An Improved Directed Diffusion Protocol based on Opportunistic Routing

Yi Xu
School of Information Science and Engineering, Shandong University, Jinan, China
Email: sduyxu@gmail.com

Yixian Yang, Yang Xin, and Hongliang Zhu
National Engineering Laboratory for Disaster Backup and Recovery, Beijing University of Posts and Telecommunications, Beijing, China
Email: {yxyang, yangxin, zhuhongliang}@bupt.edu.cn

***Abstract*—Researchers are paying more and more attention to the application of wireless sensor networks (WSNs), where routing is one of the vital techniques. An advanced Directed Diffusion protocol, named DDOR, is presented in this paper based on Opportunistic Routing to improve the disadvantage of mono-forwarder of traditional routing protocol. Packet head has been modified in order to implement a forwarder list in DDOR. Instead of fixed next-hop forwarding in transmission, DDOR selects the optimal node to forward. DDOR mechanism can effectively save energy of WSNs by decreasing the hops from sources to sinks, thereby extends the life of WSNs. A large number of simulations prove that DDOR is feasible. Compared with Directed Diffusion, DDOR does decrease the energy consumption on packets forwarding.**

***Index Terms*—WSNs; Directed Diffusion; Opportunistic Routing; Forwarder List; ETX; Energy Consumption**

I. Introduction

Recent advance in processor, memory, and radio technology enables small and cheap sensing nodes to perform wireless communication and significant computation. Sensor networks [1-3] may contain hundreds or thousands of sensing nodes. It is desirable to make these nodes as cheap and energy-efficient as possible and rely on their large numbers to obtain high quality results. Sensor networks should be reduced in its energy-consumption to minimize its maintenance, which thereby can be applied in inhospitable terrain inaccessible to any service and embedded structures.

Network protocol is one of the significant techniques of sensor networks, and also the field received with most attention of network researchers. Network protocols must be designed to avoid the early failure of individual node. In addition, since the limited wireless channel bandwidth must be shared among all the sensors in the network, routing protocols for these networks should perform local collaboration to reduce transmission collision.

Eventually, the data sensed by the nodes in the network must be transmitted to the sink node. In this work, we consider wireless sensor networks where the unique sink node is fixed and all the other nodes located in a large area where communication between the sensor nodes and the sink node is expensive. Traditional routing faces difficulties in coping with reliable and energy-efficient communications. It is imperative to design protocols in wireless sensor networks which will implement efficient measures to enhance communications reliability and minimize energy loss. Our work takes inspiration from one class of promising techniques known as opportunistic routing (ExOR) [4], which takes advantage of the broadcast nature of wireless communication to increase throughput and save energy in retransmissions. We propose an improved directed diffusion protocol based on opportunistic routing (DDOR). The main contributions of DDOR are summarized as follows:

1. DDOR proposes a novel transmission strategy. Intermediate nodes forward packets to their next nodes dynamically, which are determined opportunistically by the priorities of reinforced nodes.
2. DDOR solves the problem of retransmission caused by packets mission.

This paper is organized as follows: Section II surveys related works on routing of wireless sensor networks and describes their characteristics and application areas. Section III presents the mechanism of DDOR and the form of data and ACK packets. Section IV evaluates the performance of DDOR, and compares with directed diffusion. Section V concludes this paper.

II. Related Work

In this section, we provide a brief overview of some related research work.

SPIN attempts to reduce the cost of flooding data [5]. The advantage of SPIN is that topological changes are localized since each node needs to know only its single-hop neighbors. However, the data advertisement mechanism of SPIN can not guarantee the delivery of data.

