Evaluation of Power-aware Routing for Sensor Networks with Forwarder Nodes

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***Abstract*— Wireless sensor networks are envisioned to consist of many small devices that can sense the environment and communicate the data as required. The most critical requirement for widespread sensor networks is power efficiency since battery replacement is not viable. Many protocols attempt to minimize the power consumption by using complex algorithms. However, it is difficult to perform these complex methods since an individual sensor node in sensor networks does not have high computational capacity. On the other hand, many sensor nodes should transfer the data packet to the sink node that collects the required data. Therefore, the operations of the sensor nodes over the route are terminated; it is difficult to deliver the data packet to the sink node even if some sensor nodes are active.**

In this paper, we propose a simple power-aware routing protocol for sensor networks. Our proposed protocol is based on the ad hoc on-demand distance vector (AODV) protocol, which is one of the reactive routing protocols. In addition, we introduce forwarder nodes in the sensor networks in order to extend the lifetime of the entire sensor network. From the simulation results, we evaluate the performance of the protocols and clarify the effect of forwarder nodes on the sensor networks.

***Keywords*— Sensor networks, Power aware routing, Forwarder nodes, Life time**

I. Introduction

Wireless sensor networks are envisioned to consist of many small devices that can sense the environment and communicate the data as required[1]. The sensor network is one of the multi-hop networks similar to the ad hoc networks. Therefore, each sensor node forwards the data if it receives the data from another sensor node. In ad hoc networks, researchers focus on the communication performance like as the throughput. However, the most critical requirement for widespread sensor networks is power efficiency since battery replacement is not viable.

Various protocols for sensor networks usually attempt to minimize the power consumption required for communication across the network. In a media access control (MAC) layer, some researchers have proposed a special MAC method to reduce the power consumption of the sensor node[2]-[5]. In this method, each sensor node suspends periodically when it does not communicate. Therefore, some circuits can be temporarily shutdown in order to reduce the power consumption. In a network layer, some protocols attempt to minimize the power consumption by using complex algorithms[6]-[8]. However, it is difficult to perform these complex methods since an individual sensor node in sensor networks does not have high computational capacity. Moreover, these complex methods require much information like as a remaining battery of each sensor node, sensor network topology, etc. Therefore, a large amount of battery power will be consumed to find the route with minimized power consumption. Recently, a lifetime of sensor networks is focused. Therefore, some protocols attempt to maximize the lifetime of sensor networks by constructing a semi-optimized route[9]-[12]. In addition, many integrated approaches are also used to improve the performance.

On the other hand, each sensor node has two roles. One is to detect an event, and the other is to forward a data from neighbor sensor nodes. Therefore, many sensor nodes should transfer the data packet to the sink node that collects the required data. As a result, the operations of the sensor nodes over the route are terminated; it is difficult to deliver the data packet to the sink node even if some sensor nodes are active.

In this paper, we propose a simple routing protocol for sensor networks. The object of this paper is to extend the lifetime of sensor networks by extending the lifetime of each sensor node. Our proposed protocol is based on the ad hoc on-demand distance vector (AODV) protocol[13], which is one of the reactive routing protocols. In the proposed protocol, each sensor node checks a remaining battery capacity and determines the activity of route construction process. In addition, we introduce forwarder nodes in the sensor networks in order to extend the lifetime of the entire sensor network. From the simulation results, we evaluate the performance of the protocols and clarify the effect of forwarder nodes on the sensor networks.

