Multi-Gateway-Based Balanced Energy Consumption Routing Protocol for Wireless Ad Hoc Sensor Networks

E. Gayathri[1]

Research Scholar, Department Of Computer Science and Technology,
Sri Krishnadevaraya University, Anantapuramu,
Andhra Pradesh, India

Dr. N. Geethanjali
Professor, Department Of Computer Science and Technology,
Sri Krishnadevaraya University, Anantapuramu,
Andhra Pradesh, India

Abstract

To prolong the network lifetime in wireless adhoc sensor networks the energy consumption is considered as the prominent feature. In this paper, a multi - gateway - based approach is used to optimize the routing between the cluster nodes and base station, to balance the energy consumption and to acheive better network limetime. Optimal routing scheme has been designed for the sensors to transmit the data directly with the base station being in their own regions. Our proposed protocol have been compared with the standard protocols such as LEACH and GSEP. When compared with other protocols this protocol is better in acheiving residual energy, balanced energy consumption, throughput and network lifetime. This protocol also provides a good topological arrangement of nodes for transmission of data.

Keywords: wireless adhoc sensor network; energy depletion; subareas; gateway nodes; energy consumption; routing protocol, lifetime.

1. Introduction

Many applications such as military, natural terrains and smart home detectors are capable to check regions, gather all the data and transfer it towards the base station by using sensors. Optimal routing, energy efficiency, network lifetime are considered as important aspects in designing a routing protocol for wireless adhoc sensor networks. In wireless sensor networks, each and every node varies in energy depletion, but the node nearer to sink or base station depletes faster than other sensor nodes in the network. Several techniques have been developed to increase the network lifetime by providing uniform energy consumption like clustering[1] , data fusion[2], optimal node arrangement[3] and gateway nodes [4].

We propose a region based multi-gateway protocol for wireless networks. The distance while transmitting the data from the sensor nodes to base station is reduced, optimal routing and energy consumption is balanced. The network is divided into different areas such as gateway area, cluster area and the base station area. The area based multi-gateway provides the solution for long routes. In many existing research techniques gateway nodes improves the lifetime but they have not been placed properly in the network.

This protocol arranges the gateway nodes in an better way with respect to the size of the network area. In previous techniques, the gateway nodes are dependant on the no of clusters i.e. for every two clusters one gateway node has been placed . Scalability and throughput ratios per round were poor in the existing techniques.

A gateway based model has been proposed by Nadeem et al., in [5] which the sensor nodes are deployed in the logical regions. In this a single gateway node has been placed at the middle of the sensing region to improve the network lifetime. But, when the network area increases the centralized gateway node fails. In [6] gateway nodes are situated at the borders of heterogeneous sensor networks. Cluster heads choose the gateway nodes nearer to it and transmit the data to the base station. Approximate no of gateway nodes in heterogenous network is not possible. The gateway nodes nearer to the sink consume less power than the nodes far from the sink.

2. Related Work

Different methods such as distribution of nodes, uneven clustering, data aggregation, gateway based are available in the literature to increase network lifetime and to reduce the energy consumption. The most important and related approach to our protocol are Gateway based approaches.

One of the problem which cannot be totally

removed from the network is energy depletion problem. To avoid the energy depletion near the sink, a non uniform distribution of nodes has been used in [17]. A transmission – range based energy consumption is established to maintain uniform energy consumption among nodes in [19]. Transmission based schemes have used in [20] to stop energy depletion and to upgrade the network lifetime by restricting the duplication of messages. By resizing the cluster size for better energy consumption rates have represented by authors in [21]. In [23] the energy consumption of nodes have been computed for different regions at different times . Bencon in [24] have considered different heterogeneous clustering techniques where many rings contain sensor nodes with variant initial energies. The transmission of data in inner rings is direct from cluster heads to the base station, but the Chs in outer ring transmits the data to the CH of inner ring and then the inner ring CH forwards it to the base station.. Authors in [26] have divided the network area into different sized circular regions by calculating the density of nodes. The Chs are taken from the inner circular regions at the first stage . When the battery energy of the CH at inner regions deplete then the Chs are selected from outer regions.

Gateway based approaches

Extraordinary nodes called Relay nodes or gateway nodes with excess energy than the normal nodes have been suggested by some researchers in [7-9]. Gateway based energy effecient method have been proposed in [10], where the duties of a cluster head are performed by a gateway node. The distance and residual energy parameters are considered in some distributed algorithms such as for fault tolerance routing. Here the next hop gateways have been used to balance the energy utilisation.

