Functional Analysis of Cluster-Based Routing Protocols for Wireless Sensor Networks

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Abstract

Wireless Sensor Networks (WSNs) have gained worldwide attention in recent years with the wide deployment of smart sensors. These sensors are small, with limited processing resources and limited battery life. Sensor nodes can sense, measure and gather information from the environment and based on some local decision process, they can transmit the sensed data to the base station. WSNs are large networks made up of numerous number of sensor nodes with sensing, computation and wireless application capabilities.

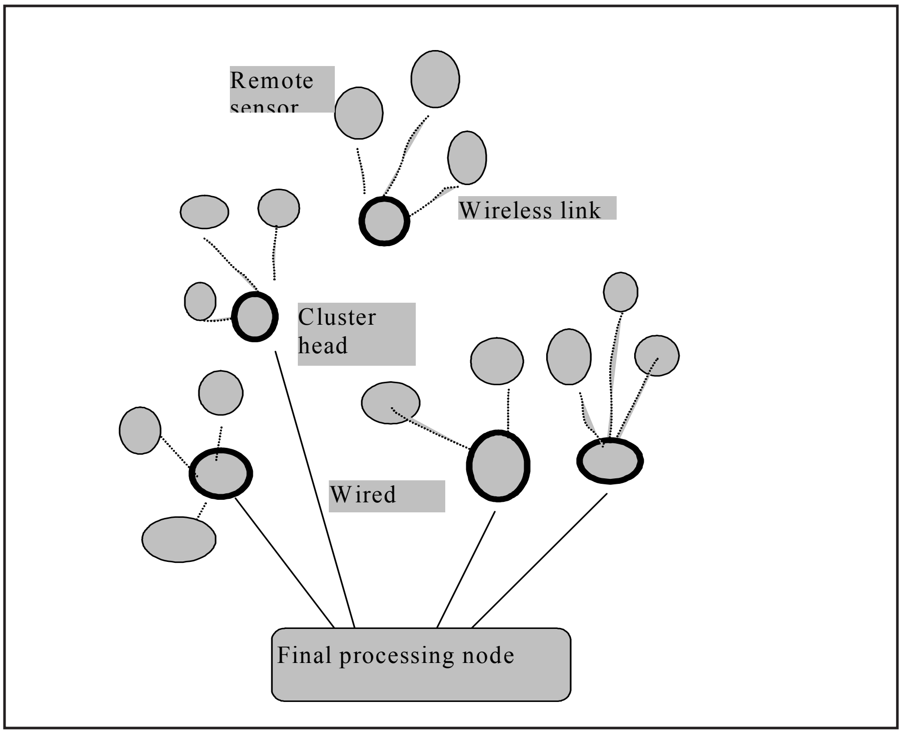
Due to the non-uniform node distribution, the energy consumption among nodes is more imbalanced in cluster-based wireless sensor networks. Here we give a brief summary of the analysis and simulation of cluster-based routing protocols, based on the energy consumption and conclude that the non-uniform node distribution protocols like EADUC and EADC can give better energy consumption than the uniform node distribution algorithm like LEACH.

Keywords

Wireless Sensor Networks, cluster-based routing protocols, non-uniform node distribution protocols

Introduction

A wireless sensor network consists of hundreds or thousands of inexpensive, low-powered sensing devices with limited memory, computational and communication resources [1].



As sensor nodes have limited and non-rechargeable energy resources, energy is a very scare resource and has to be managed carefully in order to extend the lifetime of the sensor network.

It has been proved in [3-6] that clustering is an effective scheme in increasing the scalability and lifetime of wireless sensor networks. In clustering scheme, there are two kinds of nodes in cluster, one cluster head (CH) and several cluster members (CMs). Cluster members gather data from the environment periodically and send the data to the base station (BS). There are two kinds of communication between cluster heads and BS, single-hop communication clustering and multi-hop communication. In multi-hop communication clustering algorithm[2], the energy consumption of cluster heads consists of the energy for receiving, aggregating and sending the data from their cluster members(intra-cluster energy consumption) and the energy for forwarding data for their neighbor cluster heads (inter-cluster energy consumption).

