International Journal of Information Processing, 4(3), 9-16, 2010
ISSN : 0973-8215
I. K. International Publishing House Pvt. Ltd., New Delhi, India.

Energy Aware Cluster-based Multihop Routing Protocol for Sensor Networks

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Clustering combined with multihop communication is a promising solution to cope with the energy requirements of large scale Wireless Sensor Networks. In this work, a new cluster based routing protocol referred to as Energy Aware Cluster-based Multihop (EACM) Routing Protocol is introduced, with multihop communication between cluster heads for transmitting messages to the base station and direct communication within clusters. We propose EACM with both static and dynamic clustering. The network is partitioned into near optimal load balanced clusters by using a voting technique, which ensures that the suitability of a node to become a cluster head is determined by all its neighbors. Results show that the new protocol performs better than LEACH on network lifetime and energy dissipation.

Keywords : Energy Efficient Routing Protocols, Multihop, Voting, Wireless Sensor Network.

1. INTRODUCTION

Wireless Sensor Networks [1–3]consists of a large number of small scale low cost devices which integrate simple processing, storage, sensing and communication capabilities. The sensor nodes once deployed over a geographical area organize themselves to analyze some complex phenomena, which opens door to a plethora of new applications. Despite the wide range of applications, data gathering in sensor networks is very challenging due to the inherent characteristics of sensor networks such as large number of nodes, data flow from multiple sources to a sink, data redundancy as well as energy, storage and processing constraints.

Routing protocols [4] for sensor networks might differ depending on the application and network architecture. Sensor nodes usually operate under severe energy constraints due to their non rechargeable battery feature. So sensor nodes should try to minimize energy consumption in order to maximize the network lifetime. The sources of energy consumption for a sensor node are communication, data computation and sensing. Of these three domains, a senor node expends maximum energy on data communication. Communication energy can be minimized by reducing the number of messages transmitted, by using different power modes such as sleep and active modes for the transceiver and by using different transmission ranges. Many routing techniques have been proposed for the improvement of energy efficiency in sensor networks. Among these, cluster based technique [5] is gaining significant attention due to its inherent advantages such as minimizing the number of high energy transmissions to the sink and localization of most traffic within clusters thereby reducing contention and collisions in the networks. Clustering is especially suitable for large sensor networks.

Clustering algorithms can be centralized or distributed. In centralized clustering sensors need global knowledge of the network. But spreading and collecting all sensors information across a large network is often costly and impractical. Therefore, distributed clustering protocols are more desirable for large networks. A good clustering scheme should partition the network into clusters such that each node has at least one cluster head as its neighbor, the cluster heads form a maximal independent set and the clusters are load balanced. In addition, multihop communication is necessary for monitoring a large region since the communication range of sensor nodes are generally limited in order to conserve energy. So a combination of clustering and multihop communication is desirable for data collection on a large scale sensor network.

This paper presents a multihop cluster based routing protocol which uses voting technique for cluster head selection. We adopt the same criteria in ELCH [6] based on residual energy and distance for computing votes to neighbor nodes. EACM's clustering algorithm tries to achieve load balancing by limiting the maximum cluster size and by directing the nodes to select the cluster head that has the minimum node degree.

The rest of the paper is organized as follows. Section 2 lists some of the distributed clustering algorithms proposed before. Section 3 describes the static and dynamic clustering schemes of the proposed protocol in detail. In Section 4 the performance of our protocol is evaluated and its effectiveness with LEACH [7] is compared. Finally we give the concluding remarks and future enhancements in Section 5.

2. RELATED WORK

Many cluster based data gathering protocols have been proposed for sensor networks in literature. LEACH is the base of most cluster based protocols and it uses a stochastic model for cluster head selection. In HCR [8], each cluster is managed by a set of associates and the clusters are retained for a longer period of time. Within each cluster the role of cluster head is rotated among the associate members using a round robin technique. HEED [9] uses a hybrid approach based on residual energy and communication cost to select cluster heads. In LEACH, HEED and HCR, each node probabilistically decides on its role and hence cannot guarantee optimal distribution of cluster heads. WCA [10] and DCA [11] are weight based clustering algorithms where node with highest weight is elected as cluster head. Weight is computed based on node's local properties such as node degree, residual energy etc. But defining a good weighing function is difficult.

