Power Conservation Techniques in Wireless Sensor Networks

Baha' Alsaify and Haiying Shen
Computer Science and Computer Engineering
University of Arkansas, Fayetteville, AR 72701
balsaify@uark.edu, hshen@uark.edu

ABSTRACT

This book chapter discusses power conservation problems in Wireless Sensor Networks (WSNs). The problem arises from the fact that WSNs have limited energy since sensors are powered with small batteries (due to the sensor size constraints). Currently, some energy-efficiency methods focus on reducing energy consumption by designing sensor hardware. Other methods enable sensors communicate with each other in an efficient manner by developing new communication protocols. Some communication protocols need to have extra information such as sensor locations for determining the best possible relays to deliver data to a Base Station. This chapter will first provide a survey on current power conservation methods. It will then discuss the efficiency and effectiveness of these methods, and propose possible solutions. Finally, it concludes the chapter with concluding remarks and open issues.

INTRODUCTION

Due to the recent advancements in the wireless networks, and the manufacturing of small, costless and energy-efficient devices, WSNs have been developing in a rapid speed. WSNs consist of a large number of energy-limited sensors that are used to monitor some area. Since WSNs are comprised of a large number of collaborating sensors (usually in the order of thousands), the cost of these sensors needs to be minimized. These sensors usually operate in areas where it is difficult for humans to work in. For example, WSNs are used to monitor a battle field, monitor the temperature fluctuations in the south and north poles, and work for extended periods in high temperature deserts. One of the future applications for WSNs is to be deployed in space or on the surface of planets.

Due to the size and cost constraints, the sensors are powered with small batteries. These batteries do not hold much energy in them. Also, since the sensors operate in usually inaccessible territories, it is not possible to change the sensors' batteries. Therefore, power conservation is important to reduce energy consumption in the WSN environment. The main goal for energy conservation is to enable sensors work for the longest possible time (i.e. network life time) while maintaining the quality of service (QoS). The QoS in the WSN environment refers to the network ability to cover 100% of the area that's being monitored.

Figure 1 shows a typical WSN. Usually WSNs have several hundred sensors and a Base Station. The function of the sensors is to collect data and send it to the Base Station. Another function for the sensors is to serve as a bridge between other sensors and the Base Station. The reason for the need of relays is because the communication range for a sensor is very limited due to energy constraints. In addition, the required energy to transmit data grows with the increase of the transmission range. In a WSN, all of the sensors' data will be sent to a Base Station. The Base Station collects the information, organizes them, deletes any redundant information, and put the information in a readable format for users to read. Usually the Base Station has higher processing capability than the scattered sensors. It also has larger size and more stored energy, and may have a power link that provides with constant power supply.

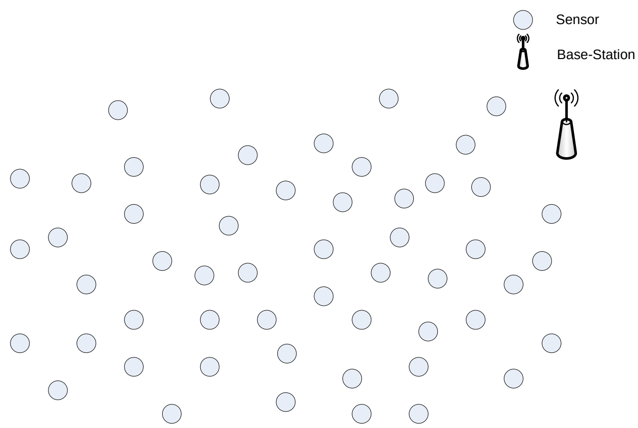

Figure 1. A typical WSN.

Figure 2 illustrates how the sensors collaborate to deliver their data to the Base Station. In the figure, sensor A wants to deliver its data to the Base Station, it uses sensors B, C, D as relays.

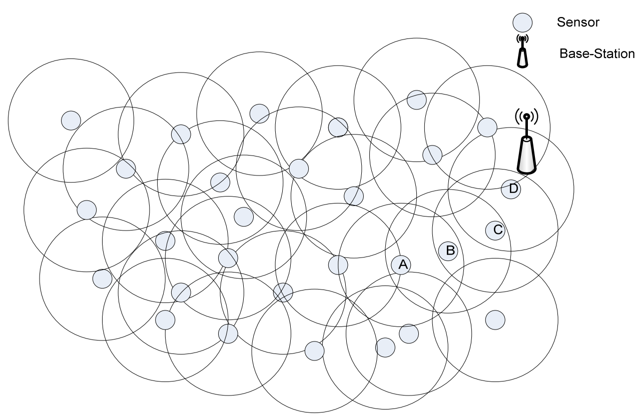

Figure 2. Sensors with their transmission ranges.

There are a number of techniques that can be used to reduce the energy used in the data collection and access operation. Some of these techniques deal with the sensors hardware (Zhong, 2007). They try to reduce the operational voltage for the sensors. Moreover, they looked into how to schedule the packets in a way that consumes the least amount of energy (Zhong, 2007). Another group of methods to reduce energy consumption is to employ sleep/awake intervals. They allow sensors not be active 100% of the time. There are a number of definitions for "sleeping" in the context of WSNs. It could mean that the only inactive part of a sensor is the radio since it is the most energy consuming part of sensor hardware. The radio is either the transmitter or the receiver (AKA transceiver). Figure 3 shows a simple sensor construction with the radio components. In another possible sleeping mode, the sensor hardware except the preprocessor is completely shutdown. The function of the preprocessor is to awake the sensor when it is time for the sensor to be active.

