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Particle Swarm Optimization with Taguchi for Cluster Heads Election in Wireless Sensor Networks

Young-Long Chen and Wan-Ren Chen*

Department of Computer Science and Information Engineering, National Taichung University of Science and Technology, 40401 Taichung, Taiwan

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Abstract: The main features of wireless sensors are energy limited, hence, the algorithm design with the enhancement of energy efficiency becomes an important topic. Divide cluster in a wireless sensor network (WSN) is a very important technology which can blend the data into the cluster to expand the lifetime of the entire network. In this paper, we are going to propose a new algorithm to be associated with a particle swarm optimization (PSO) algorithm and Taguchi algorithm to select the optimal cluster heads from a wireless cluster sensor network. In a WSN, PSO algorithm is used to select cluster head and to reach the energy dissipation balance among all nodes, which can in turn reduce the probability of the early death of the nodes. Meanwhile, the equation of optimal number of clusters is used to decide the field number of clusters of low-energy adaptive clustering hierarchy (LEACH). In PSO algorithm, the selection of parameter is very important, hence, in order to achieve optimal parameter value, too much number of experiments is usually spent, therefore, in this paper, Taguchi algorithm was adopted to reduce the number of experiments and the energy dissipation of the node. Consequently, we can get the optimal parameter value of PSO algorithm, and the energy dissipation of each node can then be balanced. From the simulation result, it can be seen that our proposed PSO-LEACH architecture with Taguchi algorithm has reduced energy dissipation as compared to LEACH architecture and PSO-LEACH architecture, meanwhile, the energy balance of each node can be reached, and the lifetime of the entire wireless sensor network can then be extended.

Keywords: Cluster head, particle swarm optimization, time delay, Taguchi

1 Introduction

As technology moves forwards, the volume of a node becomes smaller and smaller, and it is also of lower cost and more powerful. Therefore, node can be supplied in massive number, and its applicable scope becomes wider and wider, for example, military surveillance, environmental monitoring, medical care and disaster rescue action, etc. [1]. In the design of the entire wireless sensor network (WSN), many important aspects have to be considered, for example, small size node, the hardware complexity and extremely low energy dissipation, hence, energy efficiency is seen as the key design target. Moreover, since each node is assigned with only limited cell to supply the energy, the energy of the node is limited and unreplenishable [2].

It was proposed in [3] that the objective of power-efficient gathering in sensor information systems (PEGASIS) was to enhance the life cycle of the network, and the use of greedy algorithm lets the nodes form a chain, and each node thus can only transmit and receive data from its neighboring node. In each round, one node was selected randomly from the chain, the data was then gathered and sent to the base station so as to reduce the number of nodes of direct communication with the base station. The method proposed in literature [4] was base station controlled dynamic protocol (BCDCP), in that method, the generated cluster size was the same so as to avoid the loading of cluster head and to balance the energy dissipation of each node. The cluster protocol introduced in [5] is called low-energy adaptive clustering hierarchy (LEACH). LEACH architecture is a basic cluster protocol, which includes the formation of distributed cluster, and cluster head will be randomly selected among the nodes. That algorithm operates periodically, and it has the probability to become cluster head in each period so as to ensure that each node will become cluster head once at least within $1/P$ round. Here, P is the preset cluster head percentage. LEACH

* Corresponding author e-mail: ylchen66@nutc.edu.tw

architecture organizes its operation into two phase [5,6,7,8], and the first phase is the setup phase which is used to form the cluster, the second phase is stable-state phase which is used for data communication process. The application of particle swarm optimization (PSO) algorithm in solving cluster issue of a WSN had been proposed in [9]. The author tried to, within each cluster, balance the number of node and candidate cluster head, at the time while energy dissipation was reduced, the data transmission of node was also enhanced. The effective selection of cluster head can balance the energy dissipation of each node so that WSNs can reach optimized energy efficiency [10]. In [11], PSO algorithm was proposed to be applied in selecting optimal node as cluster head, the protocol proposed by the author can make nearest distance between the cluster head within the cluster and the cluster member, and the energy dissipation of the entire network was thus optimized. However, the parameter selection of PSO algorithm will affect the selection of cluster head. The difference between our proposed algorithm and that of [11] is that the parameter selection of PSO algorithm is the optimal value calculated using Taguchi algorithm. Since Taguchi algorithm is capable of using smaller number of experiments to find optimal parameter value, in literature [12], the author used Taguchi algorithm to find optimal cost function for economic dispatch issue. In this paper, the errors of original algorithm, generating in the method of calculating the most extreme point position in impulse function directly, are put forward and given the in-depth analysis. And the improvements are proposed accordingly, that is to combine with the method of surface fitting to calculate a local extreme point position (sub-pixel shift value). It reduced the error of original algorithm to register the image with non-integer pixels shift and improved the estimated accuracy of rotation and scaling parameters. The result of experiment proved our assumption.