When electing cluster heads, most distributed clustering techniques are based on local properties. Due to the lack of information from neighbors, cluster formations generated by many distributed clustering algorithms are often unsatisfactory. Clustering can be improved by incorporating information from neighbor nodes. ELCH and VCA [12] achieve this by using a voting technique to elect the cluster heads, where the decision of a node to become a cluster head is determined by its neighbors. VCA uses a fitness function based on energy and node degree for load balancing in clusters. But vote calculation in VCA depends only on the residual energy of nodes and does not take into account the distances between the nodes. The voting technique in ELCH uses both the residual energy and distance. But optimal cluster formation in ELCH takes place only in the first round and clusters lack load balancing.

3. PROPOSED PROTOCOL

Vote calculation in EACM is based on residual energy and distance between nodes. The protocol achieves load balancing by rejecting join request from nodes if the size of a cluster goes beyond a maximum cluster size. Also nodes select the cluster head that has the minimum number of neighbors. We propose EACM with both static and dynamic clustering schemes. The operation of EACM is broken up into fixed duration rounds, where each round consists of two phases- Set-up phase and Steady-state phase. During the Set-up phase, nodes are organized into clusters and during the Steady-state phase actual data transfer takes place. To minimize overhead, Steady-state phase is long compared to Set-up phase. In static-EACM, cluster formation takes place only in the first round and at the end of each TDMA frame the role of cluster head is rotated among the cluster members for even energy dissipation. In dynamic-EACM nodes are organized into clusters at the beginning of each round. The following sub sections discuss the two phases in detail.

3.1. Set-up phase

During the Set-up phase sensor nodes are organized into clusters. For cluster head selection a voting technique is used which ensures that the adaptability of a node to become a cluster head is reflected from all its neighbors. The cluster size is limited by a set maximum ($MAX\_CLUSTER\_SIZE$). For cluster formation, each node broadcasts residual energy level and computes the distance to its neighbors based on the strength of the received signal. Nodes compute and cast vote to neighbors based on residual energy and distance. Jalil Jabari Lotf et al. [6] introduced equation (1) to calculate the vote a node i casts to its neighbor j based on energy and distance. Nodes collect vote from neighbors and broadcast the total vote received. If a node finds that it has the highest vote among its neighbors, it declares itself as the cluster head by sending the cluster head advertisement (CH_ADV). Non cluster head nodes send join request ($JOIN\_REQ$) to the neighbor cluster head that has the minimum node degree.

$$V(i,j) = \begin{cases} \dfrac{\left[\dfrac{e_j}{dij}\right]}{\displaystyle\sum_{d_{ik} \leq R} \dfrac{e_k}{d_{ik}}} & d_{ij} \leq R \\ \\ 0 & d_{ij} > R \end{cases} \tag{1}$$

Selecting the cluster head with minimum node degree helps to balance the size of the clusters formed. If the number of JOIN_REQ a cluster head receives is more than MAX_CLUSTER_SIZE, it sends REJ_JOIN message which contains the node IDs of rejected nodes. This rejection is based on the following criteria:

1. The nodes that have heard the maximum number of CH_ADV will be rejected.

2. In case of a tie, the nodes that are far away from the cluster head will be rejected.

Cluster heads whose cluster size equals the MAX_CLUSTER_SIZE and member nodes withdraw from the clustering process by sending the WITHDRAW message and go to the sleep mode. The cluster heads whose cluster size is less than the maximum cluster size remains active to receive more JOIN_REQ in the next round. The active non cluster head nodes repeat the clustering procedure until all nodes are covered. After cluster formation, all nodes switch to the active mode. Cluster head nodes prepare and transmit TDMA schedule to cluster members.

