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EAREC: Energy Aware Routing with Efficient Clustering for Sensor Networks

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Abstract

Energy efficiency is one of the most challenging issues in wireless sensor network as the sensors have to serve unattended. Cluster based communication can reduce the traffic on the network and gives the opportunity to other sensors for periodic sleep and awake and thus saves energy. Passive clustering is less computational and light weight. In cluster based approach, cluster heads and gateways have to have maximum energy to be awaken for all the times. Existing passive clustering algorithm uses first declaration method without any priority generates severe collisions in the network and form the clusters very dense with large amount of overlapping regions. This results increased number of gateways. We have proposed several modifications for the existing passive clustering algorithm to prolong the life time of the network with better cluster formation. More -over, our proposed solution finds the optimum path between sources and sinks using the tiny cache memory of the intermediate nodes. Simulation result shows that EAREC saves significant amount of energy and at the same time keeps the delay and success rate satisfactory.

1. Introduction

Sensor network can be envisaged as a collection of thousands of small tiny sensor nodes deployed for unattended operations. Each node is equipped with a sensing circuitry, a processor, a radio transceiver for short range communication and a limited battery-supplied power. Typical applications of sensor networks are environmental monitoring which detects several environmental parameters such as fire, oil slicks, water pollution, or animal herds. Unattended and hostile environment are two basic characteristics of sensor network which instigate the deployment of huge sensor nodes to ensure standard operation of network which in turn, necessitate the design of low cost nodes. Energy efficient routing is one of the challenging and flourishing frontiers of sensor network research. There are two types of energy consumption in a sensor node i.e. useful or wasteful. Useful energy consumption can be due to (i) transmitting/ receiving data, (ii) processing query requests, and (iii) forwarding queries/data to neighboring nodes. Wasteful energy consumption can be due to (i) idle listening to the media, (ii) retransmitting due to packet collisions, (iii) overhearing, and (iv)generating/handling control packets. Several MAC protocols attempt to reduce energy consumption due to wasteful consumption, e.g. [5], [6], [7], [8]. A number of protocols have also been proposed to reduce useful energy consumption.

Directed diffusion (DD) [1] is a popular data dissemination paradigm for WSNs. The main idea of the DD is to combine the incoming data from different sources to enroute (in-network aggregation) by eliminating redundancy, minimizing the number of transmissions and thus saving network energy and prolonging its lifetime. Unlike traditional end-to-end routing, DD routing finds routes from multiple sources to a single destination that allows in-network consolidation of redundant data. Unfortunately the idea of directed diffusion does not consider the dense deployment of sensor nodes that causes huge amount of unnecessary re-forwarding of messages. The noble idea of Directed Diffusion (DD) is further improved in [3] combining the idea of Passive Clustering (PC) proposed by Kwon and Gerla [2]. Passive clustering does not consider residual energy for becoming cluster head. As a result network life time is reduces if the low energy nodes become cluster head. Moreover this approach does not consider the idle listening time of

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the nodes that eventually consume around 50% of the total energy consumption.

Two-tier data dissemination (TTDD) model for large scale wireless sensor networks with sink mobility has presented in [4]. Instead of passively waiting for queries from sinks, TTDD exploits the property of sensors being stationary and location-aware to let each data source build and maintain a grid structure in an efficient way. Queries are forwarded upstream to data sources along specific grid branches, pulling sensing data downstream towards each sink. Unfortunately this approach also has not taken the wasteful energy consumption (like idle listening) into consideration.

Sensor nodes typically have four power levels corresponding to the following states: transmitting, receiving, listening and sleeping. For mica2 mote [11], these power levels are 81mW, 30mW, 30mW and 0.003mW for transmit, receive, idle and sleep respectively. It is very evident that sensor nodes should sleep as much as possible when it is not engaged in communication. In a typical sensor network most of the energy consumption is due to idle listening. Above described protocols [1][3][4] do not consider this issue. We refer idle listening as a wasteful source of energy consumption and emphasized maximum to save energy from this source.

In this paper, we have proposed a modified passive clustering algorithm which takes account of both residual energy and distance for becoming cluster head and gateway and also eliminate the problem of idle listening through periodic sleep and awake.

