Gradual Route Modification in Mobile Wireless Multihop Network with Combination of Carrying and Forwarding

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Abstract: In a wireless multihop network, data messages are transmitted along a wireless multihop transmission route composed of a sequence of intermediate wireless nodes forwarding the data messages. However, it is difficult to detect a wireless multihop transmission route from a source wireless node to a destination one if a wireless nodes are not evenly distributed and there are some areas in which wireless nodes are sparsely distributed. Some methods have been proposed to solve this problem by combination of forwarding data messages between neighbor intermediate wireless nodes as in a usual wireless multihop network and carrying data messages to pass through such areas. In the conventional methods with the combination of forwarding and carrying data messages, some dedicated intermediate mobile wireless nodes serve the role of carrying. Hence, such nodes are required to consume more battery power which results in lower connectivity of the network. In addition, transmissions of data messages might be suspended for waiting the carrying intermediate wireless nodes which results in longer end-to-end transmission delay. In order to solve the problems, this paper proposes a novel carrying and forwarding method which gradually modifies a wireless multihop transmission route to evenly share the required mobility overhead among all the intermediate mobile wireless nodes and to reduce end-to-end transmission delay of data messages by making the route shorter. The proposed method ensures that no successive intermediate wireless nodes pass each other without neighboring.

Keywords: Wireless Multihop Network, Delay Tolerant, Carrying and Forwarding, Ad-Hoc Routing, Node Mobility.

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1. Introduction

In a wireless multihop network, a sequence of data messages are transmitted from a source wireless node to a destination one through a sequence of intermediate wireless nodes. Each pair of successive intermediate wireless nodes are included in wireless transmission ranges each other and data messages are forwarded one by one along a wireless multihop transmission route. In order to configure a wireless multihop transmission route between arbitrary pair of a source and a destination wireless nodes, enough high density of distribution of wireless nodes is required. However, in a wireless multihop network with sparsely or unevenly distributed wireless nodes, it is difficult to detect a wireless multihop transmission route, i.e., it is difficult to transmit a sequence of data messages by successive forwarding by a sequence of intermediate wireless nodes. Hence, some method have been proposed in which a part of intermediate wireless nodes carry data messages in transmission. That is, an intermediate wireless node receives a data message from its previous-hop one, holds the message in its communication buffer and moves until it becomes a neighbor of its next-hop one and forward the message to it. Then, it moves back its original position to receive the next data message from its previous hop intermediate wireless node. In the conventional wireless multihop transmission methods by combination of carrying and forwarding data messages, only part of the intermediate wireless nodes carry data messages and consume their battery capacity for mobility. In addition, a previous-hop intermediate wireless node N_{i-1} of an intermediate wireless node N_i carrying a data message might holds data messages in its buffer and waits for being a neighbor of N_i. Hence, end-to-end transmission delay of data messages becomes longer.

This paper proposes a novel method to transmit data messages by combination of carrying and forwarding with even battery power consumption among intermediate wireless nodes and shorter end-to-end transmission delay of data messages. Here, though battery consumption does not evenly share among intermediate wireless nodes and additional transmission delay of data messages due to longer wireless multihop transmission route and unreasonable synchronization between successive intermediate wireless nodes in an initial wireless multihop transmission route, the route is modified gradually in accordance with transmissions of a sequence of data messages. Each intermediate wireless node modifies its mobility section in local relation to its previous- and next-hop intermediate wireless nodes and the wireless multihop transmission route gradually modified as a result. Required overhead for carrying data messages becomes to be shared evenly among the intermediate wireless nodes, the wireless multihop transmission route gradually resembles a line segment whose terminals are the source and the destination wireless nodes and shorter additional transmission delay is required for data messages due to synchronization between successive intermediate wireless nodes. As discussed later, mobility section of each intermediate wireless node is modified locally and the modification does not share with its previous- and next-hop intermediate wireless nodes instantaneously. Thus, it is possible for successive intermediate wireless nodes to pass each other without neighboring. This paper also shows the restriction of node mobility to avoid such passing each other.

