Virtual Hierarchical Architecture Integrating Mobile IPv6 and MANETs for Internet Connectivity ⋆

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Abstract. As the demands for Internet connectivity of ad hoc networks are consistently increasing, the interconnection of Mobile Ad hoc Networks (MANETs) to fixed IP networks is emerging as an issue with considerable attention in the literature [2,3,4]. Here, we focus on connecting MANETs to the Internet by integrating Mobile IPv6. Many previous studies are suffered from some limitations that the dynamic addressing and routing protocol are not suitable in high mobility MANETs. The proposed scheme is based on the prefix delegation method in order to reduce tunneling overhead by ingress filtering and avoid unnecessary address changes. By using this method, MANETs organize a virtual hierarchical architecture for efficient gateway discovery and the optimal routing in high mobility. Comprehensive computer simulation presents that the newly proposed scheme shows up to about 50% better performance in terms of delay and signaling overhead in comparison with existing protocols.

1 Introduction

An ad hoc network is a collection of wireless mobile hosts forming a temporary network without the support of any centralized administration. These mobile nodes have routing capabilities that allow them to create multihop paths connecting nodes which cannot directly communicate. Previous work has concentrated on the development of optimal routing protocols for efficient communications among Ad hoc devices. These protocols do not consider global connectivity. Currently, as the requirement for Internet connectivity of ad hoc networks is consistently increasing, the interconnection of MANETs to fixed IP networks becomes increasingly important. Users with portable devices in ad hoc networks can access useful information on the Internet. The data collected from

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ad hoc nodes is available in central systems of the Internet for various purposes. Therefore, this study can be extended to many applications, including Sensor Networks, Home Networks, Telematics, and so on.

The Mobile IPv6 [1] is a protocol which allows mobile nodes to have seamless access to the Internet while moving between different networks. Today it provides an important global mobility solution. Since nodes in ad hoc networks are inherently mobile, it seems inevitable that some of these nodes are likely to move between different ad hoc networks and to other parts of the Internet as well. Hence, we focus on connecting MANETs to global IPv6 networks, while supporting the mobility of ad hoc nodes by integrating Mobile IPv6 and MANET. In such integrated scenarios, mobile nodes can easily be deployed and expanded through existing infrastructures. For seamless communications with Internet hosts, some ad hoc nodes act as gateways to be traversed by other nodes. The gateway discovery mechanism has an impact in terms of overall performance, and it is a key component in providing interoperability with fixed networks. Furthermore, connecting an ad hoc network to the Internet brings up several issues regarding routing and how to provide nodes in an ad hoc network with IP addresses that are routable to the fixed Internet. These are the most relevant elements to guarantee smooth interworking.

Our proposed scheme is based on the prefix delegation method to avoid unnecessary address changes in high mobility situation. It also avoids some routing problems and tunneling overhead by ingress filtering. The control message transmitted from the gateway initially contains the gateway and prefix information. By propagating this message to the overall network, MANETs automatically organize a virtual tree topology for efficient gateway discovery when unpredictable topological changes occur. The overall overhead is reduced by integrating the addressing auto-configuration information into gateway discovery messages. In addition, MANETs based on tree topology provide the optimal routing protocol for access to the Internet and reduce the handoff cost as well. By the comprehensive computer simulation, we compared the proposed scheme with existing schemes in terms of handoff delay and signaling overhead. Simulation results show that the newly proposed scheme shows up to about 50% better performance than the others.

The rest of this paper is organized as follows. In Section 2, related works are introduced with some discussion. Section 3 presents the proposed scheme integrating Mobile IPv6 and MANET. The performance of the proposed scheme is evaluated in Section 4. Finally, we conclude in Section 5.