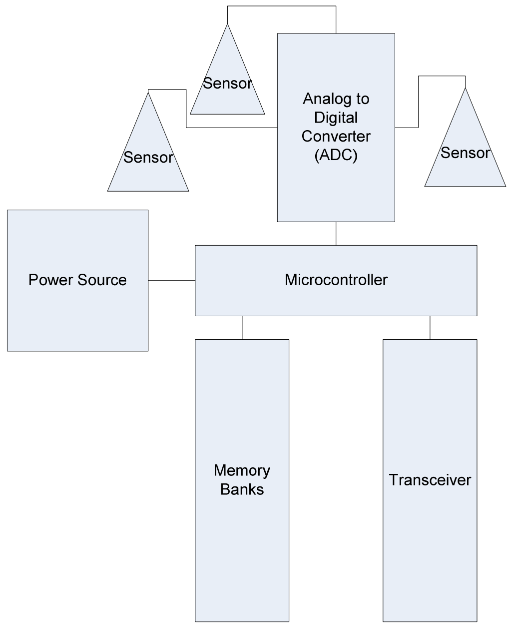

Figure 3. Sensor's internal design.

Another way to reduce energy consumption by the sensors is arranging the sensors monitor a fraction of the area (e.g. 80%, 75%). This method uses the idea of sleep/awake scheduling to activate a group of sensors for a specific period of time. These activated sensors will monitor part of the area, which will increase the system's lifetime. However, it will also affect the QoS of the network since some events may occur at the uncovered area. Energy can also be saved by controlling where data is stored. There are three methods that can be used to store and exchange sensed data.

- Storing data locally. In this method, the sensors store sensed data in its local memory banks. However, the sensor memory is limited and it cannot hold much information. Thus, this method is not suitable for applications that require information to be gathered very frequently (from the Base Station point of view). On the other hand, if sensed data is collected in the Base Station, the Base Station needs to initiate queries to the sensors for queried data. The queries in this case will be broadcasted throughout the network, which is energy draining if the queries are issued in a very intensive manner.
- Storing data at a designated location within the network. This method requires a function that processes the keywords of gathered data, and the location of the node that should hold the data is decided based on the resultant hash value. If the Base Station wants to recover some data, it will hash the keywords for the desired data and determine the location that holds the data and then send the query. In this case, the number of queries roaming among sensors is smaller than the "Storing data locally" approach since the location of the data is known. In other words, only one query is needed to retrieve the information. In this method, the sensors should be able to determine their locations. A location can be either a real geographical location or a certain point or node in the WSN.
- Sending data to the Base Station. In this method, each node sends data directly to the Base Station immediately after sensing the data. This, no node is responsible of storing data. This method will not be effective if events frequently happen. In this case, it will drain the energy in both the

sensor detecting the event and in the relay sensors. It will also create congestions in the network due to a large number of exchanged messages. The congestions lead to losing of a high number of messages, and hence a high retransmission rate. Therefore, this method is suitable for an environment with high events occurring rate.

A sensor may receive data from multiple sources to be delivered to the Base Station. Functioning as relay node, it gathers the data from all the sources and forwards it as one message. However, if the sensor just appends the data, it will end up with one giant message. To deal with this problem, the sensor can apply aggregation functions to the data including: SUM, AVERAGE, MIN, MAX and etc. As a result, the amount of data sent in one message will be substantially reduced. The amount of required energy to send a message increases exponentially with the increase of data size.

The rest of this chapter is organized in the following manner. The “Power Conservation Techniques” section will present a survey of the works for energy conservation in WSNs. Then, some problems in the area of energy conservation will be identified and possible solutions will be presented in the “Why Energy Conservation” section. After that, some insight about the future of WSNs will be presented on the “Future Trends” section. Finally a conclusion that summarizes the chapter will be the end.

POWER CONSERVATION TECHNIQUES

Reducing energy consumption has received increasing attention in the recent years. Current techniques to reduce the operational energy consumption can be divided into two main groups: (1) Hardware and (2) Software. The first group manipulates a sensor’s hardware such as IC design. In this chapter, we focus on the second group.

In order to effectively design an energy-efficient routing protocol in a WSN, a number of issues needs to be taken into consideration (Al-karaki, 2004, pp. 4-6):

- Node[i] Deployment: Node deployment is critical to designing a routing protocol. There are two possible node deployment methods:
    - Deterministic Deployment: in this method, nodes are manually placed in the monitored area. Because the nodes’ locations are known in advance, there is no need to start a localization process, which is used to determine the location of the nodes at any time of the network life time. Becase WSNs are usually used in areas that are difficult for humans to enter, this method is not commonly used. In deterministic deployment, the nodes are usually placed in a way that supports fast event reporting where data routing path is short.
    - Random Deployment: In this method nodes are randomly scattered in the monitored area. One of the possible ways to deploy nodes in a random manner is to throw them out from a plane flying over the desired area. Once the nodes reach the ground, they will start probing their neighbors and form bonds with them. In other words, they will form an ad-hoc network. Nodes usually form clusters to provide the outmost network connectivity relying on the nodes with the most residual energy as cluster heads (CHs). The nodes with the most connections can also be chosen as CHs. The responsibility of a CH includes collecting the information from the nodes in its cluster and forwarding them to the Base Station.

