Dynamic and Adaptive Organization of Data-Collection Infrastructures in Sustainable Wireless Sensor Networks

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Sensor networks are associated with the natural complex networks (such as biological networks and social networks) in the aspect of cooperative organizations of small sensor nodes into various functional patterns of network structures so as to perform ubiquitous sensing and control. A specific feature of communication in sensor networks is the many to one model of data collections, which is subject to the problem of energy overuse at some particular nodes near the sink. To enable balanced energy consumption among sensor nodes, the desirable infrastructures should organize sensor nodes to fairly share the role of data collection. In this paper, we study the construction of both dynamic and adaptive network infrastructures for data collections in a static wireless sensor network. The organization of sensor nodes in data collections is adaptive to the data aggregation capacity at sensor nodes, leading to both energy saving and balanced energy consumption.
1 Introduction

Compared with conventional communication networks such as the Internet, sensor networks enable the distributed and collective sensing of physical phenomena in wide application areas such as precision agriculture and industry automation. A wireless sensor networks are required to be sustainable for long-time sensing and data reporting with battery powered sensor nodes. A specific feature of communication in sensor networks is the many to one model of data collections that are triggered by on-demand queries from users [Intanagonwiwat 2002, Kulik 2006]. In the on-demand data collection, conventional schemes such as, the cluster, chain, and optimized tree based data collections are both costly and complex [Heinzelman 2002, Zou 2004]. A prevailing organization pattern of nodes for on-demand data collection is the reversed tree built by the query broadcast from the sink node, which is the root of the tree [Intanagonwiwat 2002].

However, the many to one traffic model of data collection leads to the unbalanced communication connectivity, in which many data packets are delivered and relayed towards nodes near the sink. Due to the multi-hop relay features of wireless sensor networks, the nodes near the sink deplete their energy much faster than nodes far away from sink, resulting unbalanced energy consumption among sensor nodes. When the nodes near the sink drain their energy, data packets from other nodes can not be relayed to the sink [Wu 2008]. Therefore, alleviating the overused energy consumption near the sink is a significant issue to maintain the network sustainability for data collection.

To achieve balanced energy consumption among sensor nodes, the desirable infrastructures should organize sensor nodes to fairly share the role of data collection. A basic idea is to utilize the sink proxy in the network, which collects and aggregate sensing data on behalf of the sink node [Teng 2007]. With adjustment of sink proxy selection in each round of the data collection corresponding to a user query, network infrastructure can be reconfigured and be dynamic changed.

In this paper, we specially discuss the organization of network infrastructures that are adaptive and dynamic according to the data aggregation capability of sensor nodes. The data aggregation capability has an essential impact on the effectiveness of network infrastructures for data collection. The adaptive selection of sink proxy according to the data aggregation capability controls the formation of network infrastructure and enables both energy saving and energy balance in the wireless sensor networks.

2 Motivation

Note that the sink-proxy based dynamic infrastructure can lead to the alleviation of the bottleneck problem in sensor networks that have static topologies and data aggregation capabilities. However, the effectiveness of dynamic infrastructures is influenced by the data aggregation capability of sensor nodes. Here, we use the term of data aggregation
degree to describe the ratio of the total size of data packet after aggregation to the total
data packet size before aggregation. Due to the indirect delivery of data packets to the
sink in the sink-proxy based data collection, we observe that in case data aggregation
can not reduce the size of sensing data packets, the dynamic infrastructure may
introduce not only the same amount of packet traffic to the sink, but also more energy
consumption in sensor network compared with direct collection of sensing data
packets by the sink without utilizing sink proxies.

From this observation, we find that there should be an adaptive construction of
network infrastructure for data collections with regard to the data aggregation degree.
This requires the adaptive selection of appropriate sink proxies in each query. The
following features are envisioned to be realized in the sink proxy selection.

(a) As for an appropriate sink proxy, the total energy consumption of data collection
is not larger than that of without using sink proxies.

(b) If there are no appropriate sink proxies that satisfy the condition of (a), sink proxy
is identical to the sink node.

(c) A sink proxy is randomly selected among the candidates of appropriate sink
proxies in each query.

3 Dynamic and Adaptive Organization of
Data-Collection Infrastructures

Dynamic and adaptive construction of network infrastructure requires appropriate
decision rules for the selection of sink proxy. At first we define the term of energy
benefit, which refers to the amount of energy saving in the data collection by
sink-proxy based approach in comparison with those do not use sink proxies. The
energy benefit $B(i)$ at a sensor node $i$ depends on the route length $R(i, sp)$ from node
$i$ to the sink proxy ($sp$), the route length $R(sp, sk)$ from the sink proxy ($sp$) to the sink
($sk$), the route length $R(i, sk)$ from the sink proxy ($i$) to the sink ($sk$) and the data
aggregation degree $\alpha$. $B(i)$ is represented as follows.

$$B(i) = R(i, sk) * E_0 - R(i, sp) * E_0 - \alpha * R(sp, sk) * E_0.$$ (1)

where, $E_0$ is the average energy consumption of a one-hop transmission of a packet.

The total energy benefit of sensor nodes in the network is given by:

$$\sum_{i=1}^{n} B(i) = \sum_{i=1}^{n} (R(i, sk) * E_0 - R(i, sp) * E_0 - \alpha * R(sp, sk) * E_0)$$ (2)

Where $n$ is total number of sensors that should report their sensing data to the sink
according to the user query.
Now we can give basic criterion of the judgement of an appropriate sink proxy by utilizing the rule of

$$\sum_{i=1}^{n} B(i) > 0$$  \hspace{1cm} (3)

In the data collection operation, if a sensor node satisfies the condition of (3), the sensor node is appropriate sink proxy.

In case the aggregation degree $\alpha$ is 1, there is no energy saving after the data aggregation is performed at the sink proxy. Given a selected sink proxy and a known query, the aggregation degree $\alpha$ has an essential impact on the amount total energy benefit.

The adaptive and dynamic sink proxy can be selected according to (3). At first the sink node calculates which sensor nodes satisfy (3), those nodes forms a group of appropriate candidates of sink proxy. A sink proxy is randomly selected among the nodes in the candidate group. If there is no candidate of sink proxy in the network, the sink node then directly query and collect sensing data without utilizing a sensor node as the sink proxy. We summarize the basic adaptive selection of sink proxy in equation (4).

$$\text{SP(ID)} = \begin{cases} 
L = \text{the ID of an randomly selected sink proxy} & \sum_{i=1}^{n} B(i) > 0 \\
M = \text{the ID of the sink} & \sum_{i=1}^{n} B(i) \leq 0 
\end{cases}$$  \hspace{1cm} (4)

Where SP(ID) is the ID of selected appropriate sink proxy. Equation (4) illustrates the integration of adaptive selection of the sink proxy in various cases of data aggregation capability. In case that $\sum_{i=1}^{n} B(i) \leq 0$, the sink proxy is identical to the sink node.

We can know observe that the more appropriate sink proxy candidates, the more nodes are able to share the role of sink with energy saving.

4 Conclusion

This paper introduces the adaptive and dynamic utilization of sink proxies for the infrastructure construction of sensor network. We discussed the adaptive selection of sink proxy according to the energy saving and the impact of data aggregation degree. The adaptive and dynamic network infrastructure alleviates the energy bottleneck problem in many-to-one data collection by enabling more nodes sharing the role of sink proxy with energy saving.
Bibliography


