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Research Article

A Simple and Energy-Efficient Flooding Scheme for Wireless Routing

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In many wireless networks, such as ad hoc, sensor, and delay-tolerant networks, the destination node is determined from the source node by the flooding process. Flooding efficiency is important for nodes, because they are driven by limited batteries. In this paper, we propose a simple flooding scheme to transmit a route request (RREQ) message based on the remaining power of its own node without using control packets and complex calculations. We applied the proposed scheme to ad hoc on-demand distance vector (AODV) routing protocol as an example and carried out computer simulations (ns3). The results showed that the proposed scheme was superior to conventional schemes in static and mobile scenarios. First, we showed the limit of node density that causes the decrease of throughput in the proposed scheme and that the proposed scheme was superior in terms of energy efficiency (bits/J), including throughput and energy consumption. Next, as the number of flooding times is made uniform in the proposed scheme, all nodes will have almost the same battery replacement time. As a result, when the nodes are static, the lifetime in the proposed scheme is longer than that in the conventional scheme.

1. Introduction

The internet of things (IoT) allows users to select the type of wireless communication methods, such as low-power wide-area (LPWA), Wi-Fi, and short-range communications based on user requirements and system specifications. Even when a base station is not operational, nodes can communicate with each other without the base station [1]. To enable communication even in such a situation, a mobile ad hoc network (MANET) based on multihop communication between many nodes is used without relying on centralized infrastructure [2–4]. In this paper, we focus on MANET. One of the critical challenges to address for MANET and sensor networks is to minimize their power consumption since they configured with battery-powered nodes [5]. This is because in a MANET consisting of many nodes, information cannot reach the destination node if a node runs out of battery power while transmitting and receiving information. Though the flooding process is necessary for route establishment, the

battery life is decreased if the flooding process is focused on specific nodes. In such a case, it is difficult to replace the battery. Therefore, reducing the energy consumption from the physical layer to the network layer is necessary from the viewpoint of both software and hardware. Several surveys on the energy efficiency of MANET, mainly with regard to the routing protocols, have been described [6–10]. In addition, various protocols for sensor networks based on MANET have been developed [11–13].

In this paper, we propose a simple flooding scheme using only the remaining energy of each node, without the need for additional information. In general, there is a trade-off between energy consumption and throughput improvement [14], and even though energy consumption can be improved, the throughput may decrease. In previous schemes, energy and transmission performance, such as throughput and delay, are evaluated separately, and the evaluation has not been always adequate. Therefore, we evaluate the proposed scheme using the energy efficiency (bits/J) [15], which is an

important index in next-generation wireless communication, combining with energy consumption and throughput. In addition, we show the dominance of the proposed scheme by comprehensively evaluating the variance of the remaining energy and lifetime of the whole network when a node is static or moving. Though the proposed scheme is widely applicable to flooding-based wireless routing in optimized link state routing (OLSR) [16] in MANET, wireless sensor network (WSN), delay-tolerant networking (DTN) [17], and so on, in this paper, ad hoc on-demand distance vector (AODV) [18] routing in MANET is used as an example.

The main contributions of this paper are as follows. In this paper, we proposed a simple flooding scheme to transmit RREQ messages based on only the remaining power of its own node in the flooding process without the other information such as control packets and complex calculations. The proposed scheme was applied to AODV of MANET routing, and we showed that the proposed scheme was superior to conventional methods [18, 26] in the following points using computer simulations:

(i) As the node density decreases, the throughput of the proposed scheme is lower compared with that of the conventional methods, whereas the throughput of the proposed scheme increases when the node density becomes higher. The limit of node density that causes the decrease of throughput is nearly 40 nodes/km^2 in this evaluation

(ii) Irrespective of the node density, the energy consumption was reduced in the proposed scheme

(iii) As a result, the proposed scheme is shown to be superior in terms of energy efficiency (bits/J), with regard to throughput and energy consumption

(iv) As the nodes to be flooded are equalized in the proposed scheme, all nodes have almost the same battery replacement time

(v) When the nodes are static, the network lifetime in the proposed scheme does not decrease regardless of the node density or the number of flows

The rest of this paper is organized as follows. In Section 2, we describe the related works. In Section 3, we show the proposed scheme, smart AODV, which is called SAODV. In Section 4, we discuss the performance of the proposed scheme using computer simulations. Finally, we present our conclusions in Section 5.

2. Related Works

Energy consumption reduction methods in MANET are mainly divided into two groups: energy-efficient route selection and flooding efficiency. The latter related to the proposed scheme is described in Section 2. For the former, methods have been proposed in which the amount of remaining energy of a node is used as a route selection metric [19–21]. Though the lifetime of the entire network can be extended, the regular exchange of control messages increases the additional energy consumption. It is a serious problem in an environment when the network topology changes every moment. If the battery level of a node falls below a certain threshold, a method of exiting the route [22] or avoiding participation in route construction [23] has been proposed. It is difficult to determine an appropriate threshold, and new items are required for the control packets, making the processing more complicated.