- Quality of Service: This criterion is application specific. It means that the application the nodes serve will specify the degree of QoS. QoS can be described as how fast the sensed events will be reported to the Base Station. In applications that are designed for battles, fast information delivery is crucial for the security and safety of a whole country. QoS can also be measured by the percentage of coverage or connectivity between the sensors in the field.
- Data Reporting Model: The choice of the data reporting model depends primarily on two factors:
    - The application.
    - The time criticality of the data.

  There are four models that can be used to report the data from the individual sensors back to the Base Station:

    - Time-driven: a time-driven model is suitable for applications that require periodic status delivery. Sensors in this model will periodically switch on their sensors, sense the surrounding environment, and send its data to the Base Station.
    - Event-driven: an event-driven model is used when reaction to certain events is crucial. Any sudden change in the sensed values will trigger the sensors, and the change will immediately be reported to the Base Station.
    - Query-driven: this model is very similar to the event-driven model, but instead of a change in the sensed value, the arrival of a query will trigger the delivery of data. The queries will be sent from a Base Station to the sensors. If the Base Station knows the location of the data, it will send it immediately to the sensor having the data. Otherwise, it simply broadcasts the query to all the nodes in the network, and only the one(s) with the intended data will respond.
    - Hybrid: this model is a combination of the previous models. It entirely depends on the application the sensors serve.
- Node/Link Heterogeneity: heterogeneity means that nodes in a WSN environment differ in power levels, communication range, computational power, and etc. The routing mechanism must be able to compensate for the differences between nodes. If the routing protocol uses clusters to organize the nodes, the node with the highest power level can be chosen to be a CH.
- Fault Tolerance: the routing protocol needs to be able to self repair. Self repair means that the protocol is able to go around failed nodes or links in delivering data. This is due to possible hardware failures and interference, which may break the links between nodes. Scalability: usually a WSN contains hundreds, even thousands of nodes. Scalability means that the routing protocol will be able to cope with that huge number of nodes and provide a routing mechanism that will provide energy savings and fast data delivery.
- Networks Dynamics: Dynamics is not that much of an issue in WSNs since most sensors are stationary. Nodes sometimes move from their original places. The reason for the movement may relate to some environmental issues, or in some rare cases, the nodes themselves have the ability to change location. The protocols need to dynamically reconnect links between nodes to provide network connectivity and area coverage.
- Transmission Media: WSNs as their name suggest are formed by placing several sensors on an area. These nodes connect with each other by wireless channels. The same problems that affect the wireless medium will affect the performance of WSNs. The main problem of the wireless

medium is its sensitivity for interference. This sensitivity will result in a high rate of retransmissions, which in turn will be very energy draining.

- Connectivity: it is one of the most important properties the WSNs should have. The higher density (i.e., nodes/area unit), the higher connectivity the network has. By having a dense connected network, the WSN will be fault tolerant. This means that the network will be able to be operational even if a large number of nodes fail.
- Coverage: Coverage is the reason for the existence of WSNs. The goal for WSN is to cover and monitor an area and report the events that occur in that area. Each sensor will be responsible to cover a certain area based on its transmission range. Any event that happens in that area will be reported to the Base Station having that sensor as the origin of the data.
- Data Aggregation: data aggregation means that some basic mathematical operations will be performed on the sensed data at relay sensors. The reason for having aggregation functions is to reduce the size of the message to be delivered. That reduction will provide fast data delivery and also cheap data delivery (energy wise).

Taking all of the previous characteristics into consideration, numerous protocols have been proposed for energy conservation. A survey of most of the protocols is presented in the following:

Sensor Protocols for Information via Negotiation (SPIN):

Sensor Protocols for Information via Negotiation (SPIN) (Kulik, 2002) is proposed to reduce energy consumption. This protocol assumes that each node in the system is a Base Station, and it sends its data to every one of these presumably base stations. The advantage of having such data dissemination is that the user (or the Base Station) can query any one of the nodes and receive the desired data. SPIN has two key innovations for energy efficiency.

- Negotiation: nodes negotiate with each other before sending the data. If the node that data are intended to be sent to already has that particular data, then no data transmission will occur. Otherwise, the sensor that has the data will send it. Negotiation helps to insure that only useful information is exchanged between the sensors and no overlap information is exchanged.
- Resource Adaptation: each one of the sensors has its own resource manager. Before a transmission, a node will poll its resource information before the transmission. The application will be responsible for contacting the resource manager and for the sensor’s status and power levels.

The negotiation in SPIN performs using a three way handshaking technique. A negotiation starts by sending an advertisement message called ADV. The ADV message contains metadata about the data the original sensor wants to send. The receiver will check its memory banks to see if it already has the data. If it has the data, it does nothing. Otherwise, it replies back using a special message called request for data (REQ). When the REQ message is received by the sensor advertising for the data, it will immediately send the data (i.e., the whole package) to the sensor that sent the REQ message.

