Genetic Algorithm-Based Energy-Efficiency via Role Sharing Protocol for Wireless Sensor Networks

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Abstract - *This study proposes a genetic algorithm-based (GA-based) ERoS (Energy-efficiency via Role Sharing) protocol with capable of predicting the optimal probability of cluster heads to enhance the performance of cluster-based wireless sensor networks. The proposed GA-based ERoS protocol, termed ERoS-GA, which basically includes set-up and steady-state phases for each round in the protocol, and a preparation phase is added at the beginning of the first round to obtain the optimal probability of nodes being cluster heads from the base station via genetic algorithm computation. The preparation phase is performed only once before the set-up phase of the first round, and the processes of following set-up and steady-state phases in every round are the same as ERoS. Simulation results show that the proposed genetic-algorithm-based ERoS protocol can produce optimal energy consumption effectively for the wireless sensor networks, resulting in a prolongation for entire network lifetime.*

Keywords: Genetic Algorithm, Clustering Heads, Optimal Probability, ERoS-GA, Network Lifetime.

1 Introduction

Wireless sensor networks (WSNs) have been extensively applied in tactical combat situations, habitat monitoring, home security, and so on [1-3]. Considering that a wireless sensor network is composed of a large number of tiny sensor nodes with limited energy, an energy-efficient network protocol is one of the essentials in the WSN design. As reviewing the proposed protocols in the literature, cluster-based communication protocols can produce superior performance to achieve more balanced patterns of energy use in WSNs [4]. The well-known cluster-based communication protocol was Heinzelman *et al.'s* LEACH, low-energy adaptive clustering hierarchy [5, 6], which energy loads could be well amortized by periodically creating a small number of clusters based on a threshold function T(s) with a priori probability p (say, 5%), in the set-up phase. The technique uses cluster heads (CHs) to aggregate the sensed data from member nodes and forward the aggregated data to base station (BS). Simulation results in [5, 6] show that sensor nodes in the sensor field tend to dissipate the same level of energy over time since the CHs are dynamically rotated among nodes. However, LEACH uses a threshold function parameterized by a probability p that is needed to specify by user. The performance of sensor network is sensitive to the value of p. When p is large, many clusters are formed as a result of high energy consumption since many CHs could dissipate more energy in transmitting aggregated data to the BS. On the other hand, when p is small, only a few clusters are formed, which could increase energy dissipation of member nodes in transmitting sensed data to CHs. Accordingly, some researchers presented that the optimal value p_{opt} depends on parameters such as the total number of nodes distributed in the sensor field, the size of sensor field, the location of BS, and so on [7, 8]. Therefore, present work proposes a genetic algorithm-based (GA-based) energy-efficiency via role sharing protocol, termed ERoS-GA, to predict the optimal values of probability effectively for WSN applications.

1.1 ERoS: An energy-efficiency via role sharing protocol

LEACH as we know it is a stochastic cluster head selection algorithm shown in Fig. 1, which CHs are selected dynamically and periodically according to a threshold function in every round. The operation of LEACH is employed via several rounds, each round consisting of set-up and steady-state phases. In the set-up phase, the sensor field is divided into a small number of clusters. Each cluster includes a CH and several member nodes. Thereafter, in the steady-state phase, each member node transmits its collected data form surroundings to the closest CH, and then each CH receives and aggregates the data from its cluster members and forwards the aggregated data to the BS through a single-hop relay. It is clearly that each CH in LEACH is responsible for cluster management, as well as data aggregation and transmission. This places an excessive energy burden on the CH. Therefore, most protocols try to distribute this energy burden across the network by rotating the CH role between nodes chosen either randomly, or according to some residual-energy metric. However, the use of residual energy in CH selection still yields sub-optimal energy balance and network lifetimes. Based on this insight, we proposed a new protocol called ERoS (Energy-efficiency via Role Sharing) protocol in the previous work [9]. In the ERoS protocol, CHs are selected randomly based on a probability p in each round, yet achieves excellent energy balance by off-loading the data aggregation and transmission functions to other selected nodes. The role of CHs is just to form clusters. Data aggregation within each cluster is performed by an aggregation node, and data transmission to BS by a transmission node.