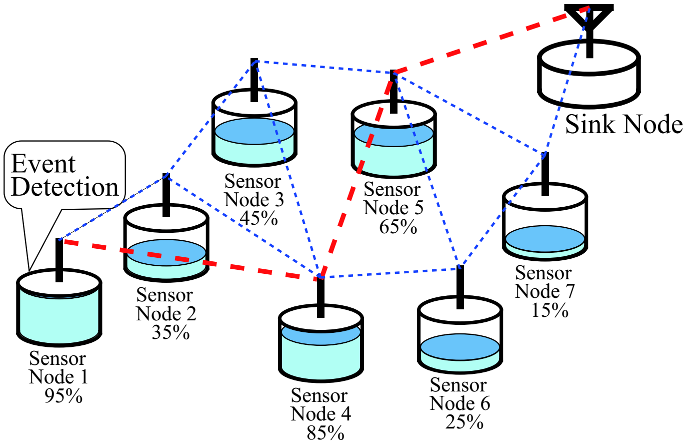


Fig. 1. Route construction of the proposed protocol.

II. Power Aware Routing

Various routing protocols have been proposed for sensor networks. The AODV protocol is one of the reactive routing protocols that can construct the route when data transmission is required. In this protocol, a source node broadcasts the route request (RREQ) packet to the entire network, and all the nodes rebroadcast the received RREQ packet immediately. Therefore, we use the AODV protocol as the basic protocol since its operation is quite simple.

A. Delay processing of RREQ

Many RREQ packets are received at the destination node in the AODV protocol. The RREQ packet that arrives first is used for the route construction. Moreover, it is not efficient that all the nodes rebroadcast the RREQ packets in the sensor network to reduce the consumed power.

In the proposed protocol, each sensor node is involved in the route construction according to the remaining battery capacity. Each sensor node adjusts the rebroadcast timing of the RREQ packet since the RREQ packet that arrives first is used to construct the route in the AODV protocol. The rebroadcast timing is determined by the remaining battery capacity. Therefore, when the sensor node receives the RREQ packet from another node, it starts the timer for the rebroadcast of the received RREQ packet by confirming the remaining battery capacity. The timer duration is set to a large value when the battery capacity is small. On the contrary, it is set to a small value when the battery capacity is large. If the rebroadcast of the RREQ packet is delayed, the duration to complete the route construction process becomes large. However, this delay is sufficiently short to convey the detected information to the sink node.

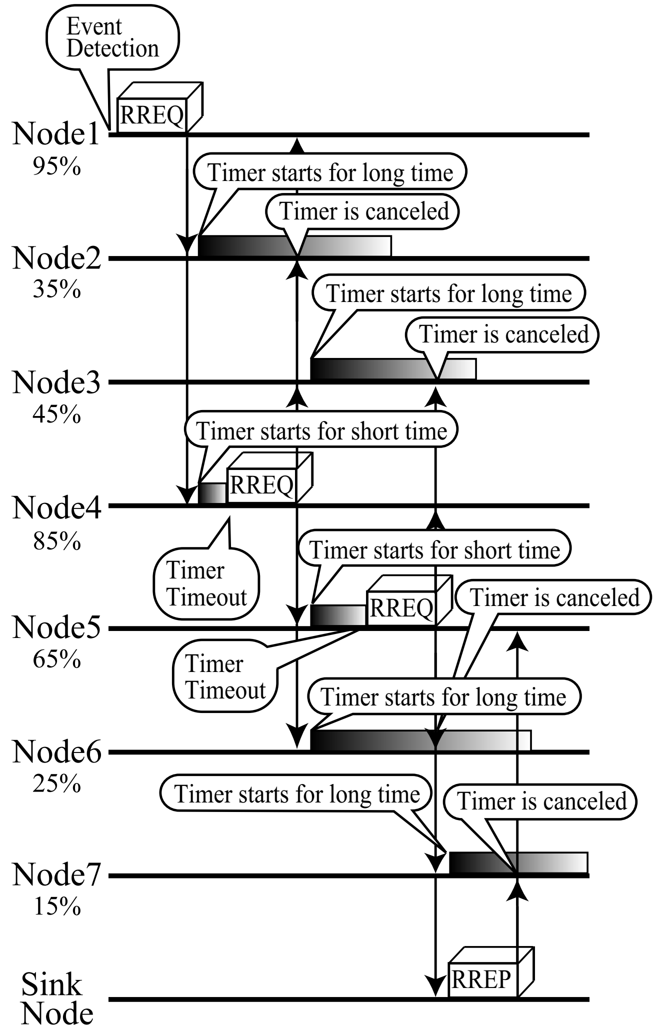


Fig. 2. Operations in the proposed protocol.

