Performance of an Energy Efficient Routing Scheme for Cluster-based Wireless Sensor Networks

Yung-Fa Huang
Chaoyang University of Technology /Dept. of Information and Communication Engineering, Taichung County, Taiwan
Email: yfahuang@cyut.edu.tw

Tung-Jung Chan and Tsair-Rong Chen
National Changhua University of Education /Department of Electrical Engineering, Changhua City, Taiwan
Email: d96621003@ncue.edu.tw, abc@abc.ncue.edu.tw

Young-Long Chen
National Taichung Institute of Technology/Dept. of Computer Science and Information Engineering, Taichung, Taiwan
Email: ylchen66@ntit.edu.tw

Neng-Chung Wang
National United University /Department of Computer Science and Information Engineering, Miaoli, Taiwan
Email: ncwang@nuu.edu.tw

Abstract—This paper proposes a novel energy efficient data clustering scheme to improve energy efficiency for cluster-based wireless sensor networks (WSNs). In order to reduce the energy dissipation of transmitting sensing data at each sensor, the fixed clustering algorithm uniformly divides the sensing area into clusters where the cluster head is deployed to the centered of the cluster area. Moreover, to perform energy efficient grid clustering (EEGC), the nodes take turns to be cluster head. Simulation results show that proposed EEGC definitely reduces the energy consumption of the sensors and prolongs network lifetime to be longer than LEACH for both life rate=50% and 70%. Moreover, the total transmission data of EEGC is more 60% than LEACH scheme.

Index Terms—wireless sensor networks; clustering algorithm; cluster head; energy efficient grid clustering; network lifetime

I. INTRODUCTION

The microchip and telecommunication technology have been developed to comprise the sensing capabilities with wireless communication and data processing [1]. Microchip sensor devices can be applied to the certain environment for surveillance. In contrast, in some environments that sensors batteries are hardly to be recharged would be considered as an important research topic [1]. Here, energy efficiency and lifetime of WSN are considered as most significant performance [2]. Therefore, minimizing and balancing the energy dissipation for all sensor nodes is investigated in this paper. Direct sending data would consume more energy than other methods in WSNs. Because every sensor node collects data and sends directly data back to the base station, “sink”, the far away sensors will run out of energy quickly. Thus, the direct transmission is not suitable for large area [3]. In order to have better performance, multi-hop routing protocol is applied to the ad hoc wireless sensors communication networks [3]-[5]. However, sensor nodes closer to the BS consume more energy than other nodes to relay data [4]. Thus, the multi-hop transmission is not suitable for densely WSN.

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

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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 collects 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 [4]. The nodes closer to the base station need more energy [4] to send data because the scheme uses hierarchy transmission. However, due 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,” in each cluster is responsible for delivering data back to the base station. In this scheme, the cluster head performs data compressing and sending back to the base station. Thus, the lifetime of cluster head may be shorter than that of other sensors [5-7]. 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, if the cluster head has more energy, the cluster can prolong the life time. Therefore, in this paper, we would like to propose a fast, centralized algorithm for organizing the sensors in a wireless sensor network into clusters with an objective of minimizing the energy dissipated in communicating the information to the cluster head and prolong the lifetime of the WSN. Furthermore, the energy efficiency of heterogeneous networks with different amount energy at the normal sensors and cluster heads is investigated in this paper.

Moreover, the cluster-based scheme performs that those closer sensors belong to their own clusters [3], [6], [7]. One of sensors, called “cluster head,” in each cluster is responsible for delivering data back to the base station. This scheme performs energy efficiency with that the cluster head can compress data and send back to the base station. Generally, the lifetime of clustering can be extended compared to the direct and multi hop transmission. Yet, the energy of cluster head is consumed more than other sensor nodes [7]. Therefore, that the nodes take turns to be cluster head would balance the energy consumptions. Then, the cluster-based WSNs can be more energy efficient for network lifetime [3]. LEACH (Low-Energy Adaptive Clustering Hierarchy) [8]-[12] is one of most famous clustering based WSN.

