A Novel Route Discovery Scheme Equipped with Two Augmented Functions for Ad Hoc Networks

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Abstract

"The delay and control overhead during route discovery for destinations outside ad hoc networks are major obstacle to achieving scalability in the Internet. To solve this issue, we propose a novel route discovery scheme equipped with two augmented functions. In this paper, the Internet gateway maintains an address cache of Internet nodes frequently accessed from the ad hoc network and replies with an extended Route Response (RREP) message to the Route Request (RREQ) message based on its routing table and the address cache called EXIT(EXternal node Information Table). These augmented functions make the source node determine the location of the destination as fast as possible. Through simulations, the proposed route discovery scheme using both EXIT and extended RREP message shows considerable reduction in both route discovery time and control message overhead.

Keywords : **ad hoc** Network, Routing, Internet, Route Discovery

I. Introduction

One of the major research topics related to ad hoc networks interworked with the Internet concerns the discovery for and selection of Internet gateways. Because the traffic between ad hoc networks and the Internet is always delivered through Internet gateways, ad hoc nodes must first acquire the addresses and route information of the Internet gateways in order for them to communicate with nodes on the Internet.

There has been some work recently in addressing the problem of interfacing wireless ad hoc networks with terrestrial networks. Most of the work has focused on providing Internet connectivity to the ad hoc network. In particular, people have studied in some detail the use of Mobile IP and registration based protocols to solve the problems of integrating the two networks. B. Andreadis [1] addresses the issue of providing global Internet access for MANETs, in particular, focusing on routing, the problem of global address resolution and gateway discovery. They provide an excellent discussion of the issues and an architecture for attempting to solve these problems.

Similarly, Y. Sun et al.[2] present a scheme for providing Internet connectivity for ad hoc mobile networks. They provide a mechanism to enable cooperation between Mobile IP and the AODV routing protocol. They use simulation results to validate their architecture by showing that it can maintain high throughput while keeping the overall control overhead low. A. Nilsson et al.[3] provide a brief description of how AODV can be used for providing inter-networking between wireless ad hoc networks and the IPv6 Internet. The primary focus is to describe the process of gateway discovery by using a multicast group, and the determination of a node address.

C. Ahlund et al.[4] differ from the above works in that it describes an actual software implementation of an integrated connectivity solution. In architecture, the solution described in [4] is similar to the solutions of [1] and [2], in that it combines the use of AODV in the wireless ad hoc network and Mobile IP in the terrestrial network. They describe the implementation of gateway nodes that run both AODV and Mobile IP software and are responsible for providing the connectivity.

While all the works described so far have focused on the use of AODV, A. Striegel et al.[5] on the other hand propose the use of a protocol independent gateway for ad hoc networks. This cluster gateway is responsible for providing Internet connectivity for the ad hoc network by acting as both a service access point as well as a MobileIP foreign agent. ad hoc nodes register themselves with the cluster gateway, which makes its location known by periodic advertisements.

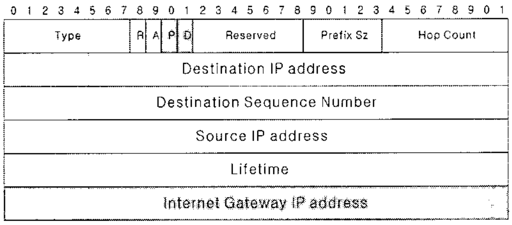
The conventional on-demand route discovery scheme, which is designed for stand-alone ad hoc network can not find out routes to the destination node outside ad hoc networks because it is based on the destination node's Route Reply (RREP) message responding to the source node's Route Request (RREQ) message. To solve this problem, a number of modified schemes based on the conventional on-demand route discovery have been proposed.

U. Jonsson et al.[6], and E. M. Belding-Royer et al.[7] proposed schemes based on the ad hoc On-Demand Distance Vector (AODV) routing protocol. In these schemes, the destination is considered Internet node outside ad hoc network after predefined number of route re-discovery fails. The repeated route discovery causes serious control overhead as well as route discovery delay since the RREQ message is flooded over the entire network. A. Striegel et al.[5] proposed a method that the Internet gateway manages a list of all ad hoc nodes and the source node queries Internet gateways to locate the destination. It allows the source node to determine the location of the destination node quickly, but requires additional memory and a new well-defined signaling to manage the addresses of all ad hoc nodes.

