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A hybrid approach to extend the life time of heterogeneous wireless sensor networks

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Abstract

In this work, we propose to use two optimization meta-heuristics that are: firefly and simulated annealing to extend the life time of a heterogeneous wireless sensors network (WSN) with a fixed base station by reducing the communication energy consumption. The proposed approach combines between the clustering and the chain approaches. Our optimization algorithm tries at first time to find the optimal clustering over the network nodes using the firefly algorithm then inside each cluster it attempts to find the best chain using simulated annealing. A particularity in our algorithm is the dynamic adjustment of clusters number over rounds.

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1. Introduction

Wireless Sensor Networks (WSNs) consist of large number of nodes, having sensing, computation and wireless communication capabilities. Each sensor node communicates wirelessly with a few other local nodes within its radio communication range. Sensor nodes are usually operated by low power batteries and are unattended after deployment. Energy utilization is a very critical issue in WSN. On the other side, it is recognized that the energy of transmitting a bit is higher than a computation and since sensor nodes life time depends on the life time of battery

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hence it is advantageous to organize the sensors in such a way, the WSN life time is extended by minimizing the energy due to communication. Two main approaches are evolved: clustering approach and chain approach. In clustering, sensor nodes are grouped into clusters controlled by the base station. One of the sensor nodes in the cluster will be elected as Cluster Head (CH) and which is responsible for relaying data from each sensor to the base station. In addition, data fusion and data compression can occur in the cluster head by considering the potential correlation among data from neighboring sensors. The CH must have much more energy than other nodes. In the chain approach, nodes are organized to form a chain so that each node in the chain needs to communicate only with its closest neighbor^{1, 4, 7, 11, 12}. According to literature, we can state that most researchers have resorted to nature and biology inspired approaches to extend the WSN life time by reducing the energy consumption^{2, 5, 6, 8, 9}. In this work, we propose to use two optimization meta-heuristics that are: firefly¹⁰ and simulated annealing³ to reduce communication energy over the WSN. Our approach combines between the clustering and the chain approaches. The proposed algorithm tries at a first time to find the optimal clustering over the network nodes using the firefly algorithm then inside each cluster it attempts to find the best chain using simulated annealing. The rest of paper is organized as follows: sections two and three detail our proposed algorithm. In section four, we show our first experimentations before the conclusion.

2. Our algorithm

We assume a sensor network model with the following properties:

- Network nodes are heterogeneous in terms of energy.
- Nodes are deployed randomly but not uniformly.
- All nodes are stationary and energy constrained.
- A fixed base station can be located inside or outside the network sensor field.
- Data delivery model to the base station is continuous: Each node performs sensing tasks periodically and always has data to send to the base station.
- A node is considered dead if its residual energy is less than E_{\min} .
- All nodes are capable of operating in cluster head mode and sensing mode.
- All communication channels are symmetric so that the energy spent in transmitting from node i to j is the same as that of transmitting from node j to i for any given value of SNR.
- Intra-cluster communication is based on TDMA.
- Communication between clusters heads and the base station is based on CSMA.

Our energy model for the sensors is based on the first order radio model. In this model, the transmitter dissipates energy to run the radio electronics and the power amplifier, and the receiver dissipates energy to run the radio electronics. The radios can perform power control and hence use the minimum energy required to reach the intended recipients. Due to attenuation with distance, an energy loss model with d^{ij} is used for relatively short distances and d^{ij} is used for longer distances, where d_{ij} is the distance between sensor nodes i and j . Thus, in order to achieve an acceptable Signal-to-Noise-Ratio (SNR) in transmitting an l -bit message over a distance d , the energy expended by the radio is given by:

$$E_{TX}(l, d) = l \cdot E_{elec} + l \cdot \mathcal{E}_{FS} d^2, \text{ if } d < d_0 \quad (\text{eq. 1})$$

$$= l \cdot E_{elec} + l \cdot \mathcal{E}_{TR} d^4, \text{ if } d \geq d_0$$

Where E_{elec} is the electronics energy dissipated per bit to run the transmitter or the receiver circuit, \mathcal{E}_{FS} and \mathcal{E}_{TR} depends on the transmitter amplifier model we use, and d_0 is the threshold transmission distance. To receive an l -bit message, the radio expends:

$$E_{RX}(l) = l \cdot E_{elec} \quad (\text{eq. 2})$$

Our optimization algorithm is applied during the cluster setup phase. It consists in:

- I. Clustering the network to a predefined number K of clusters and identify for each cluster its head and the set of nodes belonging to it using the Firefly Algorithm.
- II. Inside each cluster, find the best chain of node using Simulated Annealing (SA).

