DispersionCast: Dispersive Packets Transmission to Multiple sinks for Energy Saving in Sensor Networks

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Abstract- This paper proposes two schemes for wireless sensor networks with multiple sinks in order to save battery energy and to improve network lifetime performance. In these schemes, each sensor node transmits sensing data to randomly chosen sink according to the sending rates. These schemes are referred to as DispersionCast. The first decentralized scheme called B-DOP scheme (Basic DispersionCast Of Packet), enables each sensor node to derive locally the sending rate by the number of hops to sinks. The second one is O-DOP scheme (Optimal DispersionCast Of Packet) that is partially centralized than B-DOP. In O-DOP, sinks send the information to nodes so as for them to calculate the optimal sending rates. DispersionCast is effective when the generate rate of sensing data at every sensor node is geographical nonuniformity. In such a situation, batteries of nodes in the specific area deplete fast and others late, which causes partial depletion of the entire network. As a result, network lifetime can not be extended sufficiently. We evaluate the DispersionCast schemes by simulations for several network topologies and show that DispersionCast scheme prolongs the network lifetime compared with the conventional nearest sink scheme, especially O-DOP can achieve 1.5 times longer.

I. INTRODUCTION

Recently, sensor networks in which a large number of small sensor devices with wireless communications function have attracted attention. The largest issue for sensor network is to save energy consumption. As one of the causes of energy consumption in the sensor networks, it is known that packet relay consumes a significant amount of the energy of sensor nodes[1]. Since every sensor node transmits sensing data to the sink in multi-hop communications, the sensor nodes near the sink consume more battery than the nodes far away from the sink. On the other hand, the geographical nonuniformity of sensing data generation is also an important issue. For example, for observation of the movement distribution of wild animals, a significant amount of observation data is generated only near the animal trail. In such kind of sensor networks, only a subset of the sensor nodes relays data, therefore, the subset of sensor nodes depletes battery life. As a result, network lifetime is shortened significantly.

To solve the issue of sensor nodes near sink consume too much energy due to packet relay, Directed Diffusion [2],[3] is known to be effective. In Directed Diffusion, some sensor nodes aggregate several packets and eliminate the redundancy in packet relaying. Directed Diffusion can alleviate that the packet size become large as near the sink. However, Directed Diffusion cannot be adopted to all kinds of data, and it cannot prolong network lifetime under the environment with geographical nonuniformity of sensing data generation. As another solution, introducing multiple sinks has been developed [4]-[6]. In these schemes, every sensor node sends sensing data to its nearest sink. We refer to it as the NS scheme (Nearest Sink transmission scheme). With multiple sinks traffic load is balanced, therefore, the issue of large energy consumption near the sink is alleviated. However, also in the NS scheme, the geographical nonuniformity of data generation degrades network lifetime performance. In this case, packet relay is concentrated on the area of generated data extensively (hot area) near the sink. Therefore, the subset of the sensor nodes near the sink depletes battery life early, and some area is not able to be sensed. In sensor networks, it is very important that all sensor nodes can sense the data and send their sensing data to the sink in multi-hop communications. Consequently, we can say that it is difficult to extend network lifetime if a subset of sensor nodes depletes battery life early.

In this paper, in order to improve network lifetime we propose a scheme with dispersive packets transmission for sensor networks with multiple sinks. Our proposed DispersionCast schemes improve the energy consumption in sensing data generation is nonuniformity geographically. We evaluate the performance of the proposed B-DOP scheme by using computer simulation. By mean of the evaluation, we find a room to improve the B-DOP scheme. Additionally, we improve the B-DOP scheme to optimize the sending rate of each node, and evaluate the performance by using computer simulation. Eventually, we show that the proposed DispersionCast scheme is effective in improving network lifetime performance.