In clustering networks, the imbalanced energy consumption among nodes is the main factor affecting the network lifetime. In case of uniformly node distributed approaches, clusters have appropriate number of members and coverage areas. Thus, the intra-cluster energy consumption of cluster heads can be balanced. For cluster members, the maximum communicate distances of cluster members are approximate, because of the uniform cluster sizes. Thus the energy consumption of uniformly distributed cluster head set can balance the energy consumption among nodes and finally prolong the network lifetime [8].

In non-uniform node distribution [8] case, a cluster-base routing algorithm called energy-aware clustering algorithm (EADC) is developed for balancing the energy consumption among cluster heads by adjusting the intra-cluster and inter-cluster energy consumption of cluster heads. Therefore, this can achieve the balance of energy consumption among nodes and prolong the network lifetime.

Uniformly Distributed Clustering Protocols

Low energy adoptive clustering hierarchy (LEACH) is a routing protocol [1] for data gathering in wireless sensor networks. In LEACH, each node independently elects itself as a cluster head with a probability. Cluster heads receive and aggregate data from cluster members and send the aggregated data to the BS by single-hop communication. In order to balance the energy consumption, the role of cluster head is periodically rotated among the nodes. LEACH protocol is simple and does not require a large communication overhead. However, the performance in heterogeneous networks is not very well, because it elects cluster heads without considering the residual energy of nodes. .

To meet these requirements, the threshold T(n) of a competing node n can be expressed as follows:

T(n)= 0 , if $n \notin G$ -(1)

Where the variable G represents the set of nodes that have been selected to become cluster heads in $1/p$ rounds, r is the current round, $r < G$ and p is the predetermined parameter representing the cluster head probability.

Upon cluster head parameter, each cluster head creates and distributes schedule. CH also selects a CDMA code which is distributed to all members of cluster.

Shortcomings of LEACH

The assumption that all nodes can reach the BS in one heap may not be realistic. A short steady state period increases the protocol's overhead, where as a long period may lead to cluster based energy depletion .The Extended LEACH(XLEACH) protocols takes into account the nodes energy level in the cluster head selection process.

$$T(n) = p/(1 - p(r mod(1/p)))$$

$$(E_{n,current}/E_{n\max}) + (r_{n,s} div 1/p)$$
$$(1 - (E_{n,current}/E_{n\max}))] \quad -(2)$$

Where is current energy.

$E_{n,\max}$ is initial energy

The performance in heterogeneous network is not very good, because it selects cluster heads without considering the residual energy of the nodes.

EADEEG

It selects CH based on the ratio between the average residual energy of neighbor nodes and the residual energy of the nodes itself [7] which can achieve a good cluster heads distribution and prolong the network life time. It generates isolated points.

BPEC

It is a distributed energy saving clustering algorithm [8] which select cluster heads by the ratio between the average residual energy of neighbor nodes and the residual energy of the node itself as its primary probability and the nodes degree as its subsidiary probability. It can avoid the 'isolated points' problem in EADEEG and keep all cluster heads connected.

The above general algorithms based on the assumption that all the nodes are uniformly distributed in the network. However, in networks with non–uniform node distribution we have to consider the network coverage problem.

Non-uniform Node Distribution Clustering Protocols

EADC is an energy-aware clustering algorithm. In order to elect cluster heads with higher energy, the parameter of cluster head competition in EADC is based on the ratio between the average residual energy of neighbor nodes and the residual energy of the node itself. Moreover, cluster heads broadcast head messages using the same competition range to construct clusters of even sizes. Thus, the energy consumption among cluster members can be balanced well.a)Network model

To this network model we adopt a few reasonable assumptions as follows:-

1. There are N sensor nodes that are distributed in max square field.

Table 1. Description of control message

Message	Description
Node_msg	Tuple (Selfid, selfenergy)
Head_msg	Tuple (Selfid)
Join_msg	Tuple (Selfid, headid)
Schedule_msg	Tuple (Scheduleorder)
Route_msg	Tuple(Selfid, selfenergy, membernum, disttoBS)

2. All the nodes and the BS are stationary after deployment.
3. All the sensor nodes can be heterogeneous, but whose energy cannot be recharged.
4. All the sensor nodes are location-unaware.
5. All the nodes can use power control to vary the amount of transmit power.
6. The BS is out of the sensor field. It has a sufficient energy resource and the location of the BS is known by each node.