This paper, based on LEACH architecture, associated PSO algorithm and Taguchi algorithm to select the optimal cluster head so as to reduce the energy dissipation and to extend the lifetime of WSNs. Here we have proposed PSO-LEACH architecture with Taguchi algorithm, the above-average energy of each node within the cluster and the most neighboring node number was used as our cost function to find out the largest cost function of node to be used as cluster head. Meanwhile, the optimal cluster number was used to decide the needed cluster number so as to achieve the objective of the enhancement of WSNs energy efficiency. Since the parameter selection of PSO algorithm has very large influence on the system performance, hence, in order to achieve the reduction of the energy dissipation in the node and to increase the utilization lifetime of WSNs, this paper also proposed the use of Taguchi algorithm to find out the optimal parameter value of PSO algorithm.

The rest architecture of this paper is as in the followings, section 2 is detailed introduction of our network and wireless model used under our protocol, section 3 is our proposed PSO-LEACH architecture with Taguchi algorithm within WSNs, and section 4 is the simulation result, section 5 is the conclusion of this paper.

2 System Model

A. Radio Energy Dissipation Model

Data transmission model can calculate the energy dissipation in node transmission and packet reception. Figure 1 is the representation of data transmission model. Suppose the transmitting node is to transmit b bits of data packet, during the transmission process, signal strength will be amplified through amplifier, meanwhile, depending on the distance, the signal strength will also be different.

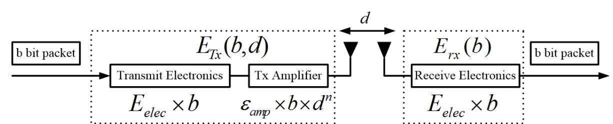

Figure 1: Radio energy dissipation model.

E_{TX} is the energy dissipation when the transmitting node needs to transmit b bits of data, and E_{TX} is calculated as follow:

$$E_{TX}(b,d) = \begin{cases} b \times E_{elec} + l \times \varepsilon_{FS} \times d^2, & d < d_0 \\ b \times E_{elec} + l \times \varepsilon_{MP} \times d^4, & d \geq d_0 \end{cases} \quad (1)$$

where b represents bits number to be transmitted in the transmitting node, E_{elec} represents the energy dissipation of each bit, ε_{FS} and ε_{MP} represents the amplifier model at the transmitting end, d represents the distance between the transmitting node and the receiving node, α means the radio wave attenuation exponent, in free space model, α is 2, and in multi-path attenuation model, α is 4, $d_0 = \sqrt{\varepsilon_{FS}/\varepsilon_{MP}}$ is the threshold value.

In radio wave, transmitting node will need energy to transmit data, and the energy is equal to the energy dissipated in transmitting electron and the energy needed by the power amplifier. And the receiving end only dissipates the energy needed for receiving electron [5]. E_{RX} is the energy needed to be dissipated in the receiving node, and E_{RX} is calculated as follow:

$$E_{RX}(b) = b \times E_{elec} \quad (2)$$

B. LEACH Architecture

LEACH architecture is the construction method that can be divided into two phases. The first phase is the setup phase, and in the beginning, fixed cluster number is divided in the entire WSN. The average expected value of cluster head number is defined as in the following:

$$E[CH] = \sum_{i=1}^{K} p_i(t) \times 1 = k \tag{3}$$

where $E[CH]$ is the average expected value of the number of cluster head, K is the total deployed number of nodes in a WSN, $p_i(t)$ it that the node will use certain probability function to decide whether it is to become a cluster head, i is the number of each node, k is the cluster quantity.

