Global Connectivity for Mobile IPv6-based Ad Hoc Networks

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Abstract

The IPv6-enabled network architecture has recently attracted much attention. In this paper, we address the issue of connecting MANETs to global IPv6 networks while supporting IPv6 mobility. Specifically, we propose a self-organizing, self-addressing, self-routing IPv6-enabled MANET infrastructure, referred to as IPv6-based MANET. The proposed self-organization addressing protocol automatically organizes nodes into tree architecture and configures their global IPv6 addresses. Novel unicast and multicast routing protocols, based on longest prefix matching and soft state routing cache, are specially designed for the IPv6-based MANET. Mobile IPv6 is also supported such that a mobile node can move from one MANET to another. Moreover, a P2P information sharing system is also designed over the proposed IPv6-based MANET. We have implemented a prototyping system to demonstrate the feasibility and efficiently of the IPv6-based MANET and the P2P information sharing system. Simulations are also conducted to show the efficiency of the proposed routing protocol and the P2P file sharing system.

1. Introduction

With the rapid development in wireless communications in recent years, the necessity for sufficient IP addresses to meet the demand of mobile devices, as well as flexible communications without infrastructure, are especially considerable. The Next Generation Internet, Internet Protocol version 6 (IPv6) [1-2], targets at sufficient IP addresses to enable users to attach to the Internet and promotes mobile wireless commerce (m-commerce). Additionally, most current mobile devices are equipped with IEEE 802.11 wireless local area network interface cards. It supports infrastructure and ad hoc modes. The infrastructure mode requires all mobile devices to directly communicate to an access point. In ad hoc mode, mobile devices dynamically form a mobile ad hoc network (MANET) with multi-hop routing. Clearly, the ad hoc mode allows for a more flexible network, but its aim is not to connect to the Internet.

Much attention has been paid to IP address auto-configuration and IPv6 extension for MANETs [3-5] in recent years. IPv6 auto-configuration mechanism [3-4] allows a node to generate a link-local IP address. Extension has also been made to be suitable for MANET [5]. However, global connectivity for a mobile node is not supported in [5]. Later on, [6-7] address how to provide global connectivity for an IPv6-enabled MANET. In these works, a MANET node can acquire a global IPv6 address from an Internet gateway, and then access to the Internet through the gateway. Routing in MANETs and the IPv6 network is based on existing protocols.

Currently, existing MANET routing protocols, such as Ad-hoc On-demand Distance Vector (AODV) [8], Optimized Link State Routing Protocol (OLSR) [9], and Zone Routing Protocol (ZRP) [10], typically only maintain routes locally within the reach of a MANET and, thus, do not consider global connectivity. Surprisingly, only few studies [11] have so far been made on IPv6-enabled routing. AODV applies the embedding of Internet connectivity acquisition to support IPv6, referred to as AODV6 [11]. AODV6 adopts hierarchical routing to support IPv6 mobility, in particular, Care-of-Address (COA), and flat routing within a MANET. Clearly, most of past researches mainly focus on routing in general large-size MANET and separate the addressing protocol from routing protocol. However, in reality, we anticipate the scenario of many small-size MANETs connected to the global Internet via access routers. In this paper, we shall integrate the routing and addressing protocols for small-size, low-mobility MANETs such that routing overhead can be reduced and unique address for each mobile node can be easily achieved.

In this paper, our goal is to allow mobile nodes form an IPv6-based MANET flexibly and access the global IPv6 Internet easily and efficiently. To achieve this goal, we first propose a novel mechanism to allow IPv6 mobile nodes to form a self-organizing, self-addressing MANET into a tree structure rooted with an Internet gateway, referred to as an access router (AR), as shown in Figure 1. The forming of MANET extends the coverage of the AR. In other words, it allows a mobile node to access to the Internet even it cannot directly communicate with the AR. Each MANET is formed by mobile devices in a small geographic area, such as a meeting room, a building, or a train. Within a MANET, each mobile device will move around, but only at walking speed (low mobility). Mobile IPv6 will be supported such that a mobile node can move from one MANET to another. Next, specially designed unicast/multicast routing protocols for MANETs, which are more suitable for IPv6, will be proposed. In our design, a MANET under an access router is viewed as an IPv6 subnet that uses the access router as the default router to access global IPv6 Internet. Full functionality of IPv6/ICMPv6 [12] is supported on the ad hoc network such that each mobile node can perform stateless IPv6 address auto-configuration.