2. Related Works

Various communication methods with carrying data messages by intermediate wireless nodes for supporting DTN (Delay-Tolerant Network) have been proposed [2]. Here, not only forwarding data messages to neighbor wireless nodes but also carrying data messages, i.e., holding data messages in communication buffers and moving, are expected to contribute to wireless multihop transmissions of data messages. In Epidemic Routing [4], each mobile wireless node carrying copies of data messages encounters another node and forwards the copies to it. Mobile wireless nodes carrying a copy of a data message increases and one of them is expected to encounter its destination node and forwards the data message to it. In Message Ferrying [5], dedicated mobile wireless nodes called ferry nodes carry data messages between clusters of wireless nodes to support data message transmissions between the clusters where it is difficult to transmit data messages only by forwarding.

In these methods, only one or a few data messages are transmitted along a wireless multihop transmission route. Thus, it is difficult for them to be applied to a sequence of data messages for large-scale data transmissions or for time-continuous streaming data transmissions. Hence, as shown in Figure 1, it is expected for combination of carrying and forwarding of data messages by a sequence of intermediate mobile wireless nodes to contribute to transmit such a sequence of data messages.

NDBAR (Node Density-Based Adaptive Routing) [1] is an ad-hoc routing protocol to support such data message multihop transmissions with carrying and forwarding. This is a flooding-based routing protocol as well-known ad-hoc routing protocol such as AODV and DSR. For detection and configuration of a wireless multihop transmission route from a source wireless node to a destination one, flooding of a route request control message $Rreq$ is applied. In usual flooding-based routing protocol, all the node broadcast a $Rreq$ control message with the same transmission power. However, in NDBAR, if a wireless node receiving the first $Rreq$ control message have a less neighbor wireless nodes than the predetermined threshold, it broadcasts the $Rreq$ control message with higher transmission power to reach farther wireless nodes. In data message transmissions, the intermediate wireless node having transmitted an $Rreq$ control message with higher transmission power becomes a ferry node and repeats carrying data messages from its previous-hop intermediate wireless node to its next-hop one. This routing and data message transmission protocol provides the combination of carrying and forwarding, part of the intermediate wireless nodes are required to consume more battery power capacity to broadcast an $Rreq$ control message with higher transmission power and to carry data messages along its mobility section.

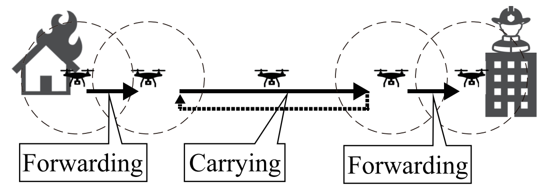

Fig. 1. Multihop Data Message Transmissions by Combination of Carrying and Forwarding.

3. Proposal

In this paper, it is assumed that a sequence of data messages are continuously transmitted from a source wireless node to a destination one along a wireless transmission route consisting of a sequence of intermediate mobile wireless nodes. In our proposal, not only a part of the intermediate nodes but also all the possible intermediate nodes carry and forward data messages in transmission, i.e., overhead for carrying data messages are evenly shared among all the intermediate nodes. Here, a source and a destination wireless nodes are stationary and it is assumed that the source wireless node have the location information of the destination one in advance. In addition, location acquisition devises such as GPS receivers are equipped in all the mobile wireless nodes which are possible intermediate wireless nodes in a wireless multihop transmission route. Hence, all the mobile wireless nodes are assumed to get their own current location information in a realtime manner. As explained in the following subsections, an initial wireless multihop transmission route from the source stationary wireless node to the destination one is detected where data message transmissions along the route are realized by combination of carrying and forwarding by the intermediate mobile wireless nodes. In the initial route, lengths of mobility of the intermediate wireless nodes for carrying data messages are distributed and the total length of the wireless multihop transmission route is longer than that of a line segment between the source and the destination nodes. During the continuous data message transmissions, the mobility segments of the intermediate mobile wireless nodes are modified gradually. The lengths of the mobility segments become equal and the total length of the end-to-end route becomes shorter. In the following subsections, a routing protocol for detection of the initial route and a data message transmission protocol by combination of carrying and forwarding with route modifications are discussed.

