Energy Efficient Routing for Highly Dense Sensor Network Based on Residual Energy and Distance

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Abstract*-Efficient energy utilization and prolonged lifetime are two most covetable targets for sensor network. For increased lifetime, each node must conserve energy as much as possible. In this paper we propose a protocol in which energy is conserved by amortizing the energy cost of superfluous packets and idle state energy consumption. To achieve our goal we have exercised well-known periodic sleep protocol and reduce redundant transmission by creating tree based on residual energy and distance based communication cost. Wasteful energy consumption of sensor nodes (e.g. idle listening, retransmission due to packet collision, overhearing etc) can be minimized by selecting minimum number of forwarding nodes. Our proposed algorithm selects minimum number of forwarding while creating broadcast tree. A portion of nodes act as forwarding (non-leaf) while all the other nodes designated as a non-forwarding (child) node. Child nodes reduce wasteful energy consumption by keeping radio transceiver off. Simulation shows our algorithm is better in terms of energy conservation and network lifetime.

I. INTRODUCTION

Sensor network has received great magnitude of attention due to its diverse application area specially, in hostile environment where human intervention is grueling or inopportune and sometimes impossible. While the exact application of sensor network is speculative, certain properties are typically assumed. First, sensors are static after initial deployment. Second, energy is scarce and it is inconvenient or impossible to replenish the energy source frequently. Sensors are deployed in a highly dense fashion. Effect of high density instigates the major problem of collision, overhearing and redundant transmission. While deployment with less density is contradictory as sensors are deployed in hostile environments and also they are energy constrained so sensor nodes are porn to failure. Such constraints combined with a typical deployment of large number of sensor nodes have posed many challenges to the design and management of sensor networks. These challenges necessitate energy-awareness at all layers of networking protocol stack. The issues related to physical and link layers are generally common for all kind of sensor applications, therefore the research on these areas has been focused on system-level power awareness such as dynamic voltage scaling, radio communication hardware, low duty cycle issues, system partitioning, energy aware MAC protocols [6][7][8]. At the network layer, the main aim is to find ways for energy efficient route setup and reliable relaying of data from the sensor nodes to the sink so that the lifetime of the network is maximized. Energy consumption in a sensor node can be due to either useful or wasteful sources. 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. While radios typically have four power levels corresponding the following states (i) transmit (ii) receive (iii) idle and (iv) sleep. Our idea is to minimize wasteful energy consumption by reducing redundant traffic and optimizing control message transmission while creating the sink rooted broadcast tree.

Our work minimizes redundant traffic transmission and collision using sink rooted broadcast tree. The nodes will be having two status forwarding (non-leaf) and non-forwarding (Leaf) based on residual energy and distance towards sink. Non-forwarding (Leaf) nodes are in charge of sensing the vicinity and transfer sensed data through forwarding (non-leaf) nodes. Our proposed algorithm tries to select one forwarding node with in the transmission range. We also introduced a timer parameter to control the transmission while creating the tree and thus reduce collision and also reduce control message transmission required to generate the tree.

II. RELATED WORK

Routing protocols of sensor network can be classified into two according to network structure and protocol operation. According to network structure proposed protocols can be further classified into (i) Flat [5][10][11], (ii) Hierarchical [1]-[4][9][14] and (iii) Location based [13]. While based on protocol operation is further classified into (i) Negotiation based (ii) Multipath, (iii) Query based, (iv) QoS based and (v) Coherent based.

We focus on hierarchical routing protocols. In a hierarchical architecture, higher energy nodes can be used to process and send the information while low energy nodes can be used to perform the sensing in the proximity of the target. This means that creation of clusters and assigning special tasks to cluster heads can greatly contribute to overall system scalability, lifetime, and energy efficiency. Hierarchical routing is an efficient way to lower energy consumption within a cluster

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and by performing data aggregation and fusion in order to decrease the number of transmitted messages to the BS.

