Non-uniform hierarchical clustering method for improving lifetime of energy constrained Wireless Sensor Networks

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Abstract— ***The field of Wireless sensor networks is the main attraction of various researchers due to its practical applications in daily life. It comprises of sensor nodes geographically distributed over an area, which sense the environmental conditions like temperature, humidity etc and pass this information to the sink .As these nodes are non-rechargeable means energy constrained, so main focus of the researches in this field is to make it energy efficient as par as possible and prolong its network lifetime .Clustering is one of the hierarchical routing technique which is used to make the network energy efficient. It can be further improved by adopting non-uniform cluster size techniques and sub-clustering in farther as well as larger clusters. Cluster heads of distant clusters will need to communicate with only sub-cluster heads which further covers the entire cluster members. This proposed model effectively improves lifetime over LEACH.***

Keywords— Wireless Sensor Networks, effective lifetime, sub- clustering, cluster head and residual energy.

I. Introduction

As sensor nodes have limited and non-rechargeable energy resources, energy is a very scarce resource and has to be managed carefully in order to extend the lifetime of the sensor networks [1]. In recent years, researchers have done a lot of studies and proved that clustering is an effective scheme in increasing the scalability and lifetime of wireless sensor networks [2-5]. In clustering schemes, there are two kinds of nodes in one cluster, one cluster head (CH) and several cluster members (CMs). Cluster members gather data from the environment periodically and send the data to cluster heads. Cluster heads aggregate the data from their cluster members, and send the aggregated data to the base station (BS). There are two kinds of communications between cluster heads and the BS, single-hop communication and multi-hop communication. In multi-hop communication clustering algorithms, 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) [1].

Cluster-based communication protocols have significant savings in total energy consumption of a sensor network. In these protocols, creation of clusters and assigning special tasks to cluster heads can greatly contribute to overall system scalability, lifetime, and bandwidth efficiency [6].Clustering reduces the energy dissipation in the network by aggregating the messages of cluster members ,thus reducing the number of messages being transferred to the sink.

Moreover, the size of the clusters must be optimum as exploiting both small and large clusters would make the sensor networks energy inefficient. When the cluster size is very large (e.g. one cluster of whole network), the nodes have to transmit data very far to the cluster head, consuming more energy. And when the cluster size is very small (e.g. one node in each cluster) the number of messages to be transferred to the sink increases, so the energy saving by aggregation would be reduced, thus resulting in more dissipation of network energy. [6]

Clustering is grouping of sensor nodes. Here, each cluster is managed by a special node or leader, called cluster head (CH), which is responsible for co-ordinating the data transmission activities of all sensors in its group.CH is decided with a different probability [7,8].The selection of cluster head in the clusters contribute a lot to the overall efficiency. In clustering networks, the imbalanced energy consumption among nodes is the key factor affecting the network lifetime. In order to balance the energy consumption among nodes, clustering algorithms for networks with uniform node distribution tend to construct uniformly distributed cluster heads, so that the clusters have the approximate number of members and coverage areas. Thus, the intra-cluster energy consumption of cluster heads is approximate and the 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 cluster members can be balanced too. Therefore, the uniformly distributed cluster head set can balance the energy consumption among nodes and finally prolong the network lifetime [1].

Leach is the very basic protocol used for uniformly distributed nodes. It is simple and does not require a large communication overhead. But its performance in heterogeneous networks is not very well; because it elects cluster heads without considering the residual energy of the nodes .To solve this problem. Researchers improved LEACH and proposed new algorithms [1, 9-11]. Also, LEACH has a disadvantage of non-uniform energy consumption by the cluster heads, so they dissipate their energy quickly. Its proposed solution is non uniform clustering.

II. MOTIVATION

LEACH is the very basic low power clustered routing algorithm. It is based on the concepts of rounds. Each round has two phases- Initialization phase and set-up phase. In initialization phase, clusters are formed and cluster heads are selected on the basis of probability function. In set up phase, communication take place between the nodes and the cluster heads which further forward to the sink. LEACH is energy efficient as cluster heads are re-elected after every round.