3.1 Initial Route Detection

An initial wireless multihop transmission route from a source stationary node N^s to a destination one N^d is detected by location based forwarding of a route request control message $Rreq$ in accordance with GEDIR [3] ad-hoc routing protocol. N^d and each intermediate mobile wireless node N_i

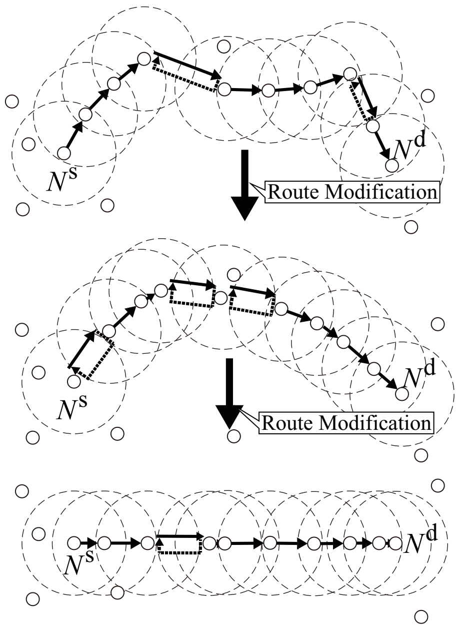

Fig. 2. Gradual Route Modification in Proposed Method.

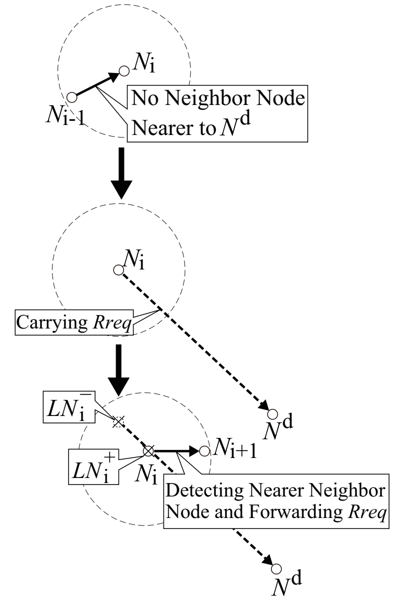

Fig. 4. *Rreq* Carrying in Initial Routing.

having received an *Rreq* control message from its previous-hop intermediate wireless node N_{i-1} sends the *Rreq* control message to the neighbor wireless node N_{i+1} nearest to N^d if $|N_{i+1}N^d| < |N_iN^d|$ is satisfied as shown in Figure 3.

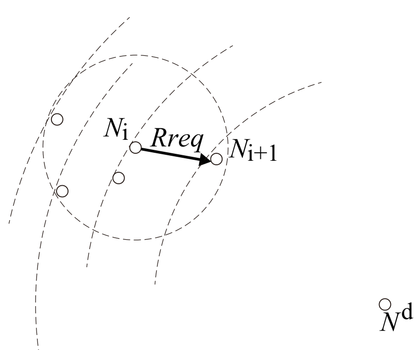

Fig. 3. *Rreq* Forwarding in Initial Routing.

If there are no such neighbor wireless node N_{i+1}, the route detection is aborted in the original GEDIR, which is called a deadend. Different from the original GEDIR, since data message transmissions along a wireless multihop transmission route are realized by combination of carrying and forwarding, N_i carries the *Rreq* control message along a line segment N_iN^d until it detects the N_{i+1} satisfying $|N_{i+1}N^d| < |N_iN^d|$ in our proposal. Then, N_i stops at the instance and sends the *Rreq* control message to N_{i+1} as shown in Figure 4.

