Power Control Based Topology Construction for the Distributed Wireless Sensor Networks*

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Abstract

A distributed algorithm for the multihop wireless sensor networks is proposed to construct a novel energy efficient tree topology. The topology is constructed, without taking location information of the sensor nodes and energy conservation of the network is accomplished by controlling the transmission power levels. Experimental results of our protocol show that, total energy consumption of the network is very less as compared to the energy consumption of the network without any power control. Our protocol, being a distributed one, attains the energy conservation up to an optimum level and extends the network lifetime better than the centralized algorithms that we have considered.

1 Introduction

Wireless Sensor Networks (WSNs) distinguishes themselves from the traditional wireless networks in many different ways, such as it consists of hundreds to thousands of nodes that are operated with very low powered batteries. Signal processing, communication activities using higher transmission power and forwarding of similar data packets in the multi-hop wireless sensor network are main consumers of sensor energy. Besides, in most of the sensor network applications, replenishing energy by replacing and recharging batteries on hundreds of nodes, particularly in harsh terrains is very difficult and sometimes infeasible too. So energy conservation [1,9,10] of the sensor nodes is a critical issue in wireless sensor network as the network lifetime totally depends on the durability of the battery.

In WSNs, communication is the main factor of energy consumption. However, transmission power adjustment during communication can extend the network lifetime and reduce the capacity of the sensor network. But the disadvantage is that it may split the whole network. Since the collected sensed data may contain some important information as required by the sink, providing a connected topology for the multi-hop network is very important for the wireless sensor network. In [3], Javier Gomez et al have proposed an analysis of the routing protocol based on the variable transmission range scheme. From their analysis, it is observed that the variable transmission range scheme can improve the overall network performance. The LEACH based algorithm [4] let some nodes to be the cluster leader and uses the higher transmission power to help the neighbor transmitting data to the sink. Lindsey et al. have proposed the Power-Efficient Gathering in Sensor Information Systems (PEGASIS) [7], a near optimal chain-based protocol that is an improvement over LEACH. In PEGASIS each node communicates to a close neighbor, only to construct a chain, fuse the neighbor's data packet, and then transmit to the leader. In every round of transmission, each node has a chance to become the leader and transmitting data to the sink. However, the LEACH and PEGASIS need the global knowledge of the sensor network and assume each node in the radio proximity of the sink, which may not be suitable in multi-hop sensor networks.

In [8], Ramanathan et al. present a centralized greedy algorithm to construct an optimized topology for a static wireless network. Initially, each node has its own component that works interactively by merging the connected components until there is just one. After all components are connected, a post-processing will remove the loop and optimize the power consumption of the network. Although this algorithm [8] is

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meant for an optimized topology of wireless network, it is a centralized one and can't change the transmission power dynamically. In [5], Kubisch et al. have proposed the distributed algorithms for the transmission power control in WSNs. They assign an arbitrarily chosen transmission power level to all sensor nodes which may cause the split of the network. Also they propose the global solution with diverse transmission power (DTP) algorithm that creates a connected network and set different transmission ranges for all the nodes, even if the topology construction is over. So the energy consumption of the sensor nodes may be more as they are close to each other. In [2], it is analyzed that the power consumption comparison of each unit of sensor node is due to the energy consumption of the received power and the idle state are almost the same, and the power consumption of CPU is very low. So in our work, we only care about how to control the transmission power to save energy and present here a distributed algorithm to adjust the transmission power level to construct different groups of tree topologies. In our protocol, child nodes use the suitable transmission power level to connect to its parent node, fuse their collected data into a single packet and forward it to the sink through the parents. This algorithm works in a multi-hop wireless sensor network without having the location information of the nodes and it can adjust the transmission power and maintain a connected topology for a distributed wireless sensor network.

The rest of this paper is organized as follows. System model of our protocol is presented in Section 2. Section 3 describes the details of our distributed protocol. Performance analysis and simulation results are presented in Section 4 and conclusions are made in Section 5 of the paper.

