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# ENERGY FORECAST FOR HETEROGENEOUS WIRELESS SENSOR NETWORKS USING CLUSTERING TREE TOPOLOGY SCHEME

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**Abstract:**

A Clustering-tree Topology control algorithm based on Energy Forecast (CTEF) introduced for Heterogeneous Wireless Sensor Network (HWSN) to solve the problems of energy consumption and to ensure the network load balancing. In HWSN, forecasting the energy consumption per round in the network lifetime and the actual lifespan of network is difficult than homogeneous wireless sensor network. CTEF algorithm is proposed for solving this problem. A CTEF is proposed for ensuring the network load balancing and saving energy by considering the link quality and packet loss rate. Energy consumption can be predicted more accurately in each round by considering the network lifetime. The difference between the ideal and actual average residual energy can be calculated using central limit theorem and normal distribution mechanism. The best nodes are selected as per the cluster-head cost function including the energy, link quality, packet loss rate and their distance. If the distance among cluster heads is short, more nodes will be judged to join to the cluster, which will consume more energy. Several non-cluster heads in each cluster are chosen as per the relay nodes for transmitting data through multi-hop communication in order to decrease the load of each cluster-head and prolong the lifetime of the network. CTEF has longer network lifetime and receives more data packets at base station.The network lifetime of CTEF is higher than other three algorithm because more nodes deployed to increase the total energy of the network. It also brings a burden to the cluster heads during their communications which will consume more energy. The network throughput is to be increased by increasing energy heterogeneity and parameter value.

**Key Words:** HWSN, Topology, Multi-Hop Communication, Base Station & Energy Heterogeneity

## 1. Introduction:

HETEROGENEOUS wireless sensor network (HWSN) isa wireless ad hoc network which is consisted of a largenumber of different types of sensor nodes. Unlike homogeneousWSN, nodes are randomly deployed in the monitoredarea, which are equipped with extremely different energy. Heterogeneity can sharply increase the average delivery rateand the network lifetime if nodes are deployed as an effective network [1]. Therefore, HWSN has more realistic and broaderapplications than homogeneous WSN. However, due to theirreplaceability of nodes and the limitations [2], one of the major challenges is how to effectively use the energy andextend the network lifetime in such a complex heterogeneous network. Topology control is one of the most important techniques used for reducing energy consumption and maintaining network connectivity [1]. For topology control, there are manyreactive and proactive techniques in WSN. Recently, clusteringtechnology has already been proven that it has certainadvantages in energy efficiency and scalability, e.g., lowenergyadaptive clustering hierarchy (LEACH)[8]. Specially, stable election protocol (SEP) [9] and distributed energy efficientclustering (DEEC)[10] are proposed for heterogeneousnetwork. But the previously proposed algorithms still haveissues as follows: 1) Lacking consideration of more complicatedscenarios, e.g., the link quality and packet loss rate;2) Lacking consideration of the distance among the clustersduring the cluster-head selection; 3) Lacking consideration ofthe overload problem of cluster-head. In many scenarios, wehave to face such a complicated real networks which sufferfrom the resource limitations that the traditional method cannotbe suitable for them. Thus, we focus on how to design anenergy-efficient algorithm or protocol for HWSN to maximizethe network lifetime while considering the link quality, packet loss rate and any other complex scenarios. A clustering-tree topology control algorithm based on energy forecast (CTEF) is introduced for HWSN inorder to solve the problem how to save energy and ensurethe network load balancing. In HWSN, forecasting the energyconsumption per round during the network lifetime and theactual lifespan of network is much more difficult than homogeneousWSN. We propose CTEF algorithm for solvingthis problem in an efficient way in terms of the estimateddifference between the ideal average residual energy and theactual average residual energy to obtain the average energyof network at the next round. The cluster heads are selecteddepending on the synthesized cost function and their distance, while the clusters are formed by combining with the factorsof the energy, distance and link quality. Moreover, to reducethe burden of the cluster-head, several non-cluster head nodes in each cluster are chosen as the relay nodes for transmittingdata through multi-hop communication. The performance ofCTEF is evaluated and found better than other typical protocols and algorithms via simulation.