For the following discussion, LN_i^- and LN_i^+ are the locations where N_i receives an *Rreq* control message from N_{i-1} and N_i sends it to N_{i+1}, respectively. If N_i has the neighbor wireless node nearer to N^d than N_i when it receieves an *Rreq* control message from N_{i-1}, $LN_i^- = LN_i^+$. A route reply control message *Rrep* is transmitted along the detected wireless multihop transmission route from N^d to N^s for confirmation of the route detection and for update of routing tables in the intermediate wireless nodes in the original GEDIR. In our proposal, the *Rrep* control message is also transmitted by combination of carrying and forwarding. N^d sends an *Rrep* control message to N_{n-1} since it is surely a neighbor wireless node of N^d and an *Rreq* control message has been forwarded. Each intermediate mobile wireless node N_i receives an *Rrep* control message from N_{i+1} at LN_i^+, carries the *Rrep* control message along a line segment $LN_i^+LN_i^-$, stops at LN_i^- and sends the *Rrep* control message to N_{i-1} which is at LN_{i-1}^+. Finally, the *Rrep* control message reaches N^s.

By this route detection and configuration, it is possible for data messages to be transmitted along the wireless multihop transmission route by combination of carrying and forwarding. Each intermediate mobile wireless node N_i waits for receiving a data message from N_{i-1} at LN_i^-. On receipt of a data message, N_i carries the data message along its mobility segment $LN_i^-LN_i^+$. Then, N_i waits for N_{i+1} being its neighbor wireless node at LN_{i+1}^-, sends the data message to N_{i+1} and moves back to LN_i^- for the transmission of the next data message. By this combination of carrying and forwarding, a sequence of data messages are transmitted from N^s to N^d along the wireless multihop transmission route. However, as shown in Figure 5, the initial transmission route is longer than the line segment N^sN^d which results in longer transmission delay of data messages and higher mobility overhead in the intermediate mobile wireless nodes. In addition, the lengths of the mobility segments of the intermediate mobile wireless nodes are widely distributed. Since some intermediate mobile wireless nodes have to wait for receiving data messages from its previous-hop wireless nodes and for sending data messages to its next-hop wireless nodes at the ends of their mobility segments, end-to-end transmission delay of data messages becomes longer. Uneven sharing of mobility overhead among multiple intermediate mobile wireless nodes cause uneven battery power consumption and mobile wireless nodes with exhausted battery capacities have to be removed from the wireless multihop network. Therefore, the connectivity of the wireless multihop network becomes lower.

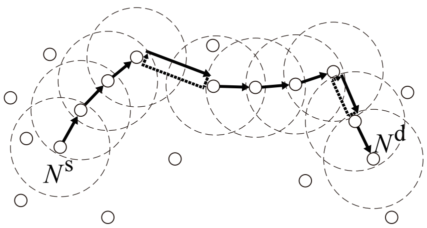

Fig. 5. Initial Wireless Multihop Transmission Route.

3.2 Gradual Route Modification

In order to solve the problems shown in the previous subsection, the ends LN_i^- and LN_i^+ of a line segment $LN_i^- LN_i^+$ which is the mobility segment of an intermediate mobile wireless node N_i are updated at the instances of receiving and sending data messages by N_i. If the previous-hop intermediate mobile wireless node N_{i-1} does not reach LN_{i-1}^+ when N_i reaches LN_i^-, it is impossible for N_i to receive a data message from N_{i-1}. Though N_i waits for N_{i-1} to reach LN_{i-1}^+ at LN_i^- in the conventional methods such as NDBAR, N_i contiguously moves along a line segment $LN_i^- LN_{i-1}^-$ to LN_{i-1}^- as shown in Figure 6. This is because the mobility segment of N_{i-1} seems to be relatively longer than the mobility segment of N_i and it is required for the mobility segments of N_{i-1} and N_i to become shorter and longer, respectively. During the contiguous mobility of N_i along the extended mobility segment from LN_i^- to LN_{i-1}^-, if N_i encounters N_{i-1}, i.e., N_i and N_{i-1} become included in the wireless signal transmission ranges each other, both N_i and N_{i-1} stop and a data message is forwarded from N_{i-1} to N_i. Here, LN_i^- is updated to the current location of N_i and LN_{i-1}^+ is updated to the current location of N_{i-1} as shown in Figure 7.

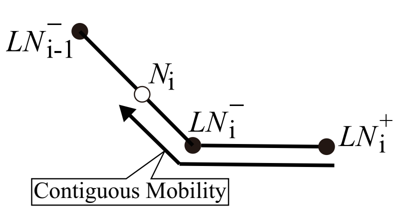

Fig. 6. Contiguous Mobility (Backward) of N_i.