$\in_{fs}$ $ET_x(l,d) = l*E_{elec} + l*\in_{fs}*d^2, d < d_0$

7. Each node has an identity (id).

To transmit an l-bit data to a distance d, the radio expands energy

-(3)

$$l*E_{elec} + l*\in_{mp}*d^4, d \geq d_0$$

where E_{elec} , fs and mp mp are parameters of the transmission/reception circuitry. Depending on the distance between the transmitter and receiver, free space ( ) or multi-path fading ($\in_{mp}$) channel models is used. While receiving, the radio expands energy

$$E_{Rx}(l) = l*E_{elec}$$

Cluster-based routing protocol

This protocol contains an energy-aware clustering algorithm EADC and a cluster-based routing algorithm. In order to elect cluster heads with higher energy, the parameter of cluster head competition in EADC is based on the ratio between the average residual energy of neighbor nodes and the residual energy of the node itself. Moreover, cluster heads broadcast head messages using the same competition range to construct clusters of even sizes. Thus, the energy consumption among cluster members can be balanced well. However, the even cluster size also makes the energy consumption among cluster heads imbalanced, due to non-uniform distribution of nodes. Cluster heads in dense areas have more member nodes, so they have high intra-cluster energy consumption. For this, an inter-cluster energy-efficient multi-hop routing protocol is proposed, in which cluster heads select the neighbor cluster head with higher residual energy and a smaller number of cluster members as the next hop to balance the energy consumption among cluster heads.

EADC details:

The whole process is divided into three phases: information collection phase, whose duration is T1; cluster head competition phase, whose duration is T2 ; cluster formation phase, whose duration is T3 .

Information collection phase:

The duration of the phase is defined as T1 , during which each node broadcasts a Node_msg with the following two values: one is the node id, and the other is the residual energy of this node within radio range r. At the same time, it receives the Node_msg from its neighbor nodes, according to which, each node si calculates the average residual energy Eia of its neighbor nodes by using the following formula.

$$E_{ia} = \frac{1}{d}\sum_{j=1}^{d} E_{jr}$$

where E_{jr} denotes the residual energy of s_j one neighbor node of s_i and d is the number of all neighbor nodes of s_i. For each node,we give the following formula using which to calculate its waiting time for broadcasting Head Msg message.

$$t_i = \frac{E_{ia}}{E_{ir}} T_2 V_r \ , \qquad E_{ir} \geq E_{ia} \qquad \text{-(4)}$$

$$T_2 V_r \ , \qquad E_{ir} \prec E_{ia}$$

Cluster head competition phase:

When T_1 has expired, EADC begins the cluster head competition phase whose duration is T_2 . In this phase, if node s_i receives no Head Msg when timer t_i expires, it broadcasts the Head Msg within radio range Rc to advertise that it will be a cluster head. Otherwise, it gives up the competition. we will construct a routing tree on the elected cluster set. The duration of the phase is T_4 . This multi-hop communication from cluster heads to the BS will further reduce the energy consumption

Cluster formation phase:

After T_2 expires, the last phase of EADC is the cluster formation phase, we define the duration as T_3 . In this phase, each non-cluster-head node chooses the nearest cluster head and sends the Join Msg which contains the id and residual energy of this node. According to the received Join_Msgs, each cluster head creates a node schedule list including the Schedule Msg for its cluster members

Cluster-based routing algorithm:

In this phase, we will construct a routing tree on the elected cluster head set. The duration of the phase is T_4 . This multi-hop communication from cluster heads to the BS will further reduce the energy consumption. Each cluster head broadcasts a Route Msg message within the radio radius Rr with the following values: the id, the residual energy, the number of cluster members and the distance to the BS of itself. According to [7], if nodes' radio radius Rr for communicating with other nodes is twice larger than its covered range Rc, and if these nodes can fully cover the monitoring area, then the connectivity can be maintained. As we will analyze in the Theorem 2, the cluster heads generated by EADC can cover all network nodes. Therefore, to ensure the connectivity of cluster heads, we set the radio radius $R_r = 2R_c$. If the distance from cluster head si to the BS d(s_i , BS) is less than DIST TH, it chooses the BS as its next hop. Otherwise, it chooses its next hop according to the received Route_Msgs. Cluster head si chooses the neighbor cluster head with higher residual energy, smaller number of cluster members and no further away from the BS as its next hop. Here, we give the formula of the indicators "relay" when cluster head s_i chooses cluster head s_j as its next hop.

$$relay(s_i, s_j) = \alpha E_{jr} / E_{\max} + (1-\alpha) 1 / s_{j(cm-num)} \quad \text{-(5)}$$

Here E_{jr} is used to measure the residual energy of cluster head s_j and we define $E_{\max}$ as the maximum initial energy of node in the network. $s_{j(cm-num)}$ is the number of cluster members of s_j and α is a real value uniformly distributed in . We can see from the formula, the cluster head with higher residual and fewer cluster members will have a larger "relay". Cluster head s_i chooses the neighbor cluster head with the largest "relay" and closer to the BS as its next hop. If there are more than one cluster heads have the largest "relay", cluster head s_i chooses the one with larger $d(s_j, BS)$ to avoid the premature death of the cluster heads close to the BS, due to forwarding too much data. Data transmission phase:

Intra-cluster communication:

The probability that only one node broadcast the Head Msg within the cluster range will fulfill the following inequality

$$P \geq C^0_{n_{\exp}-1} (1 - (\Delta t / T_2))^{n_{\exp}-1} \text{ P}$$

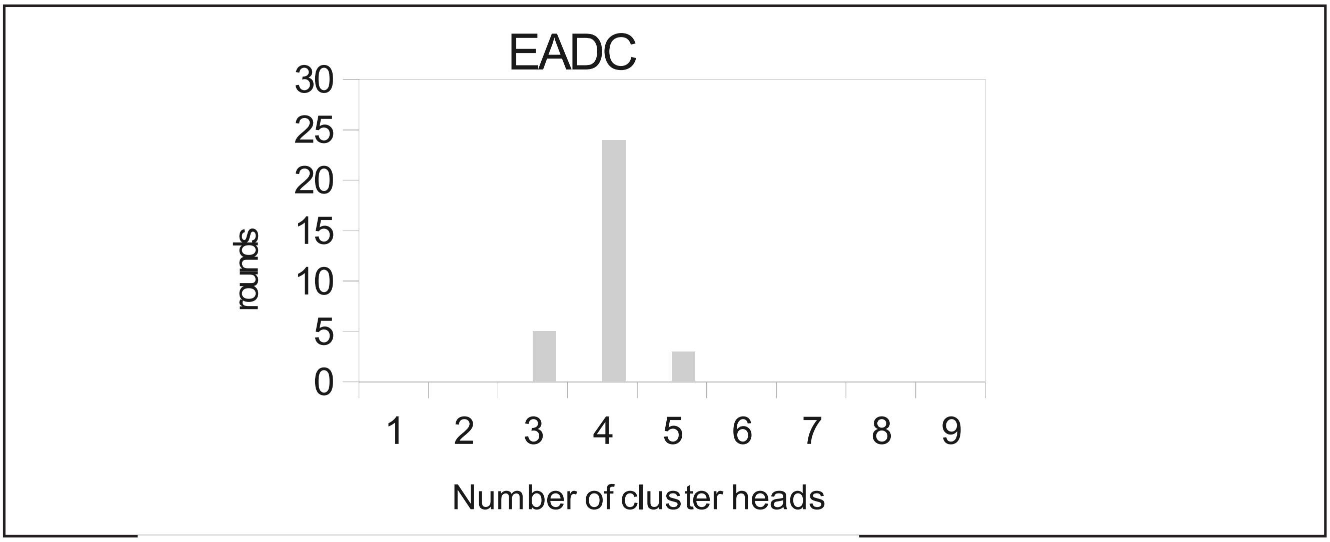
For example, we assume that $r = 15m$, , $N = 100$, $t = 10ms$, according to the above inequality, we can obtain $P \geq 0.994$ it means the probability that multiple nodes broadcast the Head Msg at the same time is rather low here is one and only one cluster head within any Rc range. Thus, the cluster heads are distributed evenly, and the energy consumption among cluster member nodes is balanced. Routing algorithm analysis The value of DIST TH determines the number of cluster heads which communicate with the BS directly. In the case that DIST TH is smaller than the minimize distance between the BS and the network field, there are no cluster heads communicate with the BS. As a result the data from the network cannot be transmitted to the BS leading to an unavailable network. In the case that DIST TH is larger than the minimize distance between the BS and the network field, if DIST TH is small, the number of cluster heads which communicate with the BS directly will be small and the forwarding load of these nodes will be larger correspondingly. As a result, these nodes will die prematurely which can reduce the network lifetime. On the contrary, if DIST TH is too large, and even larger than the maximum distance between the BS and the network field, all the cluster heads communicate with the BS directly which will undoubtedly result in a waste of energy. Therefore, the value of DIST TH should be controlled in an appropriate range. In the case that cluster heads distribute uniformly in the net-work, the number of cluster members of clusters is uneven due to the non-uniform node distribution. Therefore, the intra-cluster energy consumption of cluster heads in densely populated parts of the network is larger than that of cluster heads in scarcely covered areas. As the energy consumption of cluster heads consists of intra-cluster energy consumption and inter-cluster energy consumption. We mitigate the imbalance of intra-cluster energy consumption by adjusting inter-cluster energy consumption. Cluster heads in scarce areas take more forwarding tasks to achieve a balance of total energy consumption of cluster heads. Taking into account the heterogeneity of the nodes, each cluster head chooses the cluster heads with more residual energy as its next hop. High-energy cluster heads take more forwarding tasks, which prolongs the network lifetime by taking full advantage of the heterogeneity of nodes. In formula (5), the value of "relay" is affected by two factors: sj · Er and sj · Nummem making a cluster head choose a cluster head with higher energy level and fewer cluster members as its next hop. Constant (determines which factor is more important in choosing the next hop.