2 System Model

Let us consider a multi-hop homogeneous wireless sensor network in which sensor nodes are deployed randomly with certain coverage holes among different group of nodes as shown in Fig. 1. In our protocol, it is assumed that at the time of deployment, each sensor node possesses equal amount of battery energy and minimum and maximum power levels are same for all the sensor nodes as it is a homogeneous network. We consider 0 as the minimum (P_{min}) and 3 as the maximum (P_{max}) transmission power level for communication among the nodes. We define here a few terms that are used in our protocol.

2.1 Definitions

- Local Hop Count (LHC): When a packet is transmitted from one node to other within the same group, the number of hops it traverses is known as the Local Hop Count (LHC). Initially LHC = 0 and it is incremented by 1 for each subsequent packet hopping from one node to other within the same group.

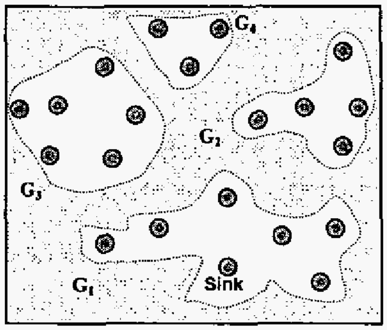

Figure 1: Randomly deployed sensors with coverage holes among different groups.

- Group Hop Count (GHC): For each group of sensors, there will be a unique group hop count (GHC) that is incremented by 1 for each time a packet is transmitted from one group to other. Initially GHC = 0 and in general GHC = GHC+1 for the subsequent packet hopping from one group to other.

- Upstream and Downstream groups: The group containing the sink node is considered as the first group (G_1) of the network. As shown in Fig. 1, if a packet is forwarded from G_1 to G_2, then G_2 is the downstream group for the nodes of G_1 and G_1 is the upstream group for the nodes of G_2.

- Parent Gateway ID (PGID): The root node of the tree topology of any group is known as the Parent Gateway of that group and its ID is denoted as PGID. In each group there must be only one Parent Gateway. In Fig. 5(a), C and D are the Parent Gateways of two different groups.

- Child Gateway ID (SGID): This is the ID of the second gateway of a group which is connected to the Parent Gateway of another group. In a group there must be at least one Child Gateway. In Fig. 5(a), nodes A and B are the Child Gateways for the nodes D and C respectively. Generally, the Parent Gateway of a downstream group is connected with the Child Gateway of the upstream group.

- Upstream Group ID(UGID): The ID of the Parent Gateway of the upstream group of a group is

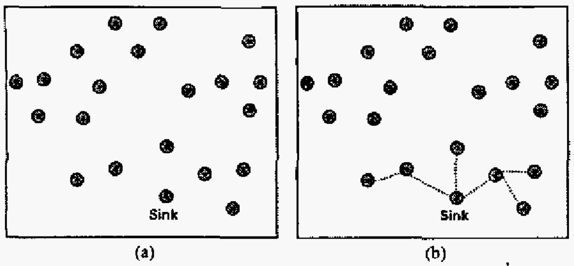

Figure 2: (a) Randomly distributed sensor nodes over an area. (b) Construction of the first tree topology.

called UGID. For example, in Fig. 1, G_1 is the upstream group for the group G_2 and Sink is the Parent Gateway of G_1. So ID of the Sink is the UGID for all the nodes of G_2.

- Upstream Gateway Power Level (UGPL): It is the transmission power level of the Parent Gateway of any group, by which it can be connected with the Child Gateway of the upstream group. Since sink is always the Parent Gateway in its group, its UGPL is assigned to 0. However, for the Parent Gateways of any other group, the UGPL may have value between 0 to 3.
- Source ID (SID): If A and B are two different sensor nodes of the same group such that A sends packet to B, A is the source for B and device ID of node A is termed as the source ID (SID).

3 The Distributed Power Control Protocol

In this section we present the power control protocol for the distributed WSNs that constructs the topology dynamically taking different group of nodes. Different groups of the network are being connected using an effective power level ($P_{effective}$) such that $(P_{min} = 0) < P_{effective} \leq (P_{max} = 3)$.

