An Efficient Multi-hop ARP Scheme for Wireless LAN based Mesh Networks*

Sung-Hee Lee, and Young-Bae Ko

Graduate School of Information and Communication
Ajou University, Suwon, Republic of Korea
{sunghee, youngko}@ajou.ac.kr

Abstract – One of the important functions of wireless mesh networks is a multi-hop packet forwarding among fixed wireless routers. The current proposal for the IEEE 802.11s specification (i.e., the standardization effort for WLAN-based mesh networks) focuses on adding such a mesh functionality into wireless LAN devices in the MAC layer (L2). Here, a route discovery process for a destination will be based on its MAC address to find a multi-hop path towards the destination. Clearly, in order to achieve the destination's MAC address before route discovery, ARP request/reply packets will be delivered in a multi-hop fashion. This may cause significant bandwidth consumption due to uncontrolled ARP flooding. In this paper, we propose a novel multi-hop ARP scheme (MARP) for more efficient MAC address resolution in WLAN-based mesh networks.. Two different approaches are presented; one for utilizing a proxy ARP when there is a root portal available, and the other for integrating route discovery information into ARP request/reply frames (for on-demand route establishment) when there is no root portal available. The preliminary simulation results show that our proposed MARP reduces the end-to-end latency as well as the control packet overhead.

1. Introduction

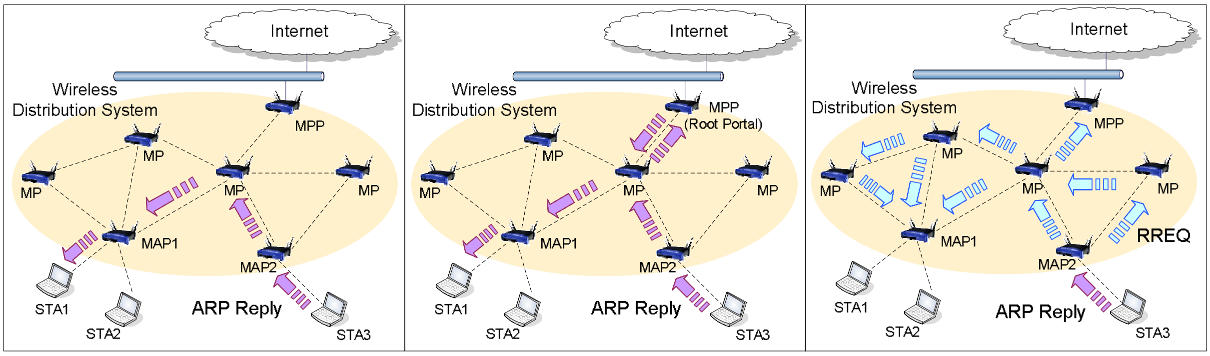
Recently, the wireless mesh network has become an exciting research area and a popular commercial application of the ad hoc network. In the traditional ad hoc network, freely moving nodes can participate in the network without any pre-built infrastructure. Instant network organization and mobility support are important for special purpose applications (e.g. military or disaster recovery), which are the main purposes to develop ad hoc technologies. However, due to their technical difficulties and inherent stand-alone feature, it is far from the viewpoint of public users who might want to access the Internet with low cost.

Wireless mesh networks consist of a number of fixed mesh routers that act as a wireless infrastructure. The multi-hop wireless connectivity among these routers can reduce the significant cabling cost for building infrastructure while supporting Internet access to the users. Therefore, wireless mesh networks are achieving commercial success compared to traditional ad hoc networks. Intelligent transportation systems, public safety and public internet access are expected to become popular commercial applications for wireless mesh networks [1].

A variety of mesh products and technologies [2] have driven international standardization activities to develop wireless mesh standards. Especially, the IEEE 802.11s TG has been playing a key role with the aim of enabling multi-hop communication between WLAN devices which constitute ESS (Extended Service Set) mesh to build a small-to-medium-scale wireless infrastructure [3]. Their current proposal defines several functions, such as mesh topology learning, path selection protocol, and forwarding scheme [4]. It also adopts some enhanced medium access mechanisms developed in previous standards, for example EDCA [5]. These functions shall be incorporated in the MAC layer because the IEEE standardization targets MAC and physical layers only. Although the 802.11s standardization activity is still on-going, most of major specifications are already defined, so just trivial changes will be made before adoption.