B. Interruption of RREQ rebroadcast

Each node immediately rebroadcasts the RREQ packet in the AODV protocol. However, many sensor nodes are positioned in sensor networks, and the sensing areas of each node overlap. Therefore, many RREQ packets are rebroadcasted and a considerable amount of the wireless resource is consumed by these packets if each node rebroadcasts them, as in the AODV protocol. Moreover, these redundant rebroadcasts cause the node to waste battery power.

In the proposed protocol, until the timer timeout each sensor node interrupts the rebroadcast process of the received RREQ packet when the same RREQ packet is received. Our protocol can prevent the broadcast storm problem of the RREQ packets and reduce the power consumed to rebroadcast redundant RREQ packets.

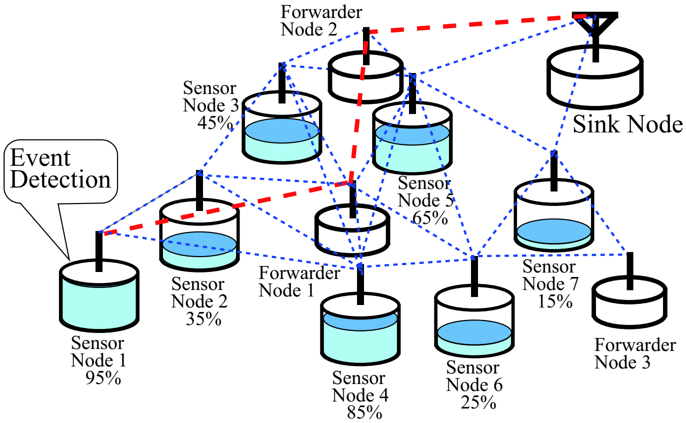


Fig. 3. Example of route construction with forwarder nodes.

C. Example of operations

Figure 1 is an example of sensor network, and the operations in the proposed protocol are shown in Fig. 2. In the example, the network comprises seven sensor nodes and one sink node. The sink node has a large-capacity battery. In contrast, the sensor node has a small-capacity battery. The value under the sensor node in Fig. 1 indicates the remaining battery capacity. In the proposed protocol, a sensor node that has a large value of the remaining battery capacity actively constructs the route. The operations are follows.

1) Sensor node 1 detects an event and starts a route construction process.
2) Sensor node 1 broadcasts a RREQ packet to the network to find a route to a sink node.
3) Sensor nodes 2 and 4 that receive the RREQ packet from sensor node 1 set a timer with a duration that depends on the remaining battery capacity.
4) Sensor node 4 rebroadcasts the RREQ packet in advance since the remaining battery capacity of sensor node 4 is larger than that of sensor node 2.
5) Sensor node 2 receives the RREQ packet from the sensor node 4 and detects that sensor node 4 retransmits the RREQ packet in advance. Therefore, it stops the timer and interrupts the rebroadcast of the RREQ packet.
6) Sensor nodes 3, 5, and 6 that receive the RREQ packet from sensor node 4 set a timer with the same duration as that of sensor nodes 2 and 4.
7) Sensor node 5 rebroadcasts the RREQ packet in advance since the remaining battery capacity of sensor node 5 is larger than that of sensor nodes 3 and 6.
8) Sensor nodes 3 and 6 receive the RREQ packet from the sensor node 5 and detect that sensor node 5 retransmits the RREQ packet in advance. Therefore, they stop the timer and interrupt the rebroadcast of the RREQ packet.