A load balancing model based on gateway nodes was proposed in [11], which replaces the sensor nodes in place of gateways, to minimize the load of gateway nodes. The distributed gateway based cluster head scheduling algorithm have been suggested by Kannan et al. [12] splitted the network into primary and secondary tiers by using received signal strength indicator of the sensor nodes from the base station. Cluster head is elected in the primary tier and the cluster member nodes are present in the secondary tier.The gateway node operates in between the two tiers.

Koteswararao et al. [14] also proposed cluster routing by avoiding energy depletion of gateway nodes. In this model, one cluster head is associated with one gateway node. (GDEEC) Gateway based distributed energy effecient clustering protocol have been proposed by Sheenam et al.[15]. The authors proposed the facility of transmitting data to any one of the gateway node which is nearer. If a cluster head selects a far gateway node then the energy will be consumed more. A multi level hierarchy model have proposed by Taruna et al.[13] with the unlimited battery power in the gateway nodes. But, in this model the no of cluster heads are fixed.

Gateway based sensor networks in wireless networks are supported by real world. In our protocol, as the size of the network increases the no of gateway node also increases. The cluster heads are possible to transmit the data to their own area gateway nodes. The gateway nodes failure is not possible as they are not energy constrained. Due to the unlimited battery power supply in the cluster heads and the gateway nodes, more no of nodes are taken care by the gateway nodes.

3. Energy consumption model

The first order radio model [1] is used to transmit the dat between the sender and the receiver. The distance is denoted by `d` and the transmission energy is denoted by E_{trans} . When the distance is far away when compared , the multiple-path fading channel model is used(ε ; $d4$ power loss), or the free space multiple-path fading channel model (εtwo-ray-amp;d^4 power loss) is used, or the free space model (εfriss-amp; d^2 power loss) is used [7]. The `r` no of messages from `d` are transmitted as follows:

$$E_{trans}(r,d) = \begin{cases} r * E_{elec} + r * \varepsilon_{friss\text{-}amp} * d^2, d < d_0 \\ r * E_{elec} + r * \varepsilon_{two\text{-}ray\text{-}amp} * d^2, d > c \end{cases} \quad (1)$$

The `r` no of messages are received over distance d is as follows:

$$E_{recv}(r) = E_{elec} * r \quad (2)$$

Where E_{trans} denotes the energy consumption while receiving the m data bits and E_{elec} is the energy used to turn on the sender and receiver circuit board. The amplifier energies such as free space and multipath models are denoted by $\varepsilon_{friss\text{-}amp}$ and $\varepsilon_{two\text{-}ray\text{-}amp}$. The distance d_0 denotes threshold value and the energy consumption in the data aggregation phase (E_{agg}) of M messages with `r` no of bits.

$$E_M(M, r) = r * M * E_{agg} \quad (3)$$

4. Deployment of nodes

Our protocol consists of sensor nodes, cluster head, cluster members and the gateway node. All the nodes are normal except the gateway nodes , but after the clustering process, some sensor nodes are elected/selected as Cluster heads and some as Cluster members. A cluster member consumes its battery power in sending the packets whereas a cluster head consumes its battery power in transmitting the data to gateway node and base station, receiving the data from its cluster members and data aggregating the received data. Basic assumptions are:

1. N no of homogeneous sensor nodes are equipped with equal initial energy and a unique identifier in a two dimensional area.

2. The base station is placed at the middle of the network area, surrounded by cluster members, CHs and gateway nodes.

3. Cluster members, Cluster heads, Sink node, Gateway nodes are stationary.

4. Sink node and Gateway nodes have unlimited power

supply.

5. GPS device or any location finding algorithm is used by sensors and gateway nodes to access the location information.

Fig 1. Two dimensional view of 500m*500m area

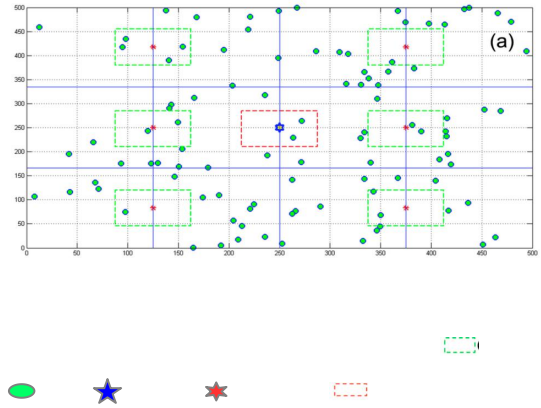
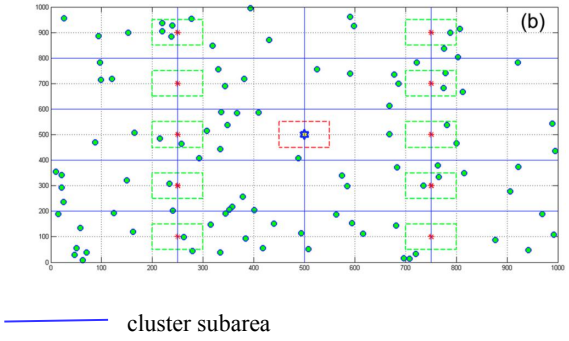


