International Journal of Future Generation Communication and Networking
Vol. 5, No. 4, December, 2012

An Density-based Energy-efficient Routing Algorithm in Wireless Sensor Networks Using Game Theory

Zhanyang Xu[1,2], Yue Yin[2] and Jin Wang[2]

[1]*Institute of Information Network Technology, Nanjing University of Posts and Telecommunications, Nanjing 210003, China*

[2]*School of Computer and Software, Nanjing University of Information Science & Technology, Nanjing 210044, China*

Abstract

Clustering is an efficient technique that is widely adopted in wireless sensor networks. It divides network into clusters and let cluster heads be responsible for forwarding aggregated data to the sink. With energy efficiency in account, the conflict between an individual node and the entire network remains to be solved. In this paper, we propose a Density-based Energy-efficient Game-theoretic Routing Algorithm (DEGRA). As a clustering algorithm, DEGRA adopts game theory and set a utility function based on the nodes' density, residual energy and average energy consumption of its neighboring nodes. Cluster heads are iteratively selected. We also design the intra-cluster and multi-hop inter-cluster routing algorithms. Simulation results show that cluster heads are evenly distributed and our proposed routing algorithm do consume much less energy than algorithms such as LEACH and DEER. The network lifetime is also largely prolonged.

Keywords: *wireless sensor networks; clustering; density; game theory; muti-hop*

1. Introduction

Wireless sensor networks (WSNs) [1] consist of hundreds or thousands of sensors that work cooperatively to monitor the environmental conditions of the sensor field. Sensor nodes collect the sensed data and pass it to the sink node. WSNs are featured with large-scale deployment, dynamic topology, self-organization etc., which makes them data-centric and application-oriented. They can monitor wide areas while maintaining high precision. They are becoming increasingly useful in various critical applications, such as military, environmental monitoring, agricultural technology, industrial manufacturing and medical care. The physical world, information field and human society are therefore integrated to some extent.

Routing in WSNs has been the subject of intense research efforts for years. The essence of routing algorithms is to find an optimal path that enables the efficient exchange of information between source nodes and base station, and to ensure correct transmission of data along the path. As the battery, capability of computing, storage and data processing of a sensor are limited, how to reduce the energy consumption while prolonging the network lifetime stays the key problem.

Clustering is an efficient routing method, where the entire network is divided into multiple clusters. Each cluster has one cluster head and it is responsible for data aggregation. Instead of direct communication with the sink, all the member nodes in one cluster send data to the cluster head. In this way, the traffic load can be reduced. It has the advantages of low energy consumption, simple routing scheme and good scalability, and it is especially suitable for WSNs.

In fact, there often meet the conflicts between the interests of one sensor node and the entire network. For an individual of sensor nodes, it would like to send its data directly to the sink node. It is because having cooperation during the routing path not only stands for enjoying other nodes relaying its data, but also includes relaying data without its direct interest for others. It consumes its limited energy and in turn makes its own routing less efficient. On the contrary, taking the entire network into consideration, it is obvious that such direct communication between all sensor nodes and the sink would cause much traffic load, and it leads to anything but energy-efficiency. Moreover, energy consumption of certain sensors near the sink or on critical paths is much faster than other nodes even in some comparably energy-efficient algorithms. Such energy hole problem alleviates the network lifetime. In clustering, the selection of cluster heads is of vital importance.

Game theory [2] is a branch of mathematics that models situations where players (participants in a game) participate in a strategic situation. It mainly studies the conflict and cooperation between intelligent rational decision-makers. In WSNs, sensor nodes can be modeled as game players. Here, game theory can be adopted to balance the interests between the individual and overall, namely between any sensor node and the network as a whole

In this paper, we propose a Density-based Energy-efficient Game-theoretic Routing Algorithm (DEGRA) for WSNs. DEGRA is a hierarchical routing algorithm which adopts clustering and ensures even distribution of cluster heads due to the evaluation of nodes' density. Moreover, the residual energy and average energy consumption of one's neighboring nodes are under consideration. Via selecting relatively powerful cluster heads, DEGRA alleviates the energy hole problem and maximizes the network lifetime. An intra-cluster routing algorithm and a multi-hop inter-cluster routing algorithm are proposed aiming at saving energy consumption.