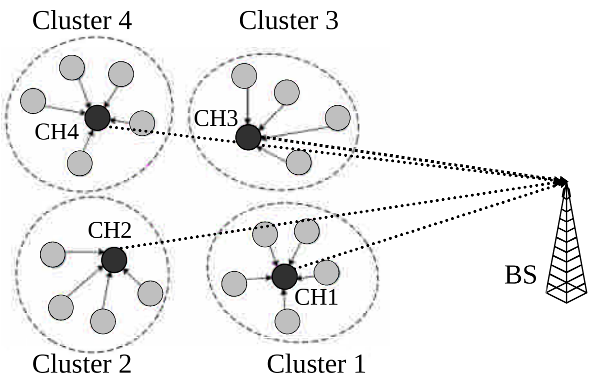


Figure 1. Clustering-based protocol with clusters in the wireless sensor network.

Each round in ERoS is divided into set-up and steady-state phases, just as in LEACH. The selection of CHs is determined purely using a probability value *p*. At the beginning of set-up phase, each sensor node picks a random number *t* in the interval [0, 1]. If $t < p$, the node advertises itself as a CH. Since CHs in ERoS are randomly selected, based only on a specified parameter *p*, several CHs could be located near each other, causing a local imbalance in energy consumption. To distribute the CHs more uniformly, a crowding distance check [10] is applied. After employing this crowding distance check, the surviving CHs advertise themselves to the other nodes in the sensor field via broadcast messages. Cluster formation proceeds with each of the non-CH nodes selecting the closest CH, that is, the CH whose broadcast signal appears the strongest. Picking the closest CH minimizes the energy required for member nodes to communicate with the CH. Each node sends a join-request message to its chosen CH, with its ID, geographical position, and a header. Cluster formation is complete when all nodes in the network have joined a cluster.

1.2 Selections of aggregation and transmission nodes

The energy required to transmit a wireless message over a distance *d* is proportional to d^{α} , where the value α depends on the distance between transmitter and receiver. The values $\alpha = 2$ and $\alpha = 4$ represent the free-space and multi-path fading models, respectively. Since data is aggregated in ERoS by the aggregation node (AN), the total data transmission energy used by nodes within the cluster is minimized when the AN is at the center of the cluster. Accordingly, the AN is chosen by the CH to be the node closest to the cluster center with residual energy higher than the average value within the cluster (see Fig. 2). The AN accepts data packets from member nodes and aggregates them to eliminate redundancy for reducing the size of data.

Each CH also selects the node with the highest residual energy level within the cluster to be the transmission node (TN), as shown in Fig. 2. The TN receives aggregated packets from the AN and forwards them to the BS. Since the TN has the highest residual energy in its cluster, it is the best candidate to transmit data packets to the BS located far from the cluster. Next, the CH sends a message with the IDs of AN and TN to its cluster members via a unique sub-area code. Finally, each CH creates a time division multiple access (TDMA) schedule and a unique spreading code, and transmits them to the members of its cluster. Clearly, the CH plays the role cluster administrator only in ERoS protocol.

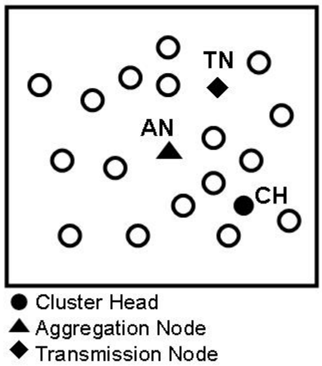


Figure 2. The distribution of CH, AN, and TN in the field.

After clusters have been formed, the steady-state phase begins, and the network starts its transmitting and receiving procedures. In this phase, all cluster members transmit their sensed data to the local AN. The time assigned for each data transmission slot depends on the number of nodes in the cluster. Except when transmitting, the member nodes remain in sleep mode to save energy. As described, ANs aggregate the received data packets and send them to the TN. At the end of the schedule, the TN receives aggregated data from the cluster AN, and forwards them to the BS.