This algorithm is executed by the BS. For a sensor network with N nodes and K clusters, the network can be clustered as follows:

Algorithm

Begin

1. Initialize S Fireflies to contain K randomly selected cluster heads among the eligible cluster head candidates.

**Each firefly represents a possible solution; it is encoded as a vector $X = (x_1, x_2, \dots, x_k)$ where x_i corresponds to the residual energy of the cluster header i

f_j is the mean of distances means inside $K+1$ clusters:

We have $K+1$ cluster, C_1, \dots, C_K, C_{K+1} ;

C_{K+1} is the cluster which is formed of K clusters headers and the BS.

$$f_1 = \frac{\sum_{i=1}^{K+1} M_i}{K + 1}$$

Where;

$$M_i = \frac{\sum_{j=1}^{C_i} d(n_j, CH_i)}{|C_i|} \text{ if } i \leq K$$

Where $d(n_j, CH_i)$ designates the distance between node n_j and its cluster header CH_i

$|C_i|$ is the number of nodes belonging to cluster C_i

$$M_i = \frac{\sum_{j=1}^{C_i} d(CH_j, BS)}{K} \text{ if } i = K + 1$$

Where $d(CH_j, BS)$ designates the distance between cluster header j and the base station BS.

$t = 1$

2. While $t \leq \text{MaxGen}$ do

 For $i = 1$ to S do

 For $j = 1$ to S do

 Calculate the cost function of each firefly:

 i. For each node $n_i, i = 1, 2, \dots, N$

 Calculate distance $d(n_i, CH_{p,k})$ between node n_i and all cluster heads $CH_{p,k}$ using eq.1

 Assign node n_i to cluster head $CH_{p,k}$ where:

$$d(n_i, CH_{p,k}) = \min_{v \in \{1, 2, \dots, K\}} \{d(n_i, CH_{p,k})\}$$

 ii. Calculate light intensity L_i for each firefly

$$L_i = \frac{1}{f_1(x_i)}$$

 If $L_j > L_i$ then

 Move firefly i towards firefly j

 Update firefly i position; calculate the new position

 Map the new position with the closest node

 End if

 End For j

 End For i

Sort the fireflies and find the current best x_{best} ;

Move x_{best} randomly using the formula:

$$x_i^{t+1} = x_i^t + \alpha_t (rand - 0.5)$$

Map the new position with the closest node

$t = t + 1$

End While

Output: K clusters; each cluster has a well known header CH and a number of nodes m .

* inside each cluster find the best chain

Step1: Initialization

θ_i (initial temperature) *The higher the initial temperature, the better the result is.

θ_f (final temperature),

α (the rate of cooling) * α is, usually $(0.7 \leq \alpha \leq 1.0)$

L is maximum number of iterations at a certain temperature.* the number of iterations may vary from temperature to temperature, it is important to spend sufficiently long time at lower temperatures.

MaxIter is the maximum number of iterations for the total process.

f_2 is the summation of transmitted (E_{TX}), received (E_{RX}) and aggregated data (E_{DA}) energies of all nodes and the cluster header forming the chain.

$$f_2 = \sum_{i=1}^m (E_{TXi} + E_{RXi} + E_{DAi})$$

```

For each cluster do
Randomly construct an initial solution  $C_{old}$ ; form a nodes chain  $N_1, N_2 \dots N_m, CH$ 
 $t = 1$ 
 $\theta(t) = \theta_i$ 
Step 2:
While  $t \leq \text{MaxIter}$  and  $\theta(t) > \theta_f$  do
 $C_{best} := C_{old}$ 
 $k = 1$ 
While  $k \leq L$  do
Make a random binary swapping, where two positions in a chain (Cold) are randomly selected and exchanged, resulting in a new chain (Cnew).
Calculate  $\Delta f = f_2(Cnew) - f_2(Cold)$ 
If  $\Delta f \leq 0$  then  $Cold := Cnew$  * we accept this solution
Else
Calculate:

$$P = e^{\frac{-\Delta f}{\theta(t)}}$$

Generate a random number between 0 and 1; rand (0,1)
If  $P > \text{rand}(0,1)$  then  $Cold := Cnew$  ** we accept this solution
else * we reject this solution
end if
end if
 $k = k + 1$ 
End While
 $\theta(t) = \theta_f + \theta_i \cdot \alpha_t$  * cooling schedule
 $t = t + 1$ 
End While
 $C_{best}$ : the best chain inside the cluster.
End for
End algorithm.

```

3. Cluster setup using our algorithm

The overall algorithm looks like:

For each round

During setup phase:

- All nodes in the network transmit their locations and energy levels to the BS.
- The BS checks whether is node is dead or not. If a node is dead it is excluded from the network.
- The BS calculates the number of clusters K (usually K is set to be 5% of the total nodes).
- The BS computes the average energy level of all nodes; the nodes with an energy level above the average are eligible to be a cluster head candidate for this round.
- The BS executes the optimization algorithm to find optimal clusters and chains inside clusters.
- The BS transmits back all information to nodes.

During steady state phase. Each cluster head has to:

- Execute its TDMA schedule so that: each node in the chain transmits, receives and aggregates packets coming from its neighbor node during its slot time.
- The header aggregates data and transmit it to the BS (using CSMA).
- Update its residual energy.
- Furthermore, each node in a cluster updates its residual energy.

