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Group-Based Ad-hoc Routing in High Density Environments

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In an ad-hoc routing protocol based on flooding of a route request control message such as AODV and DSR, all reachable mobile computers are required to broadcast the message. Especially in a high density ad-hoc network, a broadcast storm causes higher battery consumption and lower connectivity. This paper proposes G-AODV routing protocol which is a group-based extension of AODV where only mobile computers belonging to the same group as a source one are engaged in flooding of a route request control message. Due to the group based flooding of the message, connectivity gets lower and detected transmission routes get longer. For the former, this paper proposed dynamically determined equivalence between two groups based on density of neighbor mobile computers is introduced. In addition, in order to reduce the length of a message transmission route detected by G-AODV, PCMTAG (Passive Contribution for Message Transmission in Another Group) is also proposed. Here, mobile computers in another group are engaged in message transmission only when it provides a shorter message transmission route detected without or with limited control message exchanges.

高密度分布環境におけるノードグループを用いたアドホックルーティング

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AODVやDSRといった経路探索要求メッセージのフラッディングに用いたアドホックルーティングプロトコルでは、送信元移動コンピュータから到達可能なすべての移動コンピュータがこのメッセージのブロードキャストを行なう。特に移動コンピュータの分布密度が高いアドホックネットワークでは、ブロードキャストストームが問題となり、バッテリ消費の増大と制御メッセージの衝突による接続性の低下を引き起こす。本論文では、送信元移動コンピュータと同一のグループに属する移動コンピュータのみが経路探索要求メッセージのフラッディングに参加する手法を提案し、AODVの拡張プロトコルとしてG-AODVを提案する。ただし、G-AODVではすべての移動コンピュータがフラッディングに参加する場合と比べて経路の検出率が低下するすなわち接続性が低下する問題や検出される経路が長くなる問題がある。そこで、受信した経路探索要求メッセージのブロードキャストを行なうか否かの判定を移動コンピュータの分布密度に応じて動的に変更する手法を導入する。さらに、他のグループに属する移動コンピュータが短縮経路を提供することが可能であることを制御メッセージの交換なしに検出して1ホップからなる短縮経路を提供する、あるいはごく限られた制御メッセージの交換のみによって検出して複数ホップからなる短縮経路を提供する場合にのみ配送経路に加わるPCMTAG(他グループのメッセージ配送への消極的貢献手法)を提案する。

1 Introduction

An ad-hoc network consists of only mobile computers, i.e. no base stations, which communicate with each other by using wireless signal transmission. Since each mobile computer works with only limited battery capacity, transmission power of sending wireless signal is also limited and it is impossible for a mobile computer to communicate all the other mobile computers directly. Hence, multihop message transmission is introduced and many kinds of ad-hoc routing protocols have been researched and developed. Here, all mobile computers are assumed to equally contribute to detect a message transmission route. For example, in a flooding-base ad-hoc routing protocols such as DSR [2], AODV [7], TORA [6] and LBSR [9], on receipt of a flooded copy of an *Rreq* (route request) control message, every mobile computer also broadcasts a copy of the received *Rreq* message in order to detect a message transmission route. However, in order to detect the message transmission route, it is required not to broadcast the *Rreq* message by all mobile computers but to reach the flooded *Rreq* message to the destination mobile computer. Hence, especially in an ad-hoc network with high density of mobile computers, only part of mobile computers are required to broadcast an *Rreq* message to reach the destination mobile computer. In this case, though enough high reachability to the destination is guaranteed, a detected multihop message transmission route tends to be longer than one detected by pure flooding of an *Rreq* message. This paper also proposes two methods to shorten a detected multihop transmission route with no and few additional control messages.

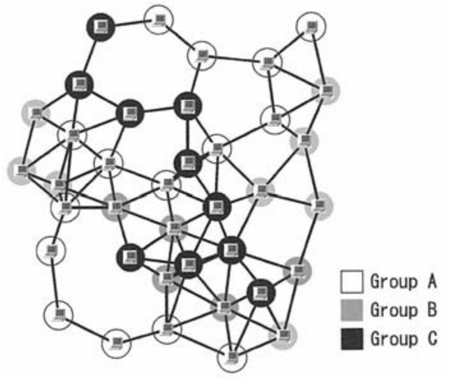

Figure 1: Multi-Group Multihop Network.

