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OPTIMAL CLUSTER HEAD NUMBER BASED ON ENTROY FOR DATA AGGREGATION IN WIRELESS SENSOR NETWORKS

Mingxin Yang
College of Economics Management
Hebei University of Science and Technology
Shijiazhuang 050018, China
Emails: ymxspj@163.com

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Abstract-- In-network data aggregation plays an important role on energy consumption from the point of reducing the amount of communication in cluster-based wireless sensor networks. The selection of cluster heads is usually based on two criteria which are the number of cluster heads network needed and the times of every node serving as the cluster head. Too much or too little cluster head number will shorten the network lifetime for the energy premature depletion of some sensor nodes, so it has a great significance to select the optimal cluster heads number for wireless sensor networks. Based on the information rate-distortion function and network energy model, we propose an algorithm OCHN which calculates the optimal cluster head number for the minimal energy consumption, and further gets the optimal cluster head ratio in the process of data aggregation. Simulation results demonstrate that our proposed algorithm is energy efficient, and the comprehensive performances of network lifetime and data transmission are good for data aggregation in wireless sensor network.

Index terms*:* wireless sensor networks, data aggregation, cluster head number, information entropy.

I. INTRODUCTION

Over the last decade wireless sensor networks are increasingly used in several real-world applications. Wireless sensor networks have been utilized for a variety of applications such as healthcare, target tracking, environment monitoring, military surveillance, industrial and agricultural producing, and intelligent home furnishing [1-4]. In most cases, the sensor nodes form a multi-hop network while the base station (BS) acts as the central point of control. Typically, a sensor node has limitation in terms of computation capability and energy reserves. Applications of wireless sensor network are illustrated in Figure1. The main responsibility of the sensor node is to collect the sensed data of the target area and transmit the data to the base station (sink).

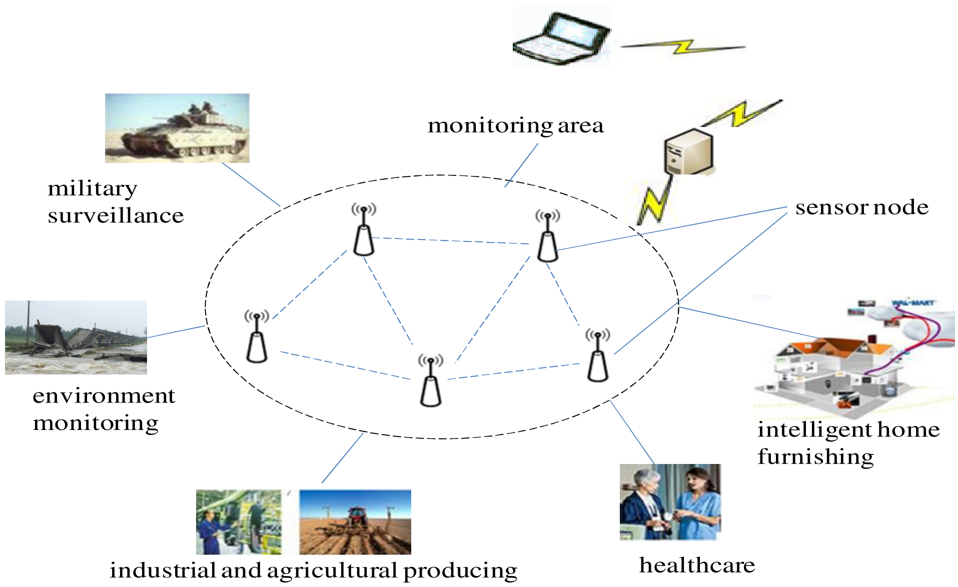

Figure 1 Applications of wireless sensor networks

In-network data aggregation [5-7] may save the energy according to reducing the amount of communication. The main idea is to combine partial results at intermediate nodes on the data routing. Data aggregation is defined as the global process of gathering data from multiple nodes, routing data through a multi-hop network and processing data along the path to the sink with the object of reducing data redundancy and power consumption. The way of processing data is application-oriented, which usually implies combining several data packets into a single one according to some aggregation functions such as MAX, MIN, SUM and so on. The energy limitation needs more efficient routing protocols for wireless sensor networks.

To reduce the energy consumed by sensor nodes, the cluster head plays more and more important role in cluster-based wireless sensor networks. In order to reduce overall energy consumption and enhance the network lifetime, many researchers proposed protocols to improve the method of selecting the cluster head [8-11]. In some algorithms, the cluster heads are selected on the basis of residual energy to reduce energy consumption [8, 12-15], because most of energy consumption comes from the communication between sensor nodes in wireless sensor networks, so how to reduce the overall communication is the critical factor to extend the network lifetime [16-17]. The other method applies different ways of electing cluster heads to reduce the energy consumption [18-20].

There are two criteria in selecting cluster heads which are the number of cluster heads network needed and the times of every node serving as the cluster head in cluster-based wireless sensor networks. During the process of studying, the problem of the most appropriate cluster head number is ignored, which will lead to too much or too little cluster head number, too much cluster heads will result in the increase of unnecessarily frequent data integration operations, while too little cluster heads will result in the longer distance for transmitting data between nodes, whether too much or too little cluster head number will shorten the network lifetime. So it has a great significance to select the optimal number of cluster heads for wireless sensor networks. During the past few years, the study mainstream of optimizing cluster heads number is to analyze the energy consumption. Throughout the literature, the problem of optimal cluster head number has been richly explored [21-24]. Recent years one approach has been proposed that minimizing the cluster head number through adjusting the relationship between the cluster head and the Intra-cluster nodes, for example taking trade-off between total intra-cluster distance and total distance of cluster heads to base station [18], applying the topology control method to ensure the connection between cluster heads and other nodes [25].

