FFDA
A Tree based Energy Aware Data Aggregation Protocol In Wireless Sensor Networks

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Abstract: In wireless sensor networks (WSN's), data aggregation is used to increase energy efficiency by means of eliminating redundancy and forwarding the collected abstract data of sensor nodes toward the sink. One of the most important challenges in WSN is to keep the remaining energy of nodes high and balanced to achieve longer system lifetime. In this article we propose an energy efficient data aggregation protocol named FFDA (Feed Forward Data Aggregation) for constructing the spanning tree, we also represent a new parameter called EAT (Energy After Transmission). This protocol considers EAT as the main parameter to select a node as root for spanning tree in the beginning of each round of data aggregation. Using this new parameter the remaining energy of nodes remain more balanced thus the first node die is delayed significantly and it also improves the system's lifetime as indicated by simulation results.

1 INTRODUCTION

A wireless sensor network consists of some nodes constructing a wireless network in order to sense the environment and collect the sensed data for processing and analyzing.

Each node consists of several parts including radio antenna, memory, processor, sensor and a power resource. Some of these resources have constraint, specially the power resource which usually is a small embedded battery. These nodes are deployed in the environment often randomly and stationary. In monitoring applications, when an event occurs in the environment, the wireless sensor network is triggered. Then all the nodes which sensed that event capture the relevant data and send their data to a base station (BS).

"Since wireless communications consume significant amounts of battery power, sensor nodes should spend as little energy as possible receiving and transmitting data" (Lindsey and Raghavendra, 2002, p. 1). It's been a challenge to find a way to decrease the energy consumption of nodes through the process of data transmitting to get a longer system lifetime from these limited resources. One of the possible solutions to this problem is a process called data aggregation. Data aggregation is any process in which information is collected and expressed in an abstract form. The idea is to combine all the data coming from different sources, eliminating redundancy, minimizing the number of transmissions and thus saving energy (Mohajerzadeh and Yaghmaee and Eskandari, 2008)**.**

In the case of tree based data aggregation, at first nodes constitute a spanning tree based on the applied protocol, then each node aggregates data received from other nodes along with its own sensed data and sends it to its parent. "This achieves a large reduction in the energy dissipation, as computation is much cheaper than communication" (Heinzelman and Chandrakasan and Balakrishnan, 2000, p. 2).

We may continue the process of aggregation based on the constructed spanning tree or we can change it each round depending on the application and distance of BS to the field. When BS is far away from the field, a few transmissions from a node to the BS could run its power out completely. therefore considering the computation energy is a lot less than long distance data transmission, we may prefer to change the root and so the spanning tree each round.

In this article we introduce a tree based data aggregation protocol FFDA (Feed Forward Data Aggregation) in which we used EAT (Energy After Transmission) factor as a new parameter to construct the spanning tree. In section 2 we describe some of

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the proposed tree based data aggregation protocols and describe their strengths and weaknesses. In section 3 we explain our protocol FFDA in detail along with the factor EAT and in section 4 we evaluate the performance of FFDA algorithm and compare it with some of recently proposed algorithms.

2 RELATED WORKS

There are several tree-based aggregation algorithms and each of them considers one parameter as the main parameter to determine the aggregation tree's root and then construct the spanning tree based on the selected root. Some of them select the node with highest remaining energy among all nodes as root while others consider the shortest distance to BS as the main parameter. Moreover, many different methods and parameters are used to construct the spanning tree, either as a single factor or as a combination of factors.

For example, Espan protocol (Lee and Wong, 2005) selects the node with the highest remaining energy within the entire network as tree's root, then each node selects the closest neighbor to root as its parent and if there are more than one neighbor with same distance then the node with highest remaining energy is selected as parent. So distance and remaining energy are two parameters used in Espan protocol to construct the aggregation tree while distance has higher priority. This way it is possible that a node with low remaining energy level is selected as parent because of short distance to root, therefore after data aggregation is done, this node loses its energy quickly because of high traffic passing through it and it leads to incomplete coverage and system failure.

In LPT (Lee and Wong, 2005) nodes with higher remaining energy are chosen as parents in aggregation tree in order to increase the lifetime of nodes with high traffic. This way a node far away from root may be selected as parent because of its high remaining energy levels but it will be drained quickly due to long distance transmission energy consumption.