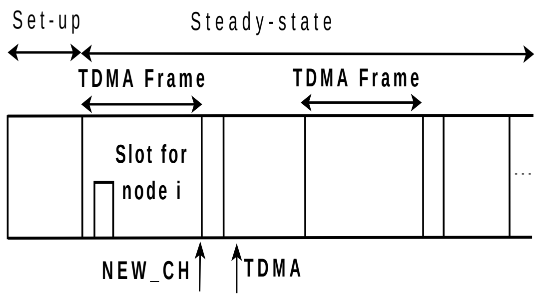


Figure 1. Network operation of static-EACM

3.2. Steady-state phase of static-EACM

In static-EACM, clusters are formed during the Set-up phase of the first round. These clusters remain same throughout the network lifetime but the role of cluster head rotates among the members of the cluster. Nodes send their data to the cluster head at most once per frame during their allocated TDMA slot. The duration of each slot in which a node transmits data is constant, so the time to send a frame depends on the number of nodes in the cluster. Nodes wake up only during their allocated slot and transmit data and residual energy level to the cluster head. Figure 1 shows the network operation of EACM with static clusters.

Cluster heads aggregate the data collected from their member nodes and transmit the compact data to the base station. Cluster heads communicate with other cluster heads to form multihop paths by sending beacons at inter cluster communication range. This helps to avoid redundant transmissions to the base station during multihop communication. The next hop cluster head that has the highest residual energy is selected to forward the data packet to the base station. At the end of each TDMA frame cluster head nodes select the node that has the highest energy among its members as the new cluster head for the next round by sending the NEW_CH message. The

Algorithm 1 Cluster Generation

Initialize Broadcast Neighbour_Msg (NodeID, Res_Energy)
S_{nbr} = {n |n is within my transmission range R}
S_u=$S_{uncovered}$=S_{nbr}, $S_{CH} = \emptyset$, S_{WD}=∅, IS_CH=false, cluster_size=0, IS_CLUSTER_MEMBER=false, MY_CH=∅, degree(node)= $|S_u|$
node i estimates distance d_{ij} to j ∈ S_u
Clustering
repeat
  Node i computes and casts vote v(i, j) to neighbor j S_u using equation (1) and collects the votes
  total vote(NodeID) = $\sum_{j \in S_u} v(j, NodeID)$
  Broadcast total vote and then collect total vote from neighbors
  if (total vode(NodeID) ≥ max {total vote(n) | n ∈ S_u}) **then**
    IS_CH= true, MY_CH=NodeID, send CH_ADV
  end if
  collect incoming CH_ADVs
  $S_{CH} = S_{CH} \cup$ {n | CH_*ADV* heard from n}
  if (IS_CH && $S_{CH} \neq \emptyset$) **then**
    MY_CH = {n | n S_{CH} && degree (n) is minimum}
    IS_CLUSTER_MEMBER=true, send JOIN_REQ to CH
  end if
  if (IS_CH) **then**
    collect JOIN_REQ
    cluster_size = $\sum$ JOIN_REQ
  end if
  if (IS_CH && cluster_size > MAX_CLUSTER_SIZE) **then**
    send REJ_JOIN to (*cluster_size* - MAX_CLUSTER_SIZE) nodes based on JOIN_REQ rejection criteria
  end if
  collect REJ_JOIN
  if (node ∈ REJ_JOIN) **then**
    MY_CH =∅, IS_CLUSTER_MEMBER=false
  end if
  if (IS_CH && *cluster_size* == MAX_CLUSTER_SIZE || IS_CLUSTER_MEMBER) **then**
    send WITHDRAW message, go to sleep mode
  end if
  collect WITHDRAW message $S_{WD} = S_{WD} \cap$ { n | WITHDRAW heard from n}
  S_u = { n | n S_{nbr} and n S_{CH} and n S_{WD}}
until (MY_CH ≠ ∅)