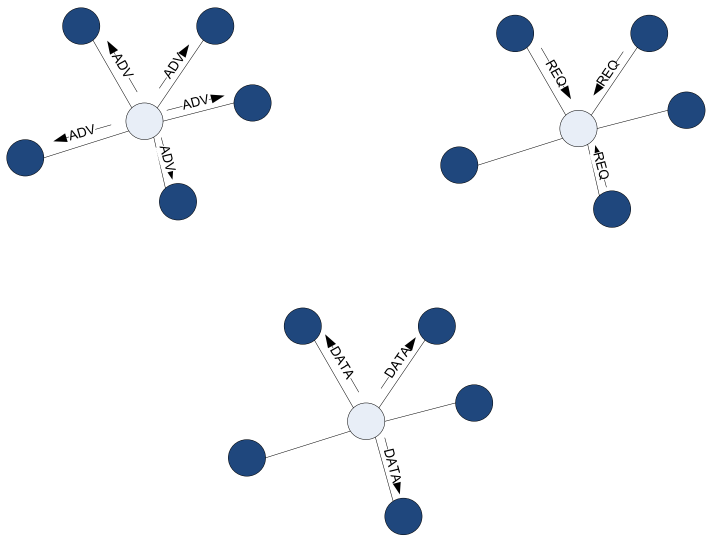

Figure 4. Handshaking in SPIN.

Figure 4 shows a graphical representation for the handshaking procedure. In the figure, the middle node is the node that sensed the event. It will try to decimate its data to its neighbors. The blue nodes are the ones that the middle node assumes they do not have the data. The middle node will send ADV messages to all of its neighbors. The ones that do not already have the data will respond back with a REQ message. The middle node will then send the information to those nodes. There are a number of families of the SPIN protocol: SPIN-1 and SPIN-2. The described SPIN protocol is called SPIN-1. SPIN-2 is a threshold-based resource aware protocol. This SPIN version is the one that is energy efficient and make use of the resource manager. It uses the same handshake procedure as SPIN-1, but only starts a negotiation procedure if it knows that it can complete the transaction without its power level dropping below a threshold value.

Low Energy Adaptive Clustering Hierarchy (LEACH):

Another energy-efficiency protocol is Low Energy Adaptive Clustering Hierarchy (LEACH) (Heinzelman, 2000). LEACH is a cluster based routing protocol. The authors of this paper specify that only 5% of all the nodes in the system have the opportunity to act as CHs in any given round. They assume that the Base Station has a fixed location and that all the sensors are homogeneous in capability and power levels. Because of the second assumption, the selection of the CHs is operated randomly. In LEACH, the CHs have the responsibility to gather data from nodes in its cluster, combine them using some aggregation technique, and send the final aggregated data to the Base Station. Data aggregation can be helpful in avoiding information overload, and provide reliable data from several unreliable sources. The lifetime of a network using LEACH protocol is divided into rounds. Each one of these rounds has two operational phases:

- Advertisement Phase: each node in the system will decide whether to become a CH or not. The decision will be based on how many times the node already became a CH in previous rounds, and the percentage of CHs in the network (e.g., 5% in the paper). Specifically, the node punches the information into a pre-determined formula and if the result is less than a threshold value, the node will become a CH. Once becoming a CH, the node sends an advertisement message to the rest of the nodes. After receiving the advertisement messages from the CHs, each one node decides which CH is the most appropriate for itself.

- Cluster Set-Up Phase: after each node decides which cluster it belongs to, it informs that CH about being a part of its cluster. During the setup time period, the CH keeps their receiver on.

The reason behind dividing the network lifetime into rounds is to spread the energy usage among the nodes in the system. If there was only one round, then the CH is fixed, which means that the CH will be the same for the whole system lifetime. Consequently, the CH has more responsibility than other nodes in the cluster. It uses more energy than the rest of the nodes, and drains its energy faster than the others. Having a dead CH means that the cluster will not be able to perform its duties, which will lead to a poor network performance.

Threshold-sensitive Energy Efficient Protocols (TEEN & APTEEN):

Two other protocols for energy-efficiency are called Threshold-sensitive Energy Efficient Protocols (TEEN and APTEEN) (Manjeshwar, 2001; Manjeshwar, 2002). These protocols are designed so they are well suited for time critical application in addition to energy aware performance. TEEN and APTEEN are cluster based routing. In TEEN, the CH will send its members a value called hard threshold. The sensors continuously sense the environment and only relay information to the Base Station if the sensed value exceeds the specified hard threshold. Another value given to the cluster members is called soft threshold. Soft threshold indicates the required change in the sensed value to trigger the transmitter activation. Therefore, the hard threshold specifies the range of values that will activate the transmitter if the sensed values reached them. This in turn will reduce the number of transmissions by restricting the transmitter to work if and only if the sensed values are in the hard threshold range. The soft threshold will further reduce the number of transmissions by specifying the rate of change that needs to occur while the sensed values in the hard threshold range to activate the transmitter. In other words, if there is no soft threshold, the nodes will report the events as long as those events are in the hard threshold range. But with soft threshold, the events will not be reported unless they are changing in a rate faster than what is specified in the soft threshold and they are in the hard threshold range. If the application wants an accurate view of the environment, the soft threshold value can be small. This means that the rate of transmission will go up. Energy savings using the TEEN model can be achieved by the reduction in the number of transmissions. Therefore, there is a trade-off between accuracy and energy savings in TEEN. APTEEN. on the other hand, provides even more energy savings. The CH sends the following four values to the nodes in its cluster:

- Attributes: the set of parameters that users are interested in. In other words, they are the types of events the sensors will provide data.
- Thresholds: it contains the values for both the hard and soft thresholds.
- Schedule: a Time Division Multiple Access (TDMA) slot scheduling. This scheduling will be assigned to nodes in the cluster to allow simultaneous communication between the nodes in the cluster and the CH. Each one of the members will be assigned a time slot to communicate within.
- Count Timer: it specifies the shortest time period between two successive reports from one node. It can be specified as a multiple of a TDMA slots.