2 Proposed ERoS-GA protocol

Our work introduces a genetic algorithm-based ERoS to determine the optimal value of *p* for various base station placements and sensor sizes. The GA-based optimization procedure is performed only once, before the set-up phase of the first round. The pseudo-code of the proposed protocol is described as follows.

Pseudo-code of the Proposed Protocol
BEGIN
Specify the probability (p_{set}), number of nodes (n);
$E_{init}(s)=E_0$, s=1,2, …, n;
I. PREPARATION PHASE
if ($E_{init}(s)>0$) **then**
$r \leftarrow$random(0,1);
if ($r < p_{set}$) **then** //p_{set} can set≥0.5
CCH{s}=TRUE; //node "s" be a candidate CH
else
CCH{s}=FALSE; //node "s" not be a candidate CH
end if
end if

```
SendToBS(ID_u, (x_u,y_u), CCH(u)) ← All nodes send messages to BS;
GAinBS(p_opt) ← Optimal probability is determined;
BC (p_opt) ← BS broadcasts a message back to all nodes;
do {                        //repeat for specified rounds
II. SET-UP PHASE
  t←random(0,1);
  if (E_init(s)>0)  then
    if (t < p_opt)  then
      CCH{s}=TRUE; //node "s" be a candidate of CH
    else
      CCH{s}=FALSE; //node "s" not be a candidate of CH
    end if
  end if
  if  (CCH{s}=TRUE) then
      if (distance>distance threshold) then
          CH{s}=TRUE;     //crowding distance check
      else
          CH{s}= FALSE;   //give up to be a CH;
      end if
  end if
  if  (CH{s}=TRUE) then
      BC (ADV) ← broadcast an advertisement message;
      Join(ID_i, (x_i,y_i), E(i)); //non-cluster head node "i" join
                                    into the closest CH
      Cluster(c);          //form a cluster c;
      GC{c}← (x_c, y_c);   //compute the geometric center
       do{
         AN{u}=TRUE; //node "u" be the aggregation node
             } while (E(u)> Ē(c) & min{dist(u,GC(c))})
       do{
         TN{v}=TRUE; //node "v" be the transmission node
             } while (E(v)=max{E(c)})
  end if
III. STEADY-STATE PHASE
  If (AN(s)=TRUE) then
     Receive(ID_i, DataPCK) //receive data from members;
     Aggregate(ID_i, DataPCK) //aggregate received data;
     TansToTN(ID_AN, DataPCK); //transmit received data;
  else
     If (MyTimeSlot=TRUE) then
         TansToAN(ID_i, DataPCK); //transmit sensed data;
     else
        SleepMode(i)=TRUE;      //node "i" at a sleep state
     end if
  end if
  If (TN(s)=TRUE) then
         Receive(ID_AN, DataPCK); //receive data from AN
      If (MyTimeSlot=TRUE) then
         TansToBS(ID_TN, DataPCK); //transmit data to BS;
      end if
  else
        SleepMode(s)=TRUE;      //node "s" at a sleep state
  end if
}              // one round is completed
END
```

3 Analysis of energy dissipation in ERoS

We use a first-order radio model [5] in analyzing ERoS protocol. The parameter values used in our simulation model are listed in Table I. According to the radio energy dissipation model illustrated in Fig. 3, the energy required by the transmit amplifier $E_{Tx}(l,d)$ for transmitting a l-bit message over a distance d between a transmitter and a receiver is given by

$$E_{Tx}(l,d) = \begin{cases} l \times E_{elec} + l \times \varepsilon_{fs} \times d^2 & if\ d \le d_0 \\ l \times E_{elec} + l \times \varepsilon_{mp} \times d^4 & if\ d \ge d_0 \end{cases} \quad (1)$$

where $d_0 = \sqrt{\varepsilon_{fs} / \varepsilon_{mp}}$ expresses the threshold distance, E_{elec} represents the energy consumption in the electronics circuit to transmit or receive the signals, and the terms of $\varepsilon_{fs} d^2$ and $\varepsilon_{mp} d^4$ represent amplifier energy consumption for a shorter and longer distance transmissions, respectively. To receive the l-bit message, the energy $E_{Rx}(l,d)$ required by the receiver is given by

$$E_{Rx}(l) = l \times E_{elec} \quad (2)$$

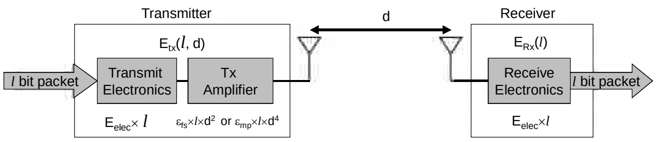


Figure 3. First-order radio model.

