

Energy Efficient Route Construction Scheme with Continuous and Discrete Power Control in Ad Hoc Sensor Networks

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Abstract—In this paper, we propose a novel energy efficient route construction scheme with transmission power control in ad hoc sensor networks. The proposed scheme is very simple and can improve energy consumption performance without any information of neighbor nodes. In the proposed scheme, when a node receives a route request (RREQ), the node calculates the standby time inversely proportional to the received power of the RREQ. The node relays the RREQ with full power when the standby time expires in order to construct the least energy consumption route. After the route construction, source and intermediate nodes transmit packets with power controlled medium access control (MAC) protocol. In addition, we propose the extended version of the proposed scheme to construct energy efficient route in discrete power control environment. Simulation results show the proposed scheme can construct more energy efficient route than the conventional schemes in both continuous and discrete power control environment.

I. INTRODUCTION

The rapid progress in sensor devices and wireless technologies enables ad hoc sensor networks to be realized. They have an advantage that they need no specific predefined infrastructure, so that they are expected to be applicable to a wide variety of fields, e.g. agriculture, environment assessment, civil engineering, disaster mitigation, animal tracking, and so forth. For such applications ad hoc sensor networks are required to provide an effective way for small nodes to communicate with significant restriction on batteries. Several protocols and methods have been proposed in medium access control layer (MAC), routing layer, and application layer to extend network lifetime and to achieve high energy efficiency [1].

Among them routing algorithms are proposed in [2]-[6]. [2] constructs a route which contains nodes so as to level off residue of batteries of all nodes. However it does not decrease the total battery consumption. Moreover, if a specific path is always used to meet application requirements, these methods fail to level off the batteries. The Friis transmission equation and its extensions indicate that transmission power is in proportion to the n -th (n varies from 2 through 4.) power of the distance between a transmitter and a receiver. That means that shorter distance of a hop greatly decreases transmission power. According to this simple observation, some routing algorithms for constructing an energy efficient route have been

also proposed in [3]-[6]. These methods request that a node chooses a nearest node as a next hop, which reduces not only transmission power but also exposed nodes along the route from sources to destinations to achieve better throughput because of spatial reuse over time. However, these routing methods require much control traffic to obtain information of neighbor nodes. However, location information is not sufficient to derive the optimally energy efficient route. Additionally, the conventional methods cannot construct the accurate energy efficient route, if nodes have different types of antennas.

In this paper, we propose a novel energy efficient route construction scheme with transmission power control in ad hoc sensor networks. The proposed scheme is very simple and can improve energy consumption performance without any information of neighbor nodes. In the proposed scheme, when a node receives a route request (RREQ), the node calculates the standby time inversely proportional to the received power of the RREQ. The node relays the RREQ with full power when the standby time expires in order to construct the least energy consumption route. After the route construction, source and intermediate nodes transmit packets with power controlled MAC protocol. In addition, we propose the extended version of the proposed scheme to construct energy efficient route with discrete power control environment. Simulation results show the proposed scheme can construct more energy efficient route than the conventional schemes in both continuous and discrete power control environment.

II. RELATED WORKS

In order to extend network lifetime, [2] constructs a route which contains nodes so as to level off residue of batteries of all nodes. In the conventional routing algorithm, nodes make routing decisions solely on the basis of location of their neighbors and destination. However, these routing algorithms cannot decrease the total battery consumption.

According to the Friis transmission equation, it is known that shorter distance of a hop greatly decreases transmission power. There are some power efficient route construction methods [3]-[6]. Power-aware routing optimization (PARO) is proposed in order to minimize the transmission power between

source and destination [3]. In PARO, one or more intermediate nodes called “redirectors” is elected to forward packets even when the source and destination can communicate directly. However, since the intermediate nodes are selected locally, the route between source and destination may become longer.

Directionality-based power efficient routing (DPER) [4] is a routing protocol which constructs a power efficient route by selecting a node locating close to the destination as the next hop. In the route constructing phase, DPER divides the area into some round areas in which it centers on the destination. The source node selects a node which can communicate with the lowest power, located in the adjoining area for the next hop. In DPER, each sender can select the intermediate node through which the overall route is gradually approached to the destination. However, since DPER needs location information of other nodes, much control traffic is generated.

