

Equalization of Energy Consumption at Cluster Head for Prolonging Lifetime in Cluster-based Wireless Sensor Networks

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Abstract: - In cluster-based wireless sensor networks (WSN), the most of energy is consumed in cluster head which performs data aggregations and relaying. The lifetime in cluster-based WSN is subjected by the lifetime of cluster heads. Therefore, in this paper, we equalize the energy consumption of the cluster heads to prolong the lifetime of WSN. After equalization, we obtain the length of sides of cluster area. Numerical results show that the length of far site cluster is shorter than the nearest cluster to perform equalization for all three routing schemes. Moreover, simulation results show that the three-hop scheme can obtain the most energy efficiency than other two schemes.

Key-Words: - Wireless sensor network, Clustering, energy efficiency, Cluster head, Energy consumption equalization, Network lifetime.

1 Introduction

Recently, the rapidly developed technologies of microelectro-mechanical systems and telecommunication battery make the small sensors comprise the capabilities of wireless communication and data processing [1]. These small sensors could be used as the surveillance and the control capability under a certain environment. Specially, the location of wireless sensor network (WSN) could be a region where people could not easily reach and there is a difficulty to recharge the device energy. Therefore, the energy efficiency of the sensor networks is an important research topic and the lifetime of WSNs could be considered as the most significant performance in the WSN [2]. Moreover, there are two main issues in the lifetime prolong problems. One is to minimize the energy dissipation for all energy constrained nodes. The other one is to balance the energy dissipation of all nodes [2].

The energy in WSN is mainly consuming on the direct data transmission [2]. Firstly, each sensor

collects data and delivers the data to the base station directly, called as "sink". Applying this mode, the sensor will have quick energy exhaustion if it is apart from the base station. Thus, this kind transmission scheme is not suitable in a large area [2]. Then, secondly, to enable communication between sensors not within each other's communication range, the common multi-hop routing protocol is applied in the ad hoc wireless sensors communication networks [3]-[5]. In this scheme, several multi-hop paths exist to perform the network connectivity. Each path in the configuration will have one link head to collect data from sensors. Every sensor node in the WSN sends both the sensing data of itself and the receiving data from previous nodes to its closer node. Then, the destination node delivers the data collection in the path to the base station. The nodes closer to the base station need more energy to send data because the scheme uses hierarchy transmission. However, due to the highly complexity in routing protocols and the

most likely heavy load on the relaying nodes, this scheme is not suitable for the highly densely WSNs.

The third scheme is the cluster-based one that those closer sensors belong to their own clusters. One of sensors, called "cluster head (CH)", in each cluster is responsible for delivering data back to the base station. In this scheme, the CH performs data compressing and sending back to the base station. Thus, the lifetime of CH may be shorter than that of other sensors [6]-[7]. Therefore, for WSNs with a large number of energy-constrained sensors, it is very important to design an algorithm to organize sensors in clusters to minimize the energy used to communicate information from all nodes to the base station.

Moreover, the energy efficiency and the lifetime prolonging are the most important topics in WSNs [8]-[10]. As we know that both energy efficiency and energy balancing are two main issues for prolonging the lifetime WSNs. Then the structure of low-energy adaptive clustering hierarchy (LEACH) proposed by [11]-[13] is one of the initiate algorithm to balance the energy issues for cluster based WSNs. In LEACH, the CH can be elected by uniform random number to uniformly take turn being the CH. Then the energy consumption for all nodes will be nearly balanced in a round [11]. However, due to the randomly clustering the cluster area may be too large to consume large energy for the CH. Then the energy dissipation becomes inefficiently. Therefore, in this paper a fixed area clustering method is proposed to improve the energy efficiency. Moreover, to equalize the energy consumption of CHs can prolong the network lifetime effectively. Therefore, an analysis on the equalization of the energy consumption of CHs is investigated in this paper.

In the following section, the network models of the WSN are described. Then, the analysis of energy consumption of CHs is described. In order to investigate the energy efficiency on the clustering algorithms, numerical results are performed to compare energy efficiency for different channel environments. Finally, conclusions are given in final section.

2 Network Models

The sensing area is assumed to be a free space area where there are no any obstacles and all the nodes are not moveable. Then the wireless channel model can be expressed by path loss model. Thus, the received power at receiver can be expressed by

$$P_r = c \frac{P_t}{d^\alpha} \quad (1)$$

where d is the distance between the receiver and transmitter, P_t is the transmission power of the transmitter, and c is the coefficient of the antennas. Moreover, to investigate a large sensing area we set the path loss exponent α between 2 and 6 [4].

