A Reliable Route Selection Algorithm Using Global Positioning Systems in Mobile Ad-hoc Networks

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Abstract **- The routing protocols designed for wired networks can hardly be used for mobile ad-hoc networks due to unpredictable topology changes, and thus several routing protocols for mobile ad-hoc networks have been proposed. The goal of this paper is to select the most reliable route that is impervious to failures by topological changes by mobile nodes' mobility. To select a reliable route, we introduce the concept of *stable zone* and *caution zone*, and then apply it to the route discovery procedure of the existing on-demand routing protocol (i.e., AODV). The concept of the *stable zone* and *caution zone* which are located in a mobile node's transmission range is based on a mobile node's location and mobility information received by Global Positioning System (GPS). The proposed protocol was evaluated by simulation in various conditions and we got an improved performance.**

I. INTRODUCTION

Mobile multi-hop wireless networks, called ad-hoc networks, are networks with no fixed infrastructure, such as underground cabling or base stations, where all nodes are capable of moving and being can be connected dynamically in an arbitrary manner. Nodes in a network function as routers, which discover and maintain routes to other nodes in the network. A central challenge in the design of ad-hoc networks is the development of dynamic routing protocols that can efficiently find routes between two communicating nodes [5]. The routing protocols must be able to keep up with the high degree of node mobility that often changes the network topology drastically and unpredictably.

Routing protocols in conventional wired networks generally use either distance vector or link state routing algorithms, both of which require periodic routing advertisements to be broadcast by each router. However, such protocols do not perform well in dynamically changing ad-hoc network environments. The limitations of mobile nodes, such as limited bandwidth, constrained power, and mobility, make designing new ad-hoc routing protocols particularly challenging. To overcome these limitations, several source-initiated on-demand routing protocols, including Dynamic Source Routing (DSR) protocol [7] and Ad-hoc On-demand Distance Vector (AODV) routing protocol [6], have been proposed. These protocols create routes only when the source node has data to transmit. When a node requires a route to a destination, it initiates a route discovery procedure within the network. This procedure is completed once a route is found or all possible route permutations have been examined. Once a route has been established, it is maintained by a route maintenance procedure until either the destination becomes inaccessible or the route is no longer desired.

Some of existing source-initiated routing protocols like DSR and AODV, during the route discovery procedure, attempt to choose a route having the minimal number of hop-count among the available routes. However, the route having the minimal hop-count does not always mean the optimal routing path. Even the route of the smallest hop-count may be faster than other routes in packet delivery, it is highly probable that the spatial distance between intermediate nodes on the route may be larger than other routes. The larger distance between neighboring nodes may give rise to a shorter link maintenance time, which in turn affects the maintenance time of the route including the link [8][9]. If there are frequent route failures due to host mobility, it will require additional time to reconfigure the route from source to destination, which will result in increased amounts of flooding control packets. Therefore, it may not be said that a route with the smallest hop-count is optimal. The goal of our paper is to select the most reliable route that is impervious to failure by topological changes by mobile nodes' mobility, where a route discovery is performed with the location and mobility information received by Global Positioning System (GPS). To accomplish this goal, we propose a new route discovery algorithm referred to as *Reliable Route Selection (RRS)* algorithm.

In this paper, we assume that each node is aware of its current location through the use of GPS receivers equipped by each node. GPS has been successfully employed for determining a mobile host's position and speed. It is expected that the proliferation of GPS-based positioning technology will proceed at a fast pace and the accuracy of this technology will be dramatically enhanced [10].

II. AD-HOC ON-DEMEND DISTANCE VECTOR ROUTING PROTOCOL

AODV routing protocol supports the multi-hop routing among mobile nodes for establishing and maintaining an ad-

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hoc network. AODV is based upon the Destination-Sequence Distance Vector (DSDV) algorithm. The difference is that AODV is reactive, while DSDV is proactive. AODV requests a route only when it is needed, and does not require mobile nodes to maintain routes to the destination that is not actively used. To send a message to a destination, a source first initiates a route discovery procedure to locate the destination. A Route Request (RREQ) control packet is flooded through the network until it reaches to the destination or it reaches to a node that knows the route to the destination. On its way through the network, the RREQ initiates the creation of temporary route table entries for the reverse path at all the nodes it passes. Next, a Route Reply (RREP) control packet from the destination is unicast back to the source along the temporary reverse path. When the RREP is routed back along the reverse path, all nodes on this route set up forward path by pointing to the node that transmitted the RREP. These forward route entries indicate the active forward path. Through this procedure, the route is made available [6].