Heinzelman, et. al. [1] introduced a hierarchical clustering algorithm for sensor networks, called Low Energy Adaptive Clustering Hierarchy (LEACH). LEACH randomly selects a few sensor nodes as clusterheads (CHs) and rotates this role to evenly distribute the energy load among the sensors in the network. Protocol assumes that all nodes can transmit with enough power to reach the BS if needed and that each node has computational power to support different MAC protocols. Therefore, it is not applicable to networks deployed in large regions. It also assumes that nodes always have data to send, and nodes located close to each other have correlated data. It is not obvious how the number of the predetermined CHs is going to be uniformly distributed through the network. Hierarchical Power-aware Routing (HPAR) protocol [15] finds the path with the least power consumption by using the Dijkstra algorithm and maximizes the minimal residual power in the network. But wasteful energy consumption due to idle listening is not considered in the protocol. Energy Aware Data-centric (EAD) protocol [9] was proposed by Boukerche et. al. EAD consider residual energy as a parameter to construct the broadcast tree. The idea is to produce more non-leaf nodes to save energy as well as reduced transmission. Our work differ form EAD as we have considered distance as parameter. Emphasis on only residual energy may generate longer paths which is undesirable as longer path requires more energy to transmit.

Our work also generates sink rooted tree in which non-leaf and leaf nodes are considered as forwarding and non-forwarding nodes. In our proposed tree construction we emphasize both residual energy and distance which ensure a optimal forwarding node selection in terms of routing cost and thus achieve energy efficiency.

III. Energy Consumption Analysis

Sensor network is usually very dense. Certain amount of redundancy is introduced for the robustness of the network. In this section we will show the effect of idle nodes on per packet energy cost for single hop and multi hop transmission.

A. Single Hop Based Analysis

In simple case, the energy consumed by the network interface when a host sends receives or discards a packet can be represented using a linear equation

$$Energy = P \times size + f \qquad (1)$$

Trivially, there is a fixed component associated with device state changes and channel acquisition overhear and an incremental component which is proportional to the size of the packet. Here in the equation coefficient P represents the variable cost and f is the fixed cost associated with the transmission. Note that the equation does not consider about the media contention cost. The relative magnitude of the various P and f coefficients also indicate the amount of per packet energy consumption overhead.

A packet may be sent as broadcast or point-to point traffic. Broadcast traffic received by all hosts within transmission range and point-point case traffic will be discarded by non-destination hosts. Sensor network operates in promiscuous mode and any sensed data is normally broadcast to the neighbors and destined for the sink. It is very evident that some of the neighbor will be useful for forwarding the data towards the sink and some other will not (as sensor network is highly dense and good number of redundant nodes are deployed to increase the robustness of the network). So in promiscuous mode of operation there will be three (broadcast, point-to-point receive and discard traffic) types of energy consumption. Node sensing any event will broadcast the data, nodes responsible to forward data towards sink will receive data and finally nodes other than receiving or sending will discard the data. Energy consumption for three kinds of operation can be presented by

$$E_{bsend} = P_{bsend} \times size + b_{bsend} \text{ (for broadcast send)} \qquad (2)$$

Let S be the source and N(s) be the number of nodes within one hop of S. Out of N(s) neighbors let $N_{frd(s)}$ are the required number of nodes for forwarding data towards sink and $N_{idl(s)}$ are the number of idle nodes are discarding traffic. For a single source scenario total energy consumption can be represented by

$$E_{total} = E_{bsend} + N_{frd(s)} \times E_{recv} + N_{idl(s)} \times E_{disc} \qquad (3)$$

Total energy cost per bit can be calculated by

$$E_{bit} = \frac{E_{bsend} + N_{frd(s)} \times E_{recv} + N_{idl(s)} \times E_{disc}}{P_{size}} \text{ where } P_{size} \text{ represents packet size} \qquad (4)$$

It is clear form the equation that bit packet energy consumption will increase depending on number nodes receiving and discarding packets. Another significant consideration is to identify the required forwarding nodes for reliable delivery of data to the sink.

B. Multi-hop Based Analysis

Transmission of data from source to destination may require multiple hops. Energy consumption of each hop can be obtained from the single hop analysis and finally the total cost of data transmission from source to sink will be an additive matrix of each hop.

Based on analysis energy efficient routing protocol should have the following properties

i. Balance energy consumption among the nodes to ensure uniform failure rate.
ii. Energy balanced path based on residual energy and distance towards sink
iii. Optimal number of forwarding node selection

IV. Protocol Description

In this section we will describe sink rooted tree (SRT) construction process and routing using the tree. Control message for tree construction consists of following four fields

i. Node ID
ii. Residual Energy

iii. Distance up to sink

iv. Type of the message: Type 1 indicates forwarding node selection message and type 0 means notification of individual energy and distance information.