In previous works [13], the fixed-clustering algorithms (FCA) can perform uniform clustering to reduce energy consumption for sensor nodes. However, the cluster heads would suffer the high energy exhaustions due to the long-term data relaying. In this paper, we further proposed energy efficient grid clustering (EEGC) to effectively balance the relaying load for the CHs.

II. NETWORK MODELS

In cluster-based WSN, the cluster head (CH) selection and clustering are very important procedure. In LEACH, the time which all sensor nodes collect data with a round is called a “round” [8]. In the set up state, there are two steps including CH selection and clustering. In CH selection, the node decides by randomly generate a number between 0 and 1. In the rth round, a node whose random number is less than the threshold is selected as CH. The threshold \( T_n(r) \) for the rth round is defined by

\[
T_n(r) = \begin{cases} 
\frac{P_r}{1 - P_r \times (r \mod \frac{1}{P_r})} & m \in G \\
0 & m \notin G 
\end{cases}
\]

where \( p_r \) is the expectation of the probability to be selected as CH, \( G \) is the nodes set including those nodes not yet been selected a CH in recent \( 1/p_r \) rounds and \( m \) is the ID of nodes.

After the CH was generated, CHs broadcast ADV (advertisement-message) to perform clustering by CSMA/CA protocol. In Fig. 1, a 5-cluster WSN example is performed.

III. PROPOSED ALGORITHMS

In order to minimize the energy dissipation of the sensor nodes, an FCA is proposed to normalize the clustering region. The defined parameters for the FCA are depicted in Table 1. There is a cluster head located at the area centric of each clustering area. In order to divide the area into uniform clusters in size, we calculate the location of the cluster head according to the number of clusters \( q \) as shown in Fig. 2. In Fig. 2, \( x(i) \) and \( y(i) \) are the axis of corresponding position of the cluster head. Then, the fixed cluster sensor network can be deployed by FCA. The proposed FCA is described as followings.
Table I. Definition of variables in FCA

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>q</td>
<td>Number of clusters</td>
</tr>
<tr>
<td>D</td>
<td>Length of sensing area</td>
</tr>
<tr>
<td>p</td>
<td>$\sqrt{\frac{q}{n}}$</td>
</tr>
<tr>
<td>n</td>
<td>$\lceil \frac{p}{q} \rceil$</td>
</tr>
<tr>
<td>k</td>
<td>$\text{mod}\left(\frac{q}{n}\right)$</td>
</tr>
<tr>
<td>s</td>
<td>$\left\lfloor \frac{q}{n} \right\rfloor$</td>
</tr>
<tr>
<td>l</td>
<td>$\frac{D(n-1)}{q}$</td>
</tr>
<tr>
<td>L, L2</td>
<td>Length and width of clustering grid area</td>
</tr>
</tbody>
</table>

Class A: When the number of clusters equals to $p \times p$, that is, the clusters in row and those in column are the same. For example, when the number of clusters is equal to 9, the positions of the cluster heads exhibit a square matrix form by three-row and three-column.

Class B: Depending on the parameter $k$, if $k = 0$, the clustering is performed by Class B. Otherwise, Class C will be applied in the clustering. In Class B, the number of clusters are with $1 \times 2$, $2 \times 3$, $3 \times 4$, $4 \times 5$, ..., $M \times (M+1)$, $M \in \mathbb{N}$. The axes of cluster heads are obtained as shown in Fig. 2 by applying class B.

Class C: When the number of clusters does not fit in Class A or B, then the clustering algorithm is classified to class C. In Class C, we first compare the values between $s$ and $n$. Then, there are two sub-classes C1 and C2 for the conditions $s < n-1$ and $s \geq n-1$, respectively, as shown in Fig. 2.
To be easily verifying, this paper set the sensor area by a square area with 50m×50m, \( D=50 \)m. The number of clusters is denoted by \( q \). In previous works, the area of grid clustering is illustrated in Fig. 3 for \( q=9 \), 12 and 11 [13].