Some problems may newly arise when the MAC layer handles multi-hop packet routing/forwarding unlike many existing mesh implementations where the same is often handled in the network (IP) layer. Here, we address one such problem that might occur when the address resolution protocol (ARP) [6] is used without proper optimization. Note that any destination address supplied from the application layer is usually the IP address. Therefore, in general ARP is employed to achieve the corresponding MAC address of the target IP address,. If the destination's IP address belongs to the same subnet of a source node, an ARP request initiated by the source node will be disseminated within the entire subnet. After receiving the request, the destination sends back an ARP reply to the source node with its own MAC address, and hence the source can know the destination's MAC address.

* This work was supported by several grants: No. R01-2006-000-10556-0 from the Basic Research Program of the Korea Science & Engineering Foundation, the Ubiquitous Autonomic Computing and Network Project (the 21st Century Frontier R&D Program), and the ITRC (Information Technology Research Center) support program supervised by the IITA, the Ministry of Information and Communication(MIC) in Korea.



(a) Direct path (b) Via root portal (c) RREQ flooding

Fig. 1 Possible scenarios of ARP reply delivery

The IEEE 802.11s group's current proposal does not mention anything about the ARP mechanism. This is because ARP runs in the upper layer of the 802 standard, and hence out-of-scope. However, it is important to note that, in the IEEE 802.11s based mesh networks, ARP requests will be broadcasted within the entire WDS (Wireless Distribution System) according to the basic ARP mechanism similar to other wired LAN networks, resulting in the well-known *broadcast storm* problem [7]. In wireless networks, the broadcast storm caused by flooding consumes a lot of network bandwidth and significantly degrades the network performance. We believe that ARP requests will be repeatedly issued unless the destination MAC address is known, thus it might occur the broadcast storm and reduce the network performance. Moreover, in such a WLAN based mesh networks, ARP reply packets against the ARP request need to be delivered to the source in a multi-hop fashion. If a path to the source is unknown, this will require the destination node to issue an on-demand route request packet (RREQ) that would be flooded again to the whole network in the worst case. In this paper, we propose an efficient multi-hop ARP mechanism (MARP) to reduce the possible overhead of ARP flooding in the process of MAC address resolution. The proposed MARP consists of the two parts: *the use of proxy ARP with a root portal* and *the integrated ARP with a route discovery*.

The current proposal for the IEEE 802.11s specification defines a mesh portal (MPP) which acts as a bridge node between the IEEE 802.11 and non-802.11 networks (e.g. Ethernet). In the proposal, a mesh portal is also said to be designated as a root for tree based routing. If no root portal is available, on-demand routing is used. In our MARP, if there exists a root portal, a source node sends a 'unicast' ARP request to the root, and then the root responds with a proxy ARP reply to the source. Otherwise, on-demand route request information is integrated into the ARP request frame and route reply information is also integrated into the ARP reply frame to prevent redundant flooding caused by the route discovery process. Consequently, our scheme effectively reduces end-to-end latency as well as control packet overhead.

2. Problem Definition

In this section, we first describe the ARP delivery process in WLAN-based mesh networks, and then show some simulation results to support our argument of how negatively multi-hop ARP delivery would influence the network performance.

2.1 The ARP in WLAN-based Mesh Network

Fig. 1 presents an example that depicts the problem of multi-hop ARP delivery in WLAN-based mesh networks. In the figure, MP (Mesh Point) nodes relay frames to others in a router-like hop-by-hop fashion. MAP (Mesh AP) nodes are access points that provide a network service to the legacy IEEE 802.11 stations (STAs), and MPP is a mesh portal. Let us assume that STA1 associated with MAP1 wants to know the MAC address of STA3 associated with MAP2. Now, an ARP request initiated by STA1 will be converted to the IEEE 802.11s 4-address MAC header in the MAP1, broadcasted to the entire distribution system, and then eventually forwarded to the final destination, STA3, by MAP2. When STA3 sends back an ARP reply to STA1, there are several possible scenarios.