Table I. Parameters of the first-order radio model

Parameters	Values
Initial energy (E_0)	0.5 J
Transmitter Electronics (E_{elec})	50 nJ/bit
Receiver Electronics (E_{elec})	50 nJ/bit
Size of Data Packet (l)	2000 bits
Transmitter Amplifier (ε_{fs}) if $d \le d_0$	100 pJ/bit/m^2
Transmitter Amplifier (ε_{mp}) if $d \ge d_0$	0.0013 pJ/bit/m^4

We analyze the energy consumption under the first-order radio model for ERoS as follows. Let a total of n sensor nodes be distributed uniformly in the sensor field of size $M \times M$ (m^2), and be grouped into k clusters. The energy costs required to transmit/receive control messages are neglected in the following analyses of energy consumption, since data packets (l) are far larger than control messages (l_{ctrl}). The energy required per round for an AN to receive data packets from member nodes, and aggregate the received data and forward them over a distance d_{ANtoTN} to the TN is

$$E_{AN}(l,d) = l\times\left[E_{elec}\left(\frac{n}{k}-1\right)+E_{DA}\frac{n}{k}+E_{elec}+\varepsilon_{fs}\times d^2_{ANtoTN}\right] \quad (3)$$

where E_{DA} represents the energy dissipation for aggregating data. In addition, the energy required per round for a TN to receive aggregated data packets from AN and forward them over a distance d_{toBS} to the BS is

$$E_{TN}(l,d) = \begin{cases} 2l\times E_{elec}+l\times\varepsilon_{fs}\times d^2_{toBS} & if\ d_{toBS}<d_0 \\ 2l\times E_{elec}+l\times\varepsilon_{mp}\times d^4_{toBS} & if\ d_{toBS}\ge d_0 \end{cases} \quad (4)$$

The energy dissipation for a member node, or a non-aggregation node, is

$$E_{non-AN}(l,d) = l\times E_{elec}+l\times\varepsilon_{fs}\times d^2_{toAN} \quad (5)$$

where d_{toAN} represents the distance between a cluster member and its AN. Since the nodes are assumed to be uniformly distributed in the sensor field, the expected value of squared distance from a member node with coordinate at (x, y), to its AN, which located approximately at the center of a cluster in ERoS protocol, is given by

$$E\left[d^2_{toAN}\right] = \frac{1}{A}\iint (x^2+y^2)dxdy \quad (6)$$

Assuming the shape of clusters is a circle, (6) can be integrated as

$$E\left[d^2_{toAN}\right] = \frac{1}{2\pi}\frac{M^2}{k} \quad (7)$$

The expectation of d^2_{toAN} in (7) is the same as that of d^2_{toCH} in the work of Heinzelman *et al.* [6], since they assumed the CH to be at the center of cluster. Clearly, the assumption used in LEACH is incorrect, since the CHs are not located at the center of clusters in most cases. In the general case, the value of d^2_{toCH} should be the twice that of d^2_{toAN} [10]. Similarly, the expected value of the squared distance from the AN to TN, assuming the TN at (x', y'), also can be approximated as

$$\begin{aligned} E\left[d^2_{ANtoTN}\right] &= \frac{1}{A}\iint (x'^2+y'^2)dx'dy' \\ &= \frac{1}{2\pi}\frac{M^2}{k} \end{aligned} \quad (8)$$