Next, we describe conventional researches on energy consumption based on efficient flooding. First, the flooding operation is briefly described using AODV routing as an example [21]. In AODV, the source node S transmits a route request (RREQ) packet to neighboring nodes to determine the route. The node that received the RREQ packet repeats the transmission of the RREQ packet in the same manner so that the RREQ packet finally reaches the destination node D. In addition to this route discovery operation, flooding is also performed in the operation of searching for the cost route of the disconnected route or route maintenance. As well as AODV, the same process can be applied to the other on-demand protocol such as dynamic source routing (DSR) [24]. In OLSR [16], which is a proactive protocol, multipoint relaying (MPR) nodes serve as the flooding nodes. The problem with flooding is that a sudden increase in traffic causes many packet collisions is known as the broadcast problem [25]. To reduce this problem, improved flooding schemes have been proposed. In the original flooding operation, gossip-based routing protocol has been proposed as a method to determine whether RREQ messages can be transmitted or not, based on a predetermined probability p [26]. In Section 3, AODV implementing this processing is called gossip-based AODV, which is called GAODV. Though this method can reduce the energy consumption of the entire network, the setting of the probability p is difficult. This is because the appropriate value of p differs depending on the density and moving speed of nodes. In [27], the impact of various parameters such as node speed on the performance of a fixed probabilistic approach [26] has been shown. Particularly, mobility and pause times have a substantial impact on the reachability of data transmitted from the source node to the destination node. In [28], a probabilistic approach that dynamically adjusts the rebroadcasting probability according to the node density and node movement has been proposed. Although the node density can be estimated using the packet counter, it is necessary to set the time interval and 1threshold for checking the packet counter appropriately according to the environment. In [29], a probabilistic approach that dynamically adjusts the rebroadcasting probability by considering the network density has been proposed. Simulation results have shown that the scheme can improve the saved broadcast up to 50% without affecting the reachability, even under high mobility and density conditions. However, because the average number of neighboring nodes is determined by the number of mobile nodes in the network and the area of the network, throughput performance affects them. In [30], a probabilistic approach that dynamically adjusts the rebroadcasting probability according to the number of neighboring nodes is presented. This method has been shown to outperform the results in [29]. However, it requires

complicated processing to determine the probability; moreover, the optimal value depends on the environment and should be evaluated by various models.

In [28–30], a method has been proposed in which each node periodically transmits hello packets to recognize the number of surrounding nodes and dynamically determines the probability p. Because the probability should be calculated and the average number of neighboring nodes should be assessed in advance, the energy consumption associated with these overheads is a concern, as in [19–21]. However, [27–30] mainly demonstrate the throughput and reachability performance, whereas the energy consumption performance is not discussed. Moreover, the effect of the dynamical and probabilistic approach on the lifetime of the entire network has not been clarified. Reference [28] has highlighted the necessity for a new strategy that can dynamically adjust the broadcast probability based on the current state of the node. In [16, 31, 32], the energy consumption of MPR nodes, which are the targets of flooding in OLSR routing, is reduced based on the same concept described above.

3. Proposed Scheme

We propose a simple flooding scheme to transmit RREQ based on only the remaining power of own node in the flooding process without the other information such as control packets and complex calculations to grasp the network status. This paper shows the case where the proposed method is applied to AODV [18] routing as an example. The proposed scheme is shown in Figure 1. The node that receives the RREQ packet generates a random variable X from 0 to 100 by itself. The value of X is compared with the ratio of the remaining energy of the node, Y (%). If the value of Y is greater than or equal to the value of X, flood the received RREQ packet to the adjacent node; otherwise, discard it. As a result, though a node with a large amount of remaining power tends to flood, the opposite is said for a node with a small amount of remaining power. The proposed scheme is widely applicable to flooding-based wireless routing in OLSR [16], WSN, DTN [17], etc. Moreover, as the proposed scheme modifies only the flooding process, it has little impact on other processes and can therefore be easily implemented to the previous methods.

4. Performance Evaluation

4.1. Setup and Definition. We evaluate the performance of the proposed scheme using a discrete-event network simulator, ns3 [33] (version 3.20). Figure 2 shows the basic simulation model.

After the source node (S) sends the packets, the relay nodes (R) use a routing scheme to transport the packets to the destination node (D). For example, Figure 2 shows an ad hoc network in an evacuation area in a disaster situation [1]. Important information transmitted from the victim S arrives at the gateway D connected to the internet via the rescuer R with an ad hoc terminal. As a wireless channel, the path loss, with an exponential coefficient, α is considered. According to the implementation of ns3 [33], some energy
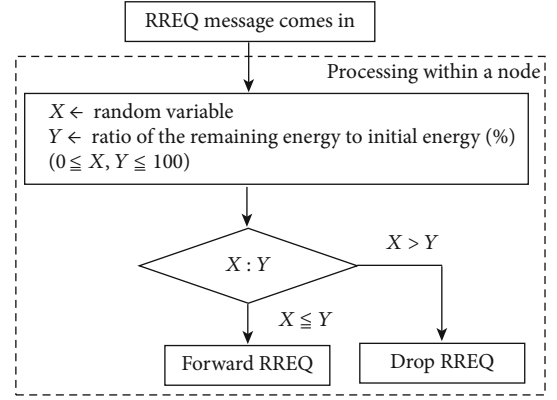