2. Protocol Outline

We proposed EAREC (Energy Aware Routing with Efficient Clustering) cluster-based communication to reduce network traffic and periodic sleep-awake time maintenance for the nodes to save energy. There will be one CH (cluster head) and at least one GW (gateway) in each cluster. All the nodes within a cluster are reachable from CH within one hop. The ordinary nodes will maintain two states Sleep & Idle. During sleep state, nodes turn their radio off and monitor the environment. If any detection occurs, they turn their radio on and send the data to the CH. During idle state, nodes turn their radio on to receive new query from CH and at the same time monitors the environment. CH communicates with other clusters via GW. CH and GW spends maximum energy to remain awake all the time to communicate with other clusters. So after a certain period (based on application) new clusters will be formed to select new CH and new GW.

2.1. Cluster formation

Passive clustering [2] can be used to form the clusters as it is less computational and light weight. Generally in a cluster based approach, cluster heads and gateways have to have the maximum energy as it performs all the communications. We modify the clusterhead and gateway selection considering residual energy and distance.

Cluster Head: Residual energy can be considered with highest priority to be the cluster head as it requires sufficient energy to survive its turn properly. The distance is another criterion that should be considered to form better clusters in terms of density. With this end in view, a required threshold value R_{th} should be defined to be a cluster head. Nodes having more residual energy than R_{th} will wait for T_i time and then claim as a Cluster head. The waiting time T_i can be calculated as follows:

$$T_i = t/(X*R_i + Y*D_i) \quad (1)$$

Where, t= constant value (based on application). R_i (must be greater than R_{th}) and D_i are the residual energy and distance respectively of node i.

Suppose in the following figure 2 node 1 initiates the search. Let $\mathbf{N_2,N_3,N_4,N_5}$ nodes have the residual energy respectively 100,80,80 and 40 unit with the distance of 2,10,3 and 6 unit respectively from node 1. And R_{th} is 35.

So their waiting times are as follows:

T2 = t/(100*2) = t/200 , T3 = t/(80 * 6) = t/480 ,
T4 = t/(80*8) = t/640,T5 = t/(40*10)=t/400

Thus considering residual energy and distance node 4 will claim first. And according to the first declaration wins method it will be the cluster head. Here is a typical example of forming cluster considering distance and without considering distance.

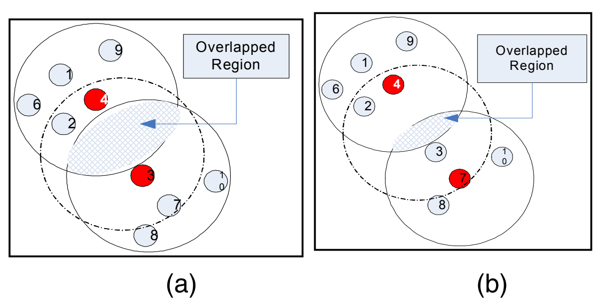


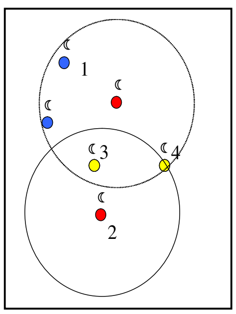
Figure 1. Resultant clusters (a) Considering Distance (b) Without considering distance

Considering distance (Figure 1(a)): Resultant clusters have less overlapping area. Without Considering distance (Figure 1(b)): Resultant clusters have more overlapping area

Gateway: Sensor nodes in the overlapping region of two or more clusters can claim themselves as a gateway. The number of gateway is directly proportional to the network performance and inversely proportional to energy efficiency. So the maximum number of gateways should be specified to save the energy as well as getting stable network performance. Moreover priority should be given to the nodes with more residual energy and serving number of clusters. According to our proposal, all candidate gateways will store the waiting time [maximum waiting time of the existing gateways] if there is one or more gateways serving already. If there is no gateway serving then the stored value is infinity. The candidate gateway (that receives message from 2 or more CH) will be able to claim to be a gateway after T_i time if the value of T_i is less than the stored waiting time. This ensures that the current candidate is more eligible than the previous last one at least, to be a gateway. The waiting time T_i can be calculated as follows:

$$T_i = t/(N*R_i) \quad (2)$$

where, t is constant based on application, N is the number of clusters, R_i is the residual energy of node i.



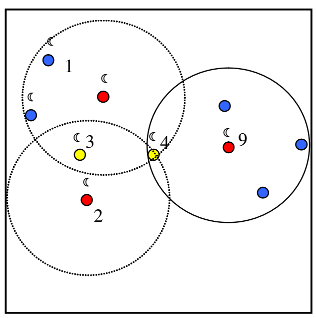


Figure 2. Considering 2 clusters **Figure 3.** Considering 3 clusters.