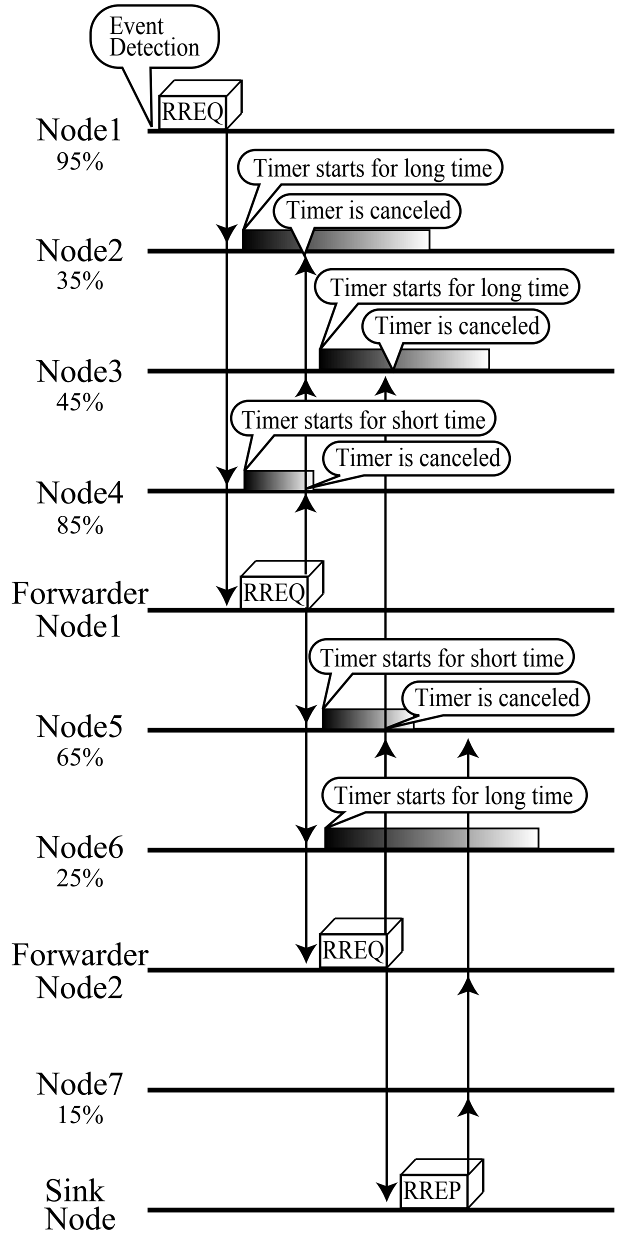


Fig. 4. Operations in the proposed protocol with forwarder nodes.

9) The sink node receives the RREQ packet from sensor node 5 and replies with a route reply (RREP) packet to sensor node 1. Finally, the route via sensor nodes 4 and 5 is constructed.

III. Sensor Networks with Forwarder Nodes

Our proposed protocol can reduce the power consumed for transmitting RREQ packets. Moreover, the lifetime of the sensor network can be extended since the sensor node with large remaining battery capacity actively constructs the route. However, sensor nodes near the sink node are used to forward data packets. Therefore, these sensor nodes consume

TABLE I

SIMULATION PARAMETERS

Simulator	sQualNet[14]
Simulation time	50 [h]
Number of sensor nodes	200
Number of forwarder nodes	8, 16
Number of sink nodes	1
Area	200 [m] × 200 [m]
Sensor node placement	Random
Node mobility	None
Data packet size	400 [byte]
Communication system	IEEE 802.11
Bandwidth	2 [Mbps]
Communication range	50 [m]
Sensing range	20 [m]
Battery capacity	500 [Ah]
Propagation pathloss model	free space
Wireless environment	AWGN
Routing protocol	AODV, Proposed routing
Routing timeout	10 [m]
Number of events	200 [Events/h]
Event occurrence	Random
Event position	Random