FIGURE 1: Proposed flooding scheme based on the remaining power of own node.

is consumed whenever an event occurs. The energy consumption of a node n is linearly approximated and expressed by

$$E_n(t + \Delta t_0) = E_n(t) + V \cdot \Delta t_0 \cdot I_i, \tag{1}$$

where $E_n(t)$ (J) is the energy consumption at time t (s), V (V) is the supply voltage, I_i (mA) is the current consumption defined for each event $i \in \{1, 2, \cdots, 5\}$, and Δt_0 (s) is the time interval. The simulation parameters are presented in Table 1. The energy left in the node n is expressed by

$$\tilde{E}_n(t) = \beta \times E_0 - E_n(t), \tag{2}$$

where E_0 is the initial power of the battery (J), and β (%) is the ratio of the remaining energy to the full energy at the initial state. Hereafter, β is called the initial energy ratio.

We define five quantities to evaluate the proposed method. Throughput $\text{TH}(t)$ (Kbps) is the amount of data that arrives from the node S to the node D per unit time, expressed by

$$\text{TH}(T_{\text{sim}}) = \frac{P_D(T_{\text{sim}}) \cdot P_{\text{size}}}{T_{\text{sim}}}, \tag{3}$$

where $P_D(T_{\text{sim}})$ (packets) is the total number of packets received by the node D during one simulation time, T_{sim} (s), and P_{size} (Kbits/packet) is the packet size. $\text{EC}(T_{\text{sim}})$ (W) denotes the energy consumption per unit time; it is the total energy consumption in the whole network system during one simulation time, expressed by

$$\text{EC}(T_{\text{sim}}) = \frac{1}{T_{\text{sim}}} \sum_{n=1}^{N} E_n(T_{\text{sim}}), \tag{4}$$

where N is the number of all nodes. Energy efficiency EE (Kbits/J) is a combined measure of throughput and energy consumption. Using expressions (3) and (4), it is expressed by

$$\text{EE}(T_{\text{sim}}) = \frac{\text{TH}(T_{\text{sim}}) \cdot T_{\text{sim}}}{\text{EC}(T_{\text{sim}})}, \tag{5}$$
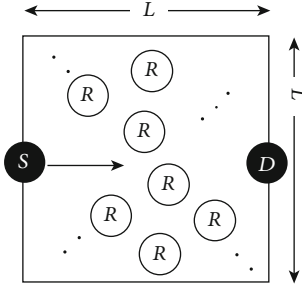
FIGURE 2: Simulation model. In a static scenario, the relay nodes R are static randomly. In a mobile scenario, the relay nodes R are moving randomly. In both scenarios, source node, S, and destination node, D, are fixed static.

where T_{sim} is one simulation time. The variance in remaining energy with all nodes, E_σ, at time, T_{sim}, is expressed by

$$E_\sigma(T_{\text{sim}}) = \frac{1}{N} \sum_{n=1}^{N} \left(\tilde{E}_n(T_{\text{sim}}) - E(\bar{T}_{\text{sim}}) \right)^2, \qquad (6)$$

where N is the total number of relay nodes, $\tilde{E}_n(T_{\text{sim}})$ is expressed by (2), and $\overline{E(T_{\text{sim}})}$ is the average remaining energy of all nodes at time, T_{sim}. The lifetime, LT (hour), is defined as the time until the ratio of total remaining power with all nodes becomes 10%. Table 1 shows the basic simulation parameters. Some routing-related parameters use request for comment (RFC) default values of AODV [18], and energy consumption parameters use the default values for ns3 (version 3.20). One simulation time, T_{sim}, is 300 seconds, and packet transmission from node S is suppressed for 20 seconds after the start of simulation to stabilize the routing operation. We consider two scenarios: (1) all relay nodes (R) are static, which is called the static scenario, (2) all relay nodes (R) are moving randomly, which is called the mobile scenario. Nodes S and D are always at a fixed position in these scenarios. In the static scenario, the random placement of nodes R is initialized in each simulation. In the mobile scenario, a random waypoint model defines the movement of node R. In this paper, we evaluated the performance of the proposed SAODV compared with the conventional schemes, GAODV and AODV as described in Section 2. In GAODV, the RREQ transmission probability, p, is set to 0.6 and 0.8 according to Reference [26].

4.2. Impact of the Initial Energy Ratio. We evaluated the case where the node density, ρ (nodes/km^2), is 30. Each item is evaluated by uniformly increasing the ratio of the remaining energy, β from 10% to 100% in steps of 10% step for all nodes. Figure 3 shows the result of throughput, TH. In both static and mobility cases, when β is larger, all methods have the same performance, but when β is about 40% or less, the performance of the proposed method is degraded. Because the range that the RREQ message can reach is limited. For the entire range of β, the throughput of the mobile scenario is lower than that of the static scenario. This is because route disconnection occurs due to the node movement. Figure 4 shows the result of energy consumption, EC. Contrary to the throughput, energy consumption is reduced due to the

TABLE 1: Simulation parameters.

