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Autonomous Decentralized Control Scheme for Large Scale and Dense Wireless Sensor Networks with Multiple Sinks

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***Abstract*:** A wireless sensor network has great potential as a key network to facilitate ubiquitous environments. A wireless sensor network is generally made up of many sensor nodes limited resource. Therefore, a data gathering scheme saving and balancing energy consumption of each sensor node is needed to prolong the lifetime of a wireless sensor network. This paper proposes an autonomous decentralized control scheme for a large scale and dense wireless sensor network, which is 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. The proposed scheme is evaluated by computer simulations.

***Keywords*: Data gathering, Autonomous load-balancing, Transmission power control, Wireless sensor networks.**

I. INTRODUCTION

A wireless sensor network has great potential as a key network to facilitate ubiquitous environments [1]. In this study, a large scale and dense wireless sensor network made up of static sensor nodes with GPS is assumed. In a large scale and dense wireless sensor network, generally, hundreds or thousands of static sensor nodes limited resource are placed in an observation area and sensing data of each node is gathered to a sink node by inter-node wireless communication. Therefore, a data gathering scheme capable of meeting the following two requirements is mainly needed to prolong the network lifetime.

1) Efficiency of data gathering
2) Balance on communication load among sensor nodes

In a large scale and dense wireless sensor network, the communication load is generally concentrated on sensor nodes around a sink node during the operation process. In case sensor nodes are not placed evenly in a large scale observation area, the communication load is concentrated on sensor nodes placed in an area of low node density. As the scheme that satisfy the above two requirements, gradient-based routing protocol has attracted attention [2]. However, this does not ease the communication load concentration to sensor nodes around a sink node that is the source of problems on the long-term operation of a wireless sensor network. Intensive data transmission to specific nodes, such as sensor nodes around a sink node and sensor nodes placed in an area of low node density, brings on concentrated energy consumption of them and causes them to break away from the network early. This makes the long-term observation by a wireless sensor network difficult. To solve this communication load concentration problem, a data gathering scheme for a wireless sensor network with multiple sinks has been proposed [3]. Each sensor node, in this scheme, sends sensing data to the nearest sink node. In comparison with the case of a one sink wireless sensor network, the communication load of sensor nodes around a sink node is reduced. In each sensor node, however, the destination (sink) node cannot be selected autonomously and adaptively. In case 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 paper proposes an autonomous decentralized control scheme for a large scale and dense wireless sensor network, which is 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. The proposed scheme is an autonomous load-balancing data transmission one devised by considering the application environment of a wireless sensor network as a typical example of complex systems where the adaptive adjustment of the entire system is realized from the local interactions of components of the system.

II. PROPOSED SCHEME

For facilitating the long-term operation of an actual sensor network service, recently, it has been considered to introduce multiple sinks in a wireless sensor network

[3]. In a wireless sensor network with multiple sinks, sensing data of each node is generally allowed to gather at any of the available sinks. The proposed scheme is a new data gathering one based on this assumption, which can be expected to produce a remarkable effect in a multiple sink wireless sensor network. In this study, it is assumed that each sensor node can select either of high power and low power for packet transmission. In the proposed scheme, high power corresponds to normal transmission power and low power is newly introduced for moreover balancing the load of each sensor node.

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 multiple sink wireless sensor network, 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, the location information and IDs on its own neighbor nodes, and the hop counts from each sink node of neighbor nodes.

Initial connective value of each sensor node, which is the connective one 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), and dr represents the value attenuation factor accompanying 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 Eq.(3), $vm_i(0)$ represents the greatest connective value before starting data transmission in neighbor nodes of node (i).

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

2. Data Transmission

For a while from starting data transmission, each sensor node selects the neighbor 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 case more than one node shares the greatest connective value, however, the relay node is determined from them at random. In each sensor node, the data packet is not sent to a specified sink node. By repetitive data transmission to the neighbor node with the greatest connective value, data gathering at any of the available sinks is completed. In the proposed scheme, the connective value of each sensor node is updated by considering residual node energy. By repetitive data transmission to the neighbor node with the greatest connective value, therefore, data transmission routes are not fixed.