2 Related Works

One of the first proposals by Broch *et al.* [2] is based on integration of Mobile IP and MANETs based on DSR. In order for a Mobile Node (MN) within an ad hoc network to communicate with a destination node outside the ad hoc network, it simply initiates route discovery of DSR. When a gateway receives this Route Request (RREQ), it transmits a proxy reply containing itself and the destination node's address as the final point in the route instead of the destination node. If the MN moves from another network, it will transmit agent solicitation piggybacked on RREQ to discover its Foreign Agent (FA). When the FA receives a solicitation, it unicasts an agent advertisement in Route Reply (RREP). After this message reaches the MN, the MN registers to the FA and its Home Agent (HA). Then, the MN's HA will forward packets for the MN to the FA and the FA will deliver them locally to the MN using DSR.

Jonsson *et al.* [3] propose a method, called MIPMANET, to connect an ad hoc network to the Internet using Mobile IP with FA's Care-of Address (CoA) and reverse tunneling. MIPMANET combines the use of Mobile IP protocol and AODV. In MIPMANET, nodes in the ad hoc network that require Internet access, register with the FA and use their Home Address (HoA) for all communications. The MNs tunnel all packets to their FAs, which decapsulate the packets and forward them to their destinations. The packets from hosts on the Internet addressed to MNs are delivered to the FA, using the ordinary Mobile IP protocol. Then, the AODV protocol is used to deliver packets to the MNs in the ad hoc network. Moreover, as for handoff, MIPMANET utilizes a mechanism called MIPMANET Cell Switching (MMCS), which allows the MN to determine when it should register with another FA.

Almmari *et al.* [4] analyze the performance of mobile gateways in a MANET based on the DSDV routing protocol. This paper proposes an approach which integrates the MANET and the Internet into a hybrid unified network. The hybrid network assists MANET nodes to obtain Internet connectivity through a special entity set called mobile gateways. These gateways are arranged at the second layer between the fixed FA of the first layer and MANET nodes of the third layer. As a result, this will shorten the paths between them and act as a means to widen the coverage range of FAs in a transparent manner. Some MANETs may be far away from fixed Internet gateways, known as FAs, because MANET nodes move frequently in a random fashion. This approach is based on mobile gateways instead of fixed gateways.

Since these proposals are based on existing protocols, they are limited in supporting all routing protocols and do not provide scalability in heterogeneous network environments. The gateway discovery function of them is done proactively or reactively by using any routing protocol. It suffers from the flooding overhead for rediscovering a default route toward the gateway whenever handoff is performed. In addition, addressing protocol of these schemes cannot solve the ingress filtering problem in MANETs with multihop routing. It incurs the routing overhead by reverse tunneling, since the packet size is increased in each hop.

3 The Proposed Scheme

3.1 Virtual Hierarchical Architecture for Mobility Management

In this paper, we consider the special property of the MANETs with the dynamic multihop topology and focus on the issue that the protocol overhead should be kept at minimum due to the scarcity of resources. To reduce the routing overhead by ingress filtering, the prefix delegation mechanism is proposed. This technique is also used to create virtual trees which are dynamically maintained and updated when unpredictable topology changes occur. In this section, we describe how to form and maintain a virtual tree with minimum overhead, and provide the optimal gateway discovery and efficient addressing mechanism based on the tree topology.

1) Prefix delegation: Prefix delegation is a method where all nodes of the MANET share the same prefix advertised from the Access Router (AR), to reduce the tunneling overhead according to ingress filtering. It is assumed that AR and MANET nodes operate under the IPv6 protocol, therefore all entities broadcast periodically the Router Advertisement (RA) message to their neighbors. Based on that, the solution uses the RA message, so that nodes can simply relay the prefix without any special control message or operation. Unfortunately, the multi-hop nature of an ad hoc network makes it impossible to use the advertisement message defined in IPv6. Therefore, the original RA message is extended to propagate over multiple hops through the ad hoc network and to share a common global network prefix using MANET nodes. The added fields in the prefix information option are represented as follows.

- The M flag means that this message is relayed over multi-hops.
- Hop count is the distance (in hops) from the gateway to the sender node.
- The IP address of the gateway is contained and the prefix length field represents the length (in bits) of the prefix part of this address.

