A Hybrid Cluster and Chain-based Routing Protocol for Lifetime Improvement in WSN

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Abstract. The main challenge in the field of Wireless Sensor Networks (WSNs) is the energy conservation as long as possible. Clustering paradigm has proven its ability to prolong the network lifetime. The present paper proposes two algorithms using an approach that combines fuzzy c-means and ant colony optimization to form the clusters and manage the transmission of data in the network. First, fuzzy c-means is used to construct a predefined number of clusters. Second, we apply Ant Colony Optimization (ACO) algorithm to form a local shortest chain in each cluster. A leader node is randomly chosen at the beginning since all cluster nodes have the same amount of energy. In the next transmission, a remaining energy parameter is employed to select leader node. In the first algorithm, leader nodes transmit data in single hop to the distant base station (BS) while in the second the ACO algorithm is applied again to form a global chain between leader nodes and the BS. Simulation results show that the second proposed algorithm consumes less energy and effectively prolongs the network lifetime compared respectively with the first proposed and the LEACH algorithms. *abstract* environment.

Keywords: Wireless sensor network; fuzzy c-means; clustering; ant colony optimization; network lifetime.

1 Introduction

The progress made in recent decades in the fields of microelectronics, micromechanics, and wireless communication technologies, have produced at a reasonable cost components in volume of a few cubic millimeters, called sensor nodes. A sensor node is typically equipped with a sensing subsystem, a processing subsystem, a radio subsystem and a power supply subsystem [1]. Standalone deployment of several of them, to collect and transmit environmental data to one or more collection points form a wireless sensor networks (WSNs). Sensor networks can be very useful in many applications when it comes to collecting and processing information from the environment. Among the areas where these networks can offer the best contributions we quote the following areas: military, environmental, home, health, safety, etc.

The constraints imposed by these networks are very well known: very limited computation, communication, storage capabilities, and energy resources. This last aspect, which limits the lifetime of the network and therefore its utility, has received considerable attention by the research community over the last several years. The design of energy-aware protocols, algorithms, and mechanisms, with the goal of saving as much energy as possible, and therefore extending the lifetime of the network, has been the topic of many research studies [3]. Since communication task consumes the most energy during the network operation, clustering is introduced to WSNs because it has proven to be an effective approach to provide better data aggregation and avoid longest link. Clustering consists to breakdown network into groups of entities called clusters by giving to network a hierarchical structure [2]. A cluster is composed of cluster-head and member nodes. Choosing cluster centers is a crucial to clustering. One of the most used approaches in this regard is Fuzzy C-Means (FCM), which assists to optimize the clusters based on minimizing the distance between the sensor node and the cluster center [4]. In addition to cluster-based protocols, chain-based protocols reduce against the total energy of the network [5–10]. An ant colony optimization (ACO) algorithm can be used to form a chain between multiple nodes [11]. As the energy is inversely proportional to the distance, the construction of short-chain is highly recommended while the ACO algorithm be the best suited for this kind of problem. In this paper in order to enhance network lifetime, we combine the above two approaches, cluster-based and chain-based, for routing data to the BS. We propose two protocols where the second protocol is an improvement of the first one. The rest of this paper is organized as follows: section II introduces related works. Section III describes the proposed protocols. The simulation is then analyzed in Section IV in order to validate our approaches and this paper is concluded in Section V.

2 Related work

One of the fundamental problems in WSNs is how to prolong the network lifetime. In order to achieve this, many researchers proceed in grouping sensor nodes into clusters. Clustering routing protocols have been developed in order to reduce the network traffic toward the BS [12–19]. Low-Energy Adaptive Clustering Hierarchy (LEACH) [16] is one of the most common cluster routing protocols, which aims to achieve the load balancing in sensor nodes so it can prolong the network lifetime. Each sensor node elects itself as a cluster-head based on the probability model. Each sensor node will become cluster-head in every cycle to evenly distribute the works load. Hybrid Energy- Efficient Distributed (HEED) [19] clustering approach is one of the most recognized energy-efficient clustering protocols. It extends the basic scheme of LEACH by using residual energy and node degree or density. In HEED, the clustering process is divided into a number of iterations, and a node is selected as a cluster head depending on whether other cluster heads are its one hop neighbors and its own residual energy. Hoang et al in [4] proposed an approach based on fuzzy cmeans for clustering calculation, cluster head selection and data transmission.