The rest of the paper is organized as follows. Section 2 introduces some related work. In Section 3, we build a game-theoretic model and discuss the procedure of the cluster head selection. Then we describe the details of its inter-cluster and intra-cluster routing algorithms. Simulation evaluation and performance comparison are given in Section 4 and Section 5 concludes this paper.

2. Related Work

Many energy-efficient routing algorithms have been proposed based on the hierarchical topology.

LEACH [3] is a classical clustering algorithm. In a periodical way, it randomly chooses the cluster heads. It evenly distributes energy consumption of the entire networks to each sensor node, which aims to reduce energy consumption and improve the network lifetime. LEACH is simple, however, it has some deficiencies: First and foremost, it does not guarantee about even distribution of cluster heads over the network. Some very big clusters and very small clusters may exist in the network at the same time. Second, cluster head selection is unreasonable in heterogeneous networks where nodes have different energy. Third, in this protocol it is assumed that each cluster head transmits data to base station over a single hop, which may consume much energy.

Besides LEACH, PEGASIS [4] is a chain-based protocol. Each node communicates only with a close neighbor and takes turns to transmit data to the sink. In HEED [5], cluster heads are decided based on the average minimum reachability power. Unequal clustering algorithms like [6] aim to solute the energy hole problem. For the clusters, the closer they are to the sink, the smaller size they are formed. It saves energy for the inter-cluster communications. However, too many clusters around the sink will produce a large number of summary packets that leads to heavy traffic load.

Appropriate cluster-head election is an essential consideration and nodes' location and connectivity have been primarily focused. NECHS [7] uses fuzzy logic technique considering two factors: neighbor nodes and remaining energy. Cluster heads elected in [8] are determined to have minimum composite distance of sensors to cluster head and cluster head to base station. In [9], the cluster-head selection depends on remaining energy level of sensor nodes for transmission. H. Munaga, et al. [10] provide the first trajectory based clustering technique for selecting the cluster heads and meanwhile extenuate the energy hole problem. DBCP [11] improves LEACH on the basis of a metric of nodes' relative density.

Game theory in general and mechanism design in particular have been used with great success in analyzing routing algorithms, most of which based on the planner network topology. Ad hoc-VCG [12] pays intermediate nodes a premium, which covers the incurred cost so as to achieve the cost-efficiency and truthfulness. However the message overhead is high. In TEAM [13] message complexity is reduced. Intermediate nodes bid to redirect the path by advertising the aggregate transmission power, the route may not be energy-efficient though. FDG [14] is a game theoretic approach with the probability of strategy selection based on the mixed strategy Nash equilibrium of the game. Comparing to AODV [15], it limits the number of redundant broadcasts in dense networks while still allowing connectivity. VGTR [16] judges the energy consumption of the paths and takes notice of nodes with low remaining energy or high information value. In [17], the distance between nodes, remained energy and load traffic together contribute to the cost of transmission. The algorithm aims to maintain a positive profit of all nodes.

Some routing algorithms adopt game theory on the hierarchical topology. DEER [18] adopts a game-theoretic model with both remained energy and average energy loss on among neighboring nodes under consideration while evaluating the utility function for determining cluster heads. DTTR [19] includes both intra-cluster and inter-cluster routing schemes. With the utilization of multistage finitely repeated games and the link quality indication (LQI) based metric method, the energy consumption is balanced. F. Kazemeyni, et al. [20] combine a modified version of the AODV protocol with coalitional game theory to find the cheapest route in a group with respect to power consumption. How to choose corresponding leaders is not mentioned though. G. Z. Zheng, et al. [21] analyze routing in WSNs based on a Bayesian game. Harsanyi transformation is introduced to form a static game of complete but imperfect information. In [22], the Nash bargaining solution (NBS) is used for analyzing clustering based sensor network.

3. Our Proposed DEGRA Algorithm

3.1. Energy Model

We use the same energy model in [23]. Based on the distance between transmitter and receiver, a free space (d^2 power loss) or multi-path fading (d^4 power loss) channel models are used.