Intanagonwiwat et al. introduced a data dissemination paradigm called directed diffusion (DD) for sensor networks [6]. It includes three phases, interests diffusion, gradients establishment and paths reinforcement in that

doi:10.4304/jnw.9.5.1163-1168

TABLE I. NATURE OF ROUTING PROTOCOL IN WSNS

Routing protocols	Network structure	Routing metric	Advantages	Drawbacks
SPIN	flat	Single-hop neighbors	Every node only has to know its single-hop neighbors.	It does not guarantee delivery of data.
DD	flat	Best path	It extends the lifetime of the network.	It can not be used for continuous data delivery.
COUGAR	flat	Best path	It provides energy efficiency when generated data is huge.	Overhead, complexity of the synchronization in network data computation
E-TORA	flat	Best path	It minimizes the energy consumption and results in the balance of the energy consumption of nodes.	It does not consider multicast in the basic operation.
LEACH	hierarchical	Shortest path	Low energy, distributed protocol	It is not applicable to networks deployed in large regions.
HEED	hierarchical	Shortest path	It considers residual energy of nodes and results in reasonable selection of cluster heads.	Its hierarchy establishment requires high energy consumption.
DHAC	hierarchical	Best path	It prolongs the network lifetime.	The performance is worse as the network with heavy load.

order. Directed diffusion selects reasonable paths to forward requests and replies on, on the assumption that the network is data-centric.

COUGAR uses declarative queries in order to abstract query processing from the network layer functions such as selection of relevant sensors [7]. COUGAR utilizes data aggregation to obtain more energy savings. The abstraction is supported through an additional query layer. On the other hand, the overhead of the additional query layer for the energy consumption and storage is increasing, as well as the complexity of the synchronization in network data computation and the dynamic maintenance of leader nodes to prevent failure.

TORA chooses the routes with the least hops as long as the network topology doesn't change. This may cause to the nodes that are on the main route heavy load. E-TORA takes into consideration the level of power of each node and avoids using nodes with low energy [8]. In addition, the energy consumption of nodes is balanced in order to avoid that some nodes exhaust their energy too soon if they are used too frequently.

As the sensor nodes are far from sink node, out of energy-efficiency concern, hierarchical architecture is also a reasonable choice to reduce the cost of transmission.

LEACH is one of the most popular hierarchical routing algorithms for sensor networks [9]. The idea is to form clusters of the sensor nodes based on the received signal strength and use local cluster heads as routers to the sink. LEACH uses single-hop routing where each node can transmit directly to the cluster-head and the sink. Therefore, it is not applicable to networks deployed in large regions.

Since LEACH ignores the energy consumption issue of intra-clusters, the formation and structure of clusters may not be optimal. HEED presented by Younis and Fahmy periodically selects cluster heads based on the node's residual energy and a secondary parameter, such as node proximity to its neighbors or node degree [10]. However, the residual energy cannot be calculated precisely, and hierarchy establishment requires high energy consumption.

DHAC presents that a node needs the knowledge of only one hop neighbor to build the clusters [11]. DHAC uses the sequence of nodes merging into the current cluster as the schedule. Each cluster member gets its assigned role and sends data to its cluster head in turns. DHAC gains much better performance when the network has light traffic.

TABLE I summarizes all the above protocols discussed.

III. DDOR PROTOCOL

A. Introduction of Opportunistic Routing

Suppose data forward through a fixed path, such as Source - 1 - 2 - 3 - 4 - Sink, as demonstrated in Fig. 1. In WSNs, sensor nodes communicate with other nodes by broadcasting, and broadcasting communication is under influence of the environment. If source node broadcasts a message to node 1, it is possible that node 2 or 3 which is not far from node 1 also receives the broadcasting message (The ratio of successful reception of node 2 or 3 is lower than node 1 undoubtedly). If node 2 or 3 instead of node 1 sends the message to the sink, it will save the energy of broadcasting from node 1. Through the fixed path Source - 1 - 2 - 3 - 4 - Sink, there may be one or more opportunities to skip an intermediate node so as to save more energy. Especially in a large scale and distribution-intensive WSNs, the more hops from sources to sinks, the more energy will be saved by skipping intermediate nodes.