2 Related Works

In a mobile wireless multihop network, a mobile computer does not achieve location information of all the other mobile computers since it requires high communication and synchronization overhead. Hence, routing protocols are designed under an assumption that each mobile computer does not achieve location information of any other mobile computers or achieves only limited information. For example in the latter, a source mobile computer achieves location information of a destination one in LAR (Location Aware Routing) [4], FACE [8] and GPSR (Greedy Perimeter Stateless Routing) [3] and each mobile computer achieves location information of its 1-hop neighbor ones in FACE and GPSR and achieves connectivity information with its 1-hop and 2-hop neighbor mobile computers in OLSR (Optimized Link State Routing) [1].

On the other hand, in the former, since a source mobile computer maintains no location information of a destination one, in order to detect a message transmission route between them, a flooding of copies of a control message is applied. A flooding of a control message is realized by successive broadcasts in all multihop-connected mobile computers from a source one. For example, in DSR [2], AODV [7], TORA [6], LBSR [9] and so on, a source mobile computer broadcasts a route request control message *Rreq* to all mobile computers included in its wireless signal transmission range. On receipt of the first *Rreq* message, each mobile computer also broadcasts a copy of the received *Rreq* message to all the mobile computers included in its wireless signal transmission range. By using the successive broadcasts of copies of an *Rreq* message, all mobile computers reachable from the source mobile computer in a wireless multihop transmission receives the *Rreq* message. That is, if the destination mobile computer is reachable from the source mobile computer, at least one copy of the *Rreq* message is received by the destination one. A transmission route of the copy of the *Rreq* message received by the destination is available for the source mobile computer as an application message transmission route, i.e. a required message transmission route is detected. Since each mobile computer does not achieve any location information of a source and a destination mobile computers, it always broadcasts a copy of a received *Rreq* message even though it is located far away from the finally detected message transmission route. In addition, since each mobile computer broadcasts copies of a received *Rreq* message distributedly, a mobile computer cannot detect that one of the copies of the *Rreq* message is received by a destination mobile computer. Hence, even though one of the copies of the *Rreq* message has already been received by a destination mobile computer, other mobile computers which receives the first copy of the *Rreq* message broadcasts its copies which is not efficient for detection of message transmission route. Therefore, a flooding-base routing protocol in a wireless multihop network requires very high communication overhead though a route detection is guaranteed.

In order to reduce the overhead, i.e. a number of mobile computers which broadcast a copy of an *Rreq* messages is reduced, each mobile computer sets certain conditions and broadcasts a copy of an *Rreq* message only if the conditions are satisfied. For example, in LAR, only mobile computers included in a rectangle whose one of the diagonal lines ends at a source and a destination mobile computers broadcast a copy of an *Rreq* message. Though connectivity of the mobile multihop network may get lower, a number of mobile computers required to broadcast a copy of a received *Rreq* messages is reduced. On the other hand, in an ad-hoc routing protocol proposed in [5], in order to achieve higher end-to-end throughput, only when distance between a mobile computer and a previous hop mobile computer from which the mobile computer receives the first copy of an *Rreq* message is shorter than distance between the previous hop mobile computer and a one more previous hop mobile computer. In this protocol, connectivity of the ad-hoc network also gets lower, a number of mobile computers required to broadcast a copy of a received *Rreq* messages is reduced. In one extension of LBSR routing protocol supporting ad-hoc networks with uni-directional wireless communication links, on detection of a message transmission route from a source mobile computer to a destination one, a control message for suspension of transmission of control messages is transmitted along a looped route containing both the source and destination mobile computers.

3 Group-Base Routing

It is required for mobile computers to reduce battery consumption for achieving longer life-time. Since a broadcast of a copy of a received *Rreq* message in a certain mobile computer is not always useful for detection of a message transmission route as discussed above, a certain criteria for the broadcast is required. One possible strategy for reduction of consumption of battery capacity is that each mobile computer belongs to one of groups of mobile computers and a mobile computer broadcasts a copy of a received *Rreq* message only when it receives the *Rreq* from a mobile computer included in the same group according to modulo N equivalence where N is determined by density of mobile computers. Otherwise, one possible strategy for reduction of consumption of battery capacity is that a mobile computer broadcasts a copy of a received *Rreq* message only when it receives the *Rreq* from a mobile computer included in the same group. Otherwise,