Fig 2. Two dimensional view of 1000m*1000m area



5. Multi -gateway based protocol

Though the Leach protocol[1] is best in consuming the energy , it leads to energy depletion problems. The cluster size (small or large) is not estimated. The arrangement of nodes in Leach protocol is not satisfactory in the case of large clusters. The cluster heads and cluster member node s are situated far away from the sink. So, the transmission distance increases and the nodes will exhaust quickly. After some rounds the nodes completely exhaust and they die.

The transmission distance between the sink and the CH has been reduced by placing a gateway node between them. Network lifetime is improved as the energy consumption is reduced in transmission . Leach protocol uses direct and single hop communication to transmit the data to the sink but in our protocol multihop communication is used.

a) Partitioning area into subareas

If the network area is not divided/partitioned then the Chs will be scattered in the network i.e. Some Chs will be nearer to the sink and some will be far away to the sink. While transmitting the data, the Chs nearer to the sink do not exhaust quickly but the Chs far away to the sink deplete its energy for some rounds. So, the network area is divided into subareas. The no of subareas depends on the size of the area. In M-GEAR protocol[5], the no of regions is fixed. The whole area is partitioned into base station subarea(BSS), gateway subarea(GS), and cluster subarea(CS). Each CS has its own clustering process and CH. The distance between the sensor nodes and the Chs is also minimized. As a result of this subareas, energy consumption, communication cost is reduced, and optimal routing is acheived.

Partitioning 100m*100m area to 4 CS, 2 GS and 1 BSS is possible as it is considered a small area in network. 1 GS is placed between every two CSs. But, to increase the network lifetime the same area is partitioned into 8 CS, 4 GS and 1 BSS.

b) Arrangement of Gateway nodes and Sensor nodes

The gateway nodes are the control nodes and the mediators between the CH and sink, sensor nodes and the sink. The gateway nodes in GS are placed at equal distance from the BSS. To reduce enrgy consumption , large network areas are partitioned into more subareas. The proportions of all the subareas are equal. As the base station is placed at middle of the area, all the gateway subareas can transmit the data from equal distance.

Our algorithm is feasible to partition into many subareas based on the network area. Suppose, if the network area is 500m*500m then it can be partitioned into 12 CS, 6 GS and 1 BSS. The way of partitioning is left to the user by considering the constraints such as cost, lifetime, energy consumption. A gateway node sends a request to all of the nodes in the area through HELLO packet. The sensor nodes receive a packet and sends its information to the gateway node. The gateway node sends their corresponding subareas by calculating the distance from itself and the base station. All the information of the nodes such as initial energy, residual energy, unique id, location, distance to base station, distance to gateway, etc. are stored in their own node table by gateway node.

c) Area partitioning method into subareas

The size of basestation subarea and gateway subarea changes according to network area i.e. If area is increased then both subareas increases, if it decreases then both decreases. If the network area is partitioned into 100m*100m then the BSS and GS are of 20m*20m with 4CS, 2 GS and 1 BSS. Cluster subareas are formed by partitioning the midpoint of the xy coordinates. Arrange the basestation at the middle of the area (in between all of the four CS) and form it as subarea called BSS. Place a gateway node at the midpoint of the line straight forward to the BS and form that area as GS. Arrange anothe gateway node at the midpoint of the line straight backward to the BS and form that area as another GS. If the CS are of 8 then consider the midpoint of the xy coordinates and partition the area into 4 CS. After partitioning into 4CS take the minimum and maximum xy coordinates to intersect the area again into another 4 CS via the diagonals. The length of GS and BSS is of 10m*10m.

Our protocol mainly considered 500m*500marea to partition into subareas same as 100m*100m. All of the subareas are equally partitioned by minimum and maximum values of xy coordinates. The Cluster subareas are of 12, the gateway subareas are of 6 and the 1 BSS.