Connectivity set protocol (CONSET) [5] is a cross-layer solution to construct a power efficient route. CONSET maintains the connectivity set (CS). CS is the most energy efficient set of nodes that guarantees the node’s connectivity to the network. When receiving a request to send (RTS), clear to send (CTS), or Hello, CONSET estimates distance and angle of arrival of the sender node. The node is added into CS if the node is detected first and can communicate with the lowest power directly. CONSET constructs a power efficient route by transmitting RREQ with power which reaches the farthest node in CS. CONSET needs much traffic to estimate the location of neighbor nodes. Moreover, CONSET has a problem of not operating normally in the environment which has nodes equipped with different characteristic antenna.

In addition, it is not considered for the above route construction schemes to operate discrete power control environment. It is required a simple power efficient routing algorithm under continuous and discrete power control environment operating with different characteristic antennas, without using position information.

III. PROPOSED SCHEME

A. Proposed route construction algorithm

The proposed scheme operates in the following procedures in order to construct an energy efficient route. The proposed scheme has two phases, the route constructing phase and data transmission phase.

In the route constructing phase, when a node receives a RREQ, the node calculates the standby time inversely proportional to the received power of the RREQ. The node relays the RREQ with full power when the standby time expires, so that the node with less standby time relays earlier than other nodes receiving the same RREQ. This means that a node with the strongest receiving power dominates in relaying the RREQ in order to create the least energy consumption route in data transmission phase. When the destination receives the earliest RREQ, it sends back the route reply (RREP) to the source node along the route. After receiving RREP, nodes transit to data transmission phase.

In the data transmission phase, the source and intermediate nodes transmit data packets with minimum transmission power by power control MAC protocol [7]-[10].

B. Standby time

In the proposed scheme, a node receives a RREQ calculates standby time according to the received power of the RREQ. Standby time T_{stby} [sec] is calculated as follows.

$$T_{stby} = a \left(\frac{1}{P_r} \right)^b \quad (1)$$

where P_r [mW] is the received power of a RREQ, a is a parameter which adjusts the scale of the standby time, and b is a parameter which adjusts the priority of short hop. If the standby time calculated by (1) is shorter than backoff time of the MAC protocol, it may happen to unintended change of the order of RREQ forwarding. Therefore, enough large a should be chosen to set longer standby time than backoff time of MAC layer. However, too large a causes increasing the route construction delay. Therefore, largest a which satisfies required route construction delay should be set. On the other hand, large b reduces the standby time when a strong received power is observed.

When a node receives multiple RREQs from different nodes, the standby time is updated to the shortest one.

C. An example operation

We assume a topology which has five nodes of the same characteristic antenna as shown in Fig. 1(a). A route construction request to node D is generated in node S. Node S broadcasts a RREQ, and nodes A and B receive the RREQ. We define that the calculated standby time according to the RREQ from node S denotes T_s . Nodes A and B calculate T_s according to the received power of the RREQ, respectively. Since node A observes a stronger power than that at node B, node A calculates shorter T_s than node B’s T_s . We assume $T_s = 10$ at node A and $T_s = 120$ at node B, respectively.

At $T = 10$, node A expires standby time first, the RREQ is broadcasted by Node A. The RREQ is received by nodes S, B, C as shown in Fig. 1(b). Each node checks the sequence number of the received RREQ. Node S judges the RREQ which has been already transmitted by checking the sequence number, and it cancels to forward the RREQ. Nodes B and C calculate T_a , the standby time until re-broadcasting the RREQ from each node. We assume $T_a = 20$ at node B and $T_a = 140$ at node C, respectively.

Then, node B receives two RREQs from Node S and Node A. Node B compares the remainder of standby time, T_s and T_a , calculated from the received power of RREQs, and the RREQ which has a longer standby time is canceled. In this example, since $T_s = 120 - 10 > T_a = 20$, T_s is canceled. As shown in Fig. 1(c), the above procedure is repeated, and RREQ is forwarded only through the power efficient route. As result, the route $S \rightarrow A \rightarrow B \rightarrow C \rightarrow D$ is constructed by the proposed scheme. On the contrast, in the dynamic state routing (DSR), since the route with smallest number of hops