Clearly, the The expectation of d^2_{ANtoTN} in (8) is the same as that of d^2_{toAN}. Since the energy dissipation for a cluster ($E_{cluster}$) is the summation of E_{AN}, E_{TN} and E_{non-AN}, the total energy consumption for the entire sensor field can be computed by $k\times E_{cluster}$ and formulated as

$$\begin{aligned} E_{total} &= k\times\left(E_{AN}+E_{TN}+(\frac{n}{k}-1)E_{non-AN}\right) \\ &\approx k\times\left(E_{AN}+E_{TN}+\frac{n}{k}E_{non-AN}\right) \end{aligned} \quad (9)$$

Therefore, the total energy dissipation for a round is given by

$$E_{Total} = \begin{cases} l\times\left[2(n+k)E_{elec}+nE_{DA}+k\varepsilon_{fs}E[d^2_{toBS}]+\varepsilon_{fs}\frac{(n+k)M^2}{2\pi k}\right] & if\ d_{toBS}<d_0 \\ l\times\left[2(n+k)E_{elec}+nE_{DA}+k\varepsilon_{mp}E[d^4_{toBS}]+\varepsilon_{fs}\frac{(n+k)M^2}{2\pi k}\right] & if\ d_{toBS}\ge d_0 \end{cases}$$

(10)

where $E\left[d_{toBS}\right]$ is the expectation of d_{toBS}. Equation (10) shows that the total energy dissipation is most significantly affected by the distance between TN and BS, and the size of the sensor field. We assume the coordinates of the BS to be (0.5M, 0.5M+B), the values of $E[d^2_{toBS}]$ and $E[d^4_{toBS}]$ can be obtain to be

$$E[d^2_{toBS}] = \frac{M^2}{6}+B^2; \quad E[d^4_{toBS}] = \frac{7M^4}{180}+\frac{2}{3}B^2M^2+B^4 \quad (11)$$

The corrected equations for total dissipation in LEACH are presented in [10] as follows.

$$E_{Total} = \begin{cases} l\times\left[2nE_{elec}+nE_{DA}+k\varepsilon_{fs}E[d^2_{toBS}]+\varepsilon_{fs}\frac{nM^2}{\pi k}\right] & if\ d_{toBS}<d_0 \\ l\times\left[2nE_{elec}+nE_{DA}+k\varepsilon_{mp}E[d^4_{toBS}]+\varepsilon_{fs}\frac{nM^2}{\pi k}\right] & if\ d_{toBS}\ge d_0 \end{cases}$$

(12)

Comparing (10) and (12), we can see that although ERoS increases required power by $2lkE_{elec}$, this increase is small, since number of cluster k is small. However, it reduces the energy consumption roughly by $\frac{l\varepsilon_{fs}nM^2}{2\pi k}$ when $(n-k)\approx n$. Therefore, it is beneficial to assign the AN function to a node whose locates at or near the cluster center rather than the CH.

4 Analysis of optimal number of cluster in ERoS

From the mathematical expressions of (10), the total energy consumption E_{Total} is a function of the number of clusters k. Assuming that $(n+k)\approx n$, the analytical optimal solution for k can be obtained via setting the derivative of E_{Total} to k equal to zero. Therefore, the optimal number of clusters (k_{opt}) and probability for generating CHs (p_{opt}) can be formulated as

$$k_{opt} = \begin{cases} \sqrt{\frac{n}{2\pi}} \frac{M}{\sqrt{E[d_{toBS}^2]}} & \text{if } d_{toBS} < d_0 \\ \sqrt{\frac{n}{2\pi}} \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \frac{M}{\sqrt{E[d_{toBS}^4]}} & \text{if } d_{toBS} \geq d_0 \end{cases} \quad (13)$$

and

$$p_{opt} = \begin{cases} \sqrt{\frac{1}{2n\pi}} \frac{M}{\sqrt{E[d_{toBS}^2]}} & \text{if } d_{toBS} < d_0 \\ \sqrt{\frac{1}{2n\pi}} \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \frac{M}{\sqrt{E[d_{toBS}^4]}} & \text{if } d_{toBS} \geq d_0 \end{cases} \quad (14)$$