6. Cluster Setup Phase

Setup of clusters is same as Leach[1] where Chs are selected by the nodes in the CS. In CS, the assumed no of Chs are determined with a probability of P_j in the current round cr. Let Tch be the number of Chs in CS and Tn denotes the total no of nodes in the CS.

$$\sum_{j=1}^{Tn} P_j = Tch \qquad (4)$$

Tn_j denotes the probability of a node to be selected as a CH in CS around cr.

$$P(Tnj) = \left\{ \frac{Tch}{Tn\text{-}Tch \times (Crmod\ Tn/Tch)} \right\} \qquad (5)$$

S is the group of non-chs in (cr mod Tn/Tch) rounds.
$P(Tn_j) = 1$, not selected as CH. $P(Tn_{j)} = 0$, selected as CH.
(cr mod Tn/Tch) denotes nodes selected as Chs in CS.

In CS the total no of nodes which satisfy to be CH at current round cr is denoted by

$$Q(cr) = Tn\text{-}Tch*(cr \bmod Tn/Tch) \qquad (6)$$

In each and every CS the energy is consumed in equal number after each round. The CH in eachh CS is independant and sends an ADV message to its corresponding sensor nodes. The nodes reply to CH with an ACK message and becomes cluster members of that CS.

7. Data Collection and Transmission Phase

The CH in CS receives data from cluster members aggregates, sends the data to the gateway node in its GS. The gateway node aggregates the data from different Chs, from nodes in its own GS and then forwards to the basestation. The data is transmitted to the gateway node if the distance between the CH and the basestation is more otherwise the CH directly forwards the data to the basestation. The nodes in the GS send data to the gateway node. The nodes in the CS transmit the data to the Chs , again to the gateway node and finally to the basestation avoiding direct communication. Multi hop transmission exists in this case, but the energy of all nodes is depleted in a uniform way

8. Proposed Algorithm

The notations used in the Algorithm are as follows,

(a) N = the no of sensor nodes in the area.
(b) CS = no of cluster subareas.
(c) E_i = Initial energy.
(d) E_{ch} = CH energy in CS
(e) E_{cm} = Cluster member node energy in subareas.
(f) E_{nsn} = Normal sensor node energy.
(g) Area = network area.
(h) $A_{basestation}$ = Basestation area.
(i) $A_{gateway}$ = gateway area.
(j) D_{CHG} = distance between CS and GS.
(k) D_{CHS} = distance between CS and BSS.
(l) E_{trans} = Energy consumption while transmitting data.
(m) E_{recv} = Energy consumption while receiving data.
(n) E_{agg} = Energy consumption while aggregating data.

1. Initialize CS, N, E_{TX}, E_{RX}, E_{DA}, k, E_i, Area, A_{sink}, $A_{gateway}$
2. $E_{ch} \leftarrow E_i$, $E_{cm} \leftarrow E_i$ and $E_{nsn} \leftarrow E_i$
3. Partition the Area into CS subareas.
4. Arrange Basestation at midpoint of Area.
5. Set $A_{basestation}$ as basestation area.
6. while a gateway node is not placed do
   6.1. for(j=1 to CS) do
      At midpoint of two CS arrange a gateway node.
      Arrange $A_{gateway}$ around the gateway node.
      endfor
endwhile.
7. (for j= 1 to CS) do
   7.1. Cluster setup phase in CS
   endfor.
8. Nodes in $A_{basestation}$ transmit data to basestation.
9. Nodes in $A_{gateway}$ transmit data to gateway node.
10. $E_{nsn} \leftarrow E_{nsn} - E_{Trans}$
11. Cluster member nodes in CS transmit data to their CH.
12. $E_{cm} \leftarrow E_{cm} - E_{Trans}$
13. $E_{ch} \leftarrow E_{ch} - E_{Recv}$
   13.1. for j = 1 to CS then
      Calculate D_{CHG} and D_{CHS}.
      13.1.1. if ($D_{CHG} > D_{CHS}$) then
      CH sends aggregated data to the base station
      else
      CH sends aggregated data to the gateway.
      13.1.2. $E_{ch} - E_{ch}(E_{agg} + E_{Trans})$
      endif
   13.2. Basestation gets the aggregated data from all the gateway nodes.
   endfor.

9. Simulation

The quality of the protocol is measured in terms of throughput, network lifetime, residual energy and the no of packets transmitted to the sink by using optimal and shortest routes. GSEP and LEACH protocols are used for comparision to prove the effeciency of the protocol.