Another family of solutions is chain-based protocols [5–10]. In this category, PEGASIS [5] was the first protocol. It forms a chain including all nodes in the network using a greedy algorithm so that each node transmits to and receives from a neighboring node. In each round, nodes take turns to be leader and transmit the aggregated data to the base station. Kemei Du et al. proposed a multiple-chain scheme [10] to decrease the total transmission distance for all-to-all broadcasting in order to prolong network lifetime. The key idea is to divide the whole network into four regions centered at the node that is closest to the center of the network. Also, the linear sub-chains in each region are constructed by minimum total energy algorithm.

3 Proposed algorithms

Before explaining the proposed approaches, we briefly introduce the principle of the cluster formation using fuzzy cmeans algorithm and the formation of the chains using ant colony optimization algorithm.

3.1 Cluster formation using Fuzzy C-Means algorithm

Fuzzy C-Means (FCM) is an unsupervised fuzzy classification algorithm. It introduces the concept of fuzzy set in the definition of clusters: each node in the deployed area belongs to each cluster with a certain degree, and all clusters are characterized by their center of gravity.

Like other non-supervised classification algorithms, it uses a criterion of minimizing intra-cluster distances and maximizing inter-cluster distances, but giving a degree of belonging to each cluster for each node. This algorithm requires prior knowledge of the number of clusters and generates clusters through an iterative process by minimizing an objective function. Thus, it provides a fuzzy partition of the environment by giving each node a degree between 0 and 1 in a given cluster. The cluster, which is associated with a node, is one whose degree of membership is the highest. FCM is based on minimizing the following objective function [20]:

$$J_m = \sum_{i=1}^{c} \sum_{j=1}^{N} \mu_{ij}^m . d_{ij}^2 \tag{1}$$

Where m is any real number greater than 1, μ_{ij} is node j's degree of belonging to cluster i, c is the number of clusters, N is the number of nodes and d_{ij} is the Euclidean distance between node j and the center of cluster i.

The algorithm is composed of the following steps:

1. Fix an arbitrary membership matrix.

2. Compute the centers of the clusters using the following equation:

$$z_j = \frac{\sum_{i=1}^{N} \mu_{ij}^{m} . o_i}{\sum_{i=1}^{N} \mu_{ij}^{m}} \tag{2}$$

3. The readjustment of the membership matrix according to the position of the centers is done according to the equation below:

$$\mu_{ij} = \frac{1}{\sum_{k=1}^{c} \left(\frac{d_{ij}}{d_{kj}} \right)^{\frac{2}{m-1}}} \tag{3}$$

4. Computes the minimization and return to step 2 if there is no convergence criterion.

3.2 Chains formation using ant colony algorithm

The basic idea in ant colony optimization algorithms (ACO) is to imitate the cooperative behavior of real ants to solve optimization problems. ACO metaheuristics have been proposed by M. Dorigo [21]. They can be seen as multiagent systems in which each single agent is inspired by the behavior of a real ant. Traditionally, ACO have been applied to combinatorial optimization problems and they have achieved widespread success in solving different problems (e.g., scheduling, routing, assignment) [**?**].

To construct a local chain in each cluster, we use the ant colony algorithm. The idea is borrowed from the Traveling Salesman Problem (TSP) [22] where a shortest open chain is constructed in each cluster using the ant colony algorithm. Initially, each ant is randomly put on a node. During the construction of a feasible solution, ants select the following node to be visited through a probabilistic decision rule. When an ant k states in node i and constructs the partial solution, the probability moving to the next node j neighboring on node i is given by:

$$p_{ij}^{k}(t) = \begin{cases} \frac{\tau_{ij}(t)^{\alpha} . \eta_{ij}^{\beta}}{\sum_{l \in J_i^k} \tau_{il}(t)^{\alpha} . \eta_{il}^{\beta}} \; if \; j \in J_i^k \\ 0 \; otherwise \end{cases} \tag{4}$$

Where J_i^k is the list of possible moves for an ant k when it is on a node i, η_{ij} is the visibility which is equal to the inverse of the distance between two nodes i and j $(1/d_{ij})$ and $\tau_{ij}(t)$ is the intensity of the runway at a given iteration t. The two main parameters controlling the algorithm are α and β which controls the relative intensity and the visibility of an edge.
Once the tour nodes performed, an ant k deposits a quantity of pheromone $\Delta\tau_{ij}$ on each edge of the course:

$$\Delta\tau_{ij}^{k}(t) = \begin{cases} \frac{Q}{L^k(t)} \; if \; (i,j) \in T^k(t) \\ 0 \quad otherwise \end{cases} \tag{5}$$

Where $T^k(t)$ is the tour done by ant k at iteration t, $L^k(t)$ the length of the path and a Q parameter setting.
At the end of each iteration of the algorithm, the pheromone deposited at previous iterations by ants evaporate from:

$$\rho \Delta\tau_{ij}^{k} \tag{6}$$

And at the end of the iteration, we have the sum of pheromones that have not evaporated and those who have just been laid.

$$\tau_{ij}(t+1) = (1-\rho).\tau_{ij}(t) + \sum_{k=1}^{m} \Delta\tau_{ij}^{k} \tag{7}$$

Where m is the number of ants and ρ is an adjustment parameter.