After deciding the cluster number of the WSN, the next thing is to calculate the probability for each node to become the cluster head, which is to ensure that the same node will not act continuously as cluster head, meanwhile, the probability for the node that does not act as cluster head to become cluster head will then be increased, The probability to be elected as cluster head is

$$P_i(t) = \begin{cases} \frac{k}{K-k\times\left(r \bmod \frac{K}{k}\right)}, & C_i(t) = 1 \\ 0, & C_i(t) = 0 \end{cases} \tag{4}$$

where r is the current round, and each node will act once as cluster head for an average period of K / k round. $C_i(t)$= 1 means that the node does not act as cluster head before, $C_i(t)$= 0 means that it has acted as cluster head, after all nodes have acted as cluster head, it will be reset the status into 1, that is, all nodes are $C_i(t)$= 1.

When cluster head is decided, the next thing is to prepare the size of each cluster. Each cluster head will use one media access control (MAC) layer protocol: non-persistent carrier-sense multiple access (CSMA) [13] will send out one advertisement (ADV) to all the nodes. Each node will, depending on the ADV message strength received, decide which cluster it belongs to. In order to ensure no collision occurs during the transmission process of data, cluster head will set up a time division multiple access (TDMA) schedule to the member of the cluster, TDMA [14] to divide the transmission time using time slot so as to avoid the occurrence of collision during the transmission. In the time not belonging to its own time slot, node can be converted into sleep mode so as to save the energy dissipation, the next is the stable-state phase.

The second phase is the steady-state phase, the data sensed by nodes within the cluster does not need to be transmitted to base station directly, instead, it is transmitted to the cluster head first. Cluster head will then make cluster operation on the collected data and the data collected by itself, next, it will be transmitted to the base station. Therefore, LEACH architecture, within each cluster, will have significant decrease in the total frequency of data transmitted to base station, and the energy dissipation will be greatly decreased too.

C. LEACH Optimal Cluster Number

Ideal cluster mathematical model supposes the distance between cluster head and cluster head is the expected average distance, and the distance between cluster member and cluster head, that is, the distance between cluster head and cluster head is the same, and the distance between each node is also the same. The mathematical induction of optimal cluster number had been proposed by [5].

In the sensing range of $M \times M, K$ nodes are evenly deployed. In a WSN with k clusters, on the average, each cluster will have K / k nodes, and there will be one node as cluster head, and d_{toBS} is the distance between cluster head and base station. k_{opt} is the optimal cluster number which can be represented as:

$$k_{opt} = \frac{\sqrt{K}}{\sqrt{2\pi}} \sqrt{\frac{\varepsilon_{FS}}{\varepsilon_{MP}}} \frac{M}{d_{toBS}^2} \tag{5}$$

3 PSO with Taguchi for Cluster Heads Election

A. Particle Swarm Optimization Algorithm

PSO algorithm was proposed by Dr. Kennedy and Dr. Eberhart in 1995, through the observation of the group habit of the flight of bird's food-finding and fish's swimming in the water, PSO algorithm [15,16] that is currently under wide discussion was then developed.

In the search spa ce, each particle has two features of velocity and location. N means that there are N particles in the sensing field, n is the particle number, $n = 1, 2, \ldots, N$, dim means that each particle has D dimension, $dim = 1, 2, \ldots, D$. $V_{n,dim}(t+1)$ means at $t+1$ time, the speed of particle n in dim dimension, which is as shown in the following:

$$V_{n,\dim}(t+1) = \omega \times V_{n,\dim}(t) + c_1 \times rand(t) \times (P_{best} - X_{n,\dim}(t)) + c_2 \cdot rand(t) \cdot (g_{best} - X_{n,\dim}(t)) \tag{6}$$

