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Improving Power Efficiency in Clustered Wireless Sensor Networks

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Abstract Wireless sensor networks are event-based systems based on the collaboration of several micro sensor nodes. Due to the limited supply of power at sensor nodes, power efficient configuration of wireless sensor network has become a major design goal to improve the lifetime of the network. The cluster-based wireless sensor network can enhance the whole network lifetime by aggregating the collected sensory information. The cluster head plays an important role in aggregating and forwarding data sensed by other common nodes. In this paper, we proposed architecture of power efficient clustered wireless sensor network by use of power harvesting cluster head nodes.

Keyword power efficiency , wireless sensor network , energy harvesting, clustering.

1. Introduction

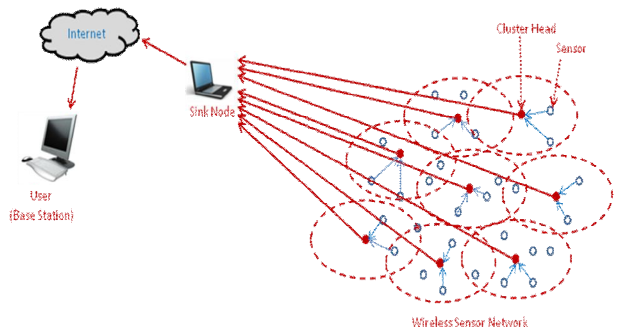

Figure 1. Cluster-based WSN architecture: red points remark cluster head nodes, white points remark member nodes.

Recent advance in micro-electro-mechanical systems (MEMS), embedded processing, and battery technology have facilitated the development of low-cost and low-power sensors with the functions of sensing, wireless transmission, computation and data processing [1]. A wireless sensor network (WSN) is formed by a large number of sensor nodes to monitor the objects of interest or environmental conditions such as sound, temperature, light intensity, humidity, pressure, motion and so on through wireless communications. Thus WSN has become popular to sense and collect data for application specific analysis.

As the technology of WSNs matures, the scope of their applications has become more extensive, e.g., environmental monitoring, home automation, intelligent office, energy saving, intelligent transportation, health care, and security monitoring [2]. A major limitation of untethered nodes is finite battery capacity and thus power efficient configuration of WSN has become a major design goal to improve the lifetime of the network. Several solution techniques have been proposed to maximize the lifetime of battery-powered sensor nodes. Among the various techniques, it is well-known that cluster architecture enables better resource allocation and helps to improve power control.

In the clustered environment, the data gathered by the sensors are communicated to the base station (BS) through a hierarchy of cluster-heads (CHs) nodes [3]. With clustering in WSN, as shown in Figure 1, the randomly distributed sensor nodes are formed as many clusters and each sensor node has to transmit the collected data to its CH. After deployment, the CH is responsible for collecting data from its cluster member sensors, and those collected sensor data are aggregated and then forwarded to the BS via the sink. Thus, the CH plays an important role in aggregating and forwarding data sensed by other common nodes and as a consequence CH consumes more energy than the other common sensors. In this paper, we propose architecture of cluster-based WSN with the use of energy-harvesting CH nodes to prolong the lifetime of the sensor networks.

The remaining of this paper is organized as follows. We first discuss the related works and existing problems in Section 2. We then briefly present our proposed network architecture in Section 3. Simulation results and discussions are presented in Section 4. Finally, we conclude our paper in Section 5.

2. Related Works

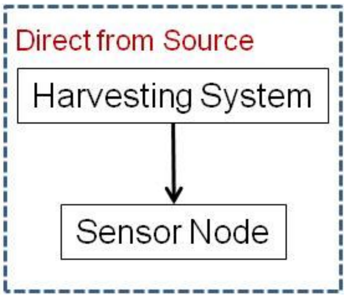

Figure 2. Energy harvesting architecture: Harvest-Use.

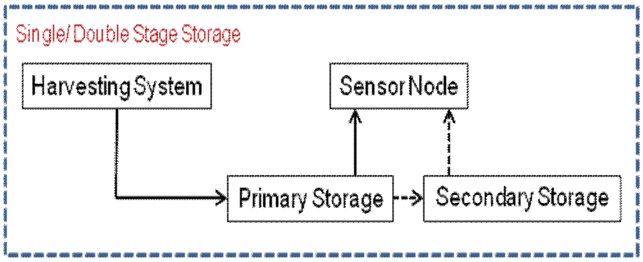

Figure 3. Energy harvesting architecture: Harvest-Store-Use.

