The Fifteenth International Symposium on Artificial Life and Robotics 2010 (AROB 15th '10),
B-Con Plaza, Beppu,Oita, Japan, February 4-6, 2010

Autonomous Load-Balancing Data Transmission Scheme to Multiple Sinks for Long-Term Operation of Wireless Sensor Networks

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Abstract: There is growing expectation for wireless sensor networks as a means of realizing various applications, such as natural environmental monitoring, object tracking, and environmental control in residential spaces or plants. In wireless sensor networks, hundreds or thousands of micro-sensor nodes with such resource limitation as battery capacity, memory, CPU, and communication capacity are placed in an observation area and used to gather sensor information of environments. Therefore, a routing algorithm or a data gathering scheme saving and balancing energy consumption of each node is needed to prolong the lifetime of wireless sensor networks. This paper proposes a new data transmission scheme for the long-term operation of wireless sensor networks. By using the proposed scheme, autonomous load-balancing data transmissions to multiple sinks are actualized. We evaluate the proposed scheme using computer simulations and discuss its development potential. In simulation experiments, the performance of the proposed scheme is compared with those of the existing ones to verify its effectiveness.

Keywords: Wireless Sensor Networks, Multiple Sinks, Data Gathering, Autonomous Load-Balancing.

I. INTRODUCTION

Wireless sensor networks have a wide range of applications, such as natural environmental monitoring, object tracking, and environmental control in residential spaces or plants [1]. In wireless sensor networks, hundreds or thousands of sensor nodes, which are generally compact and inexpensive, are placed in a large-scale observation area and sensor information of each node is gathered to a sink node by inter-node wireless multi-hop communication. Each node consists of a sensing function to measure the status (temperature, humidity, motion, etc.) of an observation point or object, a limited information processing function, and a simplified wireless communication function, and generally operates on a resource of a limited power-supply capacity such as a battery. Therefore, a routing algorithm or a data gathering scheme capable of meeting the following requirements is needed to prolong the lifetime of wireless sensor networks.

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

Clustering-based data gathering scheme [2] and synchronization-based data gathering scheme [3] are under study as communication protocols for the long-term operation of wireless sensor networks, but not all the above requirements are satisfied.

Recently, ant-based routing algorithms have attracted attentions as the algorithms that satisfy the above three requirements [4]. In ant-based routing algorithms, the routing table of each node is generated and updated by applying a process in which ants build routes between their nest and feed by chemical substances (pheromones). The advanced ant-based routing algorithm of [5] is an efficient route-learning algorithm, which shares route information between control messages (ants). In contrast to the conventional ant-based routing algorithms, this algorithm can suppress the communication load of sensor nodes and adapt itself to network topology changes. However, this does not positively ease the communication load concentration to specific nodes that are the source of problems on the long-term operation of wireless sensor networks. Intensive data transmission to specific nodes brings on concentrated energy consumption of them and causes them to break away from the network early. This makes long-term observation by wireless sensor networks difficult.

In wireless sensor networks, the communication load is generally concentrated on sensor nodes around a sink node during the operation process of wireless sensor networks. 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. To solve this node load concentration problem, data gathering scheme for wireless sensor networks with multiple sinks has been proposed [6]. Each node, in this scheme, sends sensing data to the nearest sink node. In comparison with the case of one sink-wireless sensor networks, the communication load on sensor nodes around a sink node is reduced. In each node, however, the destination (sink) node is not selected autonomously and adaptively.

This paper proposes a new data transmission scheme that adaptively reduces the load on load-concentrated nodes and facilitates the long-term operation of wireless sensor networks. The proposed scheme is an autonomous load-balancing data transmission scheme devised by considering the application environment of wireless sensor networks 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. In the proposed scheme, the load of each node is autonomously balanced. The routing table of each node is composed of the pheromone value of every neighbor node. Each node determines a relay node of sensing data from the pheromone value updated by considering the residual energy of neighbor nodes. Consequently, the destination sink node and the data transmission route to the sink node are determined.

The rest of this paper is organized as follows. In Section II, the proposed scheme is first detailed, and its novelty and superiority are described. In Section III, the results of simulation experiments are reported, and the effectiveness of the proposed scheme is demonstrated by comparing the performance of it with those of the existing ones. Finally, the paper closes with conclusions and ideas for further study in Section IV.

