

Energy Efficient Clustering Communication Protocol for Wireless Sensor Network

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Abstract—The clustering communication sensor network structure is a main energy efficient communication protocol. The cluster heads collect information transmitted from the cluster members to process the data in the base station far beyond. In this structure, the unstable and unevenly distributed cluster heads can increase power of the network system. In this paper, we propose a energy efficient cluster head selection to select the cluster heads in higher density so that the cluster members are almost in the transmission range of the cluster heads for wireless sensor network. The experimental results show the proposed method can extend the lifetime of the wireless sensor network system.

Keywords— energy, cluster, routing, wireless, and sensor network

I. INTRODUCTION

In contrast with traditional sensors, sensor networks offer a flexible proposition in terms of the ease of the deployment and multiple functionalities [1]. In the wireless sensor network architecture, a large number of low-energy wireless sensor nodes are first deployed, either by pre-planning or dropping by a flying vehicle, to cover the sensor field. The wireless sensor nodes can configure themselves, in an ad hoc fashion, to form a communication infrastructure so that sensed data can be transmitted according to some protocols across the sensor field hop by hop. When the users assign a task with a high-level description, the interface analyse the task and send a low-level description of mission update of the task to sensor nodes via BS (Base Station) or sink, which can be the combination of wired and wireless networks. After the mission of a sensor node is updated, it monitors the interest of user and reports data as interesting phenomena appear. The BS collects reported information and sends it back to the user [2]. By integrating a large number of wireless sensor nodes distributed over a geographical area to form a wireless sensor network, the user can monitor the remote physical environments which may not be easily arrived. However, the sensor nodes are powered by batteries, which are difficult to recharge. Thus, energy efficiency is an important issue in wireless sensor network.

This work was supported by National Science Council, Taiwan 98-2221-E-024-005

To reduce energy consumption in wireless sensor network, some previous researches focus on the low energy hardware designs in a sensor node, which include micro-sensor, ADC, signal processor, and transceiver [3]. However, an energy efficient communication protocol is a better method to greatly reduce the energy consumption [4]. In the energy-efficient communication protocols, we can classify into three classes: 1) direct [5], 2) multi-hop [6], and 3) clustering communication sensor network structure [7-12]. In the direct communication structure, sensor nodes directly transmit the sensing data to the base stations. It is easy to be implemented but suffers from large energy dissipation when the base stations are far from the sensor nodes. The multi-hop communication structure makes each sensor to report the data to the base stations in the form of hop-by-hop. Low energy consumption is achieved due to shortening the communication distance, but the nodes near the base stations have to work most of time and hence will die quickly. The clustering based communication structure offers an excellent protocol choice for wireless sensor network. In the clustered environment, the data gathered and fused by the sensors is communicated to the base stations through a hierarchy of cluster heads. Data redundancy is minimized greatly due to the aggregation process fuses strongly correlated measurements as shown in Figure 1. By periodic re-clustering, a uniform energy consumption pattern could be achieved. According to the above discussions, this paper will focus on the energy efficient clustering communication structure design.

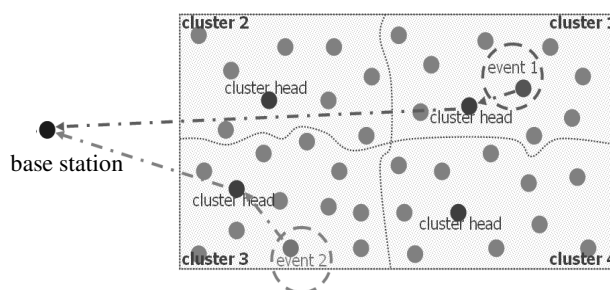


Figure 1. Clustering communication protocol structure

In the past, there are many energy efficient clustering communication methods including LEACH [7], LEACH-C [8],

(PEGASIS) [10], TEEN [12]. The drawbacks of those schemes lie on 1) the determination of threshold value will affect the sensitivity of the whole system greatly; 2) there is no mechanism to distinguish a node which does not sense a “big” change from a dead or failed mode. In this paper, we will propose an energy efficient clustering communication protocol to select the cluster heads in higher density so that the cluster members are almost in the transmission range of the cluster heads for wireless sensor network.

