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A cluster-based topology control algorithm for wireless sensor networks

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Abstract

Wireless sensor networks and limitation of their energy resources are big challenges for the researchers at present. Topology control is one of the mechanisms for improving energy consume of these networks. The protocol which is presented is a Neighbor-based Clustering Topology Control Algorithm which is called NCTC. NCTC uses centralized and distributed algorithms. For this reason, it is regarded as a hybrid approach. In addition, it doesn't need local information for topology construction. NCTC consumes low energy and also it has low complexity message. Simulation results show that in NCTC algorithm network lifetime is prolonged significantly.

Keywords: *Wireless Sensor Network, Topology Control, Clustering, Residual Energy.*

1. Introduction

Wireless sensor networks include some nodes of sensor which are deployed for obtaining information in an environment in random or predetermined manner. These nodes are responsible for sending information to a remote observer (e.g., a base station)[1]. Each one of the tasks which nodes of sensor perform leads to consumption of their battery and because they are limited in energy, the techniques which are applied for optimizing their energy consumption are very important. One of the techniques effective on optimization of energy consumption in sensor networks is topology control. Topology control is defined as limitation of transmission power of sensor nodes. Topology control tries to select the smallest power which can keep the network connected and creates a reduced topology[2]. Topology control techniques are classified into two general groups: Power control techniques and hierarchical techniques[3]. In the first group, a appropriate power is determined for nodes using the distributed or centralized algorithms. In the second group, a selected set of nodes is chosen and constituents a reduced graph. Clustering methods are included in this group. In clustering methods, a selected set of nodes is chosen as Cluster Head(CH) which assumes main task of information exchange. The nodes which are selected as CH receive information from their cluster members and send it to a base station. Cluster members can send information to CH nodes only in their time slot and be sleep at other times and preserve their energy. Clustering techniques are implemented in a distributed style, consume energy of network fairly and efficiently and have the lowest overhead[4]. One of the examples of known clustering algorithms is Leach[5] which is a random, single hop and distributed algorithm. To apply clustering in topology control, Cluster-based Topology Control (CLTC)[6] framework has been introduced. Mst-Based Clustering Topology Control (MCTC)[7] algorithm is one of the examples of this framework. MCTC is a hybrid protocol which uses centralized and distributed algorithms. It uses MEMD algorithm (maximum energy, minimum distance) for clustering. To adjust power of nodes, MST algorithm is applied for intra-cluster topology control and inter-cluster topology control. Cluster heads in MCTC form a spanning tree and a two-leveled, scalable and energy efficient topology is created. In this paper, we intend to use a neighbor-based distributed algorithm called Kneigh[8] for connectivity between CH nodes. Kneigh is a simple algorithm which is based on maintenance of k number of neighbor. This algorithm doesn't need local information and nodes estimate their distance from the neighbor nodes using distance estimation techniques such as Received Signal Strength Indication(RSSI)[9].

2. Neighbor-based Clustering Topology Control

The method which is proposed based on a clustering method and is adapted from Kneigh's neighbor-based algorithm. Therefore, name of this algorithm is neighbor-based clustering topology control(NCTC). NCTC protocol doesn't need local information for clustering and each one of the nodes can obtain distance information its neighbor nodes using RSSI distance estimation technique.

NCTC is regarded as a hybrid protocol because it applies centralized and distributed algorithms to regulate appropriate power of nodes. In centralized topology control algorithms, base station determines appropriate power of nodes and each one of the nodes regulates its power in distributed manner. Final goal of NCTC is to determine appropriate power level for nodes. For this purpose, it uses smaller power for intra-cluster communication and larger power for inter-cluster communication. It also uses a topology maintenance mechanism for increasing network lifetime.

3. NCTC algorithm

NCTC algorithm has four phases as follows:

Phase 1(cluster formation): In this phase, clusters are formed and CH nodes and cluster members are specified. Each node belongs to a cluster and is connected to a CH node with one hop but communication of CH nodes to base station includes multiple hop. The presented clustering is inspired by MEMD clustering with this difference that nodes in MEMD have local information but nodes in this clustering become aware of the location through RSSI technique. Therefore, first, nodes in this clustering which is presented broadcast their information using their maximum power. The information which is broadcasted includes ID number, RSSI and residual energy(R_E). Nodes investigate this information after receiving it to determine CH nodes. Each node has weighted value in which a node which has higher weighted value more likely becomes CH node. The node with higher residual energy has higher weighted value. The nodes which have equal residual energy but larger ID will take more weighted value and are prioritized for becoming CH. This relation is defined in Eq. (1):

$$W(i) > W(j) \leftrightarrow R_E(i) > R_E(j) \text{ or } R_E(i) = R_E(j) \ \&\& \ ID(i) > ID(j) \quad (1)$$

After selecting CH nodes, each cluster member select the nearest CH and join that cluster. The nearest CH is determined based on RSSI parameter. The CH node which has larger RSSI is nearer to node and its CH becomes node.

