G-AODV: Group-Based Extension of AODV Routing Protocol

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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 mobile computers are required to broadcast the message. However, it causes consumption of battery capacity and lower connectivity of the network. Some ad-hoc networks consist of multiple groups of mobile computers. This paper proposes PCMTAG (passive contribution for message transmission in another group) in which each mobile computer only broadcasts a received route request message only when a source mobile computer belongs to the same group. For solving the longer route detection problem, a mobile computer engages to application message transmission only if it is a neighbor of multiple intermediate mobile computers along a message transmission route and is possible to provide a shorter one. Based on PCMTAG, we design G-AODV, group-based extended AODV, routing protocol.

G-AODV: 移動コンピュータグループに基づく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を用いたアドホックルーティングプロトコルでは、すべての移動コンピュータが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うこととしている。しかし、これによって各移動コンピュータの限られた電力が消費され、ネットワークの接続性が低下する。ここで、ある種のアドホックネットワークでは、異なるグループに属する移動コンピュータ群が地理的に同一の空間に分布している。これに注目し、本論文では 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。ここでは、送信元移動コンピュータが異なるグループに属する場合、経路探索要求メッセージを受信してもブロードキャストを行わないことにより経路探索による電力消費量を削減する。ただし、これによって検出経路長が大きくなる問題が発生する。これを解決するために、他グループに属する移動コンピュータが 1 ホップまたは 2 ホップの経路で検出経路を短縮する手法を提案する。また、AODV に本手法を取り入れた G-AODV ルーティングプロトコルを設計する。

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 a 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, some mobile networks may consists of mobile computers belonging to different groups of mobile computers. For example, mobile computers maintained by different organizations or mobile computers supported by different cellular phone carriers may configure a mobile ad-hoc network. In this case, each mobile computer does not contribute all the route detection processes equally, i.e. actively to route detections for mobile computers in the same group and passively to ones for mobile computers in a different group. This paper proposes an ad-hoc routing protocol for mobile ad-hoc networks consisting of multiple groups of mobile computers.

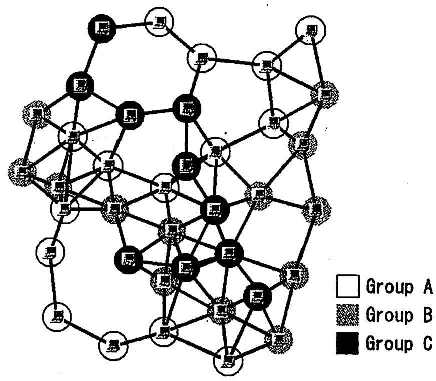

Figure 1: Multi-Group Multihop Network.

2 Related Works

In a mobile wireless mutihop 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 computers 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 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* message 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* message 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* message 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 which are not *Rreq* messages is transmitted along a looped route containing both the source and destination mobile computers.

3 Group-Base Routing

Since a mobile computer works with only limited battery capacity, battery consumption is required to be reduced. 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. If a mobile computer network consists of multiple groups of mobile computers, e.g. each mobile computer belongs to an organization, communication of each mobile computer is supported by a wireless network carrier, and so on, one possible strategy for

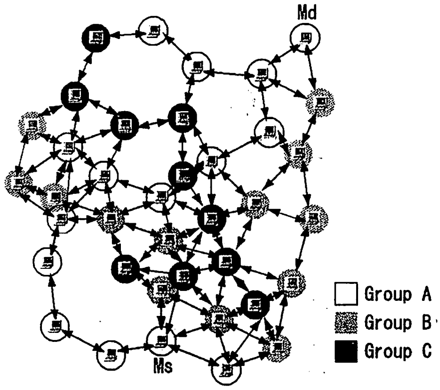

Figure 2: Full-Flooding Protocol.

