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An adaptive cluster based routing scheme for mobile wireless sensor networks

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Abstract

Clustering schemes improve energy efficiency of wireless sensor networks. The inclusion of mobility as a new criterion for the cluster creation and maintenance adds new challenges for these clustering schemes. Cluster formation and cluster head selection is done on a stochastic basis for most of the algorithms. In this paper we introduce a cluster formation and routing algorithm based on a mobility factor. The proposed algorithm is compared with LEACH-M protocol based on metrics viz. number of cluster head transitions, average residual energy, number of alive nodes and number of messages lost.

1. Introduction

A mobile wireless network consists of a collection of wireless connected mobile nodes equipped with a variety of sensors. In such a system, each mobile node has sensing, computation, communication, and locomotion capabilities. Sensor nodes are mobile either by external force or their own mobility capability. The mobile nodes spread out across the sensor field and share sensory information through an ad hoc wireless network. Mobile sensor networks have a myriad of civilian and military applications ranging from foraging, surveillance, search and rescue to mobile target tracking. A mobile sensor network can be rapidly deployed in hostile environments, inaccessible terrains or disaster relief operations for sensing and reconnaissance tasks, where a task is generally achieved by coordination of nodes' activities.

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Node mobility brings with its own challenges, but also alleviates some of the traditional problems associated with static sensor networks. Mobility of nodes can potentially be used to improve network performance [1]. For example node mobility can be used to deploy sensors at optimal locations for monitoring, increase throughput while keeping small delay. In mobility-centric environments, wireless sensor networks are designed to accommodate energy efficiency, dynamic self-organization and mobility. Existing routing protocols for static sensor networks may not be efficient in mobility centric environments. Also, clustering based protocols [2] are found energy efficient in the case of static sensor networks. Inclusion of mobility as a new criterion for the cluster creation and maintenance adds new challenges for the clustering techniques. Research for the maintenance of the cluster organization under this new scenario is seldom seen. Due to the mobility of nodes, the topology of connections between communication nodes may be quite dynamic. Hence, mobile wireless sensor networks require a highly adaptive routing scheme to deal with cluster head selection and frequent topology changes.

In this paper we propose a clustering and data routing scheme based on relative direction of node mobility. Performance of the proposed scheme is compared with LEACH-M protocol.

2. Cluster based protocols for Mobile Sensor Networks

2.1 Zone-Based Clustering

In this work Chen and Liestman [3] introduces cluster formation and maintenance in the presence of network topology changes. The protocol consists of two stages cluster formation and maintenance. The cluster formation in the beginning stage is performed in three phases. Phase 1 divides the network into zones, creating a set of trees. Phase 2 finds dominating sets within each zone. The border vertices are fixed in the phase 3. Maintenance stage consists of four operations edge-down, edge-up, vertex-down and vertex-up. This algorithm assumes unique node deployment at the beginning of the sensor network setup; this limits the applicability of the scheme.

2.2 Cluster-Based Graph Network

In this protocol [4] the network is treated as a bidirectional graph. The nodes in the sensor network are grouped into disjoint clusters, where the backbone is a tree consisting of the cluster heads and gateway nodes. The cluster head has an edge to each other cluster member and no edges exist between two cluster members in the cluster. Two operations are defined to treat the node movement viz. node-move-in and node-move-out. When a node joins a cluster node-move-in operation is performed and when a node wishes to leave the network, it must perform the node-move-out operation.

2.3 LEACH-Mobile

LEACH-Mobile [5] uses the same probability based clustering procedure as in LEACH. But LEACH does not consider the mobility of nodes during the data transfer phase, which may lead to serious data loss in mobile environments. LEACH-M overcomes this problem by confirming whether a mobile sensor node is able to communicate with its cluster head within a time slot allotted in TDMA schedule. For this purpose, at the beginning of each TDMA slot the cluster head nodes transmit a message requesting data transmission from the member node. If the member node is not reachable to its cluster head, it misses the request message from the cluster head and waits for the request message in the next TDMA frame. The member node that does not receive the request message from its cluster head for two successive TDMA frames considers itself as uncovered and searches for a new cluster head. Similarly the cluster head nodes delete those members from which no data is received for two successive TDMA frames.

The decision of a node to join a new cluster head depends on the received signal strength of the cluster head advertisement message. After mobile node has decided its membership of a cluster to which it belongs, it informs the cluster head that it will be a member of the cluster. The head of the cluster in which the mobile node newly joins updates the cluster membership list and TDMA schedule. The head then broadcasts the updated TDMA schedule to its cluster members.

In LEACH-Mobile protocol, transmitted message overhead is increased for membership declaration and dynamic organization of the cluster with mobile nodes in every TDMA time slot than original LEACH protocol. It however, increases the rate of successful data transmission from mobile nodes to the sink.