where $rand(t)$ is random number between 0 and 1. ω is the internal weighting, a smaller ω value means the search directing towards the current field, a larger ω value means the search directing towards new field. c_1 , c_2 is learning constant, which is in charge of the forwarding velocity of that particle. Appropriate adjustment of c_1 , c_2 , ω values can create a balance effect between exploit and explore. P_{best} is the appearing best location of the movement of each particle until now. g_{best} means the appearing best location of the movement of all particles until now. $X_{n,\dim}(t+1)$ means at time of $t+1$, the location of n particle at dim dimension, which is as shown in the following:

$$X_{n,\dim}(t+1) = X_{n,\dim}(t) + V_{n,\dim}(t+1) \tag{7}$$

B. Cost Function

In this paper, all the particles of PSO algorithm follow cost function to judge the location of the current node, and the defined cost function is as in the following:

$$Cost = \beta \times f_1 + (1-\beta) \times f_2 \tag{8}$$

where β is constant, $0 \le \beta \le 1$. f_1 is the ratio between neighboring node number and average node number, which is as in the following:

$$f_1 = Nei(i) / \left(\sum_{i=1}^{K} Nei(i) / K \right) \tag{9}$$

where $Nei(i)$ is the neighboring node quantity of node i, $i = 1, 2, \ldots, K$. f_2 is the ratio between node energy and mean node energy, which is as in the following.

$$f_2 = E(i) / \left(\sum_{i=1}^{K} E(i) / K \right) \tag{10}$$

where $E(i)$ is the residual energy by node i. According to the description of cost function, we know that the value of f_1 and f_2, cost function is the larger the better, and the optimized cluster head location has the features of above-average energy and the most neighboring nodes. In PSO algorithm, appropriate adjustment of the value of c_1, c_2, ω and β will affect the search result, hence, in the next section, we are going to use Taguchi algorithm to adjust these four factors.

C. Taguchi algorithm

Taguchi algorithm design of experiment is a way that can quickly optimize different factors to acquire the most perfect result [12,17]. Typical orthogonal array is named by $L_T(Q^H)$, where T is the total number of experiments. Q is the number of level of each factor. H is the number of factor. Letter L is the original name of orthogonal array: Latin square.

Table 1: Orthogonal array $L_9(3^4)$

Test Number	c_1	c_2	ω	β	Cost
1	1	1	1	1	J_1
2	1	2	2	2	J_2
3	1	3	3	3	J_3
4	2	1	2	3	J_4
5	2	2	3	1	J_5
6	2	3	1	2	J_6
7	3	1	3	2	J_7
8	3	2	1	3	J_8
9	3	3	2	1	J_9
Contributions of level 1	$S_1^{(1)}$	$S_2^{(1)}$	$S_3^{(1)}$	$S_4^{(1)}$	
Contributions of level 2	$S_1^{(2)}$	$S_2^{(2)}$	$S_3^{(2)}$	$S_4^{(2)}$	
Contributions of level 3	$S_1^{(3)}$	$S_2^{(3)}$	$S_3^{(3)}$	$S_4^{(3)}$	

Table 2: Total contribution cost function for each level of each factor.

level \ factor	c_1	c_2	ω	β
level 1	$S_1^{(1)} = J_1 + J_2 + J_3$	$S_2^{(1)} = J_1 + J_4 + J_7$	$S_3^{(1)} = J_1 + J_6 + J_8$	$S_4^{(1)} = J_1 + J_5 + J_9$
level 2	$S_1^{(2)} = J_4 + J_5 + J_6$	$S_2^{(2)} = J_2 + J_5 + J_8$	$S_3^{(2)} = J_2 + J_4 + J_9$	$S_4^{(2)} = J_2 + J_6 + J_7$
level 1	$S_1^{(3)} = J_7 + J_8 + J_9$	$S_2^{(3)} = J_3 + J_6 + J_9$	$S_3^{(3)} = J_3 + J_5 + J_7$	$S_4^{(3)} = J_3 + J_4 + J_8$

In this paper, Taguchi algorithm is adopted to adjust PSO algorithm parameter and the weighting cost function. Our selected factors are c_1, c_2, ω and β, each factor has three levels. The appropriately selected orthogonal array is $L_9(3^4)$, which is as in table 1. $L_9(3^4)$ means that there are 9 sets of experiments and 4 factors, each factor has three levels, where J_j is cost function representation as calculated by jth experiment, $j = 1, 2, \ldots, 9$. S_h^q is the total contribution cost function, h is the factor number, $h = 1, 2, \ldots, H$. q is level number, $q = 1, 2, \ldots, Q$.