Fig. 1(a) represents the simplest scenario that MAP2 knows a direct path to the destination (i.e., STA1) already. In this case, MAP2 can simply use this path for delivering the ARP reply. Whereas, Fig. 1(b) represents the case when MAP2 does not know any path to the destination but knows the fact that there is a root portal. In this case, MAP2 forwards the ARP reply to the root portal. In the Hybrid Wireless Mesh Protocol (HWMP) which is a default path selection protocol [3] in the current IEEE 802.11s proposal, a MPP can be configured for building a tree based topology. It means that a MPP becomes a root portal to make a tree-shaped routing path rooted in itself, and other nodes send packets to the root unless they know a direct path to the destination. Since a root knows a path to each node, it can deliver the receiving ARP reply to the destination.

Finally, the scenario depicted in Fig. 1(c) shows the case when on-demand route discovery is necessary for

MAP2 because neither a path to the destination is known nor any portals do play a role as a root. That is, MAP2 broadcasts a RREQ frame to find a path to the destination. Notice that in this scenario, flooding may occur twice when a user intends to send only one data frame. In general, as can be seen in Table 1, the value for ARP timeout is much larger than that of active route timeout (5 seconds, recommended in the current proposal of IEEE 802.11s). Therefore, when a node needs to know the MAC address of a certain destination, the path to that destination would already be invalid with high probability. It clearly causes a RREQ flooding even after the flooding of ARP request. In the wireless network, flooding overhead is severe than in the wired network [7]. Although there is a root portal, ARP requests are always broadcasted within the entire network, degrading the network performance.

Table 1. Default ARP timeout values

Operating System	ARP timeout
Microsoft Windows 2k/XP	2 min
BSD	20 min
Solaris	5 min
Linux	1 min

2.2 A Simulation Study

We have performed a simulation study to examine how multi-hop ARP delivery impacts the network performance. We modified ns-2 [8] codes to emulate the operation of the WLAN mesh network based on the current proposal for the IEEE 802.11s standard. As seen in Fig. 2 for the modified block diagram, we replaced the routing agent to the dummy agent in the network layer so that the application data directly pass to the lower layer. The L2 routing agent lies under the link layer to resolve routing paths with the MAC address. As a result, an ARP request is generated before initiating the route discovery operation and forwarded within the entire network.

In our simulation model, total 32 nodes are randomly deployed in $1000m \times 1000m$ square area, and one of them is configured as a mesh portal. We assume the last scenario in the previous section, so a portal does not make a tree-shape route path, and the only on-demand route discovery is performed. A packet is sent at every half second with 512-byte payload. We vary traffic patterns according to how many packets are destined to the Internet. Packets towards the Internet are sent to the mesh portal, but other packets are sent to randomly selected destinations within the network. Total simulation time is 200 seconds and we repeat each scenario five times with different random seed numbers. Link speed is set to 11Mbps.

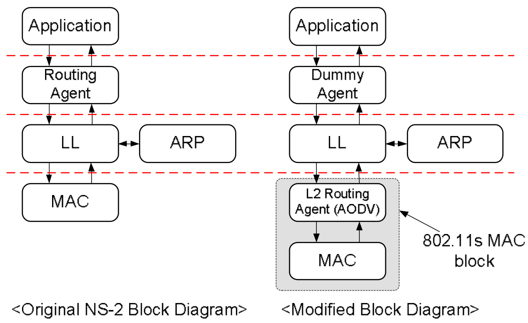


Fig. 2 Ns-2 modification

Fig. 3 depicts the proportion of the total size of control and data packets. When all traffic is sent towards the Internet, control packet overhead including ARP and RREQ/RREP is relatively small. Since the destination is always the mesh portal, each node requires route discovery and ARP request/reply to be performed only once. However, when all traffic is internal, the total size of control packets increases up to almost half of the entire traffic.