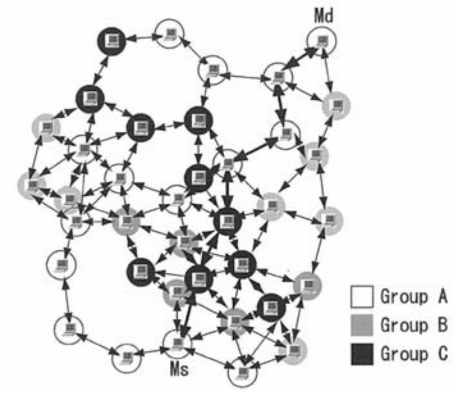

Figure 2: Full-Flooding Protocol.

i.e. if a mobile computer receives an *Rreq* message from a mobile computer which belongs to a different group, it does not broadcast the *Rreq* message for reduction of its battery consumption. Thus, this paper proposes the following group-base routing protocol G-AODV which is designed based on AODV [7]. Here, each mobile computer belongs to at least one group of mobile computers.

[G-AODV (naive)]

1) A source mobile computer broadcasts a route request control message *Rreq* to all mobile computers included in its wireless signal transmission range. The *Rreq* message carries an addresses of a source mobile computer *Rreq.src* and a destination one *Rreq.dst*, a group identifier *Rreq.gid* to which the source mobile computer belongs and a route detection identifier *Rreq.did* assigned by a source mobile computer.
2) On receipt of an *Rreq* message, an intermediate mobile computer, i.e. its address is different from *Rreq.src* and *Rreq.dst*, broadcasts a copy of the received *Rreq* message to all mobile computers included in its wireless signal transmission range if it belongs to a group whose identifier is *Rreq.gid* and it has not yet received an *Rreq* message carrying the same route detection identifier as *Rreq.did*. Otherwise, it only discards the received *Rreq* message.
3) On receipt of an *Rreq* message, a destination mobile computer, i.e. its address is the same as *Rreq.dst*, sends back a route detection reply message *Rrep* to the mobile computer which broadcasts the received copy of the *Rreq* message. The *Rrep* message carries *Rreq.did* as a route detection identifier *Rrep.did*.
4) On receipt of an *Rrep* message, the intermediate mobile computer registers a mobile computer which sends the *Rrep* message as a next hop mobile computer for transmission of application messages destined to the destination mobile computer in its routing table. Then, it forwards the received *Rrep* message to a mobile computer which broadcasts the first received copy of the *Rreq* message.
5) On receipt of an *Rrep* message, the source mobile computer registers a mobile computer which sends the *Rrep* message as a next hop mobile computer for transmission of application messages destined to the destination mobile computer in its routing table. Now, it starts transmission of application messages according to its updated routing table. □

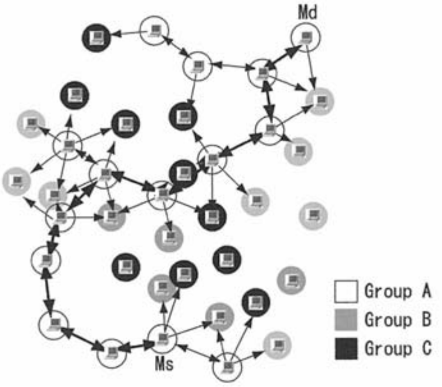

Figure 3: Partial-Flooding Routing Protocol.

By using this protocol, the number of mobile computers which broadcast received *Rreq* messages is reduced. However, a hop count of a detected message transmission route is increased since the route is composed of only mobile computers belonging to the same group as the source mobile computer. For example in Figures 2 and 3, though by using full-flooding AODV, a 6-hop message transmission route from M_s to M_d is detected, by using partial-flooding in G-AODV (naive), a 10-hop one is detected.

In order to solve this problem, this paper proposes a method for a passive contribution for message transmission in another group (PCMTAG). Same as the above naive protocol, each mobile computer does not engage in a flooding of an *Rreq* message in another group of mobile computers. In the naive protocol, an *Rrep* message is transmitted along a detected message transmission route from a destination mobile computer to a source one. An *Rrep* message is unicasted by a destination and intermediate mobile computers to their previous hop mobile computers along the detected message transmission route. However, the wireless signal transmitting the unicasted *Rrep* message is also broadcasted to all mobile computers included in a wireless signal transmission range of a sender mobile computer. Hence, other mobile computers within the range overhear the *Rrep* message even if the mobile computers belong to a different group from mobile computers along the message transmission route. If a mobile computer overhears two *Rrep* messages carrying the same route detection identifier from two different mobile computers which are apart more than 2 hops, it is possible for the mobile computer to provide a shorter message transmission route by being included in it and forwarding application messages.