In this paper, we propose an algorithm of optimizing the number of cluster heads for data aggregation based on information entropy in clustered-based wireless sensor networks. Based on the energy consumption model, we calculate the optimal cluster head number according to the data aggregation framework, so the optimal ratio of cluster head is determined during the process of data aggregation. We also evaluate the efficiency of the proposed algorithm by extensive simulations under various network settings and the results further demonstrate the efficiency of our algorithm.

The rest of the paper is organized as follows. Section II reviews the related work. Section III introduces the network model. The proposed algorithm of optimizing cluster head number is provided in section IV. Results of the simulation are shown in section V. Finally, we conclude the paper and give directions for future research in section VI.

II. RELATED WORK

The problem of optimizing cluster head number based on the network energy consumption model or the information entropy is also studied in the literature. Yang et al [26] propose a method for achieving an optimal number of aggregation which points with a power consumption model and analyzes the effect of different numbers of aggregation points on the performance. Deng et al [27] establish a communication model and analyze energy consumption under two different circumstances, i.e., collecting data once per round and collecting data several times per round in which an optimal data collection scheme is designed by determining the optimal times of data collection to optimize data acquisition for hierarchical networks. Gu et al [28] present a method of using Gaussian process regression to model spatial functions for mobile wireless sensor networks, which is a distributed Gaussian process regression (DGPR) approach related to the information entropy. De San Bernabe et al [6] present entropy-based mechanisms to improve energy efficiency and robustness of transmission errors in camera-based object tracking systems. The main mechanisms are: an entropy-based algorithm that dynamically activates/deactivates nodes; a method that dynamically selects the cluster head using entropies and transmission error rates between the cluster nodes; and a distributed Extended Information Filter (ElF) that integrates measurements gathered within the cluster. Sinha et al propose [29] energy efficient multi-level aggregation strategy which considers data sensing as continuous stochastic process. The proposed strategy performs filtration of sensed data by removing the redundancy in the sensed data pattern of the sensor node using Brownian motion. Further, the filtered data at the sensor node undergoes entropy-based processing prior to the transmission to cluster head.

III. NETWORK MODEL AND PROBLEM DEFINITION

a. Network model

To simplify the network model, we make some reasonable assumptions about the wireless sensor network as follows.

(1) All of nodes in wireless sensor network own their ID.

(2) The energy of the base station is unlimited.

(3) The proposed algorithm is based on LEACH protocol in cluster-based wireless sensor network.

(4) Each node has the ability of calculating and searing for its cluster head in wireless sensor network.

(5) The loop energy coefficient, characteristic radius and other parameters are stored in the base station.

(6) The state of each sensor node is made up of activating state and sleep state. When the node is in activating state, it will collect the data or transmit the sensed data.

We refer the energy model in the LEACH protocol in our study, which consists of two phases: cluster establishment phase and stable data transmission phase. Regarding the different types of energy consumption, we assume that there is electron energy consumption, energy consumption of the power amplifier when a node transmits data and electron energy consumption which can occur only when a node receives data in a wireless sensor network. If S_{elec} is the energy consumption for transmitting or receiving one bit of data, lS_{elec} is then the energy consumption for transmitting or receiving an l-bit message. Our power amplifier consumption adopts the Free Space Model (FS) and the Multipath Fading Model (MP) according to the distance between the sources and the sink node. When the distance d between two nodes is shorter than a threshold value, the FS model is applied. When the distance d between two nodes is longer than a threshold value but shorter than the maximum communication distance d', the MP Model is applied. Therefore, energy consumption S_s for sending an l-bit message of one node is as follows:

$$S_s = \begin{cases} lS_{elec} + l\varepsilon_{fs} d^2 & d < d_0 \\ lS_{elec} + l\varepsilon_{mp} d_{to-BS}{}^4 & d_0 \le d < d' \end{cases} \tag{1}$$

b. Problem definition

(1)Is the cluster head computable in cluster-based routing protocols?

(2)What energy consumption model uses?

(3)What is the relationship between information rate-distortion function and the data amount?

(4)How to calculate the distance between the sensor nodes and the base station?

(5)How to calculate the optimal cluster head number according to the information rate-distortion function and energy consumption model?

(6)How to apply the optimal cluster head number to the data aggregation process?

Assuming that all of wireless sensor nodes are distributed in a circular area with radius ‘a’ and the sink node is located in the center of the circle and that there are one or more clusters in the same circular area. The process of transmitting data from regular sensor nodes to the sink node is to transmit the data to the corresponding cluster heads along the way. Finally, the data is transmitted from the cluster heads to sink node. Thus, the transmission paths form a hierarchical network. Assuming also that the center of the circular area that that is covered by cluster C is denoted by a node (x_0, y_0) and the distance that the sensor nodes in cluster C can transmit data to the sink node is S.