End for

Print performance graphs:

- Number of dead nodes over rounds
- The energy expended by the network over rounds

Note that the proposed algorithm focuses on estimating energy due to data communication which is the differentiator between solutions. Communication due to control (control signals) is not taken into account.

4. Experimentation

We have implemented our algorithm using Java under NetBeans IDE 7.0 environment. Our first experimentations are done on the base of parameters described in table 1. We tested our algorithm with two options: FA with randomization term and without randomization term. These tests will help us to understand the impact of FA randomness in the quality of results. Figures 1 and 2 show respectively the results of algorithm execution (clustering and chaining) for the first and the second option over 100 rounds. Figures 3 and 4 show the progression of the number of dead nodes over 100 rounds for the two options. According to preliminary experiments, we can conclude that the FA with randomization term averagely gives the best solutions with comparison to the FA without randomization term. This result was expected because the FA with randomization term can escape from local optima in search of global optimum, while the FA without randomization term can easily fall into local optima.

5. Conclusion and perspectives

In this work, we presented a new algorithm to extend the life time of heterogeneous WSNs with fixed base station by minimizing the communication energy consumption. The proposed algorithm takes advantage of both clustering and chaining approaches and applies two optimization metaheuristics that are firefly and simulated annealing. Our first experimentation show that our algorithm works well, however in order to confirm this statement, we have to do more tests. As short term perspectives, we plan to execute our algorithm on other more complex examples, compare our results with existing algorithms, and target a WSN with mobile nodes/base station.

Table 1. Simulation parameters.

Parameter	value
Nodes number	100
Clusters number	5%
Field dimensions	500 m * 500m
Base station position	250,250
d_0	75 m
E_{elec}	50 nJ/bit
ϵ_{FS}	10 pJ/bit/m ²
ϵ_{TR}	0.0013 pJ/bit/m ⁴
E_{DA}	5nJ/bit
E_{min}	0.1J
S (number of fireflies)	25
β_0	1
α (for FA)	0.6
γ	1
Max generations for FA	100
θ_i	400
θ_f	0
α (for SA)	0.7
L	70
Max iterations (SA)	70
Message size (bits)	2000

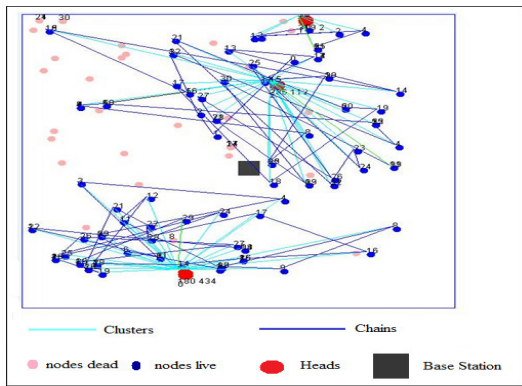


Fig. 1. Result of clustering and chaining.

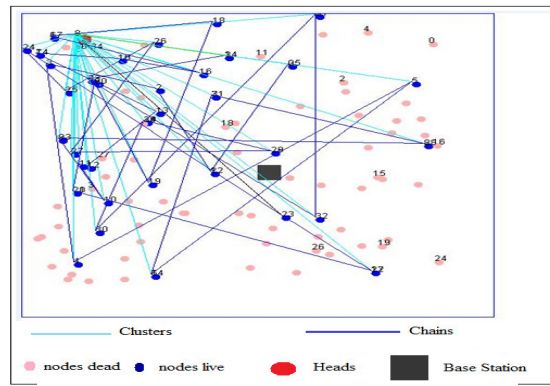


Fig. 2. Result of clustering and chaining.

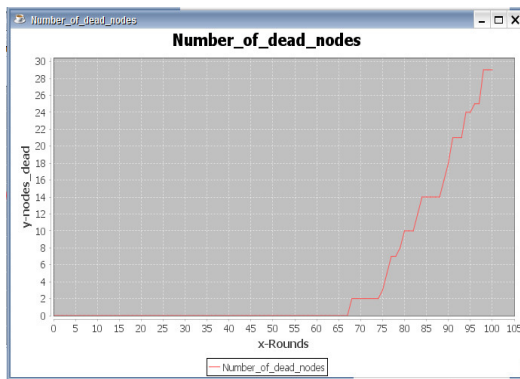


Fig. 3. Number of dead nodes over rounds.

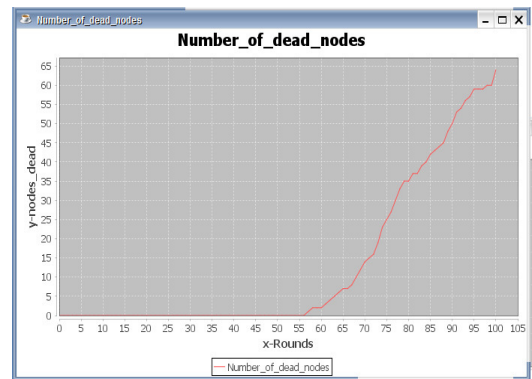


Fig. 4. Number of dead nodes over rounds.

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