**2. Related Work:**

Clustering scheme is one of the most typical ways for topology control in WSN. Most of cluster-based algorithms alwaysadopt data fusion scheme and pursue clustering objectives [6]such as load balancing, fault-tolerance, increasing connectivity,reducing time delay, maximizing network longevity, etc.. In the past few years, LEACH [8] and its improved algorithms werepresented as one of the most well-known distributed clusterbasedtopology control algorithm with scalability and energyconservation in WSN. However, it may not be suitable forheterogeneity because of its ideal network model [11]. Recently; quite a lot of energy-oriented algorithms forHWSN are proposed. For instance, energy efficient heterogeneousclustered (EEHC) algorithm is proposed based on thethree-level network model in [7], which is composed of supernodes, advanced nodes and ordinary nodes. EEHC utilizes thebest number of clusters calculation method proposed fromLEACH, and it selects cluster heads by residual energy ofnodes and weighted probability mechanism. Then the non-clusterhead nodes are attracted by the cluster heads to formclusters and the network begins to transmit data. Zhou etal.[12] propose a clustering protocol energy dissipation forecastand clustering management (EDFCM) based on the two-levelnetwork composed of super nodes and ordinary nodes. Similarto EEHC, the method for calculating the best number ofclusters from LEACH is also cited by EDFCM. Furthermore, a mathematical model of energy consumption is proposed tocompute the weighted probability of node for selecting clusterheadby residual energy and the approximate average energyconsumption at the next round of network lifetime. However, the approximate average energy consumption at the next roundof network is likely to cause deviation in practice because itis an ideal energy value. An efficient and dynamic clustering scheme (EDCS) is proposed for multi-level heterogeneous wireless sensor networksin [11]. EDCS determines the probability of nodeto be a cluster-head through estimating the average residualenergy of the network in the next round by average energyconsumption forecast according to ideal state and the referencevalue of historical energy consumption, simultaneously. Analogousuniversal gravitation is introduced to ensure non-clusterhead nodes join cluster in terms of gravitation during clusterformation. Kuila et al [13] propose a load balancing methodbased on genetic algorithms. Sensor nodes are regarded as the chromosome number and the chromosomes are assignedto the corresponding gateway. Also, the standard deviationof load is utilized to determine whether the node is withload balancing. Dabirmoghaddam et al.[14] propose an optimaluniform clustering (OUC) for prolonging the network lifetimeand strengthening the network scalability. In OUC, the generalproblem of optimal clustering with arbitrary cluster-headselection is demonstrated to be NP-hard. Sensor nodes formclusters in a distributed manner using a probabilistic clusterheadselection.The main difference between what we mentioned in aboveand our solution described in the following lies in networkmodel. We use more general network model with multilevelheterogeneous features, which means we need to furthertake into account more complicated and actual factors andsituations. As a clustering-tree topology control scheme, CTEFhas advantages both from the clustering and tree algorithms.Energy consumption can be predicted more accurately in eachround during the network lifetime, which results to be morereasonable for cluster-head selection and cluster formation.In addition, to avoid excessive energy consumption from thecluster-head, several non-cluster head nodes are chosen to bethe relay node to further reduce the burden of each clusterhead.That is why CTEF with multi-hop communication canhave longer lifetime.

**3. Heterogeneous Model for WSN:**

**A. Types of Heterogeneity and Impact on WSN:** Unlike homogeneous WSN, there are many special features in HWSN. Generally, the common types of heterogeneity inWSN are classified as follows:

- ✓ Computational heterogeneity: Different nodes have different capabilities to store information or deal with emergentevents. Some super or advanced nodes have more powerfulprocessor and memory than any other normal nodes. Withhigh performance hardware, these nodes which own powerfulcomputational capabilities can provide more and more abilityfor data storage and complex data processing, e.g., data fusionis executed when the node receives a large number of data atthe same time.
- ✓ Link heterogeneity: With similarity to the computational heterogeneity, due to the powerful electronic devices, somenodes have more channels, higher bandwidth and longer communicationdistance than normal nodes. So they can providemore reliable and robust data transmission network.
- ✓ Energy heterogeneity: It is the most important and key point in these three common types of heterogeneity. Computationalheterogeneity and link heterogeneity always lead toconsuming more energy than nodes in homogenous network sothat their lifetime will fall down quickly. Energy heterogeneitycan be represented as which nodes are equipped with differenttimes of energy virtually.

In homogeneous WSN, each node has the same computational and communication capability, initial energy, anddissipates equivalent energy per round. However, the practicalWSN is always composed of multiple sensors which are given different processing capabilities and initial energy. Each nodehas multi-level power options such that it consumes differentenergy per round in the normal working time depending onits current power level. Also, the link quality and packet lossrate should be taken into account for HWSN firstly because itcould easily exist in such a complicated wireless situation.In addition, the interference can happen among nodes andclusters.Thus, the heterogeneous WSN with limitations is more suitable for research and more approximated to actualnetwork.

**B. Network Model:** Assume that *N* sensor nodes, which are all different from each other, are dispersed uniformly in an $M \times M$ squareregion. Besides, it has some features as follows:

- ✓ Each node is equipped with a different initial energy which determines thevalue of the maximal initial energy;
- ✓ The communication cost is different between nodes, and link quality and packet loss rate are arbitrary values;
- ✓ The non-cluster heads cannot be allowed to communicate with the base station (BS) directly, only the cluster-head cansend data directly to the base station;
- ✓ The fusion strategies are executed by the cluster-head to aggregate correlated data before transmitting to the basestation;
- ✓ The distance between nodes is calculated by the received signal strength indicator (RSSI);
- ✓ The interference can be neglected by using CSMA/CA in MAC layer.
- ✓ The sink node is located at the center of region, and it is not restricted by energy, etc.

