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Quantized Routing Models for Clustering Scheme in Wireless Sensor Networks

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Abstract

Clustering routing protocols are effective topology approaches which can increase the scalability of wireless sensor networks and efficiently utilize the limited energy resources of the sensors. However, the loading or energy consumption of sensors in networks is heterogeneous so that some sensors may die earlier than the others. In this case, data from sensors will not be delivered properly to the base station. Many previous studies have focused on energy-efficient routing protocols to prolong the network lifetime without considering the influences of transmitting range or availability of compression. In this paper, we propose quantized models to simulate the operations of clustering routing protocols and evaluate the energy consumption of networks as well as the load distribution of sensors. Besides, the cluster head selection algorithm is developed correspondingly. The comparison of data reception rate for LEACH with our model in cases of different compression rates by simulations is also presented.

Keywords: Wireless Sensor Network, Clustering, Quantized model, Energy consumption

1. Introducton

In clustering routing protocols, the network is divided into several logical groups by a fixed area. The logical groups are called clusters. Each sensor delivers the sensing data to a head node in the corresponding cluster and the head node delivers an aggregated data to the BS (Base Station) [1, 2]. Many previous literatures [3, 4] thought that the clustering routing protocols were more energy-efficient than the multi-hopped routing protocols since the intra-cluster sensed information is highly correlated and the cluster head can aggregate all collected data packets into a single length-fixed packet [5]. However, many

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studies [6, 7] considered putting some redundant sensors into sleep mode to save energy. In such a case, each sensor monitors and collects its own data which is different from the data gathered by other sensors as possible. Therefore, the data compression rate done by cluster heads may be insignificant. This will influence the energy consumption of routing protocols very much. Also, there are nearly no complete and practical models to describe the operations of cluster routing protocols in wireless sensor networks (WSNs).

In this paper, we take the effect of compression into consideration and develop quantized models to simulate the operations of transmitting and receiving in clustering routing protocols. Based on the models, load distribution of networks can be obtained systematically and analytically. The analytic results will help understand the load distribution of sensors in the network so that data routing protocols or sensor deployment strategies can be developed properly to enhance the network availability.

The rest of paper is organized as follows. Section 2 introduces some related work. Section 3 defines quantized models for clustering routing protocols and the formation of clusters. Section 4 evaluates the energy consumption of sensors in networks. The simulation of LEACH and the proposed model are also given in this section. Our conclusions are presented in Section 5.

2. Related Works

The clustering routing protocols were proposed in many previous literatures [1-4, 8]. LEACH [1] is a well-known distributed cluster formation algorithm. In LEACH, each sensor decided whether or not to become a cluster-head based on the suggested percentage of cluster heads and the number of times the sensor had been a cluster-head so far. However, it is difficult to balance the loading of sensors without the knowledge of load distribution of sensors in networks. Also, to assume that the cluster head can aggregate all collected data packets into a single length-fixed packet is not reasonable.

Padmanabh et al. [9] thought that the density of the sensors required depended upon the distance from the BS, probability of event occurrences, the transmitting range of the sensors and the coverage area. If any of these parameters was changed, the required density of the sensors would also change.

Li et al. [10] divided the network into clusters of unequal size, and clusters closer to the BS had fewer sensors than those farther away from the BS. Therefore, cluster heads closer to the BS consumed less energy in intra-cluster communication and could preserve some energy for the inter-cluster data forwarding. Can et al. [3] designed a non-uniform sensor deployment scheme to balance the energy consumption among the cluster heads. In clusters with higher density, the sensors worked by probability to ensure that the numbers of working sensors in all clusters were same. It is clear that an accurate evaluation model for energy consumption of networks will help these methods to get better results.

In this paper, we propose quantized models to analyze the loading of sensors in networks. The distance from the BS, the transmitting range of the sensors and the data compression in forwarding processes are included to evaluate the energy required for the whole networks.

3. Quantized Routing Models

A general wireless sensor network with a single BS can be viewed as the uniform-random deployment of N_s sensors in a circle with radius R. In clustering routing protocols, sensors are grouped into N_c clusters. In ideal case, the number of sensors in clusters will be the same as possible [5]. And the average distance from sensors to the cluster head is as small as possible to reduce the energy consumption. Assume each cluster member transmits its data to the corresponding cluster head with the transmitting range r, and each cluster can be covered by a circle with radius r. Since some sensors may have more than one cluster head candidates, they can choose the closest one as their corresponding cluster head. For the uniform distribution of sensors in networks and properly setting up of the cluster heads, the whole networks will be covered completely by the minimum number of circles with radius *r*.