II. DISPERSIONCAST SCHEME

In order to prolong network lifetime, we propose two novel packet transmission scheme referred to as the DispersionCast schemes. In the DispersionCast scheme, when a sink detects that battery consumption of a subset of sensor nodes becomes large, the sink orders the sensor node in hot area to send its sensing data to multiple sinks. The DispersionCast scheme attempts to solve the disproportionate energy consumption by geographical nonuniformity of sensing data generation. In addition, the DispersionCast scheme aims to prolong network lifetime. We consider two sink modes for simplicity.

A. Overview

In the NS and DispersionCast schemes, each sink floods a control packet called a hop-count packet to the entire network periodically. Every node knows the number of hops for each sink. In the DispersionCast scheme, all sinks assume to communicate with one another by means of an independent communication channel, such as wireless or wired networks. In the DispersionCast scheme, every sensor node has two modes. One of the modes is the SingleCast mode, and the other mode is the DispersionCast mode. In the SingleCast mode, every sensor node sends sensing data to its nearest sink, same as the NS scheme. On the other hand, in the DispersionCast mode every sensor node sends its sensing data packet to two sinks according to a sending rate. We assume the sending rates of node i for sink 1 and sink 2 are \( P_{i1} \) and \( P_{i2} \), respectively. Therefore, the sum of \( P_{i1} \) and \( P_{i2} \) is equal to one. In this paper, we consider two sink modes: SingleCast and DispersionCast.
becomes 1. We can say that in SingleCast mode, when a node $i$ near sink 1, $P_{1i} = 1$ and $P_{2i} = 0$ are adopted. The mode transition in every sensor node is ordered by the sink.

We consider the DispersiveCast scheme as sub-layer of Network layer. Because the DispersiveCast scheme decides the sending rate of packets to each sink at all sensor nodes, but does not decide the route from all sensor nodes to each sink.

B. Mode transition order from the sink

In the DispersiveCast scheme, every sensor node sends its packet to the nearest sink basically by the SingleCast mode. Each sink monitors data traffic from sensor nodes. According to the monitored traffic, the sink determines whether mode transition is necessary at each sensor node, periodically. If necessary, the sink sends a control packet referred to as the mode-transition packet. The period is decided optionally by the user or application. The algorithm of mode transition order in a sink is shown in Fig. 1. In Fig. 1, $d_i$ is the total generated sensing data at node $i$ (1 $\leq i \leq N$ : $N$ is the total number of nodes) in a period. In addition, we assume node $i$ near sink 1 and sink 2 belong 1 $\leq i \leq N_1$ and $N_1 + 1 \leq i \leq N$, respectively. $N_1$ and $N_2$ are the number of nodes which are near sink 1 and sink 2, respectively, and $N_1 + N_2 = N$. $D_{ave}$ is the average amount of sensing data generation in the entire network, and $D_{ave1}$ and $D_{ave2}$ are the average received data at sink 1 and sink 2, respectively, and those are intended by the formula in Fig 1. $\alpha$ is a threshold of proportion of $D_{ave1}$ and $D_{ave2}$ to do not send mode-transition packets when the proportion of average received data at each sink become much small.

In Fig. 2(a), every sensor node sends its sensing data packets to the nearest sink in SingleCast mode. The data packets include the number of hops for each sink and the battery residue. Each sink obtains this information as well as the sensing data due to receiving the data packet.

When $\frac{D_{ave1}}{D_{ave2}} \geq \alpha$, and the black node in Fig. 2(b) generates a significant amount of sensing data and the data generation is over $D_{ave2}$ in a period, sink 1 decides for the black node to transit from the SingleCast mode to DispersiveCast mode. Sink 1 sends a mode-transition packet to order the black node to transit.

If the black node (node $i$) receives the mode-transition packet, it becomes the DispersiveCast mode and sends its data packet to sink 1 at a ratio $P_{1i}$ and to sink 2 at a ratio $P_{2i}$.

