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Autonomous Decentralized Control Scheme for Long-Term Operation of Large Scale and Dense Wireless Sensor Networks with Multiple Sinks

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1. Introduction

Various communication services have been provided. They include environmental monitoring and/or control, ad-hoc communication between mobile nodes, and inter-vehicle communication in intelligent transport systems. As a means of facilitating the above advanced communication services, autonomous decentralized networks, such as wireless sensor networks (Akyildiz et al., 2002; Rajagopalan & Varshney, 2006), mobile ad-hoc networks (Perkins & Royer, 1999; Johnson et al., 2003; Clausen & Jaquet, 2003; Ogier et al., 2003), and wireless mesh networks (Yamamoto et al., 2009), have been intensively researched with great interests. Especially, a wireless sensor network, which is a key network to construct ubiquitous information environments, has great potential as a means of realizing a wide range of applications, such as natural environmental monitoring, environmental control in residential spaces or plants, object tracking, and precision agriculture (Akyildiz et al., 2002). Recently, there is growing expectation for a new network service by a wireless sensor network consisting of a lot of static sensor nodes arranged in a service area and a few mobile robots as a result of the strong desire for the development of advanced systems that can flexibly function in dynamically changing environments (Matsumoto et al., 2009).

In this chapter, a large scale and dense wireless sensor network made up of many static sensor nodes with global positioning system, which is a representative network to actualize the above-mentioned sensor applications, is assumed. In a large scale and dense wireless sensor network, generally, hundreds or thousands of static sensor nodes limited resources, which are compact and inexpensive, are placed in a service area, and sensing data of each node is gathered to a sink node by inter-node wireless multi-hop communication. Each sensor node consists of a sensing function to measure the status (temperature, humidity, motion, etc.) of an observation point or object, a limited function of information processing, and a simplified wireless communication function, and it generally operates on a resource with a limited power-supply capacity such as a battery. Therefore, a data gathering scheme and/or a routing protocol capable of meeting the following requirements is mainly needed to prolong the lifetime of a large scale and dense wireless sensor network composed of hundreds or thousands of static sensor nodes limited resources.

1. Efficiency of data gathering
2. Balance of communication load among sensor nodes
3. Adaptability to network topology changes

As data gathering schemes for the long-term operation of a wireless sensor network, cluster-ing-based data gathering (Heinzelman et al., 2000; Dasgupta et al., 2003; Jin et al., 2008) and synchronization-based data gathering (Wakamiya & Murata, 2005; Nakano et al., 2009; Nak-ano et al., 2011) are under study, but not all the above requirements are satisfied. Recently, bio-inspired routing algorithms, such as ant-based routing algorithms, have attracted a sign-ificant amount of interest from many researchers as examples that satisfy the three require-ments above. In ant-based routing algorithms (Subramanian et al., 1998; Ohtaki et al., 2006), the routing table of each sensor node is generated and updated by applying the process in which ants build routes between their nest and food using chemical substances (pheromon-es). Advanced ant-based routing algorithm (Utani et al., 2008) is an efficient route learning algorithm which shares route information between control messages. In contrast to conven-tional ant-based routing algorithms, this can suppress the communication load of each sen-sor node and adapt itself to network topology changes. However, this does not positively ease the communication load concentration on specific sensor nodes, which is the source of problems in the long-term operation of a wireless sensor network. Gradient-based routing protocol (Xia et al., 2004) actualizes load-balancing data gathering. However, this cannot su-ppress the communication load concentration to sensor nodes around the set sink node. Int-ensive data transmission to specific sensor nodes results in concentrated energy consumpti-on by them, and causes them to break away from the network early. This makes long-term observation by a wireless sensor network difficult.

In a large scale and dense wireless sensor network, the communication load is generally co-ncentrated on sensor nodes around the set sink node during the operation process. In cases where sensor nodes are not placed evenly in a large scale observation area, the communica-tion load is concentrated on sensor nodes placed in an area of low node density. To solve this communication load concentration problem, a data gathering scheme for a wireless sen-sor network with multiple sinks has been proposed (Dubois-Ferriere et al., 2004; Oyman & Ersoy, 2004). In this scheme, each sensor node sends sensing data to the nearest sink node. In comparison with the case of one-sink wireless sensor networks, the communication load of sensor nodes around a sink node is reduced. In each sensor node, however, the destinati-on sink node cannot be selected autonomously and adaptively. In cases where original data transmission rate from each sensor node is not even, therefore, the load of load-concentrated nodes is not sufficiently balanced. An autonomous load-balancing data transmission scheme is required.

This chapter represents a new data gathering scheme with transmission power control that adaptively reduces the load of load-concentrated nodes and facilitates the long-term operati-on of a large scale and dense wireless sensor network with multiple sinks (Matsumoto et al., 2010). This scheme has autonomous load-balancing data transmission devised by consider-ing the application environment of a wireless sensor network as a typical example of compl-ex systems where the adaptive adjustment of the entire system is realized from the local int-eractions of components of the system. In this scheme, the load of each sensor node is auton-omously balanced. This chapter consists of four sections. In Section 2, the above data gather-ing scheme (Matsumoto et al., 2010) is detailed and its novelty and superiority are described. In Section 3, the results of simulation experiments are reported and the effectiveness of our scheme (Matsumoto et al., 2010) is demonstrated by comparing its performances with those of existing schemes. In Section 4, the overall conclusions of this work are given and future problems are discussed.

2. Autonomous decentralized control scheme

To facilitate the long-term operation of an actual sensor network service, a recent approach has been to introduce multiple sinks in a wireless sensor network (Dubois-Ferriere et al., 2004; Oyman & Ersoy, 2004). In a wireless sensor network with multiple sinks, sensing data of each node is generally allowed to gather at any of the available sinks. Our scheme (Matsumoto et al., 2010) is a new data gathering scheme based on this assumption, which can be expected to produce a remarkable effect in a large scale and dense wireless sensor network with multiple sinks. In our scheme, each sensor node can select either of high power and low power for packet transmission, where high power corresponds to normal transmission power and low power is newly introduced to moreover balance the load of each sensor node.

2.1 Routing algorithm

Each sink node has a connective value named a "value to self", which is not updated by transmitting a control packet and receiving data packets. In the initial state of a large scale and dense wireless sensor network with multiple sinks, each sink node broadcasts a control packet containing its own location information, ID, hop counts(=*0*), and "value to self" by high power. This control packet is rebroadcast throughout the network with hop counts updated by high power. By receiving the control packet from each sink node, each sensor node can grasp the "value to self" of each sink node, their location information, IDs, and the hop counts from each sink node of its own neighborhood nodes.

Initial connective value of each sensor node, which is the connective value before starting data transmission, is generated by using the "value to self" of each sink node and the hop counts from each sink node. The procedure for computing initial connective value of a node (i) is as follows:

1. The value [$v_{ij}(0)$] on each sink node (j=1, … ,S) of node (i) is first computed according to the following equation

$$v_{ij}(0) = vo_j \times dr^{hops_{ij}} \quad (j = 1,\ldots,S) \tag{1}$$

   where vo_j(j=1, … ,S) is the "value to self" of sink node (j), $hops_{ij}$(j=1, … ,S) is the hop counts from sink node (j) of node (i). dr represents the value attenuation factor accompanying the hop determined within the interval [0,1].
2. Then, initial connective value [$v_i(0)$] of node (i) is generated by the following equation

$$v_i(0) = \max v_{ij}(0) \quad (j = 1, \ldots, S) \tag{2}$$

   where this connective value [$v_i(0)$] can be also conducted from the following equation

$$v_i(0) = vm_i(0) \times dr \tag{3}$$

In the above Equation (3), $vm_i(0)$ represents the greatest connective value before starting data transmission in neighborhood nodes of node (i).

