Grid based Enhanced Routing Scheme in MANET

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Received November 24, 2015; revised February 11, 2016; accepted March 26, 2016; published May 31, 2016

Abstract

In this paper, we propose a hybrid routing scheme that utilizes location information to support reliable data transmission in mobile ad hoc networks. The proposed scheme determines and maintains routing path by considering the directionality and connectivity of nodes using grid zones and information on neighbor nodes. In addition, it generates alternative paths with consideration for node distance and reliability. To show the superiority of the proposed routing scheme, a performance evaluation was conducted using simulations. The performance evaluation results show that the proposed scheme offers faster and more reliable data transmission than the existing routing schemes, and the number of messages decreases by approximately 31% compared to the existing schemes on average.

Keywords: MANET, Grid routing, Reliable path, Alternative path

This research was supported by the MSIP(Ministry of Science, ICT and Future Planning), Korea, under the ITRC(Information Technology Research Center) support program (IITP-2015-H8501-15-1013) supervised by the IITP(Institute for Information & communication Technology Promotion), by the MSIP(Ministry of Science, ICT and Future Planning), Korea, under the C-ITRC(Convergence Information Technology Research Center) (IITP-2015-H8601-15-1008) supervised by the IITP(Institute for Information & communications Technology Promotion), and by “Human Resources Program in Energy Technology” of the Korea Institute of Energy Technology Evaluation and Planning (KETEP), granted financial resource from the Ministry of Trade, Industry & Energy, Republic of Korea(No. 20144030200450).

http://dx.doi.org/10.3837/tiis.2016.05.015 **ISSN : 1976-7277**

1. Introduction

Due to the sharp increase in mobile device use caused by advances in wireless communication technology and mobile computing devices, mobile ad hoc networks (MANETs) are drawing significant attention. A MANET is easy to install and expand, enables a broader range of communications through multi-hop communications, and is applied in a wide range of applications, including disaster areas and military environments [1, 2]. A MANET consists of a set of autonomous mobile nodes that communicate with one another over wireless links without an infrastructure [2, 3, 15]. That is, mobile nodes form a network with one another without repeaters, such as base stations or access points (Aps) [7].

A characteristic of MANETs is that their network topology changes dynamically due to unpredictable mobility and limited power source and bandwidth [6, 20]. This feature allows nodes to move freely and in an unpredictable manner. Therefore, the message delivery paths to destinations often break, which leads to a reduction in the overall performance of networks [5]. Therefore, in MANETs, a routing scheme with strong reliability that can also effectively respond to network changes is required [21, 22]. In addition, due to the increased use of mobile devices, including smartphones and tablet PCs, in recent years, ongoing research is needed on MANET environments that can provide faster and more reliable support for devices [4, 8, 9, 10].

Recently, several studies on routing schemes using location information on MANETs have been conducted [11]. Location-based routing utilizes physical location information on source and destination to determine routing paths using GPS [15, 16, 18, 19, 27, 28]. These schemes have the advantages of reducing power consumption, overhead, delays, and bandwidth when exchanging control packets or data. Using this location-based service, a grid-based routing scheme partitions network areas into 2D grid zones [12, 13, 14]. In the existing schemes, when a node on a routing path becomes disconnected, the entire path breaks, which can lead to high routing overhead and the discontinuity of data in the process of reconnecting or restoring the path. However, grid-based routing is performed via virtual grid paths that connect target nodes and partition fixed-sized grid network zones, reducing costs for path maintenance and extending network lifetime due to reduced path losses [25, 26]. Each grid zone has a header node (also called gateway node), which processes routing. The gateway node of each grid is selected such that it relays all packets passing through. However, this has the limitation that packets can be transmitted by a gateway node with limited network throughput. Therefore, when leaving the current grid zone, selecting a new gateway node requires significant overhead. The overhead increases significantly with the increase in node velocity.

Providing a MANET service requires a routing scheme responsive to changing network topology resulting from node mobility and that can transmit data reliably from a source node to a destination node [19, 22, 23, 24]. The existing schemes require considerable communication costs because they transmit messages to the entire network to generate and maintain a routing path, as well as additional costs to generate a new path when data transmission is not feasible. In addition, the existing schemes have additional header costs because they maintain various types of information with a header in each zone. In this paper, we propose a hybrid routing protocol that applies routing methods selectively and generates and maintains paths by taking connectivity into account in a grid-based environment. The proposed scheme reduces message delivery to generate paths by sending messages to specific zones in the direction of the destination based on the location information on a destination node, and it generates reliable paths by considering the connectivity between the source node and destination node. In addition, because it does not keep a header in each grid zone, any node can be a candidate for delivering a message, significantly reducing management costs, including header selection, neighbor node management, path discovery, and response procedures. Moreover, it reduces the cost for alternative path generation, because it generates an alternative path to a new destination node by considering the connectivity and distance of nodes in the event that message delivery is made impossible by the movement of mobile nodes.

The rest of this paper is organized as follows. Section 2 describes the existing ad hoc routing protocol and existing schemes to generate and maintain routing paths. Section 3 introduces the proposed grid-based schemes for path generation, path selection, and alternative path generation in a MANET environment. Section 4 describes the simulation environment and demonstrates the superiority of the proposed scheme through an experimental evaluation. Finally, Section 5 concludes this paper.

2. Related Work

B. Karp proposed a Greedy Perimeter Stateless Routing (GPRS) to provide scalability when the number of nodes grows and mobility rate of nodes are increased in MANETs [11]. All nodes maintain a neighbor table which stores the addresses and locations of their 1-hop neighbors to provide all state required for GSPR's forwarding. GPSR forwards perimeter mode packet using a simple planer graph traversal. GPSR recovers by routing around the perimeter of the region, when a packet reaches a region where greedy forwarding is impossible.

R. Cheng and N. Meghanathan proposed a location prediction based routing using mobility in MANETs [27, 28]. In [28], a dynamic location updating was developed to determine the appropriate update time, and a location prediction search. To search location of destination nodes for routing, a source node sends out a location query using the prediction destination location. In [27], LPBR is developed to minimize the number of route discoveries and hop count of the routing path. Each node forwards the RREQ packet exactly once after incorporating its location update vector in the RREQ packet. When the routing path detected through the flooding-based route discovery fails, the destination node attempts to predict the current location of each node using the location and mobility information collected during the latest flooding based route discovery.

N. Arora developed proposed a Geographic Location Aware Adaptive Routing (GLAAR) to reduce the computation and communication cost for selecting next node for forwarding [18]. GLAAR use three tables such as NNAT of Intra-zone, NNAT of Inter-zone, NZAT to store information of nodes in a zone. NNAT of Intra-zone stores information of all nodes in zone, NNAT of Inter-zone stores neighbor to requesting zone, and NZAT stores information of three zones that exist in the direction of destination. To forward the packet, a node updates NZAT and NNAT tables using the response of beacon message. To select a next forwarding node, compare distance of three zones from destination. The least distance zone is chosen as next the forwarding node.

B. Mehul proposed a Location Based Minimal Overhead Shortest Path Routing Protocol (LBMOSRP) to minimize the routing overhead in MANETs [15]. To minimize the management cost of routing table, location information is acquired by a source node only when the routing path finding is requested. LBMOSRP calculate the shortest distance between the source node and the destination node using the location information of nodes, and send the routing message to the node containing the shortest distance.

W. Liao proposed a reactive routing protocol called GRID in MANETs [12]. GRID partitions the network area into 2D logical grids. In each grid, a header is selected as the gateway of the grid for forwarding route discovery requests and propagating data packets to neighbor grids. To reduce the broadcast storm, the range in a RREQ message is used to restrict the route discovering area. X. Zhang proposed a Multicast Zone Routing Protocol (MZRP) extending ZRP in MANETs [26]. MZRP use a shared tree multicast routing protocol that proactively maintains the multicast tree membership for nodes' local routing grids. The first member of a multicast group becomes the leader of the group until it decides to leave that group or until two partitions of the multicast tree merge.

Z. Wang proposed a Virtual Grid Aided (VGA) to provide an energy efficiency routing using location information [25]. VGA partitions the network area into virtual grids and forwards to all eight neighboring grids through eight-direction forwarding scheme. The VGA scheme performs intra grid routing and inter grid routing. Intra grid routing is used for selecting gateway within the grid. Inter grid routing is used for route discovery, data packet relay, and route maintenance.

H. Al-Maqbali proposed Efficient Grid-based Routing Protocol (E-GRP) extending GRID [17]. E-GRP selects the node with highest id in zone as the zone header. Each node manages two tables such as a neighbors table and a routing table, where the neighbor table stores all its neighbor nodes and the routing table stores routing information about destination. If a zone header receiving the RREQ isn't destination node, it rebroadcasts the RREQ. Otherwise send a RREP back to the source node. If non-zone header node isn't the destination, it stores the zone location information of the forwarding node and then discards the RREQ packet.

