An Energy-efficient and Reliable Protocol in Wireless Networks

Emi Ogawa, Shigenari Nakamura, and Makoto Takizawa

Abstract In recent years, wireless ad-hoc networks which do not use network infrastructure are getting more important in various applications like vehicle-to-vehicle (V2V) networks. Especially, it is easy for nodes to communicate with one another without network infrastructure like access points and base stations. Here, ad-hoc routing protocols are needed to deliver messages to destination nodes. In wireless ad-hoc networks, neighbor nodes with which each node can directly communicate may be changed, e.g due to movement of nodes and faults of nodes. Besides, since nodes in ad-hoc networks work with their electric batteries, it is required to reduce electric energy consumed by nodes to send and receive messages. It is difficult to always find a best route to a destination node due to complex parameters like bandwidth and message loss ratio. In this paper, we newly propose a reliable one-to-one communication protocol named TBAH (Trustworthiness-Based Ad-Hoc communications) protocol where routes to the destination nodes are found by using the fuzzy logic in wireless networks.

1 Introduction

We are able to take advantage of kinds of service supported by various types of networks like wireless networks. Wireless ad-hoc networks [6] [9] [8] are getting important in various types of applications, especially in disaster environments [10]. In wireless ad-hoc networks, nodes can communicate with other nodes in wireless networks without network infrastructure like access points. Nodes which are

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in wireless communication range of a node are first-neighbor nodes of the node. A node can deliver messages to first-neighbor nodes in a wireless network. If a node p_i would like to send messages to another node p_j which is out of communication range of the node p_i, some first-neighbor node p_k of the node p_i has to forward the messages to the node p_j. Thus, we have to discuss ad-hoc routing protocols to deliver each message to a destination node in wireless ad-hoc networks.

Many routing protocols are so far discussed in wireless ad-hoc networks [6] [8] [9] [11]. The routing protocols can be categorized into reactive and proactive types. In reactive routing protocols like the AODV protocol [9], routes from a source node to a destination node is not *a priori* fixed until the source node is required to send messages. A route is tried to be found on-demand. Here, it takes time to start communication between a pair of source and destination nodes because a source-to-destination route has to be found. However, control messages are not transmitted to maintain a route if the nodes are not communicating. On the other hand, in proactive routing protocols like the DSDV protocol [8] and the OLSR protocol [6], routes to all destination nodes are always kept in the network. Here, the network traffic increases because nodes periodically send control messages to obtain the topology information of network. The advantage of proactive protocols is that protocols can immediately provide the required route when needed.

In this paper, we newly propose a reactive type of ad-hoc routing protocol named trustworthiness-based ad-hoc communication (TBAH) protocol based on the trustworthiness concept [14]. In this paper, the trustworthiness of a neighbor node is defined in the Fuzzy logic [7]. A more trustworthy first-neighbor node is selected to be in a route in the TBAH protocol. We evaluate the TBAH protocol compared with the AODV protocol in terms of energy consumption of nodes and show the total electric energy of nodes can be reduced in the TBAH protocol.

In section 2, we present a system model. In section 3, we discuss the Fuzzy-based Trustworthiness. In section 4, we present the TBAH protocol. In section 5, we evaluated the TBAH protocol.

2 System Model

A group G of n ($\geq$1) nodes $p_1, \ldots, p_n$ are cooperating with one another by exchanging messages in wireless networks like wireless sensor networks [3], [4], [**?**] and wireless ad hoc networks [5]. Let d_{ij} be the distance between a pair of nodes p_i and p_j. In this paper, we make the following assumptions on nodes:

1. The distance d_{ij} between every pair of nodes p_i and p_j are *a priori* known.
2. Each node does not move in networks.

A node p_i sends a message m with electric energy SE_i [J] in a wireless network. Some node p_j can receive the message m in the group G depending on the distance d_{ij} and electric energy SE_i. With the stronger electric energy SE_i a node p_i sends a message, the farther node from the node p_i can receive the message. Let $wd_i(SE_i)$

show the maximum communication range in which every node can receive messages which the node p_i sends with electric energy SE_i. That is, a node p_j can receive a message sent by a node p_i if $d_{ij} \leq wd_i(SE_i)$. The electric energy SE_i is proportional to a square of the distance $wd_i(SE_i)$ [15]. That is, $SE_1/SE_2 = wd_i(SE_1)^2/wd_i(SE_2)^2$ for a pair of electric energy SE_1 and SE_2 of each node p_i. Let $maxSE_i$ be the maximum electric energy [J] of a node p_i to send a message. Let $maxd_i$ show the maximum distance $wd_i(maxSE_i)$. A *first-neighbour* node p_j of a node p_i is a node which is in communication range $maxd_i$ of a node p_i, i.e. $d_{ij} \leq maxd_i$ $(= wd_i(maxSE_i))$. In this paper, we make the following assumptions on the energy consumption of a node p_i:

1. The electric energy SE_i to send a message to a node p_j is d_{ij}^2 where $d_{ij} = wd_i(SE_i)$.
2. Each node p_i can change the electric energy SE_i $(0 \leq SE_i \leq maxSE_i)$ to send a message.
3. Each node p_i does not consume electric energy to receive messages.