For sensors located in the intersection area between circles will select the closer center of circle as their cluster head, the intersection area should be split into two parts so that the whole networks are covered by non-overlapping hexagons. It is obvious that each hexagon is corresponding to a specific cluster whose cluster head is the center of the hexagon. The BS is a cluster head and also a center of a hexagon. All centers of hexagons are arranged by layers, namely 0, 1, 2 … and *h* where layer *h* is the outermost one and layer 0 contains only the single one hexagon with its center at the BS. The connection of centers in the same layer, *i*, constructs a bigger hexagon, namely $H(i,r)$ with its center at the BS and its length of side is $\sqrt{3}\times i\times r$ shown in Fig. 1. The number of hexagons in *i* layer will be $6\times i$ for i=1 to *h*.

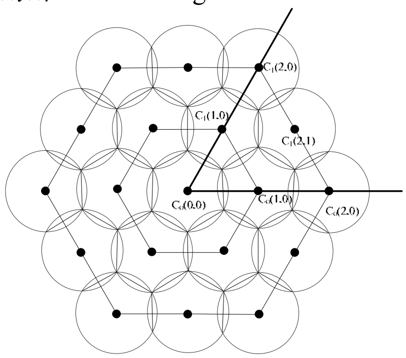

Fig. 1. Arrangement of hexagons

For convenience, we can split the whole network into six parts by half lines from the BS to the centers of hexagons in the first layer respectively. And all parts, namely part 0, 1 … and 5, are ordered by their polar angles with respect to the BS. Fig. 2 shows that each part, *k*, contains centers arranged and denoted as $C_k(i,j)$ where *i* is the number of layer, $0\leq i\leq h$, *j* is the sequence number of center, $0\leq j<i$, *k* is the number of part and $0\leq k<6$.

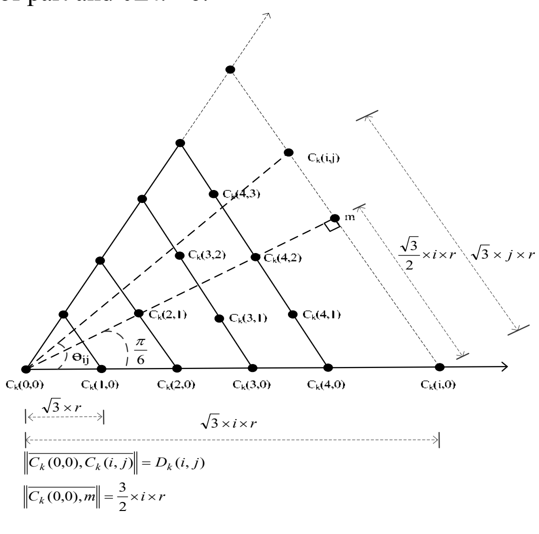

Fig. 2. Arrangement of centers of hexagons

The total number of clusters, N_c, is equal to the sum of hexagons in each layer, i.e.

$$N_c = 1 + 6 + ... + 6 \times i + ... + 6 \times h == 3h^2 + 3h + 1$$

The number of sensors in $C_k(i,j)$ is N_s/N_c which is the same for all i, j and k.

In this paper, we assume the polar angle of the half line from the BS to the center of $C_k(i,0)$ is θ_k and the distance between the BS and $C_k(i,j)$ is $D_k(i,j)$ respectively. It is clear that $D_k(i,j)$ is the same for any k and $\theta_k=\theta_0+k\times\pi/3$. The coordinate of center of $C_k(i,j)$ is denoted as $p_k(i,j)$. Assume $\angle p_k(i,j), p_k(0,0), p_k(i,0) =\theta_{ij}$ for all k. For the distance between any two neighbor sensors is $\sqrt{3}r$, $D_k(i,j)$ and $p_k(i,j)$ can be computed for each $C_k(i,j)$ by the Pythagorean Theorem. That is,

$$D_k(i,j) = \sqrt{(\frac{\sqrt{3}}{2}i - \sqrt{3}j)^2 + (\frac{3}{2}i)^2}\, r$$

Since $D_k(i,j)\sin\theta_{ij} = \sqrt{3}r \times j \times \sin\frac{\pi}{3}$,

$$\sin\theta_{ij} = \frac{\sqrt{3}r \times j \times \sin\frac{\pi}{3}}{D_K(i,j)}$$ and

$$\theta_{ij} = \sin^{-1}\left(\frac{3/2 \times j}{\sqrt{(\frac{\sqrt{3}}{2}i - \sqrt{3}j)^2 + (\frac{3}{2}i)^2}}\right)$$