In the following formula, we assume that ‘a’ is the radius of the circular area C, α' is the energy consumption coefficient, α_1 is the loop energy consumption coefficient, α_2 is the antenna energy consumption coefficient, n is the number of wireless sensor nodes in the circular area, r is the rate of data transmission, δ is the routing influence coefficient, k is the number of cluster heads in the circular area, d_{char} is the regional characteristic radius, γ is the compression ratio, c is the number of over-compression and β is data compression coefficient c. Computability of the Number of Cluster Heads

In WSNs, hierarchical topology for data aggregation is generally preferred in which each round of the collection process will result in a fixed number K of sensor nodes as the cluster heads. At the beginning of each round of the process, every sensor node generates a random number between 0 and 1 and compares the random number with a probability value $P_i(t)$. If the random number is smaller than $P_i(t)$, the sensor node will periodically broadcast an ADV message to its neighboring nodes to inform that it will be the cluster head. The formula for the probability value $P_i(t)$ is defined as follows [30]:

$$P_i(t) = \begin{cases} \dfrac{K}{N - K * (r \bmod \dfrac{N}{K})} & C_i(t) = 1 \\ 0 & C_i(t) = 0 \end{cases} \tag{2}$$

Where $P_i(t)$ is the probability that node i would act as the cluster head at time t. Let N denote the number of sensor nodes in a WSN, K denote the number of cluster heads at each round and r denotes the current working round. $C_i(t)$ is the right of node i to become a cluster head at time t. When there exists $C_i(t)=1$, node i is entitled to become a cluster head at time t and when $C_i(t)=0$, node i isn't entitled to become a cluster head at time t.

It is clear that each node will be able to function as a cluster head once within N/K rounds. Every node has the opportunity to serve as the cluster head, those nodes that have already served as the cluster heads in the first round can no longer serve as the cluster heads in the next $N/K-1$ rounds. Those nodes that can serve as the cluster head fall off, the probability that a remaining node can become a cluster head would go up. After $N/K-2$ rounds, the probability that the remaining nodes who never serve as cluster head can become a cluster head would be 1.

Lemma 1: For a WSN with N nodes, if there are K clusters upon completing each round, then P=K/N and every node can become a cluster head once during N/K rounds.

Proof：In round (r+1), if the probability that a remaining node can become a cluster head at time t is $P_i(t)$, the expectation of the cluster head denoted as N_{ch} is as follows:

$$E(N_{ch}) = \sum_{i}^{N} P_i(t) * 1 = K \tag{3}$$

Since the number of nodes that have not served as the cluster heads in the previous r rounds is $N-K*r$, after N/K rounds, every node should become a cluster head exactly once. Regarding the meaning of $C_i(t)$, symbol $\sum_{i=1}^{N} C_i(t)$ represents the total number of nodes that can serve as the cluster heads at time t and we can then get the following formula:

$$\mathrm{E}\left[\sum_{i=1}^{N} C_i(t)\right] = N - K * (r \bmod \frac{N}{K}) \tag{4}$$

According to Formulas (3) and (4), we can get the mathematical expectation for the cluster head number, which is $E(N_{ch})$:

$$\begin{aligned} E(N_{ch}) &= E(\sum_{i}^{N} P_i(t) * C_i(t)) \\ &= \sum_{i}^{N} P_i(t) * E(\sum_{i}^{N} C_i(t)) \\ &= (N - K * (r \bmod \frac{N}{K})) \times \frac{K}{N - K * (r \bmod \frac{N}{K})} \\ &= K \end{aligned} \tag{5}$$

Where N_{ch} is the number of cluster heads, $E(N_{ch})$ is the expectation of cluster head number, $P_i(t)$ is the probability that node i will act as a cluster head at time t, $C_i(t)$ indicates whether node i has the right to function as a cluster head at time t. Again, N is the number of sensor nodes in a WSN, K is the number of cluster heads after each round and r is the current working round.

IV. AGORITHM OF OPTIMIZING CLUSTER HEAD NUMBER

Based on LEACH protocol，the algorithm ONCH_LEACH(Optimal Number of Clusters Heads based on LEACH) is also divided into three phases which are cluster head selection phase, cluster formation stage and the data transmission phase. The difference between two algorithms is that the number of cluster head in LEACH protocol is not explicit, while which is explicit and optimal expressed in ONCH_LEACH. So the algorithm of Optimizing Cluster Head Number (OCHN) is the key part of ONCH_LEACH, the main steps of which are summarized as follows.

a. Algorithm of OCHN

Based on the node number, area radius, routing influence coefficient and the coordinates of cluster center, data aggregation energy coefficient, circuit energy consumption coefficient, the data transfer rate, compression rate and network energy consumption model, the basic idea of OCHN algorithm is that firstly we calculate the distance from sensor nodes to cluster heads and the optimal number of cluster heads for data aggregation based on the rate-distortion function, then we can get the optimal ratio cluster head for the data aggregation according to the practical experiment. The principle of OCHN algorithm is shown in Figure 2.

