Particle Swarm Optimization Compared to Ant Colony Optimization for Routing in Wireless Sensor Networks

Asmae EL Ghazi and Belaïd Ahiod

Abstract Wireless Sensor Networks (WSNs) are an emerging technology that used to monitor various environments. Despite of WSN advantages, it suffers from intrinsic limitations related to communication failures, computational weaknesses and limited energy. Hence, many challenges are considered as NP-hard optimization problems, and resolved by metaheuristics. This paper, proposes a routing approach based on Particle Swarm Optimization (PSO). Compared to the ACO approach, PSO reduces the energy consumption and extends the life of WSN. Through performing many experimentations the PSO efficiency is validated.

Keywords Wireless sensor network · Metaheuristic · Routing · Ant colony optimization · Particle swarm optimization

1 Introduction

Wireless Sensor Network (WSN) is a new technology receiving increased interest. It's composed of sensors working in uncontrolled areas [1]. There are different kinds of sensor node according to physical parameters (temperature, humidity, pressure, …) [2]. Thus, WSN is used for many applications such as disaster relief, environmental control, precision agriculture, medicine and health care [3]. Nonetheless there are some intrinsic limitations for sensors like low processing capacity and low power [4]. Hence, new issues appear in operations research and optimization field [5, 6]. Rather than all problems many researches have tended to focus on routing problems. Routing in WSN is very challenging, as it has more different characteristics than that in traditional communication networks [7]. It's qualified as an NP-hard optimization problem [5]. That means we need robust and efficient techniques to solve this kind of problems, such as metaheuristics [8].

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A. El Oualkadi et al. (eds.), *Proceedings of the Mediterranean Conference on Information & Communication Technologies 2015*, Lecture Notes in Electrical Engineering 381, DOI 10.1007/978-3-319-30298-0_23

Many metaheuristics, such as Genetic Algorithms (GA) [9], Artificial Bee Colony (ABC) [10], Particle Swarm Optimization (PSO) [11] and Ant Colony Optimization (ACO) [12] are used to solve routing problems [13]. The ACO metaheuristic has been successfully applied to solve routing problem in WSN [12, 14, 15]. Recently, also PSO becomes more used due to its performance.

We propose a new approach based on PSO for routing problem in WSN. The proposed approach gives better results compared to our advanced ACO [15].

The remaining of this paper is organized as follows: Sect. 2 gives the WSN routing problem and ACO. Section 3 introduces Particle Swarm Optimization (PSO). Section 4 presents our PSO-based algorithm for the routing problem. Section 5 shows the performance evaluation of our results. Finally, Sect. 6 concludes our work.

2 Ant Colony Optimization and Routing in Wireless Sensor Networks

Inspired from Ant behavior, M. Dorigo and G. Di Caro have developed in 1999 ant colony optimization algorithms [16]. Ants are insects that have a very high capacity to explore and exploit their environment despite their displacement way which is very limited (walking) compared to other species (flying). This moving inconvenience is offset by skills in manipulating and using environment. They use their environment as a medium of storage, processing and sharing information between all the ants in the colony. ACO basic steps are summarized in the Algorithm 1 [17].

Algorithm 1 ACO

Objective function $f(x_{ij})$, $(i, j) \in \{1, 2, ..., n\}$
Initialize the pheromone evaporation rate ρ
while (criterion) **do**
  for *Loop over* n *nodes* **do**
    Generate the new solutions (*using probabilistic rule* [15])
    Evaluate new solutions
    Mark the best routes with the pheromone $\delta\tau_{ij}$
    Update Pheromone : $\tau_{ij} \leftarrow (1 - \rho)\tau_{ij} + \delta\tau_{ij}$
  end for
  Daemon actions
end while
Output the best results and pheromone distribution.

In our paper "Improved Ant Colony Optimization Routing Protocol for Wireless Sensor Networks" [15], we propose a routing protocol ranked among flat networks. The purpose is to find the optimal path, with minimal energy consumption and reliable links.

After detecting an event, source node splits data to N parts. Each part is transmitted by an ant. Ant used the probabilistic decisions' rule, to travel between nodes from source until sink.

This approach gives good results, comparing to routing protocol EEABR and original ACO approach [14]. However, the novel optimization technique based on PSO, promises better performances.

