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A Reliable and Energy-Efficient One-to-one Ad-Hoc Routing Protocol in Wireless Networks

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Abstract

In wireless ad-hoc networks, messages have to be energy-efficiently delivered to destination nodes by exchanging the messages among neighboring nodes. In our previous studies, the reactive type EAO and IEAO protocols are proposed to unicast messages. The electric energy consumption of a node p_i in the EAO and IEAO protocols is defined as the square of the distance between a pair of nodes p_i and p_j . In the EAO protocol, the total electric energy of nodes and delay time from a source node to a destination node can be reduced compared with the AODV protocol, but a source-to-destination route may not be found if the communication range of each node is shorter. We proposed the IEAO protocol to overcome this difficulty. However, each node in reality spends electric energy to perform a process, not communication device to send messages. Hence, it is necessary to reduce the number of transmissions of each node in a source-to-destination route. In this paper, we newly propose an REO (Reliable and Energy-Efficient One-to-one routing) protocol to reduce the number of transmissions of each node. In the REO protocol, for each node, a neighboring node to which the node can deliver a message with low message loss ratio and which has an uncovered neighbor node is selected as a prior node. In the protocol, if a node fails to deliver a message, the node retransmits the message. This means, the higher message loss ratio, the more number of retransmissions, i.e. the more electric energy is consumed. In the evaluation, we show the number of transmissions of each node in a source-to-destination route can be reduced in the REO protocol compared with other protocols.

Key words: *Wireless ad-hoc network, Unicast protocol, Energy-efficient prior node, REO protocol*

1 Introduction

Wireless ad-hoc networks [3] [6] are widely used in various types of applications, especially in vehicle-to-vehicle (V2V) communication [7] and delay-tolerant networks (DTN) [2]. Here, each node forwards messages to neighbor nodes which are in the communication range of wireless networks.

In this paper, we would like to discuss a unicast routing protocol, where messages are energy-efficiently delivered from a source node to a destination node in wireless ad-hoc networks. In our previous studies, the reactive type of ad-hoc routing protocols [6], EAO (Energy-Aware One-to-one routing) [4] and IEAO (Improved EAO) [5] protocols are proposed to reduce the total electric energy consumed by nodes in a source-to-destination route and the route length, i.e. number of nodes in the route. However, the total electric energy consumed by nodes is in reality rather dominated by performing programs to send a message than communication devices to emit radio. This means, the electric energy consumed by each node depends on the number of transmissions of the nodes.

In this paper, we newly propose an REO (Reliable and Energy-Efficient One-to-one routing) protocol to reduce the number of transmissions in a source-to-destination

route in order to reduce the electric energy consumed by nodes.

We evaluate the REO protocol compared with the IEAO, EAO, and AODV [6] protocols in the simulation.

In section 2, we present the system model. In section 3, we propose the REO protocol. In section 4, we evaluate the REO protocol.

2 System Model

A network N is composed of n (≥ 1) nodes p_1, \dots, p_n which are cooperating with one another by exchanging messages in wireless networks [1]. Let d_{ij} be the distance between a pair of nodes p_i and p_j . In this paper, we assume the distance d_{ij} between every pair of nodes p_i and p_j is *a priori* known. Each node does not move, i.e. stays at fixed location.

Let $maxSE_i$ show the maximum electric energy [J] consumed by a node p_i to send a message. $wd_i(maxSE_i)$ shows the maximum communication range of a node p_i . A node p_j can receive a message sent by a node p_i if the node p_j is a first-neighbor node of a node p_i , i.e. $d_{ij} \leq wd_i(maxSE_i)$. Otherwise, a node p_j cannot receive the message from a node p_i . We assume the maximum communication range $wd_i(maxSE_i)$ of each node is the same. Let $maxd_i$ be $wd_i(maxSE_i)$, i.e. maximum communication range of a node p_i . This

means, the maximum electric energy [J] consumed by each node is also the same, i.e. $\max SE_i = \max SE$.

In our experiment, a node consumes so large electric energy to perform the protocol modules that the electric energy consumed by communication devices can be neglected. Hence, it is necessary to reduce the number of retransmissions of each node to deliver a message to a neighbor node. A way to reduce the number of retransmissions is to choose a node to which a message can be delivered with a lower message loss ratio. The larger the message loss ratio is, the more number of times a message is retransmitted. Let PL_{ij} show the message loss ratio of a node p_i to send a message to a node p_j . In this paper, we assumed $PL_{ij} = PL_{ji}$ for every pair of nodes p_i and p_j . PL_{ij} depends on the distance d_{ij} between nodes p_i and p_j .