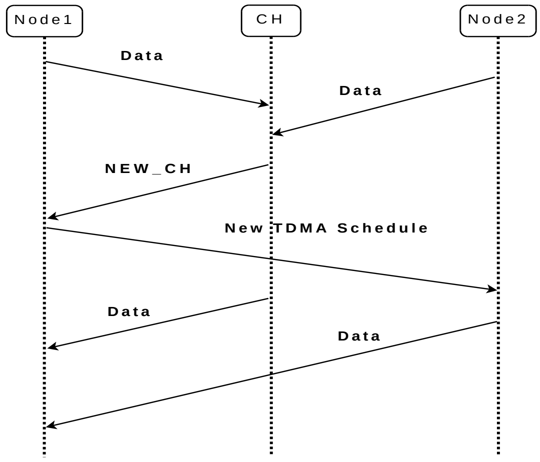


Figure 2. Network operation of static-EACM

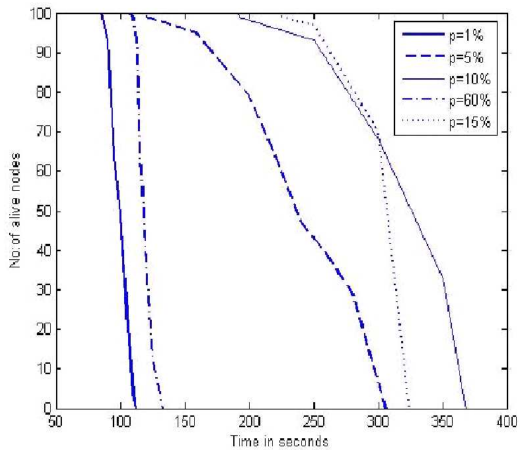


Figure 3. Clusters generated in LEACH

sequence of messages transmitted during Steady-state phase of static-EACM is shown in Figure 2.

3.3. Steady-state Phase of Dynamic-EACM

The problem with static-EACM is that the nodes that belong to small sized clusters deplete their battery power rapidly since they have to perform the energy consuming task of cluster head more frequently. In order to avoid this clustering is made dynamic where nodes organize into clusters during the Set-up phase of each round using the same clustering algorithm described in subsection

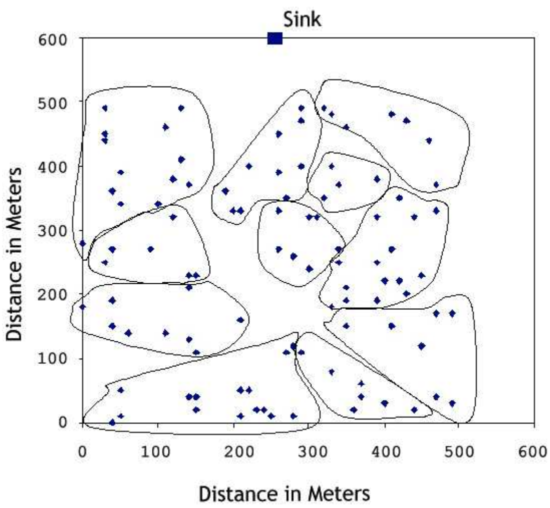


Figure 4. Clusters generated in LEACH

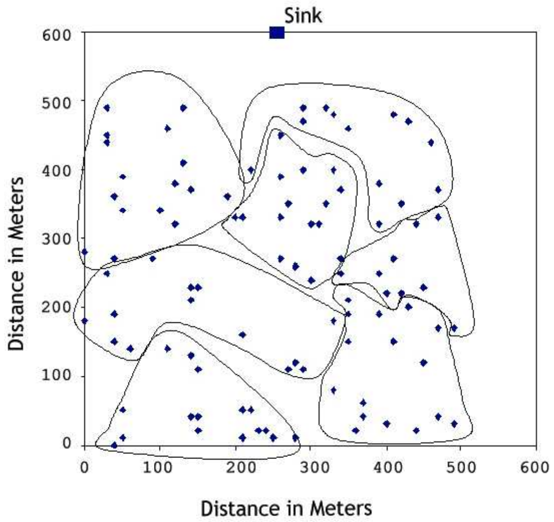


Figure 5. Clusters generated in dynamic-EACM

3.1. To minimize the clustering overhead Steady-state operation is divided into fixed number of TDMA frames. Nodes sense and transmit their data to the cluster head on the allocated TDMA slot. The cluster head receives data from all its members, aggregates it and transmits it to the base station by using multihop communication. Choosing the cluster head with more residual energy as relay node helps to balance energy consumption.