3 Particle Swarm Optimization

Particle swarm optimization (PSO) [18] is originally attributed to Kennedy, Eberhart [19]. It is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality. PSO optimizes a problem by having a population of candidate solutions, here dubbed particles, and moving these particles around in the search-space according to simple mathematical formulae over the particle's position and velocity (Eq. 1).

$$\upsilon_{i+1} = \omega\upsilon_i + \eta_1 rand()(Pbesti - x_i) + \eta_2 rand()(Gbest - x_i) \tag{1}$$

$$x_{i+1} = x_i + \upsilon_{i+1} \tag{2}$$

where υ_i is the velocity of particle i. x_i is current position of particle i. $Pbesti$ is the best position of particle i and $Gbest$ is the best position of the group.

Each particle's movement is influenced by its local best known position and global best in search-space. This is expected to move the swarm toward the best solutions. The Algorithm 2 describes PSO procedure.

Algorithm 2 PSO

```
A population of particles with random values positions and velocities from D dimensions in the search space
while Termination condition not reached do
  for Each particle i do
    Adapt velocity of the particle using Equation 1
    Update the position of the particle using Equation 2
    Evaluate the fitness f(x_i)
     if f(x_i) < f(Pbesti)
        Pbesti ← x_i
    end if
     if f(x_i) < f(Gbesti)
        Gbesti ← x_i
     end if
  end for
end while
```

4 Routing in WSN and PSO

In [15] we present an improved routing protocol based on ACO where we maximized WSN lifetime and minimized energy consumption of sensors. In this paper we use PSO strategy with the same settings as ACO and we find better results. To search an optimal path from source to destination node, PSO routing approach initialization is needed, as described in [20].

1. *Initialization*:
   Initial paths, are formed by employing two agents; forward and backward [20]. The forward agent moves to determine the next node on the path, creates and maintains the routing table. At the same time, it collects many informations about nodes in the path. Backward agent is created by destination node and moves back from destination to source node.
2. *Optimal path*:
   The initialization of particle swarm (paths) is achieved, it is expressed as $\{x_1, \ldots, x_i, \ldots, x_m\}$. Every path x_i is a potential best routing path. Note that the best x_i as *Pbesti* when x_i modified. The best path in all paths is expressed as *Gbest*. Assume that x_i with k hops consists of a set of nodes $\{n_s, \ldots, n_k \ldots, n_{sink}\}$. In order to find the best path we implement the PSO algorithm. The formula (Eq. 1) is useless in this case. Therefore, as described in [20] some permutations between *Pbesti* and x_i, *Gbesti* and x_i are performed. For a credible comparison, the evaluation of particle is insured by the same metrics used for ACO approach [15].

5 Results

Performing many simulations of both approaches PSO and ACO, using Matlab and same experimentation conditions, we used a model of sensors based on “First Order Radio Model” of Heinzelman et al. [21]. To send and receive a message, power requirements are formulated as follows (Eqs. 3 and 4):

To send k bits to a remote receiver by d meters, transmitter consumes:

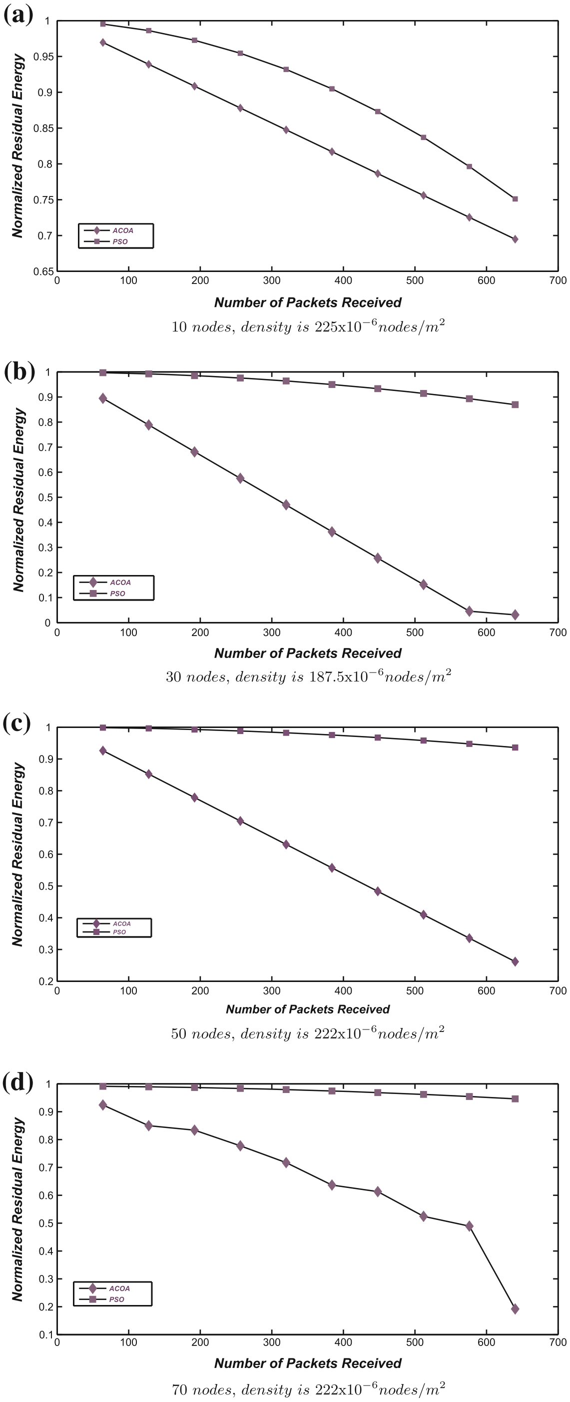
$$E_{Tx}(k, d) = (E_{elec} \times k) + (\epsilon_{amp} \times k \times d^2) \tag{3}$$