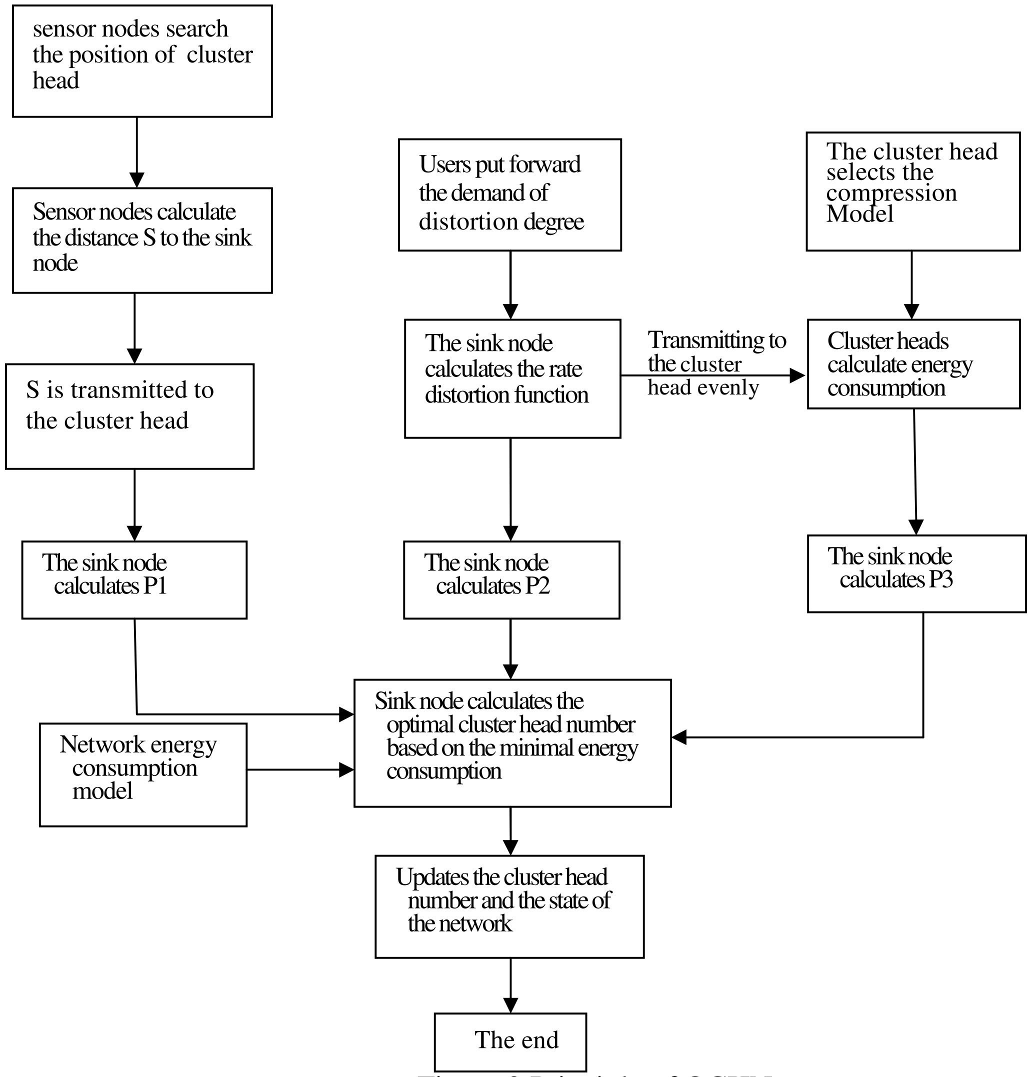

Figure 2 Principle of OCHN

Step 1: the sink calculates the radius of each cluster according to the area radius and the initial cluster k_0, and transmits the result to all of sensor nodes.

$$k_0 \pi x^2 = \pi a^2 \quad (6)$$

$$x = a / \sqrt{k_0}$$

Where a is the area radius, k_0 is the number of cluster, and x is the radius of each cluster.

Step 2: The sensor nodes search for the position of their cluster head, calculate the distance 'S' according to the formula (3), and put the results back to the sink node [30-31].

$$S = \frac{n\times\delta}{\pi a^2}\times\int\int_{(x,y\in C)}\sqrt{(x-x_0)^2+(y-y_0)^2}\,d_x d_y$$
$$= \frac{n\times\delta}{\pi a^2}\times\int_0^{2\pi} d_\theta \int_0^{\frac{a}{\sqrt{k_0}}}\sqrt{r^2}\times r d_r$$
$$= \frac{n\times\delta}{\pi a^2}\int_0^{2\pi} d_\theta \times\frac{1}{3}\times r^3 /_0^{\frac{a}{\sqrt{k_0}}}$$
$$= \frac{n\times\delta}{\pi a^2}\times\frac{1}{3}\times\frac{a^3}{k_0^{\frac{3}{2}}}\times\theta /_0^{2\pi}$$
$$= \frac{2an\delta}{3k_0^{\frac{3}{2}}} \quad (7)$$

Step 3: The sink node calculates the energy consumption P_1 that sensor nodes transmit data to the cluster head according to the circuit energy consumption parameters, area radius, the transmission rate, routing coefficient and the distance S obtained in Step 2.

$$P_1 = \frac{2\alpha' anr\delta}{3k_0^{\frac{1}{2}}} \quad (8)$$

Where $\alpha' = (\alpha_1 + \alpha_2 d_{char}) / d_{char}$

Step 4: Based on the information distortion degree D that the user can accept, the sink node calculates the minimal data amount that is rate-distortion $R(D)$. Typically, the energy consumption required for data aggregation which we call P_2 is proportional to the amount of data compression. Where $R(D)$ is the minimal total data amount that the sink can receive, β is the energy coefficient for data aggregation.

$$P_2 = \beta R(D) \quad (9)$$

Step 5: The sink node divides $R(D)$ evenly according to the cluster number and transmits to every cluster head node. Based on the data amount received and the compression model adopted, the cluster head calculates the third part of energy consumption P_3 and transmits the result of P_3 to the sink node.