Each sensor node will consume the following E_{Tx} amount of energy to transmit a *l*-bits packet over distance *d,* where the E_{elec} is the energy dissipated per bit to run the transmitter or receiver circuit, ε_{fs} and ε_{mp} represent the transmitter amplifier's efficiency and channel conditions:

$$E_{Tx}(l,d)=\begin{cases} lE_{elec}+l\varepsilon_{fs}d^{2}, d<d_{o} \\ lE_{elec}+l\varepsilon_{mp}d^{4}, d\geq d_{o} \end{cases} \qquad (1)$$

To receive a packet, radio consumes energy

$$E_{Rx}(l)=lE_{elec} \qquad (2)$$

Cluster heads aggregate m l-bits data packets received from its members into a single l-bits fixed packet. With E_{DA} being the data fusion cost of a bit per signal, the energy consumption is calculated as

$$E_{aggr}(m,l)=mlE_{DA} \qquad (3)$$

3.2. Game-theoretic Model

We assume that the network consist of n uniformly dispersed intelligent sensor nodes that are denoted as $\{s_1,s_2,...,s_n\}$. In the game-theoretic model, they are regarded as players, and aim to transmit data to the sink node *BS* which is often far from the sensing field.

We have the following assumptions:

（1）All nodes are homogeneous and stationary after deployment.

（2）Nodes can adjust their transmission power according to the relative distance to receiver

（3）Links are symmetric. A node can compute the approximate distance to another node based on the received signal strength, once the transmitting power is given.

Figure 1 shows the scenario of a uniform dispersion of 100 sensor nodes in a $100\times100m^2$ square region. Without loss of generality, here we assume that the base station is located at the coordination of (-100,-100).

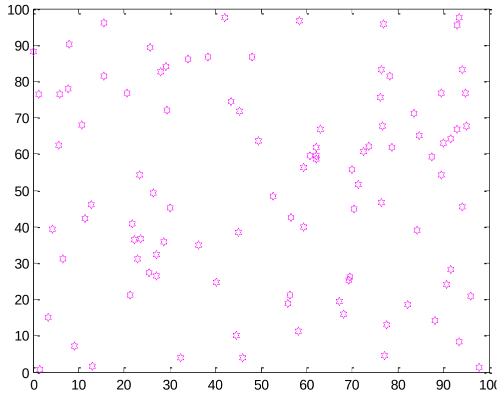

Figure 1. Network Model

Sensor nodes are intelligent and have the rational tendency to pass data with its own interest reliably to the sink. It pays more attention its individual benefit, so it is often reluctant to cooperate with others in transmission even if it may save energy for the entire network. However, in a hierarchical topology, roles of cluster heads are of vital importance. Cluster heads provide service for others and save the energy consumption of the entire network. However, along with its contribution to the network, a cluster head consumes relative large amount of energy and has more risk to run out of resources. Thus as an individual a sensor node tends not to be the cluster head. Such problem in cluster head selection remains to be solved.

We formally define the determination of cluster heads as a game denoted by $G=<N,L,U>$, where N $(|N|=n)$ is the set of players, namely sensor nodes in the network; $L=\{L_i\}$ is the set of available strategies and $U=\{U_i\}$ is the set of utility functions.

In a hierarchical network topology, players participate in a strategic situation of deciding whether to become a cluster head. The strategy set is denoted as $L=\{L_1,L_2,...,L_n\}$. Let “1” be the strategy “become CH” and “0” be the strategy “not become CH”, then we have the strategy space of a node s_i be $L_i=\{1,0\}$, where $L_i=1$ denotes that s_i becomes a cluster head.

In this paper, we assume *n* sensor nodes in a $M\times M$ square region are divided into *k* clusters, with R representing the standard transmission radius for message exchange during the set-up stage of clusters. With the assumption that nodes are uniformly located, we would have:

$$M\times M=k\pi R^2 \Rightarrow R=\frac{M}{\sqrt{\pi k}} \tag{4}$$

Basically, we determine the cluster heads according to the density (denoted as Den) of each node. Here, the metric of density represents the number of nodes located within a circle transmission region of neighboring nodes. With itself as the center and *R* as the radius, the density of node s_i can be calculated via searching the entire network as formula (5), where $d(s_i,s_x)$ represents the distance between s_i and another node s_x.

$$Den(s_i)=\sum_{0<x\le N\ \&\ d(s_i,s_x)\le R} 1 \tag{5}$$

Nodes’ connectivity is under consideration by evaluating *Den*. Thus ensure the even distribution of cluster heads and alleviate energy hole problem. Despite nodes’ connectivity, we also focus on the residual energy and average energy consumption of its neighboring nodes. It is because cluster heads have relative heavy responsibility due to data fusion. More residual energy and less energy consumption along the routing path make the determined cluster heads survive longer lifetime.