Phase 2(intra-cluster topology control): In this phase, CH nodes determine power of their cluster members. This work is performed using the information which they have obtained in cluster formation phase. Each one of the CHs is notified of place of its cluster member using RSSI technique and determines their sending power considering this distance. Each cluster member sends information to CH using the determined power and in its time slot. Local synchronization within a cluster is assumed to apply the TDMA scheme.

Phase 3(inter-cluster topology control): In this phase, power of CH nodes is determined. CH nodes determine power for reach to their neighbor CHs using Kneigh algorithm. In Kneigh, nodes select k nearer neighbor among their ordered neighborhood list and exchange this list (KNL) with their neighbors. Each of the clusters determines its asymmetric neighbors by receiving this list from its neighbors and deletes them from its neighborhood list. In KNL list of CH nodes, there are their symmetric neighbors and there are no asymmetric links. Fig. 1, Fig .2 and Fig. 3 show an example of topology created with Kneigh, NCTC and MCTC.

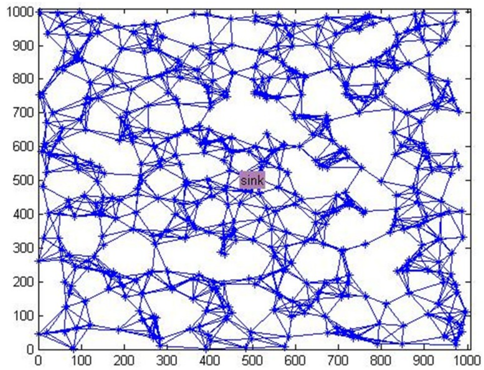

Fig 1. Kneigh Topology(k=9)

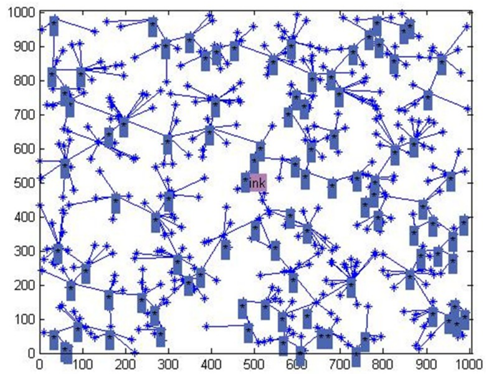

Fig. 2 NCTC topology

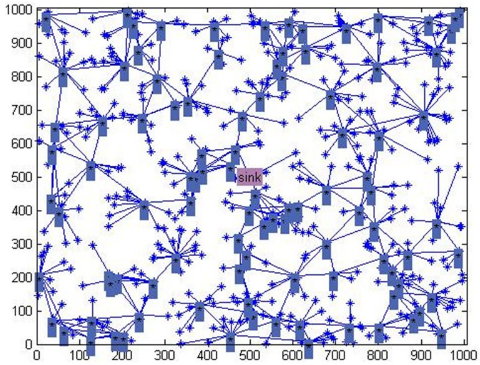

Fig. 3 MCTC topology

Phase 4(topology maintenance): In NCTC, it is assumed that all nodes of the network have equal energy but speed of energy consumption is different between CH nodes and cluster members. To overcome this problem and keep balance of energy consumption, residual energy threshold of T_E has been used in NCTC. T_E means the minimum residual energy in CH nodes. Each CH node which find its residual energy equal to T_E informs sink by sending Reform message and clustering algorithm will be locally performed for that area. If sink receives this message from more than half of CHs, total topology of the network will be constructed again for that area, afterward a new round will begin. A round basis of topology construction in NCTC can be like Fig. 4.

Cluster formation	Intra-cluster topology control	Inter-cluster topology control

Fig. 4 Working round interval

4. Simulation and Results

In this section, we simulate the proposed NCTC algorithm with the determined parameter and with MATLAB simulator. MATLAB is a very powerful simulator; it is easily used and seems enough for simulation of all parameters of topology control. In these results, we compared the performance of NCTC with Kneigh and MCTC algorithms. In simulation scenario, we randomly distribute 1000 nodes in an environment with dimensions of 1000m ×1000m. The maximum transmission range of all sensor nodes is equal to 100m. The sink node is in center of the area (500×500). Table 1 presents a summary of the simulation parameters used in the experiments.