For providing a shorter message transmission route, the mobile computer which overhears multiple *Rrep* messages transmitted along a message transmission route in another group and the sender mobile computers are apart more than 2 hops, the mobile computer sends a shorter route proposal message *Rprop* to the most upstream neighbor mobile computer in the route as shown in Figures 4 and 5. On receipt of the *Rprop* message, the most upstream neighbor mobile computer updates its next hop mobile computer to the sender mobile computer of the *Rprop* message and sends back an acknowledgment message *Rack* to it (Figure 6). On receipt of the *Rack* message, the sender mobile computer of *Rprop* updates its next hop mobile computer to the most downstream neighbor mobile computer in the route. The above method for achieving shorter message transmission route by including one mobile computer in another group does not require much additional overhead. That is, if no candidates of shorter message transmission routes are detected by overhearing *Rrep* messages, no additional control messages are transmitted by mobile computers included in different group of mobile computers from a group to which mobile computers along a message transmission route belong. The additional communication overhead is two control messages, *Rprop* and *Rack*, which are required only when shorter route is achieved.

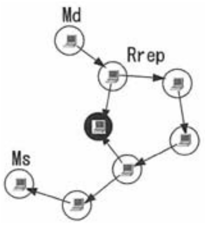

Figure 4: *Rrep* Overhearing in 1-hop PCMTAG.

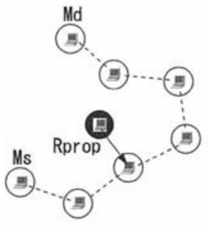

Figure 5: Route Modification Proposal in 1-hop PCMTAG.

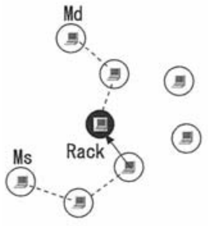

Figure 6: Route Modification in 1-hop PCMTAG.

However, message transmission routes are tends to be still long since no successive mobile computers are included in a message transmission route in different group. Thus, in the following method, not only 1-hop but also multiple-hops mobile computers in different groups are allowed to engage in provision of a shorter message transmission route. Here, each mobile computer which overhears *Rrep* messages broadcasts an *Rinfo* message to which information of its most upstream and downstream neighbor mobile computers in the route is piggybacked. In case that another mobile computer belonging to a different group of mobile computers from ones in the message transmission route receives multiple *Rrep* messages or both *Rrep* and *Rinfo* messages, it sends an *Rprop* message to one of the senders of the received *Rrep* messages if it is the most upstream mobile computer among the senders of the received *Rrep* messages and the mobile computers whose information is piggybacked to the received *Rinfo* messages. On receipt of the *Rprop* message, the receiver mobile computer updates its next hop mobile computer for the destination one to the sender mobile computer of the *Rprop* message and sends back an *Rack* message to the sender of the received *Rprop* message. On receipt of the *Rack* message, the mobile computer in a different group of mobile computers from ones in the message transmission route registers the most downstream neighbor mobile computer in the route as its next hop one if it is the most downstream mobile computer among the senders of the received *Rrep* messages and the mobile computers whose information is piggybacked to the received *Rinfo* message. Otherwise, i.e. a mobile computer whose information is piggyed back to one of the received *Rinfo* messages is the most downstream one, it registers the sender of the *Rinfo* message as its next hop mobile computer and sends an *Rack* message to it. Now, a shorter message transmission route is configured with help of multiple mobile computers in a different group of mobile computers.

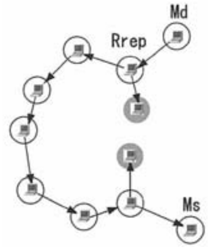

Figure 7: *Rrep* Overhearing in 2-hop PCMTAG.

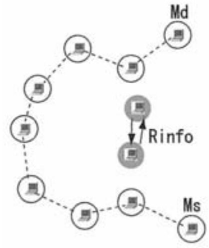

Figure 8: Shorter Route Detection in 2-hop PCMTAG.