At the end, when all tours are completed, we remove in each chain the longest distance between two nodes in order to obtain a shortest open chain.

3.3 Description of the proposed algorithms

n the present work, we combine different tools to deal with the problem of energy conservation in the field of WSNs. We propose two algorithms where we first applied FCM algorithm to form a predefined number of clusters. The number of clusters is chosen equal to square root of the total nodes. Second, an ACO algorithm is used to construct a local chain in each cluster. Figure 1 shows an example of cluster containing eight nodes interconnected to form a closed chain. This chain is obtained using the ant colony optimization algorithm as used in TSP. Then, we remove the longest distance between two consecutive nodes in order to obtain the shortest open chain. In Figure 2, the line between node 1 and node 8 is deleted. For routing data from nodes to the BS, we proceed as follows: At the beginning, a randomly node elects itself a leader node since all cluster nodes have the same amount of energy. For data gathering and fusion, each cluster member node senses and transfers data along the local chain to reach one particular node, which is leader node; the latter receives and aggregates data. When a node dies in a local chain, this latter is reconstructed by bypassing the dead node. The data transmission mode to the BS constitutes the difference between the two proposed approaches. In the first, the leader nodes send data directly to the BS meaning in one hop while in the second data transmission is performed in multiple hops by forming a global chain connecting all the leader nodes using again the ACO algorithm. Leader node rotation in each cluster is performed according to the remaining energy of nodes. The proposed algorithms are centralized controlled by the BS. Figure 3 and 4 illustrate the operating principles of our algorithms where the red lines represent the shortest chain that links nodes in each cluster while the blue dashed lines join the leader nodes and the BS respectively in single hop and multi-hop.

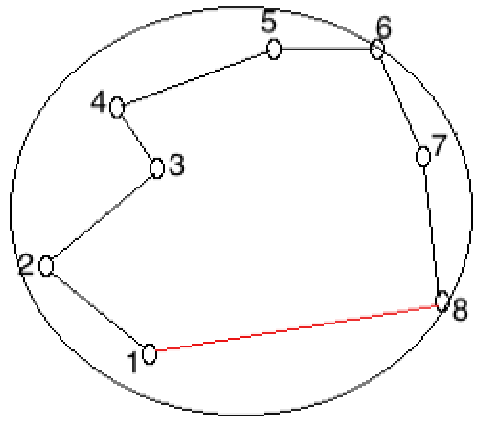

Fig. 1. Formation of closed chain.

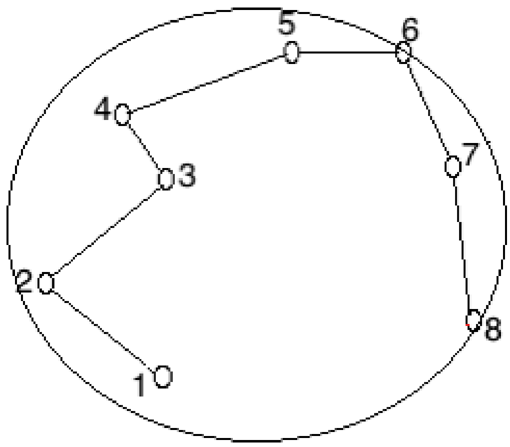

Fig. 2. Formation of the open chain.

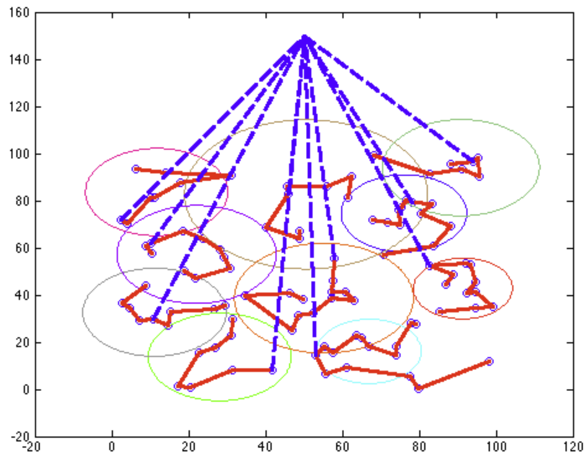

Fig. 3. Operating principle of the first algorithm.