In the proposed algorithm by Mohajerzadeh et al. (2008) they had introduced an efficient algorithm in which nearly most of the problems we described in Espan and LPT are solved, and the simulation results has shown their algorithm has better performance than Espan and LPT algorithms in terms of both first node die and system's lifetime. But there is a big disadvantage in their protocol that causes an unbalanced energy consumption throughout the network. In presented algorithm by Mohajerzadeh et al. (2008) the main factor to choose a node as root for spanning tree is residual energy of nodes, so a node with highest remaining energy (HRE) is selected as root.

In the following section we describe the drawbacks of HRE factor and introduce the new factor EAT, then we will explain the proposed protocol.

3 PROPOSED ALGORITHM

As mentioned earlier, in the beginning of each round we have to select a node as root for spanning tree, and then construct the tree based on selected root until every single node is covered. In (Mohajerzadeh et al., 2008), LPT and many other tree based protocols, the node with highest remaining energy is selected as root. while this method causes an unbalanced network in terms of energy, we replaced it with the factor EAT as a new parameter to keep the remaining energy of nodes more balanced through the process and thus prolong the lifetime of the system and delay the first node die. In the following section we describe the factor EAT in details and then we represent the complete protocol.

3.1 EAT Factor

Suppose 5 nodes named N1 to N5 with initial energy of 1300, 1300, 1800, 1600 and 1700 are respectively positioned in a field. Distances between nodes and BS are 16, 18, 15, 20 and 10 respectively. One of these nodes is selected as root depending on which factor we use to determine the root node. Then all the nodes constitute a spanning tree to gather the captured data and send the data towards the root, where the root sends the aggregated data to BS in order to analyze.

In figure 1 it is shown how the BS and nodes are positioned in the field. Using the proposed algorithm in Mohajerzadeh et al. (2008) the node number 3 is selected as root since it has the highest remaining energy among nodes. This may seem logical since sending packets to BS drains the energy of root node specially when BS is positioned far away from field, but this is not the best way to select the root amongst the nodes because it ignores the distances between nodes and BS in root selection.

Therefore we introduce the new factor EAT and replace the HRE factor with it. We calculate EAT for each node and then select the root using this new factor, then we compare the results to show how EAT factor helps to keep the average remaining energy of nodes higher and also how it makes the remaining energy of nodes more balanced within the network.

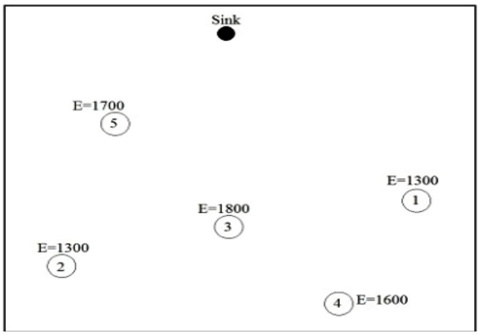

Figure 1: physical placement of nodes and base station.

We assume the aggregated data is a 10 bit packet which will be sent from the root to BS. To calculate the required amount of energy for a node to send a packet to BS, we use formulas that will be described later on section 4. To calculate the EAT for each node, we need to calculate the required amount of energy to send a 10 bit packet to BS from the node and then subtract it from residual energy of the node.

For node number one, sending a 10 bit packet to BS consumes a total energy of 1024, so the remaining energy will be 276. Therefore EAT for node number one is 276. We calculate the EAT factor for each node before we actually send any data to BS and before constructing the spanning tree. As a matter of fact we use this factor to choose a node as root for spanning tree. Therefore we choose the node with highest EAT as root instead of the node with highest remaining energy. Although node number five has less energy than node number 3, a shorter distance to BS results in a higher EAT 1300, and we select it as the root for the spanning tree.

As you can see in table 1, after selecting the root with two different parameters, EAT and HRE, total energy of network is 7300 for EAT mode and 6800 for HRE mode. Total energy of system is the sum of remaining energy of all nodes in the network. Furthermore with EAT factor we have a more balanced network in terms of energy.

In short, we can describe EAT as remaining energy of each node if it is selected as root and sends the aggregated data to BS. By using the EAT factor we delay the first node die in the network by means of keeping the remaining energy of nodes more balanced and also keep total remaining energy of nodes higher through the process.

Table 1: EAT and Highest Remaining Energy.