D. Decision of Sending Rate in B-DOP scheme

In the B-DOP scheme, when a sensor node receives a mode-transition packet, the sensor node $i$ decides its sending rates $P_{1i}$ and $P_{2i}$. Each sensor node decides the sending rate according to the following a criterion. It is based on the number of hops from each sink. In this criterion, the following formula is adopted:

$$P_{1i} = \frac{H_{2i}}{H_{1i} + H_{2i}}, \quad P_{2i} = \frac{H_{1i}}{H_{1i} + H_{2i}}$$

(1)
Where $H_1$ and $H_2$ are the number of hops from sink 1 and sink 2, respectively. Formulas (1) indicate that the sensor node near the sink tends to send more data packets to the sink.

III. BASIC PERFORMANCE EVALUATION

We evaluate the network lifetime performance of the proposed B-DOP scheme by computer simulation.

A. About the MAC and Routing

For the evaluation of B-DOP scheme and NS scheme, we use the CSMA/CA 2-way in MAC layer. The sequence is DATA and ACK. We configure the maximum number of retransmission to seven.

In this simulation, we use the simple hop count based routing. Every sensor node uses only the neighbor node’s information which is the number of hops to each sink and the residual battery. In this routing, in order to forward the packet to the destination sink, the node which is less the number of hops than now relay node is selected. Furthermore, in order to aware network energy, the most residual battery node in neighbors is selected to the next relay node. The neighbor information is snooped by the MAC Layer transmission.

B. Evaluation of B-DOP scheme

We show a fundamental simulation model in Fig. 2, and simulation parameters in Table 1.

In Fig. 3, sensor nodes are deployed in the lattice array of 5*20, and the gap of nodes is 10 meters. Two sinks are deployed at both ends of the network. Sensor nodes in the circle area of Fig. 3 (not area) generate 1.2 sensing data packets per minute, and other sensor nodes generate 0.12 sensing data packets per minute. The simulation parameter is decided by the references of the Zigbee[7] and the Mote2[8]. In this parameter, every sensor node can transmit eight neighbor nodes in Fig. 3. We define the network lifetime that the period in which the data arrival ratio is 100%.

In Fig. 4, we show the data arrival ratio. The data arrival ratio is defined as the ratio in which the total received data at the sinks is divided by the total generated sensing data at all sensor nodes.

From Fig. 4, it is shown that the B-DOP scheme can prolong the network lifetime more than that of the NS scheme. The network lifetime is about 350 minutes in the NS scheme, and about 430 minutes in the proposed B-DOP. It is found that the B-DOP scheme can prolong the network lifetime up to 1.2 times that of the NS scheme. It is considered that the network lifetime ends because of depletion of the battery from the 1-hop neighbor node to sink 1. In the B-DOP scheme, when a sink detects that a sensor node sends a large amount of sensing data, the sensor node is ordered to send the data packet to multiple sinks by a sink. Therefore, the traffic in the network is well load-balanced. Hence, the lifetime of the sensor nodes from 1-hop neighbor to sink 1 is prolonged. Generally, in a sensor network, when the battery life of some sensor nodes is depleted, the data arrival rate to sinks degrades excessively. This is because the links between nodes are disconnected by depletion of battery. From Fig. 4, the B-DOP scheme can decrease the number of nodes in which the battery is depleted early. Therefore, the period of good data arrival ratio can be prolonged in the B-DOP scheme. However, after the period, the number of nodes in which the battery is depleted increase. Therefore, the link between nodes is disconnected and the data arrival rate performance degrades excessively. This is because the total energy consumption of the B-DOP scheme becomes larger than that of the NS scheme in order for the node which is DispersiveCast node sends its sensing data to far sink as well as near sink.

As mentioned above, it is shown that the proposed B-DOP scheme can prolong the network lifetime compared with that for the NS scheme.

IV. O-DOP SCHEME

From Fig. 4, we have shown the B-DOP scheme can prolong the network lifetime. However we can see the period in which the data arrival ratio is about 40% in Fig. 4. This is because that the battery of the 1-hop neighbor node to sink 1 is depleted in spite that the battery of the 1-hop neighbor node to sink 2 is not depleted. We consider that we can prolong further the network lifetime by shortening this period. This period occurs because the sending rate of nodes in
DispersiveCast mode is not optimal, and we refer this period to bad-period.