The remainder of this paper is organized as follows. In Section II, an energy efficient clustering communication protocol is introduced. Section III describes the proposed low energy consumption cluster-head selection algorithm in detail. The experimental results are shown and discussed in Section IV. Finally, Section V concludes this paper.

II. ENERGY EFFICIENT CLUSTERING COMMUNICATION PROTOCOL DESIGN

Assume that the base station is located far from the sensors and all nodes in the network are energy constrained. In the clustering protocol design, the whole process is divided into several rounds and each round is separated into two phases: 1) the set-up phase and 2) the steady-state phase as shown in Figure 2. The operations of those phases are described as follows:

A. Set-up Phase

The main activities in this phase are cluster setup. The set-up phase is constituted by the cluster selection algorithm and the cluster formation algorithm. During each setup phase, the base station receives information on the current energy status from all the nodes in the network. The cluster selection algorithm first computes the average energy level of all the nodes from the base station, and then chooses a set of nodes, denoted S , whose energy levels are above the average value. Finally, the cluster selection algorithm will chose cluster heads for the current round from the set S , which ensures that only nodes with sufficient energy. The proposed low energy consumption clustering head selection algorithm will be further introduced in Section III.

After selecting the cluster heads by using clustering head selection algorithm, the cluster formation algorithm is used to determine which cluster head is a non-cluster head node v belongs to. The distance between the source node and the destination node is selected as the key factor in our cluster formation algorithm. For a non-cluster head node v , a set of the distances between v and each cluster head is denoted as $dis(v)$. If the distance between the cluster head u and v is minimal in $dis(v)$, the non-cluster head node v belongs to the cluster whose cluster head is u .

B. Steady-state Phase

After partitioning all nodes into clusters, we must sense and transmit data of the nodes in a cluster to the cluster head. The cluster heads aggregate the collected data and sending the data to the base stations steady-state phase. In our design, the steady-state phase is divided into many frames. For every frame, the cluster members exchange messages with their

cluster head once in a frame and in order with the slot time. The number of exchanging messages with the cluster head is the same as the number of the frames. In this steady-state phase, all cluster members collect the information from the environment and transmit the packets to the cluster head. The cluster-head may process some data fusion to reduce redundant data avoiding energy inefficient.

To reduce energy dissipation, each non-cluster head node uses power control to set the amount of transmitting power based on the received strength of the cluster head advertisement. Furthermore, the radio of each non-cluster head node is turned off until its allocated transmission time. Since we optimize our design for the situation when all the nodes have data to send to the cluster head, using a time-division multiple-access (TDMA) schedule is an efficient choice of bandwidth and represents a low-latency and energy-efficient approach. The cluster head must be awake to receive all the data from the nodes in the cluster. Once the cluster head receives all the data, it performs data aggregation to enhance the common signal and reduce the uncorrelated noise among the signals.

Data is sent from the cluster head nodes to the base station using a fixed spreading code and persistent carrier-sense multiple access (CSMA) protocol [15]. When a cluster head has data to send, it must sense the channel whether anyone else is transmitting using the base station spreading code or not. If so, the cluster head waits to transmit the data. Otherwise, the cluster head sends the data using the base station spreading code. This operation is repeated in every round, so the high energy dissipation in communication with the base station is spread to all sensor nodes and energy is saved extremely due to data aggregation in a cluster.

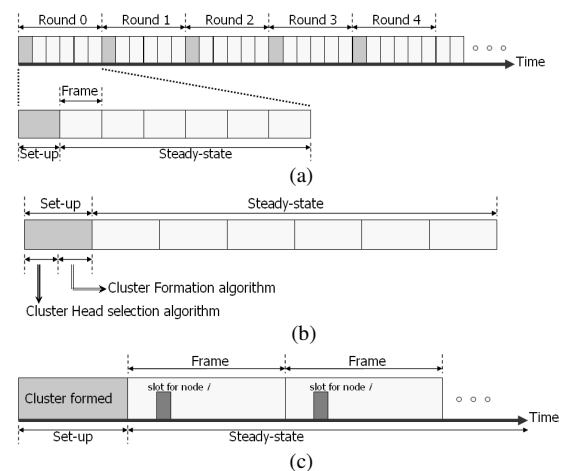


Figure 2. Time line (a) clustering communication protocol; (b) set-up phase; (c) steady-state phase

C. Clustering Protocol Flow

One of the main contributions in this paper is the design of the clustering protocol flow. In the traditional clustering protocol flow [7-12], if there are nodes that are redeployed, all nodes must perform repeat the set-up and the steady-state phases. Obviously, the traditional clustering protocols can increase latency and causes energy inefficiency in the redeployment procedure.