In order to encourage a sensor node to become cluster, we provide a proper payoff in returns for its contribution to the entire network. The utility function U for cluster head determination is defined as follows:

$$U_i = \frac{E_{residual}(s_i)}{E_{total\_\cos t}(s_i) / Den(s_i)} \tag{6}$$

Here, $E_{residual}$ denotes the residual energy for one node and $E_{total\_\cos t}$ denotes the total energy consumption of its Den neighboring nodes; $E_{total\_\cos t}(s_i) / Den(s_i)$ represents the average energy consumption among its neighboring node, namely a standard of average cost of energy in its cluster. Therefore, we have sensor nodes with the larger utility functions be the cluster heads in the network. Thus total energy consumption is relative low and the energy hole problem is reduced.

3.3. Cluster Head Selection

Based on the game-theoretic model, the cluster head selection specifically turns into a nodes' decision-making procedure which can be described as:

Step 1:

All sensor nodes calculate its utility value u and broadcast a massage to announce it to others.

Step 2:

If the received node owns a smaller utility value, it broadcasts the original received message; If any received node has a larger utility value, it becomes a new cluster head candidate and broadcasts a new message with its own information instead; Else, nodes with equal utility value compare the ID and assume that node with a smaller ID wins.

Step 3:

Once all sensor nodes have been compared, node with the largest utility value is chosen as one cluster head.

As we aim to find k cluster head, the procedure performs in k rounds iteratively. However, different from DEER, we notice that neighboring nodes of the determined cluster head often have similar density value which is large enough for disturbing the determinations in following rounds. Such neighboring nodes should be excluded.

A selected cluster head broadcast a NEIGHBOR_MSG which contains its ID, a communication radius R_{comm_radius} and other information such as its residual energy. Any node within its communication radius becomes its neighbor and quit the current round of the cluster head selection. Flags are used to ensure all nodes have been studied. Once k cluster heads are all determined, the selection ends. Pseudocode of the procedure is shown in Figure 2.

```
$\mu \leftarrow 0$
$Flag_{\alpha} \leftarrow 0,\ \alpha = 1, 2, ..., n$
while $\mu < k$ do
    if $u_i = mac\{u_{\alpha}\},\ Flag_{\alpha} = 0$ then
        $beClusterHead \leftarrow TRUE$
        $Flag_i = 1$
        broadcast a $NEIGHBOR\_MSG(s_i.ID)$
    end if
    on receiving a $NEIGHBOR\_MSG(s_i.ID)$ for node $s_j$
    if $d(s_i, s_j) \le R_{comm\_radius}$ then
        $Flag_j = 1$
        broadcast a $QUIT\_SELECTION\_MSG(s_j.ID)$ and then EXIT
    end if
    $\mu \leftarrow \mu + 1$
end while
```

Figure 2. Pseudocode of the Cluster Head Selection

We focus on nodes outside the transmission range of the determined cluster heads. Recalculate nodes' density and its corresponding utility function. The rest cluster heads are still determined for the maximum utility value per round, following the procedure described above. It can be deduced that cluster heads are more evenly distributed.

Lemma 1. There is no chance that two nodes are both cluster heads if one is in the other's communication range.

Proof: Suppose sensor node s_i and s_j are both tentative cluster heads. Node s_j locates within the communication range of s_i, which makes it a neighbor of s_i. If s_i first become a cluster head, it will notice its current state to its neighboring nodes, so all nodes in the neighborhood will quit the competition and becomes an ordinary node until a next round of cluster head selection; Vice versa.

The cluster head selection can be regarded as a k-stage dynamic game. Moreover, since every player knows the utilities and strategies available to other players and each choose its strategy based on the observation of previous stages, it is a finite complete and perfect information game [24] for determining the cluster heads. With the maximum utility value chosen, the finite game of complete and perfect information has a pure-strategic Nash equilibrium (every player is playing a best response to the strategy choices of its opponents) for each stage. And all stages constitute a subgame-perfect Nash equilibrium of the dynamic game.

3.4. Routing Procedure

After determining all cluster heads, sensor nodes send data to one cluster head directly within one hop. The corresponding cluster head should be determined with the least energy consumption as the transmission cost along the path. According to formula (1) in the energy model, distance plays a significant role. We can use the distance between nodes rather than precise information to define the energy cost along the path. Therefore the intra-routing algorithm can be formulated as to find:

$$\underset{k}{Min}(d(s_x, CH_k)), \quad x = 1, 2, ..., n \ \& \ s_x \neq CH_k \tag{7}$$

In LEACH, cluster heads send data to the base station directly within one hop. There is high chance that it consumes large energy due to the remote location of some cluster head. In our DEGRA, energy efficiency is one of our top concerns. That is we aim at decreasing the energy cost per packet. Here, we perform a greedy geographic forwarding inter-cluster algorithm.