Before data transmission is started, each sensor node computes initial connective value of each neighborhood node based on the above Equations (1) and (2), and stores the computed connective value, which is used as the only index to evaluate the relay destination value of each neighborhood node, in each neighborhood node field of its own routing table.

2.2 Data transmission and connective value update

For a while from starting data transmission, each sensor node selects the neighboring node with the greatest connective value from its own routing table as a relay node, and transmits the data packet to this selected node by high power. In cases where more than one node shares the greatest connective value, however, the relay node is determined between them at random. The data packet in each sensor node is not sent to a specified sink node. By repetitive data transmission to the neighboring node with the greatest connective value, data gathering at any of the available sinks is completed. In our scheme, the connective value of each sensor node is updated by considering residual node energy. Therefore, by repetitive data transmission to the neighboring node with the greatest connective value, the data transmission routes are not fixed.

To realize autonomous load-balancing data transmission, in our scheme (Matsumoto et al., 2010), the data packet from each sensor node includes its own updated connective value. We assume that a node (l) receives a data packet at time (t). Before node (l) relays the data packet, it replaces the value in the connective value field of the data packet by its own renewal connective value computed according to the following connective value update equation

$$v_l(t) = vm_l(t) \times dr \times {e_l(t)}/{E_l} \tag{4}$$

where $vm_l(t)$ is the greatest connective value at time (t) in the routing table of node (l). $e_l(t)$ and E_l represent the residual energy at time (t) of node (l) and the battery capacity of node (l), respectively.

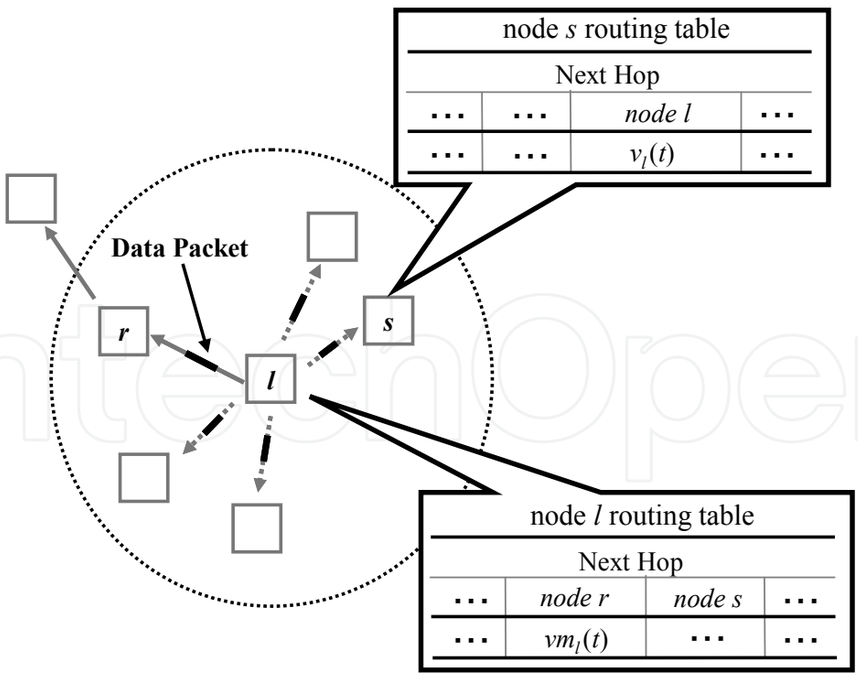


Fig. 1. Data packet transmission and connective value update

In our scheme, the data packet addressed to the neighboring node with the greatest connective value is intercepted by all neighboring nodes. This data packet includes the updated co-

nnective value of the source node based on the above Equation (4). Each neighborhood node that intercepts this packet stores the updated connective value in the source node field of its own routing table. Fig.1 shows an example of data packet transmission and its accompanying connective value update. In this example, node (l) refers to its own routing table and addresses the data packet to node (r), which has the greatest connective value [$vm_l(t)$]. When this data packet is intercepted, each neighboring node around node (l) stores the updated connective value [$v_l(t)$] in the data packet in the node (l) field of its own routing table.

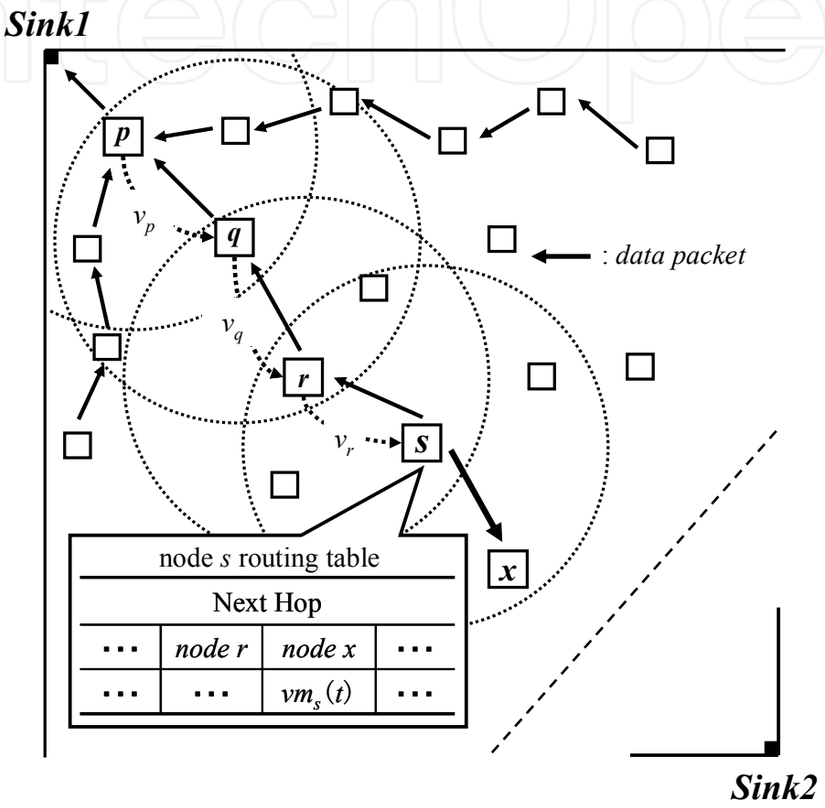
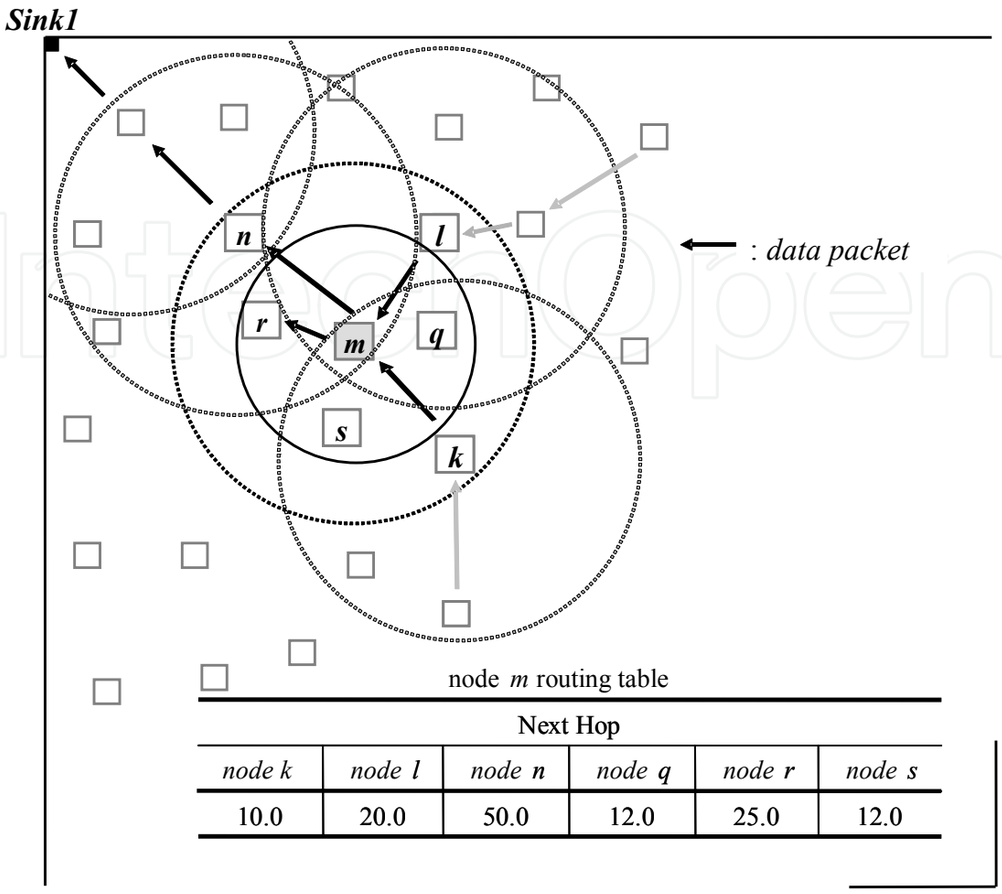