On the other hand, if the next-hop intermediate mobile wireless node N_{i+1} does not reach LN_{i+1}^- when N_i reaches LN_i^+, it is impossible for N_i to send a data message to N_{i+1}. Though N_i waits for N_{i+1} to reach LN_{i+1}^- at LN_i^+ in the conventional methods such as NDBAR, N_i contiguously moves along a line segment $LN_i^+ LN_{i+1}^+$ to LN_{i+1}^+ as shown in Figure 8. This is because the mobility segment of N_{i+1} seems to be relatively longer than the mobility segment of N_i and it is required for the mobility segments of N_{i+1} and N_i to become shorter and longer, respectively. During the contiguous mobility of N_i along the extended mobility segment from LN_i^+ to LN_{i+1}^+, if N_i encounters N_{i+1}, i.e., N_i and N_{i+1} become included in the wireless signal transmission ranges each other, both N_i and N_{i+1} stop and a data message is forwarded from N_i to N_{i+1}. Here, LN_i^- is updated to the current location of N_i and LN_{i-1}^+ is updated to the current location of N_{i-1} as shown in Figure 9.

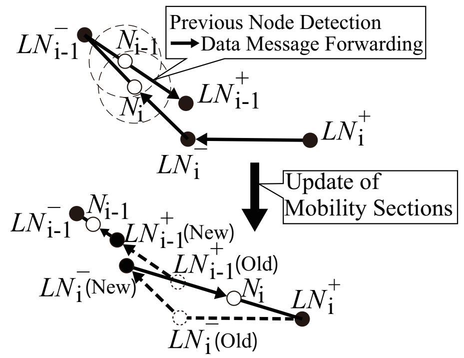

Fig. 7. Contiguous Mobility (Backward) and Updating of Mobility Section of N_i.

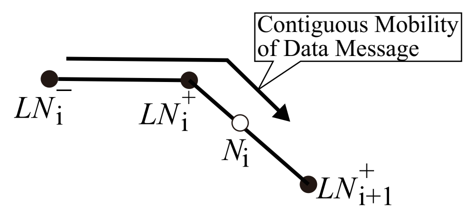

Fig. 8. Contiguous Mobility (Forward) of N_i.

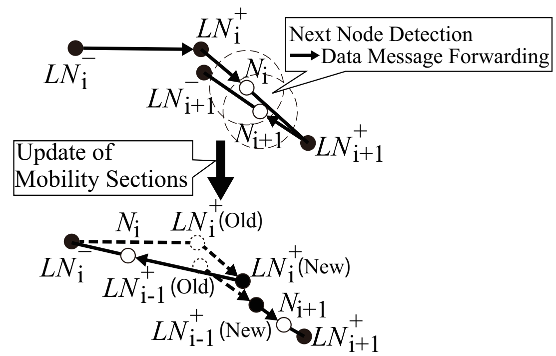

Fig. 9. Contiguous Mobility (Forward) and Updating of Mobility Section of N_i.

The proposed contiguous mobility of N_i is limited only one extended mobility segment $LN_i^- LN_{i-1}^-$ or $LN_i^+ LN_{i+1}^+$.

Thus, if N_i reaches LN^-_{i-1} or LN^+_{i+1} without encountering N_{i-1} or N_{i+1}, N_i waits for N_{i-1} or N_{i+1} to become its neighbor wireless node, i.e., to be included in its wireless signal transmission range for forwarding a data message as shown in Figures 10 and 11, respectively.

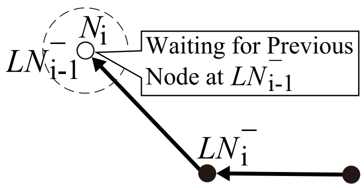

Fig. 10. Termination of Contiguous Mobility (Backward) and Waiting for Previous Node.