Here, δ is a selection parameter ($0 \leq \delta \leq \max D_{ij}$). If $d_{ij} < \delta$, PL_{ij} is 0. The message loss ratio PL_{ij} is defined as $(d_{ij} - \delta)^2 / (\max D_{ij} - \delta)^2$ if $\delta \leq d_{ij} < \max D_{ij}$ [Figure 1]. If $d_{ij} \geq \max D_{ij}$, PL_{ij} is 1. The node p_j can receive every message sent by the node p_i if $d_{ij} < \delta_{ij}$. The rest ratio exponentially increases for $\delta_{ij} \leq d_{ij} < \max D_{ij}$. $\max D_{ij}$ is the maximum distance in which the node p_i can deliver a message. We assume $\max D_{ij}$ and δ_{ij} for every pair of nodes p_i and p_j .

Each node p_i sends a message m to a node p_j . If the node p_j fails to receive a message m from a node p_i , the node p_i retransmits the message m to the node p_j . In this paper, we assume each node p_i retransmits a message m to a node p_j until the node p_j receives the message m . NT_{ij} is the average number of transmissions of a node p_i to deliver a message to a node p_j . Here, $NT_{ij} = 1 / (1 - (d_{ij} - \delta)^2 / (\max D_{ij} - \delta)^2) = 1 / (1 - PL_{ij})$ for $PL_{ij} < 1$.

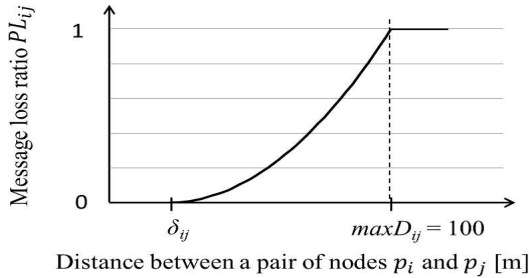


Fig. 1: Message loss ratio.

3 REO Protocol

In this paper, we newly propose an *REO* (Reliable and Energy-Efficient One-to-one routing) protocol for a source node to unicast messages to a destination node so that the number of transmission of each node in a source-to-destination node can be reduced. This means, the electric energy consumed by a source-to-destination route can be reduced and the time of sending a message from a source node to a destination node also can be reduced.

3.1 Overview

The REO protocol is composed of two phases, forwarding and backtracking phases as discussed in the IEAO [5] and EAO [4] protocols. At first, a source node p_s initiates the forwarding phase. Here, each node obtains information of first-neighbor nodes in the network N by flooding *RQ* (request) messages to the destination node in a similar way to the EAO [4] and AODV [6] protocols. A shortest source-to-destination route is found by using the first-neighbor information. Here, a directed link $p_j \rightarrow p_i$ shows that the node p_i is a first neighbor node of the node p_j , i.e. p_j receives an *RQ* message q from p_i . If the destination node p_d receives an *RQ* message q , a shortest route $p_s \rightarrow \dots \rightarrow p_d$ is obtained as the forwarding route. Here, the forwarding phase terminates.

Then, the destination node p_d initiates the backtracking phase to find a more energy-efficient route from the destination node p_d . Until the source node p_s is found, the backtracking procedure is iterated. Thus, a new route from the source node p_s to the destination node p_d is found.

Each node p_i manipulates the following variables to find a route.

- $p_i.l$ = level parameter of the node p_i , initially 0.
- $p_i.FN$ = set of first-neighbor nodes of the node p_i , initially ϕ .
- $p_i.p_j.FN$ = set of first-neighbor nodes of each first-neighbor node p_j of the node p_i , initially does not exist.
- $p_i.Nfs$ = set of nodes which are not only first-neighbor nodes of the node p_i but also first-neighbor nodes of a first-neighbor node p_j of the node p_i , i.e. $p_i.Nfs = p_i.Nfs \cup (p_i.FN \cap p_i.p_j.FN)$, initially ϕ .

A variable $p_i.p_j.FN$ is created and $p_i.p_j.FN = \phi$ if the node p_i finds a node p_j to be a first-neighbor node of the node p_i , i.e. $p_j \in p_i.FN$ in the forwarding phase.

An *RQ* message q sent by a node p_i is composed of the following fields:

- $q.l$ = level parameter of the source node p_i , i.e. $q.l = p_i.l$.
- $q.FN$ = set of first-neighbor nodes of the source node p_i , i.e. $q.FN = p_i.FN$.
- $q.src$ = source node p_s .
- $q.dst$ = destination node p_d .