Fig. 2. An example of autonomous load-balancing data transmission to multiple sinks

Our scheme (Matsumoto et al., 2010) requires the construction of a data gathering environment in the initial state of a large scale and dense wireless sensor network with multiple sinks, but needs no special communication for network control. The above-mentioned simple mechanism alone achieves autonomously adaptive load-balancing data transmission to multiple sinks, as in Fig.2. The lifetime of a wireless sensor network can be extended by reducing the communication load for network control and solving the node load concentration problem.

2.3 Transmission power control

For data packet transmission, the transmission power of each sensor node is switched to low power if its own residual energy is less than the set threshold [T_e]. In this case, each sensor node selects the neighboring node with the greatest connective value within range of radio wave of low power as a relay node, and transmits the data packet to this selected node by low power.



node *m* routing table

Next Hop					
node k	*node l*	*node n*	*node q*	*node r*	*node s*
10.0	20.0	50.0	12.0	25.0	12.0

Fig. 3. An example of transmission power control

Fig.3 shows an example of the above transmission power control, which means that the tra-nsmission power of each sensor node is switched to low power according to the above con-dition. In this example, node (*m*) is a load concentration node. Node (*m*) has autonomously transmitted the data packet to node (*r*) with the greatest connective value within low power range by low power because its own residual energy has become less than the set threshold [T_e]. By switching to low power, the energy consumption of node (*m*) is saved, but node (*k*) and node (*l*) may continue to transmit the data packet to node (*m*) because they cannot grasp the updated connective value of node (*m*). In our scheme, therefore, every tenth data packet from the node switched to low power is transmitted by high power.

3. Simulation experiment

Through simulation experiments on a wireless sensor network with multiple sinks, the perf-ormances of our scheme have been investigated in detail to verify its effectiveness.

3.1 Conditions of simulation

In a large scale and dense wireless sensor network with multiple sinks consisting of many static sensor nodes placed in a large scale observation area, only sensor nodes that

detected abnormal data set were assumed to transmit the measurement data. The conditions of the si-mulation which were used in the experiments performed are shown in Table1. In the initial state of the simulation experiments, static sensor nodes are randomly arranged in the set ex-perimental area, and multiple sinks are placed on the boundaries containing the corners of this area. The network configuration is shown in Fig.4. In the experiments performed, the value attenuation factor accompanying hop (*dr*) and the "value to self" of each sink node in-troduced in our scheme were set to 0.5 and 100.0, respectively.

Simulation size	*2400m × 2400m*
Number of sensor nodes	*750, 1000, 1250*
Range of radio wave	*150m or 200m*
Number of sinks	*2 or 3*
Size of each data packet	*18 [bytes]*
Size of each control packet	*6 [bytes]*
Battery capacity of each sensor node	*0.2 [J] or 0.5[J]*

Table 1. Conditions of simulation

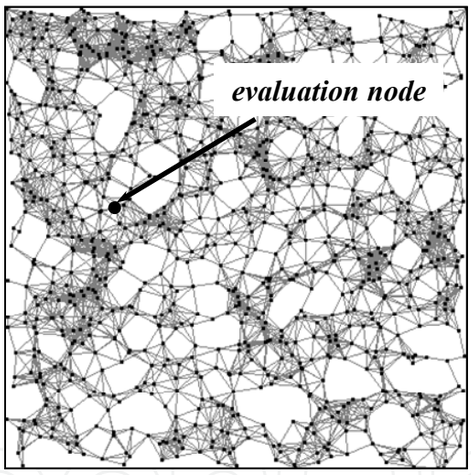
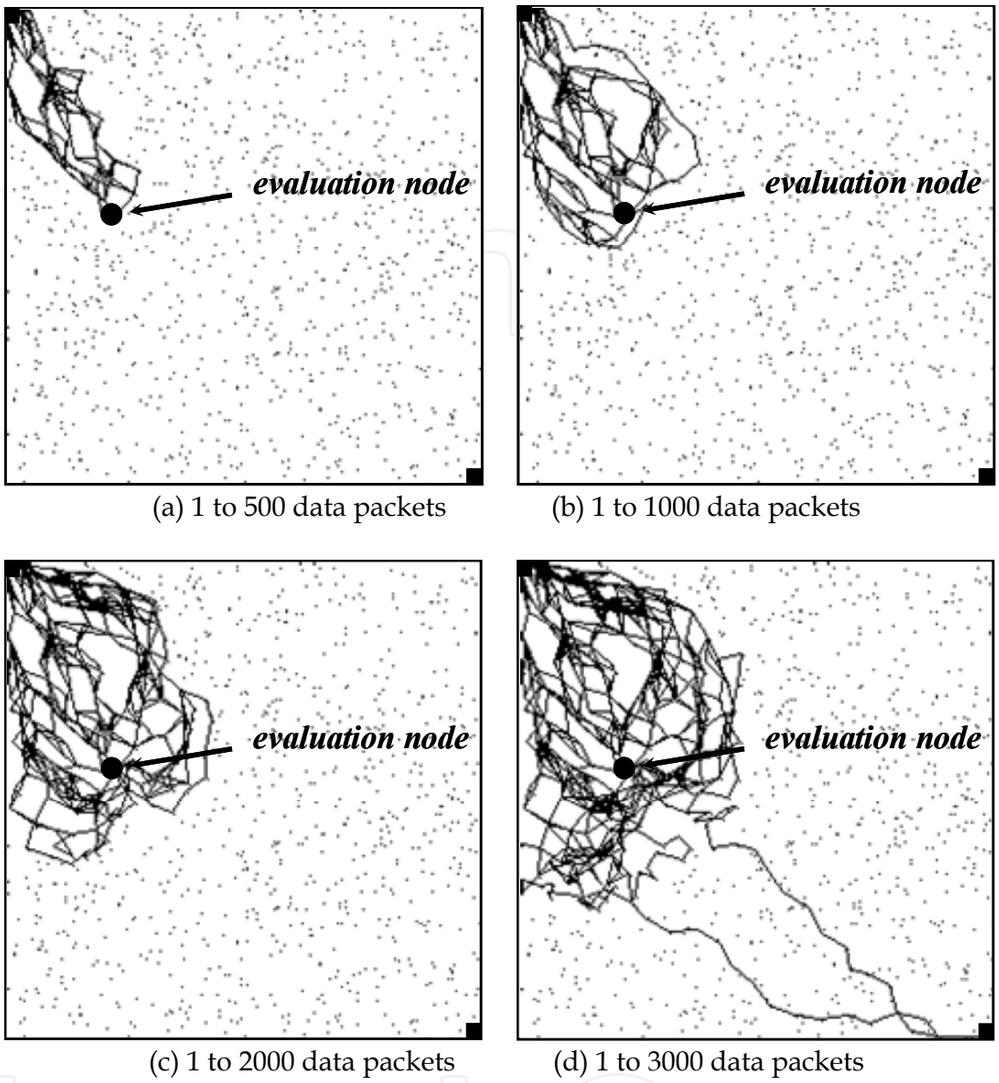