Communication standards	IEEE 802.11b
Simulation time (T_{sim})	300 sec
Side length of the target area (L)	1 km
Number of trials in one simulation	100
Number of relay nodes (N)	30
Velocity of relay node (v_r)	1.41 m/sec
Pass loss exponent (α)	3.5
Antenna gain	1
Limit coverage of direct transmission	250 m
Bit rate	1.0 Mbps
Application protocol	UDP
Traffic type	CBR
Generate traffic	2.0 Mbps
Packet size	1500 bytes
Routing protocol	AODV
Initialization energy of a node (E_0)	3600 J
Transmission power (P_t)	28 dBm
Receiver threshold	-96 dBm
Supply voltage (v)	3 V
Idle current (I_1)	0.426 mA
Clear channel assessment (CCA) busy state current (I_2)	0.426 mA
Channel switch current (I_3)	0.426 mA
Tx current (I_4)	17.4 mA
Rx current (I_5)	19.7 mA

operation of the proposed scheme. The energy consumption is almost constant in the conventional schemes, AODV, GAODV ($p = 0.6$), and GAODV ($p = 0.8$) regardless of the value of β. However, the energy consumption in the proposed scheme decreases as the value of β decreases in both static and mobile cases. Thus, a disadvantage related to throughput is an advantage with regard to power consumption. Figure 5 shows the result of energy efficiency, EE. Though all methods are almost equal in the static scenario, the proposed method has the best performance in the case of mobility.

Figure 6 shows the variance of the remaining energy for all nodes, E_σ. Although it is almost constant in the conventional schemes, it decreases as β decreases in the proposed scheme. In the proposed scheme, the remaining energy of all nodes can be equalized, and the battery replacement time is expected to remain approximately the same. This reduces the effort required for battery replacement.

4.3. Impact of Node Density. We evaluated the performances described in Section 4.1 for various node density ρ when β is 50%. Figure 7 shows the result of throughput, TH. In both static and mobile cases, when ρ is approximately 40 nodes/km^2 or more, the throughput of the proposed scheme becomes the highest. This contrasts with the result shown in Figure 3, where ρ is 30 nodes/km^2. Moreover, in a situation where ρ is higher, the throughput decreases as the RREQ
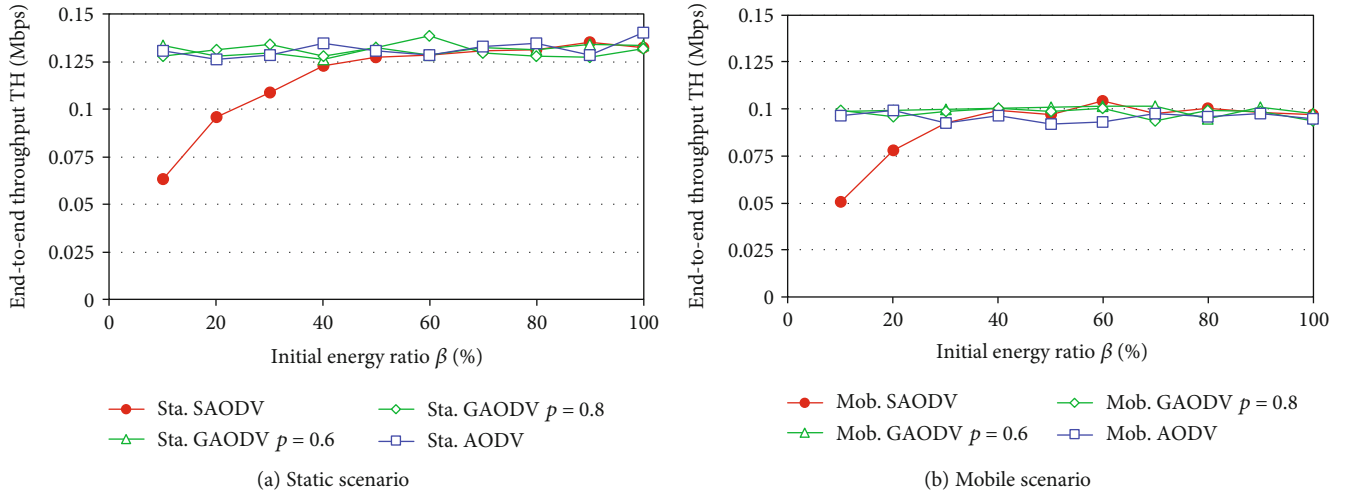
(a) Static scenario

(b) Mobile scenario

FIGURE 3: End-to-end throughput, TH with the initial energy ratio, β ($\rho = 30$ nodes/km^2).