We define three different statuses of nodes depending on operation

i. Non-forwarding: Each sensor node is having a sensing circuit and a radio transceiver. In this status nodes will turn off their radio transceiver and continue to sense for events within the sensing rage. If any node senses any stimuli, will turn on their radio and transmit to the nearest forwarding node.

ii. Forwarding: Both the circuitry will remain on for the nodes in forwarding status.

iii. Active: While constructing the tree all nodes will remain in active status. There is node major difference between forwarding and active status. We need this status to differentiate from normal operational state and tree construction state

Initially all nodes will be in status 0 (active status). Sink node initiates tree construction with a type 0 message indicating s as node ID, 0 as distance toward sink and α as the amount of residual energy. Nodes within the 1-hop of sink will receive the message and calculate parameter T_{active} and T_{wait} (We describe the calculation and necessity of these two parameters in section V-A). Each node upon receiving type 0 message will check whether the node has selected forwarding node. If the forwarding node is not selected the node will store the node ID, residual energy and distance towards sink. Then sense the channel, if the channel is idle it will wait for another T_{wait} time and if the channel is still idle it will transmit type 0 and type 1 message consecutively noticing its residual energy and distance towards sink and its forwarding node. Each node will select forwarding node based on the neighbor's residual energy and distance towards sink. It should be noted that for each round of tree construction each node will transmit the messages once. Any node receiving type 1 message will check the incoming message node ID. If the node ID matches with own ID the node will change its status to forwarding node. It means any of the neighbor need the node to relay the data towards sink. If any node does not receive type 1 message with matching with its own ID with in T_{active} time, the node will change its status to non-forwarding node.

After the construction of the tree all nodes will be either in forwarding or non-forwarding state. Nodes settled in non-forwarding state will turn off their radio transceiver while keeping the sensing circuitry turned on. On the other hand forwarding nodes will keep both radio and sensing circuitry turned on. All nodes will continue to sense within the vicinity and if any stimuli detected for non-forwarding node, it will turn its radio on and transmit data to the pre-defined sink while forwarding node having radio turned on will transmit to its forwarding node. After tree construction each node will dynamically set transmission range according to the distance of the parent or forwarding node. Tree construction algorithm will be executed every after T time where T is an application dependent parameter. T depends on amount of events and event generation rate as well on the load of the network. Each node participating in tree construction must have threshold energy. It is obvious that nodes with higher ratio of residual energy and distance will transmit first. Which ensures the chance to choose the best forwarding node among the neighbors.

A. Timer parameter for Tree construction and message Transmission

All the nodes will be in active status while constructing the tree. But the question is how long the nodes will be in active status? Another important consideration is transmission of control message for constructing the tree. As the nodes participate in a competition to notify residual energy and status to the neighbors, good scheduling among the neighbor for control message transmission is needed to reduce collision. Considering these two points we define two timer parameters for determining each node's active status time and control message transmission time.

Determining Active Status Time: Let v be a node and $N_1(v)$ is the set of 1-hop neighbor of v for a particular transmission range r. We define T_{rtt} as the round trip time for data propagation between any two pairs within the one hop neighbors. Active status time for node v is given by the following equation

$$T_{active} = T_{rtt} \times N_1(v) \quad (5)$$

It should be noted that, within T_{active} nodes will be able to determine its necessity to be a forwarding node. If a node does not receive any message from any of the neighbor to become as forwarding node within T_{active} time, the node will change its status to non-forwarding (2).

Determining Control Message Transmission Time: Tree construction algorithm will be initiated by sink and nodes within in the transmission range will receive the message first. Waiting time before further transmission can be obtained using the following equation

$$T_{wait} = E_r / D_s \quad (6)$$

Where Er is the residual energy and Ds is the distance upto sink

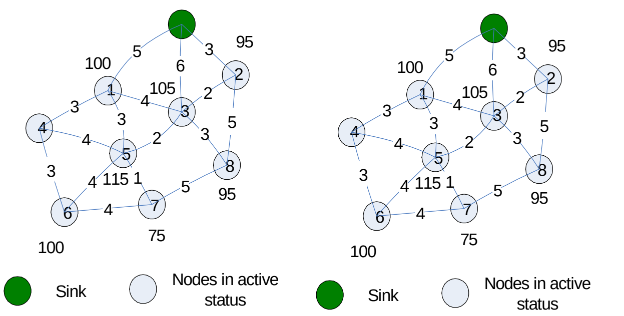
Each node receiving the message will sense the channel and if the channel is idle, it will wait until T_{wait} time and then transmit own status and residual energy. T_{wait} mainly depends on E_r and D_s which prioritize the node with better energy and transmission cost towards sink.