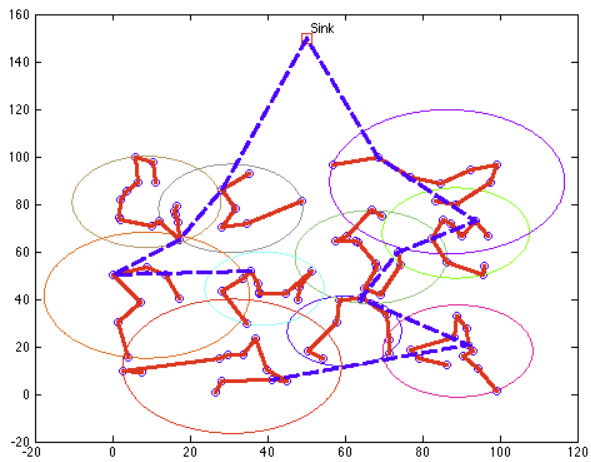

Fig. 4. Operating principle of the second algorithm.

4 Simulation and evaluation

In this section, we evaluate the performance of our proposed algorithms in Matlab. We consider 100 nodes randomly deployed in an area of $(100 \times 100)\, m^2$, the BS is located outside the area at the coordinate $(50, 150)$ so it is at least $50m$ from the closest sensor node. The following properties are assumed in regard to the sensor network being studied:

- The nodes are homogeneous and they are static.
- All the nodes have the same initial energy and the BS is not limited in terms of energy, memory and computational power.
- Links are symmetric so that the energy required to transmit a message from node i to node j is the same as energy required to transmit a message from node j to node i.

In the simulation part, we use the same radio model as introduced in [**?**] which is the first order radio model. This radio model uses both of the open space (energy dissipation d^2) and multi path (energy dissipation d^4) channels by taking amount the distance between the transmitter and receiver. So energy consumption for transmitting a packet of l bits in distance d is given by (8).

$$E_{TX}(l,d) = \begin{cases} l.E_{elec} + l.E_{fs}.d^2 \text{ i}f \quad d < d_0 \\ l.E_{elec} + l.E_{mp}.d^4 \text{ i}f \quad d \geq d_0 \end{cases} \tag{8}$$

Where d_0 is the distance threshold value, which is obtained by (9), E_{elec} is required energy for activating the electronic circuits. E_{fs} and E_{mp} are required energy for amplification of transmitted signals to transmit a one bit in open space and multi path models, respectively.

$$d_0 = \sqrt{\frac{E_{fs}}{E_{mp}}} \tag{9}$$

Energy consumption to receive a packet of l bits is calculated according to (10).

$$E_{RX}(l) = l.E_{elec} \tag{10}$$

The full simulation parameters are listed in table 1. where E_{DA} represents the energy required for data aggregation.

Two metrics are chosen in order to evaluate the proposed schemes, which are energy consumption and the number of alive nodes. Figure 5 illustrates the residual energy in the network for the three algorithms.

From the simulation results shown in figure 6, it was observed that the *proposed*2 algorithm consumes less energy than the *proposed*1. This is due to the presence of global chain, which reduces the long transmission from leader nodes to the remote BS. We see again that *proposed*1 is a few better than LEACH in term of energy consumption.

Figure 7 shows the evolution of the number of alive nodes per the number of rounds. We observe that the first node dies in LEACH after 653 rounds while in

Table 1. Simulation parameters

Parameters	Values
Network size	(100 x 100) m^2
Number of nodes	100
Initial energy	0.1 J
Packet size	1000 bits
E_{elec}	50 x 10^{-9}
E_{fs}	10^{-11}
E_{mp}	1.3 x 10^{-15}
E_{DA}	5 x 10^{-9}

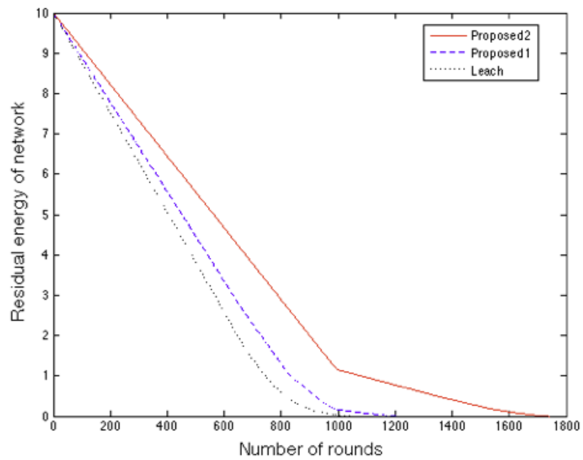

Fig. 5. Residual energy of the network vs. number of rounds.