Routes selected by the route discovery procedure are maintained as follows. If a route is broken due to the movement of the source, it reinitiates the route discovery procedure to find a new route to the destination. If a route is broken due to the movement of a node on the route, its neighboring upstream node notices the movement, and propagates a link failure notification message through its all of the active upstream nodes to the source. The source may then perform route reconstruction for that destination if a route is still desired. In addition, a node periodically transmits *hello message* with TTL = 0 to inform each mobile of the information concerning other neighbors. *Hello messages* can be used to maintain the local connectivity of a node. When mobile nodes use its shared link layer protocol such as IEEE 802.11, instead of using *hello messages*, nodes may listen to the retransmission of data packets to ensure that the next-hop node is still within transmission range.

III. RELIABLE ROUTE SELECTION ALGORITHM

In AODV, the source node transmits the data through the route which is determined by the first RREQ arrived at the destination. This selected route generally has the least hop-count, which means intermediate nodes on the route are remotely located from each other. Accordingly, the route maintenance time may not last long, causing a link failure, in an ad-hoc network environment where mobile nodes frequently move. Therefore, selecting a reliable route is important on discovering a route. In order to achieve the reliability of the selected route, we propose the RRS algorithm using the concept of a *stable zone* and a *caution zone* based on a mobile node's position, speed, and direction information obtained from GPS.

A. Stable Zone and Caution Zone

Fig. 1 shows the concept of a virtual zone, which is composed of a *stable zone* and a *caution zone*. *Stable zone* means the area on which a mobile node can maintain a stable link with its neighbor node since they are located close to each other. *Caution zone* means the area on which a mobile node can maintain an unstable link with its neighbor nodes since they are located far from each other. These zones are used for deciding whether the link state between any two nodes is reliable or not. The *stable zone* and the *caution zone* change dynamically depending on the mobile node's speed and direction information. As mentioned previously, we know the position, speed, and direction of the mobile nodes using the GPS information (i.e., latitude, longitude, and altitude). For simplicity, we assume that all mobile nodes have the same altitude value and transmission range.

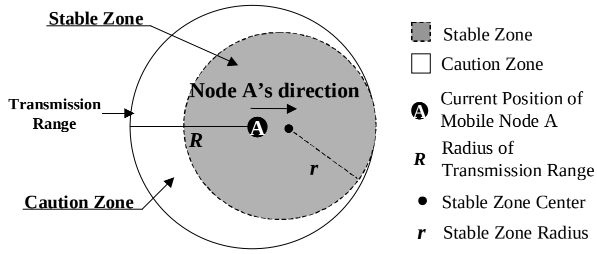


Fig. 1. Stable Zone and Caution Zone

In Fig. 1, if the radius of the transmission range is *R*, we define the *stable zone* is a smaller inner circle that has a *stable zone radius (r)* in the transmission range. We also define that a *caution zone* as a relatively unstable area is the transmission range excluding the *stable zone*. An inner circle that indicates the *stable zone* is inscribed in an outer circle that indicates the transmission range. The *stable zone radius (r)* is determined from the speed of a mobile node. If the mobile node's speed is 0, *r* will be the same as *R* and it decreases as the mobile node moves faster. In RRS algorithm, adequate selection of *stable zone radius (r)* for node's speed is very important. This will be discussed in detail later.

In addition to a mobile node's speed, we should also consider a mobile node's moving direction. Even when the mobile node is located in the border range of a neighbor node, if two adjacent nodes progress into the face-to-face direction, the link between the two nodes will remain stable. Thus, the location of *stable zone center* shown in Fig. 1 should account for the direction of the mobile node's movement. This means that *stable zone center* should be located on the line of the mobile node's movement direction. Since the radius of the *stable zone* is determined from the mobile node's speed, finding the location of *stable zone center* is rather intuitive.

B. Protocol Description

Now, we describe the *Reliable Route Selection (RRS)* algorithm using the concept of *stable zone* and *caution zone*, and then apply this algorithm to the route discovery procedure of the existing on-demand routing protocol (i.e., AODV). In this paper, we name the modified AODV as AODV-RRS. In AODV-RRS, GPS information is added into the RREQ control packet of AODV that is initiated by a source when a route discovery is performed. The added fields are as follows:

[*current_mn_position (x, y), stable_zone_center (x', y'), stable_zone_radius (r)*]

Current_mn_position (x, y) indicates the current position of a mobile node, *stable_zone_center (x', y')* indicates the center of *stable zone*, and *stable_zone_radius (r)* indicates the radius of *stable zone*.