(a) Static scenario

(b) Mobile scenario
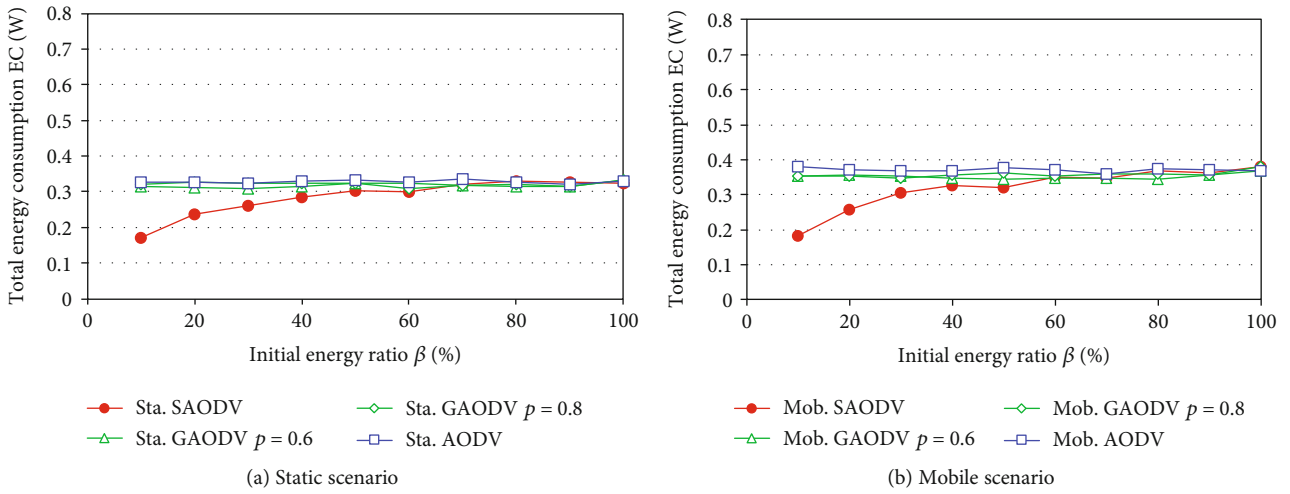
FIGURE 4: Energy consumption, EC, with the initial energy ratio, β ($\rho = 30$ nodes/km^2).

(a) Static scenario

(b) Mobile scenario
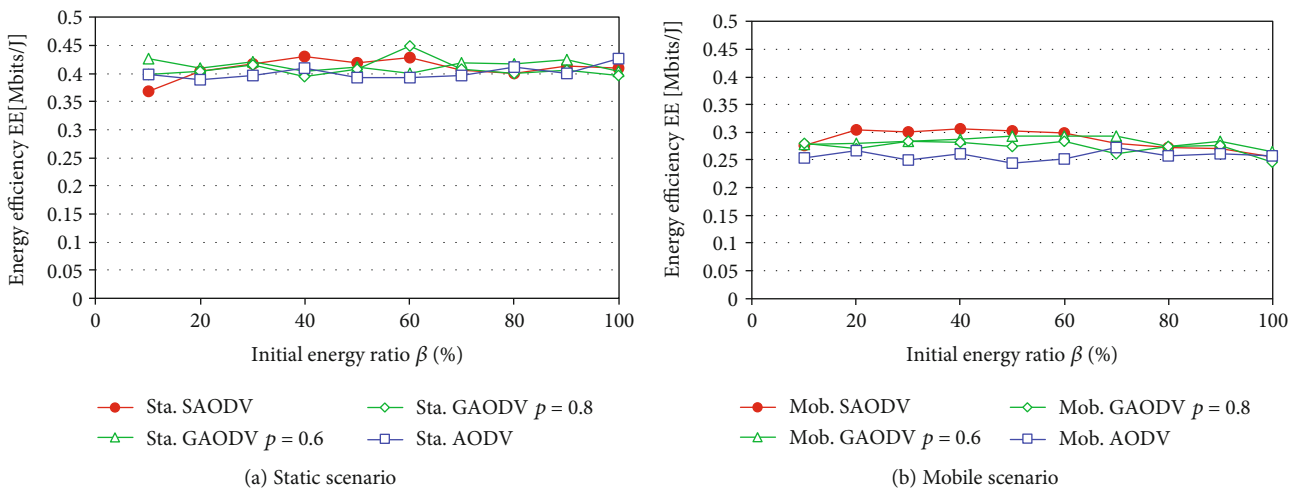
FIGURE 5: Energy efficiency, EE, with the initial energy ratio, β ($\rho = 30$ nodes/km^2).
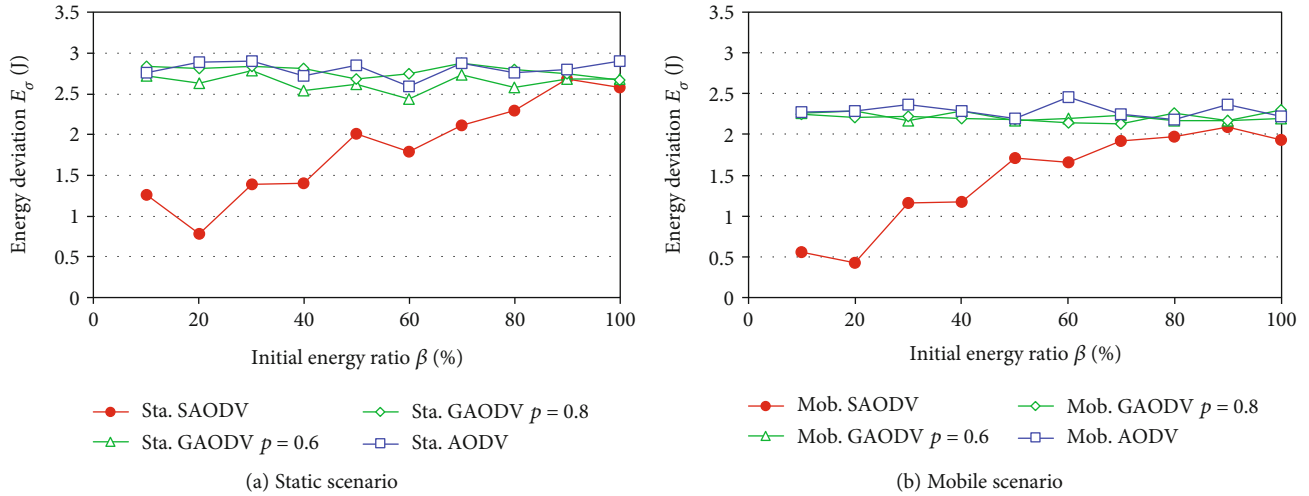
(a) Static scenario