In FCA, we assume that the sensor nodes are uniformly distributed in the area of the cluster. Therefore, the power dissipation of a cluster head to relay the information of the cluster in one round can be obtained by

\[
E_{ch,i} = \eta_i \cdot e_j \cdot W_j \cdot \frac{Q}{q},
\]

where \( e_j \) is the energy dissipation sending one packet per square meters, the energy dissipation due to the path loss of a distance between the \( i \)th cluster head and the base station is expressed by

\[
W_i = d_i^a / c = d_i^2 = x^2(i) + y^2(i) + B^2,
\]

where \( a = 2 \) and \( c = 1 \). Moreover, the energy dissipation for a sensor node to transmit one packet in a clustering area can be obtained by

\[
E_{n,j} = e_j \cdot Z_j,
\]

where \( Z_j = d_j^2 \) is the random variable of the rectangular square of the mean distance between the normal sensor nodes and the CH of the \( j \)th cluster.

In the proposed energy efficient grid clustering (EEGC) scheme, in the \( i \)th cluster the probability of being selected CH is set \( p_{c,i} = 1/n_i \), where \( n_i \) is the deployed number of nodes in the \( i \)th cluster, \( i=1,2,\ldots,q \). To analyze the network lifetime, we calculate the energy consumption of network in a round by

\[
E_r = \sum_{i=1}^{q} \left( \eta_i \cdot E_{ch,i} \cdot \frac{Q}{q} + \sum_{j=1}^{q-q} E_{n,j} \right),
\]

where \( \eta_i \) is the factor of data fusion, \( 0 < \eta_i \leq 1 \), \( E_{ch,i} \) and \( E_{n,j} \) are the energy consumptions for CHs and normal sensor nodes respectively, for transmission a packet. The energy consumption for transmission is mainly the path loss depending on transmission distance.

Moreover, in FCA, the expected power dissipation for a sensor node to transmit one packet in a rectangular clustering area can be obtained by

\[
Z_{j,FCA} = E[Z] = E\left[ (x - L_1/2)^2 + (y - L_2/2)^2 \right] = \frac{1}{12} \left( L_1^2 + L_2^2 \right),
\]

where \( L_1 \) and \( L_2 \) are the width and length of the rectangular area of the cluster in which the cluster head is located at \( (L_1/2, L_2/2) \).

In the LEACH, the cluster head is selected randomly. Therefore, the energy dissipation of each cluster in transmitting one packet is expressed by

\[
Z_{j,LEACH} = E[Z] = E[x^2 + (y + B)^2] = \frac{5D^2}{12} + B \cdot D + B^2,
\]

where \( D \) is the length of the square and \( B \) is the distance between the sensing field and the base station. Therefore, by the number of clusters we can choose the suitable algorithm to equally cluster the cluster area.

After the clustering is finished, the sensor nodes are uniformly random deployed in the rectangular area. Fig. 4 shows an example of the deployed nodes. In this clustering and deployed scheme, the relaying data of CHs would be almost equal to be extending the network lifetime. In Fig. 4, to distinguish the range of clustering the different symbols are used to denote the sensing nodes of different clusters. After the clustering, the CHs are selected as the nodes in which a random number is less than threshold \( T_{m,i}(r) \) in (1) for the \( i \)th cluster.

Figure 3. The area of grid clustering for number of clusters: (a) \( q=9 \), (b) \( q=12 \) and (c) \( q=11 \).
Figure 4. Sensing area of the proposed EEGC with $q=4$

**TABLE II. SIMULATION PARAMETERS**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q$</td>
<td>Number of sensor nodes</td>
</tr>
<tr>
<td>$q$</td>
<td>Number of clusters</td>
</tr>
<tr>
<td>$n_i$</td>
<td>Number of nodes in the $i$th cluster</td>
</tr>
<tr>
<td>$D$</td>
<td>Length and width of sensing area</td>
</tr>
<tr>
<td>$p_c$</td>
<td>Probability of been CH</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Path loss exponent of radio</td>
</tr>
<tr>
<td>$B$</td>
<td>Distance between base station and sensing area</td>
</tr>
<tr>
<td>$\eta_i$</td>
<td>Factor of data fusion</td>
</tr>
</tbody>
</table>