Therefore,

$$P_k(i,j) = (D_k(i,j)\cos(\theta_k + \theta_{ij}), D_k(i,j)\sin(\theta_k + \theta_{ij}))$$

With the knowledge of the number of clusters and the corresponding positions of cluster heads, the BS can assign the sensor which is closest to the specified head position as the cluster head. All other sensors will select the closest cluster head as the destination where they transmit data. For the high density and uniform distribution of sensors, the cluster distribution will be similar to the arrangement shown in Fig. 1. The simulation presented later will show the same cluster distribution. For the loading of cluster heads are much larger than others, it is necessary to balance the loading by rotating cluster heads round by round. For the positions of cluster heads are determined by the setting of radius r and orientation θ_0, the cluster head selection can be done by setting r in the range $[r1,r2]$ where $r1<r2$ and θ_0 in $[0, \pi/3]$ randomly. Thus the loading of cluster heads can be distributed among sensors except those around the BS.

4. Energy Consumption Evaluations and Simulation Results

The energy consumption and load distribution of networks in clustering routing protocols based on the quantized routing models will be evaluated in this section. And the comparison of data reception rates under clustering routing protocols of LEACH and our proposed model will be given by the simulations below.

4.1. Energy Consumption Evaluations

Assume that V events are randomly triggered among sensors. The expected amount of packets triggered and transmitted by a sensor is V/N_s. We use $\rho=V/N_s$ for abbreviation. As explained in [1], the energy required to transmit and receive a packet of information is assumed as $\xi_T\times r^2$ and ξ_R in this paper respectively. Each data packet received for a sensor is assumed to be compressed into μ packet before forwarding. The compression ratio is denoted as μ, which is the ratio of the amount of data after and before compression. The value of μ is in [0, 1]. When μ is equal to 1, it means no compression is executed.

The energy required for sensors in $C_k(i,j)$ should satisfy the operations described below.

(i) Since sensors except the cluster head in $C_k(i,j)$ transmit data directly to the corresponding cluster head with the transmitting range r, the energy required is

$$\rho(\frac{N_s}{N_c}-1)(\xi_T r^2+\xi_R)\ . \tag{1}$$

(ii) The energy required for the cluster head in $C_k(i,j)$ to receive data is

$$\rho(\frac{N_s}{N_c}-1)\xi_R\ . \tag{2}$$

(iii) The cluster head compresses the received data by compression ratio μ and transmit directly to the BS by the transmitting range $D_k(i,j)$. The energy required for the cluster head in $C_k(i,j)$ to transmit data to the BS is

$$\rho\frac{N_s}{N_c}\mu(\xi_T D(i,j)^2+\xi_R)\ . \tag{3}$$

From the above three kinds of energy consumption, the total energy consumption of sensors in $C_k(i,j)$, denoted as $\overline{E}_c(i,j,r)$, is equal to the sum of (1), (2) and (3), i.e.

$$\overline{E}_c(i,j,r)=(1)+(2)+(3)\ .$$

And the average energy consumption for a sensor in $C_k(i,j)$ is equal to

$$\overline{E}_c(i,j,r)/(\frac{N_s}{N_c})\ .$$

For the analysis of load distribution of networks, we find the energy required for sensors in hexagons in i layer where i=0 to h, denoted as $\overline{E}_c(i,r)$. That is,

$$\overline{E}_c(0,r)=\rho\frac{N_s}{N_c}(\xi_T r^2+\xi_R)\ \text{and}$$

$$\overline{E}_c(i,r)=6\times\sum_{j=0}^{i-1}\overline{E}_c(i,j,r)\ \text{for } i=1 \text{ to } h. \tag{4}$$

Therefore, the total energy consumption of networks is denoted as $\overline{E}_c(r)$ and

$$\overline{E}_c(r)=6\times\sum_{i=1}^{h}\ \sum_{j=0}^{i-1}\overline{E}_c(i,j,r)+\overline{E}_c(0,0,r)\ . \tag{5}$$

We obtain the average energy consumption for a sensor in i layer, i.e. $\overline{E}_c(i,r)$ /(6×i×N_s/N_c) and in the whole terrain, i.e. $\overline{E}_c(r)/N_s$ respectively which can be used to illustrate the load distribution of sensors in different layers.