To realize autonomous load-balancing data transmission, in the proposed scheme, the data packet from each sensor node includes its own updated connective value. Let's 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), and $e_l(t)$ and E_l represent the residual energy at time (t) of node (l) and the battery capacity of node (l), respectively.

In the proposed scheme, the data packet addressed to the neighbor node with the greatest connective value is intercepted by all neighbor nodes. This data packet includes the updated connective value of the source node based on the above Eq.(4). Each neighbor node that has intercepted this packet stores the updated connective value in the source node field of its own routing table. The proposed scheme requires the construction of a data gathering environment in the initial state of a wireless sensor network but needs no special communication for network control. The above simple system alone achieves autonomously adaptive load-balancing data transmission using multiple routes and sinks. 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.

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 neighbor 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.

Fig.1 shows an example on the above transmission power control, which means that the transmission power of each sensor node is switched to low power according to the above condition. 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 the proposed scheme, therefore, every tenth data packet from the node switched to low power is transmitted by high power.

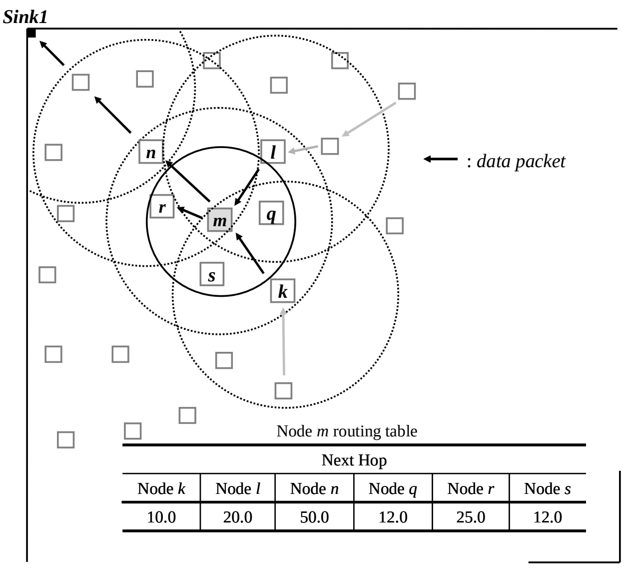


Fig.1 An example on transmission power control

III. SIMULATION EXPERIMENT

Through simulation experiments on a large scale wireless sensor network with three sinks, the performance of the proposed scheme is investigated.

1. Condition of Simulations

In a wireless sensor network with three sinks consisting of many static sensor nodes placed in a large-scale observation area, the only sensor nodes that detected abnormal data set were assumed to transmit the measurement data. The condition of simulations, which were used in the experiments performed, is shown in Table 1. In the initial state of simulation experiments, static sensor nodes are randomly arranged in the set simulation area and three sinks are placed on the three boundaries containing the two corners of this area. In Fig.2, the network configuration is illustrated.

Table 1. Condition of simulations

Simulation size	*2,400m ✕ 2,400m*
The number of sensor nodes	*750, 1,000, 1,250*
Range of radio wave	*200m(high power),150m(low power)*
The number of sinks	*3*

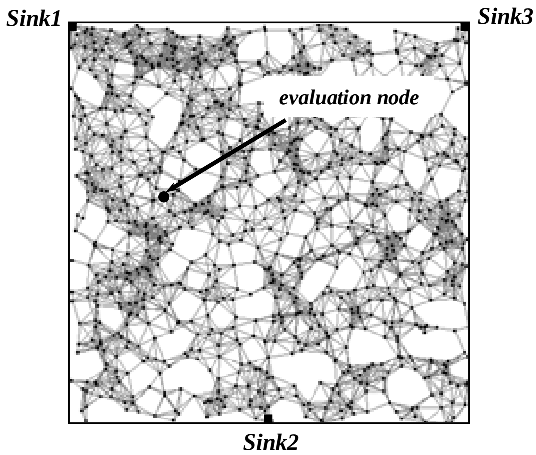
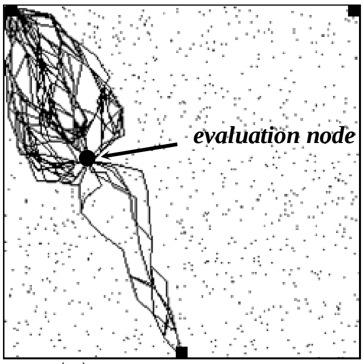