**IV. SIMULATION RESULTS**

To verify the performance of the proposed EEGC scheme, computer simulation is performed by Matlab programming. In our simulation, the energy consumed by transmitting a packet in one meter is denoted by $e_e(J)$. Then, the energy consumption of a normal sensor which is distant to the CH by $d_1$ can be obtained by $e_e d_1^\alpha (J)$ per packet. The energy consumed by CHs to transmit a packet to BS can be expressed by $e_e d_2^\alpha (J)$, where $d_2$ is the distance between CH and BS, and $e_e = 5 \times 10^{-7} (J)$. In this paper, to be simplified, the transmission data for each nodes is assume to be one packet with 400 bytes. The total number of nodes in the sensing filed equals 100. The BS is deployed at (0,-10). The path loss exponent and data fusion factor are set by $\alpha = 2$ and $\eta_i = 1$, respectively. The initial energy for each node is 5J. When $q=5$, the number of each cluster $n_i = 20$. Thus, in proposed EEGC, we obtain the probability of been CH for each node by $p_c = 1/20$.

Fig. 5 shows the life rate for WSNs. The life rate is defined by the percentage of living nodes in networks. Because the received data is not reliable for LR<50%, it is important to prolong the lifetime for LR=50%. From Fig. 5, it is observed that the propose EEGC outperform LEACH and Direct scheme for LR>50%.

The comparison of life time of LR=50% and 70% is listed in Table III. From Table III, it is obvious that the proposed EEGC improves the unbalancing of clustering. Then, in EEGC scheme, the lifetime is prolonged 1.5 times of LEACH for both LR=50% and 70%. Moreover, we depicted the total data transmission comparison as shown in Table IV. It can be observed that the data transmission for EEGC is more 60% than LEACH scheme.

To obtain the optimal number of clusters for WSNs, we simulate the total energy consumption per round for $q=1-15$ as shown in Fig. 6. From Fig. 6, it is observed that the energy consumption per round of the proposed EEGC is less than LEACH for different number of clusters, $q=1-15$. Moreover, when the number of clusters is 9, the energy consumption per round is the minimum for $q=1-15$. Therefore, when the number of clusters is 9, the network lifetime would be the longest among $q=1-15$.

**TABLE III. THE LIFETIME COMPARISON OF LR=50% AND 70% FOR DIRECT, LEACH AND EEGC.**

<table>
<thead>
<tr>
<th>LR</th>
<th>70%</th>
<th>50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct</td>
<td>2226</td>
<td>3471</td>
</tr>
<tr>
<td>FCA</td>
<td>2634</td>
<td>4351</td>
</tr>
<tr>
<td>LEACH</td>
<td>3508</td>
<td>4245</td>
</tr>
<tr>
<td>EEGC</td>
<td>5771</td>
<td>7537</td>
</tr>
</tbody>
</table>

**TABLE IV. THE TOTAL DATA TRANSMISSION COMPARISON FOR DIRECT, LEACH AND EEGC.**

<table>
<thead>
<tr>
<th></th>
<th>Total Transmission (packets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct</td>
<td>581617</td>
</tr>
<tr>
<td>FCA</td>
<td>531950</td>
</tr>
<tr>
<td>LEACH</td>
<td>450229</td>
</tr>
<tr>
<td>EEGC</td>
<td>742919</td>
</tr>
</tbody>
</table>
LEACH schemes. The transmission comparison for EEGC is more 60% than both LR=50% and 70%. Moreover, the total data transmission comparison for EEGC is more 60% than LEACH schemes.

V. CONCLUSIONS

Because the unbalance for the area of clustering, the LEACH suffer the energy inefficiency for the data gathering. Therefore, in this paper, we proposed an energy efficient EEGC scheme to perform uniformly clustering. Simulation results show that, we can prolong the lifetime of EEGC scheme to 1.5 times of LEACH for both LR=50% and 70%. Moreover, the total data transmission comparison for EEGC is more 60% than LEACH schemes.