Clearly, the value of k_{opt} is approximated as $1/\sqrt{2}$ times the value of LEACH-GA presented in Ref. [10]. When the BS located at the centroid of sensor field, the values of $\sqrt{E[d_{toBS}^2]}$ is given by [7]

$$\begin{aligned} \sqrt{E\left[d_{toBS}^2\right]} &= \frac{1}{A}\int\sqrt{x^2+y^2}dA \\ &= 0.765\frac{M}{2} \end{aligned} \quad (15)$$

and the form of p_{opt} can be simplified as

$$p_{opt} = \sqrt{\frac{1}{2n\pi}} \frac{2}{0.765} \quad (16)$$

Equation (16) states that the parameter p_{opt} is just function of the total number of sensor nodes only when the BS located at the center of sensor field. Namely, the value of probability at the center of sensor field is independent of the domain size.

5 Genetic algorithm-based clustering

At the beginning of preparation phase, each node initially determines whether or not it should be a candidate cluster head (CCH), using the following cluster head selection procedure. First, every sensor node selects a random number r from the interval [0, 1]. If r is smaller than p_{set}, based on a prescribed probability p_{set}, then the node is a CCH. The value of p_{set} can be a large value in our protocol, p_{set}=0.5 for example. Thereafter, each node sends its ID, location information, and whether or not it is a CCH to the BS. As the BS receives messages sent by all nodes, it performs GA operations to determine the optimal probability, $p_{opt}= k_{opt}/n$, by minimizing the total amount of energy consumption in each round. Therefore, the objective function used in the GA can be formulated as

$$\begin{aligned} f(\vec{x}) = &\sum_{c=1}^{k}\sum_{i=1}^{q}(E_{elec} + \varepsilon d^{\alpha}[i, CCH(c)]) \times x_c + \\ &\sum_{c=1}^{k}(E_{elec} + E_{DA} + E_{elec} + \varepsilon d^{\alpha}[CCH(c), BS]) \times x_c \end{aligned} \quad (17)$$

where $\vec{x} = [x_1, x_2, ..., x_c, ..., x_k]$. The values of x_c are one for our binary-GA when it is a CCH, otherwise, it is zero. The parameters $\varepsilon=\varepsilon_{fs}$ and α=2 were used for $d<d_0$; while, $\varepsilon=\varepsilon_{mp}$ and α=4 were set for $d \geq d_0$. The symbol q represents the number of member nodes in a cluster. The optimal probability p_{opt} is determined by the $1/\sqrt{2}$ times the value of obtain from GA based on (14). Once the optimal probability p_{opt} is found, the BS broadcasts the value of p_{opt} to all nodes. The set-up and steady-state phases begin. The procedures of set-up and steady-state phase are the same as in LEACH.

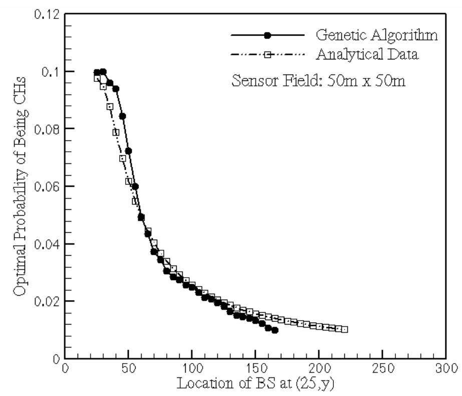
6 Simulation results

This work assumes that all sensor nodes are homogeneous and distributed uniformly over the sensor field with limited energy that the links between nodes are symmetric, and that messages from all nodes can reach the BS. The nodes are distributed randomly in a square of size $M \times M$. Two sizes of sensor field are studied for 50m×50m and 100m×100m domains. In this study, each simulation is repeated for 30 independent runs. In addition, control packet sizes for broadcasting packet and packet header were 50 bits long, and the energy dissipation for aggregating data was 10 nJ/bit/signal.