II. PROPOSED SCHEME

Wireless sensor networks are generally used to observe and monitor the status of an object area. At a set sink node, it is expected that the gathering of sensing data from sensor nodes placed in a large-scale object area can be performed. For actual sensor network service, recently, it has been considered to introduce multiple sink nodes in wireless sensor networks [6]. In wireless sensor networks with multiple sinks, the sensing data is allowed to gather at any of the available sink nodes. The proposed scheme is a new data transmission scheme based on this assumption, which can be expected to produce a remarkable effect in multiple sink-wireless sensor networks.

1. Construction of Data Gathering Environment

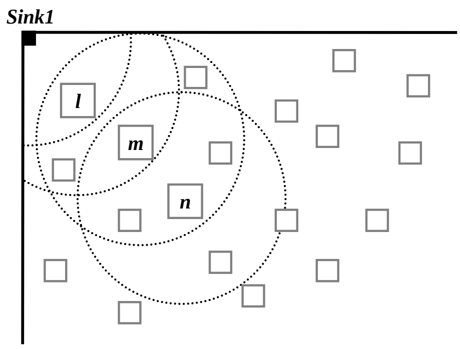
In each node, its sensing data is not transmitted to a specified destination sink node. By repetitive data transmission that is dependent on the pheromone value of every neighbor node in the routing table of each node, the data gathering at any of the available sink nodes is consequently completed. Each sink node has a pheromone value named a "value to self", which is not updated by transmitting a control packet and receiving a data packet. In the proposed scheme, this pheromone value is dispersed from each sink node to each sensor node in the initial state. In each sensor node, the pheromone value is stored in its routing table as an index to evaluate the value of a neighbor node as the relay destination.

In the initial state of a wireless sensor network, each sink node locally broadcasts a control packet composed of its own ID and "value to self". On receiving this control packet, each sensor node performs the following processing and locally broadcasts a new control packet.

1. A node (l) that has received the control packet stores the received pheromone value in the source field of the routing table first, where "value to self" is stored in case that the source is a sink node.
2. As a piece of information included in a new control packet, next, node (l) computes its own pheromone value (v_l) from the greatest pheromone value ($vmax$) in the routing table as follows:

$$v_l = vmax \times dr_{hop} \qquad (0 < dr_{hop} < 1) \qquad (1)$$

where dr_{hop} is the pheromone value attenuation factor accompanying the hop. Then, a new control packet composed of a node ID (l) and this computed value (v_l) is locally broadcast.



node *l* routing table

Next Hop		
SN*1*	NH*m*	···
100	*25*	···

node *m* routing table

Next Hop		
NH*l*	NH*n*	···
50	*12.5*	···

node *n* routing table

Next Hop		
NH*m*	···	···
25	···	···

Fig.1. Pheromone dispersion from a sink node

In Figure 1, an example of pheromone dispersion is shown when "value to self" of the sink node is 100 and the attenuation factor (dr_{hop}) is 0.5. By executing the above processing at appropriate time intervals at each node, "value to self" of the sink node is efficiently dispersed to surrounding nodes with attenuating.

2. Data Transmission and Pheromone Value Update

For data packet transmission, each node selects a node with the greatest pheromone value from the neighbor nodes as a relay node and transmits the data packet to this selected node. In case that more than one node share the greatest pheromone value, however, a relay node is determined from them at random.

To realize load-balancing data transmission by considering residual node energy, a data packet in the proposed scheme includes a pheromone value updated as follows:

$$v_l = vmax \times dr_{hop} \times dr_{lec} \quad (0 < dr_{hop} < 1) \qquad (2)$$

$$dr_{lec} = E'_l / E \qquad (3)$$

The above (2) and (3) are the pheromone update equations of a node (l), where E_l' and E represent the residual energy of node (l) and the battery capacity of each node, respectively.

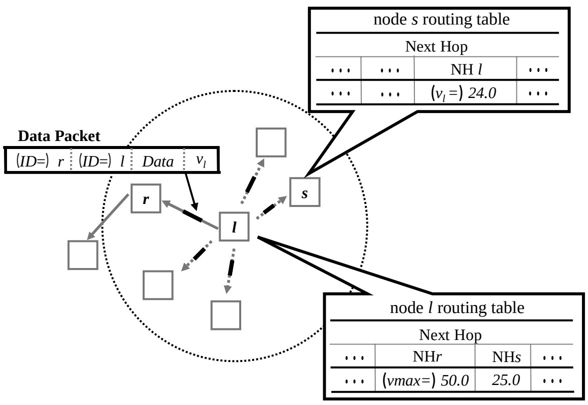


Fig.2. Data transmission and pheromone value update

In the proposed scheme, a data packet addressed to a node of the greatest pheromone value is intercepted by all neighbor nodes. This data packet includes the pheromone value of the source node updated with the residual energy taken into consideration. Each node that has intercepted this packet stores the value in the routing table and updates the pheromone value of the source node. In Figure 2, an example on the transmission of a data packet addressed to a node of the greatest pheromone value and its accompanying pheromone value update is shown. In this example, node (l) refers to its own routing table and transmits a data packet addressed to node (r), which has the greatest pheromone value. When this data packet is intercepted, each neighbor node around node (l) stores the updated pheromone value (v_l) computed by the above equations (2) and (3) in the NHl field of the routing table.