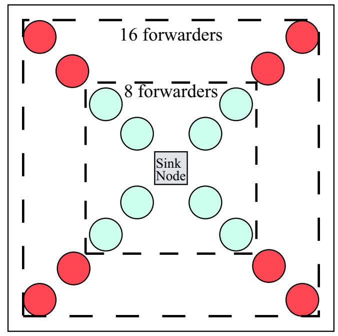
TABLE II

FORWARDING DELAY OF RREQ

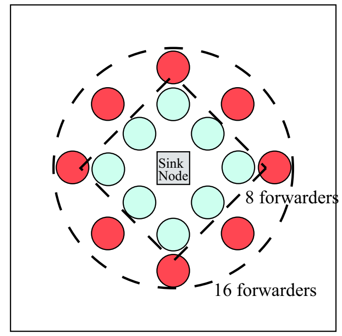
Remaining battery capacity [%]	Timer delay [ms]
90 - 100	10
80 - 90	20
70 - 80	30
60 - 70	40
50 - 60	50
40 - 50	60
30 - 40	70
20 - 30	80
10 - 20	90
0 - 10	100

a considerable amount of power to forward the data packets to another sensor node that is far from the sink node. As a result, a significant amount of detected information cannot be delivered to the sink node even if many sensor nodes that are far from the sink node are active. This is because there is no sensor node for forwarding the data packet in the area near the sink node.

In this paper, we introduce a forwarder node that has a large battery capacity and that actively forwards data packets. Figure 3 shows sensor networks with forwarder nodes, and the operations in the proposed protocol with forwarder nodes are shown in Fig. 4. In this study, the forwarder nodes are located near the sink nodes. The forwarder node quickly rebroadcasts the RREQ packet since it has a large battery capacity. In the numerical results, we discuss the number of forwarder nodes



(a) Type 1



(b) Type 2

Fig. 5. Positions of forwarder nodes.

and their locations. The operations are follows.

1) Sensor node 1 detects an event and starts a route construction process.
2) Sensor node 1 broadcasts a RREQ packet to the network to find a route to a sink node.
3) Sensor nodes 2 and 4 that receive the RREQ packet from sensor node 1 set a timer with a duration that depends on the remaining battery capacity.
4) Forwarder node 1 that receives the RREQ packet from sensor node 1 rebroadcasts the RREQ packet immediately.
5) Sensor nodes 3, 5 and 6 that receive the RREQ packet from the forwarder node 1 set a timer with the same duration as that of each sensor node.
6) Sensor nodes 2 and 4 receive the RREQ packet from the forwarder node 1 and detect that forwarder node 1 retransmits the RREQ packet in advance. Therefore, they stop the timer and interrupt the rebroadcast of the RREQ packet.
7) Forwarder node 2 that receives the RREQ packet from forwarder node 1 rebroadcasts the RREQ packet immediately.
8) Sensor nodes 3 and 5 receive the RREQ packet from the forwarder node 2, stop the timer and interrupt the rebroadcast of the RREQ packet.
9) The sink node receives the RREQ packet from forwarder node 2 and replies with a RREP packet to sensor node 1. Finally, the route via forwarder nodes 1 and 2 is constructed.

IV. NUMERICAL RESULTS

In this section, we evaluate the proposed protocol with forwarder nodes and basic AODV by using computer simulations. The simulations are performed by the network simulator sQualNet[14]. In the simulations, 200 sensor nodes are randomly located in an area of 200 [m] × 200 [m]. The

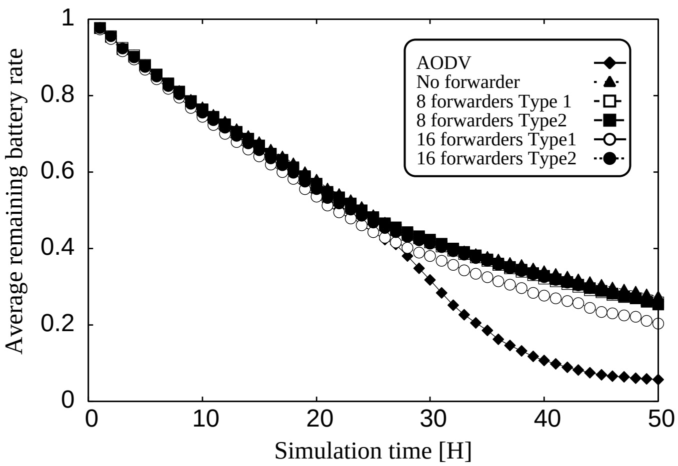


Fig. 6. remaining battery capacity rate.