WSNs are event-based systems based on the collaboration of several micro-sensor nodes [4]. The high density of sensor nodes is vital for sensing, intrusion detection, and tracking applications. When an event is detected in the network, the aggregated collaborative report of the detecting nodes is delivered to the sink. Clustering mechanisms enable the sensor nodes to collect and aggregate data at nodes called CHs in each cluster, and this avoids redundant data flow in WSN [5]. In this way, clustering removes some overhead in terms of packet generation, processing, energy consumption, and collision avoidance, because much functionality of sensors is performed by cluster heads. Hence, clustering helps prolong network lifetime and increases the scalability of WSN.

The low-energy adaptive clustering hierarchy (LEACH) proposed by Heinzelman et al. [6] is a well-known protocol applied in clustered WSNs. LEACH divides a WSN into a number of clusters, and sensor nodes in the same cluster can communicate with each other directly. A sensor node decides which cluster to join based on the strength of received signals. After joining a cluster, sensor nodes in the same cluster randomly select a CH for collecting and forwarding data to the base station. Since the CH will consume more energy, it has to be replaced regularly to reduce the power consumption.

An alternative technique that has been applied to address the problem of finite node lifetime is the use of energy harvesting [7]. Energy harvesting refers to harnessing energy from the environment (sun, wind) or other energy sources (body heat, foot strike, finger strokes) and converting it to electrical energy. Applied to sensor nodes, energy from external sources can be harvested to power the nodes and in turn, increase their lifetime and capability. There are some energy-harvesting sensor nodes which are commercially available in the market such as Crossbow MICAz node with solar energy-harvesting prototype circuit.

Current available energy harvesting architecture for sensor nodes can be broadly classified into two types:

1) Harvest-Use architecture, and

2) Harvest-Store-Use architecture.

In the harvest-use architecture [8], the harvesting system directly powers the sensor node as in Figure 3. As a result, for the node to be operational, the power output of the harvesting system has to be continuously above the minimum operating point. If sufficient energy is not available, the node will be disabled.

The harvest-store-use architecture [9], [10] and [11] consists of a storage component that stores harvested energy and also powers the sensor node as shown in Figure 4. Energy storage is useful when the harvested energy available is more than the current usage. Excess energy is stored for later use when either harvesting opportunity does not exist or energy usage of the sensor node has to be increased to improve capability and performance parameters. The storage component itself may be single-stage or double-stage. Secondary storage is a backup storage for situations when the Primary storage is exhausted. During the daytime, energy is used for work and also stored for later use. During night, the stored energy is conservatively used to power the sensor node.

Given the energy-usage profile of a node, energy harvesting techniques could meet partial or all of its energy needs. However, on the contrary, using energy harvesting techniques in the sensors will have to deal with the cost problem. If the percentage of energy-harvesting nodes is high, it is easier to extend network lifetime, but in that case the production costs will be higher, because energy-harvesting nodes are more expensive than normal sensor nodes.

3. Propose System Architecture

The main purpose of our propose system architecture is to maximize the sensor network lifetime while minimizing the deployment cost. As a basis, our propose architecture will use clustering technique in which the hybrid use of energy-harvesting sensor nodes and normal sensor nodes lengthen sensor network lifetime in a cost effective way.

Remarkable lifetime expansion can be achieved by using energy-harvesting nodes. However, the production cost of energy-harvesting nodes could dramatically increase the production cost of single node and corollary the whole sensor network. Crucial challenges in here is how to make clusters as robust as possible by using as small percentage of energy-harvesting CH nodes as possible with as maximize the lifetime as possible to obtain desire performance.

3.1. Clustering Algorithm

Clustering algorithm consists of two phases:

1) Cluster-Setup phase, and

2) Steady-State phase

In cluster-setup phase, all sensor nodes will find the proper CH in order to form for each cluster. In the beginning of cluster setup phase, the energy-harvesting nodes in the sensor network advertise themselves as CHs to the sensors within its radio range. Any sensor that receives such advertisements joins the cluster of the closest CH based upon the received-signal-strength of the advertise message.

In this steady-state phase, sensors in these clusters detect events and then transmit the data packet to their CHs. CHs are responsible for coordinating among the nodes within their own clusters and aggregate and forward the collected data to the sink on behalf of their cluster members. In order to reduce the energy usage in normal sensor nodes, CHs take responsibility for collect and aggregate the data from all member nodes and forward them to the long-distance sink node. Thus, to the cluster heads, energy consumption is composed with two parts: (1) energy consumption of receiving and aggregating the data sensed by member nodes; (2) energy consumption of transmitting the aggregated data to the sink node. This way, the energy consumption in normal sensors will be reduced and sensor nodes will be available for a longer period of time.