(b) Mobile scenario

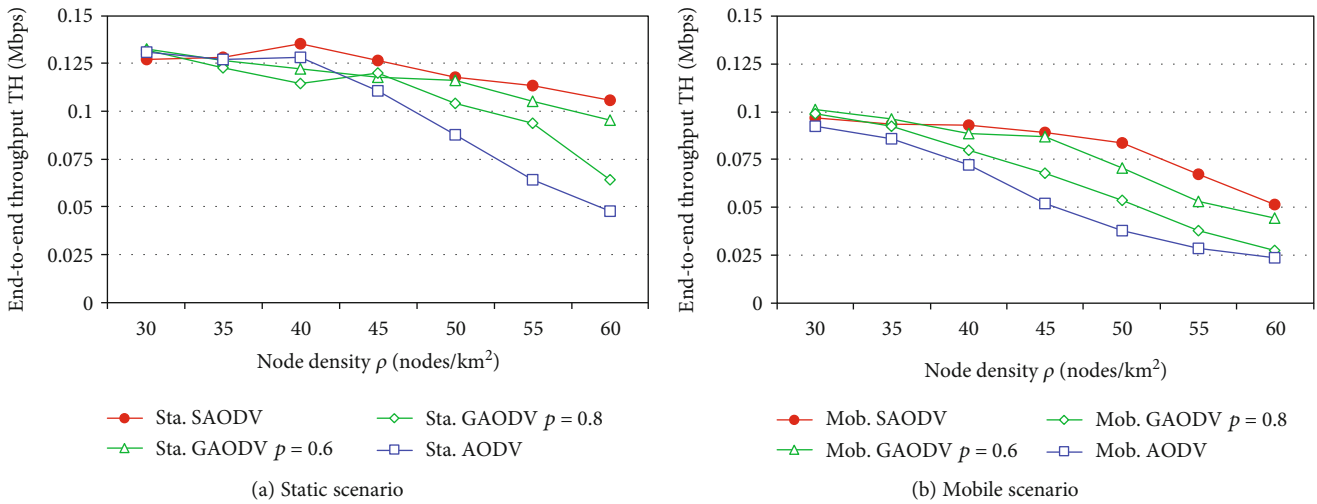FIGURE 6: Variance of remaining energy, E_σ, with the initial energy ratio, β ($\rho = 30$ nodes/km^2).

(a) Static scenario

(b) Mobile scenario

FIGURE 7: End-to-end throughput, TH, with node density, ρ ($\beta = 50\%$).