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Yung-Fa Huang was born in Changhua County, Taiwan, in 1961. He received the Diplom-Eng. in electrical engineering from National Taipei University of Technology, Taipei, in 1982, M.Eng. degree in electrical engineering from National Tsing Hua University, Hsinchu, Taiwan, in 1987 and Ph.D. degree in electrical engineering from National Chung Cheng University, Chiayi, Taiwan, in 2002. During 1982-1984, he joined the Air Forces for the military service in Taiwan. During 1987-2002, he was an instructor in Chung Chou Institute of Technology, Yuanlin, Taiwan. From February 2002 to July 2004, he was with the Department of Electrical Engineering, Chung Chou Institute of Technology, as an Associate Professor. From August 2004 to July 2007, he was an Associate Professor in Graduate Institute of Networking and Communication Engineering, Chaoyang University of Technology, Taichung, Taiwan. From August 2007 to July 2008, he was the Department Head of Computer and Communication Engineering and the Institute Chair of the Graduate Institute of Networking and Communication Engineering, Chaoyang University of Technology. Since Aug. 2008, he has been the Department Head of Information and Communication Engineering, Chaoyang University of Technology. His current research interests include multiuser detection in OFDM-CDMA cellular mobile communication systems, communication signal processing, fuzzy systems and wireless sensor networks. Dr. Huang is a member of IEEE Communications Society and IEICE Communications Society.
Tung-Jung Chan was born in Changhua County, Taiwan, in 1966. He received the Diplom-Eng. in electrical engineering from National Taipei University of Technology, Taipei, in 1986 and M.Eng. degree in electrical engineering from National Tsing Hua University, Hsinchu, Taiwan, in 1993. He is currently working toward the Ph.D. degree at the Department of Electrical Engineering, National Changhua University of Education. Since 1993, he was an instructor in Chung Chou Institute of Technology, Yuanlin, Taiwan. From August 2006 to July 2009, he was the Director of Office of Information, Chung Chou Institute of Technology. His current research interests include image processing, computer networks, and wireless sensor networks.

Tsair-Rong Chen received the B.S. and M.S. degree in electrical engineering from the National Cheng Kung University, Taiwan, in 1986 and 1988, respectively, and the Ph.D. degree in electrical engineering from the National Sun Yat-Sen University, Taiwan, in 1991. Since 1991, he was with the Department of Electrical Engineering at National Changhua University of Education, Changhua, Taiwan, as an Associate Professor, and in 1997 as a Professor. Since 2001, he was chairman of Electrical Engineering in National Changhua University of Education. And current position is Dean of extension college in National Changhua University of Education. His research interests include power electronics, battery charger, contactless power transfer, and microprocessor-based system design.

Young-Long Chen (SM’03-M’05) received the B.S. degree in automatic control engineering from Feng Chia University, Tai-Chung, Taiwan, in 1988, the M.S. degree in engineering science from National Cheng Kung University, Tainan, Taiwan, in 1995 and the Ph.D. degree in electrical engineering from National Chung Cheng University, Chia-Yi, Taiwan, in 2007. From 1995 to 1999, he worked for Formosa Petrochemical Corporation as a Design Engineer. From 1999 to 2007, he was a Lecturer with the Department of Electrical Engineering, Chienkuo Technology University, Taiwan. From 2007 to 2009, he was an Associate Professor with the Department of Electrical Engineering, Chienkuo Technology University, Taiwan. Since 2009, he has been with the Department of Computer Science and Information Engineering, National Taichung Institute of Technology, Taiwan, where he is currently an Associate Professor. His research interests include wireless communications, wireless sensor networks, digital signal processing, fuzzy neural networks and embedded systems.

Neng-Chung Wang received the B.S. degree in Information and Computer Engineering from Chung Yuan Christian University, Taiwan, in June 1990, and the M.S. and Ph.D. degrees in Computer Science and Information Engineering from National Cheng Kung University, Taiwan, in June 1998 and June 2002, respectively. He joined the faculty of the Department of Computer Science and Information Engineering, Chaoyang University of Technology, Taiwan, as an assistant Professor in August 2002. From August 2006 to July 2007, he was an Assistant Professor at the Department of Computer Science and Information Engineering, National United University, Taiwan. Since August 2007, he has become an Associate Professor at the Department of Computer Science and Information Engineering, National United University, Taiwan. His current research interests include computer networks, wireless networks, and mobile computing. Dr. Wang is a member of the IEEE Computer Society, IEEE Communications Society, and Phi Tau Phi Society.