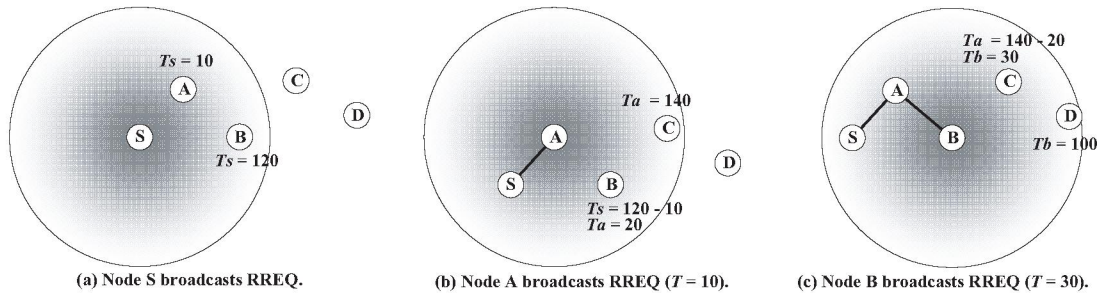


Fig. 1. An example operation of the proposed route construction scheme.

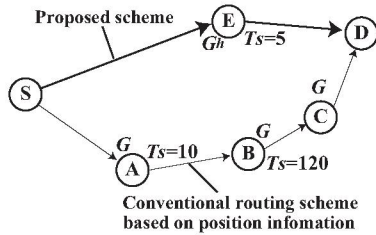


Fig. 2. Constructed route when nodes with different antenna characteristics exist.

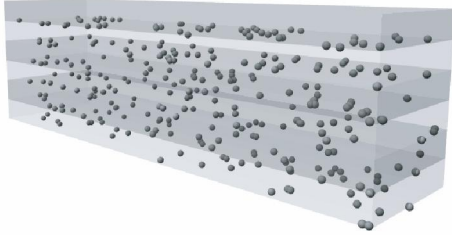


Fig. 3. The building model as simulation space.

tends to be selected, the route $S \rightarrow B \rightarrow D$ which contains short hops is constructed.

In Fig. 2, an example operation when nodes with different antenna characteristics exist is shown. In this figure, we assume that only node E has an antenna with high gain G_h . All the other nodes have antennas with normal gain G . In this case, we also assume that nodes A, B, and E receive a RREQ from node S. Then, the calculated standby times are $T_s = 10, 120$, and 5 , respectively. Among nodes A, B, and E, farthest node from node S is node E. However, since only node E is with high gain antenna, the received power of the RREQ becomes smallest among them. Therefore, in the proposed scheme, the suitable and energy efficient hop $S \rightarrow E$ is selected.

IV. NUMERICAL RESULTS

A. Evaluation in a realistic environment

We evaluate the total power consumption performance and route construction delay of the proposed scheme by means of computer simulation. The route construction delay, D_{rc} , is

TABLE I
SIMULATION ASSUMPTIONS OF THE BUILDING MODEL

Attenuation constant	3
Antenna gain	0 [dBi]
Max. Power	15 [dBm]
Receive threshold, P_{thr}	-74 [dBm]
Carrier sense threshold	-95 [dBm]
Capture threshold	10 [dBm]
Bit rate	11 [Mbps]
Carrier frequency	2.4 [GHz]
MAC protocol	CSMA/CA
Space size	80x20x4[m]x6[floors]

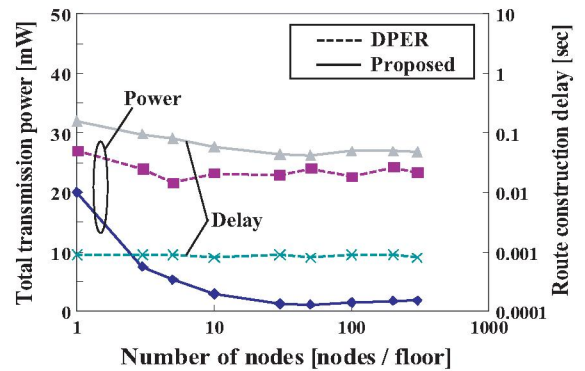


Fig. 4. Total transmission power and route construction delay.

defined as,

$$D_{rc} = T_{acceptRREQ} - T_{geneRREQ}, \quad (2)$$

where $T_{acceptRREQ}$ is the time when the destination accepts the RREQ, $T_{geneRREQ}$ is the time when the source generates the RREQ. D_{rc} is defined as the delay to construct route between source and destination. As the realistic environment, we consider a building model as simulation space. This model is a space that some rectangular parallelepipeds are piled up as a floor, as shown in Fig. 3. Each node is placed on the floor. Simulation assumptions are shown in table I.