But it has one of the disadvantages of non-uniform energy consumption by cluster head. As nodes are homogenous and clusters are uniform, so the CH at large distances covering the same member of nodes, consume more energy to transmit data to the sink.

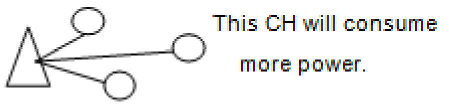

Figure 1. Uniform Cluster Size

In figure (1), we can see that in clusters of uniform size, the cluster heads at larger distances from the sink will die earlier as compared to the near ones. So, the proposed solution [12] is to use non-uniform clusters, that is, convergence radius, which is near to the sink is larger and as we move away, it gets smaller which is shown in figure (2).

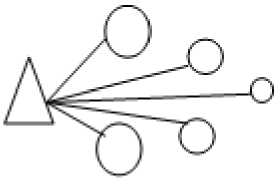

Figure 2. Non-uniform cluster size (proposed in [12])

The cluster head node, which is near to the sink node, consumes greater energy within the cluster than the cluster head node which is far away from the aggregation node. That can make all the energy consumed by cluster head nodes are close to the same. Thus it can balance the energy consumption of the cluster head node. The CH node should be dynamically selected to avoid the energy consumption of a single cluster head node.

But if we consider a general model of energy dissipation by the sensor nodes where the nodes are stationary and homogenous, we can calculate the power of cluster head as:

$$P_{CH} = E_{elec} * k * (N-1) + E_{elec} * k + E_{amp} * d_j^2 * k$$
$$P_{NCH} = E_{elec} * k + E_{amp} * r_j^2 * k$$

Where, k = data transmission rate in kbps
N = number of nodes
j = index of iteration
d_j = distance between CH and base station.
r_j = distance between CH and non-CH.
E_{elec} = energy dissipates per bit to operate transmitter/receiver circuitry.
E_{amp} = energy used per bit for the transmitter amplifier.

Consider the simplex communication means CH are only listening to their cluster members,

$$N = \pi * r^2 / \alpha = \beta * r^2$$
$$P_{CH} = E_{elec} * k * N + E_{amp} * d^2 * k$$
$$P_{NCH} = E_{elec} * k + E_{amp} * r^2 * k$$

The average power per node,

$$P_N = (P_{CH} + P_{NCH}) / N$$
$$P_N = \{ E_{elec} * k * N + E_{amp} * d^2 * k + (N-1)(E_{elec} * k + E_{amp} * r^2 * k)\} / N$$
$$P_N = \{ E_{elec} * k * (2N-1) + [(N-1)*r^2 + d^2]*E_{amp} * k\} / N$$
$$P_N = \{2 * E_{elec} * k + [(N-1) * E_{amp} * k] / \beta + (E_{amp} * d^2 * k - E_{elec} * k)\} / N$$

We want to minimize the average power per node, so differentiate the above equation and equate it to zero, we get

$$N^2 = \beta [d^2 - E_{elec} / E_{amp}] \quad (1)$$

Means, $N \alpha d$ (means N is approx. directly proportional to d).

So, with the increase in the distance from the base station, the number of nodes in a cluster must increase to minimize average power per node. And as lifetime of the network is directly related to the average power per node in the cluster, so increase in cluster size would lead to the improved lifetime.

But from the previous discussion, the radius of cluster must decrease with distance as if the radius of cluster will increase; the CH at a far distance will consume more power as to listen more number of nodes and also have to transmit over a long distance, results in quickly dissipation of energy of CH. So, the CHs at large distance will die earlier, leads to decrease in lifetime of the network.

As a solution of the above two almost contradictory solutions, we can propose an intermediatory solution by implementing sub- clustering (2- level clusters) after a specific radius (the point of sub-clustering is determined according to the variation of power consumption by the heads, decided by the user at some distance from the sink).