In this paper, we propose a new route discovery scheme equipped with two augmented functions to the conventional on-demand route discovery scheme to reduce route discovery delay and control overhead for the external Internet nodes without additional signaling. The first augmentation is that the Internet gateway maintains an address cache of external Internet nodes which frequently communicate with ad hoc nodes. The second augmentation is that on receiving the RREQ message from the source node, the Internet gateway replies with an extended RREP message based on this cache and its routing table. The extended RREP message allows the source node to determine the location of the destination as fast as possible. The extended RREP messages also allow ad hoc nodes receiving this message to update route information to the Internet gateway. This eliminates an additional route discovery for the Internet gateway, which is required if the destination is located in the Internet.

2. Conventional On-Demand Route Discovery Scheme

The on-demand route discovery scheme, which is used in the conventional on-demand routing protocols such as Ad hoc On-demand Distance Vector (AODV) [8] and Dynamic Source Routing (DSR) [5] are based on RREQ and RREP messages. Route discovery begins when a source node needs a route to some destination. It places the destination IP address and last known sequence number for that destination, as well as its own IP address and current sequence number, into a RREQ. It then broadcasts the RREQ and sets a timer to wait for a reply. When a node receives the RREQ, it first creates a reverse route entry for the source node in its route table. It then checks whether it has an unexpired route to the destination node. In order to respond to the RREQ, the node must either be the destination itself, or it must have an unexpired route to the destination whose corresponding sequence number is at least as great as that contained in the RREQ. If neither of these conditions are met, the node rebroadcasts the RREQ. On the other hand, if it does meet either of these conditions, the node then creates a RREP message. It places the current sequence number of the destination, as well as its distance in hops to the destination, into the RREP, and then unicasts this message back to the source. The node from which it received the RREQ is used as the next hop. When an intermediate node receives the RREP, it creates a forward route entry for the destination node in its route table, and then forwards the RREP to the source node. Once the source node receives the RREP, it can begin using the route to transmit data packets to the destination. If it later receives a RREP with a greater destination sequence number or equivalent sequence number and smaller hop count, it updates its route table entry and begins using the new route. If the source node does not receive a RREP by the time its discovery timer expires, it rebroadcasts the RREQ. It attempts discovery up to some maximum number of times. If no route is discovered after the maximum number of attempts, the session is aborted.[8]



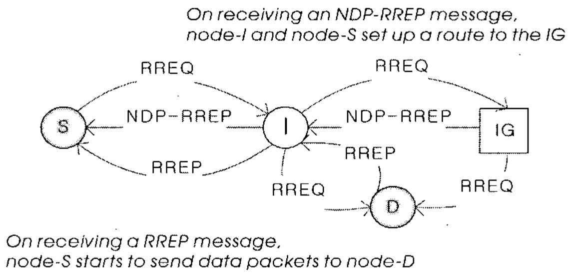
[Fig. 1] The extended RREP message format

P: Set up only in case of proxy RREP

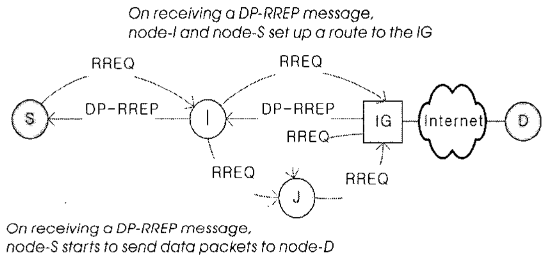
D: Type of the proxy RREP

(deterministic or non-deterministic)