To receive k bits, receiver consumes:

$$E_{Rx}(k) = E_{elec} \times k \tag{4}$$

where $E_{elec} = 50\,\text{nJ/bit}$ and $\epsilon_{amp} = 100\,\text{nJ/bit/m}^2$ are respectively energy of electronic transmission and amplification.

Fig. 1 Simulation results for different WSNs. **a** 10 nodes, density is $225 \times 10^{-6}\,\text{nodes/m}^2$, **b** 30 nodes, density is $187:5 \times 10^{-6}\,\text{nodes/m}^2$, **c** 50 nodes, density is $222 \times 10^{-6}\,\text{nodes/m}^2$, **d** 70 nodes, density is $222 \times 10^{-6}\,\text{nodes/m}^2$



(a) 10 *nodes, density is* $225\text{x}10^{-6}$*nodes*$/m^2$

(b) 30 *nodes, density is* $187.5\text{x}10^{-6}$*nodes*$/m^2$

(c) 50 *nodes, density is* $222\text{x}10^{-6}$*nodes*$/m^2$

(d) 70 *nodes, density is* $222\text{x}10^{-6}$*nodes*$/m^2$

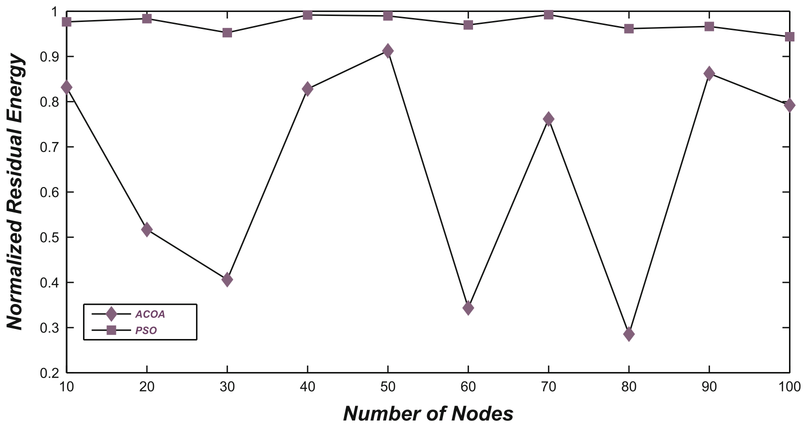


Fig. 2 Residual energy for different WSNs

We prove that the PSO approach is better than the ACO one. By random deployment of different number of nodes in spaces, we simulate data transmission from a source node to known base station. The best approach appears in results presented in Fig. 1.

Figure 1 shows that PSO is higher than ACO by considering the residual energy. Thus, the power consumption is minimized, and the WSN lifetime is maximized.

In order to confirm the efficiency of our proposal, we simulated the transmission of 256 packets in different coverage areas where we deployed randomly a number of nodes (from 10 to 100 nodes). The shown results in Fig. 2 represent the residual energy.

The found results prove the efficiency of PSO for routing problems, in term of energy consumption and wireless sensors network lifetime.