III. Proposed Model

The proposed model is based on the concept of LEACH. To minimize the average power per node of the cluster, we concentrate on the cluster size. Here, keeping in mind, both concepts i.e. non-uniform energy consumption by cluster heads in LEACH and minimization of average power per node .So in this model, the number of nodes in the cluster increases up to a level after which sub-clustering occurs. The number of sub-clusters clusters decreases with the increase in the distance from the sink. With the sub-clustering, we ensure that cluster heads at far distance will communicate only with sub-cluster heads, so the energy dissipated in receiving messages from a number of clusters would be saved as number of sub-clusters are less as compared to the total number of nodes in the cluster.

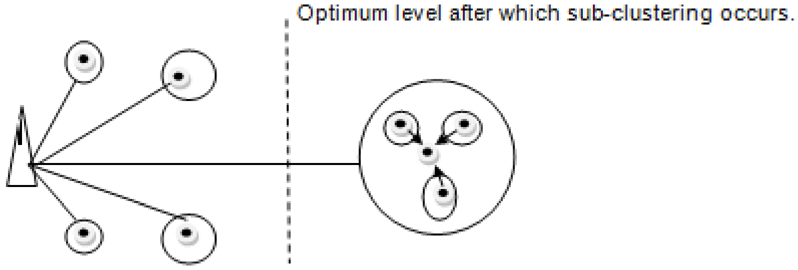

Figure 3. Clusters with sub clustering

This model presented in fig (3) will satisfy above both statements as-

- The number of nodes in a whole cluster under a CH increases as all nodes under sub- CH are ultimately is in the area of senior cluster head (CH of all sub- CHs).
- The number of nodes with which senior CH communicate will decreases to an optimum extent with increase in radius as senior CH will have to directly communicate with only sub-CHs.

Here two level of communication will occur-

- Single-hop communication till no sub-clustering occurs.
  NCH -> CH -> SINK.
- Two-hop communication when sub-clustering occurs.
  NCH -> Sub-CH -> Senior-CH -> SINK.

Assumptions : Our proposed model is based on the following assumptions-

- All the sensor nodes are identical and are stationary once deployed.
- The nodes are uniformly distributed in the network.
- Single hop communication till sub-clustering starts, 2-hop in sub-clustered regions.
- The node which communicates with the sink is called senior cluster head.
- In sub-clustered senior cluster, each node communicate directly only to its sub-CH and senior CH will communicate directly to its sub-CHs in the region.
- All the nodes are time synchronized and have power control ability.
- Nodes can compute their distance from the BS based on the received signal strength (RSS) from the BS.

Determination of number of sub-clusters: Consider the simplex communication when the CH is listening only to its members.

$\Pi r^2 \ \alpha \ N$ (proportional)

$N = \Pi r^2 / \alpha$

$r = [(\alpha N / \pi)]^{1/2}$

$P_{NCH} = E_{elec} * k + E_{amp} * k * r^2$

$P_{CHnear} = N_n E_{elec} k + E_{amp} k d_n^2$

$P_{CHfar} = N_f E_{elec} k + E_{amp} k d_f^2$

For balance energy consumption,

$P_{CHnear} = P_{CHfar}$

$N_n E_{elec} k + E_{amp} k d_n^2 = N_f E_{elec} k + E_{amp} k d_f^2$

$N_f = [\, N_n E_{elec} k + E_{amp}\, k(d_n^2 - d_f^2)] / E_{elec} k$

We get,

$N_f = N_n - E_{amp}/E_{elec}\,(d_f^2 - d_n^2)$ (2)

Where, N_f gives the number of sub-clusters in a senior cluster.

N_n gives the optimum number of nodes in the previous level just before the sub-clustering starts.

And the number of nodes in the region of senior cluster head increases according to the eq. (1).

CH and Sub-CH selection: The senior cluster head and the sub- cluster heads are selected by the function of residual energy.

The model works in rounds and each round has three phases:

1. Set-up phase 1
2. Set-up phase 2
3. Transition phase

Set-up phase 1:

1. Distribution of senior CH based on residual energy.
2. Decide the level after which sub-clustering occurs.
3. Selection of number of sub-CHs and area of senior cluster by senior cluster head.

Set-up phase 2:

1. Selection of sub-CHs in the senior clusters based on residual energy.
2. Joining of non-CH to sub-CH based on the strength of signal received of advertisement message.