3 Fuzzy-based Trustworthiness

It is not easy to find an optimal route from a source node to a destination node since there are many parameters like bandwidth and message loss ratio to obtain an optimal solution. In this paper, we consider the trustworthiness of each node [1] [2] [14]. A node sends a message to a more trustworthy first-neighbour node to deliver to the destination node. We adopt the Fuzzy logic [7] to calculate the trustworthiness of a node. Suppose a node p_j is a first-neighbor node of a node p_i. A peer p_i obtains the trustworthiness Tw_{ij} of a first-neighbor node p_j by directly communicating with the node p_j. Through communication with a neighbor node p_j, a node p_i obtains the following parameters:

1. Battery charge B_j of a node p_j.
2. Forwarding ratio F_{ij} for a nodep_i to a neighbor node p_j.
3. Availability ratio A_{ij} for a nodep_i to a neighbor node p_j.
4. Power consumption P_{ij} of a node p_i to send a message to a node p_j.

The trustworthiness [14] Tw_{ij} of a first-neighbor node p_j for a node p_i is calculated by the Fuzzy logic. A Fuzzy set of each parameter is given as follows:

- *H*(High).
- *M*(Moderate).
- *L*(Low).

The membership functions for the parameters are shown in Figures 1, 2, 3, and 4. A part of the Fuzzy inference rules to calculate the trustworthiness Tw_{ij} from the Fuzzy sets are shown in Table 1.

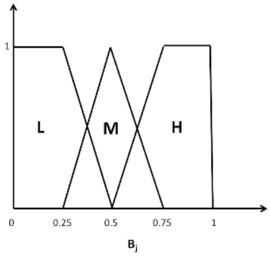

Fig. 1 Battery charge B_j.

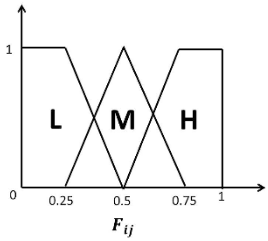

Fig. 2 Forwarding ratio F_{ij}.

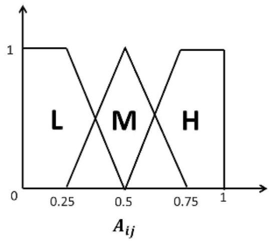

Fig. 3 Availability ratio A_{ij}.

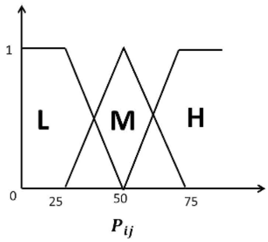

Fig. 4 Power consumption P_{ij}.

Table 1 Inference rules.

	battery charge (B_j)	forwarding ratio (F_{ij})	availability ratio (A_{ij})	power consumption (P_{ij})	trustworthiness (Tw_{ij})
1	*H*	*H*	*H*	*H*	*CT*
2	*H*	*H*	*H*	*M*	*CT*
3	*H*	*H*	*H*	*L*	*CT*
4	*H*	*H*	*M*	*H*	*CT*
5	*H*	*H*	*M*	*M*	*ST*
6	*H*	*H*	*M*	*L*	*ST*
7	*H*	*H*	*L*	*H*	*CT*
8	*H*	*H*	*L*	*M*	*ST*
9	*H*	*H*	*L*	*L*	*M*
10	*H*	*M*	*H*	*H*	*CT*
11	*H*	*M*	*H*	*M*	*ST*
12	*H*	*M*	*H*	*L*	*ST*
13	*H*	*M*	*M*	*H*	*ST*
14	*H*	*M*	*M*	*M*	*M*
15	*H*	*M*	*M*	*L*	*M*
16	*H*	*M*	*L*	*H*	*M*
17	*H*	*M*	*L*	*M*	*M*
18	*H*	*M*	*L*	*L*	*DU*
19	*H*	*L*	*H*	*H*	*CT*
...	...	...	...	...	...
78	*L*	*L*	*M*	*L*	*CU*
79	*L*	*L*	*L*	*H*	*CU*
80	*L*	*L*	*L*	*M*	*CU*
81	*L*	*L*	*L*	*L*	*CU*

Suppose a node p_j is a first-neighbor node of a node p_i and a node p_k is a first-neighbor node of the node p_j [Figure 5]. The transitive trustworthiness Tw_{ik} of the node p_k for the node p_i is a composition $Tw_{ij} \circ Tw_{jk}$.