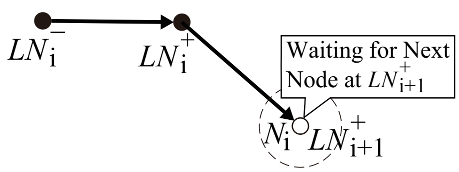

Fig. 11. Termination of Contiguous Mobility (Forward) and Waiting for Next Node.

In order to realize such modification of mobility segments of intermediate mobile wireless nodes, it is required for N_i to get the most current LN^-_{i-1} and LN^+_{i+1} updated by N_{i-1} and N_{i+1}, respectively. In the initial route detection protocol, LN^-_i is determined by N_i at the time when N_i receives an $Rreq$ control message from N_{i-1} before N_i sends an $Rreq$ control message to N_{i+1}. Thus, it is possible for N_{i+1} to get LN^-_i by piggybacking LN^-_i to an $Rreq$ control message forwarded from N_i to N_{i+1}. On the other hand, LN^+_i is determined by N_i at the time when N_i sends an $Rreq$ control message to N_{i+1} before N_i sends an $Rrep$ control message to N_{i-1}. Thus, it is possible for N_{i-1} to get LN^+_i by piggybacking LN^+_i to an $Rrep$ control message forwarded from N_i to N_{i-1}. In this way, N_i gets the far ends LN^-_{i-1} and LN^+_{i+1} of the mobility segments of its previous-hop N_{i-1} and next-hop N_{i+1} intermediate nodes in transmissions of $Rreq$ and $Rrep$ control messages in the initial route detection.

In data message transmissions, the two ends of the mobility segments of each intermediate mobile wireless node N_i is updated each time when N_i receives a data message from its previous-hop node N_{i-1} and sends a data message to its next-hop node N_{i+1}. That is, LN^-_i is updated by N_i when it receives a data message from N_{i-1} to its current location and is informed N_{i+1} when the data message is forwarded to N_{i+1}. Thus, it is possible for N_i to inform N_{i+1} of LN^-_i by piggybacking it to the data message. On the other hand, LN^+_i is updated by N_i when it sends a data message to N_{i+1} to its current location and is informed N_{i-1} when the next data message is forwarded from N_{i-1}. Thus, it is possible for N_i to inform N_{i-1} of LN^+_i by piggybacking it to the Ack control message for response to the data message. Therefore, LN^-_{i-1} and LN^+_i are exchanged each time a data message is forwarded from N_{i-1} to N_i and LN^-_i and LN^+_{i+1} are exchanged each time a data message is forwarded from N_i to N_{i+1}.

By applying the proposed route modification method, the lengths of the mobility segments is adjusted locally to be more equal between the successive intermediate mobile wireless nodes. In addition, sumation of the lengths of the mobility segments are locally reduced since $|LN^-_i(\mathrm{new})LN^+_i| < |LN^-_i(\mathrm{new})LN^-_i(\mathrm{old})| + |LN^-_i(\mathrm{old})LN^+_i|$ due to the triangle inequality and $|LN^-_{i-1}LN^+_{i-1}(\mathrm{new})| < |LN^-_{i-1}LN^+_{i+1}(\mathrm{old})|$ are satisfied. Therefore, the wireless multihop transmission route becomes to resemble a line segment N^sN^d as a sequence of data messages are transmitted along the route.

3.3 Avoidance of Passing Without Forwarding

The two ends LN^-_i and LN^+_i of a line segment which is the mobility segment of an intermediate mobile wireless node N_i are modified when N_i is a neighbor node of N_{i-1} and N_{i+} when a data message is forwarded. The location information of these ends are used for extending mobility segments of N_{i+1} and N_{i-1}, respectively. However, the updated location information is notified to these previous- and next-hop intermediate node when these nodes become neighbor. That is, these neighbor nodes are notified later after the time when they are updated so that it is possible for N_{i-1} and N_i to have different value for LN^-_{i-1} and for N_i and N_{i+1} to have different value for LN^+_{i+1}, i.e., N_i gets only delayed information of the location information of these ends. Thus, due to the unsynchronized update of the location information, it is possible for N_i moving along its updated mobility segment $LN^-_i(\mathrm{new})LN^+_i$ and N_{i+1} moving along the extended mobility segment $LN^-_{i+1}LN^-_i(\mathrm{old})$ to pass each other without being neighbor and forwarding a data message carried by N_i as shown in Figure 12. In order for avoidance of such passing, difference between $LN^-_i(\mathrm{old})$ and $LN^-_i(\mathrm{new})$ is restricted. The necessary and sufficient condition for avoidance of passing each other without forwarding a data message from N_i to N_{i+1} is to assure the time instance when the distance between N_i and N_{i+1} is less than the wireless signal transmission range R during the mobility of N_i along $LN^-_i(\mathrm{new})LN^+_i$ and N_{i+1} along the extended mobility segment $LN^-_{i+1}LN^-_i(\mathrm{old})$.