In the presented clustering protocol flow, if there are nodes that are redeployed, all nodes first broadcast a “hello” message with its ID in the transmission range. Then, we can compute the number of received messages (N_r) as the number of cluster-member nodes (CMN). Finally, we reset N_r to be zero and all nodes broadcast again a “hello” message with its ID in the transmission range. When a node receives a message from the other nodes, $N_r = N_r + 1$. Clearly, the N_r of the nodes in high density region increase faster than the N_r of the nodes in sparse region. When N_r of the node v is equal to its CMN, v immediately broadcast advertisement messages to the nodes in its transmission range. If v does not receive any advertisement message before N_r of v is equal to its CMN, v is set as the cluster head. Using the above clustering protocol flow, we can decide quickly the cluster head and form clusters in densely deployed regions. The set-up and the steady-state phases do not need to perform repeat so that the total energy can be saved in the redeployment procedure.

III. LOW ENERGY CONSUMPTION CLUSTER HEAD SELECTION ALGORITHM

From the discussions in the above section, it is seen that the cluster-head selection is an important consider for the proposed clustering communication protocols. In this section, a cluster head selection algorithm is presented to generate properly the cluster heads.

In LEACH [7], the cluster heads are selected randomly with a threshold value $P(t)$ defined as:

$$P_i(t) = \begin{cases} \frac{k}{N - k * \left(r \bmod \frac{N}{k} \right)} & , C_i(t) = 1 \\ 0 & , C_i(t) = 0 \end{cases} \quad (1)$$

where N is the number of nodes, k is the desired number of cluster heads, r is the current round, and $C = 1$ is the set of nodes that have not being selected as a cluster head in the last N/k rounds. A cluster head is elected when a random number between 0 and 1 chosen by a sensor node is smaller than $P(t)$. Randomly selecting cluster heads will cause the problem of an improper number of clusters in every round and which will lead to extra energy consumption. First, if a large number of nodes are selected as cluster heads in a round, the energy consumed between cluster heads and the base stations increases. Second, a small number of cluster heads in a round will increase the energy consumed between nodes and cluster heads. Third, in (1), the case of no cluster heads in a round may occur which will lead to the loss of important data. Fourth, if nodes have different amounts of energy or the hot-area situation is encountered, the nodes with more energy should be cluster heads more than the nodes with less energy to ensure that all nodes die at approximately the same time.

To improve the above drawbacks, we present a new cluster-head selection algorithm to generate properly the number of cluster heads. The proposed cluster-head selection algorithm uses double selection method to select the cluster

heads in each round. In the first selection, based on LEACH, some nodes are selected as the candidates of cluster heads with a given parameter k . In our algorithm, each node has to send its location and energy information to base stations in setup phase so that base stations first reject the nodes that have energy less than the average energy of the wireless sensor network. Then, according to the location information, base stations find the optimal clusters, k_{opt} , by adapting the simulated annealing algorithm. The expect number of cluster heads, k , is set larger than the optimal number of the cluster heads, k_{opt} . It means nodes have more probability to become cluster heads. From the experimental results, in order to achieve the minimum energy consumption, k is set as $2 * k_{opt}$. Afterwards, these candidate nodes send their ID and energy information to base stations to prepare for the second selection. At the second step, if the number of IDs received by base stations is larger than k_{opt} , the base stations selects k_{opt} nodes which have more residual energy among these candidates. If the received IDs are equal or less than k_{opt} , all candidates are selected as cluster heads. Through the second selection, the cluster heads are confirmed.