(a) Static scenario

(b) Mobile scenario
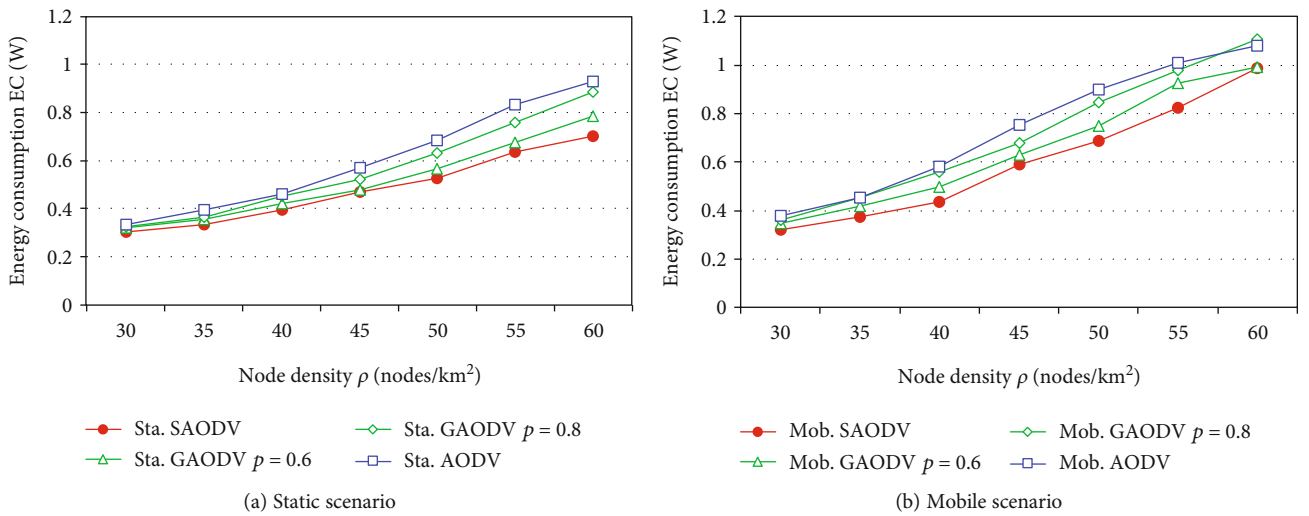
FIGURE 8: Energy consumption, EC, with node density, ρ ($\beta = 50\%$).
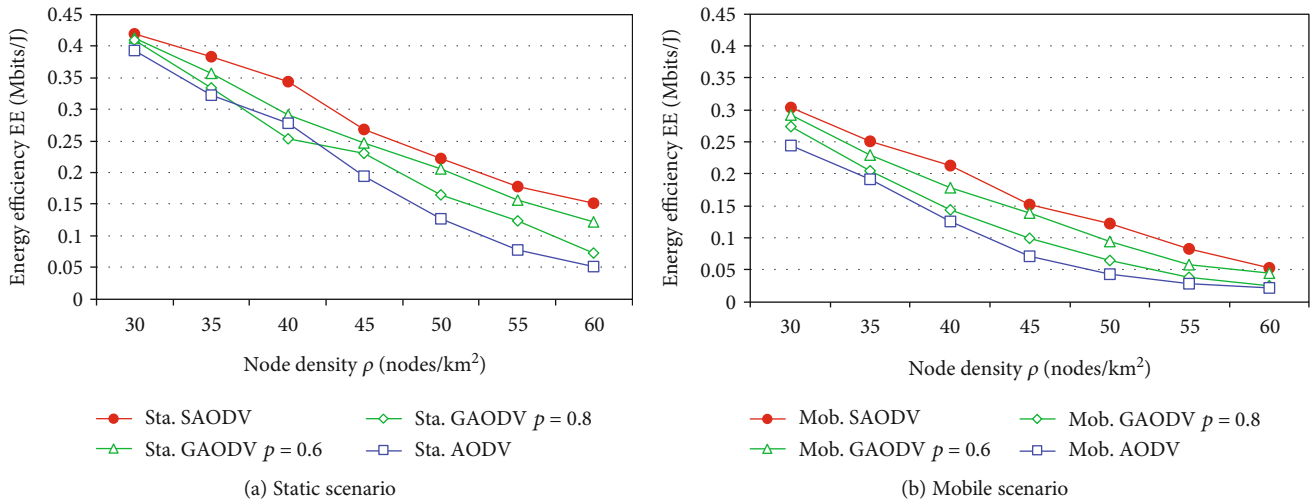
(a) Static scenario

(b) Mobile scenario

FIGURE 9: Energy efficiency, EE, with node density, ρ ($\beta = 50\%$).

transmission probability, p, increases, even in the conventional schemes. For these reasons, when ρ is larger, the ratio of RREQ messages required for route construction is larger than that required for information packets, and the throughput may be decreased. In [26], it is shown that almost every node gets the message using p between 0.6 and 0.8. Even in such a congested situation, as the proposed scheme suppresses the excessive transmission of RREQ messages, the avoidance of congestion and reduction of retransmitted packets can be achieved. As a result, higher throughput can be realized. On the other hand, in the static scenario, the best throughput is achieved when ρ is nearly 40; it should be noted that there exists an optimal ρ according to the environment in terms of throughput. Figure 8 shows the result of energy consumption. As shown in Figure 4, the proposed scheme reduces energy consumption due to its operation. Figure 8 shows that energy consumption decreases as node density increases. Figure 9 shows the result of energy efficiency, EE. From the results of throughput and energy consumption, we conclude that the energy efficiency in the proposed scheme is higher than conventional schemes regardless of the value of ρ.

Figure 10 shows the result for the lifetime, LT. In the static case, although the values of LT in conventional schemes decrease when ρ or p increases, it remains nearly the same in the proposed scheme. This is because in the conventional schemes, the energy consumption decreases LT, because of the increase in transmission and reception of RREQ messages. However, as the number of flooding times is made uniform in the proposed scheme, all nodes have almost an equal chance to transmit the RREQ messages. This consideration is also related to the results in Figure 6. The values of LT are smaller in the case of movement than those in the static scenario. It is considered that energy is consumed by transmitting and receiving control packets to retransmit when a communication path is disconnected due to node movement. However, even in the case of movement, the proposed scheme has better performance than conventional schemes. In particular, we showed that the lifetime
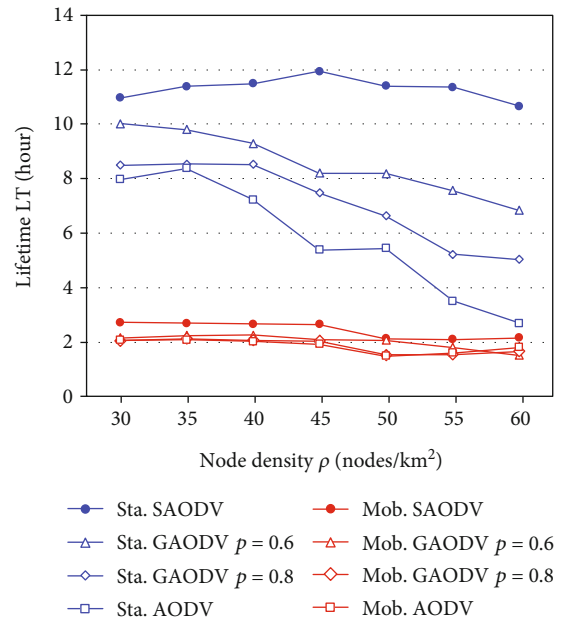