Fig. 4. Large scale and dense wireless sensor network consisting of many static sensor nodes

In the experimental results reported, our scheme (Matsumoto et al., 2010) is evaluated thro-ugh a comparison with existing ones (Dubois-Ferriere et al., 2004; Oyman & Ersoy, 2004; Ohtaki et al., 2006; Utani et al., 2008) where the parameter settings that produced good results in a preliminary investigation were adopted in preference to existing ones.

3.2 Experimental results on simulation model with two sinks

In this subsection, experimental results on the simulation model with two sinks of our sche-me without transmission power control are shown, where the number of sensor nodes was 1000, the range of radio wave and the battery capacity of each sensor node were set to 150m and 0.5J, respectively.



(a) 1 to 500 data packets (b) 1 to 1000 data packets

(c) 1 to 2000 data packets (d) 1 to 3000 data packets

Fig. 5. Routes used by applying our scheme to the simulation model with two sinks

As the first experiment on the simulation model with two sinks, it was assumed that the evaluation node marked in Fig.4 detected an abnormal value and transmitted the data packet with this abnormal value periodically. The routes used by applying our scheme are shown in Fig.5. Of the 3000 data packets transmitted from the evaluation node, the routes used by the first 500 data packets are illustrated in Fig.5(a), those used by the 1000 data packets are in Fig.5(b), those used by the 2000 data packets are in Fig.5(c), and those used by a total of 3000 data packets are in Fig.5(d). From Fig.5, it can be confirmed that our scheme enables the autonomous load-balancing transmission of data packets to two sinks using multiple routes.

Next, it was assumed that data packets were periodically transmitted from a total of 20 sens-or nodes placed in the set simulation area. In Fig.6, the transition of the delivery ratio of the total number of data packets transmitted from a total of 20 randomly selected

sensor nodes is shown, and the lifetime of the simulation model with two sinks, as in Fig.5, is compared. In Fig.6, the existing schemes in Ohtaki et al., 2006 and Utani et al., 2008, which belong to the category of ant-based routing algorithms, are denoted as *MUAA* and *AAR*, respectively. The existing scheme in Dubois-Ferriere et al., 2004 and Oyman and Ersoy, 2004, which describe representative data gathering for a wireless sensor network with multiple sinks, is denoted as *NS*. From Fig.6, it can be confirmed that our scheme denoted as *Proposal* in Fig.6 achieves a longer-term operation of a wireless sensor network with multiple sinks than the existing ones because it improves and balances the load of each sensor node by the communication load reduction for network control and the autonomous load-balancing data transmission. Through simulation experiments, it was verified that our scheme (Matsumoto et al., 2010) is substantially advantageous for the long-term operation of a large scale and dense wireless sensor network with multiple sinks.