IV. EXPERIMENTAL RESULTS AND ANALYSIS

We have implemented the proposed clustering communication protocol on AMD athlon64 CPU of 2.0GHz with 768 MB memory. In the works, the parameters are set as follows:

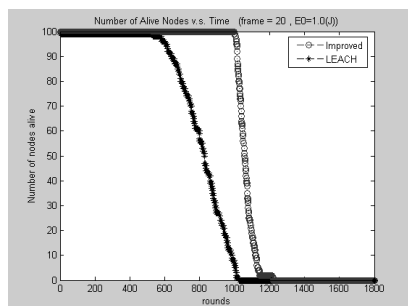
number of nodes $n = 100$
number of cluster k
network size $M * M = 100m * 100m$
deploy Region $0 < node_x < 100, 0 < node_y < 100$
base station location $BS_x = 50, BS_y = 50$
length of data message $l = 200$ bit
number of message packet = 10~20
radio electronics energy $E_{elec} = 50$ nJ/bit
radio amplifier energy $\epsilon_{amp} = 0.0013$ pJ/bit/m⁴
data aggregation energy $EDA = 5$ nJ/bit/signal
initial energy of a node is 1.0 J

Figure 3 shows that comparison of the improved clustering protocol and the LEACH protocol in system life time for various frames. We can find that the improved clustering protocol does not need to re-form the clusters and the cluster member nodes are in the transmission range of the cluster head node. Hence, it can save energy.

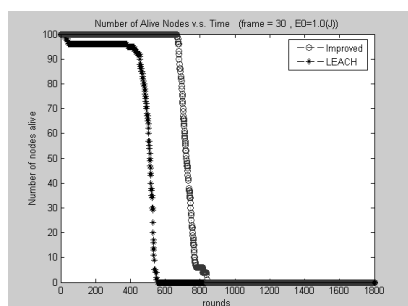
The energy dissipation of the improved clustering protocol and the LEACH protocol is shown in Figure 4. The LEACH protocol needs to process cluster formation such that it consumes some energy in each round. Moreover, the randomly distributed cluster head nodes makes the unfix cluster member nodes. Hence, the energy dissipation is unstable. It can be seen that all cluster member nodes are controlled in the transmission range of the cluster head nodes in the improved clustering protocol. If the number of the frame increases, the energy of transmitting data is fixed. Obviously, it can avoid the long transmitting distance to save energy.

Table 1 summarizes the results for three different initial energy levels in a network of diameter 100 m. In these tables,

FND and LND stand for the times at which the first and the last node die. HND stands for the time at which half of the nodes die. The results show that the proposed protocol can improve system lifetime compared with some existing approaches.



(a)



(b)

Figure 3. Number of alive nodes (a) frames = 20; (b) frames = 30

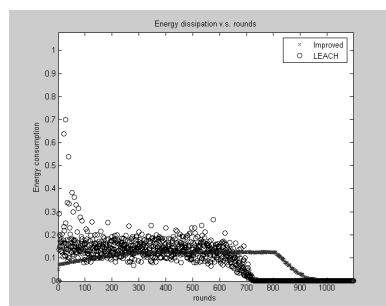


Figure 4. Energy dissipation of LEACH and improved selection method

V. CONCLUSIONS

In this paper, an energy efficient clustering communication protocol is proposed for wireless sensor network. The benefit of clustering protocol is the energy consumption can be distributed evenly to all nodes. Using the cluster-head selection algorithm in the proposed clustering communication protocol to select cluster heads in each round, the energy dissipation is reduced and the lifetime of wireless sensor network is extended. The experimental results demonstrate that the proposed protocol is efficient.

ACKNOWLEDGMENT

The authors are grateful to the support of National Science Council, Taiwan. The contributions through useful discussions with Prof. Yen-Tai Lai at Casdc Laboratory of National Cheng Kung University, Tainan are also acknowledged.

Table 1. Timings of Node Deaths

Energy (J)	Protocol	FND	HND	LND
0.25	DIRECT	596	1147	4836
	LEACH	297	1247	2223
	PEGASIS	439	2259	2667
	PROPOSED	2278	2462	4956
0.50	DIRECT	1192	2293	9672
	LEACH	1036	2927	4362
	PEGASIS	774	4496	5175
	PROPOSED	4555	4879	9872
1.00	DIRECT	2383	4586	19343
	LEACH	2627	5603	7747
	PEGASIS	1428	9036	10443
	PROPOSED	8870	9545	19343

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