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, 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 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. □

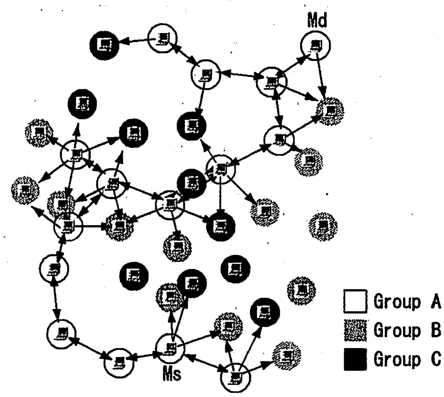

Figure 3: Partial-Flooding Routing Protocol.

By using this protocol, the number of mobile computers which broadcast received *Rreq* message 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 *Ms* to *Md* is detected, by using partial-flooding 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 (PCM-TAG). 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 overhears 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 broadcasts a shorter route proposal message *Rprop*. On receipt the *Rprop* message, the most upstream mobile computer updates its next hop to the mobile computer which broadcasts the *Rprop* message and sends back an acknowledgment message *Rack* to the mobile computer. On receipt the *Rack* message, the mobile computer in a different group from the message transmission route updates its next hop to the most downstream mobile computer from which an *Rrep* message is overhead. 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 only a broadcasted *Rprop* message.

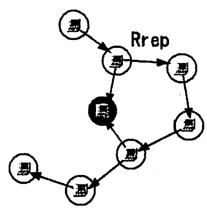

Figure 4: Multiple *Rrep* Overhearing in 1-hop PCMTAG.

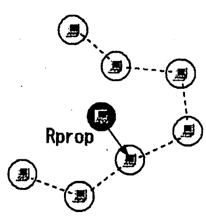

Figure 5: Shortening Proposal in 1-hop PCMTAG.

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, only 1-hop or 2-hop 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 *Rprop* message. If another mobile computer belonging to a different group of mobile computers from the message transmission route receives an *Rprop* message and an *Rrep* message, it sends an *Rprop* message to the most upstream mobile computers among a set of neighbor mobile computers of the sender and the receiver mobile computers of the *Rprop* and which are included in the message transmission route. 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, a mobile computer registers the sender of the received *Rprop* message as a next hop for the destination mobile computer and sends an *Rack* message to the registered next hop mobile computer. Then, on receipt of the *Rack* message, the mobile computer also registers the sender of the overheard *Rrep* message as a next hop mobile computer for the destination one. Now, a shorter message transmission route is configured.

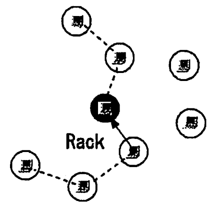

Figure 6: Acceptance of Proposal in 1-hop PCMTAG.

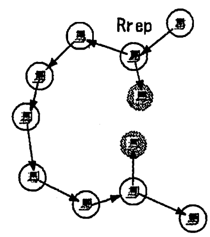

Figure 7: *Rrep* overhearing in 2-hop PCMTAG.

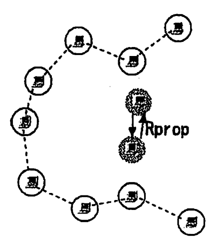

Figure 8: Shortening Route Detection in 2-hop PCMTAG.

[G-AODV with PCMTAG]

(Route Detection)

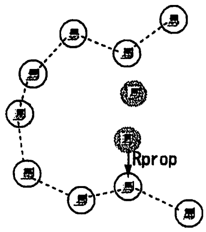

Figure 9: Shortening Proposal in 2-hop PCMTAG.

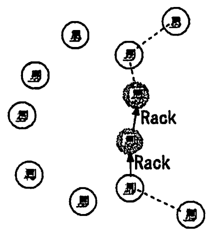

Figure 10: Acceptance of Proposal in 2-hop PCMTAG.

1) A source mobile computer broadcast 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 $\langle did, hops \rangle$ where $did := Rreq.did$ and $hops := Rreq.hops$ 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 does not belong to a group whose identifier is different from *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 $\langle did, hops \rangle$ where $did := Rreq.did$ and $hops := Rreq.hops$ into a routing information buffer and 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* and hops as a route detection identifier *Rrep.did* and *Rrep.hops*, respectively.
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 after modification of *Rrep.hops* to hops in $\langle did, hops \rangle$ stored in a routing information buffer where $did = Rrep.did$ to a mobile computer which broadcasts the 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.