3.2 Backtracking phase

On receipt of an *RQ* message, the destination node p_d initiates the backtracking phase as a current node. For each current node p_i , suppose $p_j \rightarrow p_i$ and $p_j \rightarrow p_k \rightarrow p_i$. Here, the node p_j is a prior node and the node p_k is a *candidate* prior node of the node p_i obtained in the forwarding phase. In the backtracking phase, one of the nodes p_j and p_k is selected. For example, the node p_k is selected as a prior node of the current node p_i . Suppose, p_k gets a current node. Then, for the current node p_k such that $p_j \rightarrow p_k$, a prior node is tried to be found in the same way. Thus, if a current node is a source node, the

backtracking phase terminates and a sequence of current nodes is a route from the source node to the destination node.

In the REO protocol, just a most reliable candidate prior node p_j is selected as a prior node of each node p_i . However, every neighbor node of the node p_j may be already covered in the route. In this paper, we try to find a candidate prior node p_j whose level parameter $p_j.l$ is not bigger than $p_i.l$ of the node p_i and which has at least one uncovered neighbor node whose level parameter is not bigger than $p_j.l$ to overcome the difficulty. A node p_i first selects a prior node p_j of the node p_i by using the following Algorithm 1.

First, a prior node p_i is selected for the destination node p_d according to the Algorithm 2.

Suppose a node p_i receives an *RC* message r from a node p_j . In each node p_i , $p_i.NX$ and $p_i.PR$ denote a next node and a prior node of the node p_i , respectively, in an REO route. On receipt of an *RC* message r , each node p_i behaves as Algorithm 3.

The source node p_s eventually receives an *RC* message r from a node p_i [Algorithm 4].

Here, the backtracking phase terminates and an REO route from the source node p_s to the destination node p_d is found. $p_i.NX$ and $p_i.PR$ denote a next node p_j and a prior node p_k of each node p_i in an REO route, respectively, i.e. $p_k \rightarrow p_i \rightarrow p_j$.

4 Evaluation

We evaluate the IEAO2 protocol in terms of total number of transmission and reception of nodes in a source-to-destination route compared with the IEAO [5], EAO [4] and AODV [6] protocols. In the evaluation, n (≥ 1) nodes p_0, p_1, \dots, p_{n-1} are uniformly deployed on an $m \cdot m$ mesh network N . In the evaluation, we consider a 128 times 128 mesh network, i.e. $m = 128$. We randomly select $n \cdot (n - 1)$ pairs of a source node p_s and a destination node p_d in the n nodes. Here, the maximum communication range $maxd_i$ of each node p_i is the same $maxd$. Then, REO, IEAO, EAO, and AODV routes are found for each pair of a source node p_s and a destination node p_d on the mesh network in the REO, IEAO, EAO, and AODV protocols, respectively, on each deployment of nodes in the mesh network. We assume the communication range $maxd_i$ of each node p_i is the same $maxd$.

For every pair of nodes p_i and p_j , $maxD_{ij} = maxD = 100$ in the evaluation. Figure 2 shows the total number of transmissions and receptions in a source-to-destination route in the REO, IEAO, EAO, and AODV protocols with $\delta = 30$ for $n = 30$ where $30 \leq maxd \leq 90$. The larger the communication range gets, the fewer the total number of transmissions and receptions in a source-to-destination route of the REO protocol.

Figure 3 shows the number of transmissions and receptions of each node in the REO, IEAO, EAO, and AODV route with $\delta = 30$ for $n = 30$ and the communication range $maxd$ is 30 to 90. The number of transmissions and receptions of each node in a source-to-destination route of the REO protocol is fewer than