To be simplification, the sensing nodes are assumed to be uniformly distributed by $d_s(1/m^2)$. Then the data gathering in a cluster is proportional to its cluster area. To prolong the lifetime of CHs, the energy consumption of CHs in one round is expressed by

$$E_{CH} = E_p \cdot X^2 \cdot d_x^\alpha, \quad (2)$$

where d_x is the distance between the CHs and BS, X is the length of one side of the square cluster area, $E_p(J/m^2/m^\alpha)$ is the energy consumption per area unit for transmission one meter. Due to the sensor nodes are uniformly deployed in the sensing area, the data for CH relaying is dependent on the area of cluster. Besides, with the requirement of received power by $P_r=c_1 \cdot c$ for effective communication link, where c_1 is a constant related to channel noise, from (1) and (2) we obtain

$$E_p X^2 = T_r \cdot P_t, \quad (3)$$

where T_r is the total time duration of packets transmission for one round

3 Analysis on Energy Equalization at Cluster Heads

3.1 Direct Transmission

In practical, the geometry of the WSN is non-regular. However, the square is a basic area to be consisted of non-regular area. Thus, for simplification, in this paper we adopt square area approximation for WSNs. The sensor area is with uniformly distributed CHs and is shown in Fig. 1. In Fig. 1, the symbol "•" is represented as a location of CH whereas the symbol "o" is represented as a location of the sensing node. When the cluster area is of random distributed, the energy efficiency of sensor nodes on data transmitting is terrible [3]. Based on the configuration of square area, the sensors are supposed to be spread out uniformly to the whole area. The data from each cluster will be

collected by the CH and these data will be sent back to the base station located at the point (0, -B).

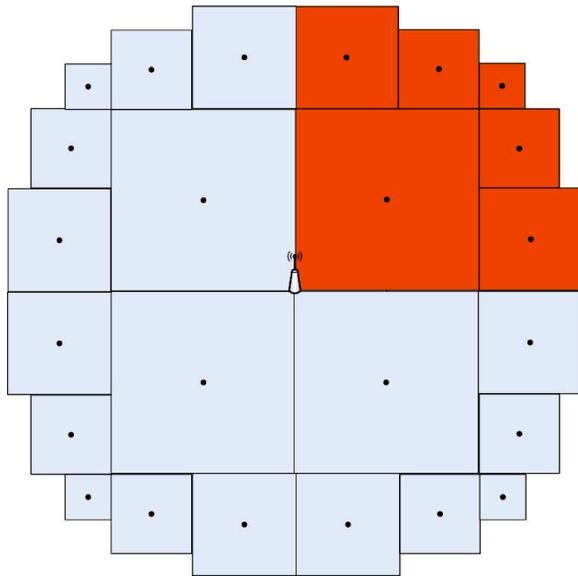


Fig. 1. The sensing area in desired wireless sensor network.

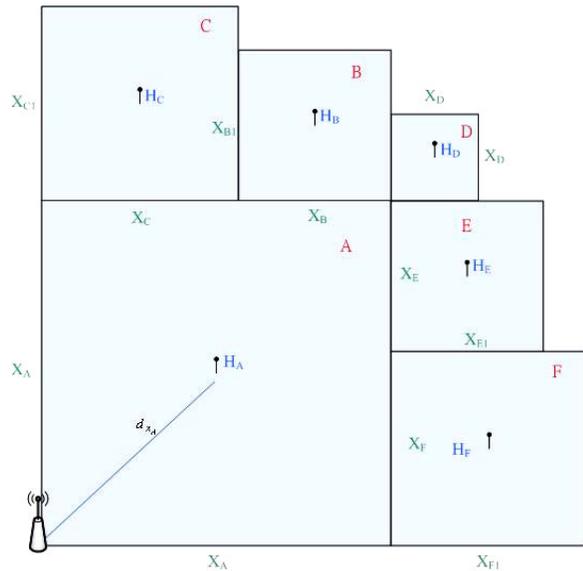


Fig. 2. The clustering topology in a quarter of the WSN.

In this paper, we define the sensing area as shown in Fig. 1 where base station is deployed at center of the area. However, to be simplification, we investigate the quarter area as shown in shadow area in Fig.1 and Fig. 2. To develop the investigation for the energy consumption equalization of the CHs, we assume that all CHs are deployed in the centroid of

the square area of cluster. Due to the uniformly deployed sensors in the area, the amount of data of CHs gathering and relaying depends on the clustering area. Furthermore, with direction transmission of the CHs to base station, the farer CHs consumes more energy. Therefore, the farer area of clusters should be smaller than those nearer clusters, as the dividing area in Fig. 1 and 2.

In the areas of Fig. 2, we denote the six clusters by A, B, C, D, E, and F respectively. The length of one side and the CH for clusters A, B, C, D, E, and F are denoted by $X_A, X_B, X_C, X_D, X_E, X_F$ and $H_A, H_B, H_C, H_D, H_E, H_F$, respectively. The distance between CHs and base station are denoted as $d_{x_A}, d_{x_B}, d_{x_C}, d_{x_D}, d_{x_E}$ and d_{x_F} , respectively.

It is obvious that the distance between different clusters to BS is different as shown in Fig. 2. Thus to simplify the analysis, the area of the cluster is assumed to be square. Moreover, to equalize to energy consumption of CHs, it is obvious that the data transmitted by the farer cluster should be less than that of near clusters. We can calculate the energy consumption of the CHs in Fig. 2 by distribute the length variable into (2). Thus, we obtain the energy consumption of six CHs in one round by

$$E_A = E_p \cdot X_A^2 \cdot \left(\frac{X_A}{\sqrt{2}}\right)^\alpha, \quad (4)$$

$$E_B = E_p \cdot X_B \cdot X_{B_1} \cdot \left[\sqrt{\left(X_C + \frac{X_B}{2}\right)^2 + \left(X_A + \frac{X_{B_1}}{2}\right)^2} \right]^\alpha, \quad (5)$$