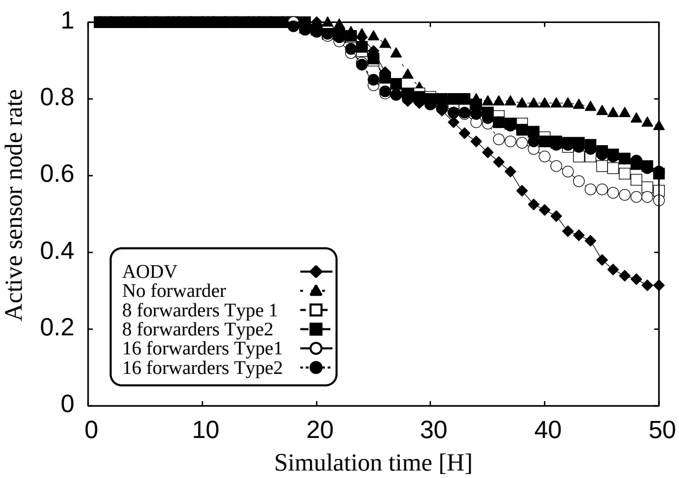


Fig. 7. Active sensor node rate.

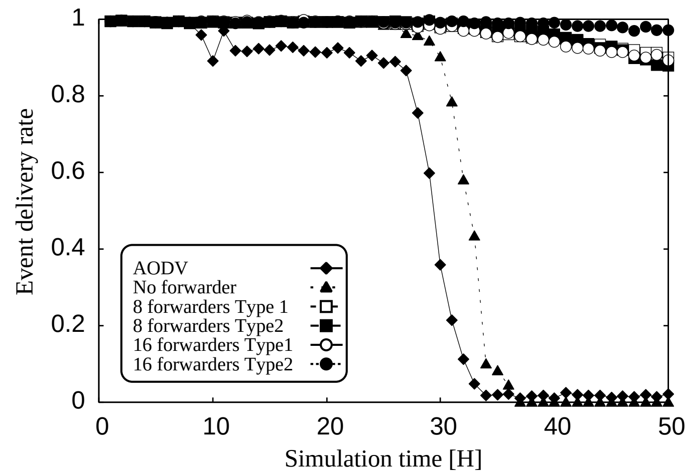


Fig. 8. Event delivery rate.

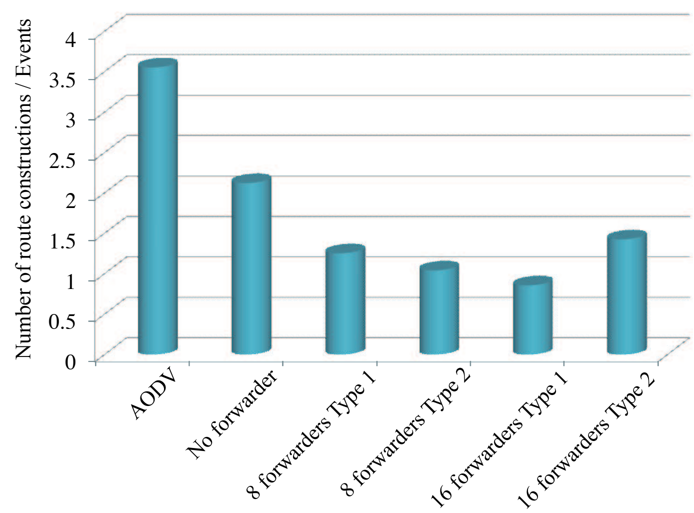


Fig. 9. Number of route constructions.