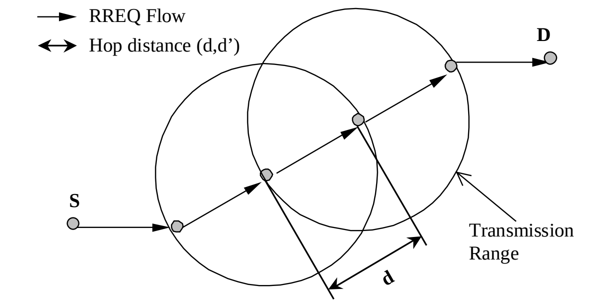
Fig. 2 shows how RREQs are flooded to the destination by AODV and AODV-RRS. When a route discovery by AODV is performed, an intermediate node floods a RREQ to other nodes as soon as it receives a RREQ, except when a duplicated RREQ is received and the node is not the destination. If we assume that two adjacent nodes on a selected route are located in the border of each other's transmission range (that is, *caution zone* shown in Fig. 1), then the adjacent nodes are likely to from escape each other's transmission range, even with their small movements. Consequently, frequent route failures may occur and thus overheads, such as time delay and flood of control packets, arise due to a new route establishment. Thus, it is not desirable that a mobile node sets up a link with a neighbor node located in the border of each other's transmission range.

With the proposed algorithm, on the other hand, when a mobile node that receives an RREQ from a neighbor node which is located in its *caution zone* (or when it is located in the neighbor node's *caution zone*), the node that receives the RREQ ignores the RREQ and thus does not flood the RREQ, which provides a reliable route that is not easily broken. Thus, the proposed algorithm reduces the control overhead that can occur when a new route is established due to a route failure.

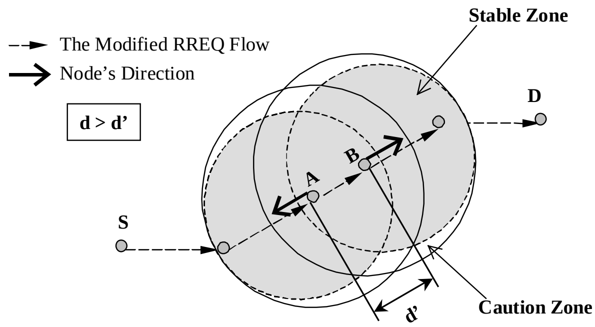
Basic route construction mechanism of AODV-RRS is identical to AODV. However, AODV-RRS requires the following additional process, where we assume that nodes A and B are adjacent to each other, and node A floods RREQs while node B receives the flooded RREQs.

When a route discovery is performed,

1) *Node A floods a RREQ that includes its own GPS information to all nodes within its transmission range.*
2) *Node B that receives a RREQ confirms whether nodes A and B are in each other's stable zone, using GPS information of its own and that received by node A.*
   - *If node A and B are in each other's stable zone and node B is not the destination, node B inserts its own GPS information in the RREQ and then floods it.*
   - *If either node A or B is (or both are) in the caution zone, the RREQ that is received by node B is discarded.*



(a) Normal AODV



(b) AODV using RRS algorithm

Fig. 2. The Comparison of RREQ Flow

A route constructed by AODV-RRS may have more transmission delay than a route by AODV due to the possibly increased hop-counts of AODV-RRS (in Fig. 2, see the difference of hop distance (*d* > *d*')). However, AODV-RRS is expected to have the important advantage that the maintenance time of the route selected by AODV-RRS lasts considerably longer than the route selected by AODV, which means that AODV-RRS is more reliable than AODV.

In this paper, we assume that the maximum speed of a mobile node is 12.5 m/sec, and *stable_zone_radius (r)* has a value in a limited range. For simplicity, we assume that *r* varies linearly with speed. Note that the smaller *stable zone* we assume for the same speed, the more hop-counts may be given for a successful route discovery on average. This is because smaller *stable zone* gives the route reliability enhancement at the sacrifice of the increased hop-counts. If the size of *stable zone* is too small, then the route discovery time, queuing delay and control overhead will be drastically increased due to the increased number of hop-counts in spite of the reliability of the route. This fact results in throughput degradation compared to the original AODV. So we need trade-offs between the route reliability and the number of hop-counts. Therefore, it is very important to determine the optimal value of *stable_zone_radius(r)*. In this paper, *stable_zone_radius(r)* is determined by the following expression,

$$r = R - \beta \times S_{MN} \quad (1)$$

where β is the constant value that determines the range of *stable_zone_radius(r)*, R is the transmission range of a mobile node, and S_{MN} is the speed of mobile node. As discussed above, although higher value of β makes a more reliable route, it causes increased number of hop-counts. In the following section, we analyze the effects of β on the performance of the proposed AODV-RRS.