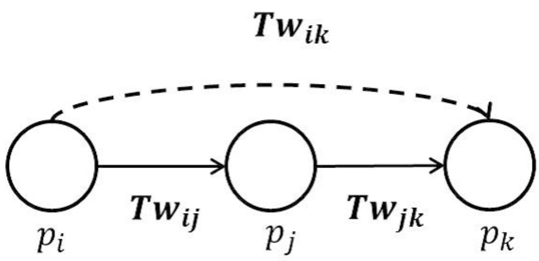

Fig. 5 Transitive Trustworthiness.

4 TBAH Protocol

Suppose a network N is composed of nodes $p_1, \ldots, p_n$ ($n \geq 1$) which are intercorrelated in wireless communication links. Each node p_i manipulates variables $p_i.l$ and $p_i.N$. Initially, $p_i.l = 0$ and $p_i.N = \phi$. First, a source node p_s would like to deliver messages to a destination node p_d in the network N. The source node p_s first sends an RQ message q to every first-neighbor node p_i with the maximum electric energy $SE_i = maxSE$. Here, the RQ (request) message q brings a level parameter $q.l = p_i.l = 0$ and first-neighbor nodes $q.N = p_s.N = \phi$. If a node p_i receives an RQ message q from a node p_j, the level parameter l is incremented by one in a node p_i, i.e. $p_i.l = q.l + 1$. $p_i.N = p_i.N \cup \{p_j\}$, i.e. p_i finds the node p_j is a first-neighbor node of p_i. Thus, each node p_i recognizes what nodes are first-neighbor nodes of the node p_i. Then, the node p_i sends the RQ message q where $q.l = p_i.l$ and $q.N = p_i.N$. If the node p_i already receives the RQ message q, the node p_i neglects the RQ message q. Here, the node p_i just recognizes the node p_j to be a first-neighbor node, $p_i.N = p_i.N \cup \{p_j\}$. In addition, the node p_i keeps in record of $q.N$, i.e. a set $p_j.N$ of first neighbor nodes.

Eventually, the destination node p_d receives an RQ message q. A first-neighbor node p_i whose $p_i.l$ is minimum is selected similarly to the AODV protocol. If there is another neighbor node p_k where $p_k.l > p_j.l$ and $p_j \in p_k.N$, i.e. p_j is a first-neighbor node of p_k, the trustworthiness is checked. Here, if $Tw_{ij} < Tw_{ik} \circ Tw_{kj}$, the node p_k gets a node between p_i and p_j in a route. Otherwise, p_j is a next node to the node p_i. Then, a node p_k which is next to p_i is taken. If there are multiple next nodes, a node p_j is selected in $p_i.N$ where Tw_{ij} is maximum. Here, suppose a node p_j is selected to be next to the node p_i. The node p_i sends an RC (request confirmation) message C, whose destination $c.dest$ is p_j, with the electric energy $SE_i = d_{ij}^2$. On receipt of an RC message C from a node p_i, a node p_j where $c.dest$ = p_j recognizes that the node p_i is next from the node p_j. The node p_j does the same procedure. Then, the source node p_s eventually receives an RC message C from a node p_i. Here, a route from the source node p_s to the destination node p_d is established.