sink node is located at center of the simulation area, and 8 or 16 forwarder nodes are located, as shown in Fig. 5. Ten thousand events occur in random positions in 50 [h]. We use IEEE 802.11 as the wireless communication device, and the transmission rate is fixed at 2 [Mbps]. We consider the additive white gaussian noise (AWGN) environment and free space propagation model. The delay duration of an RREQ packet is set between 10 [ms] and 100 [ms]. Details of simulation parameters are shown in Table I. Relations between the remaining battery capacity and the delay time RREQ retransmission are defined as Table II.

Figure 6 shows the average remaining battery capacity rate of the sensor nodes. From the results, the remaining battery capacity of AODV decreases linearly until 30 [h]. However, it decreases rapidly from 30 [h]. This is because the sensor nodes near the sink nodes consume a large amount of battery power to forward data packets from a sensor node which is located far from the sink node. Therefore, the sensor nodes far from the sink nodes cannot find the route to the sink node. If the route is not found, each sensor node tries to find it again. As results, many sensor nodes consume a large amount of battery power to find the route to the sink nodes.

On the contrary, the remaining battery capacity of the proposed method without forwarder nodes decreases linearly. Because the sensor node cancels the retransmission of the RREQ packet, if the sensor node receives the RREQ packet that it receives. Consequently, a small amount of battery power is consumed if the route delivery process is tried again. Moreover, the remaining battery capacity of the proposed method with forwarder nodes also decreases linearly. Because the forwarder nodes assist the data packets forwarding to the sink node, and each sensor node can find the route to the sink nodes easily.

Figure 7 shows the active sensor node rate. From the results, the active sensor node rate of AODV decreases rapidly from 20 [h]. This is because the sensor node consumes a large amount of battery power to find the route to the sink node. Therefore, many sensor nodes go down even if the detected events are not arrived at the sink node.

Meanwhile, the active sensor node rate of the proposed method without forwarder nodes decreases to 80 [%] at 20 [h] and keeps more than 70 [%]. Because the proposed method without forwarders cannot find the route to the sink node from 30 [h]. Therefore, almost sensor nodes do not consume the battery power a lot. Additionally, the active sensor node rate of the proposed method with forwarder nodes decreases with increasing in the simulation time. This is because the forwarder nodes assist to construct the route to the sink node, almost all sensor nodes can communicate with the sink node.

Figure 8 shows the event delivery rate at the sink node. From the results, the event delivery rates of AODV and the proposed method without forwarders decrease at 30 [h] even if each sensor node has sufficient remaining battery capacity. This is because the sensor nodes near the sink node consume a considerable amount of battery power to forward data packets from sensor nodes to long-range areas. On the contrary, the event delivery rate with forwarder nodes provides fairly good performance. In particular, the performance of 16 forwarder nodes with a Type 2 position is approximately 100 [%]. From these results, it is important to locate the forwarder nodes near the sink nodes; however, not in a large area.

Figure 9 shows the number of route constructions per events. From the results, we can find that AODV tries to construct the route to the sink node repeatedly. Because AODV may use the sensor node with a small amount of remaining battery to constructs route. Therefore, several route reconstructions are required. On the contrary, our proposed method keeps the high active sensor node rate by considering the remaining battery. As a result, our proposed method can construct the route to the sink node effectively.

V. Conclusions

This study proposed simple power aware routing for sensor networks and introduced forwarder nodes in sensor networks. Our protocol is based on the AODV protocol, which is a popular and simple reactive routing protocol in ad hoc networks. From the simulation results, we confirmed the power efficiency of the proposed protocol and the effect of the forwarder nodes on the sensor networks. Moreover, we showed that the lifetime of the sensor network was considerably increased by introducing the forwarder nodes.

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