4. SIMULATION AND PERFORMANCE EVALUATION

4.1. Radio Model

In this work, the first order radio model is used, where radio dissipates E_{elec} = 50nJ/bit to run the transmitter and receiver circuitry and ϵ = 100pJ/bit/m^2 for the transmitter amplifier. In order to transmit a k bit packet over a distance d, the energy spent on the radio is

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-amp}(k,d)$$
$$E_{Tx}(k,d) = E_{elec} * k + \epsilon * k * d^2 \quad (2)$$

and to receive a packet of length k bits the radio expends:

$$E_{Rx}(k) = E_{Rx-elec}(k) E_{Rx}(k) = E_{elec} * k \quad (3)$$

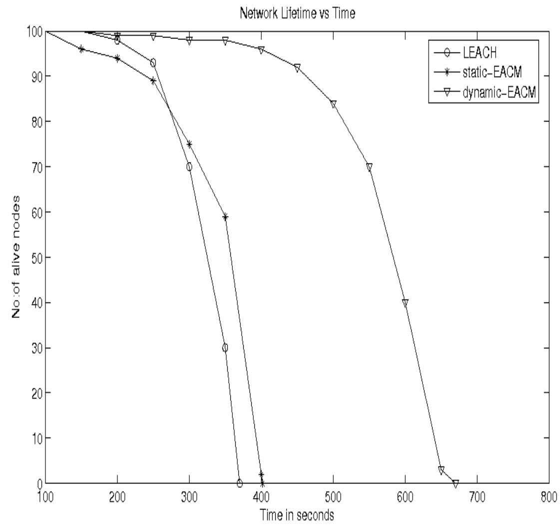
4.2. Network Model

To evaluate the performance of LEACH and EACM the following network model is used. The network consists of 100 nodes deployed randomly to continuously monitor a 500 × 500 m^2 area. Base station is located outside the sensor field. All nodes are position unaware and homogeneous. The nodes are capable of operating in active mode and low power sleep mode and they can use power control to change the transmission range for intra cluster and inter cluster communication. Initial energy of each node is assumed as 10J and data size as 250 bytes.

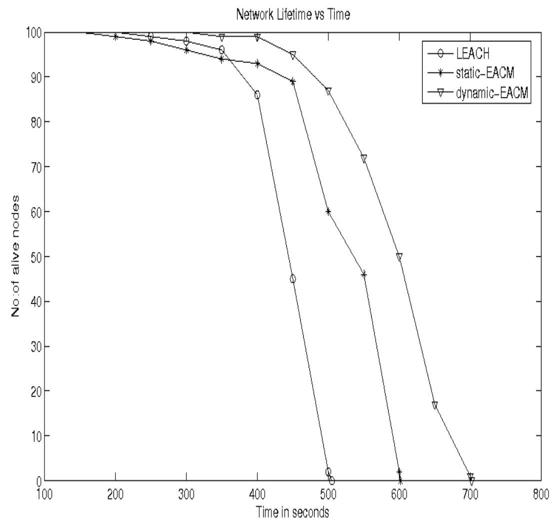
4.3. Performance Evaluation

The performance of LEACH protocol for different percentage of CHs *(p)* is evaluated for different percentage of cluster heads *(p)*. From the results (as shown in figure. 3.), it is observed that there exists an optimal range for the value of p as in [7]. If the value of p goes below this range, the number of clusters formed will be low and most communication to the base station will be direct. If it goes above the optimal range the number of clusters formed will be high, which in turn increases the number of direct communications to the base station.