We measure the end-to-end latency and compare it with the ideal case that every node already knows MAC addresses of all other nodes. In this case, ARP is not employed. We observe that the end-to-end latency with ARP is average 10 times longer than ideal case as shown in Fig. 4. We believe, this is due to the time from sending an ARP request to receiving an ARP reply.

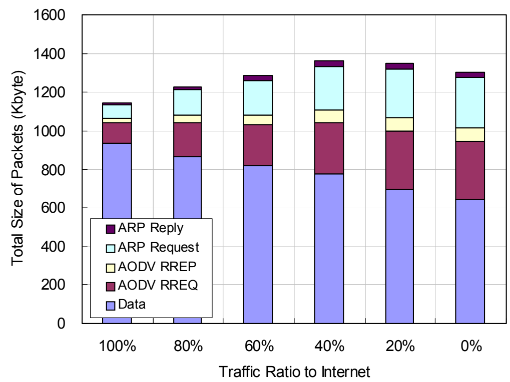


Fig. 3 Total size of control and data packets

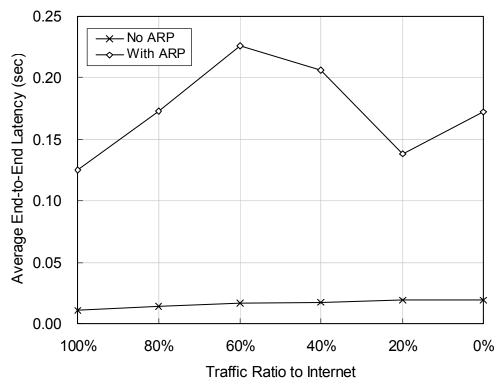


Fig. 4 Average end-to-end latency

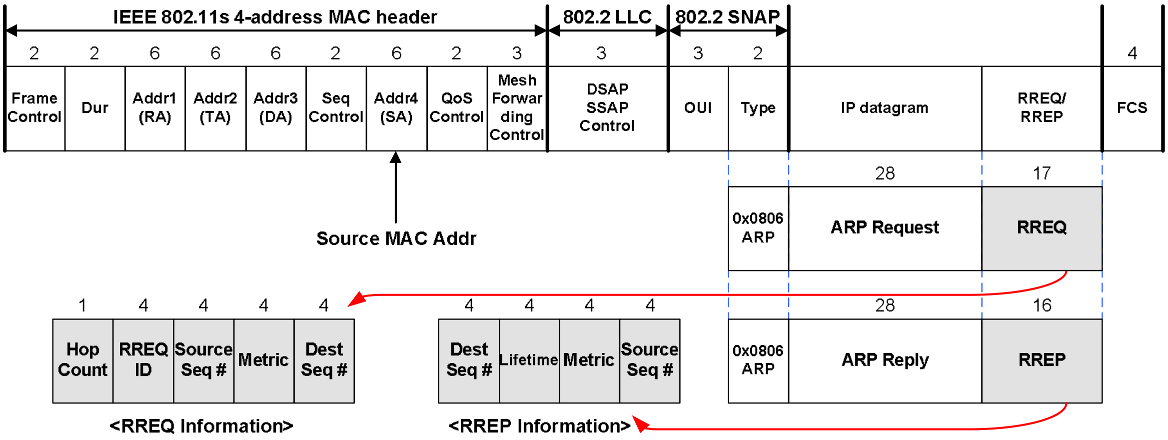


Fig. 5 Extended ARP packet format

From the simulation result above, we prove that the current multi-hop ARP delivery significantly increases end-to-end latency and also consumes network bandwidth. To alleviate this problem, we investigate an efficient multi-hop ARP delivery scheme for wireless LAN based mesh networks.

3. Proposed Scheme: Multi-hop ARP

The proposed Multi-hop ARP (MARP) scheme can be divided into two parts, based on the network environment. The first part is for the situation when there exists a root portal and tree based routing is enabled. The second case does not have a root portal and exploits an on-demand routing protocol.