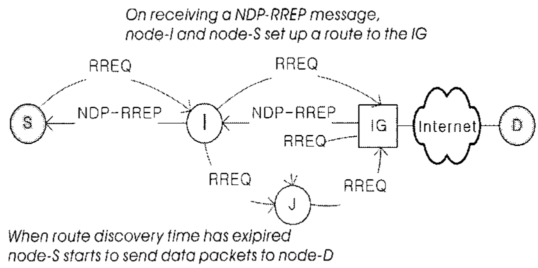
Internet gateway IP address: Address of the Internet gateway which generates this message



[Fig. 2] Route discovery for an internal node



[Fig. 3] Route discovery for an external node of a valid EXIT entry



[Fig. 4] Route discovery for an external node of no EXIT entry

3. Proposed Scheme

A route discovery scheme equipped with two augmented functions has been proposed in order to reduce the route discovery time and control message overhead for the external node. We apply this scheme to the AODV, one of the most well known on-demand routing protocols. The proposed scheme can be also applied to other on-demand routing protocols. The Internet gateway, which resides on the border between the ad hoc network and the Internet, maintains two kinds of information. On the ad hoc network side, it maintains route entries for the internal nodes with a routing table (RT)that is updated by the ad hoc routing protocol. On the Internet side, it maintains the IP addresses of the Internet nodes with which ad hoc nodes frequently communicate using a cache called EXternal node Information Table (EXIT). The EXIT is updated with data packets routed to and from Internet nodes. On the basis of this information, the Internet gateway determines whether the destination node is internal node or external node. In the following, we describe the proposed scheme in detail.

On receiving a RREQ message, the Internet gateway responds with an extended RREP message base on the RT and the EXIT. As shown in figure 1, the extended RREP message has three kinds of subtypes-RREP, Deterministic Proxy-RREP (DP-RREP), and Non-Deterministic Proxy-RREP (NDP-RREP). If the RT of the Internet gateway contains a valid route entry for the destination, the destination is considered as an internal node then the Internet gateway unicasts a RREP to the source node [Figure 2]. If the IP address of the destination node exists in the EXIT, the Internet gateway unicasts a DP-RREP to the source node [Figure 3]. If the Internet gateway has no helpful information about the destination in RT and EXIT, it generates a NDP-RREP message and unicasts this message back to the source node, and rebroadcasts the received RREQ to its neighbor nodes [Figure 4]. The proxy RREP message (DP-RREP or NDP-RREP) contains the IP address of the Internet gateway which generates this message.

If an intermediate node receives a proxy RREP message, it unicasts this message back to the source node, and adds or updates a route entry for the Internet gateway. If the source node receives a RREP message before the route discovery timer expires, it classifies the destination node as an internal node [Figure 2]. If the source node receives the DP-RREP message before the route discovery timer expires, the destination node is viewed as an external node [Figure 3]. In both cases, the route discovery timer is stopped and the source node starts sending data packets to the destination. If neither a RREP nor a DP-RREP has been received before the route discovery timer expired, the destination node is classified as an external node [Figure 4].

Route discovery delay and control

message overhead for the external destination can be reduced by two factors. First, the source node can eliminates repeated route re-discovery for the external nodes which has cached address in the EXIT. These destination nodes can be a web server or a mail server frequently accessed from ad hoc nodes. Second, Updating routes to the Internet gateway with the proxy-RREP message also eliminates an additional route discovery for the Internet gateway, which is needed if the destination is an external node.

Data packet destined for the external node should be forwarded to the Internet gateway first. Data packets can be forwarded to the Internet gateway via two methods tunneling and direct forwarding. We use the tunneling method in the proposed scheme because it has many useful features such as transparent packet forwarding to the external node, ease of route maintenance, scalability, Internet gateway selection, and similarities with IPv6's routing header option, despite of its additional overhead.

4. Performance Evaluation

4.1 Performance Criteria

To evaluate the performance of the route discovery scheme, two metrics are considered: *Route Discovery Control Overhead and Route Discovery Delay Time*, which are the major considerations for the efficient route discovery. A better route discovery scheme will show smaller values of RDCO and RDDT.