6.1 Comparison of optimal probability of CHs

The parameters ε_{fs} and ε_{mp} were specified as 100 pJ/bit/m^2 and 0.0013 pJ/bit/m^4, respectively. The total number of sensor nodes was 100. The GA simulation is repeated for 100 independent runs, and solutions are obtained from the average of the runs. Figure 4(a) shows the comparison of optimal probability obtained from model analysis and GA-based computation for a variety of locations of BS for the sensor field of 50m×50m. The comparison depicts that the distribution of present computed optimal probability using ERoS-GA quite agrees with the analytical formulas of (14). Moreover, the result shows that the optimal probability, p_{opt}, is clearly affected by the locations of BS. When the BS is located near the sensor field, the values of p_{opt} are large. On the contrary, the values of optimal probability decrease as the BS moves farther from the sensor field. Figure 4(b) displays the distributions of optimal probability obtained using model analysis and ERoS-GA for a variety of locations of BS for the sensor field of 100m×100m. The results obtained using ERoS-GA was comparable to that of analytical approaches. From Figs. 4(a) and (b), it is showed that the value of probability at the center of sensor fields is independent of the domain size, that is agree with the analytical solution of (16).

(a)



(b)

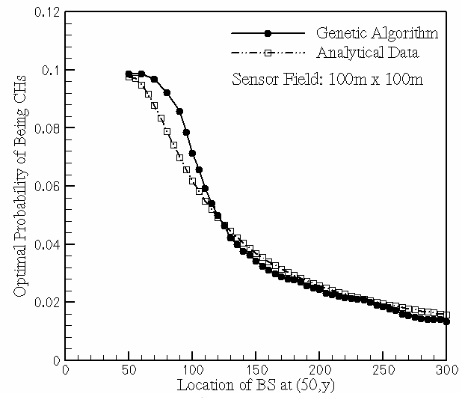


Figure 4. Comparison of optimal probability distributions between analytical analysis and ERoS-GA for the sensor fields with (a) 50m×50m and (b) 100m×100m.

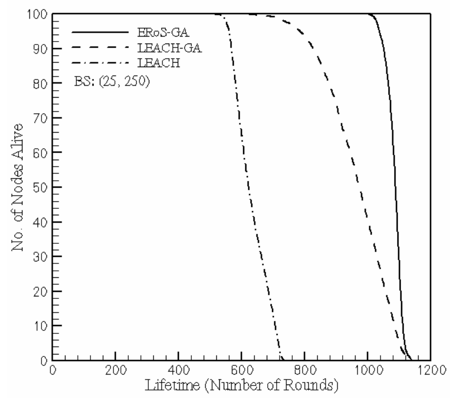
6.2 Comparison of network lifetime

The control packet sizes for broadcasting packet and packet header were 50 bits length for the present computations. Each simulation is also repeated for 30 independent runs, and solutions are obtained from the average of the runs. Table II lists the simulation results obtained using LEACH, LEACH-GA [10] and presented ERoS-GA protocols for BS located at different positions for the sensor field of 50m×50m. The initial energy for all nodes was 0.5(J). The number of rounds required when the number dead of nodes is 1%, 20%, 50%, and 100% are recorded during simulations. From our results, the values of p_{opt} clearly depend on the positions of BS. The value of optimal probability is the largest when the BS is at the center of sensor field, and it decreases when the BS moves outward. Moreover, the proposed ERoS-GA has better performance in most cases than that of LEACH and LEACH-GA in prolonging sensors' lifetime. Figures 5(a) and (b) show the comparisons of performance for BS located at two coordinates of (25, 250) and (25, 350), respectively. Our protocol clearly has excellent performance as compared with other protocols. When the location of BS is far from the sensor field, presented protocol prolongs the lifetime of network significantly since it uses ERoS protocol and with an optimal probability in forming clusters.

Table II. Comparison of network lifetimes (number of rounds) for sensor filed of 50M×50M