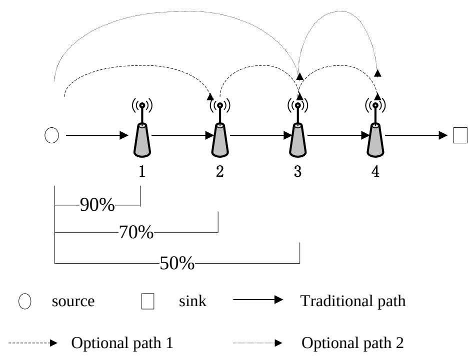
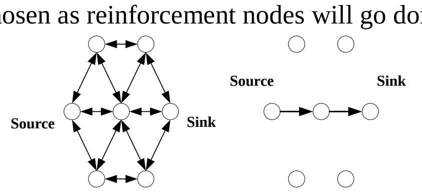


Figure 1. Opportunistic routing

From the analysis above, we have introduced opportunistic routing [4] into directed diffusion. We take two-phase-pull directed diffusion as an example. In the phase of reinforcement, sinks send the reinforcement messages to sources hop-by-hop, and the intermediate nodes with the shortest delay will be marked as reinforced neighbors. We modify the reinforcement messages, so that the nodes received reinforcement messages will write their information into forwarder lists contained in the messages. When source nodes receive the reinforcement messages, the forwarder lists which contain all the reinforced nodes are established simultaneously. Every reinforced node maintains its own forwarder list and data packet map, and the following packet will be transmitted in term of DDOR.

B. Forwarder List

Through the phases of interests diffusion and gradients establishment, elementary gradients between all the nodes have been established, as shown in Fig. 2(a). In the path reinforcement phase, a sink node broadcasts a message with reinforcement information, and announces that the neighbor who sends data to sink earliest will become the next hop of the path reinforced. After the chosen node receiving the message, ID and priority of the node will be written into the message, and forwarder list will be duplicated in the local storage. Then, the message will be forwarded to neighbors as the above rules. The whole forwarder list will be stored as in ExOR. In this paper, we shorten the length of a forwarder list to save storage resource. The length of a forwarder list stored in every node is *K* Byte, which is composed of *K-1* nodes with higher priority and the node itself. The other nodes which are not chosen as reinforcement nodes will go dormant.



(a) Gradient establishment (b) Path reinforcement

Figure 2. Gradients establishment and paths reinforcement

When an intermediate node *i* receives a reinforcement message, forwarder list in the message will be checked primarily. The maximum length of a forwarder list is *N*, which is decided by the storage of every node. If the number of nodes stored in a forwarder list is less than *K*, node *i* will write its own ID and priority into forwarder list, and duplicate the forwarder list in local storage, and then broadcast the message to neighbors. If there are *K* nodes in the forwarder list, all of which have a higher priority than node *i*, node *i* will write its own ID and priority into forwarder list to replace the node with the highest priority, and make a duplication and broadcast as well.

When a source node receives the reinforcement message, it updates and duplicates the forwarder list as other intermediate nodes do, therefore, a reinforced path has been established, as shown in Fig. 2(b). Source nodes set up a threshold *N (N<K)* according to its transmitting power, and *N* nodes with the highest priorities will be written into the forwarder list in the message to be broadcast. Suppose every node has the same transmitting power except sinks, the value of *N* is fixed.

C. Cooperation Mechanism

In consideration of QoS, ACK mechanism is introduced in this paper. When an intermediate node receives a data packet for the first time, it checks the forwarder list before it makes a decision**.**

1. If this node has the highest priority in the forwarder list, it updates local data packet map before sending an ACK to the node *i-1*. As has mentioned above, *N* nodes with the highest priorities in local forwarder list will be written into the forwarder list in the packet, and the packet will be forwarded to next hop.

2. If this node does not have the highest priority in the forwarder list, it keeps monitoring for an interval *T*. During the monitoring time, if the node receives an ACK from node *i+1* (the node with higher priority), it will update local data packet map and send an ACK to node *i-1* after interval *T*. During the monitoring time, if the node does not receive an ACK from any node with higher priority, it will operate as situation 1 after interval *T*.