The calculation of total contribution cost function is the sum of cost function value corresponding to the same level test. After the completion of nine experiments, we have calculated the total contribution cost function of level 1, level 2 and level 3 of the third factor ω, which is respectively S_3^1, S_3^2 and S_3^3, where total contribution cost function S_3^1 is the sum of J_1, J_6 and J_8, which is as shown in table 2. We then correspond three total contribution cost functions to three levels of each factor, then each factor is selected with level value that owns maximal total contribution cost function level value, and such level value is then the optimal value of each factor.

D. PSO-LEACH Architecture with Taguchi Algorithm

The method proposed in this paper which exploited PSO algorithm and Taguchi algorithm to find optimal node as cluster head according to the cost function of each particle. The architecture of our proposed is entirely based on LEACH architecture.

For our proposed algorithm, in the beginning of each round, it is first the confirmation of the formation of the cluster in the setup phase, the next is the steady-state phase. In the beginning of each setup phase, all the nodes will send the current energy state and location information to base station, base station will, based on these information, calculate the ratios of the energies of all the nodes to the average node energy so as to ensure that the elected cluster head has sufficient energy. In this round, the ones with higher energy ratios are all qualified candidate cluster head, next, base station will use Taguchi algorithm to find out the most appropriate parameters of PSO algorithm, in the same time, base station will then follow Eq (5) to calculate the optimal cluster number k_{opt} of the WSN, then PSO algorithm will select k_{opt} nodes with maximal cost function as cluster heads.

Figure 2 shows the flow chart of PSO-LEACH architecture with Taguchi algorithm in the cluster setup phase. where T is number of experiments, I is the iterative number of PSO algorithm, O is whether this parameter is optimal value or not, if yes, it is 1, if no, it is 0.

4 Simulation Results

In this paper, we have compared survival node number and node energy dissipation of LEACH architecture, PSO-LEACH architecture and our proposed PSO-LEACH architecture with Taguchi algorithm, where PSO-LEACH architecture is, under LEACH architecture, to use fixed parameter of PSO algorithm to find out cluster head, and the parameter values are $N = 10$, $c_1 = c_2 = 1$, $\omega = 1$ and $\beta = 0.5$. In the entire simulation, we have all implemented 1000 rounds to get the average calculated results.

Our simulation environment size is, in sensing field of $100M \times 100M$, to deploy randomly 100 wireless sensor node, the energy of each node is usually $0.25J$, and the size of the cluster is calculated based on the optimal cluster number. The location of base station is $(50, 175)$. The simulation result will continue until all the nodes within the network have consumed all the energies. From the simulation charts of figure 3 and figure 4, each factor of the four factors of PSO-LEACH architecture with Taguchi algorithm has three levels, which as shown in table 3.

Table 3: Parameters for Taguchi Algorithm.

factor / level	level 1	level 2	level 3
c_1	0.5	1	1.5
c_2	0.5	1	1.5
ω	0.8	1	1.2
β	0.01	0.35	0.5