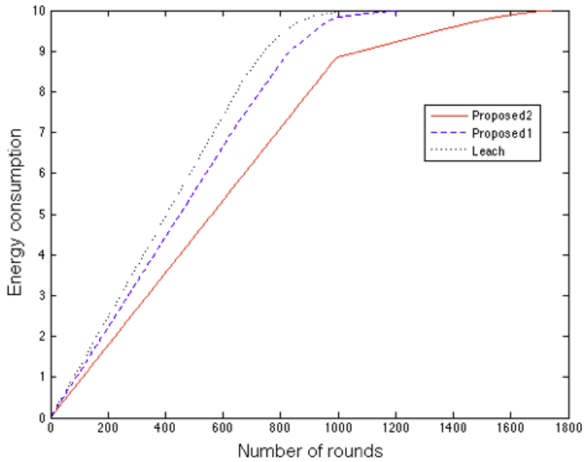

Fig. 6. Energy consumption vs. number of rounds.

*proposed*1 and *proposed*2 first node dies after 654 and 964 rounds respectively. We also observe that the last node dies in LEACH after 1046 rounds while in *proposed*1 and *proposed*2 first node dies after 1213 and 1740 rounds respectively. Therefore, we note that *proposed*2 is about 30.28% more efficient in term of network lifetime than *proposed*1 and about 39.88% than the LEACH algorithm.

5 Conclusion

In this paper, we introduced two algorithms to address the problem of energy conservation in wireless sensor networks combining cluster-based and chain-based approaches. These algorithms are characterized by partitioning nodes in a predefined number of clusters using FCM and formation of local chain in each cluster. Inter-cluster communication is performed by chain-based approach using an ACO algorithm to find the shortest chain that links all cluster member nodes. The difference between the two proposed algorithms lies in the data transmission mode to the remote BS. The first uses direct transmission from leader nodes to the BS while the second constructs a global chain connecting the leader nodes and the BS. Also, these algorithms select leader node for each chain according to the remaining energy of nodes. Simulation results show that *proposed*2 prolong the network lifetime about 30.28% and 39.88% in comparison with the *proposed*1 and LEACH.

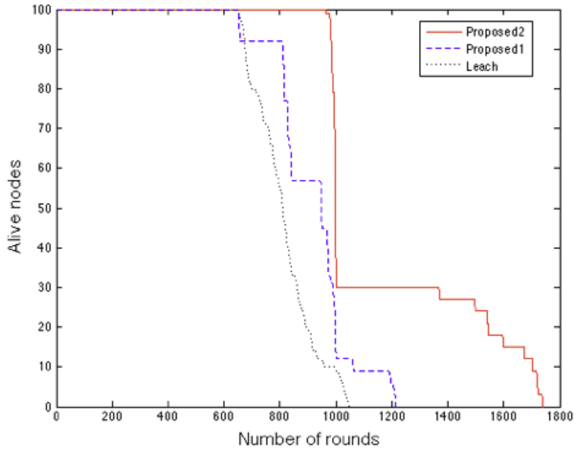

Fig. 7. Number of alive nodes vs. number of rounds.

