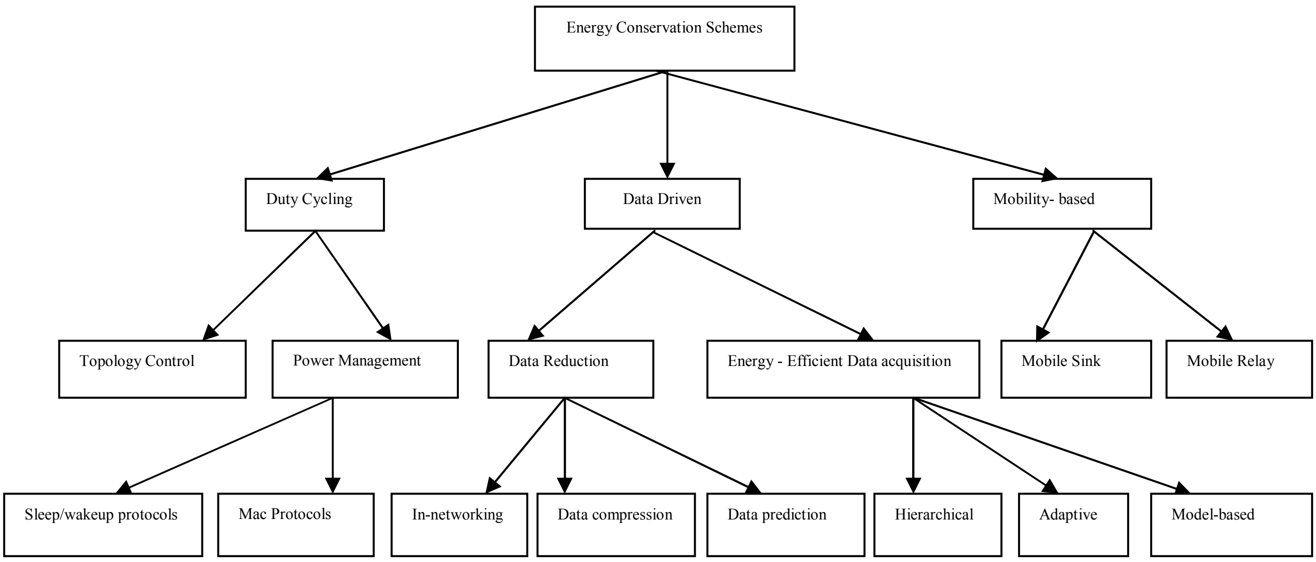

Figure3. Classification of energy conservation schemes (Anastasi et al, 2009).

Figure 3 shows the classification of energy conservation schemes