Transition phase:

Switching of sub-CH in senior cluster after time **T1**

1. Communication for T1 time.
2. Repeat from set-up phase 2 if T2>**T>T1.**

Switching of senior CH after time T2

1 .Repeat from phase 1 if **T>T2** , Reset T.

This process continues till all nodes die.

Lifetime Definition: Lifetime of wireless sensor networks is the time duration from the deployment of nodes to the instant when the network is considered non-functional. However, when a network should be considered non-functional is application-dependent. In some applications, it can be, for example, the instant when the first node dies, a certain percentage of sensors die, the network partitions, or loss of coverage occurs and it is necessary that all nodes stay alive as long as possible, since network quality decreases considerably as soon as one node dies. In these scenarios, it is important to know when the first node dies. On the other hand, in some cases, adjacent sensors can record each other's data. Hence, the loss of a single or few nodes does not automatically decline the quality of service of the network. In our model, the network lifetime is considered till 90 percentages of nodes are alive.

IV. Conclusions

This is only a proposed model. It is expected to improve effective lifetime of the network means more number of nodes are alive for the time span as it decreases the rate at which nodes die, the total energy dissipated by cluster head in receiving messages is distributed among sub-cluster heads. After covering the area for a time period, all nodes die very frequently. It is good for the applications where more coverage is required for a time span means death rate of nodes should be minimum for that span. Performance varies according to the level after which sub-clustering occurs.

References

[1] Jiguo Yua, Yingying Qia, Guanghui Wangb, Xin Gua "A cluster-based routing protocol for wireless sensor networks with non uniform node distribution" Int. J. Electron. Commun. (AEÜ) 66 (2012) 54– 61.

[2] Heinzelman WR, Chandrakasan A, Balakrishnan H."Energy-efficient communication protocol for wireless micro sensor networks". Proc. of the 33rd Annual Hawaii International Conference on System Sciences, Maui; 2000. p. 1–10.

[3] Younis O, Fahmy S." Heed: a hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks". IEEE Transactions on Mobile Computing 2004; 3:366–79.

[4] Yu JG, Qi YY." An energy-driven unequal clustering protocol for heterogeneous wireless sensor networks." Journal of Control Theory and Applications 2011; 9:133–9.

[5] Qi YY, Yu JG, Wang NN. "An energy-efficient distributed clustering algorithm for wireless sensor networks". Computer Engineering 2011; 37(1):83–6.

[6] Navid Amini, Alireza Vahdatpour, Wenyao Xu, Mario Gerla, Majid Sarrafzadeh." Cluster size optimization in sensor networks with decentralized cluster-based protocols" Computer Communications 35 (2012) 207–220.

[7] Raghunandan.G.H, Sagar Metri " A Novel Approach to Increase Overall Efficiency in Wireless Sensor Networks" 2012 International Conference on Computing, Electronics and Electrical Technologies [ICCEET].

[8] Nasrin Abazari Torghabeh, Mohammad Reza Akbarzadeh, Mohammad Hossein Y aghmaee, "Mobile base station Management using fuzzy logic in wireless sensor networks" in the proceedings of 2nd International Conference on Computer Engineering and Technology,2010.

[9] Heinzelman WR, Chandrakasan A, Balakrishnan H". An application-specific protocol architecture for wireless micro sensor networks". IEEE Transactions on Wireless Communications 2002;1:660–70.M. Wegmuller, J. P. von der Weid, P. Oberson, and N. Gisin, "High resolution fiber distributed measurements with coherent OFDR," in *Proc. ECOC'00*, 2000, paper 11.3.4, p. 109.

[10] Jia YC, Liu YH." Hierarchical clustering routing scheme based on leach in wireless sensor networks." Computer Engineering 2009; 35:74–6.

[11] Kumar D, Trilok C, Patel R, Eehc B. "Energy efficient heterogeneous clustered scheme for wireless sensor networks". Computer Communications 2009; 32:662–7.

[12] Qing Bian, Yan Zhang, Yanjuan Zhao" Research on Clustering Routing Algorithms in Wireless Sensor Networks" 2010 International Conference on Intelligent Computation Technology and Automation.