Route Discovery Control Overhead (RDCO): the average number of control messages generated during a route discovery

Route Discovery Delay Time (RDDT): the average time elapsed during a route discovery

Two performance criteria can be modeled as following equations using parameter definitions below.

α : External session ratio
κ : Average number of hops between arbitrary two ad hoc nodes
η : Hit ratio of the *EXIT*
β : Probability that a source node has a route to the Internet gateway
ρ : Repetition number of route re-discovery
TRD : Expiry time for the route discovery
Nrreq : Number of RREQ messages generated during a route discovery
Nrrep : Number of RREP messages

generated during a route discovery

In the case of external destination, the source node has to discover a route to the Internet gateway as well as a route to the destination in order to forward data packets to the Internet gateway. The average route discovery control overhead for an ad hoc network can be given by:

$$C_{co} = (1-\alpha)C_{co}^{int} + \alpha C_{co}^{ext} = (1-\alpha)C_{co}^{int} + \alpha\{\eta C_{co}^{int} + (1-\eta)(\rho C_{co}^{int} + \beta C_{co}^{int})\} \quad (1)$$

where C_{co}^{int} is an average route discovery control overhead for an internal node and C_{co}^{ext} is that for an external node measured as follows:

$$C_{co}^{int} = N_{rreq} + N_{rrep} \quad (2)$$

$$C_{co}^{ext} = \eta C_{co}^{int} + (1-\eta)(\rho C_{co}^{int} + \beta C_{co}^{int}) \quad (3)$$

The average route discovery delay time for an ad hoc network can be given by:

$$C_{dt} = (1-\alpha)C_{dt}^{int} + \alpha C_{dt}^{ext} = (1-\alpha)C_{dt}^{int} + \alpha\{\eta C_{dt}^{int} + (1-\eta)(\rho T_{RD} + \beta C_{dt}^{int})\} \quad (4)$$

where C_{dt}^{int} is an average route discovery delay time for an internal node and C_{dt}^{ext} is that for an external nodes measured as follows:

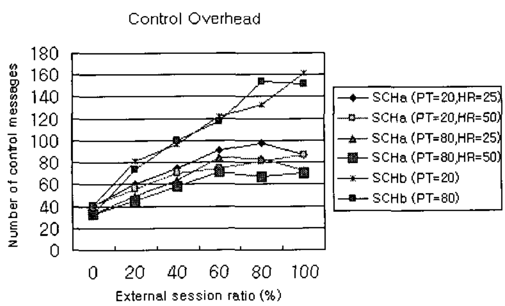
$$C_{dt}^{int} = \kappa(T_{rreq} + T_{rrep}) \quad (5)$$

$$C_{dt}^{ext} = \eta C_{dt}^{int} + (1-\eta)(\rho T_{RD} + \beta C_{dt}^{int}) \quad (6)$$

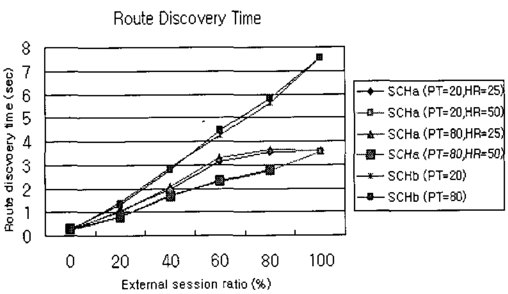
Cco and Cdt will be minimized when external session ratio is 0 and hit ratio of the EXIT is 1. If hit ratio of the EXIT is set to 0, the proposed route discovery scheme is equal to the route discovery scheme using timer expiry mechanism.