We compare the performance of the proposed scheme with DPER. The simulation results of total transmission power and route construction delay are shown in Fig. 4. Fig. 4 shows that the proposed scheme is more power efficient than

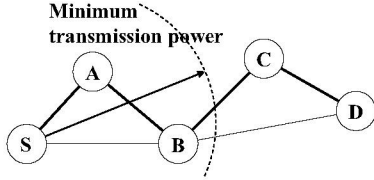


Fig. 5. The constructed route in DPC environment.

DPER because the proposed scheme can construct power efficient route. Especially, when number of nodes is large, performance improvement becomes large. The reason is as follows. The transmission power of DPER is almost constant for all number of nodes. In DPER, it is assumed that all nodes have the position information of neighbor nodes. By using the position information, the next hop is selected in adjoining area. Nodes calculate appropriate route and unicast RREQ. Therefore, although the number of nodes is large and the number of selectable small hops becomes large, the selected next hop does not change. As result, the transmission power performance is independent from the number of nodes. On contrary, the transmission power of the proposed scheme becomes small as the number of nodes increases. This is because that in the proposed scheme, when the number of nodes is large, smaller hops tend to be selected.

On the other hand, it is also shown that the proposed scheme requires longer route construction delay than DPER. This is because that in the proposed scheme, sufficient large standby time than MAC layer backoff is set for selecting small hop. However, it is considered that this is not deadly drawback since cached information is available after first construction. Note that the standby time does not relate to communication after route construction.

From Fig. 4, it is shown that the proposed scheme can improve power consumption performance in all conditions of number of nodes. Especially, the effectiveness of the proposed scheme is large when number of nodes is large.

V. EXTENSION TO DISCRETE POWER CONTROL ENVIRONMENT

A. Deterioration in discrete power control environment

We have shown that the proposed scheme can reduce transmission power consumption in the continuous power control (CPC) environment. Some consumer wireless LAN card can set 32 levels of transmission power. With such fine levels of power control environment, the proposed scheme can reduce transmission power consumption almost same as in CPC environment. However, some consumer wireless LAN cards set only several levels of transmission power. For example 0, 7, 10, 13, 15 [dBm] are available as the transmission powers in Cisco Aironet 350. With such discrete power control (DPC) environment, the proposed scheme cannot reduce transmission power consumption sufficiently.

Fig. 5 shows an example constructed route in CPC environment. The proposed scheme constructs a route $S \rightarrow A \rightarrow B$

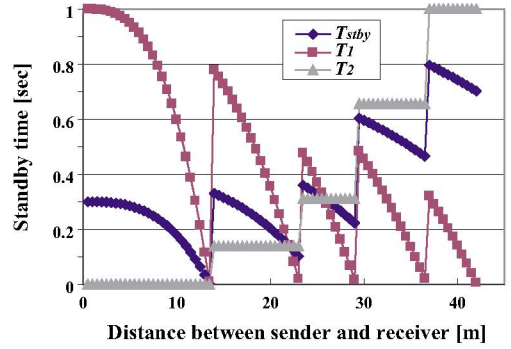


Fig. 6. Standby time in the discrete version of the proposed scheme.

which contains short distance hops, as shown in thick line in Fig. 5. It is wasteful that node S transmits to node A, despite node B can be received even if node S transmits by minimum transmission power. The performance of the proposed scheme is deteriorated because of containing such too short hops. We extend the proposed scheme to select appropriate route, such as $S \rightarrow B$ in Fig. 5.

B. Discrete version of the proposed scheme

We propose the extended version of the proposed scheme, refer to as Discrete version. In Discrete version, only the standby time calculation is modified. Discrete version selects the node located near the sender and outside of each transmission range to construct a power efficient route in DPC environment. We consider the standby time calculation T_{stby} with two members T_1 and T_2 [sec] as shown in the following expression.

$$T_{stby} = \alpha T_1 + (1 - \alpha) T_2, \quad (3)$$

where α is weight of the priority for outside of range.

T_1 is introduced to make outside of each transmission range high priority. T_1 is calculated as shown in (4),

$$T_1 = T_{max} \left(1 - \frac{P_{thr}}{P_t} \right)^\beta, \quad (4)$$

where T_{max} [sec] is the maximum standby time, β is a parameter which changes the priority to outside of the transmission range, and P_t is the minimum discrete transmission power which exceeds the receive threshold P_{thr} .

$$P_t = \min\{P | P > P_{thr}\}. \quad (5)$$

T_1 shows the discrete curve in Fig. 6.