We propose the improved scheme as refer to O-DOP scheme which derives optimal sending rate of node in DispersiveCast mode to prolong the network lifetime. In order to shorten the bad-period, we should even up the period of battery depleted of the 1-hop neighbor node to each sink. The period of battery depletions is due to the data traffic and sensing data generation rate. Hence, we derive the optimal sending rate that even up the data traffic of each sink. We show the data traffic for sink 1 and sink 2, respectively in the following the formula is adopted:

\[
T_1 = \sum_{i=1}^{N} t_i P_{1i} + T'_1, \quad T_2 = \sum_{i=1}^{N} t_i P_{2i} + T'_2. \tag{2}
\]

In formula (2), \( t_i \) is the amount of all sensing data generation of node \( i \) in the period which is explained in subsection of process for mode transition in section 2, and \( N \) is the number of nodes in the network. \( P_{1i} \) and \( P_{2i} \) are sending rates to sink 1 and sink 2 at node \( i \), respectively and \( P_{1i} + P_{2i} = 1 \). \( T'_1 \) and \( T'_2 \) are the total amount of data traffic which have achieved to the sink 1 and sink 2 since the system started, respectively. We derive the sending rates \( P_{1i} \) and \( P_{2i} \) of each node to satisfy \( T'_1 = T'_2 \) calculated by sink. The derived sending rates are included in the mode-transition packet in the process for mode transition.

In order to derive \( P_{1i} \) and \( P_{2i} \), we derive \( P_{1i} \) to satisfy \( T'_1 = T'_2 \). Hence, we calculate \( P_{1i} \) by the following the formula:

\[
\sum_{i=1}^{N} t_i P_{1i} + T'_1 = \sum_{i=1}^{N} t_i (1 - P_{1i}) + T'_2. \tag{3}
\]

In formula (3), the sending rate of node \( i \) near sink 1 is \( P_{1i} = 1 \), that of node \( i \) near sink 2 is \( P_{1i} = 0 \), respectively, the node of same distance to each sink is \( P_{1i} = P_{2i} = 0.5 \). As mentioned above, in the O-DOP scheme, nodes in DispersiveCast mode send data packet to far sink as well as to nearest sink. However, in generally, if we consider the duration or reliability, it is hopeful that nodes which are DispersiveCast mode send to nearest sink as much as possible. In formula (3), this point of view is not considered. Therefore, we add the constraint equation considering the number of hops from each node to each sink to indicate that the sensor node tends to send more packets to near sink. We show the constraint equation is adopted:

\[
P_{1i} = \frac{H_{2i}}{H_{1i} + H_{2i}} \cdot P_{1i}. \tag{4}
\]

In formula (4), \( H_{1i} \) and \( H_{2i} \) are the number of hops from node \( i \) to sink 1 and sink 2, respectively. Consequently, we obtain the following formulas to combine the formula (3) and (4):

\[
2 \sum_{i=1}^{N} t_i P_{1i} = \sum_{i=1}^{N} t_i + T'_2 - T'_1. \tag{5}
\]

In the formula (6), \( disp \) means the node in DispersiveCast mode. In order to derive \( P_{1i} \), we derive the \( P_{1i} \) by the formula (3) and (6), and we derive the \( P_{1i} \) and \( P_{2i} \).

V. PERFORMANCE EVALUATION

At the performance evaluation, we use the simulation parameter which is Table 1 and the MAC and Routing which are explained in section 3. We use the simulation model shown in Fig 3. In Fig 5, we show the data arrival ratio performance.

From Fig 5, it is shown that the proposed O-DOP shortens the bad-period and prolongs the network lifetime. The network lifetime is about 500 minutes. It is found that the O-DOP scheme prolongs the period up to 1.2 times that of the B-DOP scheme and 1.5 times that of the NS scheme. This is because the period of battery depletion of 1-hop neighbor node to each sink is prolonged and the battery depletion happened almost simultaneously. As mentioned above, it is shown that the proposed O-DOP scheme can prolong the network lifetime. However, it is found that the proposed O-DOP reaches the data arrival ratio is 0% most early. Because, in order to deplete the battery simultaneously, the load at far sink become the largest in evaluated three schemes. Hence, in the network which is network lifetime is the period which is the sink can receive the data packets from at least one node, the NS scheme achieves best performance.