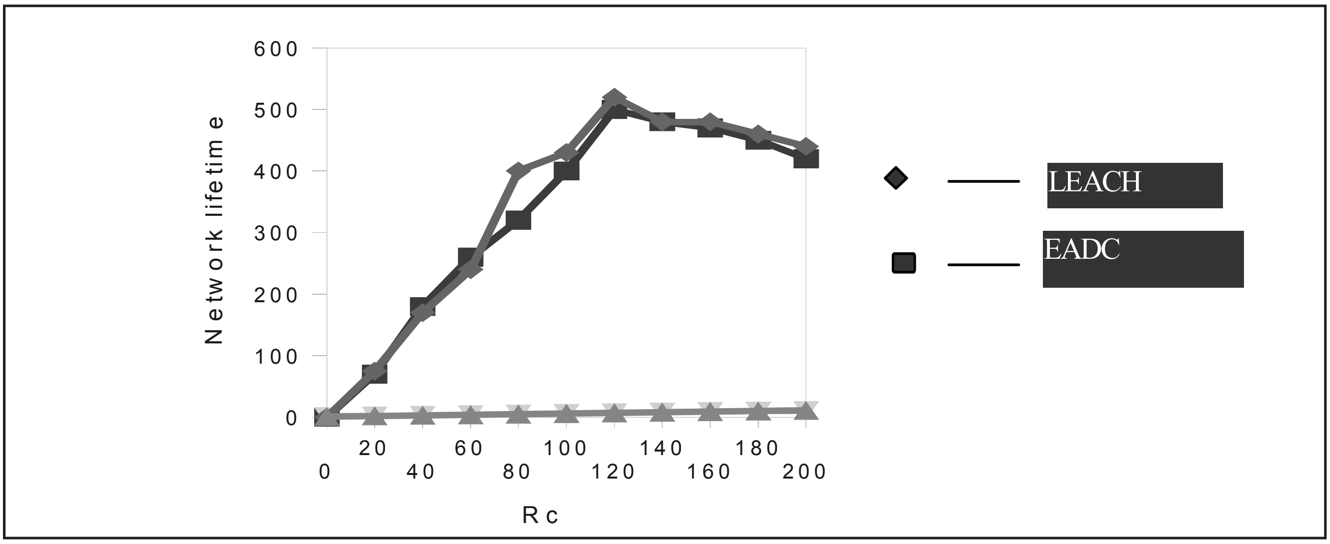
SIMULATION:

