

SWATCH: a StepWise AdapTive Clustering Hierarchy in Wireless Sensor Networks

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Abstract. Distributed clustering techniques are considered effective and practical for power-saving in Wireless Sensor Networks (WSNs). In this paper, we propose a novel cluster formation scheme in WSNs, called StepWise AdapTive Clustering Hierarchy (SWATCH). SWATCH aims to solve the ClusterHead (CH) number uncertainty problem common to existing distributed clustering schemes, while keeping the desirable properties of self-organization, simplicity and dynamic adaptation. We develop a two-tier hierarchical Markov chain model to track the operation of SWATCH. Based on this model, we derive formulations of the statistical properties of our proposed scheme. Numerical results verify the design objectives in that the number of selected clusterheads highly conforms to the optimal value.

1 Introduction

Communication cost has been shown to be the major source of energy dissipation in Wireless Sensor Networks (WSNs) [1]. Clustering is an effective framework under which different energy saving techniques, such as energy-saving MAC and local data processing, can be easily adopted. With a clustered structure, the entire network is partitioned into disjoint clusters. Each cluster consists of one ClusterHead (CH) and multiple Member Nodes (MNs). Forming the virtual backbone of the network, the CHs collect data from MNs and relay the processed data, e.g., aggregated data [2] to the base station.

Although the optimal number of CHs has been proven to exist for WSNs using certain clustering scheme [2,3], clustering schemes fail to guarantee the optimal number of CHs that will be elected in a dynamical basis. For example, LEACH [2] achieves energy saving by having the network dynamically partitioned into multiple clusters and local data processing in each of them. However, due to the randomness in the CH selection algorithm, the number of CHs is not guaranteed to be equal to the expected optimal value (according to our investigation, the percentage of time that the number of CHs is equal to the optimal value is observed to be less than 20%, see Fig. 1.) In

the worse case, when one CH serves the whole network, its energy would drain rapidly, and fairness is severely affected.

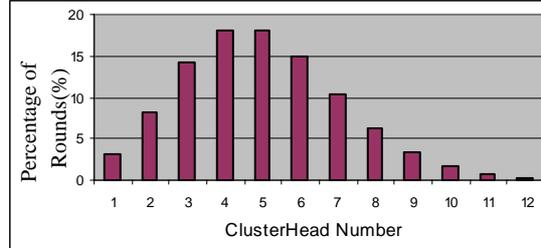


Fig. 1. CH Number Distribution of LEACH (100 nodes, Target CH Number =5. The percentage of CH number greater than 12 is negligible)

In this paper, we propose a novel single hop clustering scheme called StepWise AdapTive Clustering Hierarchy (SWATCH). SWATCH relieves the CH number variability problem by employing stepwise CH selection in two stages. It is a dynamic and straightforward scheme as LEACH. However, instead of selecting all CHs in one step, SWATCH splits the selection phase into an initial selection stage and an add-on selection stage. The initial selection is similar to LEACH. However, if the number of CHs in the initial selection is below a pre-determined target, the add-on selection will be invoked and will continue until an acceptable number of CHs have been selected. As a result, the number of CHs selected in each round tends to congregate in a narrow range around the optimal value. In other words, the variance of the number of CHs in each round is decreased. In order to evaluate the performance of SWATCH, we develop a hierarchical Markov chain model to track the behavior of the system. Numerical results verify our design objective in that the number of selected CHs highly conforms to the optimal value. Based on the results in [2,3], which show that an optimal number of CHs can greatly reduce the communication energy, we argue that SWATCH is energy efficient and fair.

The remainder of this paper is organized as follows. In section 2, the SWATCH scheme is presented. In section 3, the performance of SWATCH is evaluated by comparing to LEACH scheme.

2 SWATCH Description

2.1 Preliminaries

We make the following assumptions about the network and communication models. We assume a static network consisting of N identical stationary nodes, which are distributed randomly in a 2-dimensional sensing field (to fulfill a constant sensing

3 Performance Evaluation

To evaluate the effectiveness of SWATCH, we develop a hierarchical Markov chain model, consisting of a Primary Markov Chain (PMC) and a Secondary Markov Chain (SMC). The PMC is used to describe the CH selection procedure from round to round, while the SMC is used to describe the CH selection behavior during the CHASS. The model is omitted due to the space limitation. Based on it, we calculate the expectation and Coefficient of Variance (C.O.V) of the number of CHs, as well as the average extra number of CH selection steps.

Fig. 3 illustrates the results for the C.O.V of the number of CHs using both LEACH and SWATCH for the same WSN with different target CH numbers. In all the cases, SWATCH produces much smaller C.O.V. than LEACH. It implies that SWATCH can ensure a more stable number of CHs.

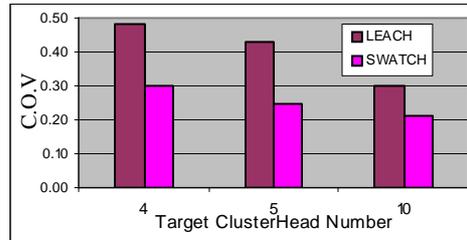


Fig. 3. C.O.V of ClusterHead Number (100 nodes, target values = 4, 5, 10)

SWATCH addresses the CH number uncertainty problem explicitly by exploiting a two-stage CH selection algorithm. Since it has been earlier shown that there exists an optimal value for individual WSNs, which leads to the minimum energy dissipation, we argue that SWATCH will provide higher energy efficiency than the existing distributed schemes.

References

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