Similar to the importance of IPv6 in the next generation Internet, Peer-to-Peer (P2P) applications are very likely to be the killer applications in the future. However, only a small amount of researches [13-14] has been performed on the issue of P2P information sharing on a MANET. Two examples are Passive Distributed Indexing (PDI) [13] and Optimized Routing Independent Overlay Network (ORION) [14]. PDI can efficiently search files scattered over mobile devices by querying locally. ORION combines application-layer query processing and overlay network construction with the network layer process of route discovery to ensure accurate search and low overhead. Both of these researches use the flooding mechanism to find files on demand. But these solutions are not scalable and curtail throughput as the size of a MANET grows. Therefore, we also designed a distributed, but structured P2P information sharing system over our IPv6-based MANET using the distributed hashing table (DHT) technique.

Feasibility and efficiency of the proposed IPv6based MANET are also evaluated in this paper. We demonstrate the feasibility of the IPv6-based MANET via prototyping a real system. The proposed tree overlay construction and maintenance protocols, unicast/multicast routing protocols, and P2P information sharing system on IPv6-based MANET are implemented. In addition, we evaluate performance of proposed routing protocol and file search/retrieval latency via simulations. The path stretch of the proposed routing protocol with routing cache performs reasonably well. The latency of file search/retrieval of the proposed P2P system significantly outperforms that of ORION.

The remainder of this paper is structured as follows: Section 2 presents the design of the IPv6-based MANET. Session 3 shows a prototyping system. Performance evaluation results are shown in session 4. Finally, section 5 concludes this paper.

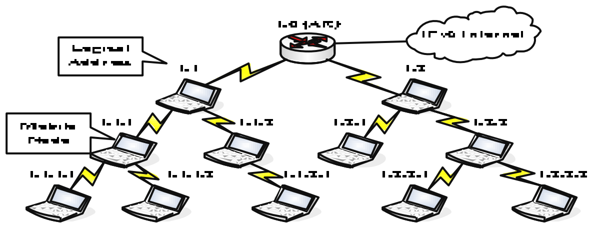


Figure 1. IPv6-based MANET framework with global connectivity

2. IPv6-based MANET

In this session, we give an overview of the proposed IPv6-based MANET. To construct an IPv6-based MANET, we propose a self-organizing addressing protocol to organize nodes into a tree structure. The logical address of a node is automatically configured when it joins and leaves. Based on the tree topology, we then propose a new routing protocol, which is based on longest prefix matching, for MANET. IPv6 is supported on MANET such that each mobile node automatically configures its global IPv6 address and connects to the global Internet via an access router. Meanwhile, mobile IPv6 is also supported to allow a mobile node moves from one MANET to another. Finally, we also show how to implement information sharing applications on the IPv6-based MANET. In the following, we shall describe more detail information of each proposed mechanism.