The clusters generated in a specific round of

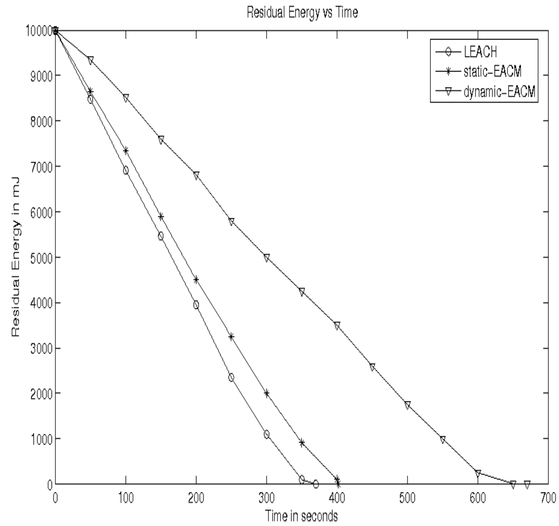


(a) Direct Communication.

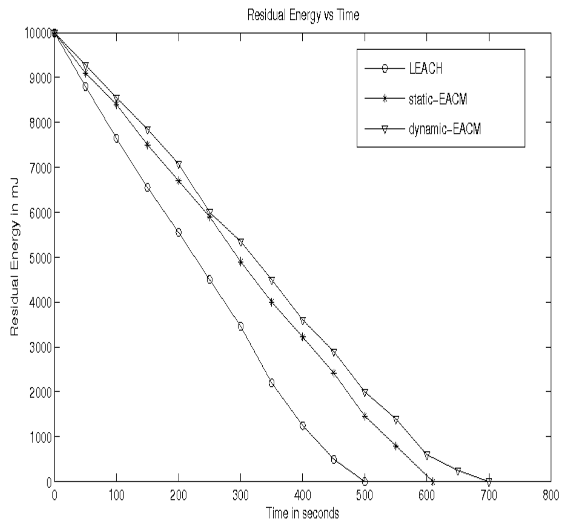


(b) Multihop Communication

Figure 6. Network lifetime comparison of LEACH, static-EACM and dynamic-EACM.



(a) Direct Communication.



(b) Multihop Communication.

Figure 7. Energy dissipation comparison of LEACH, static-EACM and dynamic-EACM.

LEACH and EACM is shown in Figure 4 and 5. It can be argued that more load balanced clusters are generated for EACM when compared with LEACH. The performance of dynamic-EACM is compared with LEACH and static-EACM for both direct and multihop communication. Figure 6a shows the number of alive nodes in the network over time with direct communication between cluster heads and base station. It can be observed that first node death occurs earlier in LEACH compared to static-EACM. This is because nodes that belong to small sized clusters dies first since these nodes have to perform the high energy consuming task of cluster head more frequently. EACM's static clustering performs better than LEACH on the average lifetime of sensor nodes. Dynamic-EACM outperforms LEACH and its static clustering version on both first node death time and average sensor lifetime. Figure 6b plots network lifetime over time with multihop communication between cluster heads for transmitting messages to the base station. Figure 6a and 6b reveal that mutihop communication protocols are more energy efficient than their direct communication counterparts.

Figure 7a and Figure 7b show the average residual energy of sensor nodes over time for direct and multi-hop communication. It can be seen that energy consumption in EACM is lower than in LEACH.

5. CONCLUSIONS

EACM takes advantage of hierarchical topology of clustering to maximize the lifetime of wireless sensor network. It uses a voting based clustering algorithm to distribute the cluster heads uniformly throughout the network. In static-EACM the role of cluster head is rotated among the cluster members to balance the energy consumption within clusters. In dynamic-EACM nodes are reclustered and new cluster heads are elected after each round for even energy dissipation. Also the cluster head nodes organize themselves to perform multihop communication to the base station which significantly reduces the energy consumption. As a future work, we intend to enhance EACM for mobile sensor networks by including mobility metric for computing votes.

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