The gateway advertises the RA message containing its prefix and setting the M flag. In addition, the initial distance transmitted by the gateway must be zero. When a node receives this message, it increments the hop count one and forwards an updated version of the RA message to its neighbors. All other message fields remain unchanged. The gateway information contained in the RA message is therefore propagated in a hop-by-hop manner, until all nodes of the ad hoc network share the gateway IP and global network prefix.

2) Virtual tree topology configuration and management: The proposed prefix propagation method leads to the creation of the virtual tree topology of the ad hoc network. Each virtual tree is rooted at a gateway, and it is formed by nodes using the global network prefix advertised by the gateway. In the proposed scheme, an AR acts as the gateway. We consider that a MANET connects to the Internet via the AR. The AR is a method of supporting Internet connectivity at the point of attachment between the Internet and MANET nodes. This overcomes the limitation that a MANET node with low power should play the role of the gateway.

In order to configure the virtual tree topology, each node tries to establish a parent-child association with its neighbor using 3-way handshake. Control packets of the procedure consist of the RA message disseminated for prefix delegation, PARENT REQUEST, and PARENT REQUEST ACK. When a node receives the RA message from a neighbor, it generates its global IP address with the prefix of the RA message. Then, it sends back a PARENT REQUEST to notify that it is selected as a parent node. As the parent node sends the ACK with the Tree ID as a logical address, parent-child association is established. The parent node keeps its children in the table to manage. After establishing parent-child association, each node keeps a default route toward the gateway. That is, a new node can easily discover the gateway without flooding message for route rediscovery of existing routing protocols.

A node may receive one or more RA messages from its neighbors. In this case, it selects the most appropriate node as a parent from among the messages and sends a PARENT REQUEST back. In the proposed scheme, the desirable algorithm for selecting the parent node is that the node keeps its current prefix as long as it has neighbors with the same prefix, *i.e.*, until it cannot find the neighbor that uses the same network prefix. The main advantage of this algorithm is that it can minimize the number of prefix changes. This greatly reduces the overhead induced by the sending of BU messages when the node changes its global address. And, the node chooses the parent node that advertises the shortest distance to a gateway, to maintain the shortest path. They ensure that one node does not concurrently generate multiple associations and avoids a tree loop. When a child node is established with a parent node, it ignores the RA message transmitted by other neighbors as long as it maintains the association.

In order to maintain the virtual tree topology, each node periodically checks its neighborhood. The nodes can detect the loss of its parent or child nodes using RA and Router Solicitation (RS) in the Neighbor Discovery Protocol (NDP) of IPv6. If a child node does not receive the RA message from its parent within a predefined time, it assumes that its parent node has moved away. In this case, as the node transmits the RS message to its neighbors, it should restart the 3-way handshake procedure to select another parent. However, if a parent node does not receive the RA message from its child and the timer associated to it is expired, the parent node releases the resource and logical address assigned to the child. Therefore, in the proposed scheme, the RA message disseminated by the node allows its parent and children to simultaneously detect its existence.

3) IP address configuration and Tree ID assignment: Each mobile node should configure its IPv6 global address to connect the Internet. In the proposed scheme, MANET nodes generate a global address with the prefix advertised by a gateway and its EUI-64 (Ethernet Unique Identifier) as the interface ID. In additional, the MANET node is proposed to have its Tree ID as a logical address, other than global IP addresses, to provide efficient routing. The logical Tree ID indicates the location of nodes on the tree topology. This is a routing information to deliver the packet between the gateway and nodes.

In the parent-child establishment process, when the parent receives the PARENT REQUEST from the child node, it selects the address which is not assigned yet in its child table and sends with the response message. The parent keeps the Tree ID and corresponding MN's address in its child table in order to perform an optimal routing and manage them easily. For example, if the parent node using ID 1.2.1 receives a request message from the child node, it selects a random number(x) from 1 to 255, which is not used by other children. Then, the ID of the child node is set to 1.2.1.x and the parent node uses the response message for notification it. The parent adds the ID and the node's address to its table.