Suppose cluster head CH_i chooses another cluster head CH_j as its relay node and let CH_j communicate directly with the sink node *BS*. In order to deliver a *l*-length packet to *BS* via CH_j, the energy consumed of CH_i is calculated as formula (8). For simplicity, we assume a free space channel model.

$$\begin{aligned}
&E_{2\_hop}(CH_i, CH_j) \\
&= E_{Tx}(l, d(CH_i, CH_j)) + E_{Rx}(l) + E_{Tx}(l, d(CH_j, BS)) \\
&= l(E_{elec} + \varepsilon_{fs} d^2(CH_i, CH_j)) + lE_{elec} + (lE_{elec} + \varepsilon_{fs} d^2(CH_j, BS)) \\
&= 3lE_{elec} + l\varepsilon_{fs}(d^2(CH_i, CH_j) + d^2(CH_j, BS))
\end{aligned} \tag{8}$$

According to formula (1) and (2), we define

$$E_{relay}(CH_i, CH_j) = d^2(CH_i, CH_j) + d^2(CH_j, BS) \tag{9}$$

The larger E_{relay} is the more energy will be consumed for forwarding collected data to the base station.

For an arbitrary cluster head CH_i, we try to find an optimal relay cluster head which maintains the least energy consumption. Compare it with the direct communication cost to *BS*, which can be defined as E_{direct}

$$E_{direct} = d^2(CH_i, BS) \tag{10}$$

The optimal inter-routing route is determined according to the minimization of energy dissipation. The pseudocode for the inter-clustering algorithm is given in Figure 3

```
while $\forall CH_x \neq CH_i$ is not null do
    compute $E_{relay}(CH_i, CH_x)$
end while
find out $s_j$ that satisfies
$E_{relay}(CH_i, CH_j) = \min\{E_{relay}(CH_i, CH_x)\}$
if $E_{relay}(CH_i, CH_j) < E_{direct}$ then
    the route is $CH_i \rightarrow CH_j \rightarrow BS$
else
    the route is $CH_i \rightarrow BS$
end if
```

Figure 3. Pseudocode of the Inter-clustering Algorithm

4. Performance Evaluation

4.1. Simulation Environment

We evaluate the performance of the DEGRA via simulations in Matlab. The simulation environment is set up with the parameters listed in Table 1.

Table 1. Network Parameters

Parameter Name	Value
Number of the sensor nodes (N)	100
Length of the packet (l)	4000bit
Initial energy of the sensor nodes (E_{init})	0.25J
Energy consumption on circuit (E_{elec})	50nJ/bit
Channel parameter in free-space model (ε_{fs})	10pJ/bit/ m^2
Channel parameter in multi-path model (ε_{mp})	0.0013pJ/bit/ m^4
Energy consumption for data aggregation (E_{DA})	5pJ/bit/signal

4.2. Simulation Results

We set the initial network according to Figure 1. Figure 4 shows the distribution of five cluster heads in LEACH. As it adopts randomization in the selection procedure, there is high chance that some cluster heads locate relatively close to each other. Thus it results in heavy traffic load for remote nodes to transmit data to any cluster head. Differently, with nodes' density under consideration in our DEGRA, cluster heads are distributed much more evenly as is shown in Figure 5.