3.2. Power Consumption Model

In order to predict the power and quality of different algorithms and protocols, it is important to have accurate models for all aspects of the sensor node. Thus, we make the following assumptions in here:

- The base station (BS) is located far from the sensor network and immobile.
- The sink node is located far from the sensor network and acts as an interface between the sensors and BS.
- There are *N* normal sensor nodes and *k* energy-harvesting nodes that are randomly distributed in the network.
- Cluster heads (CHs) nodes are special sensors which can harvest the energy from the environment and has harvest-store-use architecture.
- All sensor nodes are able to reach the sink via the corresponding CHs.

4. Performance Evaluation

TABLE I. SIMULATION PARAMETERS

Number of sensing nodes	100
Number of CH nodes	10
Area (m^2)	100 x 100
Packet Size	30 *bytes*
Data Rate	5 *pkts/ UnitTime*
Transmission Range	25*m*

We perform computer simulation using NS-2 [14], a standard tool in sensor network simulation. The default parameter setting for the simulation is shown in Table 2. In our simulation, 100 normal sensor nodes and 10 energy-harvesting sensors are randomly deployed in 100m x 100m area. The location of the sink node is far from the sensor network and the data sensed by the sensors can be reached to the sink node via CH nodes. Each sensor nodes initially has a uniform energy level. For the sake of simplicity, we assume that MAC protocol assigns a unique channel for every node to prevent possible collisions and each node receives the packets within its communication area without any failure. We also assumed that it is the responsibility of routing protocol to forward the packet towards the sink node.

It is important to determine the optimal number of CHs in order to meet the desire performance. The optimal number of CHs determines as the different density of sensors in the network and the distance between BS and sensor network system. The analytical results in [12] show that the optimal number of CHs for the network nodes (N=100) is 3 to 10 according to the distance of 50m to 100m between BS and sensor network. Thus, for better reliability, we will use the optimal number of CHs as 10 throughout the simulation.

In order to evaluate the performance of our proposed scheme, we calculate the number of lived nodes as a function of time and compare with the standard clustering protocol, LEACH. Figure 4 clearly shows that the proposed scheme can sustain the longer lifetime than the conventional clustering protocol, LEACH. According to the simulation result, we can see that our proposed scheme can maintain the considerable number of alive nodes while the number of alive nodes in LEACH promptly goes down. That is because the lifetime of the sensor nodes in each cluster will end in a balanced way due to the use of energy-harvesting CH nodes. In terms of deployment cost, our proposed scheme has a slightly higher cost than LEACH but significantly lower cost than the pure energy-harvesting WSN.

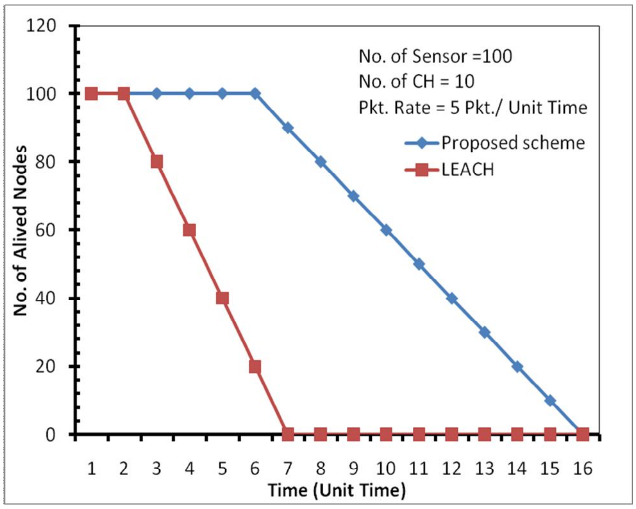

Figure 4. Comparing the number of lived nodes of proposed scheme and LEACH.

5. Conclusions

In this paper, a clustering architecture to prolong WSN lifetime was introduced and discussed. The basis of our protocol is using clustering with a percentage of energy-harvesting nodes as CHs in order to reduce energy load at normal cluster member nodes. Since CH nodes perform data aggregation and take responsibility to send the data to the sink node, it causes energy saving of member sensor nodes. Simulation results show that our proposed scheme is effective in prolonging the lifetime of the sensor networks.

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