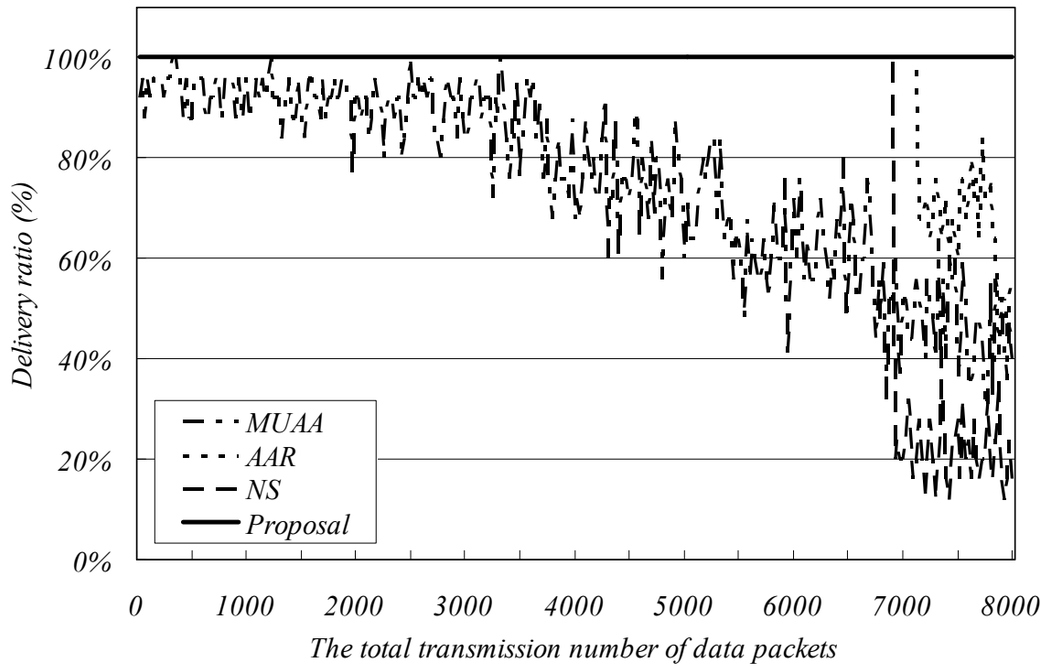


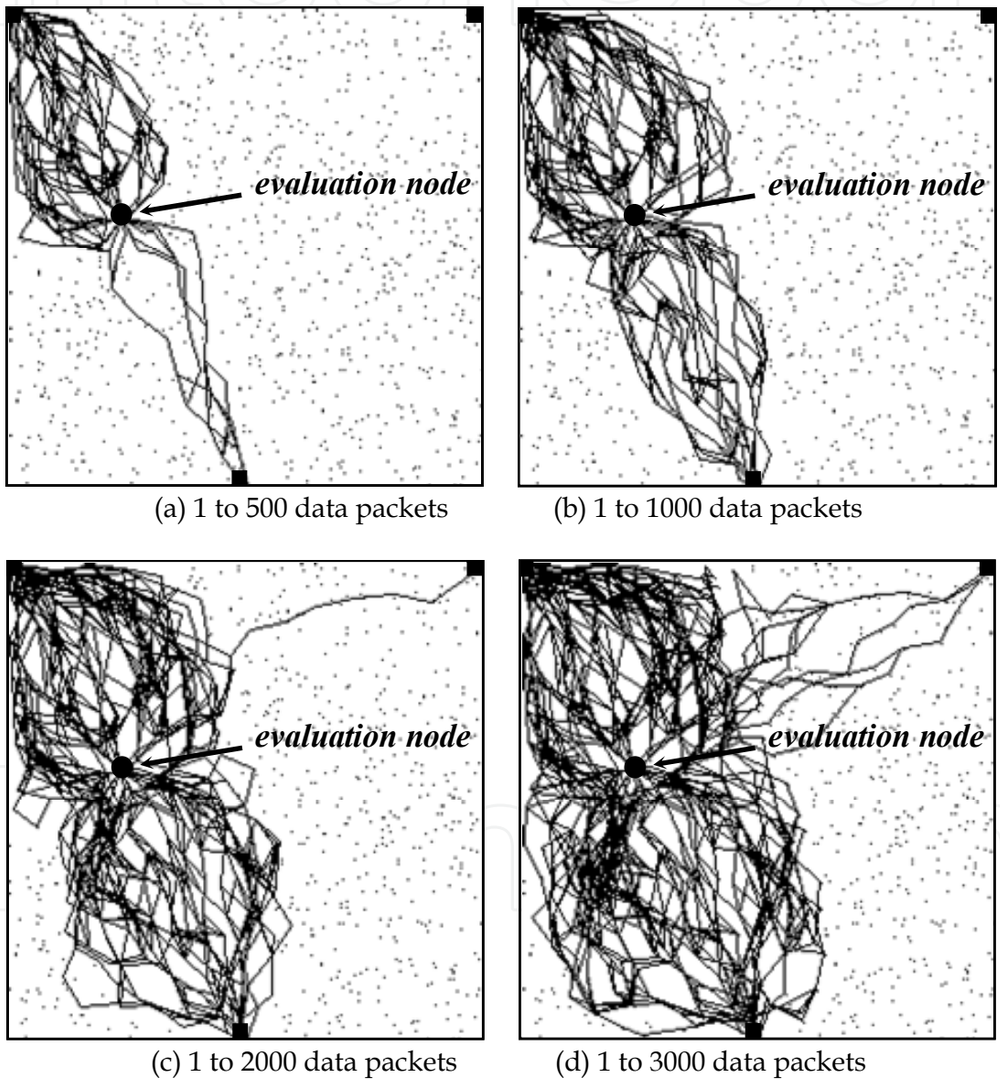
Fig. 6. Transition of delivery ratio

3.3 Experimental results on simulation model with three sinks

In this subsection, through experimental results on the simulation model with three sinks, the effectiveness of the transmission power control introduced in our scheme is evaluated. In the following experimental results, the battery capacity of each sensor node was set to 0.2J, and the range of radio wave of high power transmission in each sensor node was set to 200 m and it of low power transmission in each sensor node was set to 150m.

As the first experiment on the simulation model with three sinks, it was assumed that the evaluation node marked in Fig.4 detected an abnormal value and transmitted the data packet with this abnormal value periodically, as in the above subsection 3.2. The routes used by

applying our scheme are shown in Figs.7, 8 and 9, where the number of sensor nodes is 1000. In Figs.7, 8 and 9, T_e was set to 0.0J, E×0.5J, and E×0.9J, where E indicates the battery capaci-ty of each sensor node. Of the 3000 data packets transmitted from the evaluation node, the r-outes used by the first 500 data packets are illustrated in Figs.7, 8 and 9(a), those used by the 1000 data packets are in Figs.7, 8 and 9(b), those used by the 2000 data packets are in Figs.7, 8 and 9(c), and those used by a total of 3000 data packets are in Figs.7, 8 and 9(d). From Figs. 7, 8 and 9, it can be confirmed that the effect of our scheme is extended by early switching to low power.



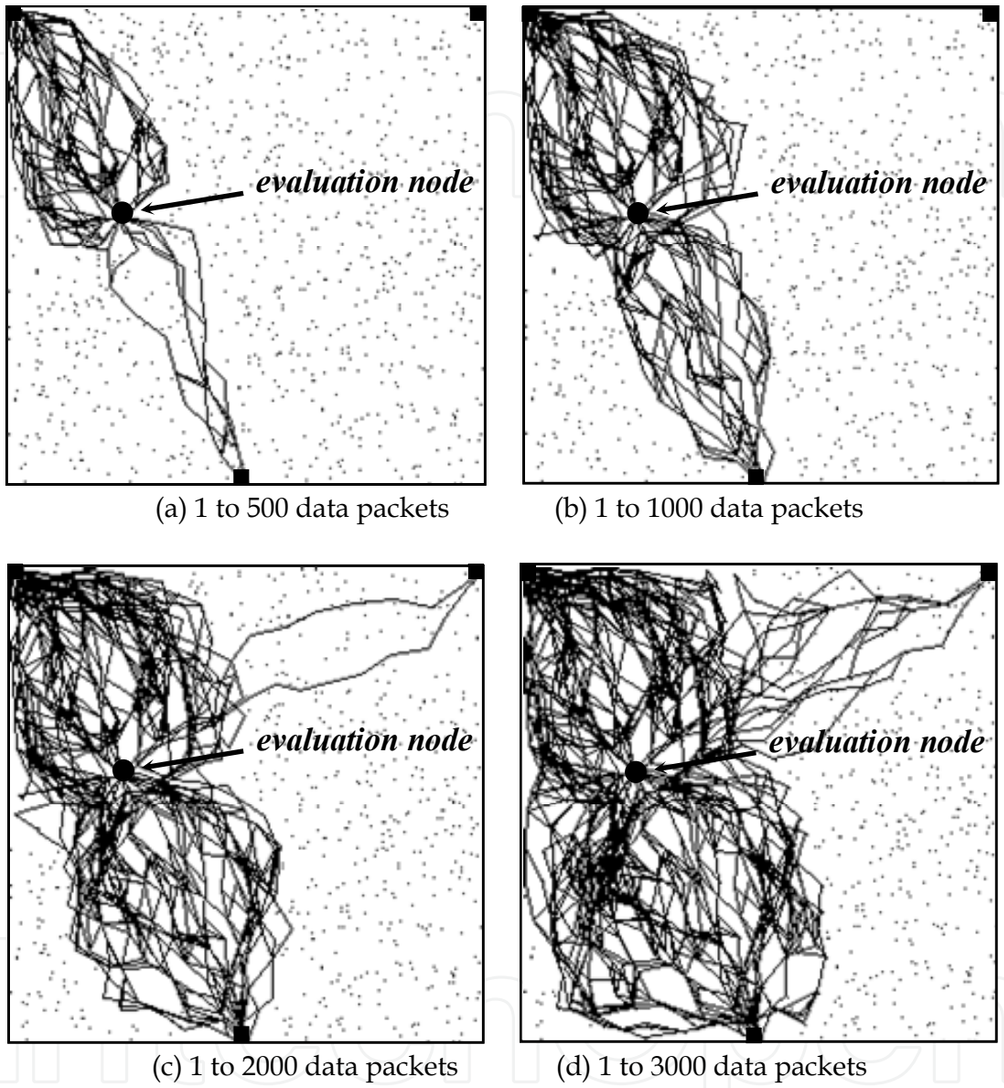
(a) 1 to 500 data packets (b) 1 to 1000 data packets