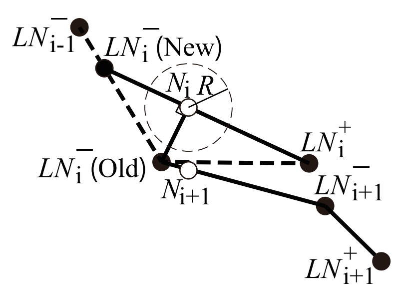

Fig. 12. Pass Each Other without Neighboring of N_i and N_{i+1}.

[Passing Avoidance Condition]

The necessary and sufficient condition for avoidance of passing each other without forwarding a data message from N_i to N_{i+1} is that the distance between $LN_i^-(\mathrm{old})$ and the line segment $LN_i^-(\mathrm{new})LN_i^+$ is less than the wireless signal transmission range R. □

In order for satisfying the condition, the mobility distance of N_i along its extended mobility segment $LN_i^- LN_{i-1}^-$ is restricted. Suppose H as a point on a line segment $LN_i^-(\mathrm{new})LN_i^+$ where $LN_i^-(\mathrm{old})H \perp LN_i^-(\mathrm{new})LN_i^+$. Since $|LN_i^-(\mathrm{old})H|$ monotonically increases according to $|LN_i^- N_i|$ which is the mobility distance of N_i along the extended mobility segment $LN^-iLN_{i-1}^-$, the following is the necessary and sufficient condition in order to assure $|LN_i^-(\mathrm{old})H| < R$.

[Restriction on Node Mobility for Passing Avoidance]
$LR(R\cos\theta + (L^2 - R^2)^{1/2}\sin\theta)/(R^2 - L^2\sin^2\theta)$ where $L := |LN_i^-(\mathrm{old})LN_i^+|$ and $\theta := \angle LN_i^+ LN_i^-(\mathrm{old})LN_{i-1}^-$. □

3.4 Protocols

The followings are descriptions of the proposed initial route detection protocol and the proposed data message transmission protocol with route modification.

[Initial Route Detection Protocol]

(Source Stationary Node N^s)

1) $N^s = N_0$ sends a route request control message *Rreq* to which its current location LN_0^- and the location LN^d of the destination node N^d of a sequence of data messages are piggybacked to its neighbor mobile wireless node N_1 nearest to N^d. N_1 is the next-hop mobile wireless node of N_0 for data messages destined to N^d which is registered in a routing table of N_0.
2) N^s receives a route reply control message *Rrep* from N_1.N^s gets LN_1^+ piggybacked to the *Rrep* control message.

(Intermediate Mobile Node N_i)

1) N_i receives an *Rreq* control message from N_{i-1}. N_i gets LN_{i-1}^- and LN^d piggybacked to the *Rreq* control message. Here, LN_i^- is the current location of N_i.
2) While there are no neighbor wireless nodes N satisfying $|NN^d| < |N_i N^d|$, N_i moves along a line segment $LN_i^- N^d$ to N^d.
3) On detection of a neighbor wireless node N satisfying $|NN^d| < |N_i N^d|$, N_i stops at once. N_i sends the *Rreq* control message to which LN_i^- and LN^d are piggybacked to N. N is the next-hop mobile wireless node N_{i+1} of N_i for data messages destined to N^d which is registered in a routing table of N_i. Here, LN_i^+ is the current location of N_i.
4) N_i receives an *Rrep* control message from N_{i+1}. N_i gets LN_{i+1}^+ piggybacked to the *Rrep* control message.
5) If $LN_i^- \neq LN_i^+$, N_i moves along a line segment $LN_i^+ LN_i^-$ to LN_i^-.
6) N_i stops at LN_i^- and sends an *Rrep* control message to N_{i-1}.