3. The Proposed Grid-Based Routing Scheme

3.1 Routing Architecture

Existing routing schemes transfer messages through a limited number of header nodes. Therefore, network throughput becomes limited and significant overhead occurs in selecting a new header node when the header node moves out of the current zone. In addition, when it is impossible to deliver data through an initially selected routing path, an additional cost occurs in generating a new path. We propose a routing scheme to reduce the cost of message delivery for path generation and minimize node management costs in MANETs. Using hybrid routing, the proposed grid-based routing scheme minimizes routing path discovery messages by managing routing information for nodes in grid zones using a table-based method. In addition, by providing the optimal routing path using communicable nodes connected to the node in the adjacent grid zone based on a demand-based method only when necessary, it reduces periodic update messages compared to existing schemes. Moreover, it does not use a hierarchical structure, as it makes the grid larger than the communication radius and does not keep headers. The headers manage all information within a grid zone and are in charge of message delivery. However, when the header moves out of the current grid zone and to a different zone, a new header is selected. As a result, an additional cost occurs that covers header management and the selection of a new header.

In the proposed scheme, any node in a grid can be a candidate for delivering messages due to the absence of a header node. Each intermediate node determines the next hop based on locations, relationships, and grid configuration. A message can be delivered to the neighbor node closest to the geographically desired grid zone based on the routing table of each node. The proposed scheme has the advantage that it is not significantly influenced by the changes of specific nodes that make up the topology in that it maintains node data within a grid-based structure. A source node is assumed to have information on its own location and the location of a destination using sensors, such as GPS. All nodes maintain information on neighbor nodes with nodes in the same coordinates using periodic messages, and they manage the information in a table. **Fig. 1** shows the whole process of the proposed routing scheme. The proposed scheme consists of three steps such as routing path discovery, routing path determination, and data transmission. The routing path discovery step sends a RREQ message from the source node to the destination node to determine an optimal routing path. Each node that receives a RREQ message chooses the delivery zone by considering the directionality to the destination node and sends the RREQ message. Each node adds the route record and the node information to the RREQ message. The destination node determines the optimal routing path by considering the node connectivity and the number of hops with the received RREQ message. When the destination node determines the optimal routing path, it sends a RREP message to the source node along the RREQ routing path. The data transmission step transfers data along the routing path. If the data transmission fails, we create a new routing path. If the node that the transmission failure occurs is near to the source node, we create an alternative routing path by sending a RERR message to the source node. Otherwise, we process a partial routing path update.

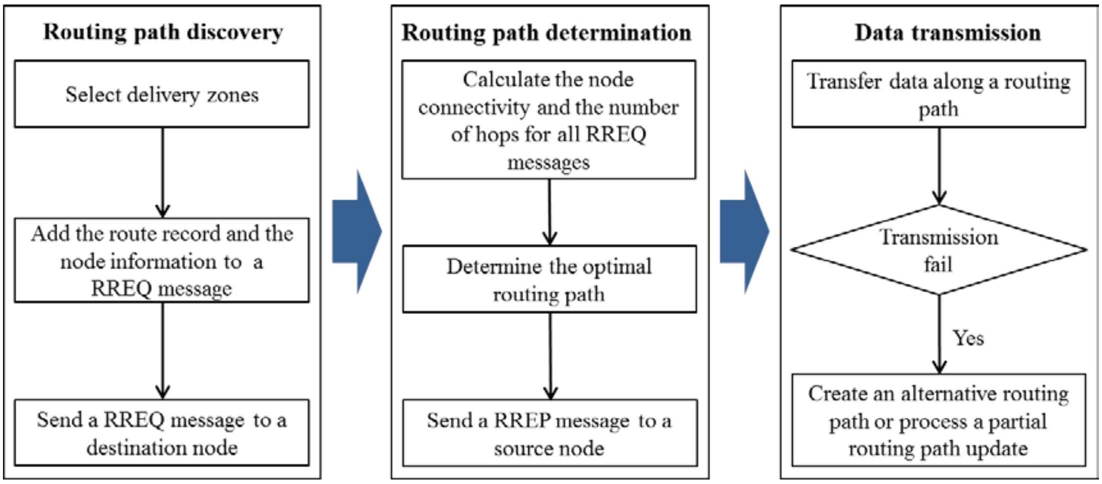


Fig. 1. The whole process of the proposed scheme

Fig. 2 shows an example of routing processing of the proposed scheme. To generate a routing path, source node 3 delivers the RREQ message to destination node 10; in response to the message, the destination node delivers a Route Response (RREP) message to the source node. Each node compares the coordinates of its own location and its destination and delivers a RREQ message to the three adjacent zones in the direction of its destination. That is, source node 3 delivers a REQ message to nodes 12, 13, and 6, and the nodes that receive the message deliver a RREQ message in the same way to reach the destination node. Node 10, which receives the RREQ message, selects the optimal routing path among the paths included in the RREQ message by considering connectivity and the number of hops. It delivers the RREP message to source node 3 via the generated path. Source node 3, which receives the RREP message, delivers actual data to the destination node via the optimal routing path included in the RREP message.

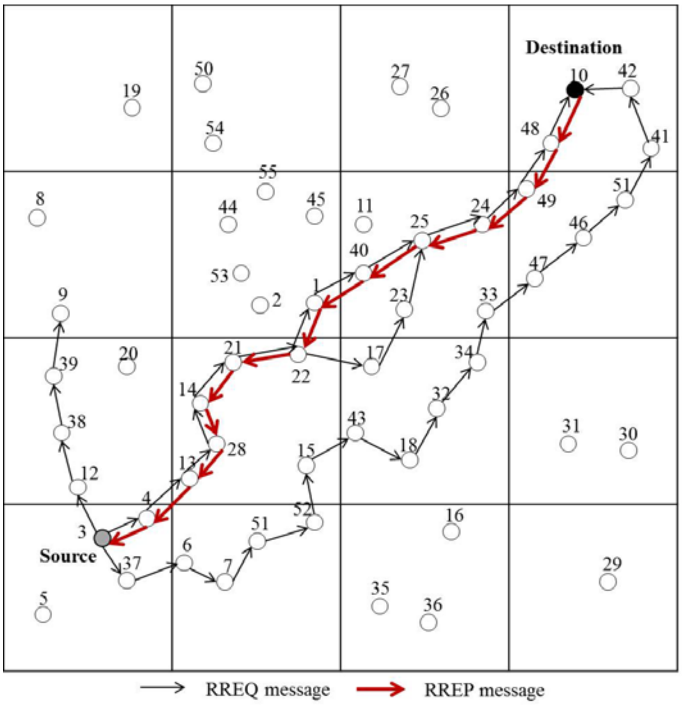
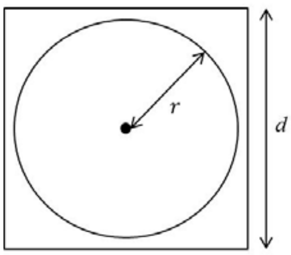


Fig. 2. An example of routing processing

3.2 Grid Structure

One of the variables affecting the performance of the grid-based routing protocol is grid size. Messages move from the current zone to another. Different grid sizes may result in large differences in performance parameters (e.g., number of messages, delivery rate, delays). **Fig. 3** shows the relationship between the lateral length of the grid and the transmission radius, where d denotes the length of the grid and r denotes the transmission radius. The proposed scheme sets up a large grid zone to reduce routing and node management costs. The transmission radius does not need to be larger than the grid size, because all nodes have information on their 1-hop nodes and the number of the zones to manage is low because the grid size is large. In addition, because headers in a hierarchical structure are not used, any node can be a candidate for delivering a message. Therefore, the costs of header management are not increased. As a result, node management costs can be reduced. In addition, because it does not send out RREQ messages to all communicable nodes when searching for paths, the number of messages decreases.



$$d = \frac{9}{4}r$$

Fig. 3. Relationship between grid length and transmission radius

Each node maintains information on neighbor nodes within its transmission radius in a table using position update messages. Each node generates the transmissible path to the destination node using its neighbor node table. The proposed scheme maintains two tables: INNT (Intra Neighbor Node Table) and NZNT (Neighbor Zone Node Table). INNT manages the nodes within the grid zone where the current node exists, and NZNT manages 1-hop nodes outside the coordinate zone of the current node. Due to node movement, a battery discharge, and power off in MANET, the connectivity states among nodes change continuously. Particularly, when a node is created or enters in a new grid zone, it should grasp whether it can communicate with its adjacent nodes or not. Each node generates its own position and velocity through GPS. It periodically deploys a position update message in order to keep INNT and NZNT. When the moving direction of the node also changes after the deployment of the position update message, it sends the position update message additionally. Each node that receives the position update message updates NZNT and sends the message to the nodes in the zone in order to make them update INNT. When nodes with the limited battery generate their own positions and velocities through GPS and transmit position update messages, their battery consumption increases. Each node should keep threshold or more lifetime for guaranteeing safe communication. Here, the threshold means the minimum battery consumption for communication among 1-hop peers. When the lifetime of a particular node is under threshold, the node does not generate its own position information because it cannot participate in data transmission. Such the node does not deliver a position update message.