FIGURE 10: Lifetime, LT, with node density, ρ ($\beta = 50\%$).

was extended up to about 2.2 times in the static scenario and about 1.4 times in the mobile scenario compared to the original AODV when the node density was 45 nodes/km^2.

4.4. Impact of the Number of Flows. We discussed the cases in which the number of flows, in other words, number of node S was one shown in Figure 1. In this section, we evaluate by increasing the number of flows to confirm the further effects of the proposed method. The number of source nodes S is increased at equally spaced positions on the left-hand line segment with one destination node D fixed, as shown in Figure 2. Figure 11 shows the impact of LT on the number of flows, F. The consideration for the result in Figure 11 is almost equal to that of Figure Communication standards IEEE 802.11b Simulation time (T_{sim}) 300 sec Side length of
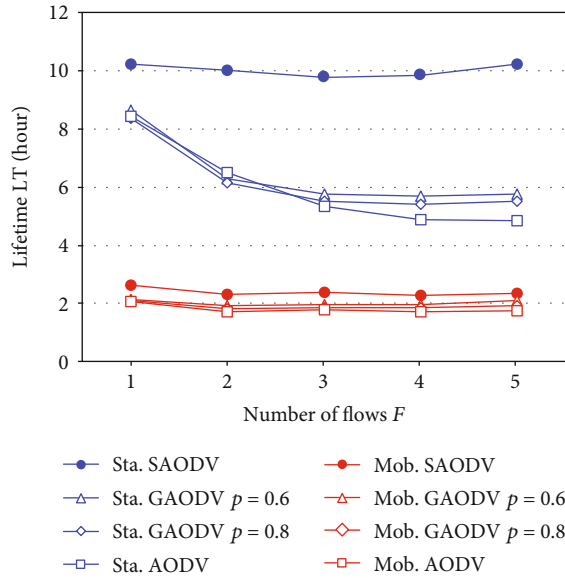
FIGURE 11: Lifetime, LT, with the number of flows, F ($\beta = 50\%$).

the target area (L) 1 km Number of trials in one simulation 100 Number of relay nodes (N) 30 Velocity of relay node (v_r) 1.41 m/sec Pass loss exponent (α) 3.5 Antenna gain 1 Limit coverage of direct transmission 250 m Bit rate 1.0 Mbps Application protocol UDP Traffic type CBR Generate traffic 2.0 Mbps Packet size 1500 bytes Routing protocol AODV Initialization energy of a node (E_0) 3600 J Transmission power (P_t) 28 dBm Receiver threshold -96 dBm Supply voltage (v) 3 V Idle current (I_1) 0.426 mA Clear channel assessment (CCA) busy state current (I_2) 0.426 mA Channel switch current (I_3) 0.426 mA Tx current (I_4) 17.4 mA Rx current (I_5) 19.7 mA . The proposed scheme can keep the lifetime constant regardless of the number of flows. This is because increasing the node density and the number of flows can be considered to have equivalent effects. In particular, we showed that the lifetime extended up to nearly 2.0 times in the static scenario and 1.3 times in the mobile scenario compared to the original AODV when the number of flows was 3. Thus, the proposed scheme is more effective, even in an environment with a larger number of flows.

5. Conclusions

We proposed a simple flooding scheme to transmit RREQ message based on only the remaining power of each node in the flooding process without additional information such as control packets and complex calculations. We applied the proposed scheme to AODV of MANET routing and showed the superiority of the proposed scheme to the conventional scheme using computer simulation. As the node density decreases, the throughput of the proposed scheme becomes lower than that of the conventional methods, whereas the throughput of the proposed scheme increases when the node density becomes higher than nearly 40 in the evaluated environment. Regardless of the node density, energy consumption was reduced in the proposed scheme.

As a result, we showed that the proposed scheme was superior to conventional schemes in terms of energy efficiency (bits/J), including throughput and energy consumption. Moreover, as the nodes to be flooded are equalized in the proposed scheme, the variance in the remaining energy of all nodes becomes smaller. The proposed approach ensures that all nodes need almost the same battery replacement time. Thus, the lifetime in the proposed scheme does not decrease when the nodes are static, regardless of the node density or the number of flows.

Future works include the evaluation of the proposed scheme for unmanned aerial vehicle (UAV) networks [34] and comparison with other dynamical and probabilistic approaches.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest in this work.

Acknowledgments

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