3.1 Proxy ARP in the Root Portal

The basic idea here is that a node unicasts a ARP request to the root portal, expecting a corresponding ARP reply from the portal[1]. To do this, the root portal must know the MAC and IP addresses of every node in the network. In the current IEEE 802.11s proposal [3], a root portal is defined to periodically send root announcement messages. Then, intermediate nodes are required to propagate these messages and proactively setup reverse paths towards the root portal to build a tree topology. As a result, every node can know a path to the root.

In the proposed scheme, when a node receives a root announcement message, it sends a unicast gratuitous ARP to the root portal. A gratuitous ARP is an ARP request with the destination IP address same as the sender's IP address. Generally, a node broadcasts gratuitous ARP to check for a duplicate IP address during the network initialization time. However, in our scheme, a node unicasts a gratuitous ARP in order to notify the root of its own IP and MAC addresses. If a node is a MAP, it is recommended to send additional gratuitous ARP packets of its client stations. Consequently, a root portal knows MAC and IP addresses of every node in the network, and it can reply to ARP requests for any node in the network. However, if a root portal receives an ARP request for an unknown destination, it broadcasts an ARP request to achieve the MAC address of this destination.

3.2 Integrated ARP and Route Discovery

As mentioned earlier, when the root portal does not exist, wireless LAN mesh requires to use on-demand routing schemes. The novelty in our scheme is to combine ARP flooding and the route discovery process.

Fig. 5 illustrates an ARP encapsulation in the wireless LAN and our extended ARP packet format including route discovery information. The IEEE 802.2 LLC encapsulates an IP datagram and ARP request / reply on the IEEE 802 networks [10]. From the type field in the 802.2 SNAP (Sub-Network Access Protocol) header which is an extension of the LLC header, a protocol used in the network layer can be distinguished as IP or ARP. We insert RREQ information at the end of the ARP request and RREP information at the end of the ARP reply message. We simply added extension fields at the end of the current ARP frame format, so this additional information can be easily ignored for backward compatibility.

Based on the proposed MARP, a node sends an ARP request integrating RREQ information. Receiving this packet, intermediate nodes extract RREQ information from the packet, and they check their route table. If a route for the source of the ARP request packet exists in the route table, the node updates this entry. Otherwise, it creates a new entry for the source node, and also creates a 'temporary' entry for the destination node. When the ARP request is sent, the destination MAC address is yet unknown, so intermediate nodes could not make a valid entry for the destination. Therefore, in the temporary entry, the destination address is the IP address according to ARP request information.

[1] Basically, it is similar to the proxy ARP mechanism presented in [9].

When the destination node replies to the received ARP request, it appends RREP information to the ARP reply. After receiving an ARP reply, intermediate nodes check the route table again. If a temporary entry exists that corresponds to the source IP address[2] in the received ARP reply, that node substitutes the corresponding MAC address in the ARP reply for the IP address in the temporary entry and updates it as the valid entry.

Intermediates nodes need to process integrated messages and to update their route table, so we insert MARP Packet Capture Module in the MAC layer as shown in Fig. 6. MARP module captures received broadcast data frames and check type fields in the 802.2 LLC headers. If a captured frame turns out to be an integrated ARP request or reply, it accesses the route table and updates the appropriate route entry.

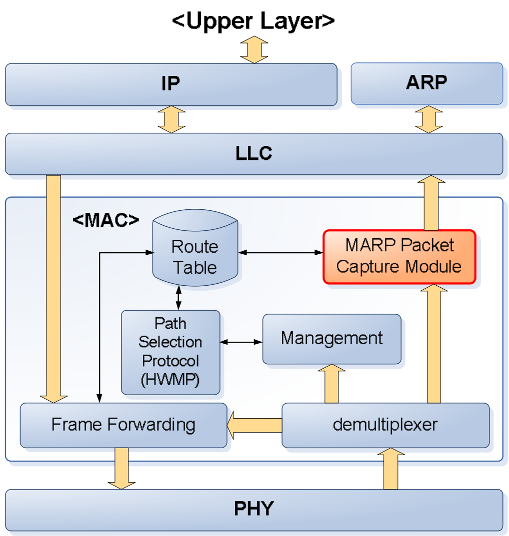


Fig. 6 Block diagram of MARP

4. Performance Evaluation

For the evaluation purpose, the proposed MARP is compared to the basic ARP and no ARP. The basic ARP is performed without any interaction to the MAC layer for optimization purpose. It is exactly same with the operation explained in section 3. No ARP is the ideal case that every node already knows MAC addresses of all other nodes, and hence ARP is not employed.