According to the above figures 2 and 3, suppose node 3 and 4 have the residual energy 15 and 12 respectively. And we assume that the maximum number of gateway is 1 for an overlapping region.

In figure 3: node 3 and 4 will claim as a gateway with the following waiting times.

$T3 = t/(2*15) = t/30$, $T4 = t/(2*12) = t/24$

So node 3 will get higher priority and claim first as it is having more residual energy.

In figure 4: node 3 and 4 will claim as a gateway with the following waiting time.

$T3 = t/(2*15) = t/30$, $T4 = t/(3*12) = t/36$

So node 4 will get higher priority and claim first, considering number of clusters and residual energy.

2.2. Data Communication

Basically there will be two types of communication:

Intra-Cluster Communication: Within a cluster there will be one CH which is reachable from all other ordinary nodes in that cluster by one hop. The ordinary nodes and CH should be synchronized in such a way, that all the nodes will be in idle state when the CH diffuses the query. During the sleep time if cluster head receives any new query, it waits up to the next idle time and then broadcast the query. The Idle time should be small enough and sleep time should be multiples of the idle time. The round time (if we consider one consecutive idle time and sleep time as a round) should be selected properly. If it is too small then the overhead of turning the radio on and off frequently will decrease the energy savings. On the other hand if it is too large, then the new query propagation will be delayed. These timings are based on the type of application and the type of requirements.

Figure 4. Sleep/Idle time synchronization (between ordinary nodes and cluster heads)

Inter-Cluster Communication: Query and requested data will be propagated between source and sink via the CH and GW by inter-cluster communication. So the CH and GW will remain active all the time throughout their turn.

2.2.1. Query Transfer. A query describes an interest in a certain series of sensor data measured at a remote location, by specifying the area, the sensor data type, the desired data update rate, and possibly the service duration. For instance, considering our environmental model a soldier can be a sink and his query may be specified as follows:

Area= [200, 500, 100, 350]
Type= enemy
Interval= 1 sec
Duration= 5 min

When a soldier will have a query, it will inject the query to its nearest CH. Upon receiving a query, a CH will take steps as the following Recv(q) function.

```
1.      Recv(q)
//checks the cache, if the query is
//already transferred with lower hop
//number than the current hop number
2.      if      isFoundinDataCache(q)      &&
isPrevHopNumSmall(q)
3.          then return
//update    cache.    [Data    table    is
//described later]
4.      StoreOrUpdateCache(q)
//checks  if  the  area  of  interest  is
//covered completely by this node
5.      if isCoveredCompleteArea(q)
//wait for next idle time of the //nodes.
6.then
        Wait_for_next_Idle_Time(T_idle)
// broadcast query within the cluster
7.      TransferQuery(q)
```

```
//checks if the interested area is
//partially covered
8.     else if isCoveredPartialArea(q)
//transfers query via one hop //Broadcast
9.     then ForwardQuery(q)
10.    Wait_for_next_Idle_Time(T_idle)
11.    TranserQuery(q)
//checks  whether  the  query  is  moving
//towards the interested area.
12.else if isMovingTowardsSource(q)
13.     then forwardQuery(q)
14.           else Discard(q)
```

Every CH is supposed to maintain a table in the cache memory where each entry is identified by a tuple (area, type). Different states of a query are discussed in the following table.

Table 1. Table structure for data cache

Area	100,400,50, 350	100,400,50, 350	100,400,50, 350
Type	Enemy	Enemy	Enemy
Value		Tank	Tank
Timestamp (Event generation time)	01:30.00	01:30.15	01:35.15
Remaining Interval time	30 sec	15 sec	--
Remaining Service time	5 min	4 min 45 sec	--
State	Query	Requested data	Query_Served
Nearest Node Id	Xxxx	Xxxx	Xxxx
Minimum Hop Number	5	5	5

N.B: A particular state will be available in the cache at a time. Possible states of a query are shown in the table. Different queries can exist without any duplication

Table 2. Extended table structure for data cache

Area	
Type	
…	
…	
1st Nearest node ID	
Hop Number	
2nd Nearest node ID	
Hop Number	
…	

2.2.2. Requested Data Transfer: Requested data transfer is very straight forward as the CH will maintain the nearest node ID towards the sink in its cache. When any event occurs in the area of interest, the relevant node (source) turns on the communication radio, send the requested data to its CH. CH then sends data to the nearest node (CH) according to the cache table. The steps will continue until the sink is reached.

