Delay and Energy Efficient Data Aggregation in Wireless Sensor Networks

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Abstract

Data aggregation is a fundamental problem in wireless sensor networks which attracts great attention in recent years. Delay and energy efficiencies are two crucial issues of designing a data aggregation scheme. In this paper, we propose a distributed, energy efficient algorithm for collecting data from all sensor nodes with the minimum latency called Delay-aware Power-efficient Data Aggregation algorithm (DPDA). The DPDA algorithm minimizes the latency in data collection process by building a time efficient data aggregation network structure. It also saves sensor energy by decreasing node transmission distances. Energy is also well-balanced between sensors to achieve acceptable network lifetime. From intensive experiments, the DPDA scheme could significantly decrease the data collection latency and obtain reasonable network lifetime compared with other approaches.

1. Introduction

In wireless sensor networks (WSNs), sensor nodes are often battery-powered devices deployed in wide area where is difficult for maintenance. Energy saving is therefore a critical issue to be considered when designing a WSN. Besides, data collection latency is also an important factor of WSN for detecting critical event such as earthquake notification or fire detection. Delay and energy efficiencies are actually two conflicted constraints; optimizing one of them usually requires sacrificing the other. These constraints make the design of WSNs not a trivial problem. In this paper, our goal is to build the network with minimum data aggregation latency and keep the network life time at reasonable values.

The rest of this paper is organized as follows: In the next section, we briefly review related work. Section 3 presents preliminaries and assumptions used in the paper. Our scheme is presented in section 4 and the evaluation results are shown in section 5. Finally, we conclude our work in the last section.

2. Related Work

Much prior work uses clustering algorithms for conserving sensor energy, and LEACH [1] is a typical one. The network is divided into clusters and only cluster heads transmit data directly to the sink. Hence, we can save energy by reducing the number of nodes involved in long distance transmission. However, data collection efficiency is often sacrificed in return of gaining longer network lifetime.

Cheng et. al propose a novel approach [2] that could obtain minimum latency in data collection. One problem of their scheme is it does not yield good results in term of network energy saving. Energy consumption is also not well-balanced between network nodes which may decrease the lifetime of the network. Our approach can obtain the same latency but better network lifetime compared with [2].

3. Preliminaries

To minimize data collection latency, Cheng et al. propose a delay efficient network structure with one or multiple trees [2]. In the structure, each node is given a rank which is the number of data links attached with it. A node of rank k has

$k - 1$ child nodes of different ranks varied from 1 to $k - 1$. The structure is proven to obtain minimum delay in data collection process [1]. Fig. 1 is an example of the network structure with 7 nodes.

As in [2], we assume that sensors can adjust their transmission ranges to reach to farther nodes and the BS directly. Perfect data fusion is assumed to be used; it means that the size of sending data packet is the same for every node. Each sensor is equipped with only one transceiver, thus multiple receptions by a node in the same time slot is not allowed. Interferences due to parallel transmissions can be alleviated by using CDMA-based sensors.
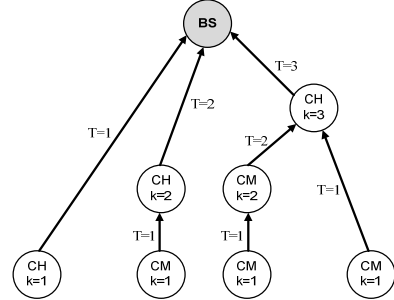

Fig. 1. The network structure with 7 nodes

4. Proposed Scheme

Our approach for solving the aggregation problem consists of two phases: network construction and scheduling. In the network construction phase, one or multiple data aggregation trees are built to satisfy the given delay efficient network structure. In the scheduling phase, each node is assigned a timeslot for transmitting data equal to its rank in the tree. The node will send data in the assigned timeslot and go to sleep in other ones. The rest of this section describes the algorithm for constructing the network structure in details.

Initially, each node generates a backoff time as (1), where C is a constant, $d_{A,BS}$ is the distance from node A to BS and R is a small random number to avoid collisions. After waiting for the backoff time, each node sends a request to its nearest neighbor to form a data link. By using (1), nodes which are far from the BS could generate smaller backoff time and select their neighbors fisrt. Nodes close to the BS select their

neighbors later, but they can also choose good neighbors because the distances between those nodes are short. After forming a connection, the two nodes become candidate cluster heads (CCH) of the new composite cluster.

$$t\_backoff_A = \frac{C}{d_{A-BS}} + R \qquad (1)$$

Each CCH calculates the weights of links to its neighbors and finds the smallest one. Two CCHs in a group then communicate the lowest weight link to find the lower one. The CCH which has lower weight link in each group waits for a random backoff time (1) and sends a connection request (CR) to the CCH corresponding to the link.

When a node receives a CR, the node accepts the request if it comes from a CCH of the same level. Otherwise, it rejects the request by replying with a rejecting packet (RP). Level of a CCH is defined as the number of nodes of its cluster. When two nodes form a connection, they become CCHs of the new composite cluster.