(c) 1 to 2000 data packets (d) 1 to 3000 data packets

Fig. 7. Routes used by applying our scheme (T_e = 0.0J)

Next, it was assumed that data packets were periodically transmitted from a total of 20 sens-or nodes placed in the set simulation area. In Figs.10, 11 and 12, the transition of the delivery ratio of the total number of data packets transmitted from a total of 20 randomly selected se-

nsor nodes is shown, and the lifetime of the simulation model with three sinks, as in Figs.7, 8 and 9, is compared. From Figs.10, 11 and 12, it can be confirmed that the effect of our scheme is extended by early switching to low power in high node density.



(a) 1 to 500 data packets (b) 1 to 1000 data packets

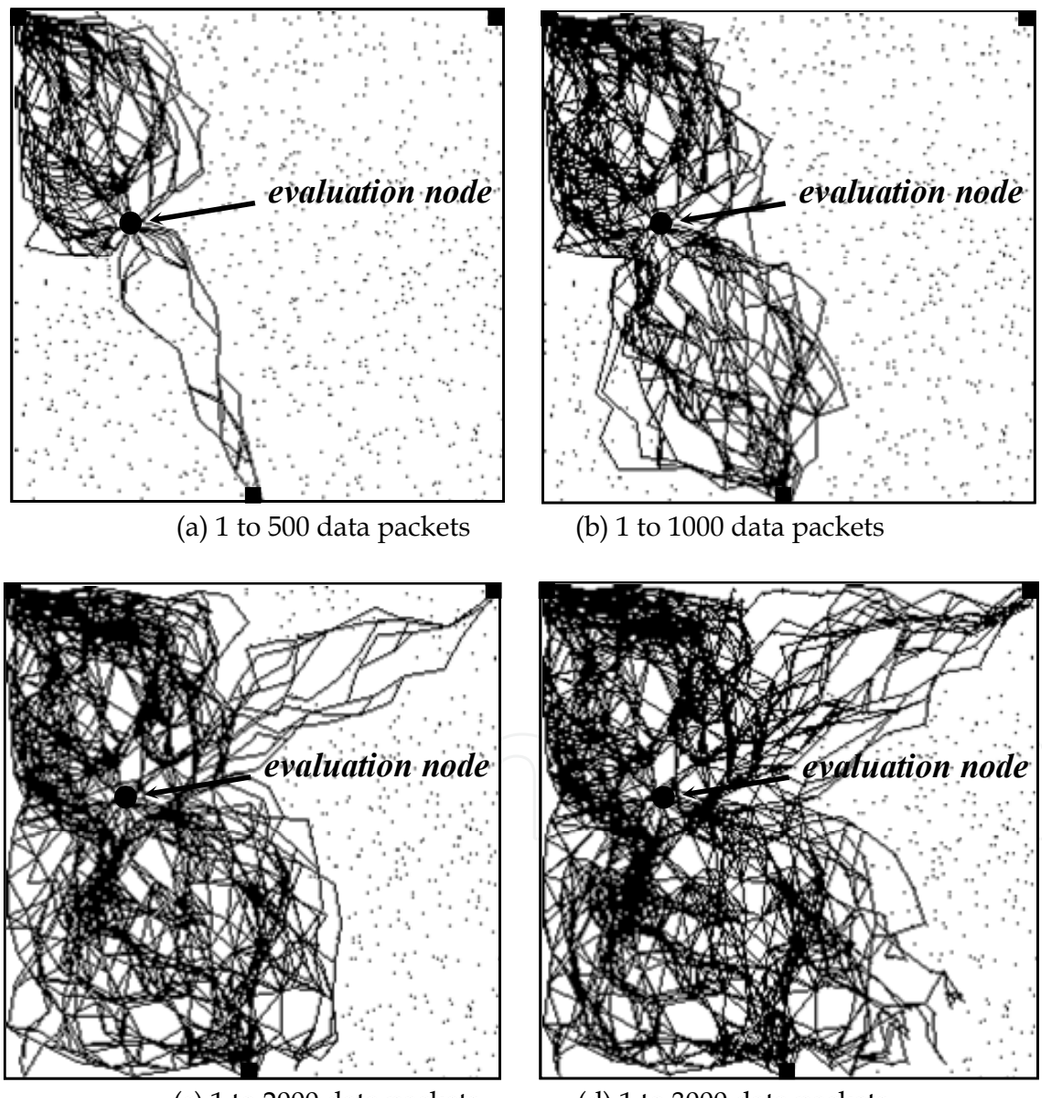
(c) 1 to 2000 data packets (d) 1 to 3000 data packets

Fig. 8. Routes used by applying our scheme (T_e = E×0.5J)

3.4 Discussion

To facilitate ubiquitous information environments by wireless sensor networks, their control mechanisms should be adapted to the variety of types of communication, depending on ap-plication requirements and the context. Currently, adaptive communication protocols for the long-term operation of the above ubiquitous sensor networks (Intanagonwiwat et al., 20-03; Silva et al., 2004; Heidemann et al., 2003; Krishnamachari & Heidemann, 2003; Wakabay-ashi et al., 2007) are under study. In

addition, the advanced design schemes of wireless sens-or networks, such as sink node allocation schemes based on the particle swarm optimization algorithms aiming to minimize total hop counts in a network and to reduce the energy cons-umption of each sensor node (Kumamoto et al., 2008; Yoshimura et al., 2009; Taguchi et al., 2010), and forwarding node set selection schemes (Nagashima et al., 2009; Sasaki et al., 2010) and forwarding power adjustment scheme (Nagashima et al., 2011) for adaptive and efficie-nt query dissemination throughout a wireless sensor network, are positively researched. By coupling our scheme (Matsumoto et al., 2010) with the above advanced design schemes, it can be expected that the lifetime of a wireless sensor network is moreover prolonged.