In the DispersiveCast schemes, it is necessary that every sensor node consumes its energy by relaying control packets. However, the effect of energy consumption according to relaying the control packet is exceptionally small. We find the energy consumption according to relaying packets until the time the battery life of a sensor node is depleted as shown in Fig 3. We find that energy consumption of the data packet is significant, and that of the control packet is insignificant. In this case, the energy consumption of mode-transition packets only account for about 0.07% of all energy consumption by
relaying packet. This is because the control packet size is small compared with that of data packets. In addition, the number of mode-transition packets is small.

We evaluate the performance of the proposed scheme in various sensing data generation models, and we show the proposed scheme is effective in every kind of concentration of data generation.

![Fig.7 Linear concentration model](image7)

In Fig. 7, the data generation is concentrated on the ellipse area (hot area). This model is considered the application for observation of the movement distribution of wild animals. In this application, the movement distribution is concentrated on animal trails. Therefore, the data generation is much closer to animal trails. Generally, an animal trail is linear. Therefore, the data generation is linear as shown in Fig. 7. The hot area generates 1.2 sensing packets per minute and the other 0.12 sensing packets per minute in Fig. 7.

![Fig.8 Complicated concentration model](image8)

In Fig. 8, the data generation is concentrated on the clear circle area by 1.2 sensing packets per minutes, the gray circle area by 6.0 sensing packets per minutes and the other area by 0.12 sensing packets per minutes. In the wild environment, it may occur that sensing data generates intricately. And in this model, the data traffic which reaches each sink is almost simultaneously. We show the network lifetimes of Liner model and Complicated model in Table 2.

From Table 2, it is found that the O-DOP scheme prolongs the network lifetime compared with that for the NS and B-DOP schemes in Liner model. In Complicated model, it is found that every scheme becomes the same network lifetime. This is because that the B-DOP and O-DOP schemes select no a node in DispersiveCast mode due to the data traffic which reaches each sink is almost simultaneously. The network in which the data traffic which reaches each sink is almost simultaneously is say as to the network in which data generation is uniform. Therefore, the B-DOP and O-DOP schemes perform similar to NS scheme in the sensor network in which data generation is uniform. The difference between the DispersiveCast and NS schemes in the sensor network in which data generation is uniform is only that mode-transition packets are sent from sink during the process for mode transition in the DispersiveCast scheme. Due to those reasons, the DispersiveCast schemes perform better than the NS scheme in any sensor network model.

<table>
<thead>
<tr>
<th>Table 2 Network lifetime of two model</th>
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<tr>
<td>Liner model</td>
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<tr>
<td>conventional NS</td>
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<tr>
<td>proposed DOP</td>
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<td>proposed O-DOP</td>
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Consequently, from all the results mentioned above, we show that the O-DOP scheme is an effective method of prolonging network lifetime due to balancing the energy consumption of the entire network.

IV. CONCLUSION AND FUTURE WORK

To prolong network lifetime, we have proposed a new scheme referred to as DispersiveCast scheme. In this scheme, every sensor node sends its packets to several sinks according to each sending rate, and the energy consumption of entire networks is balanced by using multiple sinks. From performance evaluation, we show that the proposed DispersiveCast scheme prolongs the network lifetime in the sensor network under geographical nonuniformity of data generation. In addition, though the total energy consumption of the DispersiveCast schemes are larger than that of the conventional NS scheme, especially the O-DOP scheme performs better in any sensor network. Consequently, we show that the DispersiveCast scheme balances the load which consumes energy by packet relay and achieves prolonged network lifetime.

At the future work, we extend the function of DispersiveCast scheme to adopt more than three sinks and evaluate the performance.

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