Data packet map records a group of nodes, every of which has the highest priority corresponding to different packet, sources and the sink are also contained in this group. Interval $T = kT_s$, $k(k<N)$ is the number of nodes which have higher priorities than the current node. T_s is a time margin, which should be longer than the sum of time to process and transmit a packet.

When a source node receives an ACK from the node with the lowest priority in its forwarder list, the last packet will be confirmed to have been received by a node with higher priority. Then, packets will be transmitted one by one following the same rule.

When the sink node receives a data packet, it updates the data packet map and broadcasts an ACK immediately. After receiving the ACK from the sink, intermediate nodes update their data packet maps and drop the packets received by the sink. The process will last until all the packets have been received by the sink.

D. Data packet Head and ACK Packet Head

During the transmission of data from sources to the sink, as data are based on interests from the sink, which differ from ExOR, the data packet head in ExOR should be modified, as shown in Fig. 3. The differences of the data packet head between ExOR and DDOR are as follows:

1. Interest type takes the place of Batch ID. Every forwarder can match packets with interests to decide which packets should be received and forwarded.

2. Data packet map takes the place of Batch map. As Interest type indicates the forwarding direction of a packet, Data packet map shows which packets have been received. DPMSz is similar to BatchSz, which means the size of packets.

<table>
<tr><td colspan="12">Ethernet Header</td></tr>
<tr><td colspan="4">Ver</td><td colspan="4">HdrLen</td><td colspan="4">PayloadLen</td></tr>
<tr><td colspan="12">Interest Type</td></tr>
<tr><td colspan="3">PktNum</td><td colspan="3">DPMSz</td><td colspan="3">FragNum</td><td colspan="3">FragSz</td></tr>
<tr><td colspan="6">FwdListSize</td><td colspan="6">ForwarderNum</td></tr>
<tr><td colspan="12">Forwarder List</td></tr>
<tr><td colspan="12">Data Packet Map</td></tr>
<tr><td colspan="12">Checksum</td></tr>
<tr><td colspan="12">Payload</td></tr>
</table>

Figure 3. Data packet head

After receiving a packet, a node will transmit an ACK packet. The form of an ACK packet head is shown in Fig. 4. The expression of every part in this packet head is the same as data packet head.

Ethernet Header	
Ver	HdrLen
Interest Type	
PktNum	DPMSz
Data Packet Map	
Checksum	

Figure 4. ACK packet head

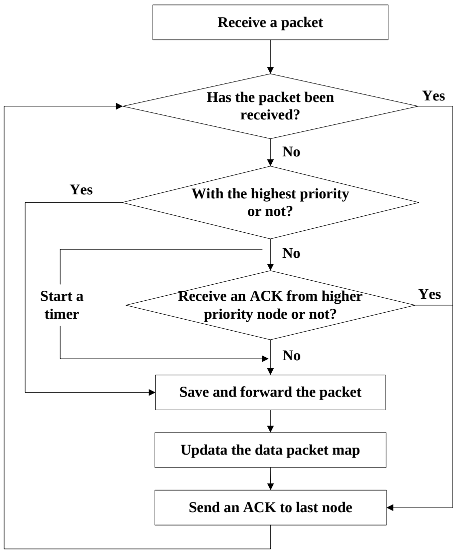


Figure 5. Flow chart of DDOR

E. Retransmission

Retransmission mechanism remedies the shortage of ExOR. In our work, after transmitting a data packet, if an ACK from node *i+1* is not received, the intermediate node *i* will retransmit the latest data packet. The reasons of retransmission may be as follows:

1. This packet is not received by nodes with higher priorities than node *i*.

2. This packet is received by one node at least with higher priority, but the ACK is missing.

A robust routing protocol has to deal with all the possible problems.

When the data packet is missing, suppose node *i* retransmits the latest packet, the node *j* with higher priority receives the packet for the first time. In this case, node *j* will check the forwarder list to determine whether it will transmit the packet immediately or keep monitoring for an interval *T*, as introduced in section III. C.