[G-AODV with PCMTAG]

(Route Detection)

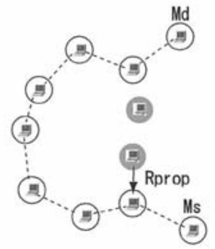

Figure 9: Route Modification Proposal in 2-hop PCMTAG.

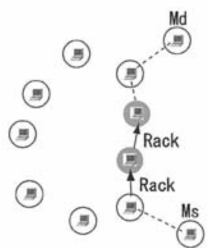

Figure 10: Route Modification in 2-hop PCMTAG.

1) A source mobile computer broadcasts a route request control message *Rreq* to all mobile computers included in its wireless signal transmission range. The *Rreq* message carries an addresses of a source mobile computer *Rreq.src* and a destination one *Rreq.dst*, a hop count from the source mobile computer *Rreq.hops* initially 1, a group identifier *Rreq.gid* to which the source mobile computer belongs and a route detection identifier *Rreq.did* assigned by a source mobile computer.
2) On receipt of an *Rreq* message, an intermediate mobile computer, i.e. its address is different from *Rreq.src* and *Rreq.dst*, registers a tuple $\langle did, prev \rangle$ where $did := Rreq.did$ and *prev* is an address of the sender of the received *Rreq* message into a routing information buffer, increments *Rreq.hops* by one and broadcasts a copy of the received *Rreq* message to all mobile computers included in its wireless signal transmission range if it belongs to a group whose identifier is *Rreq.gid* and it has not yet received an *Rreq* message carrying the same route detection identifier as *Rreq.did*. Otherwise, it only discards the received *Rreq* message.
3) On receipt of an *Rreq* message, a destination mobile computer, i.e. its address is the same as *Rreq.dst*, registers a tuple $\langle did, prev \rangle$ where $did := Rreq.did$ and *prev* is an address of the sender of the received *Rreq* message into a routing information buffer and sends back a route detection reply message *Rrep* to the neighbor mobile computer whose address is *prev*. The *Rrep* message carries *Rreq.did* and *Rreq.hops* as *Rrep.did* and *Rrep.hops*, respectively.
4) On receipt of an *Rrep* message, an intermediate mobile computer registers a sender mobile computer of the *Rrep* message as a next hop mobile computer for transmission of application messages to the destination one in its routing table. Then, it forwards the received *Rrep* message after decrementing *Rrep.hops* by one to a neighbor mobile computer whose address is *prev* stored in its routing information buffer with *Rrep.did*.
5) On receipt of an *Rrep* message, the source mobile computer registers a sender mobile computer of the *Rrep* message as a next hop mobile computer for transmission of application messages to the destination one in its routing table. Then, it forwards the received *Rrep* message after decrementing *Rrep.hops* by one to a dummy mobile computer, e.g. a destination address is a zero address. Now, it starts transmission of application messages according to its updated routing table.

(Route Shorting by PCMTAG)

1) If a mobile computer overhears an *Rrep* message to another mobile computer, even though its group identifier is different from *Rrep.gid*, it sets a timer for overhearing all possible *Rrep* messages sent by neighbor mobile computers along a detected message transmission route with a route detection identifier *Rrep.did*.
2) On expiration of the timer, a mobile computer broadcasts a shorter route detection information message *Rinfo* carrying *Rrep.did* as *Rinfo.did* and hop-counts included in overheard *Rrep* messages sent from the most upstream and downstream neighbor mobile computers along a detected message transmission route as *Rinfo.uphops* and *Rinfo.downhops*.
3) On receipt of an *Rinfo* message, a mobile computer which is not included in a detected message transmission route and has overheard an *Rrep* message sets a timer for receiving all possible *Rinfo* messages.
4) On expiration of the timer, if a mobile computer receives multiple *Rrep* messages or both *Rrep* and *Rinfo* messages, it sends an *Rprop* message to the most upstream sender mobile computer of the received *Rrep* message where $Rprop.did := Rrep.did$.
    - The minimum hop-count is *Rrep.hops* of the *Rrep* message among all hop-counts carried by received *Rrep* messages as *Rrep.hops* and by received *Rinfo* messages as *Rinfo.uphops*.
    - If the maximum hop-count is *Rrep.hops* of the *Rrep* message among all hop-counts carried by received *Rrep* messages as *Rrep.hops* and by received *Rinfo* messages as *Rinfo.downhops*, difference between the maximum and the minimum hop-counts are greater than 2.
    - If the maximum hop-count is *Rinfo.downhops* of the *Rinfo* message among all hop-counts carried by received *Rrep* messages as *Rrep.hops* and by received *Rinfo* messages as *Rinfo.downhops*, difference between the maximum and the minimum hop-counts are greater than 3.
5) On receipt of the *Rprop* message, a mobile computer along a message transmission route updates its next hop mobile computer to the sender mobile computer of the received *Rprop* message. Then, it sends back a shorter route acknowledgment message *Rack* to the sender of the *Rprop* message where $Rack.did := Rprop.did$.
6) On receipt of the *Rack* message, it updates its next hop mobile computer to the sender mobile computer of the received *Rrep* or *Rinfo* message carrying the

