An Energy Efficient and Coverage Guaranteed Wireless Sensor Network

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Abstract—In many scenarios, sensor nodes have to rely on a limited supply of energy (using batteries). To support long lifetime of Wireless sensor networks (WSN), an energy-efficient way of operation of the WSN is necessary. In this paper, we propose a new controlled layer deployment (CLD) routing protocol to guarantee coverage and energy efficiency on a sensor network. CLD outperforms PEAS (Probing Environment and Adaptive Sleeping) and the TTDD (Two-Tier Data Dissemination) protocols in that it can guarantee full area coverage and connection. It can also solve the “cascading problem” which reduces the whole network lifetime. Finally, we show the results of the simulation to prove that the new protocol can use fewer sensor nodes for coverage and increase the lifetime as compared to the PEAS protocol.

Keywords: Wireless Sensor Network (WSN), Probing Environment and Adaptive Sleeping (PEAS), Two-Tier Data Dissemination (TTDD), Virtual Grid

I. INTRODUCTION

In general, the wireless sensor networks can contain hundreds or even thousands of sensing nodes. It is desirable to make these nodes as energy-efficient as possible and to rely on their large numbers in order to obtain high quality results. Likewise, the sensor network routing protocols must be designed to achieve fault tolerance in the presence of individual node failures while also minimizing energy consumption. Moreover, since the limited wireless channel bandwidth must be shared by all the sensors in the network, routing protocols for these networks should be able to perform local collaborations in order to reduce the bandwidth requirements. Eventually, the data being sensed by the nodes in the network must be transmitted to a control center (i.e., the sink) or base station where the end sensor nodes can access the data. At present, there are many routing methods in the wireless sensor network. Direct Transmission Energy protocol (DTE) [3] proposed that each sensor node transmits the data directly to the Sink, not through intermediate nodes in order to shorten the transmission time. Minimum Transmission Energy (MTE) protocol [3] is an indirect hop-by-hop communication scheme and is a better power saving communication protocol between end sensor nodes. Two-tier Data Dissemination (TTDD) protocol [10] is also an improved indirect communication scheme. Its specialty is the use of a virtual grid dual layer transmission communication similar to the grid communication. In the Coverage-Preserving Node Scheduling scheme [8], each sensor node knows the position of all its neighboring nodes when considering full area coverage and connection. But before each node can monitor the other, it must select a “timeout interval” for the interval to finish.

Apparently, the most commonly encountered problems of the typical wireless sensor network between the Sink and the sensor node data transmission are as follows: 1) The farthest sensor nodes from the Sink will exhaust more network resources (e.g., bandwidth) and consume more power and consequently, the whole network efficiency and lifetime are reduced. 2) When the sensor nodes are making data transmissions, intermediate nodes are usually needed to help in data forwarding, especially in the hop-by-hop protocol system (e.g., MTE (minimum transmission energy) routing protocol). The farther it is to the Sink, the more intermediate nodes are needed and thus, causes more power consumption in the intermediate nodes. The nearer the intermediate nodes are to the Sink, the shorter their lifetimes because of the increase in the data transmission frequency. Ultimately, the whole network lifetime is reduced. This is referred to as the cascading effect. This paper focuses on how to solve the problem of full coverage and connection encountered in wireless sensor networks. Initially, we use the concept of virtual grids for effective full area coverage and connection [2, 4, 5, 6, 7, 8, 9]. Subsequently, we propose the CLD (controlled layer deployment) as a sensor node deployment protocol in order to prolong the lifetime of the whole network, and resolve the above-mentioned problems.

II. PROBING ENVIRONMENT AND ADAPTIVE SLEEPING (PEAS) PROTOCOL

PEAS energy saving protocol [9] is an energy saving protocol with coverage and connection. It uses massive small sensors of short energy lifetime and maintains the necessary working sensor set. It also turns off excess sensor nodes in order to save energy to establish a long term and flexible wireless sensor network. The characteristic of the PEAS energy saving protocol is that it can endure the high malfunction rate of sensor nodes. It will also result in the high change of the whole wireless sensor network topology. PEAS network can initiate at anytime the probing of the condition of the neighboring area working node in order to replace the faulty sensor node at any given time. Assumptions for the
PEAS energy saving protocol are: 1) high density and multi-quantities sensor nodes; 2) unanticipated malfunction of the independent sensor node; 3) each sensor node can change its transmission power and select the power intensity in order to cover a designated radius range.