$$E_C = E_p \cdot X_C \cdot X_{C_1} \cdot \left[\sqrt{\left(\frac{X_C}{2}\right)^2 + \left(X_A + \frac{X_{C_1}}{2}\right)^2} \right]^\alpha, \quad (6)$$

$$E_D = E_p \cdot X_D^2 \cdot \left[\sqrt{2} \left(X_A + \frac{X_D}{2}\right) \right]^\alpha, \quad (7)$$

$$E_E = E_p \cdot X_E X_{E_1} \cdot \left[\sqrt{\left(X_F + \frac{X_E}{2}\right)^2 + \left(X_A + \frac{X_{E_1}}{2}\right)^2} \right]^\alpha \quad (8)$$

and

$$E_F = E_p \cdot X_F \cdot X_{F_1} \cdot \left[\sqrt{\left(\frac{X_F}{2}\right)^2 + \left(X_A + \frac{X_{F_1}}{2}\right)^2} \right]^\alpha \quad (9)$$

,respectively. To equalize the energy consumption of CHs in one round, let E_A equal the energy consumption of H_D , E_D . Then, we obtain the relationship of X_D and X_A by

$$X_A^2 \left(\frac{X_A}{\sqrt{2}}\right)^\alpha = X_D^2 \cdot \left[\sqrt{2} \left(X_A + \frac{X_D}{2}\right) \right]^\alpha \quad (10)$$

Thus, based on the length of cluster A, X_A , we can adjust the length of cluster D, X_D . Furthermore, to arrange the length of cluster B and C, we let the energy consumption of H_B and H_C be equalized, then obtain the relations of X_B and X_C as

$$\begin{aligned} X_B \cdot X_B \cdot \left[\sqrt{\left(X_C + \frac{X_B}{2}\right)^2 + \left(X_A + \frac{X_B}{2}\right)^2} \right]^\alpha \\ = X_C \cdot X_C \cdot \left[\sqrt{\left(\frac{X_C}{2}\right)^2 + \left(X_A + \frac{X_C}{2}\right)^2} \right]^\alpha \end{aligned} \quad (11)$$

From Fig. 2, it is observed that

$$X_A = X_C + X_B \quad (12)$$

From (11) and (12), we obtain the relations of X_B , X_C and X_A by $X_B = f_1(X_A)$ and $X_C = f_2(X_A)$, respectively. Moreover, to equalize both E_B and E_C with E_A , we adjust the other side length of cluster B and cluster C by X_{B_1} and X_{C_1} , respectively. Then we obtain the relations of X_{B_1} , X_{C_1} , X_B , X_C and X_A by

$$X_A^2 \left(\frac{X_A}{\sqrt{2}}\right)^\alpha = X_C \cdot X_{C_1} \cdot \left[\sqrt{\left(\frac{X_C}{2}\right)^2 + \left(X_A + \frac{X_{C_1}}{2}\right)^2} \right]^\alpha \quad (13)$$

and

$$X_A^2 \left(\frac{X_A}{\sqrt{2}}\right)^\alpha = X_B \cdot X_{B_1} \cdot \left[\sqrt{\left(X_C + \frac{X_B}{2}\right)^2 + \left(X_A + \frac{X_{B_1}}{2}\right)^2} \right]^\alpha \quad (14)$$

,respectively. Therefore, after distributing $X_B = f_1(X_A)$ and $X_C = f_2(X_A)$ in (13) and (14) respectively, we obtain other side lengths of cluster B and cluster C by $X_{B_1} = f_3(X_A)$ and $X_{C_1} = f_4(X_A)$, respectively. Similarly, because cluster E and cluster F are symmetrical to cluster B and cluster C, respectively, the length of the sides of cluster E and cluster F, the relations of X_E , X_F , X_{E_1} , X_{F_1} and X_A can be obtained as

$$X_E \cdot X_E \cdot \left[\sqrt{\left(X_F + \frac{X_E}{2}\right)^2 + \left(X_A + \frac{X_E}{2}\right)^2} \right]^\alpha \quad (15)$$

$$= X_F \cdot X_F \cdot \left[\sqrt{\left(\frac{X_F}{2}\right)^2 + \left(X_A + \frac{X_F}{2}\right)^2} \right]^\alpha$$

$$X_A^2 \left(\frac{X_A}{\sqrt{2}}\right)^\alpha = X_E \cdot X_{E_1} \cdot \left[\sqrt{\left(X_F + \frac{X_E}{2}\right)^2 + \left(X_A + \frac{X_{E_1}}{2}\right)^2} \right]^\alpha \quad (16)$$

and

$$X_A^2 \left(\frac{X_A}{\sqrt{2}}\right)^\alpha = X_F \cdot X_{F_1} \cdot \left[\sqrt{\left(\frac{X_F}{2}\right)^2 + \left(X_A + \frac{X_{F_1}}{2}\right)^2} \right]^\alpha \quad (17)$$

,respectively. Then the length of X_E , X_F , X_{E_1} , and X_{F_1} can be obtained as the function of X_A by