$$P_3 = (\gamma R(D) + c)\times\frac{2k_0\alpha' a}{3} \quad (10)$$

Step 6: According to the adopted energy consumption model, P_1, P_2, and P_3, the sink calculates the total energy consumption E, so the minimal cluster head number can be derived based on the method of seeking the extreme value.

$$E = P_1 + P_2 + P_3 = \frac{2\alpha' anr\delta}{3k_0^{\frac{1}{2}}} + \beta R(D) + (\gamma R(D) + c) \times \frac{2k_0\alpha' a}{3} \tag{11}$$

Let E=0, the derivation of k_0 is the optimal cluster head number k. The derivation process is as follow.

$$\begin{aligned}
&E = \frac{2\alpha' anr\delta}{3k^{\frac{1}{2}}} + \beta R(D) + (\gamma R(D) + c) \times \frac{2k\alpha' a}{3} \\
&-\frac{1}{2} \times \frac{2\alpha' anr\delta}{3k^{\frac{3}{2}}} + (\gamma R(D) + c) \times \frac{2\alpha' a}{3} = 0 \\
&\frac{\alpha' anr\delta}{3k^{\frac{3}{2}}} = \frac{2\alpha' a(\gamma R(D) + c)}{3} \\
&\frac{nr\delta}{k^{\frac{3}{2}}} = 2(\gamma R(D) + c) \\
&k^{\frac{3}{2}} = \frac{nr\delta}{2(\gamma R(D) + c)} \\
&k = (nr\delta / 2(\gamma R(D) + c))^{\frac{2}{3}}
\end{aligned} \tag{12}$$

Step 7: The sink updates the initial cluster head number stored, and runs information processing algorithms to achieve the new state of network. When the sink receives the new distortion degree of users, step (1)-step (7) will be repeated. The process of OCHN algorithm is shown in Figure 3.

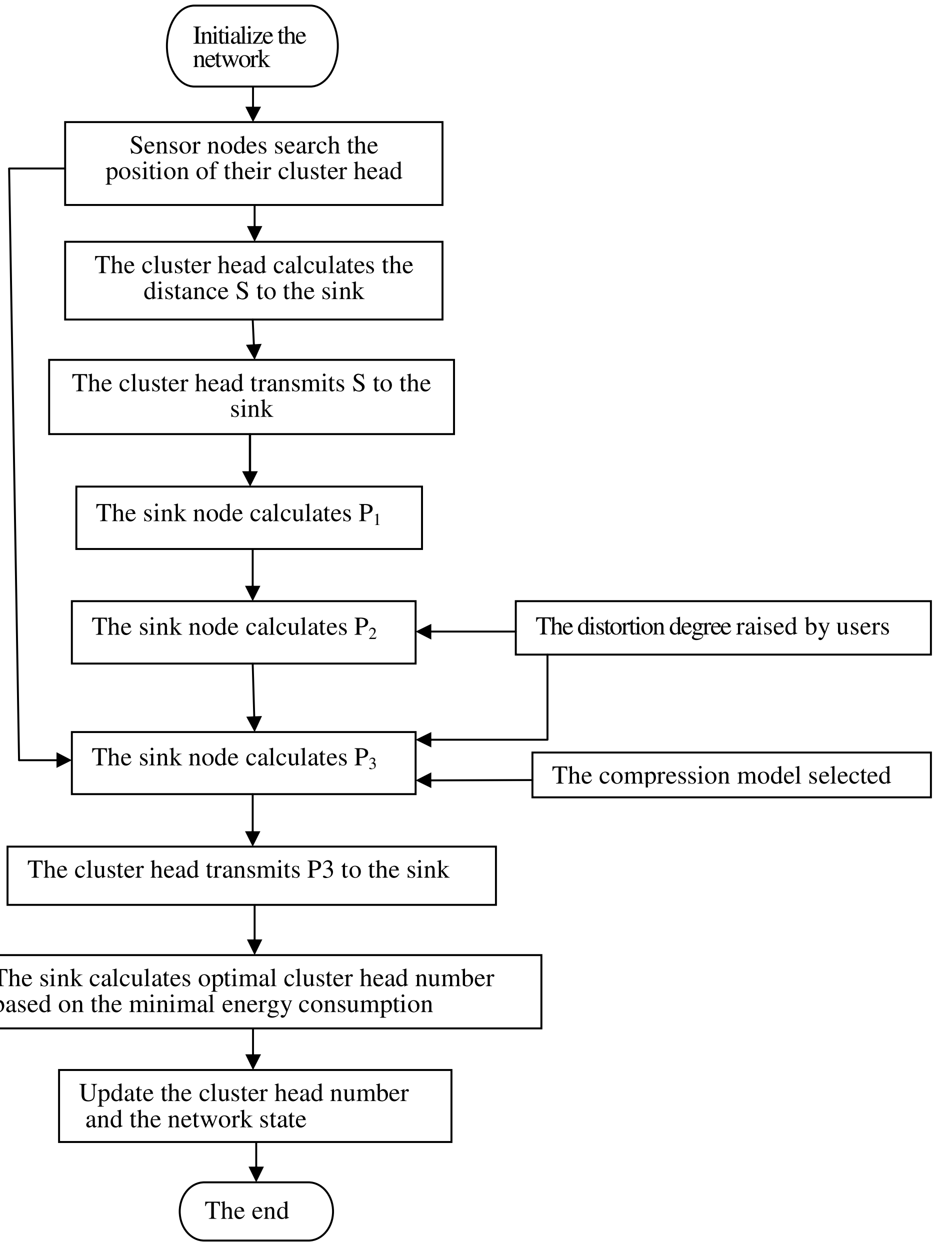

Figure 3.Process flow of OCHN

b. Example for OCHN algorithm

The topology of OCHN example is illustrated in Figure 4.