Fig. 4 shows the neighbor nodes of node 4. **Table 1** and **Table 2** show the INNT and NZNT of node 4, respectively. The tables include the information in the structure of <*Node_ID*, *Zone_ID*, *P_Coordinate*, *Node_Velocity*>, where *Node_ID* is the identifier of a node, *Zone_ID* is the identifier of a zone, *P_Coordinate* is the coordinate information of a node, and *Node_Velocity* is the moving speed of a node. *Zone_ID* is represented by (z_x, z_y) and z_x and z_y mean the coordinates of x-axis and y-aixs of a zone that a node is included in. *P_Coordinate* is represented by (x_i, y_i) and x_i and y_i mean the coordinates of x-axis and y-aixs at time t_i. *Node_Velocity* is represented by (v_x, v_y) via Equation (1) and is computed through the amount of position changes among time intervals by using position information periodically obtained by GPS.

$$(v_x, v_y) = \left(\frac{x_{i+1} - x_i}{t_{i+1} - t_i}, \frac{y_{i+1} - y_i}{t_{i+1} - t_i}\right) \tag{1}$$

Table 1. INNT (Intra Neighbor Node Table) for Node 4

Node_ID	Zone_ID	P_Coordinate	Node_Velocity
3	(1, 1)	(5, 7)	(0, 1)
4	(1, 1)	(8, 8)	
5	(1, 1)	(3, 3)	(2, 3)
6	(1, 1)	(7, 2)	(2, 1)
7	(1, 1)	(8, 5)	(-1, 0)
38	(1, 1)	(2, 6)	(0, 0)

Table 2. NZNT (Neighbor Zone Node Table) for Node 4

Node_ID	Zone_ID	P_Coordinate	Node_Velocity
13	(1, 2)	(8, 12)	(1, 2)
28	(2, 1)	(11, 6)	(2, 1)

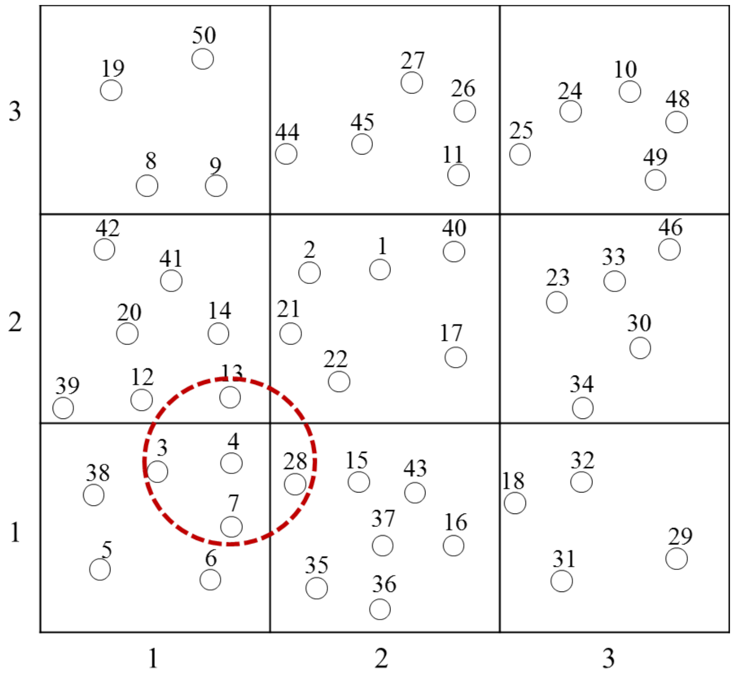


Fig. 4. Neighbor nodes of node 4

3.3 Routing Path Discovery

To establish and select the optimal routing path for delivering actual data from a source node to a destination node, the path discovery process is performed. The existing routing scheme in a MANET environment delivers the RREQ message to a destination using the broadcasting method, and in response, the destination node that receives the RREQ message delivers the RREP message to the source node. However, by using this method, the number of messages may increase exponentially and the routing cost can also increase. In addition, in the event that the node the message is to be sent to no longer exists, messages are detoured or sent to redundant paths. To solve these problems, the proposed scheme takes into account the directionality of the destination node and the information on neighbor nodes when searching for paths. Specifically, it determines the zone and the direction to send the RREQ message to by comparing the coordinates of the current node and the destination node. It selects the best neighbor node as the next intermediate node and delivers the data to the node, delivering gradually closer toward the destination node. It calculates and saves the connectivity of the nodes as it delivers the RREQ message. **Fig. 5** shows the format of the routing control message. **Fig. 5(a)** shows the format of the RREQ message, and **Fig. 5(b)** shows the format of the RREP message.

Source ID	*Destination ID*	*Sequence Number*	*Route Record (List of Node IDs)*	*Node Connectivity*	*Position Update Vectors*

(a) Format of RREQ Message

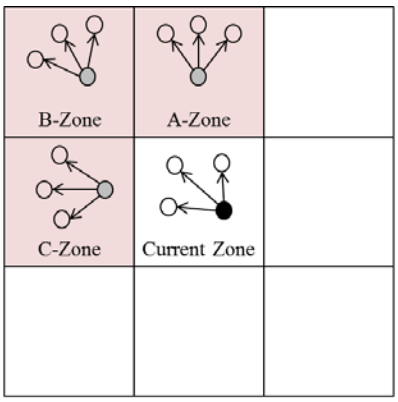
Source ID	*Destination ID*	*Sequence Number*	*Route Record (List of Node IDs)*

(b) Format of RREP Message

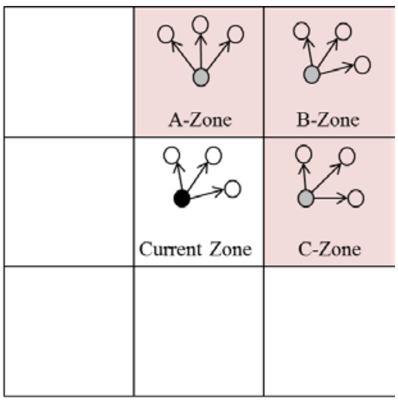
Fig. 5. Formats of routing control messages

In the proposed path discovery scheme, the DV_zone (delivery zone) to deliver the RREQ message is selected by comparing the coordinates of C_zone (Current zone) and DN_zone (destination zone). Here, C_zone denotes the grid zone in which the current node is located, DN_zone denotes the grid zone in which the destination node is located, and DV_zone denotes the grid zone in which the current node in C_zone delivers the message to. The current node selects and delivers the RREQ message to the adjacent DV_zone in the direction of the destination node by comparing the coordinates of C_zone and DN_zone.

Fig. 6 shows nine adjacent DV_zones around C_zone, where x_c is the x coordinate of C_zone, x_d is the x coordinate of DN_zone, y_c is the y coordinate of C_zone, and y_d is the y coordinate of DN_zone. As shown in **Fig. 6(a)**, when the x coordinate of C_zone is greater than the x coordinate of DN_zone and the y coordinate of C_zone is less than or equal to the y coordinate of DN_zone , we choose the left zone and the top two zones as DN_zones. As shown in **Fig. 6(b)**, when the x coordinate of C_zone is less than or equal to the x coordinate of DN_zone and the y coordinate of C_zone is less than and equal to the y coordinate of DN_zone, we choose the right zone and the top two zones as DN_zones. In the same way, as shown in **Fig. 6(c)**, when the x coordinate of C_zone is greater than the x coordinate of DN_zone and the y coordinate of C_zone is less than the y coordinate of DN_zone , we choose the left zone and the bottom two zones as DN_zones. As shown in **Fig. 6(d)**, when the x coordinate of C_zone is less than or equal to the x coordinate of DN_zone and the y coordinate of C_zone is greater than the y coordinate of DN_zone, we choose the right zone and the bottom two zones as DN_zones.