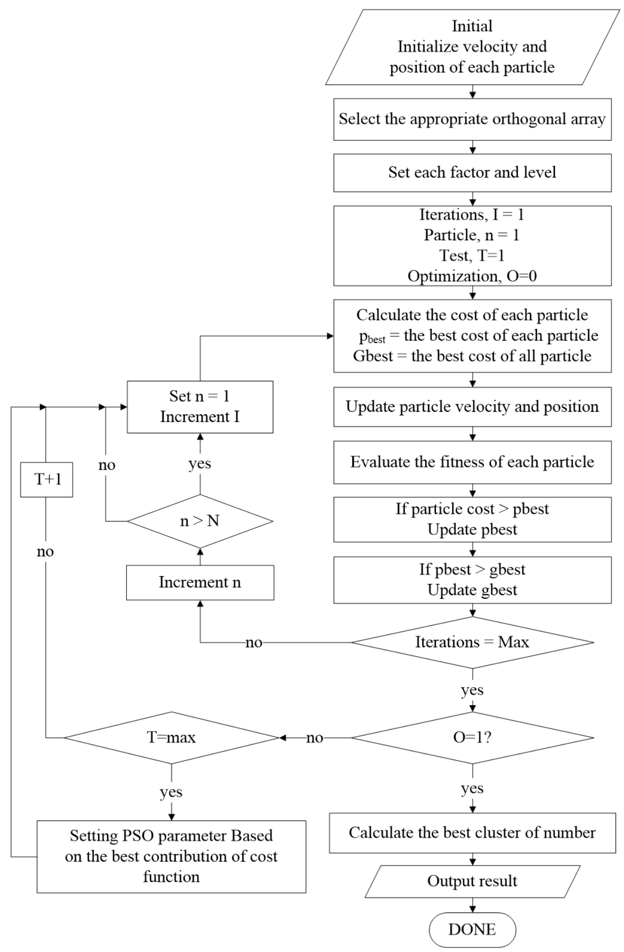

Figure 2: Flowchart of PSO-LEACH architecture with Taguchi Algorithm

In figure 3, we have compared the number of alive nodes in each round of three network architectures of LEACH architecture, PSO-LEACH architecture and PSO-LEACH architecture with Taguchi algorithm.

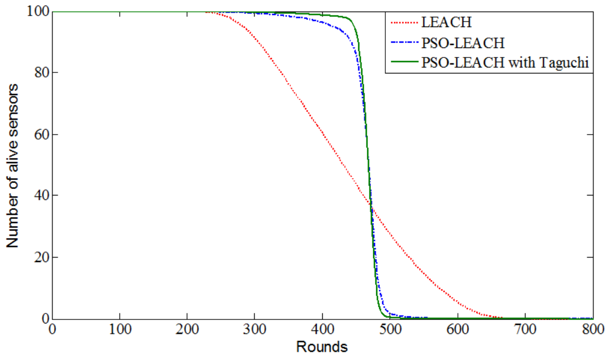

Figure 3: Comparison of network lifetime.

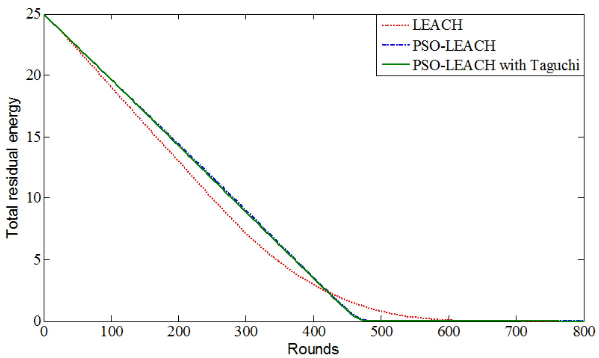

Figure 4: Comparison of total residual energy.

PSO-LEACH architecture with Taguchi algorithm has on the average, the first death node on round 387, LEACH architecture has on the average the first death node on round 249, PSO-LEACH architecture has on the average, the first death node on round 324, PSO-LEACH architecture with Taguchi algorithm has longer lifetime of the entire network by about 55% as compared to that of LEACH architecture, has longer lifetime of the entire network by about 19% as compared to that of PSO-LEACH architecture, hence, it can be seen that our proposed PSO-LEACH architecture with Taguchi algorithm has the longest node survival time,

From figure 4, we have also provided the total residual energy of the system to assess the lifetime of the entire network. From figure 4, it can be seen that PSO-LEACH architecture with Taguchi algorithm and PSO-LEACH architecture has the same node total residual energy. But from figure 3 and figure 4, it can be seen that the lifetime of the entire network of PSO-LEACH architecture with Taguchi algorithm is superior to that of PSO-LEACH architecture, hence, it can be proved that PSO-LEACH architecture with Taguchi algorithm can balance the energy dissipation of the node, and the lifetime of the entire WSN can then be extended.

In the simulation charts of figure 5 and 6, each factor of four factors of PSO-LEACH architecture with Taguchi algorithm has three levels, which are shown in table 4.