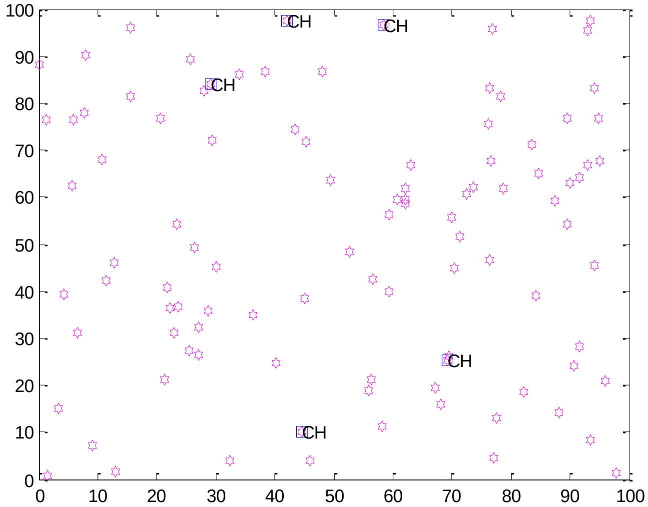

Figure 4. Location of Cluster Heads in LEACH

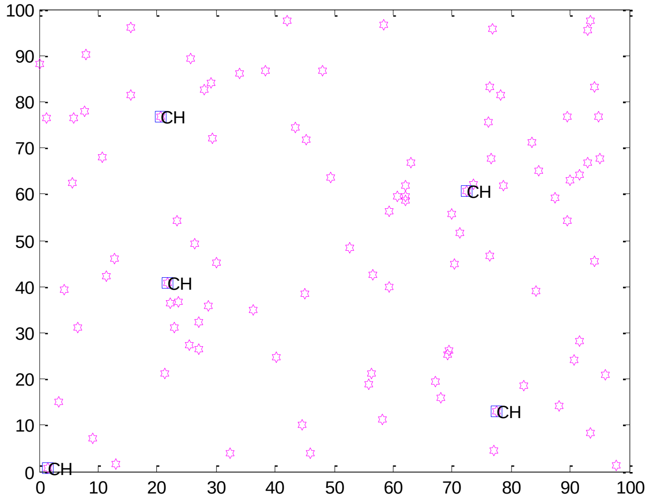

Figure 5. Location of Cluster Heads in DEGRA

We compare the total energy consumption of LEACH, DEER and our DECA, as is shown in Figure 6. During 20 rounds, DEER outperforms LEACH as cluster heads have relative small average energy consumption along the path between itself and its neighboring nodes. In comparison, DEGRA shows much better performance than both LEACH and DEER with less energy consumption. This is mainly because of the energy-efficient cluster head determination and the multi-hop inter-cluster routing that might choose a better path in order to save energy.

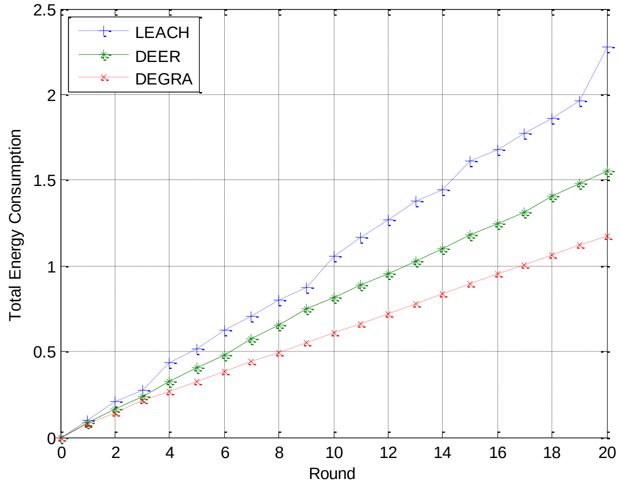

Figure 6. Comparison of Energy Consumption

Moreover, we compare the network lifetime of LEACH, DEER and our DEGRA, as is shown in Figure 7. For LEACH, the first node that becomes invalid appears in 94th round; DEER has the first inactive node in 263rd round. It is due to a more even cluster head distribution. DEGRA shows the best performance as the first node is found in 599th round, which is almost twice larger than the DEER situation. It is mainly because of having a collection of nodes' density, residual energy and average neighboring nodes' energy consumption into consideration, which makes periodically changes for proper cluster heads so as to avoid the energy hole problem