If the parent does not have an available ID, it must ignore the request so that the child chooses another parent. However, if the child moves away, it releases the resource and the Tree ID used by the child and deletes the entry of the child in its table. The reason why the Tree ID is not used as a global address of a node, is to consider the high mobility in MANETs. When an ad hoc node changes its point of attachment within the MANET tree, it must replace the global address based on Tree ID. It requires significant cost with regard to handoff. The Tree ID which is separated from the global IP addresses is proposed, in order to optimize routing in busy mobile environments.

3.2 Routing Protocol

We propose the routing protocol based on the virtual tree topology for communication with the Internet hosts. Depending on the routing protocol in use within the ad hoc network, ad hoc nodes must also be configured to be able to communicate with the Internet. Therefore, this work aims to propose a method that is independent of the underlying routing protocol, as our proposal can be used with both proactive and reactive routing protocols. In addition, the protocol does not require an additional overhead for Internet access, since it does not need to find routing path on demand. All traffic between ad hoc nodes and Internet hosts are forwarded along the path configured by parent-child association.

When the MANET node wants to transmit the packet to the Internet host, it transmits the data packets to the gateway using the IPv6 routing header. The extended routing header contains the final destination address, *i.e.*, the address of the Internet host, and the destination field of the IPv6 header contains the gateway address. If intermediate nodes from the ad hoc node to the gateway receive the packet with the destination field set to the gateway IP, they forward it to their parent node recursively. Only the ad hoc node with the IP address contained in the destination field of the IPv6 header can examine the routing header of this packet. Once the packet arrives at the gateway, the packet uses the address of the routing header as the destination field of header and the routing header is removed. The modified packet is then forwarded to the Internet host.

In contrast, if the gateway receives the packet from the Internet host to the ad hoc node, it adds the hop-by-hop option to the original IPv6 packet. It first searches its cache for the corresponding Tree ID of the destination address (MN's IP). Then, the Tree ID is inserted into the hop-by-hop option. As a result, intermediate nodes from the gateway to the ad hoc node check this option for routing and deliver the packet to the child node selected by the longest prefix matching algorithm. This algorithm is used to determine how to forward the packet to its destination using the Tree ID. Since the proposed scheme uses the Tree ID and the parent-child association based on tree topology, it can reduce the routing overhead.

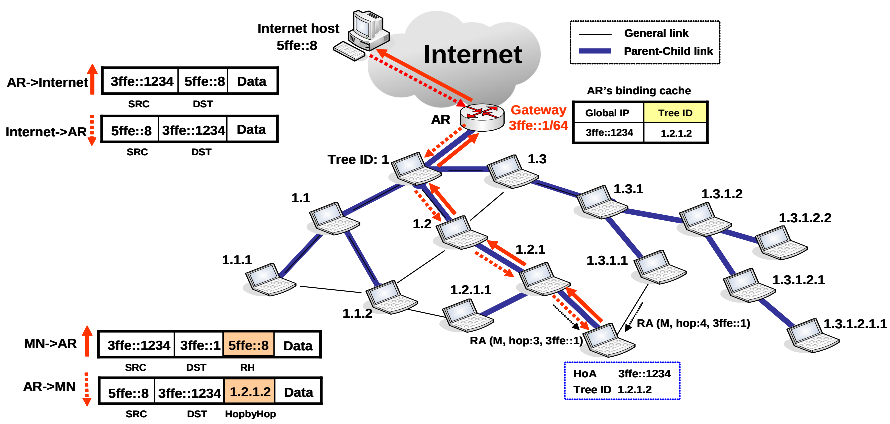

Fig. 1: The routing protocol based on virtual tree topology

3.3 MIPv6 Support for MANET Handoff

The proposed scheme supports seamless mobility of MANET nodes by integrating the Mobile IPv6 and ad hoc network. We consider that the global address acquired by an ad hoc node should be used as the Mobile IPv6 CoA of the node. Each change of global address in the ad hoc network will trigger the sending of at least one BU message. However, when the Tree ID changes, a new local registration between the gateway and node is performed to immediately provide an optimal routing.