**4. CTEF Algorithm:**

Our proposed algorithm CTEF aims to find an effective way for HWSN to save energy consumption and prolong thenetwork lifetime. We can clearly see from Fig.1 that the CTEFis mainly divided into four parts, i.e., the average energy ofthe network estimation, the cluster-head selection, the clusterformation and tree formation within cluster.

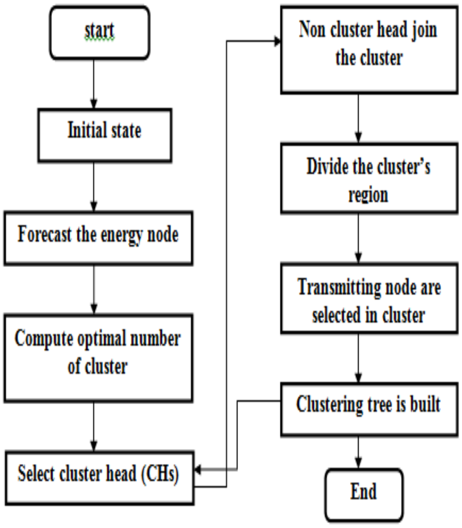


Figure 1: The flow chart of CTEF algorithm.

**A. Cluster-Head Selection:** Network load balancing is to improve the lifetime of the network, there are three factors to combine (i.e., node energy, link quality and packet loss rate) used to evaluate the cost of each node performance. The best nodes are selected as the cluster-head by cost function. The node which has more energy, higher link quality and lower packet loss rate, will be selected as the cluster-head. Compared to other nodes, these cluster heads will have more available energy, while their rate of transmitting data will be higher. The remaining nodes will collect data in the monitoring region as the member of each cluster. So the network performance will be better. Cluster heads will have high energy, and their rate of transmitting data will be higher.

$$C = \frac{1}{\beta\left(\frac{E_{res}}{E_{total}(r)}\right) + \left(p_{link} + \left(\frac{1}{p_{loss}}\right)\right)^{\frac{(1-\beta)}{2}}}$$

After the node has been selected as the cluster-head, it needs to broadcast the message to other nodes in the network and waits for response. The cluster-head can be seen at the center of the cluster region, because the communication range of nodes is always be a circle. Once each non-cluster head node receives the invitation messages from multiple cluster heads, it computes the distance d(i, j) between the sender and the receiver based on the Receiver Signal Strength Indicator (RSSI).

$$F(i, j, r) = \frac{E_{res}^{j}\,\mathrm{Plink}}{d(i,j)}$$

For cluster formation, a method is introduced to guide the non-cluster head nodes and to choose the most suitable cluster-head, which depends on the energy in cluster-head the link quality between the cluster-head and the non-cluster head nodes, and the distance d(i, j) can also be used to determine which cluster to join for the non-cluster head node. It means that the longer distance between the cluster-head and the non-cluster head nodes, the less possibility the non-cluster head nodes to join.

**B. Tree Formation Within the Cluster:** Clustering algorithm is mainly used for load balancing. If a cluster has too many members, the cluster-head will consume too much energy to communicate with the cluster members. The way to search transferring nodes from cluster members is proposed which can used to construct a tree in the cluster. It aims to reduce the energy consumption and prolong the lifetime because of sharing the load of cluster heads to balance the energy consumption in clusters.

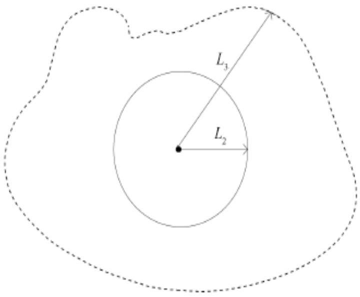


Figure 2: Cluster area divided in two regions

After the cluster formation, a cluster-head can be seen as the circle center and *L*2 is the radius to divide the cluster area into two parts, i.e., a circle and an approximate ring. It is shown in Fig.2, where *L*3 is the distance from the cluster-head to the edge of cluster.