Node number	Initial energy	Distance to base	EAT	Remaining energy (EAT root selection)	Remaining energy (HRE root selection)
1	1300	16	276	1300	1300
2	1300	18	4	1300	1300
3	1800	15	900	1800	900
4	1600	20	0	1600	1600
5	1700	10	1300	1300	1700

3.2 FFDA Protocol

In our proposed protocol, we consider the distance to root as second parameter in root selection, therefore if there are more than one node with the highest EAT amongst nodes, the node with shorter distance to BS is selected as root. This way the total energy of network remains higher**.** We also used the "maximum child number" parameter in order to prevent a node with high density of nodes in its neighborhood to get all of them as child. This parameter could be either prefixed or variable.

The next parameter we used in proposed algorithm is average path's energy (APE) first introduced by Mohajerzadeh et al. (2008). APE is the sum of remaining energy of nodes within a path (up to the root) divided by the path's length. When a node wants to choose a parent, if there are more than one option then the node with highest APE is selected. Likewise if a node which is already in spanning tree could select a new parent with higher APE (while the new parent has not reached to maximum child number limit), it does change its parent to the new parent with a higher APE. By using the factor APE we prevent a node with high remaining energy to be selected as parent while it is far away from root, APE combines both "Remaining Energy" and "Distance to Root" parameters in a single parameter.

4 SIMULATION RESULTS

We have evaluated the performance of our proposed algorithm and then compared it with proposed algorithm by Mohajerzadeh et al. (2008) which outperformed LPT and Espan protocols.

4.1 Simulation Model

We conducted the simulation in two different simulation scenarios to evaluate the performance of proposed protocol in different conditions. In first mode, nodes are deployed in a 25m*25m square area with the BS positioned in [0,0]. Number of nodes is variable from 100 to 400 and the initial energy of each node is a random variable from 80mJ to 100mJ. Radio range of all the nodes are limited to 5 meters during constructing the spanning tree while they are capable of sending data to BS when they are selected as root for spanning tree. Plus the maximum child number is prefixed to 5. In second mode, the field is a 40*40 meters square area with the BS in [20,60] to evaluate the performance of the protocol in long distance transmissions. Because the BS is located far from field in second mode we consider the initial energy of nodes higher than first mode as a variable from 120mJ to 150mJ.

We assume all the nodes sense the environment and send their data in each round of data aggregation. All the nodes are homogenous and stationary.

Energy consumption is calculated with following formulas:

$$ER_i = C_1 * K \quad (1)$$

$$ET_{ij} = C_2\, K\, dist_{ij}^2 \quad (2)$$

$$EA_i = C_3 * K \quad (3)$$

Where ER and EA are the required energy for data receiving and data aggregating for node i respectively. ET_{ij} and $dist_{ij}$ are required transmission energy and distance between nodes i and j respectively. In first order radio model there is also an energy consumption for running the transmitter circuitry though we ignored it in equation 2 because of its minor effect on the result. C1, C2 and C3 are prefixed values determined based on energy and aggregation models in (Zhang and Yu and Chen, 2005), also the values are described in details for first order radio model in (Stanislava and Heinzelman, 2009). And K is the length of receiving and transmitting packet by nodes. We assume input and output data length are equal to 2000 bit.

A run time round is defined as the process of collecting the data from all nodes in the network and transferring the aggregated data to BS. The energy consumed by each node in each round is as follows:

Leaf nodes consume the required energy to transmit a packet to their parent. Intermediate nodes consume the total energy required to receive transmitted data by their child nodes, aggregating received data and transmitting the aggregated data to their parents. The root node consumes the energy required to receive transmitted data by its child nodes, aggregating received data and transmitting the aggregated data to the BS.

The network lifetime is expressed as the rounds passed until the point in which the number of remaining alive nodes are less than 80% of the number of the nodes in the first place.

4.2 Simulation Results

In this section we evaluate the performance of proposed algorithm in different simulation environments. when an event occurs in the environment all nodes constitute the spanning tree and send the captured data to the root using the aggregation tree.

We repeated the simulation twenty times and calculated the average values to get accurate results. In figure 2, first node die round time is compared between proposed algorithm in this paper and proposed algorithm by Mohajerzadeh et al. (2008) in first simulation environment. Using the factor EAT keeps the remaining energy of nodes more balanced, therefore the first node die round time is delayed significantly regardless of the density and number of deployed nodes.