If the ad hoc node moves from another MANET or changes its point of attachment within the network, it performs a 3-way handshake procedure to reconfigure the tree structure as it can no longer contact with its parent node any more. As a result, it has a new Tree ID. Then, it transmits the registration message to the gateway in order to update the new ID. As the receiving gateway rewrites its cache entry, the gateway can insert the exact information in the hop-by-hop option when it is added to the packet transmitted by the CN. This registration signal is also delivered along the parent-child path to the gateway.

In the case of internal movement within a network, the MN only changes only its Tree ID, not its global IP CoA. Therefore, as it performs a light-weight registration procedure with the gateway, it does not require the route rediscovery mechanism of previous schemes between the gateway and the MN. Therefore it can reduce the flooding overhead of the proactive or reactive protocol. However, when an MN moves to a foreign network, it first reconfigures a new global IP which will become its CoA. After a 3-way handshake, it performs the BU to its HA and CN as well as registration of the Tree ID with the gateway. Using the method, the ad hoc MN has seamless access to the Internet while performing handoff.

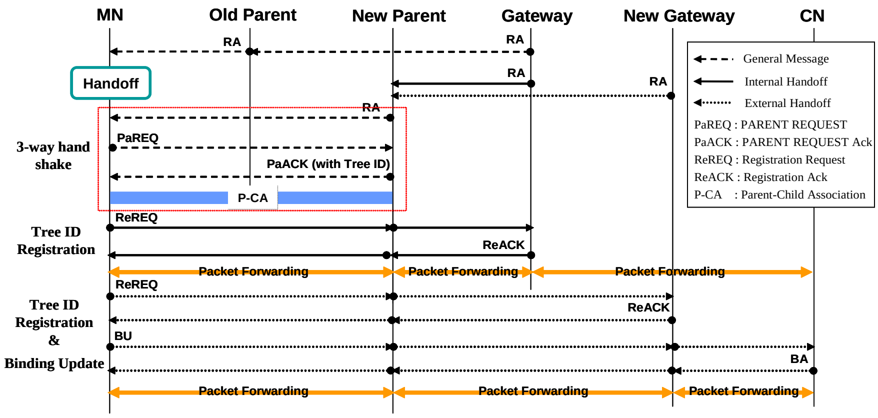

Fig. 2: Handoff procedure

4 Performance Evaluation

In this section, the performance of the proposed scheme is evaluated in comparison with integrating the Mobile IPv6 and existing routing protocol, AODV, DSR, DSDV. In order to evaluate these schemes, simulation implemented in C is conducted. Our simulation models a wireless network of 25 $\sim$ 100 mobile nodes placed randomly within a $150m \times 100m$ area. Radio propagation range for each node is $30m$. We measure the total delay required when the node performs handoff and the overhead of the gateway discovery. Performance is evaluated under various mobility rates and numbers of nodes, to analyze the performance of mobility and node density effect.

4.1 Handoff Delay

The average total delay of the proposed and other schemes is first compared for various handoff rates. This simulation varies the handoff rates between 0.1 and 0.9. The network has 50 nodes. In addition, the node moves from another network or changes its point of attachment within the network, and it is placed randomly. The total delay is measured and the delay between two nodes is represented as follows.

$$Total\ Delay = \#\ of\ Hops(Transmission + Propagation + Processing) \quad (1)$$

The total delay is the summation of transmission, propagation and processing time in each hop between two end nodes. This is calculated as follows. Table 1 represents the detailed simulation parameters. Based on these values, the average total delay of four schemes is measured in our simulation.