maximum hop-count among all hop-counts carried by received *Rrep* messages as *Rrep.hops* and by received *Rinfo* messages as *Rinfo.downhops*. If the updated next hop mobile computer is a sender of an *Rinfo* message, it sends an *Rack* message to the next hop mobile computer where *Rack.did* := *Rprop.did*. □

4 Evaluation

In order to reduce the communication overhead for flooding of an *Rreq* control message, it is required to increase a number of groups of mobile computers. However, too many groups causes lower reachability and longer transmission route detection. The latter is improved by the route shortening method proposed in the previous section. Hence, the former is critical to keep connectivity enough high. This section evaluate connectivity of pairs of mobile computers, i.e. source and destination mobile computers, in ad-hoc networks with various density of mobile computers. Here, multiple mobile computers are distributed in 400m × 400m – 1,200m × 1,200m field randomly according to a unique distribution probability function and source and destination mobile computers are selected also randomly. A message transmission route from the source mobile computer to the destination one is searched by using AODV [7]. Connectivity, i.e. ratio of successful route detection, is evaluated with various density of mobile computers. Figure 11 shows results of simulation experiments. The x-axis represents average number of mobile computers included in a wireless signal transmission range of a mobile computer and the y-axis represents connectivity. Almost independently of scale of ad-hoc networks, if each mobile computer has 8 or more neighbor mobile computers, achieved connectivity is higher than 98%.

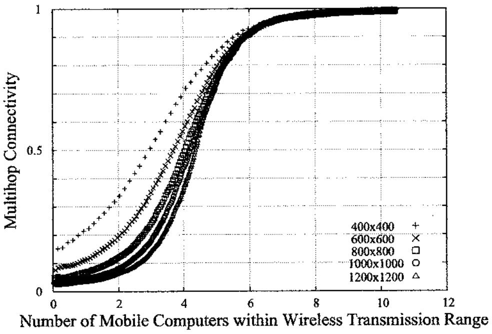

Figure 11: Multihop Connectivity vs Density of Mobile Computers.

Thus, the algorithm for judgement of same mobile computer group, i.e. equivalence of mobile computer groups, is as follows. Here, a number of mobile computer group is assumed 16 [1]. A group number ($0 \leq g < 16$) is assigned to each mobile computer statically. On the other hand, group number equivalence is dynamically determined according to density of mobile computers. Suppose that a mobile computer M has N neighbor mobile computers and its assigned group number is g_M. If a group number assigned to a source mobile computer M_s is g_{M_s}, the equivalent condition is as follows:

$$g_M \equiv g_{M_s} \pmod{\lceil N/8 \rceil}$$

5 Conclusion

This paper has proposed a routing protocol for mobile ad-hoc networks which consist of multiple groups of mobile computers. Each mobile computer only engaged in a flooding of a route request message for route detection between mobile computers in the same group. In order to keep connectivity enough high, criteria for equivalence of mobile computer groups is dynamically modified based on density of mobile computers. In addition, in order to achieve a shorter message transmission route, mobile computers in a different group contributes only when they are 1-hop neighbor mobile computers of the detected message transmission route. Our simulation evaluation shows that each mobile computer is required to have 8 or more neighbor mobile computers to keep connectivity higher than 98%, i.e. to detect multihop message transmission route with enough high probability. In future work, we evaluate the effect of our route shortening mechanism in simulation experiments.

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[1] In an ITS network, protocols are required to be designed for supporting about 150 neighbor mobile computers of each mobile computer. Since our simulation results show that connectivity is guaranteed with 8 neighbor mobile computers, 16 mobile computer groups are assumed. (16 × 8=128)