APTEEN gives the user the flexibility to choose the count timer and the threshold values. Giving the application or users the ability to control those values supplies the application has the ability to control the power consumption ratios of the system. One enhancement on the TEEN and APTEEN protocols is that if two or more nodes are in close proximity, one node of this group can send the data to the CH and the other nodes can go to sleep. The reason that justifies this enhancement is that close by sensors usually sense the same events. Therefore, if all of them were to report their data to the Base Station, data overlap will occur. Arranging one node to report data and the rest to sleep not only prevents data overlapping, but also provides energy savings. It also provides energy balancing if the role of data reporting can be rotated between close by sensors. This enhancement can only be implemented when nodes are stationary.

Minimum Cost Forwarding Algorithm (MCFA):

Another way to reduce energy consumption is to implement a way for the sensors in the system to forward their data using paths that consume the least possible amount of energy. An example of this method is Minimum Cost Forwarding Algorithm (MCFA) proposed in (Fan, 2001). Every sensor in the system using MCFA knows the cheapest (i.e., energy wise) path to the stationary Base Station. There are two main operations tackled by the algorithm:

- How does each node determine its minimum cost? Initially all the nodes in the system have a cost equal to infinity. The sink[ii] broadcasts a special message called advertise message (ADV) to its neighbors. This message initially has value 0 as its cost. Each one of the neighbors will calculate the cost for sending this message to the broadcast origin (the node that sent the ADV message), add that cost to the message value and broadcast it to its neighbors. Then, each one of the new neighbors will calculate the cost to broadcast the message to the broadcast origin, and add that cost to the one in the message. After calculating the new cost value, the cost field in the ADV message will be updated with the new value and the ADV message will be broadcasted again. If a node receives an ADV message with less cost, it will update its cost value and rebroadcast the ADV message. Since the nodes depend entirely on the cost information they have, the need for node ID is eliminated. The process used to route data without the need for ID's will be outlined in the following.
    - How to send message along the minimum cost path? If a node sensed some event(s), it is required to report it back to the Base Station. The node that wants to report some data will build a message that contains the event's data and its minimum path cost. To discover such a path, it will first broadcast a message. The nodes that receive the message will then decrement the cost between itself and the message source from the cost information in the message. If the resultant value is equal to its minimum cost value, then the path is on the minimum cost path. Only the nodes that have their minimum cost information equal to the result of the previous operation will accept the message and broadcast it in the same manner. Let's use an example to further illustrate this concept. Figure 5 shows a graphical representation of the example. Assume that node A wants to deliver a message to the sink. Nodes B and C are A's neighbors. The minimum cost value for nodes A, B, and C are 70, 40, and 50 respectively. The broadcast cost is equal to 30. The operation 70-30 = 40 will be executed on both B and C. Then both B and C will compare the result with their

minimum cost value. After conducting the comparison, only B will accept and rebroadcast the message with the value 40 in the message cost.

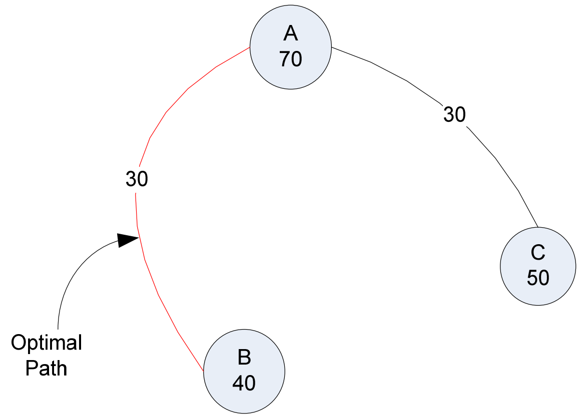

Figure 5. MCFA Forwarding.

Fractional Coverage Schemes (FCS):

Instead of developing new protocols to govern the behavior of the WSNs, sleep/awake methods only need minor modifications to WSNs. Fractional Coverage Schemes (FCS) proposed in (Ye, 2006) is an example of such methods to conserve energy. FCS also has some relaxation of the QoS constraint. The network life time is divided into rounds. In each round a subset of nodes is selected based on node power levels to perform the sensing functionality. Different subsets are chosen for different rounds to insure energy load balancing. After the deployment phase, the Base Station broadcasts a hello message. Sensors that receive the hello message rebroadcast it. Each node in the system calculates node density in its surrounding based on the hello message rate of arrival based on the hello messages received from its neighbors. After calculating the node density, the network moves into selecting the subset of nodes to be active. Selecting the active nodes has two phases:

- Advocation Phase: in this phase several nodes, called pioneer nodes, are selected. Each node in the system has the probability of becoming a pioneer node with probability T_i. The probability depends entirely on the surrounding nodes' density, and the ideal nodes' density. The ideal node density is determined by the application requirements.
- Competition Phase: the residual energy in the sensor's battery is used as a competing factor. The competition takes place in three stages:
  - Sending and receiving competition messages: each one of the nodes will send a special message that contains its residual energy value. The node will then wait until it receives competition messages from all of its surrounding competing nodes. If the node has the highest energy residual, it will then send a win message.
  - Receiving win message: if a node receives a win message from one of its neighboring competing nodes, it will conclude that it does not have the highest stored energy. The node will then send a give up message.
  - Receiving a giving up message: if a node receives a give up message, and it already sent a win message, then it is the winner of the competition and it will stay active till the end of the round.