(Destination Stationary Node N^d)

1) $N^d = N_n$ receives an *Rreq* control message from N_{n-1}. N^d gets LN_{n-1}^- piggybacked to the *Rreq* control message.
2) N^d sends an *Rrep* control message destined to N^s to N_{n-1} to which the location of N^d as LN_n^+ is piggybacked.

[Data Message Transmission Protocol with Route Modification]

(Source Stationary Node N^s)

1) $N^s = N_0$ waits for its next-hop mobile wireless node N_1 to be its neighbor.
2) N^s sends a data message to which its current location is piggybacked as LN_0^- to N_1.
3) N^s receives an acknowledgement control message *Ack* from N_1.
4) Go back to (1).

(Intermediate Mobile Node N_i)

1) When N_i encounters its previous-hop intermediate node N_{i-1}, i.e., N_i becomes a neighbor node of N_{i-1}, N_i receives a data message from N_{i-1}. N_i updates its keeping LN_{i-1}^- by that piggybacked to the received data message. In addition, N_i updates LN_i^- by its current location.
2) N_i sends back an *Ack* control message to N_{i-1} to which LN_i^+ is piggybacked.
3) Until N_i encounters N_{i+1}, i.e., N_i becomes a neighbor node of N_{i+1}, N_i carries the data message from N_{i-1} along a line segment $LN_i^- LN_i^+$ that is its mobility segment to LN_i^+. If N_i does not encounter N_{i+1} before reaching LN_i^+, N_i contiguously carries the data message along a line segment $LN_i^+ LN_i^+$ as its extended mobility segment. If N_i reaches LN_{i+1}^+ without encountering N_{i+1}, N_i waits for encountering N_{i+1} at LN_{i+1}^+.
4) On encountering N_{i+1}, N_i stops at once and sends the carrying data message to N_{i+1} to which LN_i^- is piggybacked. LN_i^+ is updated to its current location.
5) N_i receives an *Ack* control message from N_{i-1}. N_i updates LN^+i+1 to that piggybacked to the *Ack* control message. In addition, N_i updates LN_i^+ to its current location.
6) Until N_i encounters N_{i-1}, i.e., N_i becomes a neighbor node of N_{i-1}, N_i moves along a line segment $LN_i^+ LN_i^-$ that is its mobility segment to LN_i^-. If N_i does not encounter N_{i-1} before reaching LN_i^-, N_i contiguously moves along a line segment $LN_i^- LN_{i-1}^-$ as its extended mobility segment. If N_i reaches LN_{i-1}^- without encountering N_{i-1}, N_i waits for encountering N_{i-1} at LN_{i-1}^-.
7) Go back to (1).

(Destination Stationary Node N^d)

1) $N^d = N_n$ waits for encountering N_{n-1}.
2) N^d receives a data message from N_{n-1}.
3) N^d sends back an *Ack* control message to which its current location is piggybacked as LN_n^+.
4) Go back to (1) □

4. Conclusion

This paper has proposed the initial route detection and gradual route modification methods by multihop data message transmissions realized by combination of carrying and forwarding by each intermediate mobile wireless node. In route modification, each intermediate mobile wireless node updates its mobility segment locally by cooperation with its previous- and next-hop node. This results in even sharing of mobility overhead among all the intermediate mobile wireless nodes and in shorter end-to-end transmission delay by reduction of total length of the transmission route and by reduction of synchronization overhead between the successive intermediate nodes. Finally, this paper has proposed the method to avoid situations where successive intermediate wireless nodes pass each other without forwarding a data message. By introduction of the limitation to the node mobility along the extended mobility segment, though the critical problem is solved, it is expected to be required longer time for the multihop transmission route to converge. This effect will be evaluated in simulation experiments.

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Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.