3.1 Construction phase

Once the nodes are deployed randomly as shown in Fig. 2(a), this phase is initiated by the sink node to get connected with its immediate neighbors using P_{min}= 0. The format of the Construct packet is shown in Fig. 3 and initially, the parameters of the Construct packets are assigned as follows: SID = Sink's ID, PGID = Sink's ID, UGID = NULL, LHC = 0, GHC = 0, UGPL = 0. After broadcasting the Construct packet to its neighbors, the sink waits for a specific time T_1 units and goes to the Information phase as described in Section 3.2.

Header	SID	PGID	UGID	LHC	GHC	UGPL

Figure 3: Format of the Construct packet.

The neighbor nodes on receiving the Construct packets, scan all the parameters of the packet and wait for the random time which is compatible with the CSMA channel access protocol [11]. Then each of them rebroadcasts the Construct packet using the same minimum power level to their neighbors with necessary increments to the parameters and wait for the same specific time T_1 units. After the time T_1 is out, nodes who have received the Construct packets, get connected with the sink and goes to the Information phase. Similarly the nodes on receiving the Construct packets and waiting for the specific time T_1 units, records its previous hops ID and get connected to it. This process continues until each node's T_1 time is out and finally nodes within the same group get connected and form the tree topology as shown in Fig. 2(b). The sink becomes root of the tree and other nodes, those are within the minimum power level become child of the sink. Thus the first tree topology is formed during the initial construction phase.

3.2 Information Phase

This phase is accomplished by broadcasting the Inform packets using P_{max}=3. The PGID is copied from the Construct packet and GHC is incremented by 1. Format of the Inform packet is shown in Fig. 4. On receiving the packet, each node calculates their physical distance from the sender using the following formula.

$$P_r = \beta \times (d^{-\alpha}) \times P_t \qquad (1)$$

Where, P_t: is maximum transmission power level (Power level 3 here) that a node uses broadcasting the Inform packet. P_r: is the received power by a node during the transmission. α and β are some given constants, where value of α is typically taken to be 2 for the free space. The physical distance d between the sender and the receiver can be calculated using equation (1). In this phase, physical distance is now known to the receiver. So it estimates the most effective power level ($P_{effective}$) by which it can communicate with the sender of the upstream group. This effective power level may be 1 or 2 that is less than the maximum one. If a node receives Inform packets from more than one node, it selects that sender with whom it can communicate using the least effective power level. After the random time is out, the nodes who have already received the Inform packets,

Header	SID	GHC	PGID

Figure 4: Format of the Inform packet

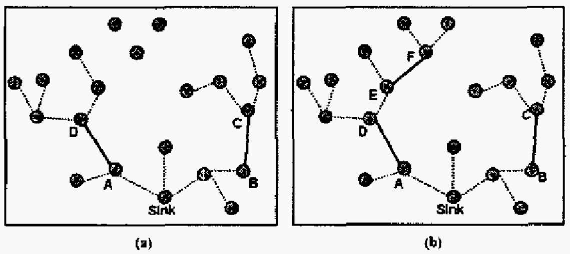

Figure 5: (a) Formation of second tree topology. (b) Formation of several tree topologies.

broadcast the Construct packets using the minimum transmitted power level and waits for the time T_1. The nodes add their own ID in PGID field of the packet and mention the effective power level in the UGPL field, with which it can be connected to the upstream group. On receiving the Construct packets, a node selects its Parent gateway for the group from the value of the GHC, UGPL and UGID based on the following rules.

i. If GHC of the received packets are different, the sender whose Construct packet contains the least GHC is selected as the Parent gateway.

ii. If value of the GHC for all packets are same, the sender having the least UGPL is selected as the Parent gateway.

iii. If the value of GHC and UGPL are same for all the packets, the sender having the least UGID is selected as the Parent gateway.

Also, the sender whose Construct packet contains the least number of LHC is considered as the parent for the receiver node. Thus another tree topology is constructed among those nodes which are within the minimum transmitted power level with the Parent gateway as the root. Then the Parent gateway selects the upstream groups' sender node as the Child gateway with whom it can be connected with the least effective power level. The construction of the second and third tree topologies are shown in Fig. 5(a) and subsequent topologies for the distributed network are constructed as shown in the Fig. 5(b).