The feature of this method that distinguishes it from other methods is that it does not require that 100% of the area be monitored. Based on the application, a percentage of the area (e.g. 70% and 80%) will be monitored. This directly affects the system's QoS, since monitoring 100% of the area is a way to measure the QoS. An enhanced version of FCS is to add another condition on the selection of nodes at any round. The selection of nodes needs to be such that it ensures the coverage of previously uncovered areas.

Directed Diffusion:

Another way to conserve energy is Directed Diffusion presented in (Intanagonwiwat, 2000). Directed Diffusion has three main goals as its reason to be:

- Achieve significant energy savings.
- Adapt to small subset of network paths. This goal means that if the network experiences some interference, then there is a way to successfully function (delivering data) without affecting the QoS.
- Achieve robust multipath data delivery. It means that data and events can be delivered by the use of many alternatives rather than just one single path. That is necessary because it ensures the ability of the system to function in case that one of the nodes on the data path breaks.

Directed Diffusion method is an example of methods that reduce energy consumption while dealing with a multi-sink environment. That means that there is more than one sink in the system that is responsible for initiating an interest in some events. Directed Diffusion works as follows:

- A sink transmits its interest in some events. The event the sink wants information about its occurrence is specified by a set of attributes and values. For example, if a Base Station wants to track the movement of a four legged animal, it sends an interest as follows:
    - Type: four legged animal
    - Interval: 10 ms; report back every 10 ms
    - Rect: [(0,100),(100,200)]; define the area to look at
- When a sensor receives an interest, it will start to sense its area looking for that specific event. A sensor may receive more than one interest either from the same sink or from other sinks. Once the sensor receives the interest, it will store it in its data banks and broadcast the interest to its neighbors to alert them to look for that event.
- If a sensor receives two interests that overlap with each other, it will send a single interest to its neighbors. The new interest contains information about the two interests merged into one message. This way, instead of sending two messages, a single message will achieve the same purpose with less amount of energy.
- When a node detects an event, it will broadcast the event to its neighbors. When a neighbor receives an event notification from a neighbor of his, it will check its database to see if any interest went through him that asks for that specific event. If no interest was found in the node database, then it will simply drop the message. If an interest was found, it will broadcast it to its neighbors and only nodes with that interest will pick up the message and broadcast it again.

The energy saving technique this method uses is simply to aggregate and combine interests (queries) into one message. This aggregation will reduce the number of messages in the system which will reduce the broadcasting burden on the nodes, and will finally result in energy consumption reduction. The responses from the nodes to the Base Station can also be combined, which provides less number of exchanged messages and helps in reducing the energy consumption of the system.

Rumor Routing:

A variation of the Directed Diffusion presented in the previous paragraph is called Rumor Routing (Raginsky, 2002). Rumor Routing is used in the case that the events do not occur very frequently, but the Base Station sends too many queries about those events. The Rumor Routing protocol sends a message called agent that contain within it metadata about that event. The agent will move within the network leaving a trail in each one of the nodes it visits. The way this routing mechanism reduces energy consumption is avoiding flooding the network with queries or events.

The model this work proposes assumes a set of densely distributed wireless sensor nodes with a short but symmetric transmission range. Symmetric transmission range in this model will exist between two neighboring nodes if these nodes can communicate with each other. Each node maintains a table that contains the set of events it witnessed. Once a node witnesses an event, will add that event to its table with a parameter zero distance from that event. It will also send a special message called an agent. This agent is a long lived packet that travels between the nodes in the network propagating some information about the event. Once it is encountered by a node in its path, the agent leaves information about the event and how to get to it (it will specify the node that will lead to the event. In other words, the one it came from). If an agent encounters a path that leads to the event with less cost, it will update its information that leads to that event based on the least cost path. But how to retrieve an event? The Base Station will send a query to the network. This query will roam the network from one node to another. It will keep on roaming the network in random manner until it reaches a nodes that already seen an agent for that event or until it’s time to live value expires. If the time to live value expired, the Base Station will simply generate another query and wait for response. If the query encountered a node that have seen an agent that holds information about the event in question, it will start tracing back the nodes that leads to the node that witnessed the event by the use of the information the agent left behind. Once the node that witnessed the event reads the query, it will send the data to the Base Station by the use of the information in the query (the query records the path it took to reach the source node). This method takes advantage from the fact that the probability two lines in a plain meet is approximately 96%.

The main theme for most of the introduced methods is to reduce the number of messages exchanged in the system or the size of the message itself, or reduce both. An assumption in most of the papers is that data sensing and processing at the nodes cost far less than forwarding these data to other nodes. In some rare cases (Alippi, 2007), this assumption does not hold true. In (Alippi, 2007), the authors proposed an adaptive sampling algorithm to dynamically estimate the optimal sampling frequency of the signal (event) to be monitored. Obtaining the optimal sensing rate means minimizing the activities in both the sensors and the radio. This minimization in turn reduces energy consumption while maintaining acceptable data accuracy.