$$Transmission_{wireless} = \frac{S_{pkt}}{B_{wl}}, \quad Transmission_{wired} = \frac{S_{pkt}}{B_{wd}} \times H_{avg}$$

$$Propagation_{wireless} = \frac{D_{wl}}{P}, \quad Propagation_{wired} = \frac{D_{wd}}{P} \times H_{avg}$$

$$Processing\ delay = T_{BU} + T_{RDP} + T_{TU} + ... \quad etc.$$

Table 1: Simulation Parameters

Parameter	Description	Value
P	Propagation speed (m/sec)	2×10^8
B_{wd}	Wired transmission Speed (bit/sec)	10^8
B_{wl}	Wireless transmission Speed (bit/sec)	10^7
T_{all}	Processing time of all procedures (sec)	0.00001
H_{avg}	Average number of hops in wired networks	10
D_{wd}	Average distance per hop in wired networks (m)	10000
D_{wl}	Average distance per hop in wireless networks (m)	30

Fig. 3(a) presents the simulation results for the variation of handoff ratios. As shown in Fig. 3(a), our proposed scheme has better performance than other schemes. In the reactive protocol of AODV and DSR, the route discovery protocol is conducted other than NDP, BU procedures when a node performs handoff. Therefore, the RREQ message is forwarded by all nodes until the gateway is discovered and RREP is then delivered by the gateway. In particular, the DSR approach has higher handoff overhead than AODV, because the size of the control message is consistently increasing for source routing. However, the proactive protocol of DSDV updates its routing table by adding a new node entry. Though the route discovery procedure is not required, it must transmit table information to all neighbors in order to notify the new node.

4.2 Gateway Discovery Overhead

The overhead of the gateway discovery is evaluated for various network sizes in each scheme. In this simulation, the overhead is defined as the total bytes of the control message when a network is configured and initially attempts to connect with the Internet. That is, it is the sum of all control messages delivered until the gateway discovery is completed. We measure the overhead of 3-way handshake, route discovery and table update of these schemes as the network size is increasing. The simulation result is presented in Fig. 3(b). The result represents that the proposed scheme can reduce the control overhead in large scale networks.

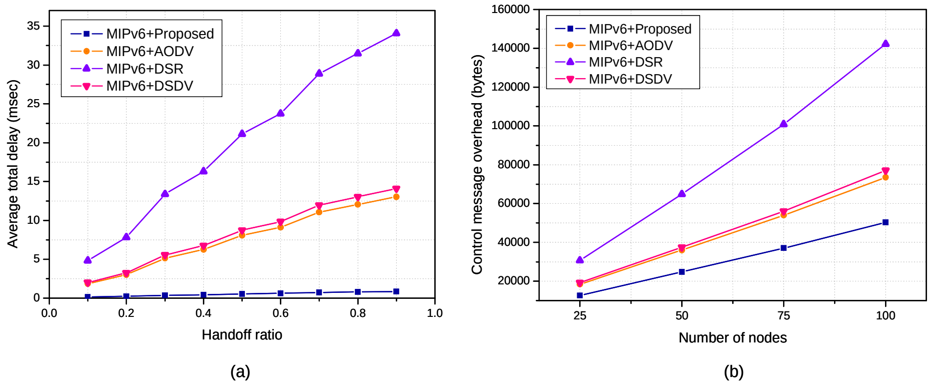

Fig. 3: Simulation results of four schemes (a)Handoff delay, and (b) Gateway discovery overhead

5 Conclusion

In this paper, we present a protocol that builds a virtual trees, where each tree if formed by nodes that share a common global network prefix. By using the tree topology, an efficient gateway discovery and optimal routing is proposed in high mobility MANETs. In addition, this connectivity method is not dependent on a particular routing protocol. Therefore, it provides the optimized communication as well as scalability in heterogeneous network environments and backward compatibility with existing mechanisms.

Our simulation represents advantages of the proposed scheme compared to integrating MIPv6 and the existing routing protocols - AODV, DSR, DSDV. According to the simulation results, our newly proposed scheme shows up to about 50% of performance improvements in comparison with other schemes. Thus our solution provides Internet connectivity of ad hoc nodes with minimum routing overhead and delay in large-scale, high mobility MANETs.

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