5 Evaluation

We evaluate the TBAH protocol in terns of electric energy consumption of nodes compared with the AODV protocol. In the evaluation, the trustworthiness Tw_{ij} of a first-neighbor node p_j for a node p_i is assumed to show the electric energy d_{ij}^2. That is Tw_{ij} = d_{ij}^2 and $Tw_{ik} \circ Tw_{jk}$ = Tw_{ik} + Tw_{jk}. First, n nodes $p_1 \dots p_n$ are deployed on $m \cdot m$ meshes. In the evaluation, $m = 5$. A network N is composed of seven nodes p_0, ..., p_6, which is shown in Figure 6. A link between a pair of nodes shows a wireless link. Here, $maxd_i$ of each node p_i is 2.0 and $maxSE_i = maxd_i^2 = 4.00$. The node p_0 is the source node and the node p_6 is the destination node. A route from p_s to p_d is selected so that the number of hops is minimum in the AODV protocol. Hence, the node p_3 is chosen to be an intermediate node between the source node p_0 and the destination node p_6. The number of hops is 2 in the route $p_0 \rightarrow p_3 \rightarrow p_6$. The electric energy SE_0 is $d_{03}^2 = 2.00^2$ and SE_3 is $d_{36}^2 = 1.98^2$. The total electric energy consumption of the nodes p_0 and p_6 in the AODV protocol is $2.00^2 + 1.98^2 = 7.94$ as shown in Table 2. The node p_2 is between the node p_0 and the node p_3. The electric energy consumption SE_0 of the node p_0 to deliver a message to the node p_2 is $d_{02} = 1.43^2$ and SE_2 to deliver a message to the node p_3 $d_{23} = 0.92^2$. Here, d_{03}^2 $(= 2.00^2) > d_{02}^2$ $(= 1.43^2)$ + d_{23}^2 $(= 0.92^2)$. Thus, a message will not be directly transmitted to the node p_3 from the node p_0. The node p_2 is selected as an intermediate node between the node p_0 and the node p_3. In the same way, the node p_1 is selected as an intermediate node between the nodes p_0 and p_2. There are three routes from p_3 to p_6. Since $d_{34}^2(= 1.39^2) + d_{46}^2(= 2.00^2)$ $> d_{36}^2(= 1.98^2) > d_{35}^2(= 1.80^2)$ + $d_{56}^2(= 0.30^2)$, nodes in the route $p_3 \rightarrow p_5 \rightarrow p_6$ to the node p_3 from the node p_6 via the node p_5 totally consume the smallest electric energy. Thus, the node p_5 is selected as an intermediate node. The route from the source node p_0 to the destination node p_6 is $p_0 \rightarrow p_1 \rightarrow p_2 \rightarrow p_3 \rightarrow p_5 \rightarrow p_6$ in the TBAH protocol. The number of hops is 5. The total electric energy consumed by nodes in the TBAH protocol is $d_{01}^2(= 0.50^2)$ + $d_{12}^2(= 1.30^2)$ + $d_{23}^2(= 0.92^2)$ + $d_{35}^2(= 1.80^2)$ + $d_{56}^2(= 0.30^2)$ = 6.14 as shown in Table 2. Table 2 shows the electric energy consumption and the number of hops of the AODV protocol and the TBAH protocol. As the result, according to Table 2, the number of hops in the TBAH protocol is larger than the AODV protocol. However, the electric energy consumption of nodes in the TBAH protocol is smaller than the AODV protocol.

Table 2 TBAH and AODV protocols.

	AODV	TBAH
Electric energy [J]	7.94	6.14
Number of hops	2	5

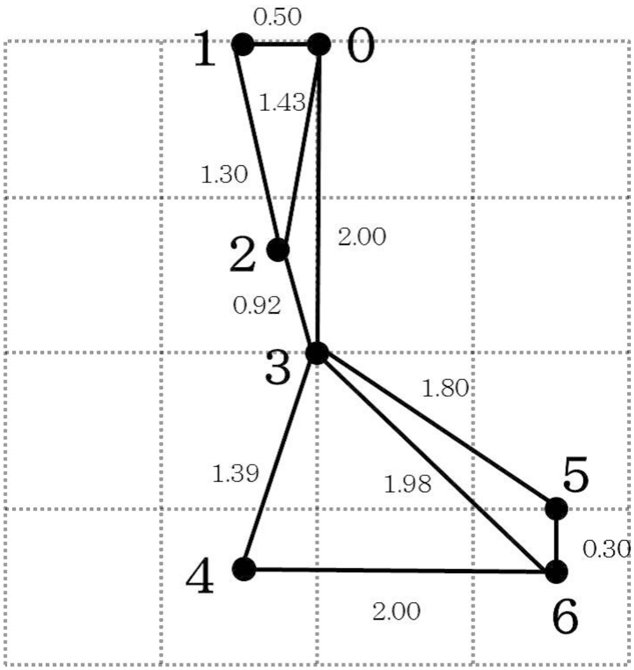

Fig. 6 Network *N*.

6 Concluding Remarks

In this paper, we proposed the trustworthiness-based ad-hoc routing (TBAH) protocol in wireless ad-hoc networks. The trustworthiness of first-neighbor nodes is obtained in the Fuzzy logic. We showed nodes in a route obtained in the TBAH protocol consume smaller electric energy than the AODV protocol.

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