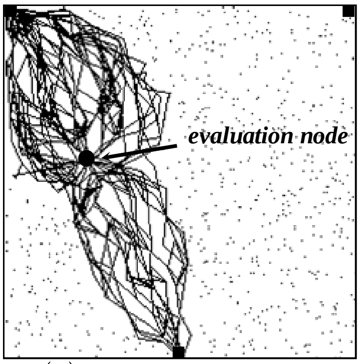
Fig.2 Wireless sensor network with three sinks

2. Experimental Results

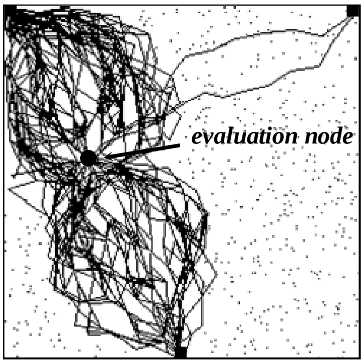
As the first experiment, it was assumed that the evaluation node marked in Fig.2 detected an abnormal value and transmitted the data packet with the detected abnormal value periodically. The routes used by applying the proposed scheme are shown in Fig.3 and Fig.4, where the number of sensor nodes is 1,000. Of the 2,000 data packets transmitted from the evaluation node, the routes used by the first 500 data packets are shown in Fig.3 and Fig.4(1), those by the first 1,000 data packets are shown in Fig.3 and Fig.4(2), and those by a total of 2,000 data packets are shown in Fig.3 and Fig.4(3). From Fig.3 and Fig.4, it can be confirmed that the proposed scheme enables autonomous load-balancing transmission of data packets to three sinks using multiple routes and its effect is extended by early switching to low power.



(1) 1 to 500 data packets

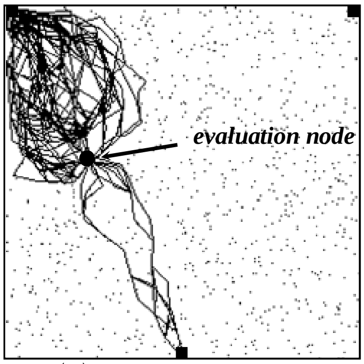


(2) 1 to 1,000 data packets

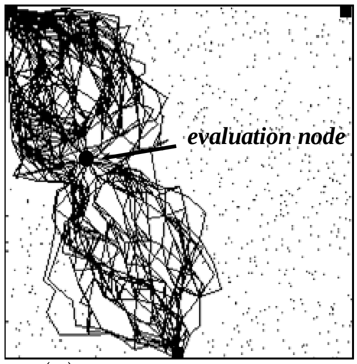


(3) 1 to 2,000 data packets

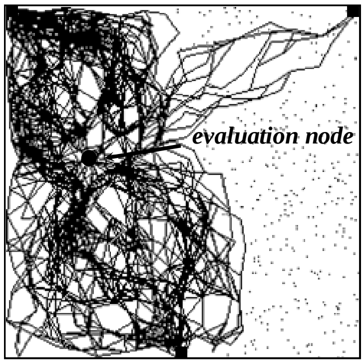
Fig.3 Routes used by applying the proposed scheme ($T_e = E \times 0.5$J)



(1) 1 to 500 data packets



(2) 1 to 1,000 data packets



(3) 1 to 2,000 data packets

Fig.4 Routes used by applying the proposed scheme ($T_e = E \times 0.9$J)

IV. CONCLUSIONS

In this paper, 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 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 proposed. Experimental results indicate that the proposed scheme is superior to the existing one and has the development potential as a promising one from the viewpoint of the long-term operation. Future works include evaluation on parameters introduced in the proposed scheme in detail and verification of its effectiveness on various network environments.

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