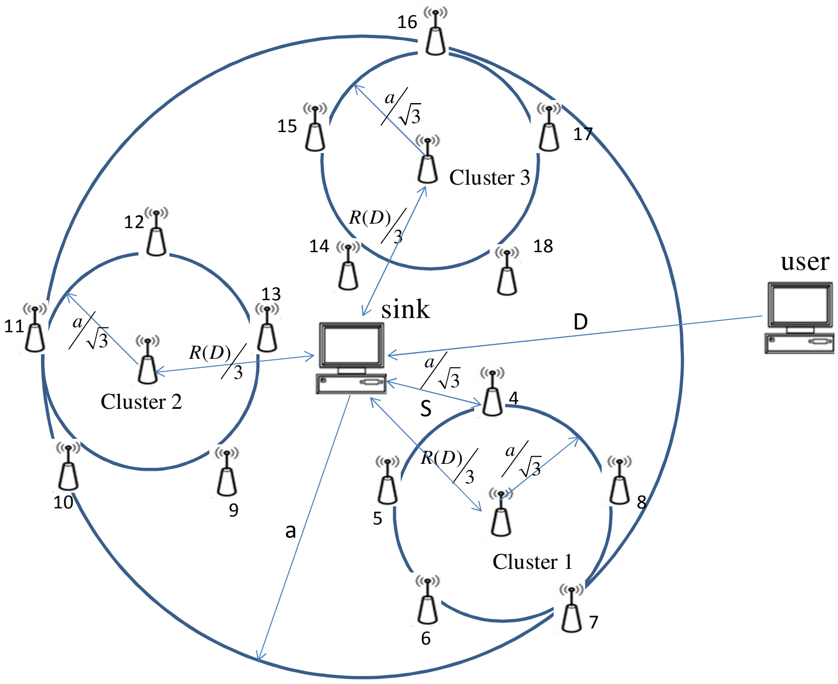

Figure 4 Topology of OCHN

Step 1: The sink is the center of wireless sensor network which is a circular area with 18 sensor nodes and a radius of 50m. Those 15 sensor nodes are divided evenly among the three clusters. All of cluster member nodes form a circular area which regards the cluster head as the center. As the direct point of contacting with the outside world, the sink (base station) communicates the user directly. Cluster heads are labeled respectively cluster 1, cluster 2, and cluster 3, while cluster member nodes are labeled node 4 -18.

Step 2: According to the area radius and the initial cluster number, the base station calculates the radius of cluster 1-3 based on the formula (2).

Step 3: Receiving instructions from the base station, sensor nodes search for the position of their cluster head. The process of searching cluster head 1 which is the cluster head of sensor node 4 is as follows: the node 4 seeks the cluster 1 as the cluster head and marks it (x_0,y_0), then calculates the distance to the cluster 1 and feedbacks the result S' to the base station. The formula (9) is as follow.

$$S' = \frac{n\times\delta}{\pi a^2}\times\int\int_{(x,y\in 1)}\sqrt{(x-x_0)^2+(y-y_0)^2}\,d_x d_y$$
$$= \frac{n\times\delta}{\pi a^2}\times\int_0^{2\pi} d_\theta \int_0^{\frac{a}{\sqrt{k_0}}}\sqrt{r^2}\times r d_r$$
$$= \frac{n\times\delta}{\pi a^2}\int_0^{2\pi} d_\theta\times\frac{1}{3}\times r^3 /_0^{\frac{a}{\sqrt{k_0}}}$$
$$= \frac{n\times\delta}{\pi a^2}\times\frac{1}{3}\times\frac{a^3}{k_0^{\frac{3}{2}}}\times\theta /_0^{2\pi}$$
$$= \frac{2an\delta}{3k_0^{\frac{3}{2}}} \qquad (13)$$

Substituted a=50m，n=18， δ=0.95，and k_0=3 into the formula (9), we will get the result S'=110m.

Step 4: step 8 are similar to step3 - step 7 of OCHN algorithm, the only explanation is that the data amount of every cluster in this example is $R(D)/3$.

V. Simulation and results analysis

a. Analysis of energy consumption

We simulate our experiments in MATLAB software. From the view of the total amount of network energy consumption, we compare the proposed OCHN algorithm with the method proposed by Yang et al [20]. The simulation parameters are set as follows: n=1000, a=1000m, α_1 =5×10^{-8}J/b, α_2 =1×10^{-10}J/b, d_{char} =22.36, β =5×10^{-8}J/b, γ =30%,v=32bit, δ =0.95, r=160b/sec.

From Figures 5 and 6, we can see that the amount of energy that is consumed decreases along with the increase of K, that is, the energy consumption decreases along with an increase in the number of fusion nodes or cluster nodes. For the same number K in the range [821, 825], the total amount of network energy consumption of in the case of the two-element source based on the rate-distortion function shown in Fig.5 is lower than that shown in Fig.6 which doesn’t employ the rate-distortion function. Moreover, under the same simulation environment, the best result occurs when the number of fusion nodes is 821 for the Gaussian source. So we conclude that the optimal ratio of cluster head is p=0.08.