Table 4: Parameters for Taguchi Algorithm

factor / level	level 1	level 2	level 3
c_1	0.5	1	1.5
c_2	0.5	1	1.5
ω	0.8	1	1.2
β	0.1	0.15	0.2

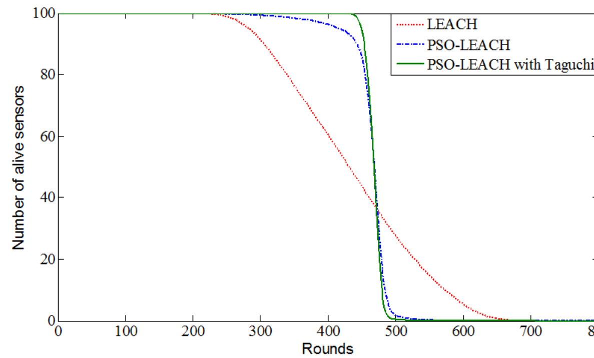

Figure 5: Comparison of network lifetime.

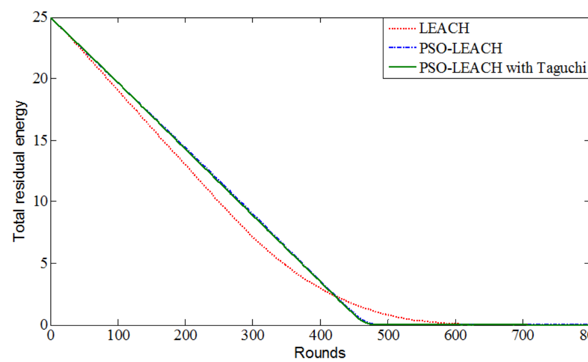

Figure 6: Comparison of total residual energy.

In figure 5, we have compared the alive node number in each round of three network architectures. In figure 5, PSO-LEACH architecture with Taguchi algorithm has on the average the first death node of round 441, PSO-LEACH architecture with Taguchi algorithm has longer life cycle of the entire network by about 77% as compared to that of LEACH architecture, has longer life cycle of the entire network by about 36% as compared to that of PSO-LEACH architecture, hence, it is clear that the parameter selection of PSO algorithm will affect the system performance.

In addition, from the node total residual energy of figure 6, it can be seen that PSO-LEACH architecture with Taguchi algorithm and PSO-LEACH architecture has the same node total residual energy. But from Figs. 5 and 6, it can be seen that the lifetime of the entire network of PSO-LEACH architecture with Taguchi algorithm is superior to that of PSO-LEACH architecture, hence, it can be proved that PSO-LEACH architecture with

Taguchi algorithm can balance the energy dissipation of the node, and the lifetime of the entire WSN can then be extended.

5 Conclusions

Through the acquisition of the energy dissipation balance of all the nodes, the life cycle of a WSN can be extended. Under LEACH architecture, we have proposed a new algorithm in association with PSO algorithm and Taguchi algorithm to select the optimal cluster head from LEACH architecture, in this paper, we have considered to use the ratio of the node energy to average node energy and the ratio of the neighboring node number of this node to the average neighboring node number of all the nodes as cost function, and Taguchi algorithm is used to adjust the parameters of PSO algorithm. From the simulation results, it can be seen that PSO-LEACH architecture with Taguchi algorithm with the use of Taguchi algorithm to adjust PSO algorithm will have not only longer lifetime as compared to that of PSO-LEACH architecture but also fewer energy dissipation in the node. Therefore, it is clear that the use of Taguchi algorithm to adjust PSO algorithm parameter can enhance the energy efficiency of WSNs.

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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 University of Science and Technology, Taiwan, where he is currently a Professor. His research interests include wireless communications, wireless sensor networks, digital signal processing, information security, fuzzy neural networks and embedded systems.

Wan-Ren Chen received the B.S. degree in department of computer science and information engineering from National Taichung Institute of Technology, Tai-Chung, Taiwan, in 2010, he is currently an Student in department of computer science and information engineering from National Taichung University of Science and Technology, Tai-Chung, Taiwan. His research interests include wireless sensor networks, and embedded systems.