Table 1. Network Simulation setup parameters

Parameter	Value
Propagation	Two ray ground
Field Size	500m*500m
No of nodes	100
Initial energy of sensor node	100J
Data packet size	512 bytes
Simulation Time	50sec
Transmission time	0.01
The energy for data aggregation	6nJ/ bit/ signal
Sleep power	10mW
Routing protocol	AODV

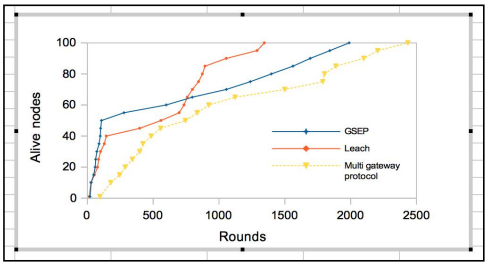
The sensor node sends data to its correponding CH at each and every round . The aggregation of data is performed by CH and it sends data to the gateway node. The gateway node aggregates data from normal nodes and the received data from Chs in the GS. The gateway node transmits the data to the basestation after the completion of the data aggregation process. The data is transmitted directly to the basestation if CH is nearer to the sink. If CH is not nearer to the basestation, the data is transmitted to it through the gateway node. This increases the throughput, reduces the energy consumption and packet delivery time. Moreover, the normal sensor nodes, CH, gateway nodes can transmit the packets to the sink via optimal shortest routes instead of long and unknown routes.

FND denotes the round number when the first node in the network deplete its energy and dies(stability period). AND denotes the round number when all nodes die. The 50% of the network depletion is denoted by HND. The total remaining energy in the network per round is defined as the residual energy.

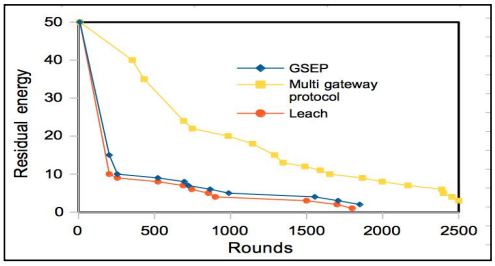
Table 2. Protocol performance of 100 nodes for 500*500 m^2 area (NETWORK LIFETIME IN ROUNDS)

	FND	HND	AND
Proposed protocol (6gw)	95	560	2435
GSEP	20	107	1989
LEACH	15	100	1345

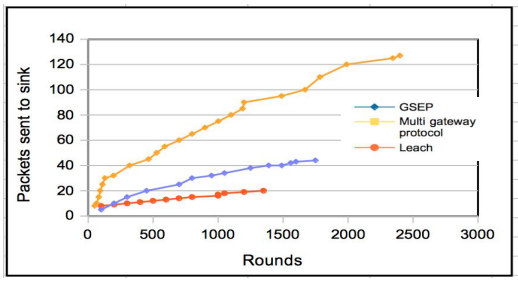
The first node dies very earlier in all the protocols. In LEACH, FND is in 15 round and in GSEP first node dies in 20 round. But in our proposed protocol FND is in 95 round. Our protocol and GSEP is based on gateways but LEACH is not gateway based. The correct placement of gateway nodes and their number improves the network lifetime. Fig 3. illustrates the network lifetime in rounds.



Before starting the transmission, a node always computes the distance between itself and all gateways and then selects the gateway node with the minimum distance. In GSEP the no of gateway nodes are more but all of them reside at the edge of the network. The distant nodes deplete their energy faster, when this happen the no of live nodes decreases in the network and all the nodes have to find the alternative paths for transmission. In our protocol, the distance between the CH and gateway node is less because a separate gateway node covers a part of the area. Due to this, energy is consumed less and alive nodes in the network affects the no of packets transmitted to the sink. Fig. 4 illustrates the residual energy per round.



Our protocol consists of more alive nodes and more no of packets (Fig 5.) are transmitted to the basestation than other protocols.



Conclusion

We have proposed an multi-gateway-based protocol to reduce energy consumption, to transmit the data quickly by shortest paths. The network lifetime is increased and transmission distance is reduced by partitioning the area into subareas, and by placing the gateway nodes at correct positions. As the Chs select nearer GS to transmit the data to BSS better network performance is acheived. Energy consumption is reduced in remote areas of network due to GS in between the CS and BSS. Our protocol is better in acheiving optimal routes, minimizing transmission energy, low energy consumption, sufficient residual energy for next rounds and saves a lot of transmission energy.

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