(a) $x_c > x_d$, $y_c \le y_d$



(b) $x_c \le x_d$, $y_c \le y_d$

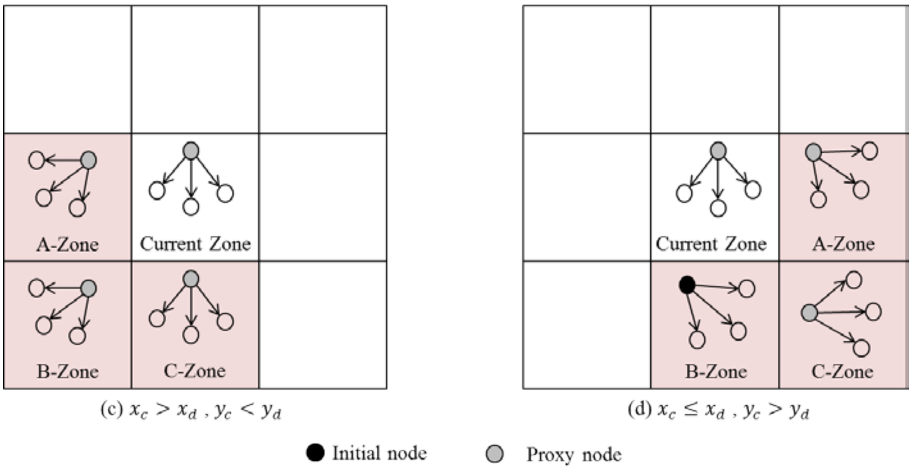


Fig. 6. Path discovery considering directionality based on coordinates

The nodes that receive the message first in the three zones selected as DV_zones of A-zone, B-zone, and C-zone (i.e., the nodes that receive the message from C_zone) are called proxy nodes. Since the size of a grid is bigger than 1-hop transmission radius, the proposed scheme performs location based routing to transmit a RREQ message in the grid. Each node keeps information about nodes in the same grid and information about 1-hop nodes in the neighbor grids in INNT and NZNT tables. A proxy node that receives a RREQ message performs location based routing using INNT and NZNT tables in order to transmit the RREQ message to the destination. If the destination node exists in the grid with the proxy node, the proposed scheme performs location based routing to the destination node using the INNT table. We transmit a RREQ message to nodes in the path to the destination node using the positions and directions of nodes in the INNT table. If the destination node does not exist in the zone that includes the proxy node, we search node D_node that can communicate with DV_zone using NZNT table. If D_node exists, we perform location based routing with D_node and 1-hop nodes that can communicate with it directly. If the NZNT does not have information on relevant nodes and delivery to adjacent zones is not possible, the messages are no longer delivered. Location based routing within a grid is performed through nodes that receives a RREQ message and nodes that satisfy a communication threshold and exist in the path to the destination node. Here, the communication threshold λ is computed using Equation (2) and MC means the minimum spent time when we transmit a message among 1-hop nodes. We eliminate the cases that a node sends a RREQ message but does not receive a RREP message through the communication threshold in advance.

$$\lambda = 2MC \tag{2}$$

Fig. 7 shows an example of a path discovery in the situation shown in **Fig. 6(b)**. The black node indicates source node 12, and the grey nodes indicate proxy nodes. Each node shares information on neighbor nodes in the grid zone it currently belongs to using periodic update messages. Therefore, all nodes in the grid zone that the source node belongs to (1, 1) have information on neighbor nodes in the same zone, and they can identify nodes that can connect with others in different grid zones. The node data are managed in a table, and they are shown in **Table 3** and **Table 4**. First, source node 12 searches its table to identify the transmissible node. It searches the NZNT first, because it needs to deliver to an adjacent zone. As shown in **Table 3**, the transmissible nodes in adjacent zones include nodes 18, 23, and 13. By searching the INNT in **Table 3**, it identifies the nodes in its zone that can be transmitted with nodes 18, 23, and 13. The INNT shows that the message can be sent to nodes 23 and 18 via node 22, and to node 13 via node 15. Eventually, source node 12 can deliver a message to node 23 in the adjacent zone via nodes 20, 21, 9, and 22 and to node 13 via nodes 7 and 15.

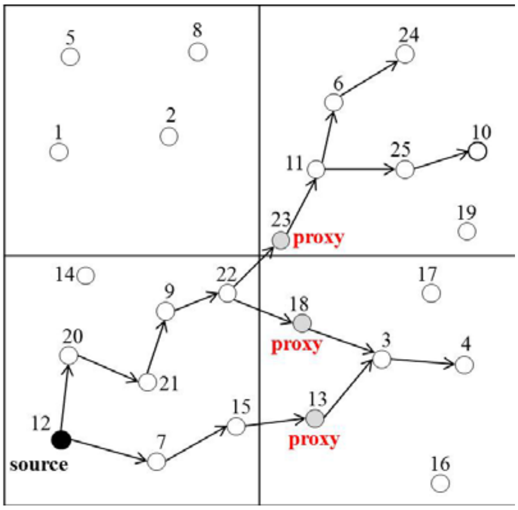


Fig. 7. Example of path discovery

Table 3. Intra Neighbor Node Table (INNT) of (1,1)

Node_ID	Zone_ID	P_Coordinate	Velocity
12	(1, 1)	(2, 3)	(0, 0)
7	(1, 1)	(6, 2)	(0, 1)
20	(1, 1)	(3, 7)	(1, 0)
14	(1, 1)	(4, 9)	(0, 2)
21	(1, 1)	(6, 6)	(1, 1)
9	(1, 1)	(7, 8)	(2, 1)
22	(1, 1)	(8, 8.5)	(1, 1)
15	(1, 1)	(9, 4)	(1, 0)

Table 4. Neighbor Zone Node Table (NZNT) of (1,1)

Node_ID	Zone_ID	P_Coordinate	Velocity
18	(2, 1)	(12, 7.5)	(1, -1)
23	(2, 2)	(11, 11)	(1, 1)
13	(2, 1)	(13, 4.5)	(1, 2)

In the course of delivering the RREQ message, when a node receives identical messages, the path with a longer connection time is selected, and if the connection time is identical, the message with a smaller sequence number is selected. Through the selection of the optimal routing path by calculating path connectivity while delivering the RREQ message, faster and more reliable delivery is performed. Path connectivity is defined as the minimum amount of time for which the connection can be maintained among the nodes on the routing path. It is the estimation of the time for which reliable transmission is possible among the nodes on the routing path, and it is estimated as the minimum value of the connection time among neighbor nodes.

Fig. 8 is the algorithm for the grid-based routing path discovery. First, the source node begins delivery of the RREQ message. All nodes that receive the RREQ message compare the coordinates of their current locations with the coordinates of the destination node, and they select the next delivery zone for the RREQ message. When the transmissible nodes are found to exist based on the NZNT table search, they send the RREQ message to them. While delivering the RREQ message, the connectivity is calculated and saved. When the identical messages are received, the message from the node with a longer connection time is accepted and the rest is deleted. If the connection times of the nodes are also identical, the message with a smaller sequence number is received.

procedure discovery_routing_path

```
begin
   send RREQ by source;
   receive RREQ;
   compare current node's coordinate with destination coordinate;
   select delivery zone;
   search table (NZNT, INNT);
   if nodes exists in table
      send RREQ message;
      calculate connectivities;
      save connectivities in RREQ;
   else
      update table;
   if receive equal message
      compare connectivities;
      receive MAX_connectivity_node's message;
   else if equal connectivity
      compare sequence_number;
      receive MIN_sequence_number_node's message;
end
```

Fig. 8. Algorithm for routing path discovery

3.4 Routing Path Determination

In a routing scheme, a source node sends a RREQ message to a destination node, and the destination node that receives the message sends a RREP message in response. In this process, when multiple transmissible paths exist, the cost involved in determining the optimal routing path for delivering actual data increases. Therefore, the proposed scheme selects the optimal routing path for delivering data by considering connection time and the number of hops. The source node delivers the RREQ message to the destination node, and the destination node that receives the message determines the optimal routing path for delivering the data and delivers a RREP message containing the information using the optimal routing path to the source node via the selected path.