When the ACK is missing, suppose node *j* receives the retransmitted data packet from node *i*, it will check the local storage to see whether the packet has been received. If the packet has been received by node *j* or other nodes with higher priorities, node *j* will understand that the latest ACK is missing and will retransmit an ACK to node *j-1*. If the packet has not been received before, node *j* will check the forwarder list to determine whether it will transmit the packet immediately or keep monitoring for an interval *T*, as introduced in section III. C.

F. Flow of DDOR

The flow chart of DDOR is shown in Fig. 5.

IV. Performance Analysis

Reference [12] describes the probability of reception with Rayleigh fading channel, which is:

$$p_R = p_R^N \cdot p_R^I \qquad (1)$$

p_R^N is the reception probability in a zero-interference network as it depends only on the noise, p_R^I is the reception probability in a zero-noise network. For a well-designed routing protocol, interference can be ignored, and therefore the probability of reception is:

$$p_R = \exp\left(-\frac{\theta N_0}{P_T d_{ij}^{-\alpha}}\right) \qquad (2)$$

P_T is the transmission power of node *i*, d_{ij} is the distance between node *i* and node *j*, N_0 denotes the noise power, α is the channel attenuation factor, θ is a certain threshold of the signal-to-noise-and-interference ratio (SINR) that is determined by the communication hardware.

Suppose the reinforced nodes are distributed as Fig. 6. The reinforced path between a source and the sink is composed of twelve hops. Transmission power is set to $P_T = 660mW$ as in Ref. [6]. According to Ref. [12], channel attenuation factor α has a value between 2 and 4, and the other two parameters are $N_0 = 0.1mW$ and $\theta = 1$. Suppose the threshold $N = 3$, the distance between two neighbors is fixed $d_{i,i+1} = d_{0,1}$. When $d_{i,i+1}$ and α change, the ETX of forwarding a packet from a source to the sink is shown in Fig. 7.

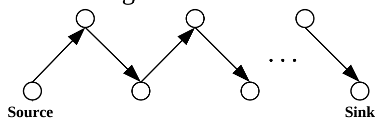


Figure 6. The nodes deployment of reinforced path

As known in Fig. 7, the longer distance between two neighbors, the larger ETX is needed to transmit a packet from a source to the sink. The larger channel attenuation factor α, the larger ETX is needed to transmit a packet from a source to the sink as well. We choose a common environment with $\alpha = 2.5$, and compare the performance of DDOR with direction diffusion, as shown in Fig. 8.

As known in Fig. 8, when the distance between two neighbors satisfies $d_{i,i+1} < 30m$, DDOR is superior to directed diffusion obviously.

We implement DDOR protocol in NS-2 simulator. Our 50-node sensor field is generated by randomly placing the nodes in a 200 × 200 m square. The ns-2 simulator implements a 1.6 Mb/s 802.11MAC layer. Our simulations use a modified 802.11 MAC layer. To more closely mimic realistic sensor network radios, we altered the ns-2 radio energy model so that the idle-time power dissipation was about 35 mW, which is nearly 10% of its receiving power dissipation (395 mW) and about 5% of its transmitting power dissipation (660 mW). Every node has 1000J energy initial, and the simulation lasts 20000s.