IV. PERFORMANCE EVALUATION

A. Simulation Environments

We studied the proposed AODV-RRS protocol by simulation and compared it to a simplified version of AODV. Both the protocols detect a link breakage using feedback from MAC layer. No additional network layer mechanism such as *hello messages* is used. For the simulation study, we used the Network Simulator (ns) [1]. To simulate the mobile wireless radio environment, we used a mobility extension of ns (i.e., ns-2) [11].

We assumed that 75 mobile nodes are distributed randomly in a flat area of 2250m x 450m. Each node in a location moves to a randomly selected location (we call it as target location) with a predetermined speed. Once a node reaches the target location, another random target location is selected. We ran our simulations with movement patterns generated by 5 different speeds (2.5, 5, 7.5, 10, and 12.5 m/sec). The reason why we limit the node's speed to 2.5 ~ 12.5 is that an ad-hoc network is not applicable to the extremely high or low speed environment. Each simulation is executed for 300 seconds. In our simulation study, the traffic is generated by 50 continuous bit rate (CBR) sources spreading the traffic randomly among all nodes. The packet size is 64 bytes, the packet generation rate is 4 packets/sec, and the bandwidth of links is 2 Mbps. Radio transmission range (R) of each node is 250 meters. In this paper, we assume that the value of β, which determines the range of *stable_zone_radius (r)*, is 2. In AODV-RRS (β = 2), when a mobile node's speed is the highest (12.5 m/sec), r is (R–25) meters, while when the mobile node's speed is the lowest (2.5 m/sec), r is (R–5) meters. Therefore, r ranges from 225 meters to 245 meters, according to mobile node's speed.

Mobility pattern of a mobile node follows a randomly selected scenario file. Multiple runs with different seed numbers are conducted for each scenario and output data are averaged over those runs. These simulations of random scenarios are similar to the approaches in [2][3][4]. For fair comparison, identical mobility and traffic scenarios are used for AODV and AODV-RRS.

The following metrics are used in our evaluations:

- ***Average Route Maintenance Time per Source Node -*** *Average time period from the time when a route for a source node is established to the time when the route is broken.*
- ***Average Route Recovery Latency per Source Node -*** *Average time period from the time when a route for a source node is broken to the time when a new route is established, which includes the route discovery latency that occurs on the start of simulation.*
- ***Number of Route Disconnection per Source Node -*** *The number of route disconnection per source node during the whole simulation time.*
- ***Overall Route Recovery Latency per Source Node -*** *The sum of time periods taken to recover a route per source node during the whole simulation time, which includes the route discovery latency that occurs on the start of simulation.*

B. Simulation Results

Figure 3 shows the average route maintenance time per source node as a function of mobility (speed) for the proposed AODV-RRS and AODV. In all values of the speed, the proposed protocol shows improved performance over AODV. This means that the route established by AODV-RRS is more stable than the route established by AODV.

Figure 4 shows the average route recovery latency per source node as a function of speed. We can observe that the average route recovery latency of AODV-RRS is longer than that of AODV. This is because the links composing a route by AODV-RRS are unlikely to be set between nodes that are located in the border area (caution zone) of each other's transmission range. Accordingly, a node establishes the link with another node in its stable zone, and thus hop-count of the route established by AODV-RRS may be a little than AODV.

Figure 6 shows the sum of time taken to recover the route during the whole simulation time (300 seconds) by the proposed AODV-RRS and AODV. As shown in the figure, the two protocols show very similar performance even though the average route recovery latency per source node of AODV is smaller than that of AODV-RRS (see Figure 4). The number of route disconnection per source node during the whole simulation time by AODV-RRS is smaller than that of AODV as shown in Figure 5. Therefore, even if the average route recovery latency of AODV-RRS is relatively larger than that of AODV as shown in Figure 4, almost the overall route recovery latency can be achieved as shown in Figure 6. From the performance study of Figure 3 and 6, we can find the fact that AODV and AODV-RRS show very comparable route recovery latency, while AODV-RRS shows an improved performance in route maintenance time.