The proposed scheme determines the routing path for delivering actual data by considering both path connectivity and the number of hops. By considering connection time, it can provide more reliable data delivery based on the transmission among nodes with a longer connectivity time. In addition, through the selection of the path with smaller hops, the communication cost required for data delivery is reduced and the data can be delivered faster. The routing path is determined by Equation (3), and the path with the largest Route Selection Value (RSV) is selected. The RSV is the value used to select a path, and it becomes higher when the connection time is longer and the number of hops is smaller. The Hop Count (HC) represents the number of hops.

$$RSV = \frac{RCT(R_i)}{HC} \tag{3}$$

Path connectivity is defined as the minimum amount of connection time among the nodes on the routing path. When the routing path R_i for delivering data from a source node to a destination node is $\{N_1, N_2, \cdots, N_k\}$, the path connectivity is computed by equation (4). The path connectivity means the minimum node connectivity that is the smallest of connection times CT_i among the adjacent nodes. The node connectivity is computed by equation (5). Here, $MAX(CT_i)$ is the maximum time that satisfies $|P_t(N_i) - P_t(N_{i+1})| \le R$, T_{cur} is a current time, and R is the communication radius of a node. When $P_t(N_i)$ the position of node N_i at time t, is computed by equation (6), $MAX(CT_i)$ means the maximum connection time that can communicate among the adjacent nodes. In equation (6), x^i_{cur} and y^i_{cur} represent the position of node N_i at the current time, and v^i_x and v^i_y represent the moving velocity of node N_i.

$$RCT(R_i) = MIN(CTI_i), 1 \le i \le k-1 \tag{4}$$

$$CTI_i = MAX(CT_i) - T_{cur} \tag{5}$$

$$P_t(N_i) = (x^i_{cur} + v^i_x t, y^i_{cur} + v^i_y t) \tag{6}$$

Fig. 9 shows an example of the routing path selection process. The entire network contains a total of 60 notes, and the routing paths indicate the RREQ and RREP message delivery routing paths from source node 12 to destination node 10. Destination node 10 selects the optimal routing path among the routing paths contained in the received RREQ message. It delivers the RREP message to the source node. The routing path information included in the RREQ message is shown in **Table 5**. A total of four routing paths are included, and each routing path is represented by the name of the routing path (e.g. node ID, number of hops, and connectivity). The destination node calculates the RSV in Equation 1 by considering the connection time of nodes and the number of hops, and it selects the optimal routing path for delivering the data. Regarding the RSV calculations, the values are 2.2 for R1, 1.8 for R2, and 1.7 for R3, and the R1 with the largest RSV value is selected as the optimal routing path. The destination node then delivers the RREP message that contains the routing path information of R1 to the source node via the selected R1 routing path. The source node that receives the RREP message delivers the actual data to the destination node via the routing path.

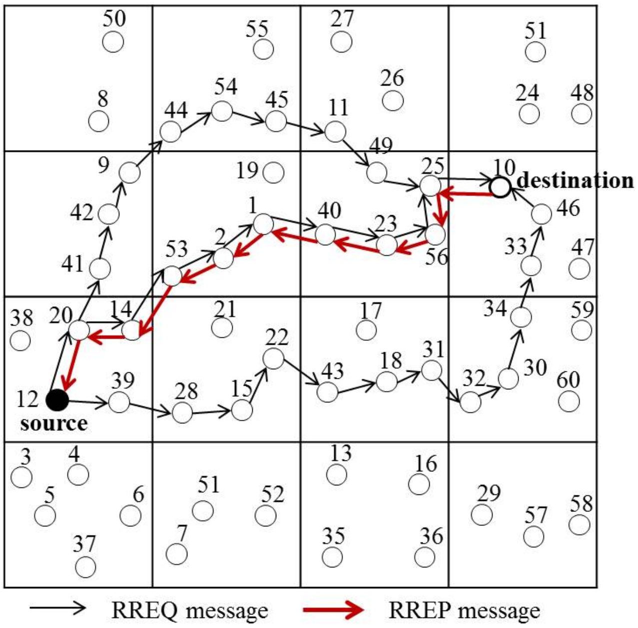


Fig. 9. Example of routing path selection

Table 5. Routes Contained in RREQ Message

Route	Route	Number of Hops	Path Connectivity
R1	12,20,14,53,2,1,40,23,56,25,10	10	22
R2	12,20,41,42,9,44,54,45,11,49,25,10	11	19
R3	12,39,28,15,22,43,18,31,32,30,34,33,46,10	13	21

Fig. 10 shows the algorithm for the routing path selection. As it delivers the RREQ message from the source node, it calculates the connection time and the number of hops. The destination nodes that receive the RREQ message select the optimal routing paths by calculating the connection time of the nodes and the number of hops. The destination node that receives the RREQ message determines the optimal routing path for delivering data using the information contained in the message, and it includes the information in the RREP message and delivers it to the source node. The destination node delivers the RREP message to the source node via the selected routing path. The source node that receives the RREP message generates the optimal routing path for delivering data to the destination node using the information contained in the received message. The cost to deliver data is determined by the number of hops. When the connectivity among nodes is short, an additional cost to generate an alternative routing path in the delivery process occurs.

procedure select_routing_path

begin
  receive RREQ;
  calculate connectivity and hop_count;
  select optimal routing path (MAX_RSV);
  send RREP message to source;
end

Fig. 10. Algorithm for routing path selection

The proposed scheme chooses a path with high connectivity by considering communicable times among nodes as an optimal routing path. Therefore, in the proposed scheme, the cases that it does not deliver a RREP message according to the movement of nodes do not almost occur. However, due to the battery discharge and service withdrawal of a node, the proposed scheme can have a problem that it does not deliver a RREP message. The proposed scheme reestablishes a path to deliver a RREP message in the same way as the alternative path generation and the partial path update when it does not deliver the message. If RREP message delivery failure in a node near to a source node occurs, we recreate a RREQ message based on a current node and then send the RREQ message to the source node and generate an alternative path to deliver a RREP message. However, if RREP message delivery failure in a node near to a destination node occurs, we send the delivery failure message to the destination node and regenerate an optimal routing path. **Fig. 11** shows how to process RREP message delivery failure. If RREP message delivery failure occurs in node 13, the previous node 28 of node 13 sends a new RREQ message to the source node and the source node generates a new routing path between node 28 and the source node since node 28 is near to the source node. If RREP message delivery failure occurs in node 25, the previous node 24 of node 25 sends an optimal path reestablishment request to the destination node since node 25 is near to the destination node. The destination node chooses a new optimal routing path except for the path that RREP message delivery failure occurs and sends the RREP message via the path.

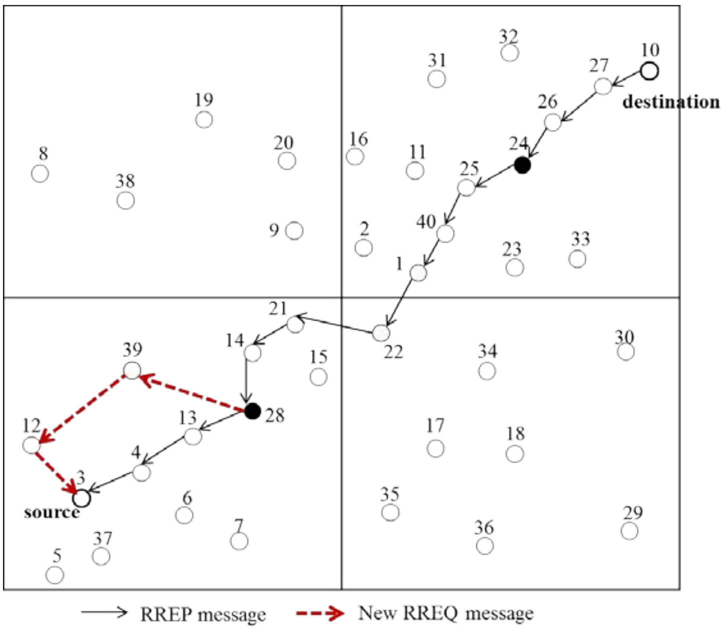


Fig. 11. Processing on RREP delivery failure

3.5 Data Transmission

In a MANET environment, position update messages are frequently not checked for a certain amount of time due to node mobility, or an initially selected routing path is unavailable for data delivery due to circumstances such as neighbor nodes moving to different locations. Consequently, when data delivery to a specific node becomes impossible in the course of delivering data via a routing path, an alternative routing path for performing data delivery must be generated. If an identical procedure to the initial routing path generation is employed for generating an alternative routing path, the routing path request and response messages must be sent again, which also causes a delay in delivery. To address these problems, in the proposed scheme, an alternative routing path and partial routing path are generated by the source node.

To reduce delays in delivery and generate an alternative routing path quickly, in the proposed scheme the distance between the source node and destination node is calculated in the node located immediately before the failed node. Based on this calculation, if the location of the node immediately before the failed node is closer to the source node than the destination node, the Route Error (RERR) message is sent to the source node to generate an alternative routing path. On the other hand, if the location of the node immediately before the failed node is closer to the destination node than the source node, a partial routing path update is performed by considering path reliability. **Fig. 12** shows the format of the RERR message.