The energy consumption of sensors in network will be different according to ratios of compression. By compressing received data in the cluster heads, the compression ratio has a lot to do with the energy consumption of networks. While the effect of compression is insignificant, clustering routing protocols will not achieve a large reduction in the energy dissipation.

The load distribution of networks can be illustrated by the average energy required for a sensor in each layer which is depicted in Fig. 3. The energy consumption for sensors in layers farther away from the BS is larger than those in layers near the BS especially in the condition that μ is big. However, while μ is small, the difference between the energy required for sensors in high layers and those for sensors in low layers will be less.

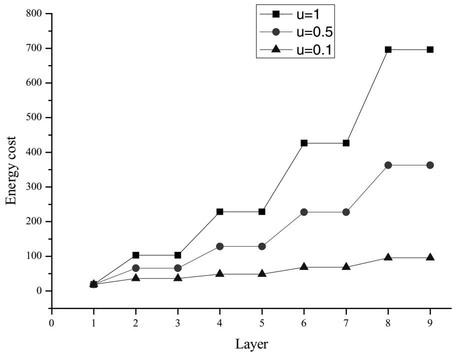

Fig. 3. Load distribution of networks

4.2. Simulation Results

In the simulations, one thousand stationary sensors are uniformly distributed in a circular area with 220 meters in radius, and a BS is set up at the center of the area. Power range of sensors is set to 60 meters at most for transmitting data to their corresponding cluster head. To simulate the network operations, 5000, 10000, 15000, 20000 and 25000 events are triggered respectively and randomly among sensors. Whenever a sensor detects an event, it will deliver a fixed-length packet to the BS. According to the energy model used by [1], the energy consumptions of transmitting and receiving a packet for a sensor are $0.01\times r^2+10$ nJ and 10 nJ respectively. The initial power of each sensor is 10000 nJ. The deploying process is executed independently 10 times to get 10 independent simulation results. We assume sensors are homogeneous and initially have the same energy.

Considering the compression effect where μ is set to 1, 0.5 and 0.1 respectively before forwarding, the simulation results show that the data received by the BS will be consistent between LEACH and our proposed clustering scheme shown in Fig. 4. Since the sizes of clusters formed in our method are much more equal than those in LEACH, the results show that our method have a little bit better data reception rate under network operations. As noticed in the case of μ =0.1, the reception rate is almost 100% for the much reduction of data transmission and energy consumption so that the lifetime of sensors in network will be long enough to complete the whole network operations.

5. Conclusions and Future Work

In this paper, quantized routing models are proposed to simulate the operations of clustering routing protocols. Under the processes of data compression in forwarding, the load distribution of sensors in the WSN and the total energy required for the whole network are derived thoroughly. Because of that the load distributions of networks are relatively balanced, the analyses show that clustering routing protocol performs better when the data received by the head can be compressed very much.

By using the quantized models, we estimate the energy consumed by sensors in different positions more precisely than previous related works do. Some proposed methods such as enlarging the battery capacity, increasing the density or increasing the sensing range of sensors around the BS can thus be more effectively. In the future, based on the quantized models derived from this paper, we will develop more practical and effective strategies for routing or deployment to prolong the network lifetime and the network availability.

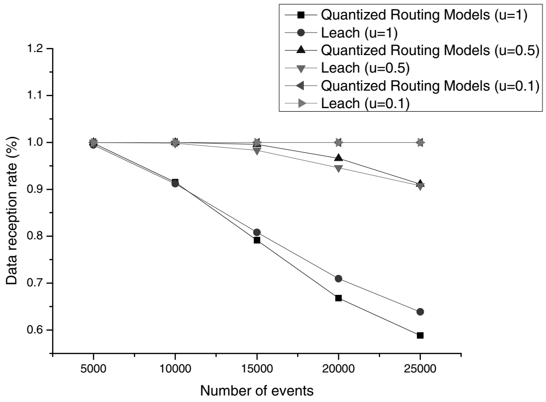

Fig. 4. Comparison of data reception rates under clustering routing protocols of LEACH and the proposed model

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