Table 1. Techniques outlined in this chapter[iii].

Technique	Hierarchy	How To Conserve Energy	Disadvantages
SPIN	Clustering	By the use of Negotiation	Consume lot of energy if the events rate of occurrence is high.
LEACH	Clustering	Use Clustering.	Assumes that nodes are homogeneous.
TEEN & APTEEN	Flat	Control the transmission recurrences.	Needs a special attention to the values of Hard and Soft threshold to effectively conserve energy.
MCFA	Flat	Setup Link Costs.	A problem will occur if a link got broken.
FCS	Flat	Select part of the nodes to be active at any given time.	Do not cover 100% of the total area to cover.
Directed Diffusion	Flat	By using data aggregation	Nodes need some location awareness.
Rumor Routing	Flat	Send agent from the source node through the network.	Use random agent and query deployment.

DISCUSSION OF THE TECHNIQUES

Issues, Controversies, and Problems

As mentioned in the previous section, energy conservation is an issue that needs to be dealt with in order to effectively implement WSN technology. All of the above techniques are valid ones, but each one of them has its own disadvantages. For example, (Heinzelman, 2000) presents a way to reduce energy consumption in WSNs, but it assumes that the nodes in the system are homogeneous. This assumption is not a valid assumption since even if the nodes were homogeneous the moment they were deployed, they will become heterogeneous after a while. The reason for such change is because the nodes responsibility and experience differ based on their location. That mean, if a node location by the highway, it will report more events than a node located at an inner small road (in case that the event is reporting car movements). Another problem in the previous sections is in (Fan, 2001). In this paper, they proposed a system that setups the cost from each node to the Base Station in advance. This system will be ineffective and useless if it has been used in a place that suffers from high interference occurring. The reason for being ineffective in the presence of interference is because interference cut the links between nodes in a WSN. Having a path that use a broken link will simply disable the whole path. The only solution for this problem is to broadcast the data hoping that it will reach the sink. Broadcasting the data will do the absolutely opposite from conserving energy. It will drain any energy left in the system leaving it setting in its place doing nothing. In (Mao, 2006), the authors proposed an energy conservation scheme called FCS. In this system the whole area will not be monitored. Therefore, it cannot deal with the situation that a crucial event happens in the uncovered area. For example, if this system is deployed as a part of an early defense alarm, a missile moving through the uncovered area will not be detected, and the results for that intrusion will be catastrophic if that missile holds some unconventional weapon. Those weaknesses are just the tip of the iceberg.

Solutions and Recommendations

A solution for the previous problems can be found through combining some of the works together. For example, if we combine (Zhong, 2007) with (Kulik, 2002), we can achieve energy consumption reduction in both of the networks. Another solution to some of the problems is by increasing the number of sinks in the system. By doing so, each node can send its data to its nearest sink. Determining the closest sink can be done by measuring the signal strength of the sinks. The sink with the strongest signal is the closest. By sending the data to the nearest sink, the path length will be reduced, which will substantially reduce the energy consumption in the overall network. Also using one sink in the system will lead to congestions in the vicinity of the sink, which will cause energy crop at the nodes located in the sink's vicinity. Also messages will be dropped in a high rate in that congested area. Hence, having more than one sink will help in balancing the load among the network. It also produces less number of dropped messages, which will reduce the amount of retransmissions, leading to less consumed energy and prolonging the network lifetime.

FUTUR TRENDS

WSNs are an emerging technology that is rapidly taking its place among the most used technologies in the world. In our point of view, there are two major routes the development of WSNs will take:

- Developing more powerful hardware for the nodes. Currently WSNs are developed to monitor an area on the surface of the earth. This area can be a battle field, the poles or the hot burning deserts. For example, in battle fields, WSNs help the soldiers on the ground to identify sources of attacks. They can use a technology called Acoustic Source Location (Svaizer, 1997). WSNs can pinpoint the source of intrusions and relay live information to the headquarters about the current status of the battle. The live information helps the command to make accurate decisions during a battle. In the future, WSNs can be use to monitor the bottom of the deep seas and oceans. They can also be employed in monitoring the outer space to act as an early alarm system against asteroids that are in a collision course with earth. Mounting wireless sensors in space is a more different than mounting them on earth. First of all, the size of the nodes is not that much of a problem. The reason for not being a problem is that on earth having thousands of big nodes in a relatively small area may affect the quality of the collected samples due to possible interference from other nodes. While in space, no matter how big the nodes are they are still tiny compared to the monitored space area. Of course, having bigger nodes will cause delivery problem, but that another problem we have no interest to tackle here. Secondly, the communication power needed in space environment exceed that on earth. This is because of the communication between an area on the earth surface and a region of space. In space, we are dealing with three dimensions instead of two dimensions on earth. The distance between two nodes in space can be in kilometers instead of meters. In addition, in space, the communications between the sensors themselves and the Base Station will be affected by interference caused by the sun radiations, which are not present on earth. Therefore, a new kind of sensors' transmitter needs to be developed to deal with these interferences.