Also We assume that initial power of nodes is 1J. We considered k to be 9 and ratio of the number of CH nodes to total nodes is 20%. Energy consumption model[10] in the network is defined in Eq. (2):

$$E_i^{tx} = \left(e_i^t + \mathcal{E}_{amp} d^2\right) m, \quad E_i^{rx} = e_i^r m \qquad (2)$$

Table 1: Simulation parameters

K	K=9
Deployment area	1000m×1000m
Number of nodes	100,250,500,750,1000
Number of Cluster-Heads	20% Number of nodes
Transmission Range -Distances based on RSSI	100m
Emax	1Joule
Energy Consumption	Eelec = 50nJ/bit; $\mathcal{E}_{amp}$= 10pJ/bit/m2

We studied simulation scenario in two experiments. In the first experiment, we studied residual energy of the network in each round between NCTC, Kneigh and MCTC algorithms. Residual energy is defined as the remaining energy in the active set of nodes at the end of an experiment. Residual energy can be used as a criterion for network lifetime. In the second experiment, we studied energy overhead for different numbers of network nodes. Energy overhead is defined as the fraction of the network energy expended during construction of the topology. In case of topology maintenance, this metric calculates the overhead during the construction of the topology under dynamic conditions. Fig. 5 shows rate of the residual energy for all the three algorithms. In this simulation scenario, we obtained rate of the residual energy which remains averagely in NCTC topology nodes at the end of each round and compared it with the conditions similar to Kneigh and MCTC. Results of these experiments are shown in Fig. 5, Fig. 6.

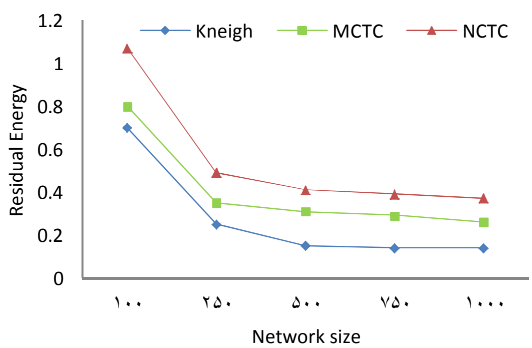

Fig. 5 Residual Energy

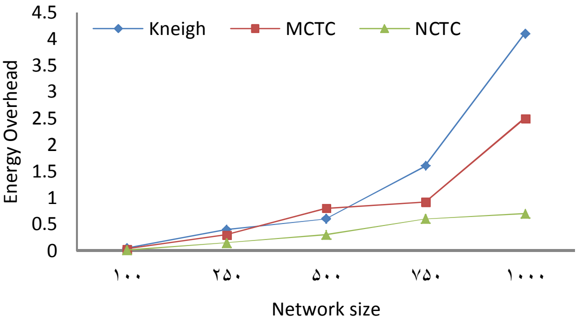

Fig . 6 Energy Overhead

Fig. 5 shows The residual energy of nodes in each executed round for all the three algorithms. The relusts reveal that NCTC provides better residual energy compared with Kneigh and MCTC. Fig. 6 shows energy overhead for Kneigh, MCTC and NCTC algorithms under varying network sizes. Hypotheses of this simulation scenario are similar to the previous experiment and have been considered equal. Considering Fig. 6, results show that energy overhead in three networks is almost equal due to small size of the network (100 nodes) but energy overhead in NCTC is much lower than that in MCTC and Kneigh with increase of the number of network nodes.

5. Conclusions

MCTC uses MST for CH nodes connectivity and MST which has higher message complexity and is about n^2 could have direct effect on residual energy of nodes. The reason for high message overhead of MCTC is need of nodes for having Local information and they exchange n^2 message with each other to obtain it. As a result, nodes consume higher energy and this leads to short network lifetime. On the contrary, NCTC uses Kneigh algorithm for CH nodes connectivity and Kneigh has much lower message complexity (2n) than MST(n^2) and this contributes to longer life of NCTC. However, MCTC has strong connected topology because it obtains this topology from formation of minimum spanning tree in CH nodes but NCTC cannot guarantee connectivity in worst-case scenario and is always dependent on proper determination of parameter k to obtain a connected network. Consequently, for the very large scale networks, it seems more reasonable and proper to use NCTC considering its lower message complexity and longer lifetime especially when the main goal of the network setup is its long lifetime but it is more proper to use MCTC to create smaller networks for which network connectivity is regarded as the main goal.

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