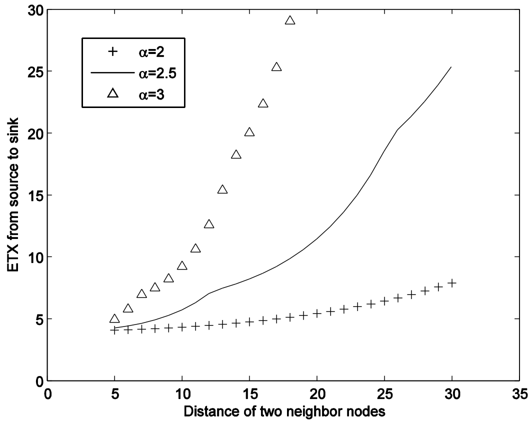


Figure 7. Impact of channel attenuation factor on DDOR

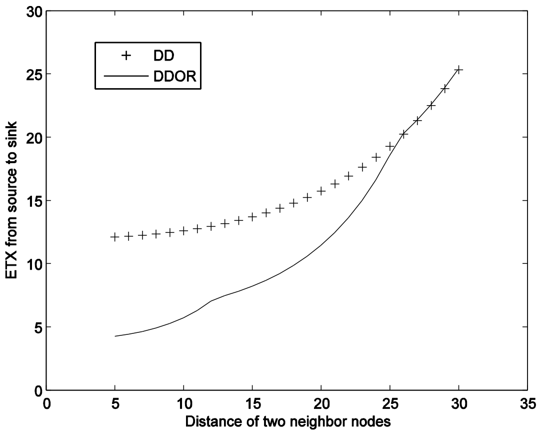


Figure 8. Impact of distance on DDOR and DD

Five source nodes and one sink node are implemented in the simulation. After simulation, the residual energy of every node is shown in Fig. 9 (except a few isolated nodes). To be precise, the average residual energy of all the nodes (except a few isolated nodes) is 287.913274 with DDOR, and 283.054134 with directed diffusion, respectively.

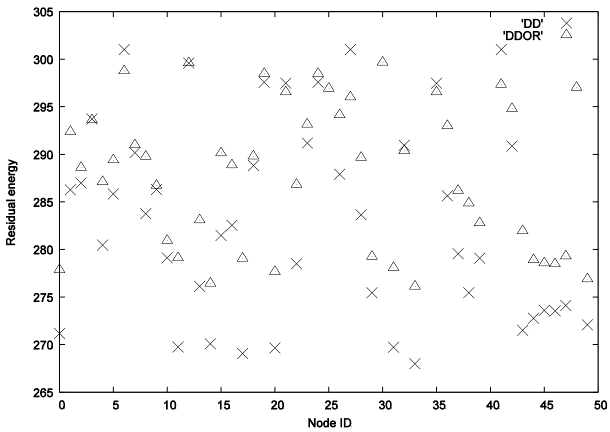


Figure 9. Residual energy

As the number of sources changes, Fig. 10 shows the average residual energy with directed diffusion and DDOR, respectively. As shown in Fig. 10, DDOR can save more energy than directed diffusion, for its efficiency in choosing the next-hop nodes.

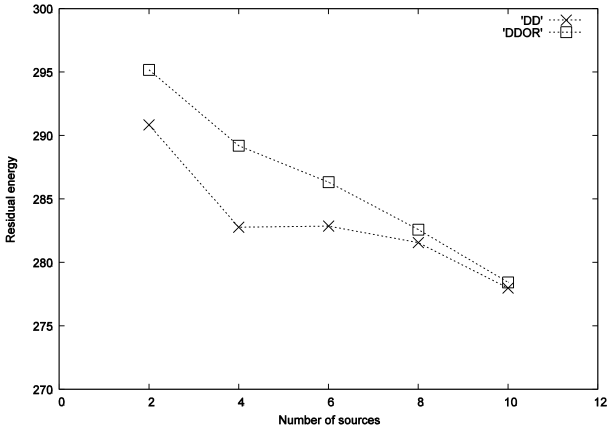


Figure 10. Impact of number of source nodes on average residual energy of nodes

V. CONCLUSION

This paper focuses on the problem of simplex and fixed next-hop nodes in traditional routing protocols, and presents an energy-efficient routing protocol based on directed diffusion and opportunistic routing. In data transmission, a forwarder list instead of a fixed next-hop destination is implemented to choose an optional next-hop node. Plenty of experiments prove that DDOR can save more energy in transmission, and prolong the life of WSNs. Comparing with directed diffusion, DDOR is more energy-efficient.

ACKNOWLEDGMENTS

This work is supported by the National Development and Reform Commission Information Security Special fund, the Key Project of Chinese Ministry of Education, the Fundamental Research Funds for the Central Universities (BUPT2010PTB0503).