Node Originating the Error Packet	*Source ID of the Data Packet dropped*	*Destination ID of the Data Packet dropped*	*Sequence Number of the Data packet dropped*	*Downstream node with which the link failed*

Fig. 12. Format of RERR message

The partial routing path update is faster than that of the existing method because it searches for a new routing path from the node located immediately before the failed node to the destination node. It reduces the discarded messages by allowing redelivery of the message to the previous node to perform routing again. This scheme for a second search for routing paths is called a back-off. However, the simple application of a back-off to routing may lead to the ping-pong effect, in which messages move back and forth between specific nodes. This can cause the messages to continue being transmitted, yet unable to reach the final destination node. To solve this problem, the node that receives the re-sent message by back-off must specify that the next hop node based on the original routing method is not required for the delivery of the message and search other neighbor nodes for the next hop for the message. This method can reduce problems of the existing schemes in terms of the significant amount of additional time and costs involved in alternative path generation. However, note that when the failed node is closer to the destination node, yet the connection time CT , is shorter than the required time for data delivery, the path reliability is uninsured. Therefore, the routing path is determined as an unreliable routing path and a RERR message is sent to the source node to search the routing paths again.

Fig. 13 shows the process of a partial routing path update. We assume that node 24 is a destination node and a transmission failure occurs in node 1 when we transmit data along the routing path. Since node 1 is near to the destination node 24, the proposed scheme processes a partial path update. A whole routing path regeneration spends much time since a RREQ message should be sent to the whole network in order to determine an optimal routing path. However, a partial path update generates a routing path to transmit data from the previous node of the transmission failure node to the destination node, not the whole network. Node 22 sends the RREQ message to the destination node in order to create a new routing path. If the adjacent nodes of node 1 do not know the transmission failure in node 1, node 34 is supposed to send the RREQ message to node 1. However, the proposed scheme sends both the RREQ message and the transmission failure node information. By doing so, the proposed scheme can reduce unnecessary message transmission and save the response time from the transmission failure node. That is, node 34 does not send the RREQ message to node 1 and do send it to node 23 in the path to the destination. As a result, the proposed scheme processes a partial routing update in this way.

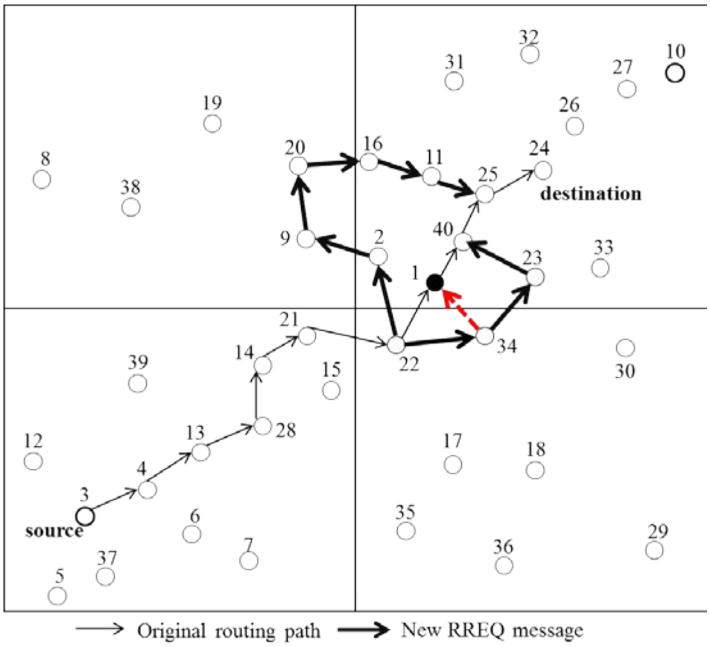


Fig. 13. Process of a partial path update

The calculation of the distance from the source node is shown in Equation (7), and the distance from the destination node is shown in Equation (7), where x_s is the x value of the source node, y_s is the y value of the source node, x_c is the x value of the current node, y_c is the y value of the current node, x_d is the x value of the destination node, and y_d is the y value of the destination.

$$Dist(S,C) = \sqrt{(x_s - x_c)^2 + (y_s - y_c)^2} \tag{7}$$

$$Dist(D,C) = \sqrt{(x_d - x_c)^2 + (y_d - y_c)^2} \tag{8}$$

When searching for an alternative routing path from the source node, the waiting time is set to reduce data loss and delays. The waiting time refers to the time that a source node delivers a new RREQ message to the search path again and receives a RREP message. The waiting time is expressed as WT and calculated as in Equation (9), where H is the message transmission time among 1-hop neighbor nodes.

$$WT = 2H \tag{9}$$

Fig. 14 shows the procedure for establishing a new routing path using an alternative path generation scheme. Let us assume that node 1 has a problem and can no longer deliver data. Since node 22 can no longer receive the message from node 1, node 1 can no longer be used. Therefore, node 22 determines an alternative path generation method by calculating the distances from the source node and the destination node. If node 22 is closer to the source node, it sends the RERR message to source node 3 and search paths again. If node 22 is closer to the destination node, node 1 is deleted from the INNT of node 22, and the node searches for a new routing path. In this case, node 22 finds and delivers the message to node 2 toward the destination node using a newly updated INNT that is managed with periodic hello messages. However, even though node 22 is closer to destination node 10 than the source node, the route is determined to be unreliable. Therefore, it sends a RERR message to the source node, where a new alternative path is generated.

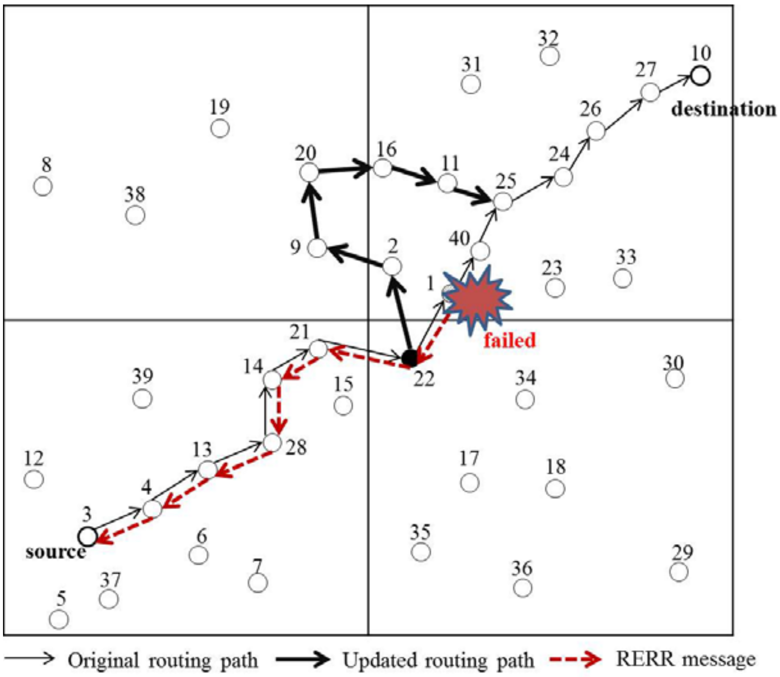


Fig. 14. Example of alternative path generation

Fig. 15 shows the algorithm for alternative path generation. The node that receives a RERR message calculates the distance between the source and the destination. When it is closer to the source node, it sends a RERR message to the source node to generate an alternative path. On the other hand, when it is closer to the destination node, it generates an alternative path by using the partial path update method with the back-off algorithm. Even when it is closer to the destination node, the path is determined to be unreliable because the connection time, CT, is smaller than the delivery time. Therefore, it sends the RERR message to the source node to generate an alternative path.

```
procedure alternative_routing_path
begin
   receive RERR
   calculate distance (source, destination)
   if distance (source < destination)
      if CT < transfer_time
         send RERR to source node
      else
         send RERR to previous node (back-off)
end
```