V. CONCLUSIONS

In ad-hoc networks, the topology changes drastically and unpredictably due to a mobile node's mobility. The existing protocol, AODV, has the problem of a fragile route. Consequently, a selected route comes to have a short route maintenance time, which causes the overhead of reestablishing a new route. To solve the problem, we propose a new route selection algorithm, AODV-RRS, to establish a reliable route. In order to achieve the goal, we used GPS information to obtain mobile hosts' directions and speeds as well as positions. Moreover, we introduce the concept of the *stable zone* and *caution zone*. These zones change dynamically depending on a mobile node's speed and direction. We find that AODV-RRS selects a reliable route that does not fail easily by the topological changes caused by mobile nodes' mobility. Our simulation study shows that AODV-RRS has an important advantage: the route selected by AODV-RRS lasts considerably longer than that of AODV. As a result of longer route maintenance time, the number of route failures is decreased. AODV-RRS is expected to show even better performance in ad-hoc networks that have especially severe host mobility.

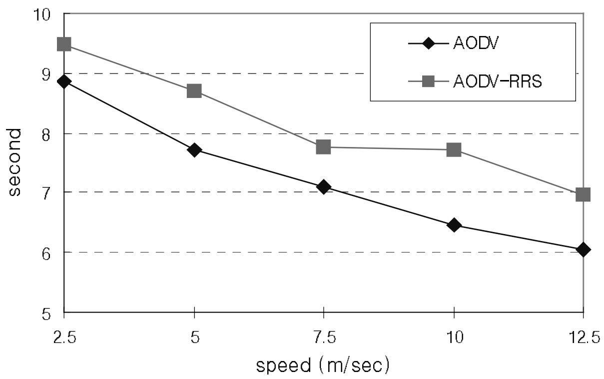


Fig. 3. Average Route Maintenance Time per Source Node

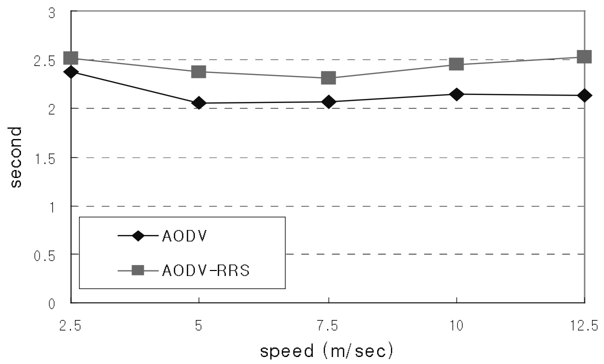


Fig. 4. Average Route Recovery Latency per Source Node

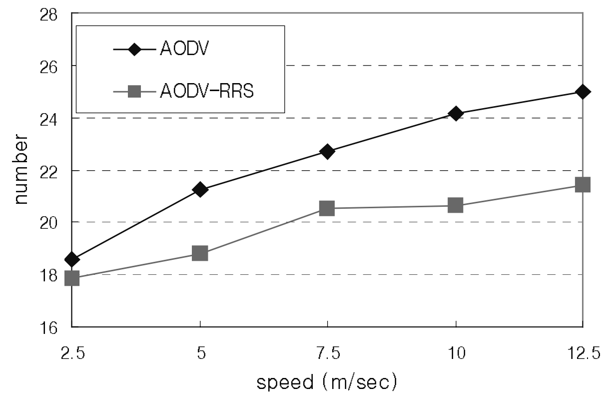


Fig. 5. Number of Route Disconnection per Source Node

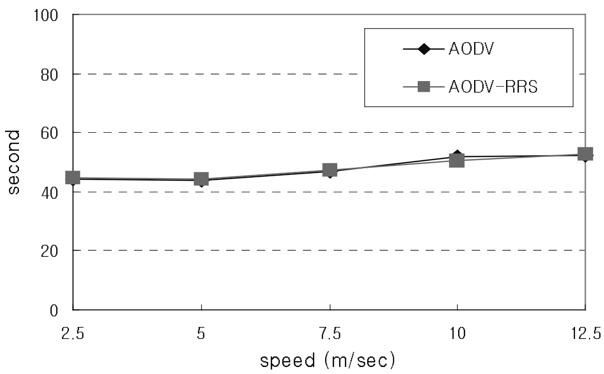


Fig. 6. Overall Route Recovery Latency per Source Node

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