(a) 1 to 500 data packets (b) 1 to 1000 data packets

(c) 1 to 2000 data packets (d) 1 to 3000 data packets

Fig. 9. Routes used by applying our scheme (T_e = E×0.9J)

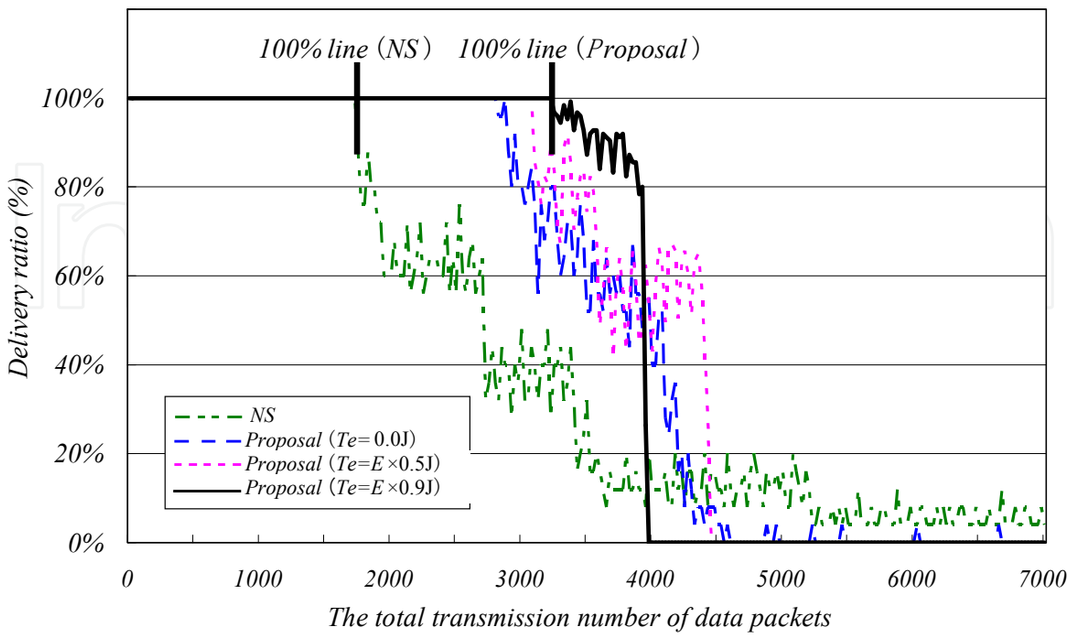


Fig. 10. Transition of delivery ratio (The number of sensor nodes is 750)

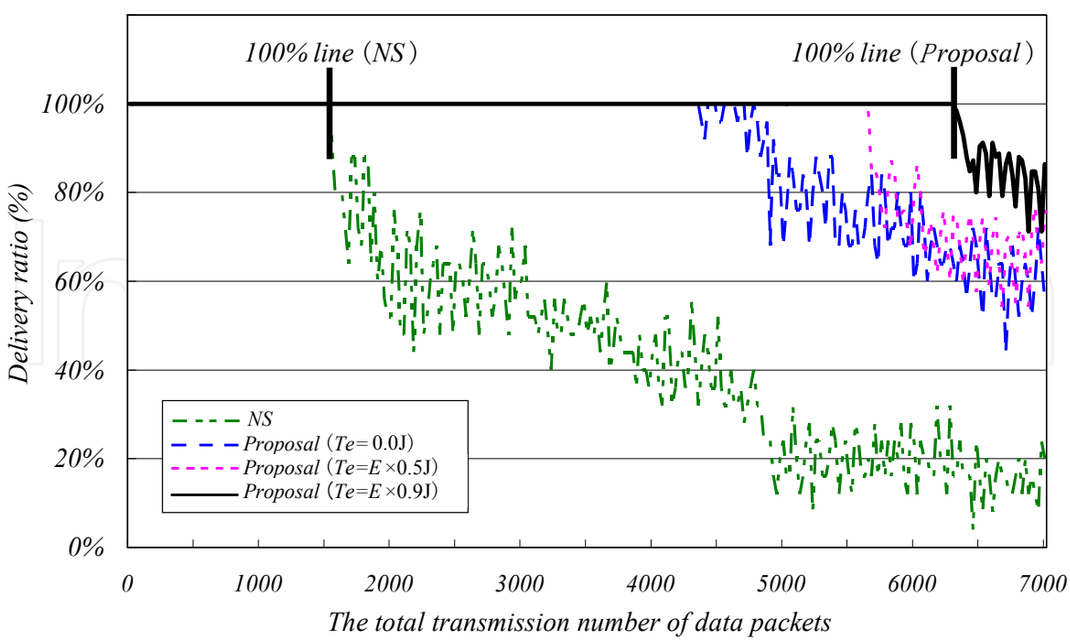


Fig. 11. Transition of delivery ratio (The number of sensor nodes is 1000)

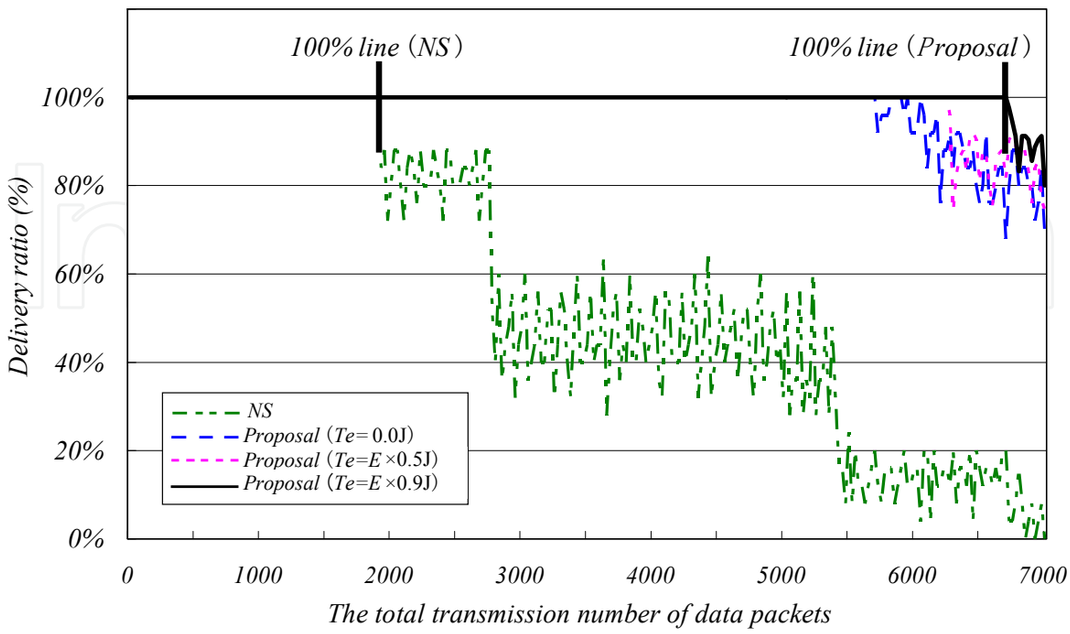


Fig. 12. Transition of delivery ratio (The number of sensor nodes is 1250)

4. Conclusions

In this chapter, a new data gathering scheme with transmission power control that adaptively reduces the load of load-concentrated nodes and facilitates the long-term operation of a large scale and dense wireless sensor network with multiple sinks, which is an autonomous load-balancing data transmission one devised by considering the application environment of a wireless sensor network to be a typical example of complex systems, has been represented. In simulation experiments, the performances of this scheme were compared with those of the existing ones. The experimental results indicate that this scheme is superior to the existing ones and has the development potential as a promising one from the viewpoint of the long-term operation of wireless sensor networks. Future work includes a detailed evaluation of the parameters introduced in this scheme in various network environments.