When a RP is received, the CCH will try with its second best neighbor and increase its transmission range if there are no other neighbors within its transmission range. A CCH will make a connection with the BS if it cannot find any neighbor.

The weight of a link between two nodes A and B is denoted by $w_{A,B}$. This weight depend on the distance between two nodes ($d_{A,B}$) and the distance of each node to the BS ($d_{A,BS}$ and $d_{B,BS}$). These two distances should be minimized to save sensor transmission energy and converge CHs to the BS, respectively. The distances between high degree nodes can be shorten by converging temporary CHs to the BS. Energy consumption of low and high degree nodes is therefore balanced. Finally, the weight of link is calculated by (2), where d_{A-B} is the distance between two nodes A and B; d_{A-BS} is the distance from node A to the BS; and $\alpha \in [0, 1]$ is a coefficient to configure the convergence speed of CCHs.

$$w_{A-B} = d_{A-B}^2 + \alpha(d_{A-BS}^2 + d_{B-BS}^2) \qquad (2)$$

If α is small, weight of a link is more biased towards the distance between two nodes. Low degree nodes take more advantages of selecting neighbors. Temporary CHs are slow converged and high degree nodes may not form connections with close neighbors. They may become the "bottle neck"' of the network. In contrast, if α is large, high degree nodes are more advantageous than the low degree ones. Hence, choosing the value of α is a crucial decision; it can affect the algorithm performance significantly. The α value is chosen by experiments and the best appropriate value of α is 0.34.

5. Performance Evaluation

To evaluate the performance of our approach, we compare our scheme with the two highly related schemes LEACH [1] and DADC [2]. The metrics that we use for comparison are the two critical factors of data aggregation schemes: data collection latency and network lifetime. The simulation parameters are set as [2]. Network size is $50 \times 50m^2$ where the BS is at the center. Packet size is 1024bits. Initial energy of sensors is 50J. Energy consumption of sensors for sending is calculated by (3). Each data point is the average of 100 runs.

$$E_{send} = (155 + 0.1d^2) \times 10^{-6} \qquad (3)$$

Fig. 2 shows that the DPDA can obtain the same results as DADC because they both build the optimal delay network structure. They therefore outperform LEACH in term of data collection latency. From Fig. 3, the DPDA also yields better results in term of network lifetime compared with LEACH and DADC. It is because DPDA can better balance energy consumption between network nodes.
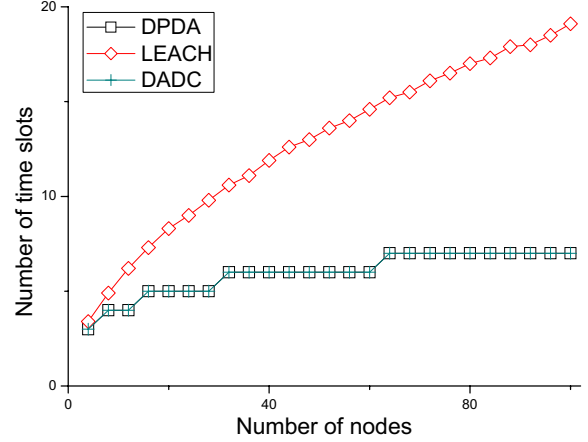

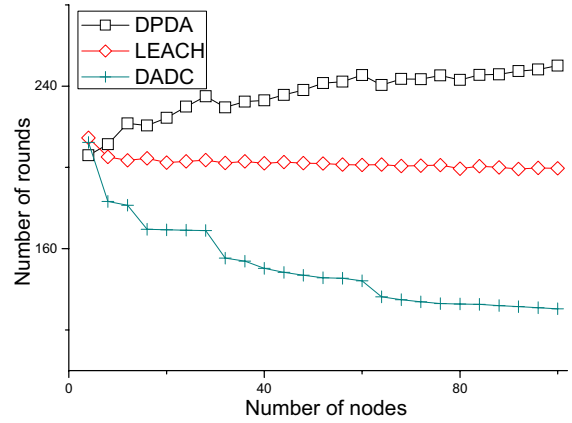**Fig. 2.** Data collection latency

Fig. 3. Network lifetime

6. Conclusion

This paper considers the problem of minimizing delay and saving network energy in data aggregation. The minimum delay is achieved by constructing a delay efficient network structure. Energy consumption is well-balanced between network nodes to obtain acceptable network lifetime. From experiments, the DPDA scheme can significantly reduce the data collection delay and obtain reasonable network lifetime compared with other existing approaches. The DPDA scheme is therefore better for applications with strict delay constraint.

References

[1] W. B. Heinzelman *et. al.* "An application-specific protocol architecture for wireless microsensor networks," IEEE Trans. Wireless Commun., 2002.
[2] C. Cheng *et. al.* "A Delay-Aware Data Collection Network Structure for WSNs," IEEE Sensors Journal, 2011.