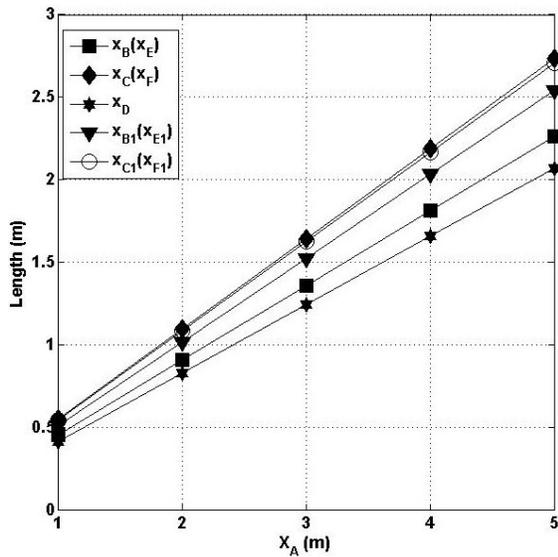
$$X_E = X_B = f_1(X_A), \quad (18a)$$

$$X_F = X_C = f_2(X_A), \quad (18b)$$

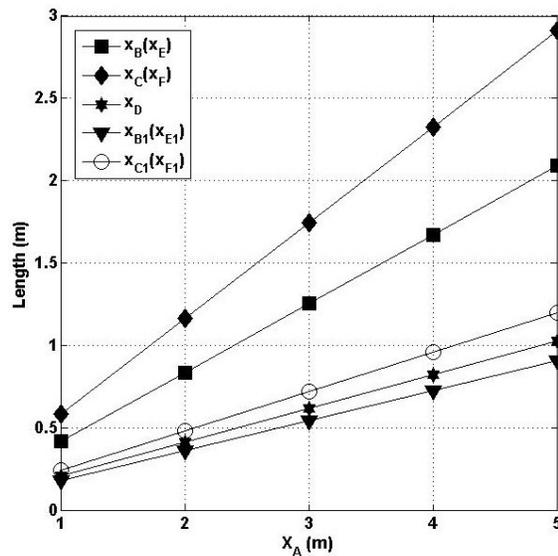
$$X_{E1} = X_{B1} = f_3(X_A), \quad (18c)$$

$$X_{F1} = X_{C1} = f_4(X_A). \quad (18d)$$

To illustrate the relations of all length of the clusters with X_A from (10) and (18), Fig. 3 shows the relations for equalization of CHs in WSNs with the path loss exponent $\alpha = 2$ and $\alpha = 4$. From Fig. 3, it is observed that with both $\alpha = 2$ and $\alpha = 4$ the length of other five sides linearly depend on X_A .



(a)



(b)

Fig. 3. The length of the clusters vs. X_A for equalization of CHs with (a) $\alpha = 2$ (b) $\alpha = 4$.

Fig. 4 shows that the length of the clusters and $X_A = 1m$ for equalization of CHs with $2 \leq \alpha \leq 5$. Thus, we can obtain the five lengths by the known X_A and path loss exponent for equalization on the energy consumption of the CHs. From Fig. 4, it is observed that other lengths of clusters decrease as α increases with $X_A = 1m$. Thus, we can obtain the five lengths of X_D , X_{B1} , X_{C1} , X_{E1} and X_{F1} by the known X_A and path loss exponent α for equalization on the energy consumption of the CHs.

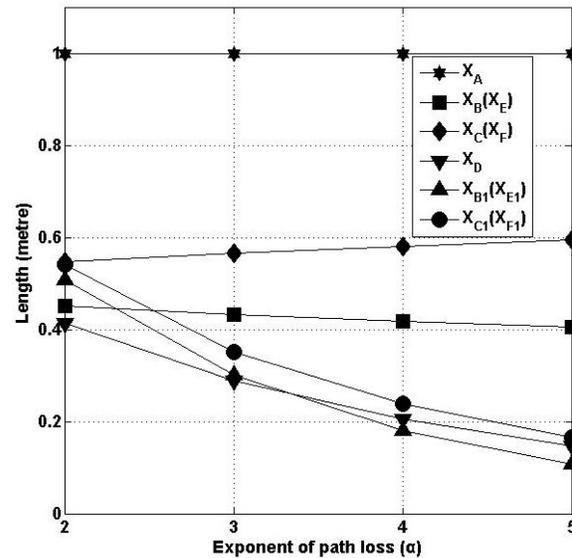


Fig. 4. The Comparisons of the length of clusters and $X_A = 1m$ for equalization of CHs with $2 \leq \alpha \leq 5$.

3.2 Two-hop Transmission

Direct transmission is the simplest scheme. However, the energy efficiency is the worst than other multi-hop schemes. In this section, we will discuss the equalization of CHs for two-hop scheme. Firstly, the network area is redefined as shown in Fig. 5.

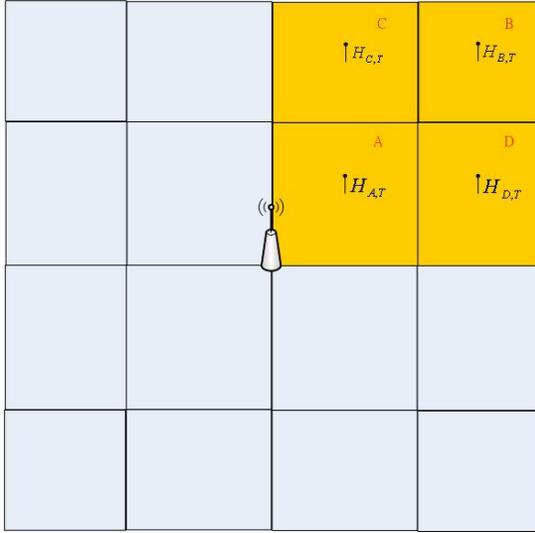


Fig. 5. The sensing area for two-hop cluster-based WSNs.