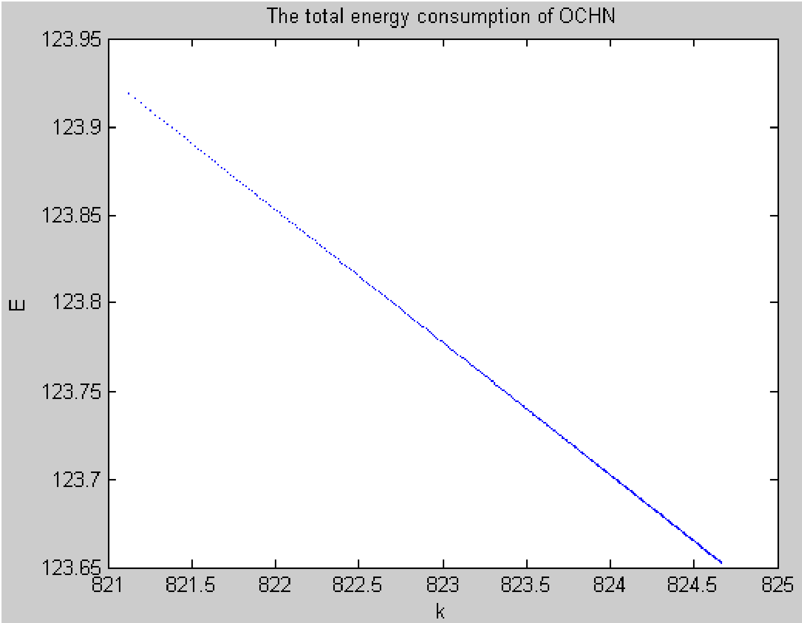

Figure 5 Overall network energy consumption of two-element source based on the rate-distortion function

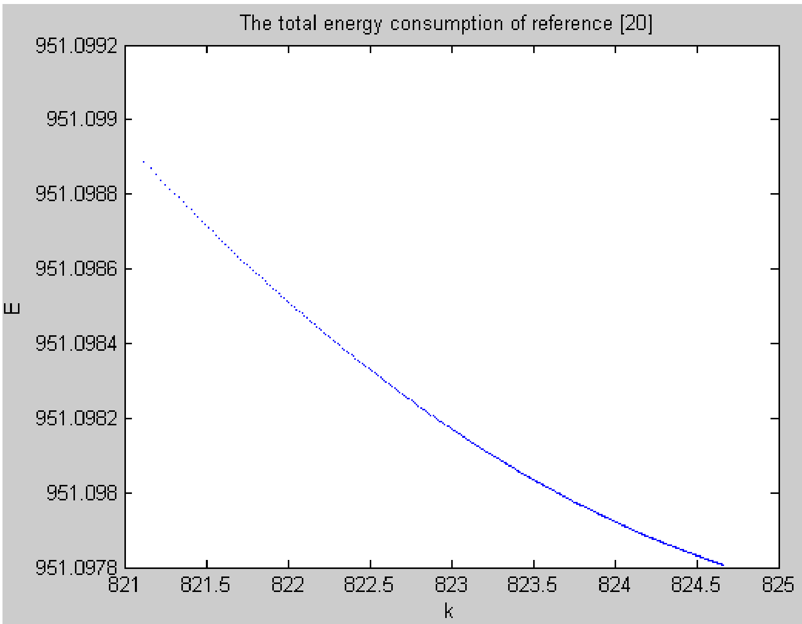

Figure 6 Overall energy consumption of network without considering the rate- distortion function

b. Analysis of network lifetime and data transmission

100 sensor nodes are randomly distributed in the area 100m*100m, the coordinate of the base station (sink) is (50, 50). The simulation parameters are set as follows: E_0=0.5J, Etx=$50*10^{-9}$; Erx=$50*10^{-9}$; Efs=$10*10^{-12}$; Emp=$0.0013*10^{-12}$; Eda=$5*10^{-9}$; r_{max}=5000. Under three different

ratios of the cluster head p=0.05, p=0.08, and p=0.1, the performances of network lifetime and data transmission are compared for four protocols as shown in Figs.7, 8 and 9.