BS (25, y)	**Protocol**	**Prob.**	**Nodes Dead**			
			1%	**20%**	**50%**	**100%**
y=25 (center)	LEACH	0.05	1467	1618	1691	1850
	LEACH-GA	0.1307	1610	1732	1818	2040
	ERoS-GA	0.0998	1796	1822	1830	1843
y=50 (border)	LEACH	0.05	1438	1583	1661	1874
	LEACH-GA	0.0946	1512	1663	1717	2078
	ERoS-GA	0.0722	1711	1736	1746	1767
y=100	LEACH	0.05	1346	1473	1543	1787
	LEACH-GA	0.0334	1356	1482	1554	1815
	ERoS-GA	0.0249	1388	1404	1419	1441
y=150	LEACH	0.05	951	1027	1098	1298
	LEACH-GA	0.0181	927	1108	1205	1357
	ERoS-GA	0.0134	1240	1256	1272	1287
y=250	LEACH	0.05	540	576	616	718
	LEACH-GA	0.010	686	874	971	1106
	ERoS-GA	0.010	1059	1073	1085	1097
y=350	LEACH	0.05	220	247	283	360
	LEACH-GA	0.010	407	574	660	757
	ERoS-GA	0.010	748	769	780	797

(a)



(b)

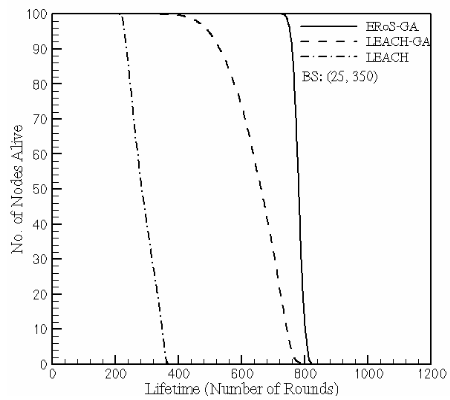


Figure 5. Performance comparisons of network lifetime for the BS located at points of (a) (25, 250) and (b) (25, 350) for sensor filed of 50m×50m.

Table III lists the simulation results obtained using LEACH, LEACH-GA and presented ERoS-GA protocols for BS located at different positions for the sensor field of 100m×100m. Generally, sensor nodes in the large sensor field tend to consume more energy per round for transmitting their sensed data to AN as compared with small one. In this case, the proposed ERoS-GA also showed better performance in most cases than that of LEACH and LEACH-GA in prolonging sensors' lifetime.

Table III. Comparison of network lifetimes (number of rounds) for sensor filed of 100M×100M

BS (50, y)	Protocol	Prob.	Nodes Dead			
			1%	20%	50%	100%
y=50 (center)	LEACH	0.05	718	992	1112	1326
	LEACH-GA	0.1394	1035	1304	1402	1693
	ERoS-GA	0.0986	1284	1351	1360	1379
y=100 (border)	LEACH	0.05	682	927	1049	1278
	LEACH-GA	0.1009	838	1042	1227	1557
	ERoS-GA	0.0714	1068	1187	1205	1264
y=150	LEACH	0.05	596	792	909	1131
	LEACH-GA	0.0483	604	790	900	1101
	ERoS-GA	0.0342	706	909	926	952
y=250	LEACH	0.05	410	503	585	724
	LEACH-GA	0.0261	395	525	611	745
	ERoS-GA	0.01845	535	707	717	726
y=350	LEACH	0.05	192	251	333	448
	LEACH-GA	0.0141	344	457	557	755
	ERoS-GA	0.0100	464	580	590	601

7 Conclusions

This paper proposed a GA-based ERoS protocol, termed ERoS-GA, to determine the optimal probability for cluster formation in WSNs. The LEACH or previous proposed ERoS protocol requires the user to specify a probability to determine whether a node becomes a CH or not. Considering that the probability value (p) for forming clusters in the protocols is difficult to obtain an optimum setting from available prior knowledge. Thus, we designed an additional preparation phase prior to the set-up phase of the first round in the ERoS-GA protocol to gather information about node status, IDs, and location and send it to the BS, which determines the optimal probability to use in the CH selection mechanism. Results showed that the distributions of optimum probability obtained using ERoS-GA was comparable to that of energy model analysis for BS located at different positions in the two sensor fields with 50m×50m and 100m×100m. Moreover, the proposed ERoS-GA method demonstrated good performance in prolonging sensors' lifetime when compared with LEACH and LEACH-GA, since the use of ERoS protocol and the optimal probability can yield optimal energy-efficient clustering.

8 Acknowledgment

The work was supported by National Science Council of Republic of China under Grant Number NSC 100-2221-E-214-040.

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