Our simulation environment is based on the second part of the proposed MARP. There is no root, and hence all nodes are fully distributed. AODV is used for on-demand route discovery. Now, we investigate to make an implementation of the current proposal of the IEEE 802.11s standard into ns-2, but this work is not completed yet. Therefore, we only show preliminary results of the simulation study in this paper. Simulation parameters are the same with the one described in section 2.

Fig. 7 compares the control packet overhead of the proposed MARP with others. We define the control packet overhead as the total size of forwarded control packets including ARP request/reply and RREQ/RREP. Although control packet overhead increases as the traffic ratio towards the Internet decreases, MARP always shows smaller overhead than the basic ARP mechanism. The reduced packet overhead of the proposed MARP is minimum 20% and maximum 52%. This result reflects the fact that MARP effectively reduces control packets by integrating ARP and RREQ flooding together.

As shown in Fig. 8, we observe the end-to-end latency of MARP is almost same with the ideal case that ARP is not employed. However, the basic ARP mechanism shows 10 times longer latency time. This is because, RREQ broadcasting contends with previous ARP broadcasting, so these consecutive broadcasted packets interfere and disturb with each other. Consequently, it delays the time to receive the ARP reply and to send the data packet.

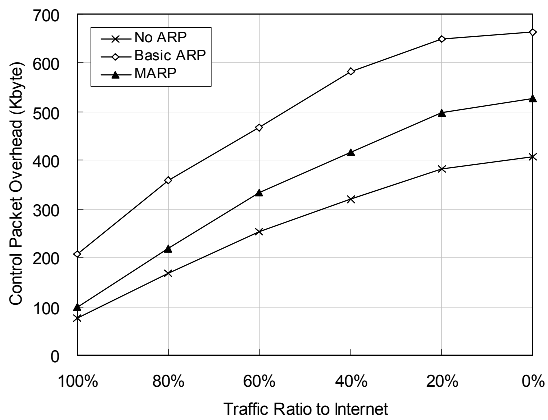


Fig. 7 Control packet overhead

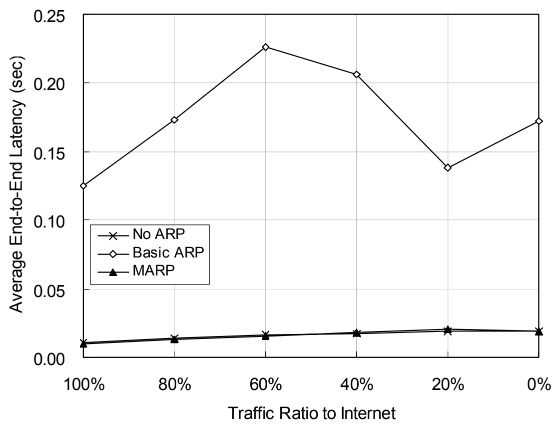


Fig. 8 Average end-to-end latency

[2] The source address in the ARP reply is same with the destination address in the ARP request.

5. Related Works

Several testbeds have been established to carry out research and development for wireless mesh networks in the academic research labs [11, 12, 13, 14]. These testbeds are usually equipped with the IEEE 802.11 WLAN devices. Routing agents such as AODV/DSR or their variants are used to handle multi-hop packet forwarding in the IP layer (L3). These routing agents can be easily modified as software modules in the Linux environment, and source codes of famous routing protocols such as AODV are freely distributed. A few companies have been developing their own products and solutions for commercial success of mesh networks [2]. They integrate existing Wi-Fi devices with their proprietary software modules for multi-hop communication and network management. Also, some companies have developed their own radio interfaces which are not compatible with existing devices [15].