3.3 Maintenance Phase

Since sensor nodes are densely deployed, during the Construction or Information phase, there is every possibility that a node may receive multiple packets of each types. So, this part of the protocol describes how a node should decides whether to accept or reject a Construct or Inform packet.

3.3.1 Conditions for Accepting or Rejecting the Construct Packets:

On receiving the packets, each node waits until a random time and we assume that by that time each node might has received multiple Construct packets. If the GHC for all the Construct packets are same, the Construct packet having least value of LHC is accepted, else the receiver accepts the packet having least value of GHC. If the Construct packets contain same GHC but different UGID, then the Construct packet having the least UGPL is accepted. If the Construct packets contain same GHC and same UGID, the Construct packet having the least UGPL is also accepted. Other than the above cases, the Construct packet is rejected by the receiver.

3.3.2 Conditions for Accepting or Rejecting the Inform Packets:

If multiple Inform packets are received by a receiver with different value of GHC, the Inform packet having least value of GHC is accepted. If the Inform packets are having same value of GHC with different UGID, the packet having the least value of UGPL is accepted. If the Inform packets are having same UGID and same value of GHC, the packet having the least value of UGPL is accepted.

4 Performance Evaluation

4.1 Experiment Scenario

In order to evaluate the energy consumption and network lifetime for different transmission power levels, we simulated our protocol using Tiny OS (TOSIM) [6]. Our experiments are conducted by distributing the sensor nodes randomly over a square sized monitoring area of 100m×100m. The deployed node numbers over that area ranges from 400~1000 and the tree topologies are formed by using low transmission power level 0. First we studied the probability of the number of nodes those who need maximum transmission power level. We run our simulation for 80 rounds and finally used power levels 1 and 2 to connect different topologies as the probability of using maximum power is very low. All nodes use the CSMA protocol for channel access. After every packet received or transmitted, the node waits a small amount of time

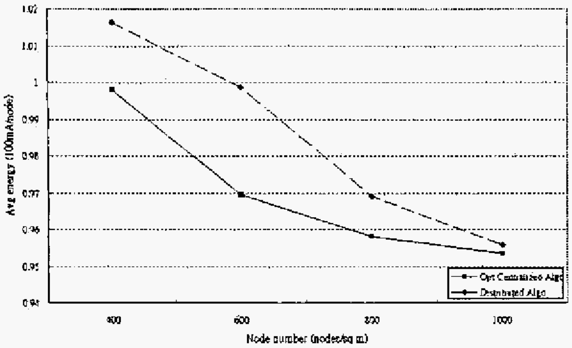

Figure 6: Average energy consumption for different node numbers with transmission power control.

which is susceptible to the hidden and exposed terminal problems. Energy consumption for all the sensor nodes based on the different transmission power levels is computed and to get an accurate measurement of the energy consumption and network lifetime, we run our simulation for 30 rounds.

4.2 Observations

4.2.1 Energy consumption

The most important performance metric for our distributed wireless sensor networks is the average energy consumption due to deployment of sensor nodes with different power levels. Fig. 6 shows the average energy consumption for different number of nodes. We found that for the higher number of nodes, being a distributed protocol, energy consumption of our protocol attains the optimality similar to the Centralized algorithm [8]. From Fig. 7, it is observed that our protocol consumes more energy as compared to the Optimal Centralized algorithm for the low node densities. However, for higher node density and for different configurations, energy consumption of our protocol is almost same to that of Optimal Centralized algorithm. Since, energy consumption of Centralized algorithm [8] is optimal one, we find that our protocol also maintains the same optimal condition for the higher number of nodes in different number of configurations. To analyze the importance of our protocol in terms of energy consumption, we estimated the total energy consumption for the different number of nodes considering with and without the transmitted power control. As shown in Fig. 8, it is interesting to note that total energy consumption of our protocol is very small as we control the transmission power. For without controlling the transmission power, total energy consumption is very high.