Fig. 15. Algorithm for alternative routing path generation

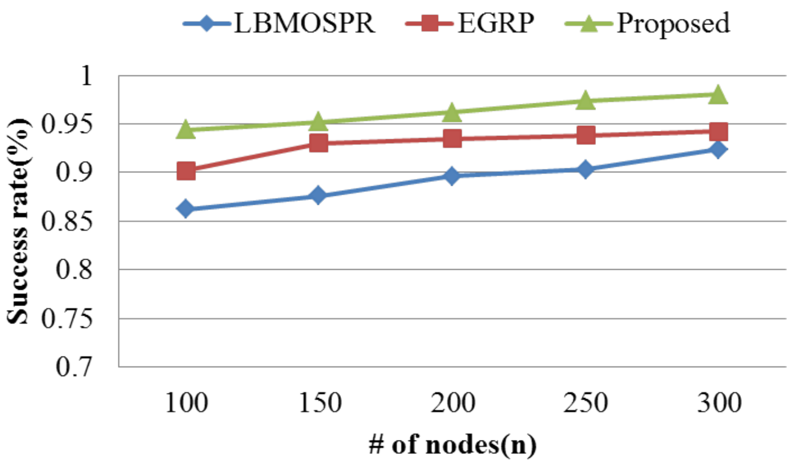
4. Performance Evaluation

In order to show the superiority of the proposed scheme, we compare it with a location based routing scheme, called LBMOSPR[15] and a grid based routing scheme, called EGRP[17] through performance evaluation. EGRP transmits a RREQ message to the grid zone that is not adjacent to a head node. EGRP manages node positions through Neighbors Table and Routing Table. LBMOSPR is one of representative location based routing schemes and processes an optimal path routing based on a current position. Therefore, we don’t have to calculate the velocity of EGRP and LBMOSPR in the experimental evaluation since they do not consider path connectivity. The experiment evaluates the performance in terms of routing cost and network lifetime. The proposed scheme is also compared with another similar grid-based routing scheme that has recently been proposed. The performance evaluation was conducted using a CPU Intel® Core(TM) i5-3570 3.40GHz, RAM 8GB and a Windows 7 64-bit operating environment. We construct simulation environments through NS-2 simulator and performed performance comparison during 1,000 seconds as the number of nodes and the velocity change. We set the communication radius to 80m, the packet size to 1kbyte, the size of transmission data to 10kbyte and used 802.11 as MAC protocol. Since there are not real data for experiments in MANET environments, experimental data on 1,000m×1,000m space was generated as shown in **Table 6**. We randomly deployed 100~300 nodes, set the directions of the nodes randomly, and changed the node velocity from 5m/s to 30m/s periodically. The routing schemes were compared in terms of data delivery success rate, the number of messages, and number of data delivery hops under varying conditions of the number of nodes and node velocity.

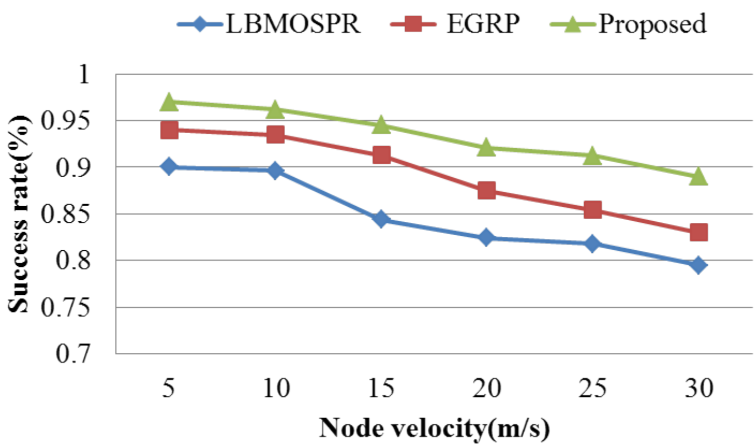
Table 6. Performance Evaluation Environment

Parameter	Value
Size of network (m)	1000 × 1000
Number of nodes (count)	100~300
Node velocity (m/s)	5~30
Moving direction(vector)	random
Transmission radius (m)	80
Packet size (byte)	1K
Size of transmission data (byte)	1,000K
MAC protocol	802.11
Simulation time (s)	1,000

In MANETs, many nodes transmit and receive data while constantly moving. Therefore, insufficient or fast-moving nodes cause reduced transmission efficiency. Therefore, it is necessary to determine how much more efficient the proposed scheme is than the existing schemes in terms of data delivery. The proposed scheme is evaluated comparatively with the existing routing schemes in an experiment on data delivery success rate according to the number of nodes and node velocity. **Fig. 16(a)** shows the results of the comparison of delivery success rate according to the number of nodes. The mean velocity was set to 10 m/s in the experiment. The experiment results showed that delivery success rates increased with the increase in the number of nodes. This suggests that, with an increase in the number of nodes for delivering the message, messages can be delivered to the destination more reliably. The delivery success rate of the proposed scheme was found to be nearly 100% when the number of nodes increased. The superiority of the proposed scheme was due to reliable delivery based on the strategy to take into account connection time. The proposed scheme showed approximately 6% improved delivery success rate compared to the LBMOSPR and EGRP schemes. **Fig. 16(b)** shows the results of the comparison of delivery success rate according to node velocity. The experiment results showed that delivery success rate decreased with the increase in node velocity. This suggests that, with an increase in node velocity, nodes moved in or out of the transmission range faster. Therefore, less nodes were available to deliver messages reliably. The proposed scheme demonstrates superior performance to the existing schemes of LBMOSPR and EGRP, because it ensures reliable data delivery by taking connection time into account in alternative path generation. The proposed scheme showed approximately 7% improved delivery success rate compared to the existing schemes.



(a) the number of nodes

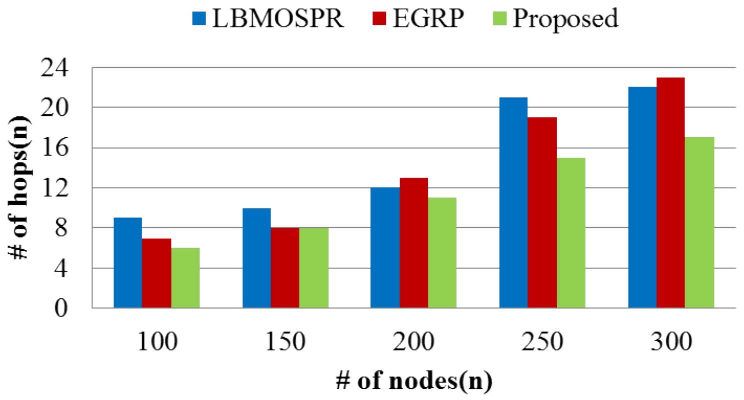


(b) node velocity

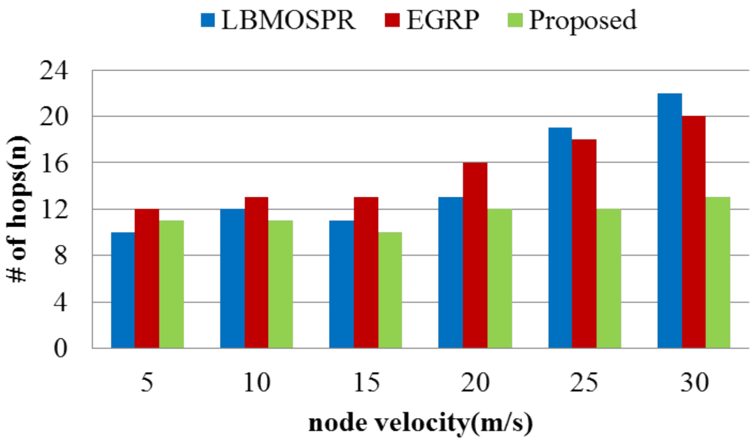
Fig. 16. Delivery success rate

Providing services in MANETs requires routing that can deliver messages quickly and reliably from the source node to the destination node. Therefore, to determine data delivery time and efficiency, an experiment on the number of hops used in data delivery was conducted, which compared the proposed scheme and existing schemes. **Fig. 17(a)** shows the results of the comparison of the number of hops used in data delivery. The mean node velocity was set to

10 m/s in the experiment. All three schemes showed a trend in which the number of hops increased with the increase in the number of nodes. This shows that, with an increased number of nodes, increased intermediate nodes became available, resulting in an increased number of hops. The existing schemes showed a sharp increase at 200 nodes or more, while the proposed schemes showed a gradual increase overall. The proposed scheme can deliver data faster and more reliably using an alternative path generation scheme that takes node connectivity into account. Consequently, the proposed scheme outperformed the existing schemes, showing approximately 21% decrease in the number of hops compared to LBMOSPR and EGRP. **Fig. 17(b)** shows the results of the comparison of the number of hops used in data delivery according to node velocity. The experiment results showed that, with increased node velocity, the number of hops increased in all three schemes. With an increase in node velocity, the network became unreliable due to the fast movement of nodes, and smooth communication via initially set-up routing paths was difficult to obtain. This is because with an increase in node velocity, the nodes moved and entered and left the zone quickly. Therefore, it was difficult to deliver messages reliably. With an increase in node velocity, the gap between the proposed scheme and existing schemes grows larger. The proposed scheme generates an efficient detour route utilizing an adaptable alternative path generation scheme. As a result, it delivers data quickly and reliably, considering information on neighbor nodes and node connectivity, without being significantly influenced by node velocity. The proposed scheme showed approximately 23% increase in the number of hops compared to LBMOSPR and EGRP.