The simulation were performed in NS-2, every simulation result shown in the paper is the average of 200 independent experiments unless otherwise specified. Where each experiment is done in different scenarios and two scenarios are chosen to be shown as follows:

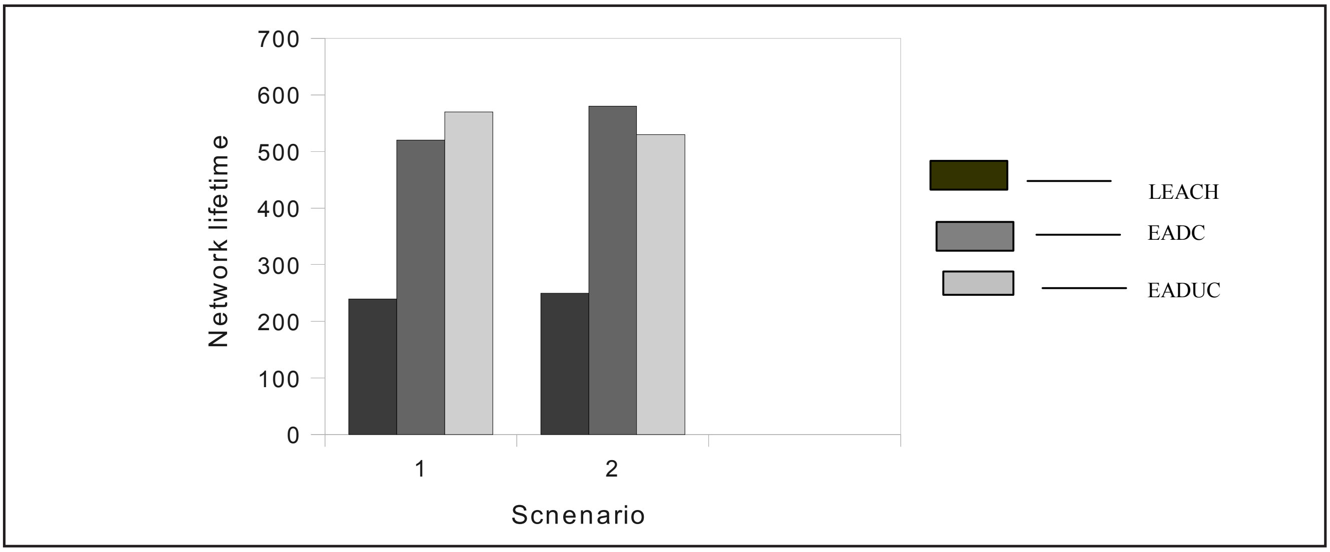
Scenario 1 100 nodes are randomly deployed over a 200 m×200 m field.

Scenario 2 100 nodes are non-uniformly deployed over a 200 m×200 m field.





(Formation of cluster heads in LEACH & EADC)



(Figure of network lifetime in LEACH, EADC & EADUC)

It can be seen that EADUC and EADC perform far better than LEACH in prolonging network lifetime. The reason is that LEACH does not take into account the energy of nodes while choosing cluster heads. In this heterogeneous scenario, the low-energy nodes restrict the network lifetime, and the energy of high energy nodes is wasted.

Conclusion

Here in this non-uniform node distribution, the clustering algorithm balances the energy consumption among cluster members by constructing equal clusters. Each cluster head chooses a cluster head with higher residual energy and fewer cluster members as its next hop. The imbalanced energy consumption caused by non-uniform node distribution is solved by increasing forwarding task of the cluster heads in sparse areas.

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