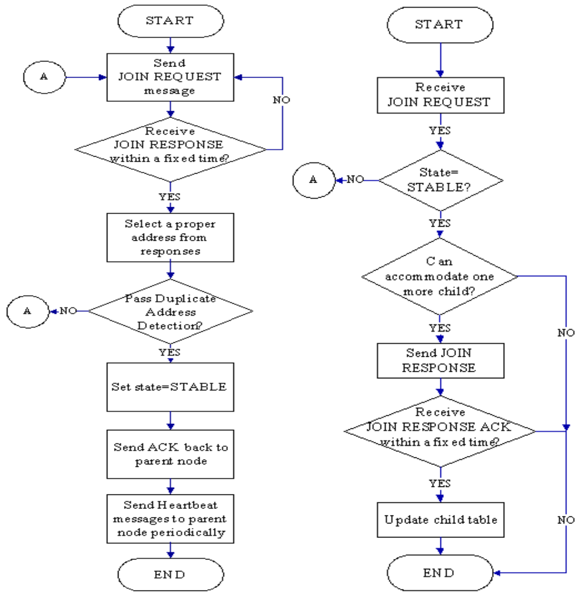
2.1. MANET tree overlay management

In this paper, we consider the scenario that a MANET is formed by nearby mobile nodes which access to the Internet via an access router, as shown in Figure 1. In this session, we describe how mobile nodes automatically form a tree overlay and configure its IPv6 addresses. Specifically, we will describe procedures for a mobile node to join the tree overlay, configure its IPv6 link local address, and maintain the tree overlay.

2.1.1. JOIN procedure. Figure 2 shows the flow chart of the JOIN process of a new joined node as well as its neighbors. When a node joins the MANET, it sends out a JOIN REQUEST message to its neighbors to request for a logic address, as shown in Figure 2(a). Each neighbor of the new node that is already on the tree topology will select a unique address among its current child nodes and response the JOIN message with the selected address, as shown in Figure 2(b). The logical address of a mobile node indicates its location on the tree. Specifically, upon receiving a JOIN request, a neighbor with address $x1,\ldots,xi$ will select an address $x1,\ldots, xi,xi+1$, which is the smallest and unique id among that of its child nodes, for this new node. On the other hand, the new node may receive one or more responses from its neighbors. In this case, it selects a "proper" address from one of the responses and sends back a RESPONSE ACK message to parent. The criteria for selecting a proper address may be the one near the tree root, higher signal strength; the sending node has more power or less mobility. We propose to select the one near the tree root, because it results in a flat tree.

2.1.2. IPv6 address configuration. Each mobile node will configure its IPv6 address according to its logic address. In the past, a mobile node may configure its IPv6 link-local or global address by attaching a network prefix to its 64-bit network interface ID. However, this could make routing in MANET quite difficult and independent of IPv6. In this paper, we propose to use a mobile node's logic address as its 64-bit interface ID when configuring its IPv6 addresses (link-local or global). The 64-bit logical address is divided into sixteen levels, each with four bits. For example, if the logical address of a node is "1.2.1", its link local address will be set to FE80::1210:0:0:0/64. Note that this addressing space should be abundant for any possible MANET under consideration.

2.1.3. Maintain the tree overlay. Heartbeat (in a child) and child timer (in a parent) are used to supervise each other's status. In order to make the routing efficient and maintain the tree structure as long as possible, a node and its parent regularly send a heartbeat and ACK to each other after a node has joined the network. However, if a child node does not receive the ACK message within a pre -defined time, it increases its heartbeat-ACK-missed counter by one. If the counter is larger than certain threshold, it assumes that its parent has crashed and restarts the JOIN procedure. On the other hand, upon receiving a heartbeat from a child, the parent node will reset the corresponding child -heartbeat timer. If a child does not send a heartbeat for a long time, the child-heartbeat timer will expire. In this case, the parent node assumes that the child has crashed and releases the resource and address of the child.



(a) A new node joins in netowrk

(b) Neighbors response to address assign

Figure 2. Flow chart of new node joins in network

2.2. Routing protocol

2.2.1. Unicast routing protocol. Based on the tree topology, we propose a novel routing protocol for the proposed IPv6-based MANET. To avoid additional overhead, the proposed routing protocol does not need to find routing path on demand. Each mobile node maintains a routing table with two kinds of information: default routing and soft state routing cache. A mobile node in the proposed MANET will have information of its parent and child nodes. This information is used for default routing, as there exists at least one path between any two nodes on the tree. Longest prefix matching is used to determine how to forward a packet to its destination. However, packets routed through the tree structure may have a relatively longer path or delay latency. Using Figure 3 as an example, a packet sent from node “1.1.1.2” to node “1.1.2.1” will be routed through the hierarchical path, which traverses node “1.1.1”, node “1.1”, node “1.1.2”, and node “1.1.2.1”. In this case, the number of routing entries is four but the destination is just one hop away from the source. The soft state routing cache ameliorates this problem.