6 Conclusion

This paper presents a routing protocol for WSN achieved by using particle swarm optimization, to optimize the node power consumption and increase network lifetime, while data transmission is attained efficiently. The evaluation of the protocol performance, is implemented in the same conditions. The conclusion is the performance of PSO is better than ACO approach [15], in terms of energy consumption and network lifetime. The future work could be investigate improvement of PSO and propose other comparisons.

References

1. Potdar, V., Sharif, A., Chang, E.: Wireless sensor networks: A survey. In: International Conference on Advanced Information Networking and Applications Workshops. WAINA'09, IEEE, pp. 636–641 (2009)
2. Akyildiz, I.F., Su, W., Sankarasubramaniam, Y., Cayirci, E.: Wireless sensor networks: a survey. Comput. Netw. **38**(4), 393–422 (2002)
3. Xu, N.: A survey of sensor network applications. IEEE Commun. Mag. **40**, 102–114 (2002)
4. Masri, W.: QoS requirements mapping in TDMA-based wireless sensor networks. Ph.D. thesis, Toulouse University III-Paul Sabatier (2009)
5. Gogu, A., Nace, D., Dilo, A., Mertnia, N.: Optimization problems in wireless sensor networks. In: International Conference on Complex, Intelligent and Software Intensive Systems (CISIS), IEEE, pp. 302–309 (2011)
6. Ali, M.K.M., Kamoun, F.: Neural networks for shortest path computation and routing in computer networks. IEEE Trans. Neural Netw. **4**, 941–954 (1993)
7. Al-Karaki, J.N., Kamal, A.E.: Routing techniques in wireless sensor networks: a survey. Wireless Commun. **11**(6), 6–28 (2004)
8. Blum, C., Roli, A.: Metaheuristics in combinatorial optimization: overview and conceptual comparison. ACM Comput. Surv. (CSUR) **35**, 268–308 (2003)
9. Hussain, S., Matin, A.W., Islam, O.: Genetic algorithm for energy efficient clusters in wireless sensor networks. In: ITNG, pp. 147–154 (2007)
10. Saleh, S., Ahmed, M., Ali, B.M., Rasid, M.F.A., Ismail, A.: A survey on energy awareness mechanisms in routing protocols for wireless sensor networks using optimization methods. In: Transactions on Emerging Telecommunications Technologies (2013)
11. Kulkarni, R.V., Venayagamoorthy, G.K.: Particle swarm optimization in wireless-sensor networks: a brief survey. Syst. Man. Cybernet. Part C: Appl. Rev. IEEE Trans. **41**(2), 262–267 (2011)
12. Fathima, K., Sindhanaiselvan, K.: Ant colony optimization based routing in wireless sensor networks. Int. J. Adv. Netw. Appl. **4**(4) (2013)
13. Iyengar, S.S., Wu, H.C., Balakrishnan, N., Chang, S.Y.: Biologically inspired cooperative routing for wireless mobile sensor networks. Syst. J. IEEE **1**(1), 29–37 (2007)
14. Okdem, S., Karaboga, D.: Routing in wireless sensor networks using an ant colony optimization (aco) router chip. Sensors **9**, 909–921 (2009)
15. El Ghazi, A., Ahiod, B., Ouaarab, A.: Improved ant colony optimization routing protocol for wireless sensor networks. In: Networked Systems, pp. 246–256. Springer (2014)
16. Dorigo, M., Di Caro, G.: Ant colony optimization: a new metaheuristic. In: Proceedings of the 1999 Congress on Evolutionary Computation CEC 99, IEEE (1999), pp. 1–8
17. Yang, X.S.: Engineering Optimization: An Introduction with Metaheuristic Applications. Wiley (2010)
18. Tillett, J., Rao, R., Sahin, F.: Cluster-head identification in ad hoc sensor networks using particle swarm optimization. In: IEEE International Conference on Personal Wireless Communications, 2002, IEEE (2002), pp. 201–205
19. Eberhart, R.C., Kennedy, J.: A new optimizer using particle swarm theory. In: Proceedings of the Sixth International Symposium on Micro Machine and Human Science, vol. 1, New York, NY, pp. 39–43 (1995)
20. Zhang, X.H., Xu, W.B.: Qos based routing in wireless sensor network with particle swarm optimization. In: Agent Computing and Multi-Agent Systems, pp. 602–607. Springer (2006)
21. Heinzelman, W.R., Chandrakasan, A., Balakrishnan, H.: Energy-efficient communication protocol for wireless microsensor networks. In: Proceedings of the 33rd Annual Hawaii International Conference on System Sciences, IEEE, pp. 1–10 (2000)