4.2 Simulation Results

To investigate the impact of our augmented functions, we simulate the following two route discovery schemes : Scheme-A *(SCHa)* and Scheme-B *(SCHb)*. Scheme-A is our proposed route discovery scheme that uses the extended RREP message and the EXIT. Scheme-B is the route discovery scheme for the external nodes which is based on timer expiry mechanism. A detailed simulation model based on Network simulator-2 *(ns-2)* is used. The network is a 300m 500m rectangular field. The radio model is based on Lucent's WaveLAN, which provides a 2 Mbps transmission rate and 250 m radio transmission range. Nodes are classified into internal nodes (ad hoc nodes) and external nodes (Internet nodes). The number of internal nodes is 21 including 1 Internet gateway, while the number of external nodes is 10. The Random Waypoint Mobility model is used with two pause times (PT) of 20 and 80 seconds. Packet traffic generated by each node is at a Constant Bit Rate (CBR) and has length of 512-bytes. The traffic is generated with 4 packets per second. The number of CBR sessions is set to 20, and sessions are classified into internal sessions and external sessions. The destination node is an external node in an external session while that is an internal node in an internal session. Various external session ratios of 0, 20, 40, 60, 80, and 100 % are used. The hit ratio (HR) of the EXIT, that is the probability of the *EXIT* containing the address of the destination node under route discovery, is set to 25 and 50 %.

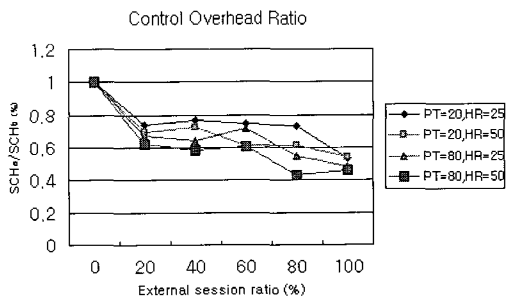


[Fig. 5] Route discovery control overhead

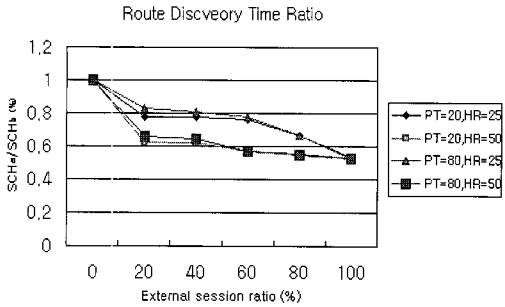


[Fig. 6] Route discovery delay time

[Figure 5] shows the control overhead during a route discovery for each combination of pause time and EXIT hit ratio. As the external session ratio increases, the control overhead also increases. The control overhead of Scheme-A increases more slowly than that of Scheme-B. Scheme-A shows less control overhead with a lower pause time, or a higher EXIT hit ratio. Figure 6 shows the route discovery time for each combination of pause time and EXIT hit ratio. As the external session ratio increases the route discovery time of Scheme-B increases much more than that of Scheme-A. The increase in control overhead and route discovery time is caused by the expanded ring search and repeated route discovery based on network-wide broadcasting. As shown in Figure 6, the average route discovery time for an internal node is about 0.25 sec, and that for an external node is about 7.5 sec.



[Fig. 7] Route discovery control overhead ratio (SCHa/SCHb)



[Fig. 8] Route discovery delay time ratio (SCHa/SCHb)

[Figure 7] shows the ratio of the control overhead of the two route discovery schemes. Figure 8 shows the ratio of the route discovery time of the two route discovery schemes. Scheme-A shows a maximum reduction of 50% in both control overhead and route discovery time. The performance enhancement is higher with a larger external session ratio and EXIT hit ratio. This means that the proposed route discovery scheme is more suitable for an ad hoc network where large number of ad hoc nodes communicate with several Internet nodes (servers) very frequently.

5. Conclusion

A route discovery scheme equipped with two augmented functions is proposed in order to reduce delay and control message overhead during route discovery for external nodes outside ad hoc networks. With two augmented functions, EXIT and extended RREP message, the proposed route discovery scheme allows the source node to determine the location of the destination node as fast as possible and easily update routes to the Internet gateways. Through simulations, we observe that the scheme reduces both route discovery time and control message overhead to a considerable degree. In particular, there is notable improvement in performance when the ratio of traffic sessions with external nodes is higher and many ad hoc nodes communicate with several external nodes commonly.

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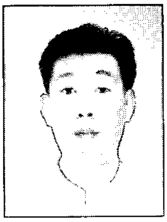

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