In [16], the authors have proposed a lightweight routing protocol for ad hoc networks, named LUNAR. LUNAR is implemented at layer 2.5 and all nodes appear as being one IP-hop away. LUNAR defines their own packet format to encapsulate IP datagram and control messages named XRP (eXtensible Resolution Protocol) for route discovery. XRP is triggered when a node wants to resolve the MAC address of some target. Intermediate nodes create a bidirectional tunnel for packet forwarding between the source and the destination when receiving XRP requests and replies. Although the architecture of LUNAR has a lot of similarities to WLAN based mesh networks, it has several limitations. For example, the authors limit the maximum hop to 3 hops that is the boundary for the efficiency of the LUNAR protocol. Moreover, it is not compatible with the new standards such as the IEEE 802.11s.

6. Conclusion

In this paper, we concentrate on the possible problems when the wireless LAN based mesh network (e.g. IEEE 802.11s) is deployed. We have shown that the current ARP mechanism might consume significant network bandwidth unless proper optimization is adopted. To alleviate this problem, we propose an efficient multi-hop ARP mechanism, named MARP. The proposed MARP utilizes proxy ARP and integrates route request/reply information into ARP request/reply frames for on-demand route establishment. Our preliminary result shows the proposed MARP reduces end-to-end latency as well as control packet overhead. Future work would include extended simulation results and experiments on the mesh testbed.

References

[1] R. Bruno, M. Conti, and E. Gregori, “Mesh Networks: Commodity Multihop Ad Hoc Networks,” *IEEE Communication Magazine*, Mar. 2005. pp. 123-131

[2] I. F. Akyildiz, X. Wang, and W. Wang, “Wireless mesh networks: a survey,” C*omputer Networks Journal (Elsevier)*, Mar. 2005.

[3] IEEE 802.11 TGs, “Joint SEE-Mesh/Wi-Mesh Proposal to 802.11 TGs,” Feb. 2006.

[4] M. J. Lee, J. Zheng, Y.-B. Ko, and D. M. Shrestha, "Emerging Standards for Wireless Mesh Technology," *IEEE Wireless Communications*, Apr. 2006.

[5] IEEE Computer Society, “Amendment: Medium Access Control (MAC) Quality of Service (QoS) Enhancements,” IEEE Std 802.11e™-2005

[6] D. C. Plummer, “An Ethernet Address Resolution Protocol,” IETF RFC-826

[7] S.-Y. Ni, Y.-C. Tseng, Y.-S. Chen, and J.-P. Sheu, “The broadcast storm problem in a mobile ad hoc network,” in Proc. *fifth Annual ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom)*, pages 151.162, 1999.

[8] *ns-2*, the network simulator. Available from: http://www.isi.edu/nsnam/ns

[9] S. Carl-Mitchell, and J. S. Quarterman, “Using ARP to Implement Transparent Subnet Gateways,” IETF RFC-1027

[10] J. Postel, and J. Reynolds, “A Standard for the Transmission of IP Datagrams over IEEE 802 Networks,” IETF RFC-948

[11] D.A. Maltz, J. Broch, and D. B. Johnson, “Lessons from a fullscale multihop wireless ad hoc network testbed,” *IEEE Personal Communications* 8 (2001), pp. 8–15

[12] J. Bicket, D. Aguayo, S. Biswas, and R. Morris, “Architecture and Evaluation of an Unplanned 802.11b Mesh Network,” *The Eleventh Annual International Conference on Mobile Computing and Networking (MobiCom)*, 2005.

[13] UCSD mesh networks testbed. Available from: http://www.calit2.net/

[14] BWM-Mesh testbed of The Broadband and Wireless Network (BWN) Lab. at Geogia Institute of Technology. Available from: http://www.ece.gatech.edu/research/labs/bwn/mesh/testbed.html

[15] Motorola Mesh Networking Technology. Available from: http://www.motorola.com/mesh/

[16] C. Tschudin, R. Gold, O. Rensfelt and O. Wibling, “LUNAR: a Lightweight Underlay Network Ad-hoc Routing Protocol and Implementation,” *Proc. of Next Generation Teletraffic and Wired/Wireless Advanced Networking (NEW2AN)*, 2004.