B. Example

We describe the execution of our tree construction algorithm for the sensor network depicted in figure 1. The network consists of 8 nodes and a sink and we took a snapshot of a particular time and execute tree construction algorithm.

Sink will initiate tree construction and node 1, 2 and 3 will get the message first and calculate T_{wait} and T_{active} value.

T_{wait} value for node 1, 2 and 3 are 0.031, 0.05 and 0.057. Node 2 and 3 are within range and 2 has lower waiting value so node 2 will broadcast its residual energy (E_r) and distance (D_s) towards sink to its neighbor and set sink as its forwarding node. Node 3 and 8 will store the 2's E_r and D_s for future computation. In case of node 1 and node 3, node 1 have less waiting time and as node 1 and 2 are not within the range, node 1 will broadcast its information simultaneously with node 2 and sets sink as the forwarding node. Node 1's message will be store by node 3, 4 and 5.



(a) **(b)**

Fig.1. Sensor network with 8 nodes and each node is labeled with node ID and residual energy and links between nodes are labeled with distance. (a) shows the network before tree construction and (b) is after tree construction

Node 1		
s	-1	6
F-node S		

Node 2		
s	-1	6
F-node S		

Node 3		
s	-1	6
2	90	5
1	100	9
F-node S		

Node 4		
1	100	8
5	115	12
6	100	12
F-node 5		

Node 1		
s	-1	6
F-node S		

Node 2		
s	-1	6
F-node S		

Node 3		
s	-1	6
2	90	5
1	100	9
F-node S		

Node 4		
1	100	8
5	115	12
6	100	12
F-node 5		

Fig. 2. Type 0 message transmission order is 1 and 2, then 3, 5, 6 and 8 and finally 4 and 7. Based on received message each node stores node ID, residual energy and distance towards sink. Finally each node selects forwarding node (F-node) based on residual energy and distance. Sink is represented by s and -1 representing infinite energy of sink

Now the competition is among node 4, 5 and 3, 5 and 8. Node 3 is having a T_{wait} value of 0.057 and node 5 with 0.069. So node 3 broadcast message and sets sink as the forwarding node. Node 3's information will be stored by node 5 and 8. Similarly E_r and D_s will be disseminated among the neighbors. At node 4's turn it will have E_r and D_s value from node 1 and 5. It will choose node 5 as a forwarding node as node 5 has the better E_r / D_s ratio than node 1. So node 4 will transmit type 1 message and node 5 will change its status from active node to forwarding node after the reception of the message. In a similar fashion all nodes will select its forwarding node. Nodes not receiving any forwarding node request within T_{active} time will change their status from active status to non-forwarding status. Data sensed by the nodes will be transmitted to sink using the tree

V. Simulation

We investigate the performance of our proposed algorithm through simulation. As our algorithm works in a hierarchical way we compare our protocol with two other hierarchical routing protocols LEACH [1] and Energy Aware Data-Centric (EAD) [9] routing. In this section we articulate simulation environment and performance matrices, experimental results and comparison with two related protocols.

A. *Simulation Environment and Evaluation Matrices*

Our simulation starts with 50 nodes uniformly distributed within an area of 100X100 m^2 and latter on we increase the number of nodes for the same area. According to specification of Mica2mote, transmit require 81mw, receive and idle require 30 and sleep status require 0.003 mw. As the ratio of transmit and receive is 3:1, in our simulation we consider 3 unit, 1 unit and 0 unit energy consumption for transmit, receive and idle, and sleep respectively. All nodes are initialized with 500 unit energy and every after 2 seconds events are generated at random location. Events sensed by the nodes transmit to the sink according to the pre-selected forwarding nodes. Initially we select transmission range 20.

We compare our proposed protocol in terms on number of forwarding node for increasing number of nodes, total energy consumption and total number of alive nodes over time. Less number of forwarding nodes and less energy consumption while having more alive nodes are the desirable properties for better performance. There will be some packet loss due to disconnectivity of the network over time. We also plotted packet loss over time but does not compare with other protocols for the deep understanding of other protocols.