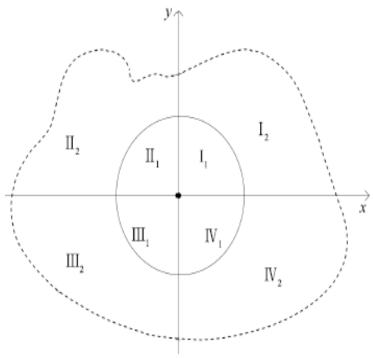


Figure 3: Division of the cluster area by the cross axis

The cluster head is regarded as the original point of cross axis. The cross axis divides the cluster area into four regions, like I, II, III and IV, which is illustrated in Fig. 3. Then in the regions (I1, I2, II1, II2, III1, III2, IV1 and IV2), the relay nodes are searched to receive the messages from others in order to transmit to the cluster-head. is a variance of the distance, which means that then lower variance of node *i*, the more uniform distribution around the node *i*. If a node has more energy and less distance variance to the cluster-head, it will be more likely to become a relay node.

## 5. Result Analysis:

The lifetime is the one of the most important performance criteria to verify the CTEF algorithm. The influence of network lifetime within different number of nodes and energy parameter

The parameter evaluations are

**Energy:** The analysis between number of nodes and energy is represented in Figure 4.

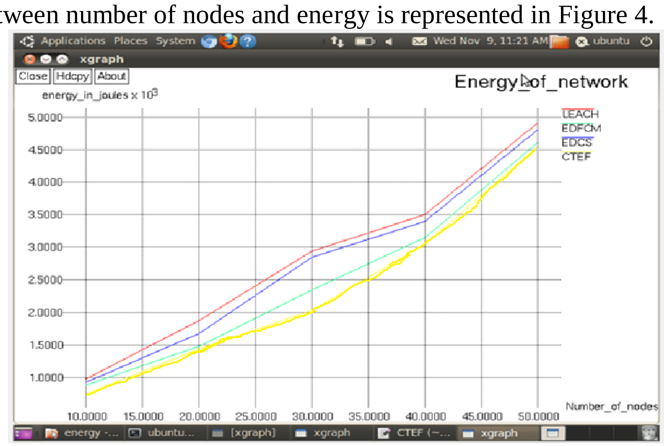


Figure 4: Energy of network

The proposed scheme incur less energy compared to the LEACH,EDCS,EDFCM algorithm.

**2. Throughput:** LEACH protocol is only suitable for homogeneous network, i.e., it can obtain good communication efficiency in the homogeneous environment, but cannot perform very well in the multi-level heterogeneous network. The EDFCM protocol has much longer steady stage of communication than LEACH which is the period from the beginning of network lifetime to the time when the first node dies. Similar with EDFCM, the EDCS protocol has much longer steady stage of communication, but both of them cannot use the node energy efficiently in the later communications which is also called unstable period. Compared with LEACH, EDFCM and EDCS, our proposed CTEF is better in terms of the network lifetime. Network lifetime decreases relatively slowly as compared to other algorithms. It means that CTEF uses the unstable period efficiently which is very critical, because under the real network environment, it is possible that some nodes will be dead at any time owing to unexpected events.The network throughput is to be increased by increasing energy heterogeneity parameter value.

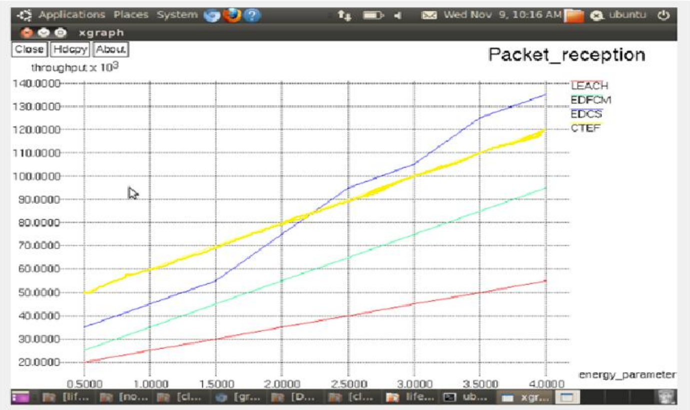


Figure 5: Packet Reception

**3. Network Lifetime:** It helpful to prolong the network lifetime with these algorithms by increasing $\lambda$, where $\lambda$ is set from 0.5 to 4.0 respectively. The network lifetime of CTEF is longer than other three algorithms regardless of how $\lambda$ changes and the rate increases when the energy parameter $\lambda$is gradually increasing. This is because of more nodes deployed to increase thetotal energy of the network, it also brings a burden to thecluster heads during their communications which will consume more energy. However, by increasing $\lambda$, total network energy increases. And the increased energy is greater than the additional energy consumption, which makes more available energy and prolongs the network lifetime.

**6. Conclusion:**

The proposed scheme on CTEF solves the problem of energy consumption through considering the energy and link heterogeneity. The network lifetime of CTEF is higher than other three algorithm because more nodes deployed to increase the total energy of the network. It also brings a burden to the cluster heads during their communications which will consume more energy. The network throughput is to be increased by increasing energy heterogeneity parameter value.

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