The design goal and method of the PEAS energy saving protocol are as follows:

A. Probing Environment:

The goal is to maintain a suitable density of working nodes and reduce the number of unnecessary working nodes in order to save energy. A sleeping sensor node will automatically awaken and, within its own probing range \((R_p)\), transmit the probing message in order to determine if there are still some working nodes existing in the neighboring area. If yes, it will receive the reply message sent by the working node. This reply message contains the probing range of the working node and the new probing rate value. Meanwhile, the sensor node will go back to sleep and to wait for the next waking time. If no, the sensor node will will awaken and serve as the working node.

B. Adaptive sleeping:

Adaptive sleeping decides when a sleeping sensor node will awaken to probe. It decides the probing rate of each sleeping sensor node and provides the guarantee that the sleeping nodes, dispersed in each area, will awaken periodically to do probing. The probing rate must be controlled properly. It must be optimized in order to minimize the probing overhead. The probing rate follows the following equation:

\[
f(t_s) = \lambda e^{2st_s}, \quad \lambda : \text{probing rate of the node}
\]

\(t_s : \text{sleeping time duration, where } f \text{ is probability density function (PDF).}\)

The basis of design for \(\lambda\) is to allow the working node to collect the probing rate of the previous neighboring sleeping sensor node. Each working node sends a reply message to the sensor node which transmitted the probing message. After extracting again the \(\lambda^{new}\) value, the new value awaits for the next waking time to probe. Each sensor node’s initial state is set to a sleeping sensor node.

The new probing rate value \((\lambda^{new})\) of each sensor node is in proportion to the collected initial total number of working nodes. The variables are defined as follows: \(d\) : dimension; \(n\) : number of nodes; \(k\) : constant; \(R_p\) : probing range; \(R_t\) : maximum transmitting range; \(c\) : cell based range (range of each basic cell)[1]; \(L\) : distribution range (range of where all nodes are distributed) \[1\]. In [9], the following Lemma and Theorem are derived:

**Lemma:** Consider the case when \(n\) nodes are uniformly distributed in \(R=[0, L]^d\) for \(d=2\), and assume that \(c^dn=kL^d \ln L\) for some constant \(k > 0\). Let \(\mu(n)\) be the random variable denoting the number of empty cells. If \(k=d\), then \(\lim_{L \to \infty} E[\mu(n)]=0\), where \(E[\mu(n)]\) is the expected number of empty cells.

**Theorem 1:** If the transmitting range \(R_t \geq (1+\sqrt{5})R_p\), and the conditions in the previous Lemma are satisfied, then \(\lim_{L \to \infty} P_{conn}(PEAS) = 1\), where \(P_{conn}(PEAS)\) denotes the probability that working nodes in PEAS are connected.

The detailed calculations, explanations and proof are shown in [9].

III. CONTROLLED LAYER DEPLOYMENT

The sensor node deployment of the wireless sensor network is generally uses the random uniform distribution, e.g., the methods of PEAS, TTDD, etc. The drawback of these methods is that they cannot completely guarantee full area coverage and connection [3]. They require many sensor nodes in order for the coverage distribution probability to be close to 1.

To explain our method, we define some terms first: Sink : the sink node responsible for collecting data or distributing the user message to each sensor node in its area of jurisdiction; sensor node : sensing device (including working node and sleeping node); working node : sensor node in actual operation, represented by \(W\); probing node : sensor node in probing action, represented by \(P\); sleeping node : sensor node which is sleeping or resting, represented by \(S\); virtual grid : the sensing area is divided into equal sizes of cells. The boundary points of cells are called virtual grid; sensing range distance : the sensing range distance of the sensor node; sensing radius : largest sensing radius of the sensor node, represented by \(r\); maximum transmitting range : the maximum transmitting range, represented by \(R_t\); probing Range : probing radius, represented by \(R_p\).

A. The Operation of CLD

CLD protocol proposes the following deployment methods:

1) The distance between two working nodes is \(2/3r\), where \(r\) is the sensing radius.

2) The sleeping nodes are deployed in a circle at the working node with a radius of \(1/6r\). Figure 1 is a schematic diagram of the deployment.
the worst condition, i.e., the two nodes’ distance from center of the circle is at its farthest (i.e., nearly 1/6r), as illustrated by the two nodes A, B of Figure 2.

Since \( O_1A \leq 1/6r, \ O_2B \leq 1/6r, \) so \( AB \leq 2/3r + 1/6r + 1/6r \leq r \)
Therefore A, B are connected.

As shown in Figure 2, if we assume that the maximum transmitting range of each working node as \( r \), each sleeping node (i.e., nodes A and B) is located at 1/6r, and the length of the diagonal line connecting the two centers of the circles (i.e., \( O_1 \) and \( O_2 \)) as 2/3r. The sleeping nodes are distributed at

\[
A, B \leq 2/3r + 1/6r + 1/6r \leq r
\]

Therefore A, B are connected.