B. *Simulation Results*

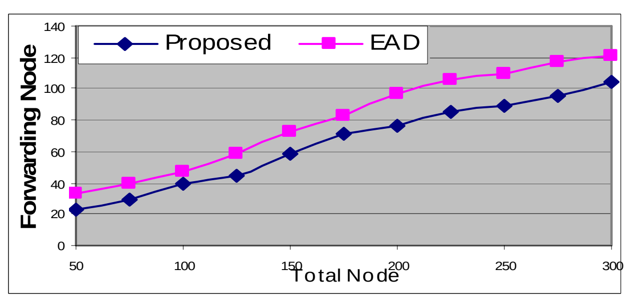


Fig. 3. Total node Vs forwarding node

Figure 3 shows number of forwarding nodes Vs total number of nodes for the network. Our proposed algorithm generates less number of forwarding nodes. EAD [9] generates leaf (non-forwarding) and non-leaf (forwarding) nodes based on residual energy while our proposed protocol considers distance and residual energy for generating forwarding and non-forwarding nodes. Higher distant nodes with in the transmission range with same residual energy will be selected as forwarding node according our proposed scheme while EAD selects less distant node.

Figure 4 and 5 shows comparison of our proposed protocol with LEACH and EAD in terms of total alive node and energy consumption over time. LEACH losses much energy as it use single hop transmission towards sink. While EAD uses only residual energy which generate longer paths and consumes more energy. Our protocol is designed constraint generates energy and distance balanced path and generates less forwarding node than EAD which in turn conserves idle energy. As a result our proposed nodes die at a less rate than other two protocols and energy of the node prevails for a longer period of time. All three protocols loss energy sharply after certain time. This is due to the failure of nodes over time. Increase in node failure require increase in transmission range to preserve connectivity of the network. As a consequence high transmission range consumes more energy to transmit. According to simulation proposed algorithm increase lifetime of the network by 35 % and 20% in comparison to LEACH and EAD respectively.

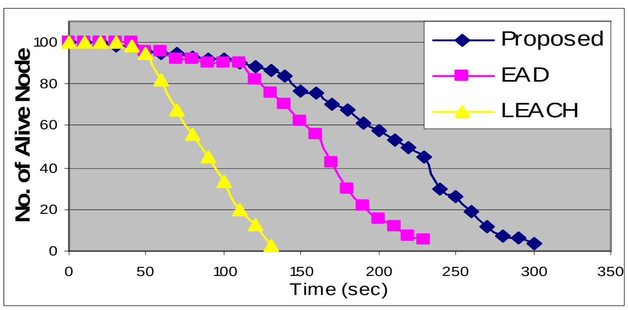


Fig. 4. Number of alive nodes Vs time

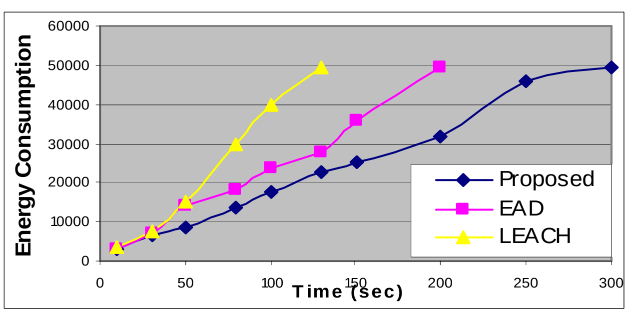


Fig. 5. Energy consumption Vs time

VI. Conclusion and Future Work

Our proposed protocol high lightens wasteful energy consumption due to idle listening. We propose a hierarchical routing protocol which creates a sink rooted tree with two different statuses (forwarding and non-forwarding) for each sensor node. Nodes in non-forwarding status turn off their radio and conserves idle energy consumption and reduce redundant transmission. Simulation shows our algorithm is better in terms of efficient energy consumption and network lifetime. Sink mobility, very attractive feature for many applications of sensor network is not included in our work. We intend to introduce sink mobility in future. Significant amount of data aggregation is possible at the forwarding nodes as same stimuli may be detected by more than one node and transmitted to one forwarding node. In future we would like to focus on data aggregation also

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