(Route Shorting)

1) If a mobile computer overhears an *Rrep* message and its group identifier is different from *Rrep.did*, it sets a timer for overhearing all possible *Rrep* messages transmitted along a detected message transmission route by the route detection whose identifier is *Rrep.did*.
2) On expiration of the timer, a mobile computer broadcast a shorter route proposal message *Rprop* carrying *Rrep.did* as *Rprop.did* and all *Rrep.hops* carried by all the received *Rrep* messages as *Rprop.hops*.
3) On receipt of the *Rprop* message, a mobile computer which is not included in a detected message transmission route and overhears an *Rrep* message sets a timer for receiving all possible *Rprop* messages.
4) On expiration of the timer, a mobile computer broadcast an *Rprop* message carrying *Rprop.did* and the minimum *Rprop.hops* carried by received *Rprop* messages only when difference between the maximum and the minimum hops carried by received *Rrep* messages and *Rprop* messages and the minimum hops is not included in the received *Rprop* messages.
5) On receipt of the *Rprop* message, if the minimum hop count in *Rprop.hops* equals to hop in $\langle did, hop \rangle$ where $Rprop.did = did$, a mobile computer updates its next hop mobile computer to the sender mobile computer of the received *Rprop* message. Then, it sends back a shorter route reply message *Rack* to the sender of the *Rprop* where $Rack.did := Rprop.did$.
6) On receipt of the *Rprop* message from the mobile computer along the detected message transmission route, a mobile computer registers the sender mobile computer of the received *Rprop* message which carries the maximum *Rprop.hop* as its next hop mobile computer. Then, it sends an *Rack* message to a mobile computer which sends the received *Rprop* message carrying the maximum *Rprop.hops*.
7) On receipt of the *Rprop* message from the mobile computer not included in the detected message transmission route, a mobile computer registers the sender mobile computer of the received *Rrep* message which carries the maximum *Rrep.hop* as its next hop mobile computer.□

4 Evaluation

In a full-flooding ad-hoc routing protocol, all the mobile computers in an ad-hoc network broadcast *Rreq* messages and the mobile computers along the message transmission route unicast *Rrep* messages. On the other hand, in the proposed protocol, only all the reachable mobile computers belonging to the same group of mobile computers as a source and a destination mobile computers broadcast *Rreq* messages and the mobile computers along the message transmission route unicast *Rrep* messages. Though, in addition, all 1-hop neighbor mobile computers along the detected message transmission routes and belonging to different group of mobile computers from the detected message transmission route broadcast *Rprop* messages and *Rack* message are transmitted for 1 or 2 hops in case of successful shorting of the message transmission route. By the reduction of a number of broadcasts of an *Rreq* messages, the total communication overhead is reduced.

This section evaluate on efficient of route shortening under the following simulation assumptions in Table1. The result in Figure11 shows that averagely 2.5 hops shorter routes are achieved by the proposed protocol.

Table 1: Simulation Environment.

Simulation Area	500m×500m
Number of Mobile Computers	100
Number of Mobile Computers in Evaluated Group	10–90
Diameter of Signal Transmission Range	100m

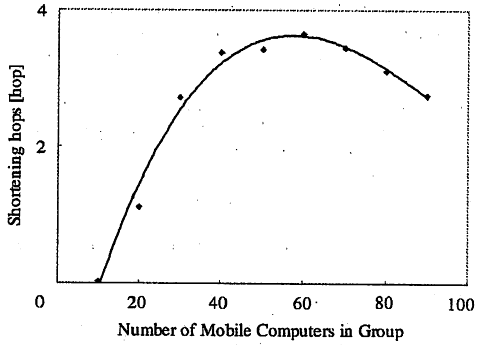

Figure 11: Shortening Hops.

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 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. In a simulation evaluation, the proposed protocol detects message transmission routes with much smaller number of control messages than the conventional protocols such as AODV.

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