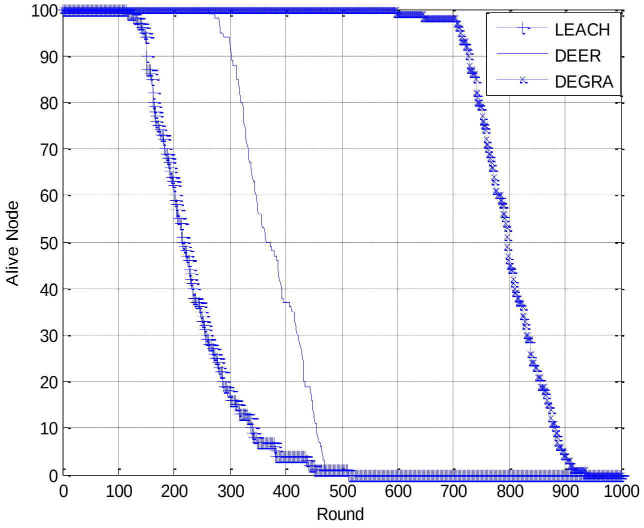

Figure 7. Comparison of Network Lifetime

5. Conclusions

In wireless sensor networks, clustering algorithms are widely used. The selection of cluster heads is one of top concerns. Each sensor node may prefer to transmit data directly to the sink node without having any extra communication with other nodes. However, it results in a conflict between its individual tendency and the efficiency of the entire network. In this paper, we propose a Density-based Energy-efficient Game-theoretic Routing Algorithm (DEGRA) for WSNs. It adopts game theory and aims at solving such conflict between the individual and the network. In our DEGRA, nodes' density, residual energy and average neighboring nodes' energy consumption all contribute to form the utility function. Cluster head selection is implemented iteratively. An intra-cluster and a multi-hop inter-cluster routing algorithm are proposed. Simulations show that both the energy consumption and network lifetime get improved comparing with algorithms as LEACH and DEER.

Acknowledgements

This work was supported by Jiangsu Province Universities Natural Science Research Program (NO.11KJB510010) and Jiangsu Province Research and Innovation Project for College Graduates (NO.CXZZ12_0515). This work was also supported by the Industrial Strategic Technology Development Program (10041740) funded by the Ministry of Knowledge Economy (MKE) Korea and the Natural Science Foundation of Jiangsu Province (No. BK2012461). Professor Zhanyang Xu is the corresponding author.

References

[1] I. Akyildiz and W. Su, Y. Sankarasubramaniam and E. Cayirci, "A Survey on Sensor Networks", IEEE Commun. Mag., vol. 8, **(2002)**, pp. 102.

[2] C. Xu and L. Cao, G. A. Zhang and J. Y. Gu, Editors, "Application Research of Computers", vol. 3, **(2010)**, pp. 816.

[3] W. Heinzelman, A. Chandrakasan and H. Balakrishnan, "Energy-efficient Routing Protocols for Wireless Microsensor Networks", Proceedings of the 33rd Annual Hawaii International Conference of System Sciences, **(2000)** January 4-7; Maui, Hawaii.

[4] S. Lindsey and C. S. Raghavendra, Editors, "PEGASIS: Power-efficient Gathering in Sensor Information Systems", Parallel and Distributed Systems, vol. 9, **(2002)**, pp. 924.

[5] O. Younis and S. Fahmy, Editors, "HEED: A Hybrid, Energy-efficient, Distributed Clustering Approach for Ad Hoc Sensor Networks", Mobile Comput., vol. 3, **(2004)**, pp. 366.

[6] B. S. Lee, H. W. Lin and W. Tarng, "A Cluster Allocation and Routing Algorithm Based on Node Density for Extending the Lifetime of Wireless Sensor Networks", Proceedings of the 26th International Conference on Advanced Information Networking and Applications Workshops (WAINA), **(2012)** March 26-29; Fukuoka, Japan.

[7] Y. Hu and X. R. Shen and Z. H. Kang, "Energy-efficient Cluster Head Selection in Clustering Routing for Wireless Sensor Networks", Proceedings of the 5th International Conference on Wireless Communications, Networking and Mobile Computing **(2009)** September 24-26; Beijing, China.

[8] X. X. Zhang and M. Zhang, Z. C. Zhang, "An Improved WSNs Clustering Routing Algorithm and Its Performance", Science paper Online, vol. 2, **(2010)**, pp. 96.

[9] M. C. M. Thein and T. Thein, "An Energy Efficient Cluster-head Selection for Wireless Sensor Networks", Proceedings of International Conference on Intelligent Systems, Modelling and Simulation (ISMS), **(2010)** January 27-29; Liverpool, United Kingdom.

[10] J. F. Qiao, S. Y. Liu and X. Y. Cao, "Density-based Clustering Protocol for Wireless Sensor Networks", Computer Science, vol. 12, **(2009)**, pp. 46.

[11] N. Xu, A. H. Huang and T. W. Hou, Editors, "Coverage and Connectivity Guaranteed Topology Control Algorithm for Cluster-based Wireless Sensor Networks", Wireless Communications and Mobile Computing, vol. 12, **(2012)**, pp. 23.