Each mobile node can improve the routing efficiency by adding its neighbor information into the routing cache. Each node can collect information of its one-hop-away neighbors by listening to the air. Therefore, a routing cache with information of one-hop-away neighbors can be built without any routing information exchange. Due to the mobility of mobile nodes, each entry of the routing cache is associated with an age timer so that obsolete information can be deleted. (So the routing cache is a soft state cache.) Routing is still based on longest prefix matching, but the routing table is expanded with routing cache. Therefore, a short-cut can be taken when forwarding packets. For example, in Figure 3, a routing path with routing cache from node “1.1.1.2” to node “1.1.2.1” will be routed within one hop.

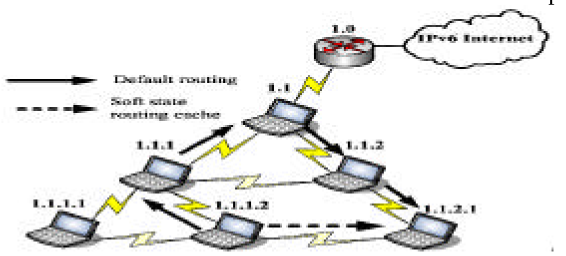


Figure 3. Example of routing path selection

2.2.2. Multicast routing protocol. Multicast is especially important for sending ICMPv6 messages. Multicast routing in the proposed MANET is quite straight forward by using flooding and utilizing the tree structure for a quicker stop. When a mobile node sends a multicast packet, it is forwarded to its neighbors. Each intermediate node, which is not a leaf node of the tree, that receives a multicast packet for the first time should forward the packet to its neighbors. Each multicast packet can be uniquely identified by its source node and unique sequence number. Clearly, the forwarding process will broadcast the packet over all the tree and stop at the leaf nodes of the tree. Since the tree is expected to be a short and wide tree, the number of leaf nodes is expected to be around one half of the number of all nodes. As a consequence, a multicast packet will be forwarded only around one half of the number of all nodes.

2.3. Global connectivity and mobile IPv6 support

As aforementioned, the proposed IPv6-based MANET allows IPv6 mobile nodes in a MANET to access the global IPv6 Internet via an access router. The global IPv6 address of a mobile node is created by attaching its logical address to the global prefix obtained from the Router Advertisement message. For example, the global prefix of the access router is “3ffe:302:11:1::/64”. Thus the global address of the node with logical address “1.2.2” is “3ffe:302:11:1:1220:0:0:0/64”.

Mobile IPv6 will be supported such that a mobile node can move from one MANET to another MANET. The scenario of supporting Mobile IPv6 in the proposed IPv6-based MANET is shown in Figure 4.

2.4. P2P Information Sharing System on IPv6-based MANET

As P2P applications become more and more popular, they could be the killer applications of IPv6. Therefore, we also design a distributed, but structured P2P information sharing system over the proposed IPv6-based MANET based on the DHT technique. The logic address of tree structure aforementioned is also used as the node id (key) of the P2P system. To share information, a node uses the filename or some keywords as the input to a hash function. The output of the hash function, called a key, will correspond to the logic address of a mobile node which will be responsible for storing the information of the shared object.