The proposed scheme requires the construction of a data gathering environment in the initial state of wireless sensor networks, but needs no special communication for network control. In the proposed scheme, each node adds a pheromone value updated by considering the residual energy to a data packet at data transmission. At the data transmission process, each neighbor node intercepts this data packet and updates the pheromone value of the source node in the routing table. This simple mechanism alone achieves autonomously adaptive load-balancing data transmission using multiple routes and sink nodes. The lifetime of wireless sensor networks can be extended by reducing the communication load for network control and solving the node load concentration problem.

III. SIMULATION EXPERIMENT

Through simulation experiments, the performance of the proposed scheme is investigated in detail to verify its effectiveness.

1. Conditions of Simulations

In a wireless sensor network consisting of many sensor nodes placed in a wide range, only sensor nodes that detected abnormal values or obtained specific information were assumed to transmit the measurement data. The conditions of simulation, which were used in the experiments performed, are shown in Table 1. In the simulation area, sensor nodes are arranged at random. Two sink nodes are placed on the two corners of this area. In Figure 3, the network configuration is illustrated.

In the experiments performed, the pheromone value attenuation factor accompanying hop (dr_{hop}) and the "value to self" of each sink node were set to 0.5 and 100.0, respectively. The sizes of data packet and control packet were set to 18 bytes and 6 bytes, respectively. The battery capacity (E) of each node was set to 0.5 J.

In the experimental results reported, the proposed scheme is evaluated through the comparison with the existing ones of [4]-[6]. On the schemes of [4]-[6], the simulation settings that were used in [7] and produced good results in a preliminary investigation were adopted for the comparison with the proposed scheme.

Table 1. Conditions of simulations

Simulation size	*2,400 m × 2,400 m*
The number of sensor nodes	*1,000*
Range of radio wave	*150 m*
The number of sink nodes	*2*

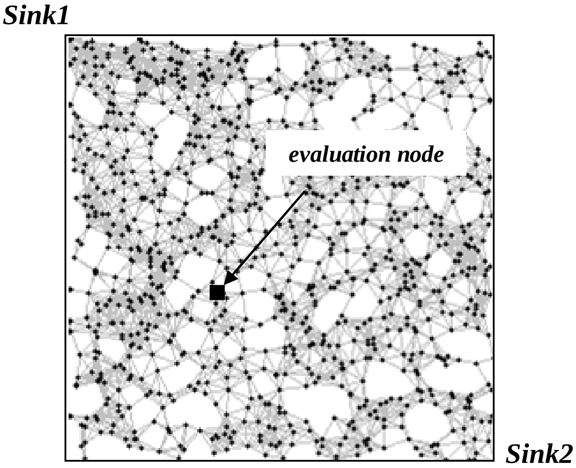
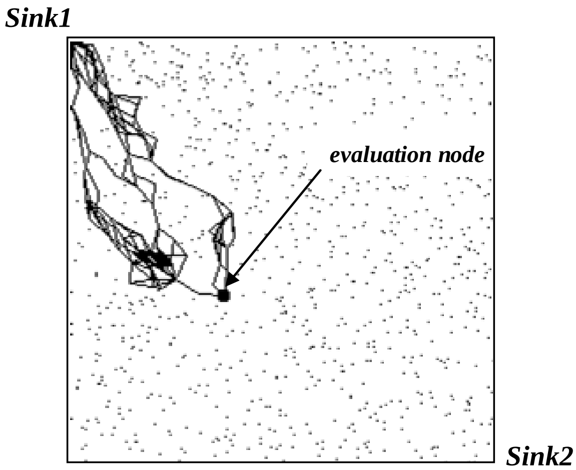