2.3. Failure Recovery

The proposed model also suggests keep tracking of alternative paths (node ID) in the cache to get rid of node failure as shown in table 2. The alternative paths should be stored in ascending order to find the next alternative best path. The number of alternative paths is based on the frequency of node failures. Failure recovery will be more tolerant, if the number of stored alternative path is greater but it will require more memory.

3. Performance Evaluation

3.1. Metrics and methodology

We implement our model in ns-2[10] simulator. We used the radio energy model of sensor prototype [11], We implemented two protocols Directed Diffusion (DD) and improved Directed Diffusion with passive clustering (PCDD) as baselines to compare with our protocol. We use three metrics to evaluate the performance of our protocol. The energy consumption is defined in terms of transmitting, receiving, idle listening and sleeping energy. We emphasized heavily on wasteful resources like idle listening and proposed periodic sleep/awake to reduce energy consumption. The delivery ratio is the ratio of the number of successfully received reports at a sink to the total number of reports generated by a source, averaged over all source sink pairs. This metric shows the effectiveness of data delivery. The delay is defined as the average time between the moment a source transmits a packet and the moment a sink receives the packet, also averaged over all source-sink pairs.

Every node has a fixed transmission power resulting in a 40 m transmission range. The sources and sinks were spread uniformly over the entire area; the size of the area varies between simulations.

Four sources and four sinks: With four sources and sinks each distributed as described above, either the area or the average density of the network are kept constant: an increasing number of nodes is placed either in an area of fixed size (160 m by 160 m) or on a growing area.

Variable number of sources/sinks: Using a 160 m by 160 m area with 100 nodes, we used either a single sink with a variable number of sources or a single source with a variable number of sinks.

For each parameter setting, we randomly generated 10 scenarios with different placements of nodes. For each scenario, we computed (after removing the initial transient) the means for all three metrics. From these ten (stochastically independent) means we computed the means over all scenarios and their 95% confidence intervals for all metrics.

3.2. Simulation Results

3.2.1 Effects of the Network Topology

We start the presentation of our results with the four sources/four sinks case in networks of either fixed area or fixed density. Figure 6 depicts the average dissipated energy per unique event for the original directed diffusion protocol (DD), Directed diffusion with passive clustering (PCDD) and for the EAREC. For each different network size, the simulation area is scaled so that the average node degree in the network remains constant at around 10. This enables us to examine the scaling properties of the protocols as a function of the number of nodes in the network in isolation. In all of the topology experiments the load of the network is generated by four sources sending unique events every two seconds.

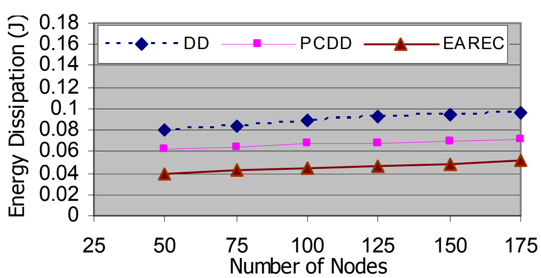


Figure 6. Energy Efficiency (Fixed Density)

The results clearly show the effectiveness of EAREC in controlling the unnecessary re-forwarding of messages and idle listening in DD and PCDD. This is a confirmation to our assumption that the reduced number of flooded messages and idle listening of the nodes, results in a neat gain in the energy metric, despite the increased size of the remaining messages. Furthermore, this gain is not achieved at the cost of either the delivery ratio or the delay.

In Figure 7 we can see the average dissipated energy per unique event for an increasing number of nodes in this fixed area. DD shows rather linear increase in the required energy with the increase of the number of neighbors. This is very usual, as the increased number of neighbors results in higher number of flooded interest messages. PCDD, on the other hand, behaves much better in dense networks but it does not avoid idle listening. But EAREC performs significantly well in terms of energy savings than others.