WSNs can be used to monitor the deep dark parts of the oceans and seas. Scientists discover new creatures living in the deepest part of the seas every day. Most of these discoveries happen by coincidence by the washed up creatures on the sea's or ocean's shore. To monitor these parts of the seas, a new hardware needs to be developed. The hardware needs to have the ability to work under water for a long time, and to be able to withstand the high pressure due to the water weight. A new transmission technology needs to be added to sensors to facilitate their communication. The reason for the need of a new transmitter is because usually sensors use high frequency signals to communicate in air medium, which provides a fast communication between nodes. In water, high-frequency signals cannot penetrate the medium. To solve this problem, we need a transmitter using a low frequency signals. Although this solution will facilitate the communication between sensors, it will create some other issues and problems. One of these possible problems is that lower-frequency signals provide slow and possibly unreliable communication. This is because low frequencies are more affected by noise than high-frequency signals. Another problem is that systems using lower frequencies need substantially longer antenna than systems using high-frequency signals. Therefore, size is an issue that the new underwater technology needs to deal with. As a trivia, some of the submarines use an antenna that has a length ranging between 610 meters and 730 meters (Lockheed Martin Corporation, 2006), and an in-line amplifier is used to boost the signals inside the antenna.

- Combining the current technology of WSNs with the technology in other areas. In the future, it is highly possible that the WSNs will not exist on their own. Actually, there has been a lot of work on integrating WSNs with Radio Frequency Identifier (RFID) technology. These two technologies are very similar to each other. WSNs are used to monitor an area rather than an object, while RFID is used to track objects and unable to monitor the changes in an area. Hence, by combining both technologies, we can monitor and track objects that are moving in an area. At the same time, we can monitor what changes are taking place at that area. In other words, if we use the hybrid technolog, we can effectively see how subjects will be affected by changes in the environment.

In (Li, 2008), the authors of the paper proposed a system that uses RFID implants on animals and sensors equipped with RFID reader. The function of the sensors is to monitor the environment changes. In addition to monitoring the environment, if one of the animals gets close to a sensor, the sensor will be able to read the RFID implants and determine the identity of that animal. By the use of the proposed system, we can effectively monitor the trends animals throughout long periods of time.

Another use or RFID technology is to design small devices called implants. One of the uses of these implants is to put them in pets to track their whereabouts and for the pet centers to identify them. There is another version of these RFID's is designed to be used under human skins. They are being used with the elderly to alarm the emergency agencies in case an accident happened. They also are used with small children as a way for their parents to track them.

Another research area that can be very helpful in the development of WSNs is the advances that can be made in the area of energy storage. Giving the sensors a small and rich power source will be extremely helpful in designing an effective WSN. Also another way to look at the energy storage is to design a way for the sensors to harvest the renewable energy that surrounds them (especially the sun and wind energy). Renewable energy a big research area these days, Germany is starting to move toward harvesting the wind energy. They are currently the biggest exporter for wind renewable equipments in the world. The usage of renewable energy in Germany has jumped to 14% of the total energy generation power in 2007 (Wikipedia, 2009).

The previous examples are only the tip of the iceberg on what the future holds regarding the use of the WSNs. There is still much to be investigated in WSNs. The research can be on the hardware used inside the node (e.g., processing unit of a node, a sensor, or a transmitter). It can also be on the operating system used inside a node. Moreover, it can be on the protocols used for exchanging information between nodes.

CONCLUSION

WSNs comprise of two essential devices, a Base Station and a set of sensors with wireless communication capability. The function of the sensors is to collect data about events occurred, and relay the data to the Base Station. The function of the Base Station is to take orders from a user who deploys the network, converts these orders to queries, and propagates them into the network. It also has the responsibility of collecting the sensor responses to quires. One of the major obstacles that limit the use of a WSN is their limited energy. In this chapter, we showed that there are numerous techniques that can be used to reduce the consumed energy. Some of these techniques force some nodes to go to sleep while keeping the other portion active to perform the network’s function. Some techniques aggregate data at the relay sensors to reduce the number of exchange message, while other techniques discover in advance the least-cost path to the Base Station.

The future holds many advances in the area of WSNs. WSNs are extremely helpful in the battlefield. WSNs can be deployed in space or in the deepest parts of the oceans.

WSNs are one of the technologies that can change the way we do things. One of the spinoffs of WSN technology is the Radio Frequency Identification (RFID) technology. The public knows that technology by the name of implants. These implants are already in use by the public who put them in their pets. A new implant has been designed to be used inside the humans to be put inside the elderly to monitor their health conditions, or in children to trace their whereabouts.

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KEY TERMS AND DEFINISIONS:

1. Sink: A device that is placed at the edge of the Wireless Sensor Network that has the responsibility of sending requests to the sensors and receiving the responses for these requests to present them to the user or organization that placed the network.
2. Node: A small limited energy device that is responsible of detecting the events in its vicinity and report it back to the sink.
3. Transmission range: Its defined by maximum distance a node can sends its data to.
4. Data Aggregation: Techniques that are used in the relay nodes to combines data together.
5. Clusters: A way the nodes use to organize themselves. Nodes that are relatively close to each other usually belong to the same cluster.
6. Cluster Head: A node in a cluster that is responsible of collecting data from the sensors in its cluster and relay these data to the Base Station. The role of Cluster Head is usually rotates between nodes in the cluster.
7. Homogeneous Nodes: Nodes that have the same properties and capabilities.
8. Heterogeneous Nodes: Nodes that differ from each other.

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[i] In this chapter, Node and Sensor are used interchangeably.
[ii] In this chapter, Sink and Based Station (BASE STATION) are used interchangeably.
[iii] Refer to the method description for information about the table used notation.