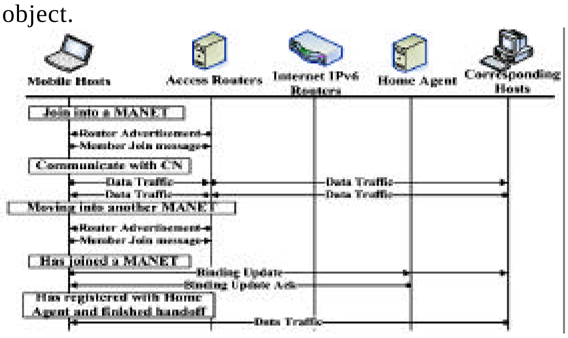


Figure 4. Procedure of handoff

3. Prototyping and implementation

In order to verify the feasibility of IPv6-based MANET, a real system is prototyped. Five notebooks equipped with 802.11b wireless LAN cards, one is used to simulate the AR and the others act as mo bile nodes, form an IPv6-based MANET. The operation systems on notebooks are Redhat Linux 9.0 (kernel v2.4.22). We implemented tree overlay construction and maintenance protocols, MANET routing protocol, and the P2P information sharing system on the IPv6-based MANET.

3.1. Implementation of Tree Overlay Maintenance Protocols

Figure 5 shows the implementation of join and maintenance procedure. The AR sets its logic address to "1.0" initially. A new node gets response from AR and sets its link local address and global IPv6 address. The maintenance messages sent and received among these two nodes and the AR are shown in Figure 6. Node "1.1" periodically receives heartbeats from node "1.1.1" as well as heartbeat responses from node "1.0".

3.2. Implementation of Routing Protocol

In order to ensure that the routing protocol is feasible, we used the traceroute tool to verify whether a routing path was established. We verify the results by running traceroute from node "1.1.1" to "1.0" which indicates that a packet from node "1.1.1" can reach node "1.0" via node "1.1".

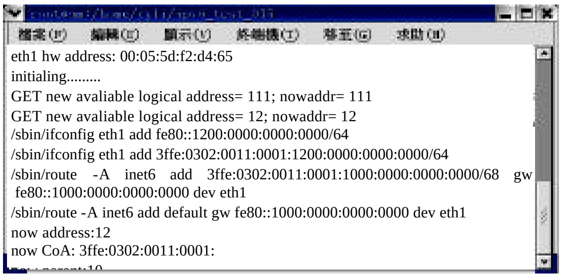


Figure 5. Demonstration of the join procedure

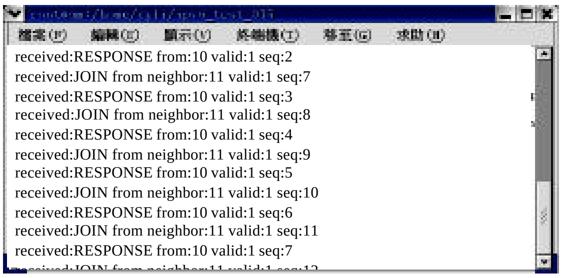


Figure 6. Demonstration of the maintenance procedure

3.3. Implementation of P2P information Sharing System

Figure 7 shows the implementation of a P2P information sharing system. In this demonstration, a node who wants to share a text file with filename "aaa.txt" uses the hash function to obtain the target node address "1.1" (key) for storing the information first. Other nodes can then retrieve the shared file via the search and retrieve protocols.

4. Performance Evaluation

In this session, we evaluate the performance of the proposed routing protocol and the P2P information sharing system. Simulations are performed in the IEEE 802.11b environment. We assume that wireless transmission range and transmission bandwidth of each mobile node are 200 meters and 11 Mbits/second, respectively. The simulation time is 300 seconds. Unless otherwise specified, the simulation area is set to $1Km^2$.