We assume that the two-hop routing is depicted in Fig. 6. Therefore, the energy consumption of four CHs, $E_{A,T}$, $E_{B,T}$, $E_{C,T}$ and $E_{D,T}$ in one round can be obtained by

$$E_{A,T} = \eta_T \cdot E_p \cdot (x_T + y_T)^2 \cdot \left(\frac{\sqrt{2}}{2} x_T\right)^\alpha, \quad (19)$$

$$E_{B,T} = E_p \cdot y_T^2 \cdot \left(\frac{\sqrt{2}}{2} (x_T + y_T)\right)^\alpha, \quad (20)$$

and

$$E_{C,T} = E_{D,T} = E_p \cdot (x_T \cdot y_T) \cdot \left(\frac{1}{2} (x_T + y_T)\right)^\alpha \quad (21)$$

,respectively. In (19)-(21), the length, x_T and y_T are the length of one side of cluster A and cluster B, respectively as shown in Fig. 6. In (19), the factor η_T is assumed to be the data fusion ratio performed by $H_{A,T}$. To equalize the $E_{A,T}$, $E_{B,T}$, $E_{C,T}$ and $E_{D,T}$ is mean to adjust the length of sides, x_T and y_T . Firstly, we equalized $E_{B,T}$, $E_{C,T}$ and $E_{D,T}$, then obtain the relations of x_T and y_T by

$$y_T^2 \cdot \left(\frac{\sqrt{2}}{2} (x_T + y_T)\right)^\alpha = (x_T \cdot y_T) \cdot \left(\frac{1}{2} (x_T + y_T)\right)^\alpha. \quad (22)$$

Thus, the length of cluster B, y_T , can be obtained as the function of the length of cluster A, x_T , as

$$y_T = f_5(x_T). \quad (23)$$

However, the energy consumption of $H_{A,T}$, $E_{A,T}$, should be also be equalized to $E_{B,T}$, $E_{C,T}$ and $E_{D,T}$. Consequently, the data fusion ratio η_T is put into (19) to perform possible equalization of $E_{A,T}$ and $E_{B,T}$. We then obtain the relations of η_T , x_T and y_T by

$$\eta_T \cdot (x_T + y_T)^2 \cdot \left(\frac{\sqrt{2}}{2} x_T\right)^\alpha = y_T^2 \cdot \left(\frac{\sqrt{2}}{2} (x_T + y_T)\right)^\alpha. \quad (24)$$

From (24), the data fusion ratio η_T can be obtained as the function of x_T , as

$$\eta_T = f_6(x_T). \quad (25)$$

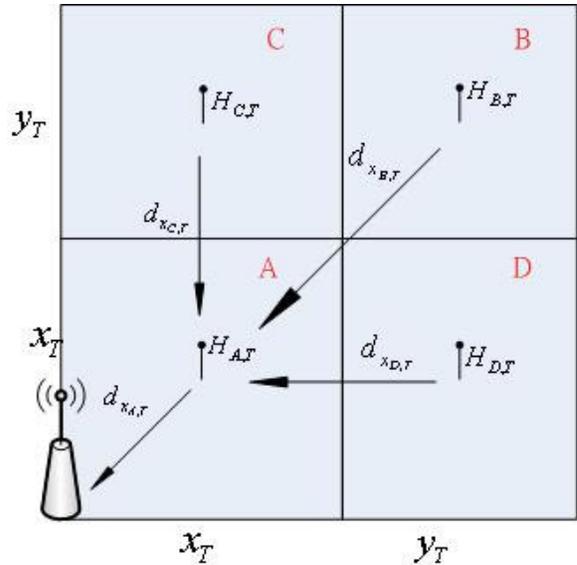


Fig. 6. The two-hop routing in WSNs.

3.3 Three-hop Transmission

To perform more energy efficiently, the three-hop transmission scheme is proposed as shown in Fig. 7. Thus, we further analyze the energy equalization of CHs for the three-hop scheme. In Fig. 7, we select two CHs, $H_{A,TH}$, in cluster A to further improve the energy efficiency. The exact position of $H_{A,TH}$ is illustrated in Fig. 8.

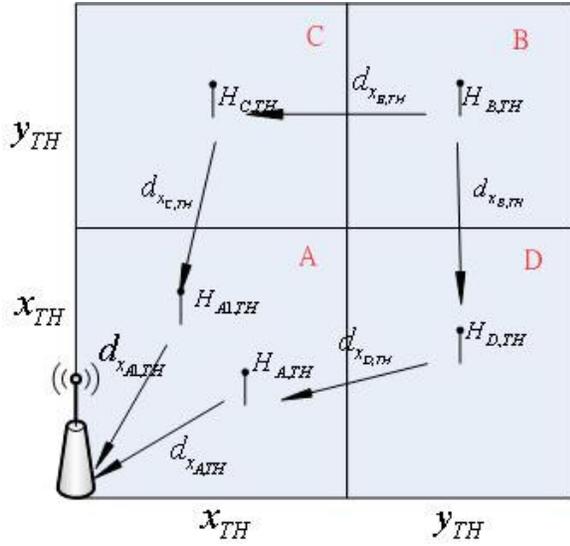


Fig. 7. The three-hop routing in WSNs.