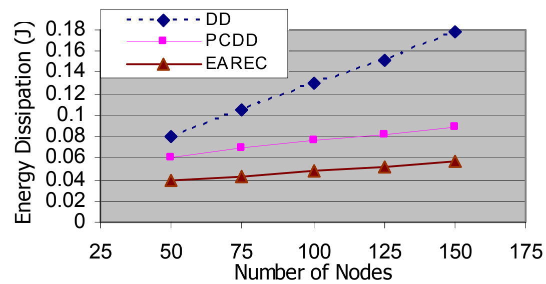


Figure 7. Energy Efficiency (Fixed Area)

Figure 8 shows, the delays are much better with PCDD and EAREC. The reduced load in the network more than compensates for this potentially negative aspect. Without this reduction in the amount of traffic in the network, plain directed diffusion faces extensive delays in the higher degree scenarios.

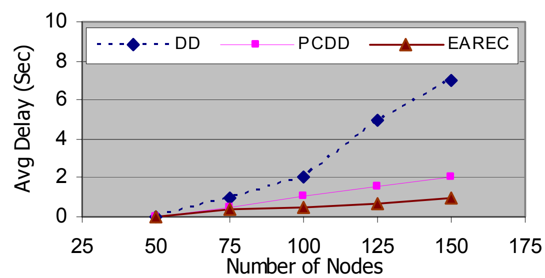


Figure 8. Delay (Fixed Area)

Figure 9 shows, the delivery rate is considerably better with EAREC compared to the fixed degree scenario. The delivery ratio of DD experiences significant degradation as the size of the neighborhood increases. By reducing the superfluous message exchange, PCDD and EAREC lead to a decrease in the collision rate that result in a very good delivery ratio even for the highest density case. EAREC performs comparatively better than PCDD because of the selection criteria for cluster head and gateway that possesses more residual energy.

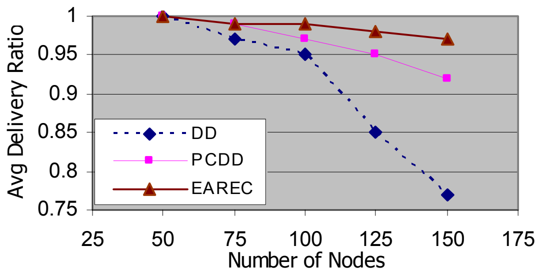


Figure 9. Delivery ratio (Fixed Area)

3.2.2 Effects of the Traffic Pattern

The following Figure 10 and Figure 11 shows, EAREC also performs well when the traffic pattern is considered. Considering single sink and different number of sources, dissipated energy is less in EAREC than other two protocols and the vice versa scenario also shows the same kind of result.

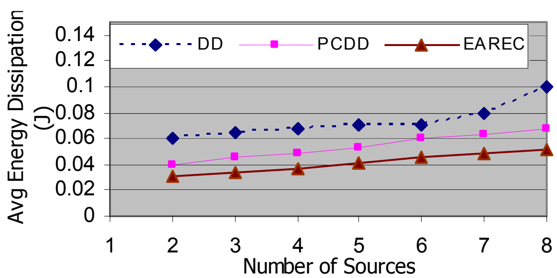


Figure 10. Energy Efficiency (Single Sink)

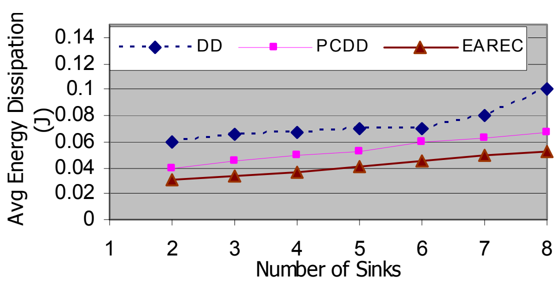


Figure 11. Energy Efficiency (Single Source)

5. Conclusion and Future Work

Our proposed solution focuses on cluster-based communication to reduce network traffic and provides the facility to the maximum number of nodes for periodic sleep/awake time maintenance that in turn leads to a significant amount of energy savings. Moreover, EAREC also shows that intermediate nodes can use their tiny memory as a cache to remarkably increase the network performance for data communication. Maintaining the minimum number of hops for path discovery in EAREC guarantees the optimum path solution and storing the alternative paths in the cache solve the problem of node failures.

EAREC is highly dependent on clusterhead and gateways. Cluster head and at least one gateway should always be alive to keep all the nodes (of that cluster) connected with the network. We have not given any solution for cluster head/gateway failure in our paper. One solution can be given by forming the clusters again, as the cluster formation algorithm is very light-weight. We are investigating this issue now and would like to provide a perfect solution in future to make EAREC stable.

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