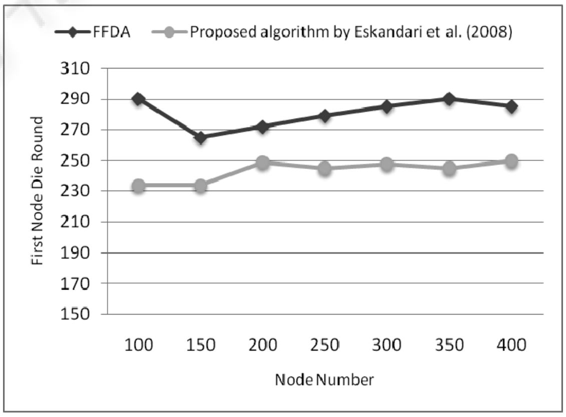

Figure 2: First node die round comparison.

In figure 3 system's lifetime is compared between the two mentioned algorithms in second simulation environment. The affect of using the EAT factor is related to the number of deployed nodes when analyzing the system's lifetime. When the density of nodes is low and the distances between them are high the effect of the EAT factor is more noticeable.

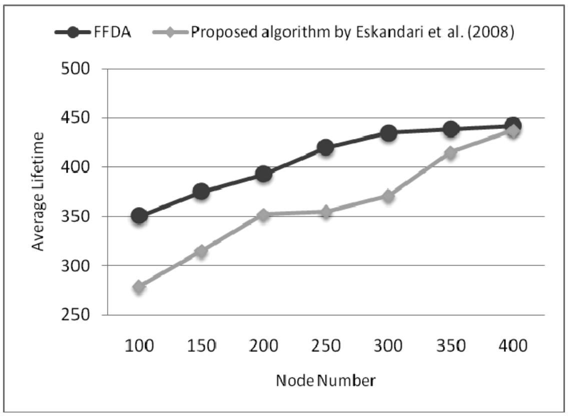

Figure 3: System lifetime comparison.

5 CONCLUSIONS

One of the most challenging parts in wireless sensor networks is to decrease the energy consumption of nodes to delay the system failure. Two important factors that have a direct effect on system failure are the energy of network and the equality of remaining energy of nodes in the network. In this paper we introduced an energy aware protocol in which we used a new factor called EAT. Using this factor as the main factor to select the root for aggregation tree the remaining energy of nodes remain more balanced. therefore the system failure is delayed. As we evaluated EAT factor in simulation section, it is shown that HRE factor can be replaced with EAT in similar protocols which use the highest remaining energy as the main factor to select the root node.

REFERENCES

Heinzelman, W. R. Chandrakasan, A. and Balakrishnan, H. (2000). Energy-Efficient Communication Protocol for Wireless Microsensor Networks. *Proceedings of the 33rd Hawaii International Conference on System Sciences,* 8, 8020.

Lee, M. and Wong , V. W. S. (2005). An Energy-Aware Spanning Tree Algorithm for data aggregation in wireless sensor networks. *IEEE Pacific RIM Conference on Communications, Computers and signal Processing(PACRIM), 300-303.*

Lee, M. and Wong, V. W. S. (2005). LPT for Data Aggregation in Wireless Sensor Networks. *Global Telecommunications Conference, GLOBECOM '05. IEEE, 5,* 6 pp. - 2974.

Lindsey, S. and Raghavendra, C. S. (2002). PEGASIS: Power-Efficient Gathering in Sensor Information Systems. *Aerospace Conference Proceeding*, 3, 1125-1130.

Mohajerzadeh, M. Yaghmaee, M. H. and Eskandari, Z. (2008). Tree Based Energy Efficient and Congestion Aware Routing Protocol for Wireless Sensor Networks. *11th IEEE Singapore International Conference on Communication Systems (ICCS2008).* 1707-1711.

Stanislava, S. Heinzelman, W. B. (2009). Cluster head election techniques for coverage preservation in wireless sensor networks. *Ad Hoc Networks*, 7(5), 955-972

Xiaowei, Z. Xiaohai, Y. and Xiangqun, C. (2005). Inter-Query Data Aggregation in Wireless Sensor Networks *international conference on Wireless Communications, Networking and Mobile Computing Proceedings.* 2, 930-933.