Algorithm 1: Select a prior node

```

1 if  $p_s \in p_i.FN$ , then
2   if  $NT_{is} \leq 2$ , then
3     return ( $p_s$ );
4   else
5     if there exists a candidate prior node  $p_k$  ( $\neq p_s$ ) in  $p_i.Nfs$  such that  $p_k \in p_i.p_s.FN$ ,  $NT_{ik} + NT_{ks} < NT_{is}$  and  $p_k.l \leq p_i.l$ , then
6       if there are multiple nodes, then
7         select a node  $p_k$  such that  $NT_{ik} + NT_{ks}$  is minimum;
8       return ( $p_k$ );
9     else
10      return ( $p_s$ );
11  else
12    if  $p_i.Nfs = \phi$ , then
13      select a node  $p_j$  in  $p_i.FN$  such that  $NT_{ij}$  is minimum,  $p_j.l \leq p_i.l$ , and  $p_i.NX \notin p_j.FN$ , i.e. which has at least one uncovered neighbor node whose level parameter  $\leq p_j.l$ ;
14      return ( $p_j$ );
15    else
16      if a node  $p_j$  in  $p_i.FN$  such that  $NT_{ij} < 2$ , then
17        return ( $p_j$ );
18      else
19        while  $p_i.FN \neq \phi$  do
20          select a node  $p_j$  in  $p_i.FN$  such that  $NT_{ij}$  is maximum,  $p_j.l \leq p_i.l$ , and  $p_i.NX \notin p_j.FN$ , i.e. which has at least one uncovered neighbor node whose level parameter  $\leq p_j.l$ ;
21           $p_i.N = \phi$ ;
22          if there exists a candidate prior node  $p_k$  ( $\neq p_j$ ) in  $p_i.Nfs$  such that  $p_k \in p_i.p_j.FN$  and  $NT_{ik} + NT_{kj} < NT_{ij}$  then
23             $p_i.N = p_i.N \cup \{p_k\}$ ;
24          else
25             $p_i.N = p_i.N \cup \{p_j\}$ ;
26             $p_i.FN = p_i.FN - \{p_j\}$ ;
27             $p_i.Nfs = p_i.Nfs - \{p_j\}$ ;
28          select a node  $p_h$  in  $p_i.N$  such that  $p_h.l$  is minimum,  $p_h.l \leq p_i.l$ , and  $p_i.NX \notin p_h.FN$ , i.e. which has at least one uncovered neighbor node whose level parameter  $\leq p_h.l$ ;
29          if there are multiple nodes in  $p_i.FN$  whose level parameters are minimum, then
30            select a node  $p_h$  such that  $NT_{ih}$  is minimum;
31          return ( $p_h$ );

```

Algorithm 2: Destination node p_d

- 1 A node p_i is selected according to the Algorithm 1;
 - 2 $p_d.PR = p_i$;
 - 3 $p_d.NX = NULL$;
 - 4 **send** an *RC* (request confirmation) message r to p_i ;
-

Algorithm 3: Node p_i on receipt of an *RC* message r from a node p_j

- 1 A node p_h is selected as a prior node of the node p_i according to the Algorithm 1;
 - 2 $p_i.PR = p_h$;
 - 3 $p_i.NX = p_j$;
 - 4 **send** an *RC* message r to p_h ;
-

Algorithm 4: Source node p_s on receipt of an *RC* message r from a node p_i

- 1 $p_s.NX = p_i$;
 - 2 $p_s.PR = NULL$;
-

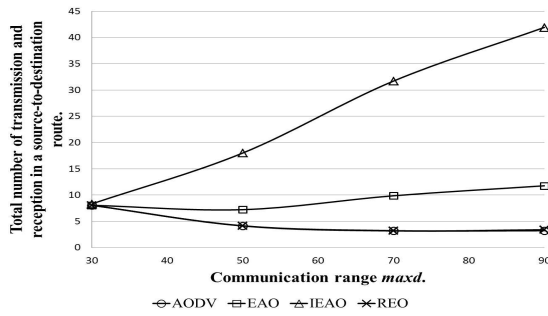


Fig. 2: Total number of transmissions and receptions in a source-to-destination route.

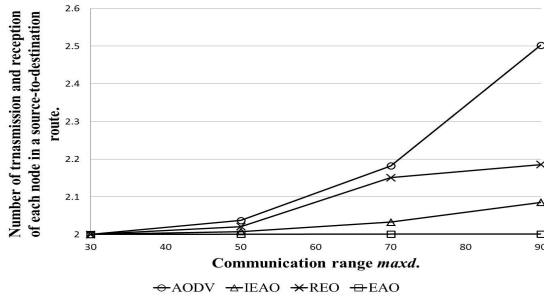


Fig. 3: Number of transmissions and receptions of each node in a source-to-destination route.

the AODV protocol and larger than the IEAO and EAO protocols.

5 Concluding Remarks

In this paper, we newly proposed the REO protocol to deliver messages from a source node to a destination node in a wireless ad-hoc network. In the REO protocol, information of first-neighbor nodes from a source node p_s to

a destination node p_d is collected by flooding *RQ* messages in a similar way to the AODV protocol. Then, starting from the destination node as a current node, a more energy-efficient prior node which has low packet loss ratio is tried to be found for each current node. We evaluated the REO protocol compared with IEAO, EAO, and AODV protocols. We showed the total number of transmissions and receptions and the number of nodes in a source-to-destination route of the REO protocol can be reduced compared with the IEAO and EAO protocols. Although the total number of transmissions and receptions in a source-to-destination route of the REO protocol is almost same as the AODV protocol, the number of transmissions and receptions of each nodes in the REO protocol is fewer than the AODV protocol.

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