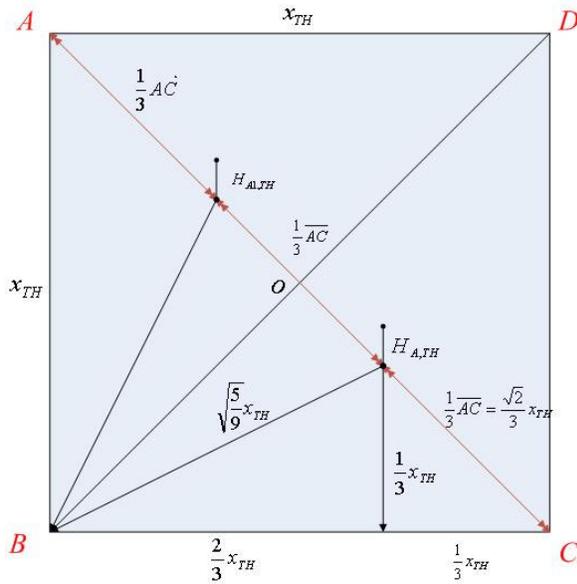


Fig. 8. The exact position of $H_{A,TH}$ in three-hop MSNs.

Similarly, we can express the energy consumption of both CHs, $H_{A,TH}$ in one round by

$$E_{A,TH} = E_{A1,TH} = E_p \cdot \eta_{TH} \cdot \frac{(x_{TH} + y_{TH})^2}{2} \left[\frac{\sqrt{5}}{3} x_{TH} \right]^\alpha, \quad (26)$$

where the distance between cluster head $H_{A,TH}$ and BS can be calculated by $\sqrt{\frac{5}{9}} x_{TH}$. Moreover, the distance between $H_{A,TH}$ and $H_{D,TH}$ is calculated by $\frac{\sqrt{2}}{3} x_{TH}$. Then, we can express the energy consumption of CHs, $H_{B,TH}$ and $H_{C,TH}$ in one round by

$$E_{B,TH} = E_p \cdot y_{TH}^2 \cdot \left[\frac{(x_{TH} + y_{TH})}{2} \right]^\alpha, \quad (27)$$

and

$$E_{C,TH} = E_{D,TH} = E_p \cdot \left(x_{TH} \cdot y_{TH} + \frac{y_{TH}^2}{2} \right) \cdot \left(\sqrt{\left(\frac{x_{TH} + y_{TH}}{3} + \frac{y_{TH}}{2} \right)^2 + \left(\frac{x_{TH}}{6} \right)^2} \right)^\alpha, \quad (28)$$

respectively. To equalize the energy consumption of $H_{B,TH}$ and $H_{C,TH}$, then we obtain the relations of x_{TH} and y_{TH} by

$$y_{TH}^2 \cdot \left(\frac{1}{2} (x_{TH} + y_{TH}) \right)^\alpha = \left(x_{TH} \cdot y_{TH} + \frac{x_{TH}^2}{2} \right) \cdot \left(\frac{x_{TH} + y_{TH}}{2} \right)^\alpha. \quad (29)$$

Thus, we obtain the length of cluster B, y_{TH} , by the function of the length of cluster A, x_{TH} , as

$$y_{TH} = f_7(x_{TH}). \quad (30)$$

However, in three-hop schemes, both the CHs of cluster A must aggregate the data sensing from whole area and send to BS. Then, likewise to the two-hop scheme, a data fusion ratio η_{TH} is applied for the $H_{A,TH}$. The energy consumption of $H_{A,TH}$ and $H_{B,TH}$ are further equalized by

$$\eta_{TH} \cdot \frac{(x_{TH} + y_{TH})^2}{2} \left[\frac{\sqrt{5}}{3} x_{TH} \right]^\alpha = y_{TH}^2 \cdot \left(\frac{1}{2} (x_{TH} + y_{TH}) \right)^\alpha. \quad (31)$$

Thus, the data fusion ratio η_{TH} can be obtained by the function of the length of cluster A, x_{TH} , as

$$\eta_{TH} = f_8(x_{TH}). \quad (32)$$

Due to the same position for $H_{A,TH}$ and $H_{A1,TH}$ and the symmetric routing shown in Fig. 8, the relations of $H_{A1,TH}$ can also expressed by (28).

4 Numerical Results

The duration that all the sensing data are transmitted to BS is say one round. In one round except the nodes transmitting and receiving data, the nodes are assumed to be in sleep mode in which the nodes do not consume any energy.

In the numerical results for two-hop and three-hop scheme, Fig. 9 shows the length comparisons of y_T and x_T and y_{TH} vs. x_{TH} with $2 \leq \alpha \leq 5$. From Fig. 9, it is obvious that when the path loss exponent increases, both lengths y_T (y_{TH}) decrease to shrink the area (data) for equalization of the $E_{B,T}$, ($E_{B,TH}$) and $E_{C,T}$. ($E_{C,TH}$). Moreover, form Fig. 10, it is observed that when the path loss exponent increases, both data fusion ratio η_T and η_{TH} decrease to shrink the transmission data of $H_{A,TH}$ for equalization of $E_{A,T}$, ($E_{A,TH}$) and $E_{C,T}$ ($E_{C,TH}$).