T_2 's purpose is to make near the sender high priority. T_2 is calculated as follows.

$$T_2 = T_{max} \left(\frac{P_t - P_{min}}{P_{max} - P_{min}} \right)^\gamma \quad (6)$$

where T_{max} and P_t are equal to explanation in (4). P_{min} and P_{max} are available maximum and minimum transmissions power, respectively. γ is a parameter which changes the priority to near the sender. T_2 shows the discrete curve in Fig.

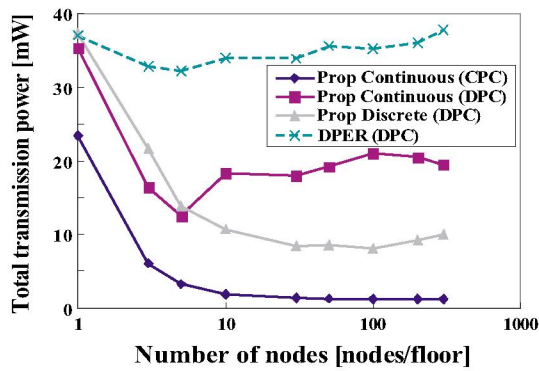


Fig. 7. Total transmission power in DPC environment.

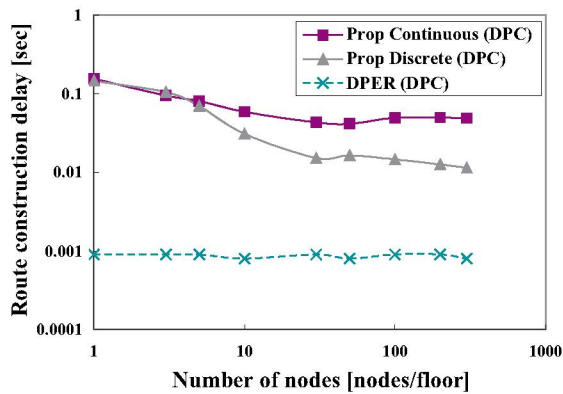


Fig. 8. Route construction delay in DPC environment.

6. T_{stby} is the weighted summation of T_1 and T_2 as shown the discrete curve in Fig. 6.

C. Performance evaluation of Discrete version

We evaluate the performance of the proposed schemes with DPC. In the following simulations, we use the empirical parameters $T_{max} = 0.1$, $\alpha = 0.2$, $\beta = 1.0$, and $\gamma = 0.5$.

The simulation results of the total transmission power are shown in Fig. 7. We call the continuous version of the proposed scheme as Continuous version. In Fig. 7, it is shown that Continuous version in DPC environment degrades its performance of power efficiency than that in CPC environment. This means that Continuous version selects too small hops in DPC environment. It is also shown that both Continuous and Discrete versions have better performance than DPER for all conditions of number of nodes. This is because that both proposed schemes can select small hops for improve power consumption performance. Moreover, it is also shown that the performance of Discrete version in DPC environment is almost same as Continuous version in DPC environment in case of small number of nodes, smaller than 8. This is because that number of selectable nodes is small in case of small number of nodes. Therefore, it is considered that the constructed route of both proposed schemes is almost same. In case of large number of nodes, larger than 8, Discrete version can achieve

better performance than Continuous version. Especially, the performance of Continuous version degrades as larger number of nodes. The reason is that Continuous version selects too small hops.

The simulation results of the route construction delay are shown in Fig. 8. In this figure, both proposed schemes degrade their route construction delay performance than DPER. This is because that introducing the standby time makes the propagation of RREQ large in both proposed schemes. However, as mentioned above, it is considered that the standby time does not relate to communication after route construction. Comparing the proposed schemes, the route construction delay of Discrete version is smaller than that of Continuous version because the number of hops of Discrete version is smaller than that of Continuous version.

From Figs. 7 and 8, it is shown the effectiveness of the discrete version of the proposed scheme in DPC environment because of its superior performance.

VI. CONCLUSIONS

In this paper, we have proposed a novel energy efficient route construction scheme with continuous and discrete transmission power control in ad hoc sensor networks. In the proposed scheme, when a node receives a RREQ, it calculates the standby time inversely proportional to the received power of the RREQ. The node relays the RREQ with full power when the standby time expires in order to construct the least energy consumption route. Simulation results show the proposed scheme can construct more energy efficient route than the conventional schemes in both continuous and discrete power control environment. In our future work, we plan to evaluate the performance of the proposed schemes under more realistic radio propagation environment.

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