[12] L. Anderegg and S. Eidenbanz, "Ad Hoc VCG: A Truthful and Cost-efficient Routing Protocol for Mobile Ad Hoc Networks with Selfish Agents", ACM Press, vol. 245, **(2003)**.

[13] F. J. Cai and U. Pooch, "Play Alone or Together-truthful and Efficient Routing in Wireless Ad Hoc Networks with Selfish Nodes", Proceedings of IEEE International Conference on Mobile Ad-hoc and Sensor Systems, **(2004)** October 25-27; Fort Lauderdale, Florida, USA.

[14] M. Naserian and K. Tepe, "Game Theoretic Approach in Routing Protocol for Wireless Ad Hoc Networks", Ad Hoc Networks, vol. 7, **(2009)**, pp. 569.

[15] C. E. Perkins and E. M. Belding-Royer, "Ad hoc on demand distance vector (AODV) routing", IETF RFC3561.

[16] A. Schillings and K. Yang, "VGTR: A Collaborative, Energy and Information Aware Routing Algorithm for Wireless Sensor Networks Through the Use of Game Theory", Lecture Notes in Computer Science, vol. 5659, **(2009)**, pp. 51.

[17] B. Arisian and K. Eshghi, "A game theory approach for optimal routing in wireless sensor networks", Proceedings of the 6th International Conference on Wireless Communications Networking and Mobile Computing (WiCOM), **(2010)** September 23-25; Chengdu, China.

[18] N. Yang, H. Tian and P. Huang, Editors, "Distributed Energy-economical Routing Algorithm Based on Game-theory for WSN", Journal of Electronics & Information Technology, vol. 5, **(2008)**, pp. 1230.

[19] J. Hu and L. F. Shen, "Clustering Routing Protocol of Wireless Sensor Networks Based on Game Theory", Jornal of Southeast Uniwersity, vol. 3, **(2010)**, pp. 441.

[20] F. Kazemeyni, E. B. Johnsen and O. Owe, Editors, "Grouping Nodes in Wireless Sensor Networks Using Coalitional Game Theory", Proceedings of the 16th IEEE International Conference on Engineering of Complex Computer Systems (ICECCS), **(2011)** April 27-29; Las Vegas, Nevada USA.

[21] G. Z. Zheng, S. Y. Liu and X. G. Qi, "Clustering Routing Algorithm of Wireless Sensor Networks Based on Bayesian Game", Journal of Systems Engineering and Electronics, vol. 1, **(2012)**, pp. 154.

[22] D. Lee, H. Shin and C. Lee, "Game theory-based resource allocation strategy for clustering based wireless sensor network", Proceedings of the 6th International Conference on Ubiquitous Information Management and Communication (ICUIMC '12), **(2012)** February; Kuala Lumpur, Malaysia.

[23] T. Rappaport, Editor, "Wireless Communications: Principles & Practice", Englewood Cliffs, Prentice-Hall **(1996)**.

[24] D. Fudenberg and J. Tirole, Editors, "Game Theory", MIT Press, **(1991)**.

Authors

Zhanyang Xu obtained his Masters in Computer Engineering from the School of Computer Science and Technology, China University of Mining and Technology (CUMT) in 2004. He graduated as the top student in the Nanjing University of Posts and Telecommunications (NJUPT) where would obtain his PhD in 2012. At the same time, he is serving as a full time faculty in the School of Computer & Software, Nanjing University of Information Science & Technology (NUIST). His research interest includes wireless communication network , wireless sensor networks and Internet of things.

Yue Yin received the Bachelor degree in Applied Computing from Nanjing University of Information and Science Technology in 2011. She is currently pursuing a Master degree in Technology of Computer Application in the former institution. Her research interests include wireless sensor networks and Internet of things, specifically in fields of algorithm improvement and data replication.

Jin Wang received the B.S. and M.S. degree in the Electronical Engineering from Nanjing University of Posts and Telecommunications, China in 2002 and 2005, respectively. He received Ph.D. degree in the Ubiquitous Computing laboratory from the Computer Engineering Department of Kyung Hee University Korea in 2010. Now, he is a professor in the Computer and Software Institute, Nanjing University of Information Science and technology. His research interests mainly include routing protocol and algorithm design, performance evaluation and optimization for wireless ad hoc and sensor networks. He is a member of the IEEE and ACM.