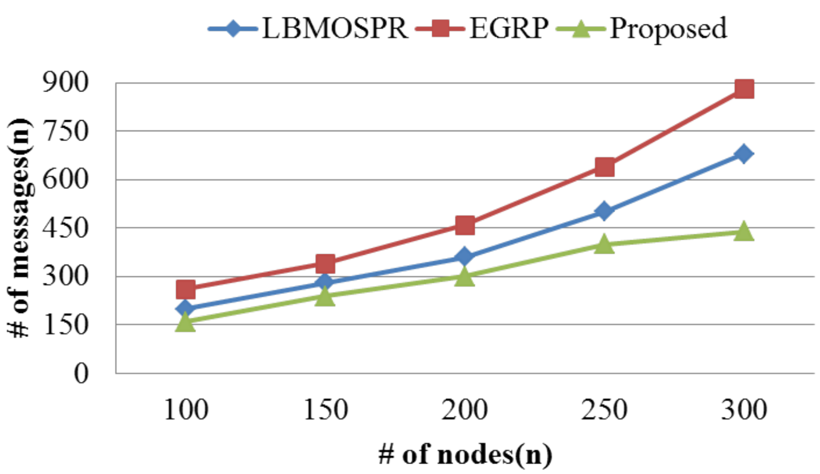
(a) the number of nodes



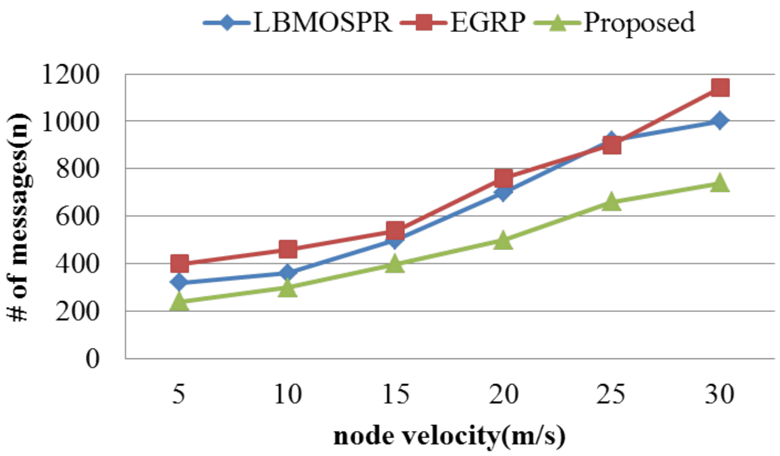
(b) node velocity

Fig. 17. The number of hops

Since nodes use the limited battery and network resources in MANET environments, it is very important to reduce routing overheads. In general, the routing overheads are evaluated as the number of messages and energy consumption. We send and receive many control messages for performing routing in MANET environments. Since the routing costs become high when the control messages increase, the transmission delay can occur. Therefore, an experiment was also conducted to evaluate the number of control messages in the entire network according to the number of nodes and node velocity. **Fig. 18(a)** shows the comparison of the total number of request/response messages in the entire network according to the total number of nodes. The average node velocity was set to 10 m/s in the experiment. The experiment results showed that the number of messages increased with the increase in the number of nodes. This shows that, with an increase in the number of nodes for delivering a message, the number of control messages required for routing increased. The proposed scheme delivers RREQ messages only to the nodes present in the direction of the destination through the use of location information. In addition, because grid size is larger than transmission radius in the scheme, the number of messages to deliver is relatively low. Due to these aspects, the proposed scheme outperformed the existing schemes in terms of the number of messages, showing 33% increase on average compared to LBMOSPR and EGRP. **Fig. 18(b)** shows the results of a comparison of the number of messages of the entire network according to the overall node velocity. The experiment results showed that the number of messages increased with the increase in node velocity. This shows that, with increased node velocity, topology became unreliable, and the number of nodes for delivering messages decreased, resulting in an increase in the number of control messages, such as request messages. The existing schemes showed a sharp increase at a node velocity of 20 m/s or higher. The proposed scheme delivers PREQ messages only to the nodes present in the direction of the destination utilizing the location information of the grid zone. This resulted in the outperformance of the proposed scheme over existing schemes in terms of the number of messages, showing approximately 29% decreased the number of messages compared to LBMOSPR and EGRP.



(a) the number of nodes



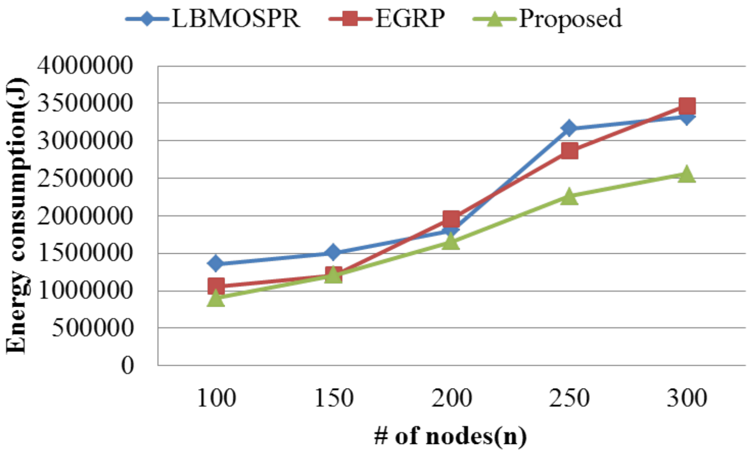
(b) node velocity

Fig. 18. The number of messages

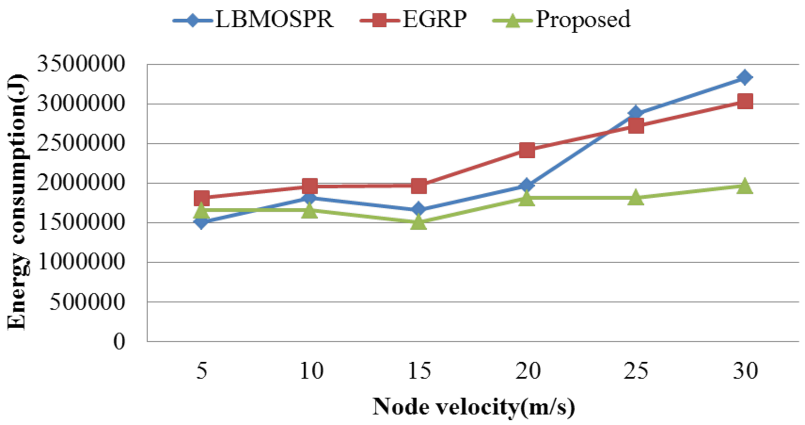
Since we send and receive messages in the routing process, high energy consumption occurs. It is necessary to measure the amount of energy consumption in order to improve the network lifetime in MANET environments. We use energy consumption models such as equations (10) and (11) to discriminate the transmitting energy T_e and the receiving energy R_e . Here, MSG_{size} is the message size and R_{cost} and T_{cost} are the receiving and transmitting costs, respectively. Both R_{cost} and T_{cost} are set to $50nJ/b$. T_{amp} is the amplification cost and is set to $100pJ/b/m^2$. T_{dist} means the transmission distance. We measured the energy consumption in the same environments as measuring the number of messages. **Fig. 19(a)** shows energy consumption according to the number of nodes. Although the proposed scheme and the existing schemes increase energy consumption when the number of nodes increases, the increase rate of energy consumption of the proposed scheme is small over those of the existing schemes. We can see through performance evaluation results that the proposed scheme reduced about 19% energy consumption rate over LBMOSPR and EGRP on average. **Fig. 19(b)** shows energy consumption according to node velocity. The amount of energy consumption of LBMOSPR and EGRP is larger than that of the proposed scheme since they increase the number of messages as the moving velocity becomes fast. It is shown through performance evaluation that the proposed scheme reduced about 20% energy consumption rate according to node velocity over LBMOSPR and EGRP on average.

$$R_e = MSG_{size} \times R_{cost} \tag{10}$$

$$T_e = MSG_{size} \times (T_{cost} + T_{amp} \times T_{dist}^2) \tag{11}$$



(a) the number of nodes



(b) node velocity

Fig. 19. Energy consumption

5. Conclusion

In this paper, we proposed a new grid-based routing scheme to reduce the cost of routing path generation and management and maintain reliable routing paths in MANETs. The proposed scheme generated routing paths using information on neighboring zones and path discovery zones with the information in the tables that each node maintains. In addition, it can reduce routing costs by adjusting grid partitioning criteria, as well as the cost of header management, as all nodes can be candidates for delivering messages. Furthermore, the proposed scheme reduced routing costs by delivering RREQ messages only to the nodes present in the direction of the destination node by utilizing location information and maintaining the largeness of the grid size. In addition, it increased delivery success rate by facilitating reliable delivery by taking connectivity into account. The performance evaluation results showed that the proposed scheme outperformed the existing schemes, showing approximately 7% increase in delivery success rate, 31% decrease in the number of messages, and 22% decrease in the number of hops used in data delivery. In the near future, we will apply the proposed routing scheme to real applications.

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