2.4 LEACH-Mobile-Enhanced

The basic idea of LEACH-Mobile-Enhanced (LEACH-ME) [6] protocol is that nodes that are less mobile relative to its neighbors should be selected as cluster heads. Initial creation of clusters in LEACH-ME is based on certain random selection. New cluster head selection need not be performed at every TDMA frame, but can be introduced after a certain number of TDMA frames. This periodicity is decided based on the active mobility of nodes. Each member node keeps track of the number of cluster head transitions it has made during the Steady-state phase. Member nodes transmit this transition count along with the data to the cluster head during its TDMA slot. Cluster head calculates the average transition count of its members for the last few cycles and if that value goes beyond a threshold it introduces ACTIVE slot during which clusters are reorganized.

During the ACTIVE slot, nodes broadcast their IDs. Each node estimates the distance to all its neighbors and calculate the mobility factor using the following equation

$$M_i(t) = \frac{1}{N-1} \sum_{j=0}^{N-1} d_{ij}(t)$$

Where Mi(t) is the mobility factor based on the “remoteness” of node i from its neighbors, N is the number of neighbors of node i, dij(t) is the distance of node i from its neighbor j. Node with least mobility factor is selected as the cluster head, provided the energy level of that node is not below a certain threshold. The Steady-state phase in LEACH-ME is same as in LEACH-Mobile.

3. Adaptive Cluster formation scheme

In this section we propose a protocol to improve the cluster formation in mobile sensor networks by considering the relative direction of node mobility. The protocol comprises of two phases: Set-up phase and Steady-state phase. Steady-state phase is divided into fixed number of TDMA frames. The following subsections discuss the two phases in detail.

Set up phase

Each node broadcasts its ID twice at time t1 and t2 with a small time gap. The distance of node from its neighbor can be estimated from the received signal strength. Distances dij(t1) and dij(t2) of node i from its neighbor j at time t1 and t2 can be calculated from the two received signals from j.

If dij(t1) - dij(t2) is negative, it means that nodes i and j are moving away from each other. Otherwise the nodes are either stationary relative to each other or moving towards each other. Each node determines its relative direction of movement to each of its neighbors and calculates the mobility factor based on the relative direction of movement using the following equation

$$Mi(t) = 1 - \frac{No: of\ nodes\ moving\ away\ from\ i}{N}$$

where Mi(t) is the mobility factor of node i and N is the number of neighbors of node i. If Mi(t)>0.5, the number of nodes moving towards or stationary relative to node i at time t is more than the number of nodes moving away from it. The basic idea is to select the nodes that have higher values of Mi(t) as cluster heads.

Nodes broadcast their mobility factor and if a node finds that it has the highest value among its neighbors, it declares itself as the cluster head by transmitting the CH_ADV. Non cluster head nodes collect the CH_ADV from neighbor cluster heads and determines the magnitude of its relative velocity to each of its neighbor cluster head. The magnitude of relative velocity of node i to its cluster CH is given by

$$\left| \frac{d_{iCH}(t_1) - d_{iCH}(t_2)}{t_2 - t_1} \right|$$

Non cluster head nodes will select the neighbor cluster head with which its magnitude of relative velocity is a minimum and transmits JOIN_REQ to that cluster head. After the clusters are organized, cluster head nodes prepare and transmit the TDMA schedule to its members

Steady-state phase

Steady-state operation is divided into fixed number of TDMA frames. Nodes wake up and transmit data at most once per frame during their allotted TDMA slot. The member declaration mechanism in LEACH-Mobile is used where the cluster head nodes send REQ_DATA message to its member node at the beginning of each TDMA slot.

If a cluster head does not receive data from a member node for two consecutive TDMA frames, it considers the node as not reachable and removes that node from its member list. Similarly if a node does not receive REQ_DATA message from its cluster head, it considers itself as uncovered and looks for a new cluster head. Cluster head nodes updates their TDMA schedule at the end of each TDMA frame and broadcasts the new schedule to its members.

4. Experimental Results

To evaluate the performance of LEACH-M and new protocol the following network model is used. The network consists of 100 nodes deployed randomly in a 500 x 500 m^2 area. The base station is static during the simulation and located outside the sensor field. All nodes are location unaware and homogeneous with same battery power and architecture. Initial energy of each node is 10J and data size is 250 bytes. Performance of the protocols is evaluated using two different speed ranges of 0-5 m/s and 0-10 m/s.