REFERENCES

[1] F. Wang, X. Y. Zhang, M. F. Zhang and G. J. Chen, “Energy-efficient routing algorithm for WSNs in underground mining,” *Journal of Networks*, Vol. 7, No. 11, pp. 1824-1829, 2012

[2] H. J. Dai, Y. Liu, F. H. Guo and Z. P. Jia, “A malicious node detection algorithm based on principle of maximum entropy in WSNs,” *Journal of Networks*, Vol. 7, No. 9, pp. 1376-1383, 2012.

[3] M. Naderan, M. Dehghann and H. Pedram, “Sensing task assignment via sensor selection for maximum target coverage in WSNs,” *Journal of Network and Computer Applications*, Vol. 36, No. 1, pp. 262-273, 2013

[4] S. Biswas and R. Morris, “ExOR: Opportunistic Routing in Multi-hop Wireless Networks,” *ACM SIGCOMM 2005*, pp. 133-143, 2005.

[5] J. Kulik, W. Heinzelman and H. Balakrishnan, “Negotiation based protocols for disseminating

information in wireless sensor networks," *Wireless Networks,* Vol. 8, No. (2-3), pp. 169-185, 2002.
[6] C. Intanagonwiwat, R. Govindan, D. Estrin, et al, "Directed Diffusion for Wireless Sensor Networking," *IEEE Trans. on Networking,* Vol. 11, No. 1, pp. 2-16, 2003.
[7] Y. Yao and J. Gehrke, "The Cougar Approach to In-Network Query Processing in Sensor Networks," *SIGMOD Record,* Vol. 31, Issue 3, pp. 9-18, 2002.
[8] F. Yu, Y. Li, F. Fang and Q. Chen, "A New TORA-Based Energy Aware Routing Protocol in Mobile Ad Hoc Networks," *The 3rd IEEE/IFIP International Conference in Central Asia on Internet (ICI)*, pp. 1-4, 2007.
[9] W. Heinzelman, A. Chandrakasan and H. Balakrishnan, "Energy-efficient communication protocol for wireless microsensor networks," *The 33rd Annual Hawaii Int'l Conf. on System Sciences,* pp. 3005-3014, 2000.
[10] O. Younis and S. Fahmy, "HEED: a hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks," *IEEE Trans. on Mobile Computing,* Vol. 3, No. 4, pp.366-379, 2004.
[11] C. H. Lung and C. J. Zhou, "Using hierarchical agglomerative clustering in wireless sensor networks: An energy-efficient and flexible approach," *Ad Hoc Networks,* Vol. 8, Issue 3, pp. 328-344, 2010
[12] M. Haenggi, "On Routing in Random Rayleigh Fading Networks," *IEEE Trans. on Wireless Communications,* Vol. 4, No.4, pp. 1553-1562, 2005.

Yi Xu was born in 1982. He received his B.S. degree in Communication Engineering from Shandong University (SDU), China in June 2005, and his M.S. degree in Communication and Information System from Guilin University of electronic technology (GUET), China in June 2009. He is currently working towards his Ph.D. degree in Communication and Information System at Shandong University (SDU), China. His current research interest includes wireless sensor networks and network security.

Yixian Yang was born in Sichuan, China, in 1961. He received his Ph.D. degree in signal and information processing from Beijing University of Posts and Telecommunications, Beijing, China in 1988. He is currently a Changjiang Scholar and Distinguished Professor with Beijing University of Posts and Telecommunications, Beijing, China. He is also the director of National Engineering Laboratory for Disaster Backup and Recovery, Key Laboratory of Network and Information Attack & Defense technology of MOE, and Information Security Center, State Key Laboratory of Networking and Switching Technology, Beijing University of Posts and Telecommunications. His research interests include network and information security theory and applications, network-based computer application technology, coding theory and technology.

Yang Xin is the associate professor in Beijing University of Posts and Telecommunications. His research interests include network and information security theory and applications, network-based computer application technology.

Hongliang Zhu is the lecturer in Beijing University of Posts and Telecommunications. His research interests include network and information security theory and applications, network-based computer application technology.