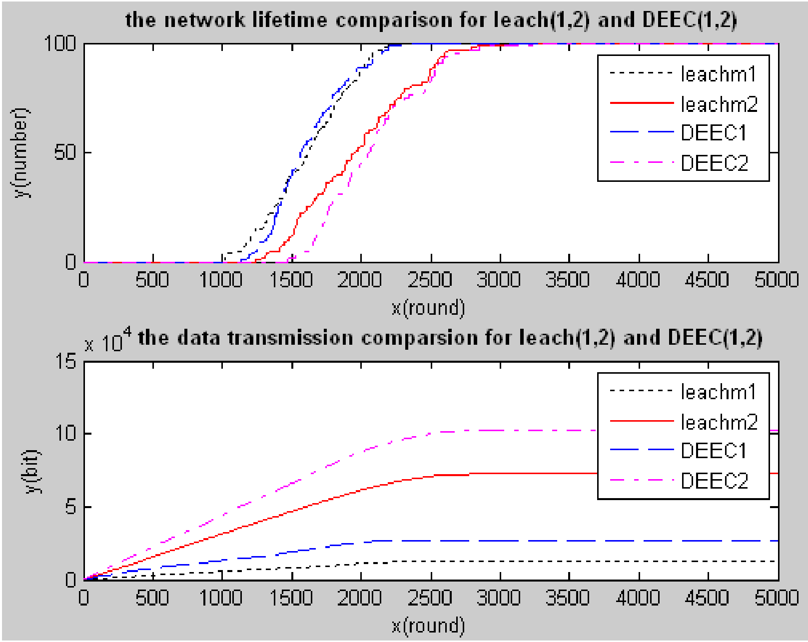

Figure 7 Performances for the ratio of cluster head p=0.05

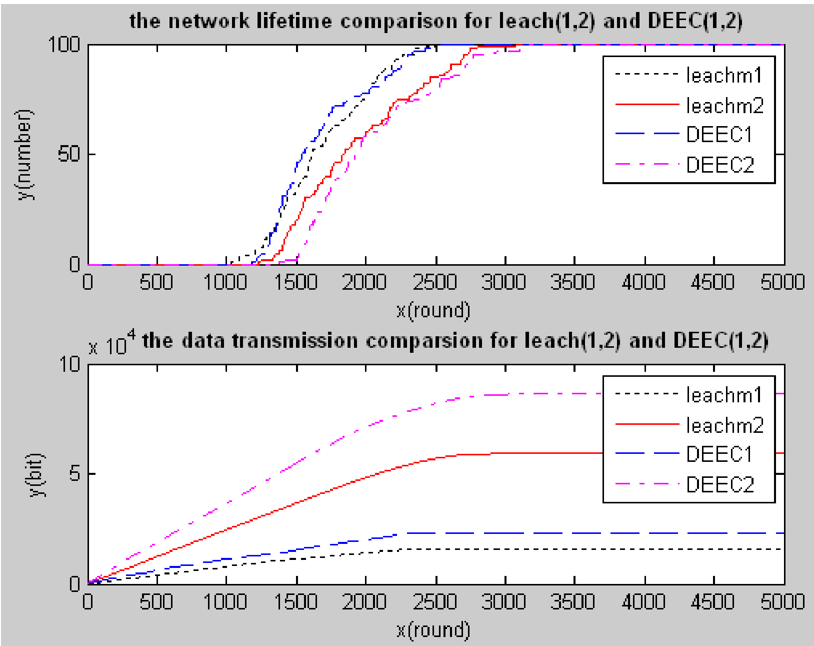

Figure 8 Performances for OCHN (p=0.08)

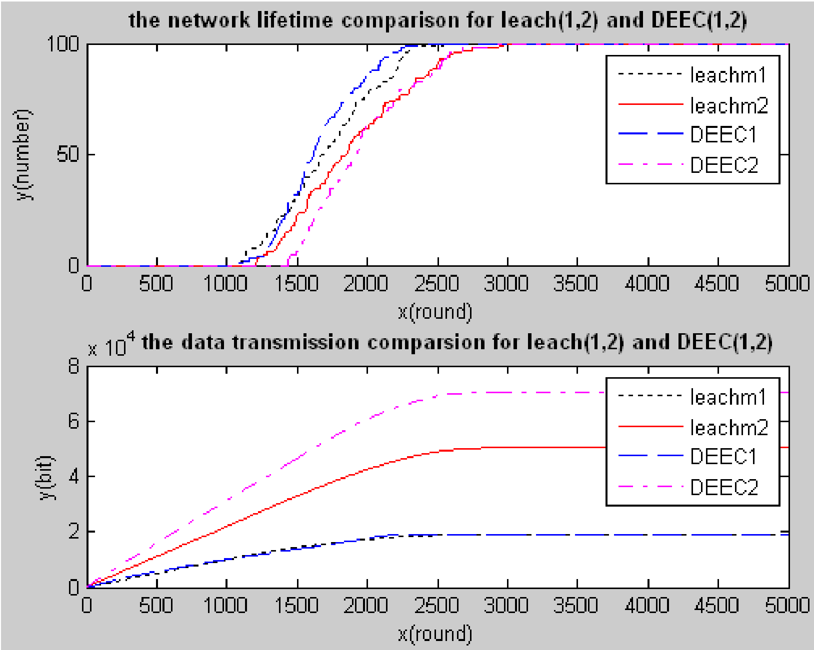

Figure 9 Performances for the ratio of cluster head p=0.1

The above simulation results show that the amount of data transmission for two LEACH algorithms, two DEEC algorithms and OCHN algorithm are almost the same. By comparing the performances of two cluster head ratios p=0.08 and p=0.05, the network lifetime of OCHN (P=0.08) is longer than that of the cluster head ratio p=0.05. On the other hand, by comparing the performances of two cluster head ratios p=0.08 and p=0.1, the simulation shows that the network lifetime for two situations is almost same, while the amount of data transmission of OCHN is much higher than that of the cluster head ratio p=0.1. In a word, the OCHN algorithm has the best comprehensive performance.

VI. CONCLUSIONS

In this paper, we propose an algorithm OCHN of calculating the optimal cluster heads number for data aggregation in wireless sensor networks. According to the established energy consumption model, the optimal number of the cluster head can be calculated based on the rate-distortion function. We do some analysis on the simulation experiments, some of results demonstrate that the total energy consumption of the proposed OCHN would consume less energy than the one that doesn't consider the information distortion, others results show that the comprehensive performance of the network lifetime and the amount of data transmission for

OCHN is good. How to take strategy of the optimal cluster head number to handle the question during the process of the secure data aggregation may be the future research direction.

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