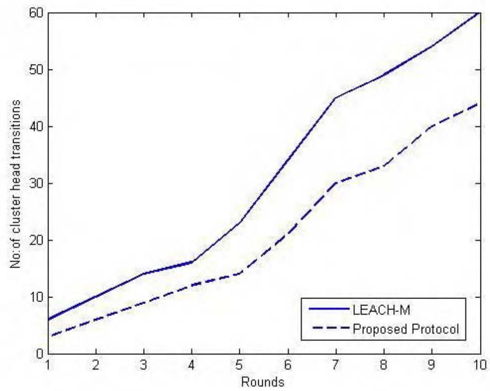

Fig. 1. No: of cluster head transitions with maximum velocity 5 m/s

LEACH-M and the proposed protocol are evaluated based on four metrics: number of cluster head transitions, average residual energy, number of alive nodes and number of messages lost. Figure 1 shows the number of cluster head transitions the nodes in the network undergo during the data transfer phase for LEACH-M and proposed protocol. The maximum speed of the nodes is assumed as 5m/s. It can be seen that the number of cluster head transitions is reduced in the proposed protocol than in LEACH-M. This is due to the random cluster head selection mechanism in LEACH, which may lead to the selection of a high mobile node as a cluster head. Also the cluster head selected may be moving in the opposite direction relative to its members. The proposed protocol reduces the number of head transitions by selecting the nodes whose ratio of number of neighbors moving away from it to the total number of neighbors is less.

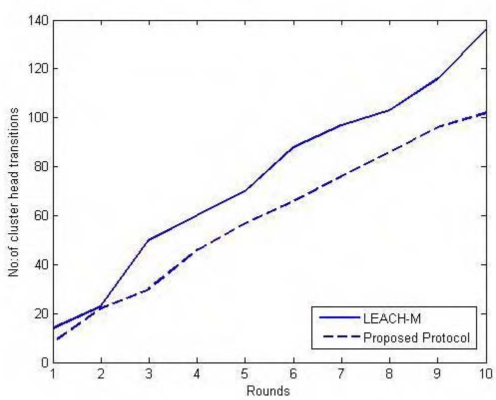

Fig. 2 No: of cluster head transitions with maximum velocity 10 m/s

Fig. 2. plots the number of cluster head head transitions for the two protocols with maximum speed of 10 m/s. Comparing Fig. 1. and Fig. 2. , it is obvious that the number of head transitions significantly increases as the speed of the nodes increases. Nodes will become uncovered from their cluster head in a faster rate due to their high mobility.

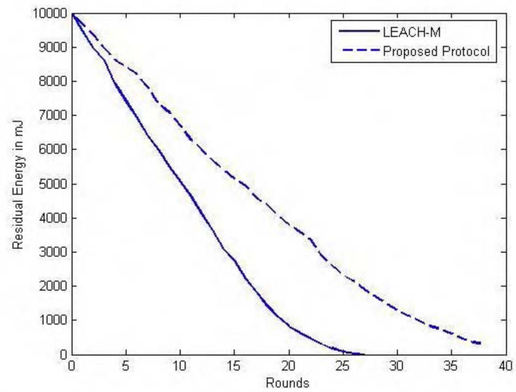

Fig. 3. Average residual energy of nodes with mobility

Fig. 3. compares the average residual energy of nodes for two protocols with maximum speed of 10m/s. It can be seen that energy consumption in the proposed protocol is less than in LEACH-M. Random cluster head selection in LEACH-M leads to uneven distribution of cluster heads and hence more energy consumption. Neighbor nodes may be elected as cluster heads and also the number of uncovered nodes in the network may be high, which in turn increases the energy consumption.

The number of alive nodes in the network over time is plotted in Fig. 4. The proposed protocol shows a significant improvement on the network lifetime over LEACH-M

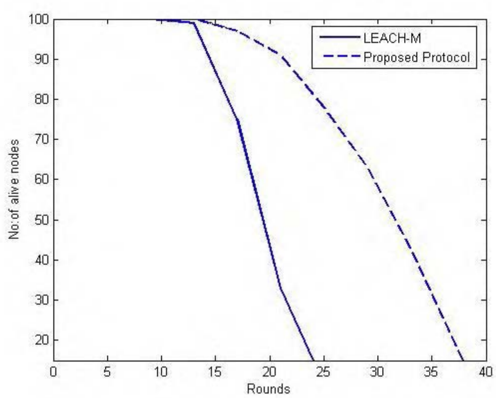

Fig. 4. Network Lifetime Comparison with increased mobility

The number of messages lost during the data transfer phase for two different maximum speeds (5 m/s and 10 m/s) is also analyzed and it is found that number of messages lost during data transfer increases with increase in mobility of the nodes.

5. Conclusions

To address the typical topological changes in mobile wireless sensor network, some of the existing clustering protocols include new operations that allow cluster formation and maintenance. A scheme based on relative direction of node mobility is proposed here. The performance of the algorithm is compared with an existing protocol. Results show that our scheme outperforms the LEACH-M protocol in terms of average number of cluster head transitions and network life time.

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