References

1. Anastasi, G., Conti, M., Di Francesco, M. Passarella, A.: Energy Conservation in Wireless Sensor Networks: A survey. Ad Hoc Networks. 7, 537–568 (2009)
2. Wightmanl, P. M., Labrador, M. A.: Topology Maintenance : Extending the Lifetime of Wireless Sensor Networks. In: IEEE Latin-American Conference on Communications, pp.1–6, IEEE, (2009)
3. Johnen, C., Nguyen, H.: Self-stabilizing weight-based clustering algorithm for ad hoc sensor networks. In Algorithmic Aspects of Wireless Sensor Networks, pp.83–94, Springer (2006)
4. Hoang, D.C., Kumar, R., Panda, S.K.: Fuzzy C-Means Clustering Protocol for Wireless Sensor Networks. In: IEEE International Symposium on Industrial Electronics (ISIE), pp. 3477–3482. (2010)
5. Lindsey, S., Raghavendra, C.: PEGASIS: Power-efficient gathering in sensor information systems. In: IEEE Aerospace conference proceedings, pp. 1125–1130. (2002)
6. Yu, Y., Song, Y.: An Energy-Efficient Chain-Based Routing Protocol in Wireless Sensor Network. In: nternational Conference on Computer Application and System Modeling (ICCASM), pp. 486–489. IEEE, (2010)
7. Guo, W., Zhang, W., Lu, G.: PEGASIS protocol in wireless sensor network based on an improved ant colony algorithm. In: Second International Workshop on Education Technology and Computer Science (ETCS), pp. 64–67. IEEE, (2010)
8. Chen, Y., Lin, J., Huang, Y., Cheung, F., Lin, J.: Energy efficiency of a chain-based scheme with Intra-Grid in wireless sensor networks. In: International Symposium on Computer Communication Control and Automation (3CA), pp. 484–487. IEEE, (2010)
9. Linping, W., Wu, B., Zhen, C., Zufeng, W.: Improved algorithm of PEGASIS protocol introducing double cluster heads in wireless sensor network. In: International Conference on Computer, Mechatronics, Control and Electronic Engineering (CMCE), pp. 148–151. IEEE, (2010)

10. Du, K., Wu, J. Zhou, D.: Chain-based protocols for data broadcasting and gathering in the sensor networks. In: International Parallel and Distributed Processing Symposium, pp. 1926–1933. IEEE, (2003)
11. Wen, Y., Chen, Y., Qian, D.: An Ant-based approach to Power-Efficient Algorithm for Wireless Sensor Networks. In: World Congress on Engineering, pp. 1546–1550. (2007)
12. Bandyopadhyay, S. Coyle, E. J.: An energy efficient hierarchical clustering algorithm for wireless sensor networks. In: Twenty-Second Annual Joint Conference of the IEEE Computer and Communications. IEEE Societies, pp. 1713–1723. (2003)
13. Banerjee, S. Khuller, S.: A clustering scheme for hierarchical control in multi-hop wireless networks. In: Twentieth Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings, pp. 1028–1037. IEEE, (2001)
14. Boukerche, A., Werner Nelem Pazzi, R., Borges Araujo, R.: Fault-tolerant wireless sensor network routing protocols for the supervision of context-aware physical environments. Journal of Parallel and Distributed Computing. 4, 586–599, (2006)
15. Boukerche, A., Martirosyan, A.: An energy-aware and fault tolerant inter-cluster communication based protocol for wireless sensor networks. In: IEEE Global Telecommunications Conference, 2007. GLOBECOM'07., pp. 1164–1168. IEEE (2007)
16. Heinzelman, W., Chandrakasan, A., Balakrishnan, H.: Energy-efficient communication protocol for wireless microsensor networks. In: Proceedings of the 33rd Annual Hawaii International Conference on System Sciences, pp. 3005–3014. IEEE (2001)
17. Manjeshwar, A., Agrawal, D.P.: TEEN: A Routing Protocol for Enhanced Efficiency in Wireless Sensor Networks. In: Proceedings of 15th International Parallel and Distributed Processing Symposium (IPDPS), pp. 2009-2015, IEEE, San Francisco (2001)
18. Manjeshwar, A., Agrawal, D.P.: APTEEN: A Hybrid Protocol for Efficient Routing and Comprehensive Information Retrieval in Wireless Sensor Networks. In: 2nd International Workshop on Parallel and Distributed Computing Issues in Wireless Networks and Mobile Computing, pp.195–202. (2002)
19. Younis, O. Fahmy, S.: HEED: a hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks. In: EEE Transactions on Mobile Computing, pp.1366–379. IEEE (2004)
20. Izakian, H., Abraham, A., Snasel, V.: Fuzzy clustering using hybrid fuzzy c-means and fuzzy particle swarm optimization. In: World Congress on Nature & Biologically Inspired Computing, pp.1690–1694. IEEE (2009)
21. Dorigo, M., Blum, C.: Ant colony optimization theory: A survey. Theoretical computer science. 344, 243–278 (2005)
22. Dorigo, M., Stutzle, T.: The ant colony optimization metaheuristic: Algorithms, applications, and advances. Handbook of metaheuristics. 250–285 (2003)
23. Dorigo, M., Gambardella, L.M.: Ant colonies for the travelling salesman problem. BioSystems. 43, 73–81 (1997)