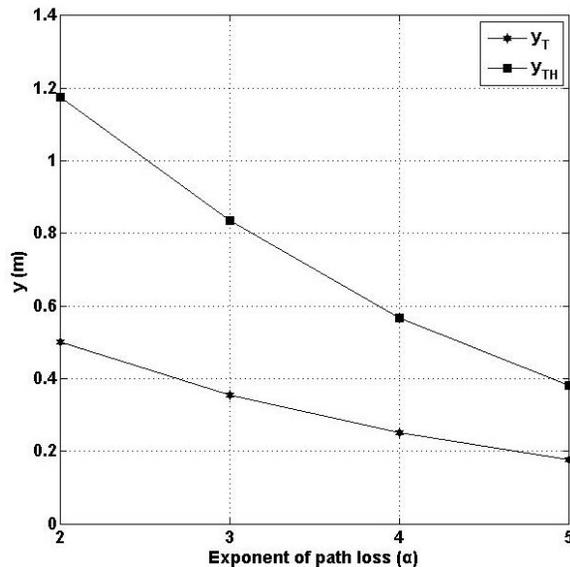


Fig. 9. The comparisons of lengths y_T and y_{TH} with $2 \leq \alpha \leq 5$, $x_T = x_{TH} = 1$ m for two-hop and three-hop scheme, respectively.

From Fig. 10, it is seen that when the exponent of path loss increases, both the data fusion ratio η_T and η_{TH} decrease. The data fusion ratio η_T of two-hop scheme decrease more deep than and η_{TH} of three-hop scheme with $2 \leq \alpha \leq 5$, $x_T = x_{TH} = 1$ m for two-hop and three-hop scheme respectively.

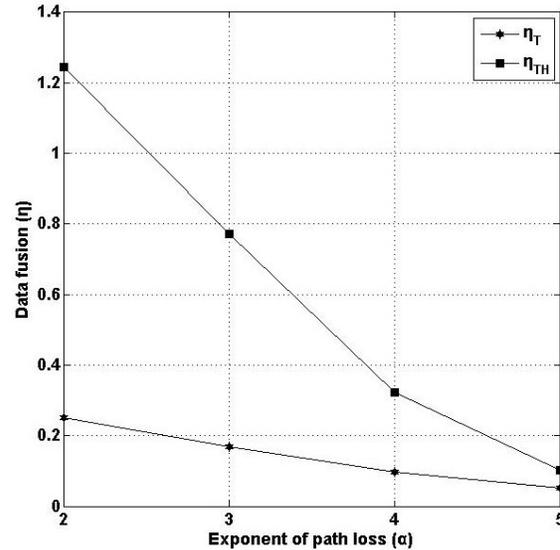


Fig. 10. The comparisons of data fusion ratio η_T and η_{TH} with $2 \leq \alpha \leq 5$, $x_T = x_{TH} = 1$ m for two-hop and three-hop scheme respectively.

Moreover, we compare the sensing area for direct, two-hop and three-hop schemes with $2 \leq \alpha \leq 5$ and $x_A = x_T = x_{TH} = 10$ m as shown in Fig. 11. From Fig. 11, it is observed that under equalization of energy consumption of CHs, the sensing area of three-hop is about double of direct and two-hop routing scheme with $\alpha=2, 3$. However, the sensing area of three-hop is slightly larger than both direct and two-hop routing scheme as $\alpha=4, 5$.

With the equalization requirements for the CHs, we further investigate the total energy consumption for the direct, two-hop and three-hop based WSNs as shown in Fig. 12. In Fig. 12, to fairly compare the energy consumption of three routing schemes in one round, we assume that 10000 nodes are uniformly distributed in the same sensing area normalized with $x_T = 10$ m. From Fig. 12, it is apparent that multihop schemes can perform more energy efficiency than direct transmission and three-hop outperform two-hop scheme in energy efficiency for various $2 \leq \alpha \leq 5$.

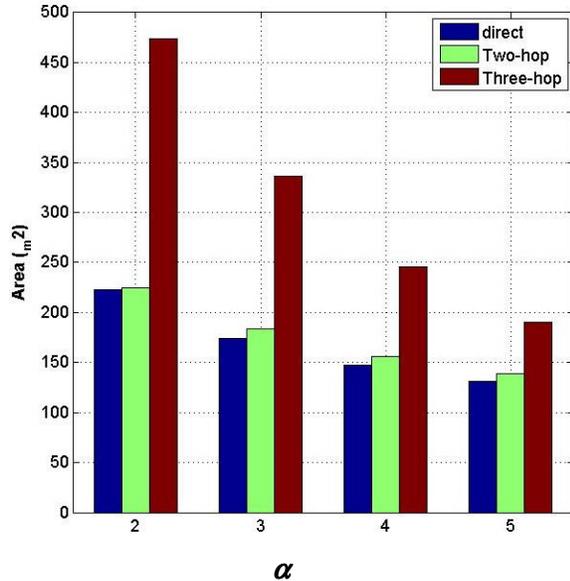


Fig. 11. The comparisons of sensing area for direct, two-hop and three-hop schemes with $2 \leq \alpha \leq 5$ and $x_A = x_T = x_{TH} = 10$ m.