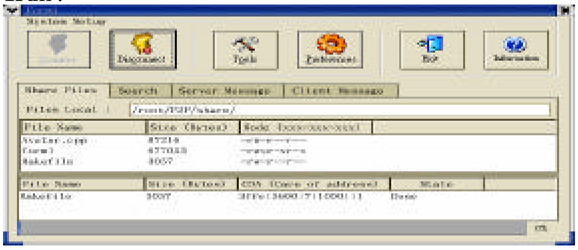


Figure 7. P2P information sharing system based on DHT

4.1. Performance of MANET Routing

To evaluate the performance of the proposed routing protocol, we measure the ratio of the average routing path yielded by our routing protocol to the shortest (optimal) path, called the path stretch. The shortest path can be viewed as the best path that can be found by on-demand routing, such as the AODV protocol. The number of nodes ranges from 100 to 1000. Figure 8 shows the path stretch with or without routing cache. The cache size is set to 16 entries. We can observe that the path stretch without routing cache, in the simulated 1Km2 and 2Km2 area, are much higher than the path stretch with routing cache. With routing cache, the proposed routing protocol performs reasonable well. Note that our routing protocol does not need to exchange routing information with neighbors, on demand or periodically, thus reduce a lot of routing overhead as compared to existing MANET routing protocols.

4.2. Performance of the P2P System

Figure 9 compares the total numbers of packets generated of IPv6-based MANET and ORION. We randomly distributed 100 shared objects to a number of randomly selected nodes, ranging in number from 10 to 100. Each node then randomly queries a shared object every second. From Figure 9, we can observe that the performance of query a shared object (file) in the IPv6-based MANET is significantly better that that in ORION.

Figure 10 compares the average file search (S) and retrieval delays (R) of the proposed P2P system and ORION during 30 minutes. A query asking for the mapping information of an object occurs according to a Poisson process with parameter ? which ranges from 0.1 to 1.0. The result shows that the proposed P2P system significantly outperforms ORION. Intuitively, this is due to that ORION is based on flooding which yield too much control overhead.

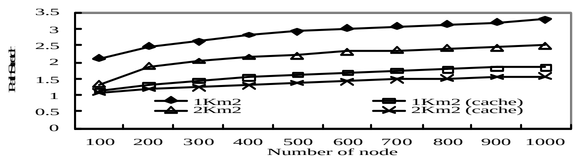


Figure 8. Routing cache performance-path stretch

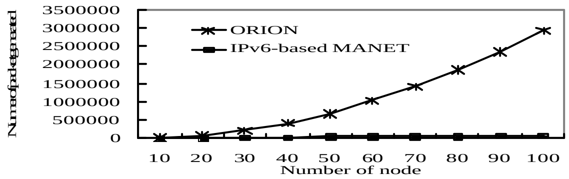


Figure 9. Performance of search shared object in IPv6-based MANET and ORION

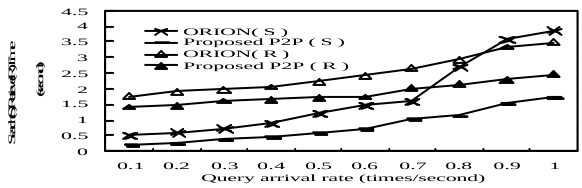


Figure 10. Comparison of search/ retrieve time of Proposed P2P and ORION

5. Conclusion

In this paper, we have proposed a self-organizing, self-addressing, self-routing IPv6-based MANET which supports global connectivity and IPv6 mobility. Unique features of our design include mobile hosts form a tree overlay automatically, self-configured logic address of a mobile host is used for IPv6 address configuration and MANET routing, efficient routing without exchanging routing information, on demand or periodically, the tree overlay also helps the development of a P2P file sharing system. Feasibility of the proposed IPv6-based MANET is demonstrated by a prototyping system. Simulation results also show the efficiency of the proposed routing and P2P system.

Several issues of the proposed IPv6-based MANET require further study. For example, we are designing a more efficient multicast routing protocol and a power saving protocol. Internet games (distributed virtual environment) over the proposed MANET are also under investigation.

Acknowledgment

The research is supported by Taiwan NICI IPv6 Steering Committee, R&D Division. Under contract number R-0401.

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