Fig.3. Multiple sink-wireless sensor network

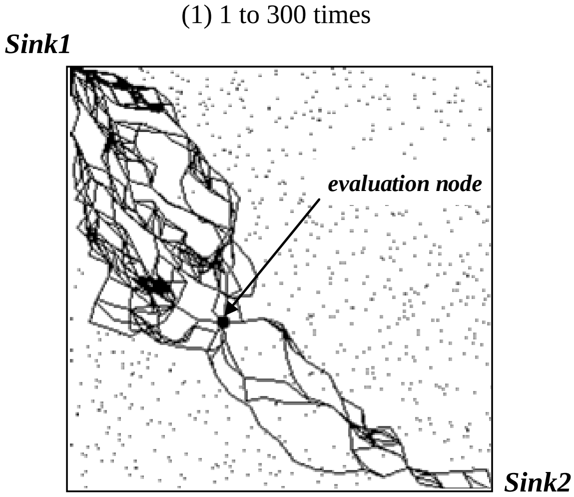
2. Experimental Results

As the first experiment, it was assumed that the evaluation node marked in Figure 3 detected an abnormal value and transmitted a data packet periodically. The routes used by applying the proposed scheme are shown in Figure 4. Of the 2,000 data packet transmissions from the evaluation node, the routes illustrated in (1) were used in the first 300 transmissions, those of (2) 1 to 1,000 transmissions, and those of (3) in a total of 2,000 transmissions. From (1)-(3) in Figure 4, the autonomous switching of destination sink nodes and routes to each sink node can be confirmed. Since the proposed scheme is not a data transmission one specifying address, autonomous load-balancing data transmissions to two sink nodes using multiple routes are enabled. The node load can be improved and balanced by applying the proposed scheme.

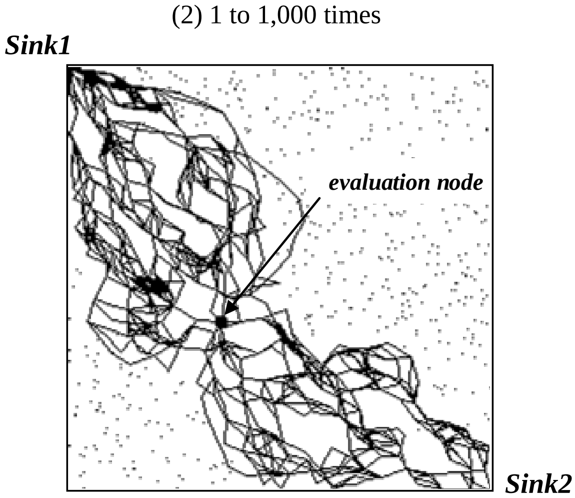
Next, it was assumed that data packets were periodically transmitted from a total of 20 sensor nodes to sink nodes. In Figure 5, the transition of the delivery ratio on the number of total transmissions from a total of 20 nodes randomly selected to sink nodes is shown and the lifetime of the multiple sink-wireless sensor network used in this experiment is compared. In this figure, two existing schemes based on ant-based routing algorithms of [4] and [5] are denoted as *MUAA* and *AAR*, respectively. The existing scheme of [6], which is a data gathering one for multiple sink-wireless sensor networks, is denoted as *NS*. The result of Figure 5 verifies that the proposed scheme is substantially advantageous for the long-term operation of wireless sensor networks.



(1) 1 to 300 times



(2) 1 to 1,000 times



(3) 1 to 2,000 times

Fig.4. Routes used by applying the proposed scheme

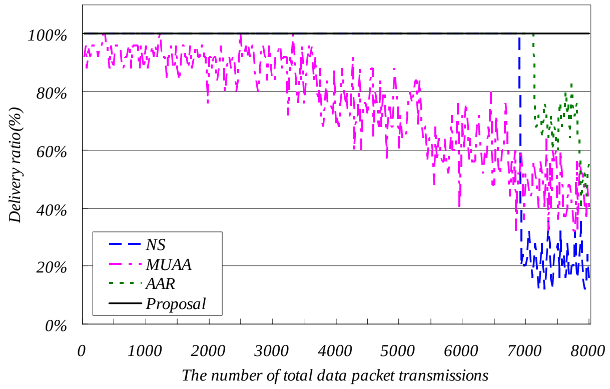


Fig.5. Transition of delivery ratio

IV. CONCLUSIONS

In this paper, a data transmission scheme that adaptively reduces the load on load-concentrated nodes and facilitates the long-term operation of wireless sensor networks, which is an autonomous load-balancing data transmission one devised by considering the application environment of wireless sensor networks to be a typical example of complex systems, has been proposed. In the experiments, the performance of the proposed scheme was compared with those of the existing ones. Experimental results indicate that the proposed 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 works include evaluation on the parameter introduced in the proposed scheme in detail and verification of its effectiveness to various network environments.

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