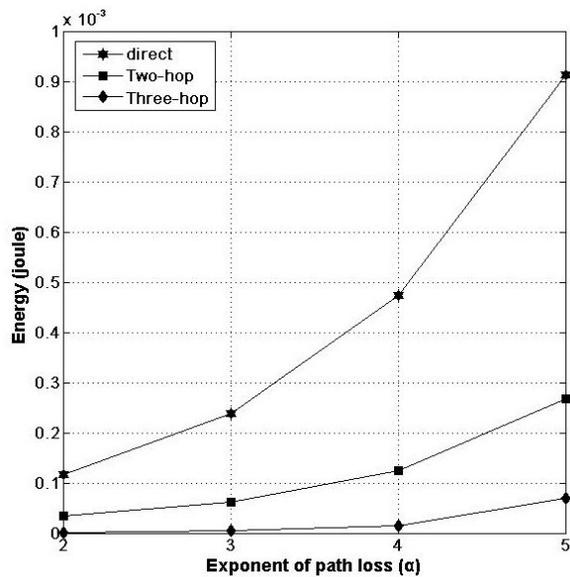


Fig. 12. The comparisons of energy consumption in one round for direct, two-hop and three-hop schemes with $2 \leq \alpha \leq 5$.

5 Conclusions

In this paper, to prolong the network lifetime we equalize the energy consumption of CHs for cluster-based WSNs. We analyze the energy consumption of CHs for direct, two-hop and three-hop routing scheme for the CHs. After the equalization of the energy consumption of CHs, we calculate the area

for each cluster. Thus, we obtain the length of sides of cluster area for the equalization. Numerical results show that the length of far site cluster is shorter than the nearest cluster to perform equalization for all three routing schemes. Moreover, simulation results show that the three-hop scheme can obtain the most energy efficiency than other two schemes.

References:

- [1] D. Culler, D. Estrin, M. Srivastava, Guest Editors' Introduction: Overview of Sensor Networks, *IEEE Computer*, Vol. 37, Issue 8, pp. 41-49, Aug. 2004.
- [2] E. J. Duarte-Melo and M. Liu, Analysis of Energy Consumption and Lifetime of Heterogeneous Wireless Sensor Networks, *Proc. of IEEE Global Telecommunication Conference*, pp. 21-25, Nov. 2002.
- [3] V. Raghunathan, C. Schurgers, S. Park and M. B. Srivastava, Energy-aware Wireless Microsensor Networks, *IEEE Signal Processing Magazine*, Vol. 19, No. 2, pp. 40-50, March 2002.
- [4] C. Schurgers and M. B. Srivastava, Energy Efficient Routing in Wireless Sensor Networks, *Proc. of IEEE Military Communications Conference*, Vol. 1, pp.357-361, Oct. 2001.
- [5] I. F. Akyildiz, W. Su, Y.Sankarasubramaniam, E. Cayirci, Wireless Sensor Network: a Survey, *Computer Networks*, Vol. 38, pp. 393-422, 2002.
- [6] O. Younis and S. Fahmy, HEED: a Hybrid, Energy-Efficient, Distributed Clustering Approach for Ad Hoc Sensor Networks, *IEEE Trans. Mobile Computing*, pp. 660-669, 2004.
- [7] J. Zhu and S. Papavassiliou, On the Energy-Efficient Organization and the Lifetime of Multi-hop Sensor Networks, *IEEE Commun. Letters*, Vol. 7, No. 11, pp. 537-539, Nov. 2003.
- [8] J. Levendovszky, A. Bojarszky, B. Karlocai, and A. Olah, Energy Balancing by Combinatorial Optimization for Wireless Sensor Networks, *WSEAS Trans. Commun.*, Issue 2, Vol. 7, pp. 27-32, Feb. 2008.
- [9] T.-J. Chan, M.-C. Chen, Y.-F. Huang, J.-Y. Lin, and T.-R. Chen, Optimal Cluster Number Selection in Ad-hoc Wireless Sensor Networks, *WSEAS Trans. Comm.*, Issue. 8, Vol. 7, pp. 837-846, Aug. 2008.
- [10] J.-Y. Choi, S.J. Yim, Y. J. Huh and Y.-H. Choi, A Distributed Adaptive Scheme for Detecting Faults in Wireless Sensor Networks, *WSEAS Trans. Comm.*, Issue 2, Vol. 8, pp. 269-278, Feb. 2009.

- [11] A. Mainwaring, D. Culler, J. Polastre, R. Szewczyk, J. Anderson, Wireless Sensor Networks for Habitat Monitoring, *Proc. of The First ACM International Workshop on Wireless Sensor Networks and Applications (WSNA '02)*, Georgia, September 2002.
- [12] Y.-F. Huang, W.-H. Luo, J. Sum, L.-H. Chang, C.-W. Chang, and R.-C. Chen, Lifetime Performance of an Energy Efficient Clustering Algorithm for Cluster-Based Wireless Sensor Networks, in *Frontiers of High Performance Computing and Networking*, LNCS 4743, Springer-Verlag Berlin Heidelberg, pp. 455–464, Aug. 2007.
- [13] R. Szewczyk and A. Ferencz, Energy Implications of Network Sensor Designs, *Tech. Rep., Berkeley Wireless Research Center*, Santa Clara, Calif, USA, 2000.