5. Acknowledgment

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6. References

Akyildiz, I.; Su, W.; Sankarasubramaniam, Y. & Cayirci, E. (2002). Wireless sensor networks: A survey, *Computer Networks Journal*, Vol.38, No.4, 393-422

Clausen, T. & Jaquet, P. (2003). Optimized link state routing protocol, *Request for Comments (RFC) 3626*

Dasgupta, K.; Kalpakis, K. & Namjoshi, P. (2003). An efficient clustering-based heuristic for data gathering and aggregation in sensor networks, *Proceedings of IEEE Wireless Communications and Networking Conference*, 16-20

Dubois-Ferriere, H.; Estrin, D. & Stathopoulos, T. (2004). Efficient and practical query scoping in sensor networks, *Proceedings of IEEE International Conference on Mobile Ad-Hoc and Sensor Systems*, 564-566

Heidemann, J.; Silva, F. & Estrin, D. (2003). Matching data dissemination algorithms to application requirements, *Proceedings of 1st ACM Conference on Embedded Networked Sensor Systems*, 218-229

Heinzelman, W.R.; Chandrakasan, A. & Balakrishnan, H. (2000). Energy-efficient communication protocol for wireless microsensor networks, *Proceedings of Hawaii International Conference on System Sciences*, 3005-3014

Intanagonwiwat, C.; Govindan, R.; Estrin, D.; Heidemann, J. & Silva, F. (2003). Directed diffusion for wireless sensor networking, *ACM/IEEE Transactions on Networking*, Vol.11, 2-16

Jin, Y.; Jo, J. & Kim, Y. (2008). Energy-efficient multi-hop communication scheme in clustered sensor networks, *International Journal of Innovative Computing, Information and Control*, Vol.4, No.7, 1741-1749

Johnson, D.B.; Maltz, D.A.; Hu, Y.C. & Jetcheva, J.G.(2003). The dynamic source routing protocol for mobile ad hoc networks, *IETF Internet Draft*, draft-ietf-manet-dsr-09.txt

Krishnamachari, B. & Heidemann, J. (2003). Application-specific modeling of information routing in wireless sensor networks, *Technical Report*, ISI-TR-2003-576, USC-ISI

Kumamoto, A.; Utani, A. & Yamamoto, H. (2008). Improved particle swarm optimization for locating relay-dedicated nodes in wireless sensor networks, *Proceedings of 2008 Joint 4th International Conference on Soft Computing and Intelligent Systems and 9th International Symposium on Advanced Intelligent Systems*, 1971-1976

Matsumoto, K.; Utani, A. & Yamamoto, H. (2009). Adaptive and efficient routing algorithm for mobile ad-hoc sensor networks, *ICIC Express Letters*, Vol.3, No.3(B), 825-832

Matsumoto, K.; Utani, A. & Yamamoto, H. (2010). Bio-inspired data transmission scheme to multiple sinks for the long-term operation of wireless sensor networks, *International Journal of Artificial Life and Robotics*, Vol.15, No.2, 189-194

Nagashima, J.; Utani, A. & Yamamoto, H. (2009). Efficient flooding method using discrete particle swarm optimization for long-term operation of sensor networks, *ICIC Express Letters*, Vol.3, No.3(B), 833-840

Nagashima, J.; Utani, A. & Yamamoto, H. (2011). A study on efficient query dissemination in distributed sensor networks -Forwarding power adjustment of each sensor node using particle swarm optimization-, *Proceedings of 16th International Symposium on Artificial Life and Robotics*, 703-706

Nakano, H.; Utani, A.; Miyauchi, A. & Yamamoto, H. (2009). Data gathering scheme using chaotic pulse-coupled neural networks for wireless sensor networks, *IEICE Transactions on Fundamentals*, Vol.E92-A, No.2, 459-466

Nakano, H.; Utani, A.; Miyauchi, A. & Yamamoto, H. (2011). Chaos synchronization-based data transmission scheme in multiple sink wireless sensor networks, *International Journal of Innovative Computing, Information and Control*, Vol.7, No.4, 1983-1994

Ogier, R.; Lewis, M. & Templin, F.(2003). Topology dissemination based on reverse-path forwarding (TBRPF), *IETF Internet Draft*, draft-ietf-manet-tbrpf-10.txt

Ohtaki, Y.; Wakamiya, N.; Murata, M. & Imase, M. (2006). Scalable and efficient ant-based routing algorithm for ad-hoc networks, *IEICE Transactions on Communications*, Vol.E 89-B, No.4, 1231-1238

Oyman, E.I. & Ersoy, C. (2004). Multiple sink network design problem in large scale wireless sensor networks, *Proceedings of 2004 International Conference on Communications*, Vol. 6, 3663-3667

Perkins, C.E. & Royer, E.M. (1999). Ad hoc on-demand distance vector routing, *Proceedings of 2nd IEEE Workshop on Mobile Computing Systems and Applications*, 90-100

Rajagopalan, R. & Varshney, P.K. (2006). Data aggregation techniques in sensor networks: A survey, *IEEE Communications Surveys and Tutorials*, Vol.8, 48-63

Sasaki, T.; Nakano, H.; Utani, A.; Miyauchi, A. & Yamamoto, H. (2010). An adaptive selection scheme of forwarding nodes in wireless sensor networks using a chaotic neural network, *ICIC Express Letters*, Vol.4, No.5(A), 1649-1655

Silva, F.; Heidemann, J.; Govindan, R. & Estrin, D. (2004). Directed diffusion, *Technical Report*, ISI-TR-2004-586, USC-ISI

Subramanian, D.; Druschel, P. & Chen, J. (1998). Ants and reinforcement learning: A case study in routing in dynamic networks, *Technical Report TR96-259*, Rice University

Taguchi, Y.; Nakano, H.; Utani, A.; Miyauchi, A. & Yamamoto, H. (2010). A competitive particle swarm optimization for finding plural acceptable solutions, *ICIC Express Letters*, Vol.4, No.5(B), 1899-1904

Utani, A.; Orito, E.; Kumamoto, A. & Yamamoto, H. (2008). An advanced ant-based routing algorithm for large-scale mobile ad-hoc sensor networks, *Transactions on SICE*, Vol. 44, No.4, 351-360

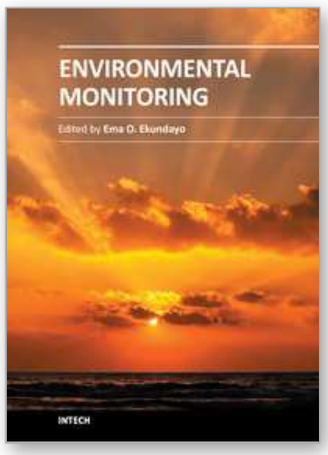
Wakabayashi, M.; Tada, H.; Wakamiya, N.; Murata, M. & Imase, M. (2007). Proposal and evaluation of a bio-inspired adaptive communication protocol for sensor networks, *IEICE Technical Report*, Vol.107, No.294, 89-94

Wakamiya, N. & Murata, M.(2005). Synchronization-based data gathering scheme for sensor networks, *IEICE Transactions on Communications*, Vol.E88-B, No.3, 873-881

Xia, L.; Chen, X. & Guan, X.(2004). A new gradient-based routing protocol in wireless sensor networks, *Lecture Notes in Computer Science*, Vol.3605, 318-325

Yamamoto, I.; Ogasawara, K.; Ohta, T. & Kakuda, Y. (2009). A hierarchical multicast routing using inter-cluster group mesh structure for mobile ad hoc networks, *IEICE Transactions on Communications*, Vol.E92-B, No.1, 114-125

Yoshimura, M.; Nakano, H.; Utani, A.; Miyauchi, A. & Yamamoto, H. (2009). An effective allocation scheme for sink nodes in wireless sensor networks using suppression PSO, *ICIC Express Letters*, Vol.3, No.3(A), 519-524



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