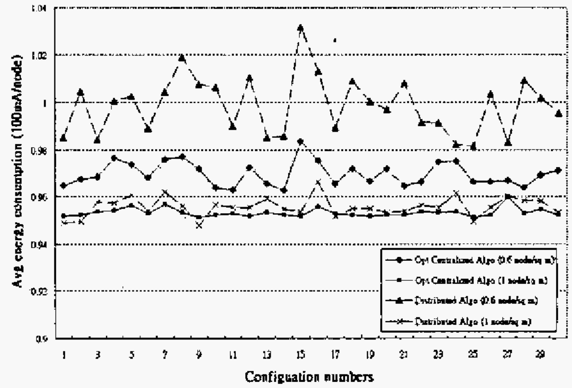

Figure 7: Average energy consumption for different configurations with different node densities.

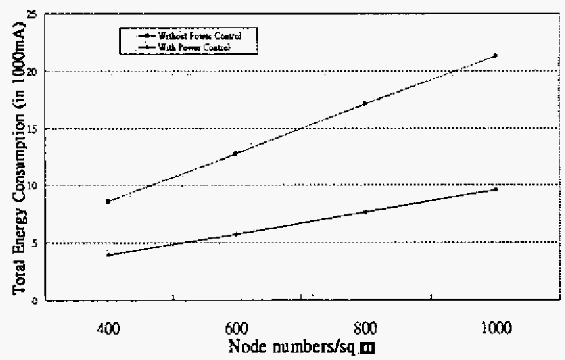

Figure 8: Total energy consumption for different node numbers with and without power control.

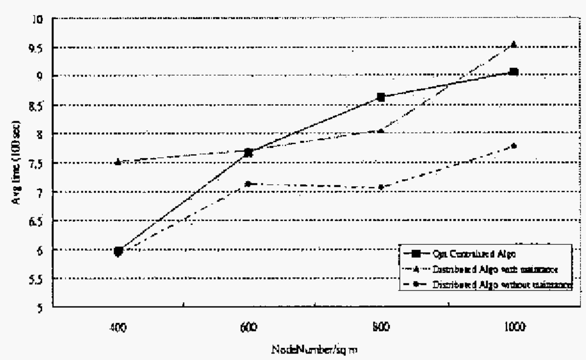

Figure 9: Average network lifetime for different node numbers with and without power control.

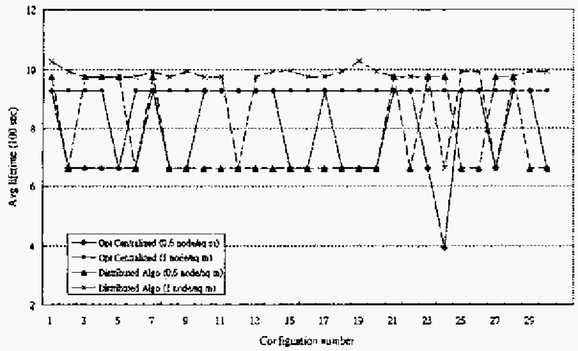

Figure 10: Average network lifetime for different configurations with different node densities.

4.2.2 Network lifetime

The network lifetime of our protocol for different number of nodes and configurations are analyzed in our simulation and are compared with the Centralized algorithm. As shown in Fig. 9, for the higher number of nodes the network lifetime of our protocol is better than the Centralized algorithm. Moreover, the network lifetime of our protocol is much better than the distributed algorithm without any power control. Also from Fig. 10, we got the mostly expected results, in which network life time of our protocol is higher than the Centralized algorithm for higher number of nodes with different configurations. Since network lifetime of the sensor nodes is a critical issue in wireless sensor network, we think our protocol is a best solution for this.

5 Conclusion

In this paper, we proposed a distributed power control protocol to achieve the energy conservation of the nodes. We construct a connected tree topology taking different group of nodes present in the network. Our protocol has two main contributions. (1) It uses a distributed algorithm to build the power saving tree topology without any location information and maintains the optimality of energy conservation similar to that of centralized ones. (2) It provides a simple way to maintain the topology. So we demand that our protocol can be useful for the wireless sensor networks in environmental monitoring applications such as collecting temperature, pressure and humidity of a locality.

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