AN ENHANCED MAC PROTOCOL STACK FOR MANETs

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ABSTRACT

This paper deals with design goals to provide seamless connection to the Internet when mobile hosts roam between MANETs and to achieve load-balancing routing when mobile hosts have multiple gateways available. We address three issues in this paper namely IP address resolution, mobility management under NAT structure, and load-balancing routing. Mobile IP and NAT traversal are adopted to provide seamless roaming capability in private networks. A load-balancing routing protocol was implemented to relieve the bottleneck problem. A prototype is implemented on Windows platform to verify our architecture and test results do show the benefit of load-balancing routing.

I. INTRODUCTION

Due to its flexibility, Mobile Ad Hoc Network (MANET) has attracted a lot of attention recently. Most existing works, however, limit a MANET as a stand-alone network. In this paper, we propose a multi-tier MANET by extending the connectivity of the MANET to the Internet and voice-networks. Some hosts in the MANET are equipped with cellular interfaces and are called gateways, which can provide Internet connections. Such extension would greatly improve the connectivity of MANET.

With the advance of embedded computing technologies, portable devices, such as laptops, Personal Digital Assistants (PDAs), and cellular phones, have been widely used. A portable device usually has several wireless interfaces, such as IEEE 802.11 Wireless LAN (WLAN), General Packet Radio Service (GPRS), Personal Handy-phone System (PHS), and/or Bluetooth. Wireless communications are typically supported in two models: infrastructure and ad hoc. Of these two options, forming a mobile ad hoc network (MANET) is more flexible since it is independent of the availability of base stations. Hence, intensive research has been dedicated to MANET [1, 2].

A MANET is typically considered as a stand-alone network. However, it is important to enable its Internet accessibility. On one hand, users in a MANET can enjoy the tremendous resources in the Internet. On the other hand, the connectivity between multiple MANETs may be greatly improved. For such connectivity, several works [4, 5, 6, 7] have proposed possible architectures by deploying gateways to help mobile hosts route packets to the Internet. Among these approaches, some takes a proactive approach by modifying DSDV [4], some takes a reactive approach by modifying AODV [5, 6], while some takes a hybrid approach [7]. In this paper, we propose a multi-tier MANET architecture in which broadband WLANs (such as IEEE 802.11 a/b/g) are equipped in all mobile stations to form the low-tier network, and cellular interfaces (such as GPRS/PHS/3G) are equipped in some stations to form the high-tier network. Stations with high-tier interfaces are called gateways and can connect to the Internet. Depending on its service range, each gateway together with the stations whose Internet connections are supported by the gateway constitutes a sub-MANET. The MANET under our scope is a collection of multiple sub-MANETs.

In this paper, we address several important design issues in MANET architecture. First, a dynamic IP address resolution is proposed. Second, observing that most cellular networks are considered private networks, causing Mobile IP [8] not usable, we propose how a station seamlessly roams between sub-MANETs without suffering from disconnection. In particular, we consider a MANET as a private network and propose NAT (network address translation) traversal mechanisms to support IP mobility under our two-tier architecture. Third, gateways in our environment are heterogeneous in nature (we allow mixture of GPRS/PHS/3G interfaces for gateways) and may become bottlenecks to the Internet. We have successfully prototyped such a MANET architecture by properly modifying Dynamic Host Configuration Protocol (DHCP) and Mobile IP and integrating them under our load-balancing routing protocol known as RITA (Routing In Total Ad-Hoc) [14].

II. NETWORK ARCHITECTURE

We consider a set of mobile hosts forming a MANETs. Each host is equipped with an IEEE 802.11 WLAN card, and these interfaces form the low-tier network. The Destination-Sequenced Distance Vector (DSDV) routing protocol [3], which adopts a proactive approach, is used on the low-tier network. A number of hosts are designated as *gateways*. Each gateway host is equipped with an extra cellular interface, such as PHS or GPRS, which enables the host to access infrastructure networks (and thus the Internet). Cellular interfaces with Internet access capability form the high-tier network. Note that these interfaces can be heterogeneous. The MANET can be physically connected (through the low- or high-tier network) or disconnected. Each gateway together with the stations whose Internet connections are supported by it is called a *sub-MANET*. A set of stations that forms a connected component but does not have a gateway inside is disconnected from the MANET and is not allowed to connect to the Internet. When the network topology changes or then gateways change their points of attachment, handoff procedure may be taken. To support seamless roaming, we adopt Mobile IP with the co-located address mode [8]. Hosts rely on their home agents to maintain their connections while roaming. Note that the high-tier interfaces may also use private IP addresses, making traditional Mobile IP unusable. Several solutions [9, 10, 11] have been proposed to support IP mobility under private networks. We apply the NAT traversal mechanism [9] to achieve seamless roaming in private networks. As mentioned earlier, we allow heterogeneous cellular interfaces in the high-tier network

III. PROTOCOL DESIGN

Our design goal is to provide seamless connection to the Internet when mobile hosts roam between MANETs and to achieve load-balancing routing when mobile hosts have multiple gateways available. We address three issues: IP address resolution, mobility management under NAT structure, and load-balancing routing. However, the full treatment of each of these issues is beyond the scope of this paper.

III.1 Address Resolution

A DHCP server is installed in each gateway. Before communicating with other hosts, a mobile host needs to retrieve an IP address from a gateway. To avoid confusion, we assign an exclusive section of IP addresses to each DHCP server. Note that we also allow a host to use its old IP address after roaming into a new sub-MANET. When a new mobile host ‘n’ joins the MANET, it first broadcasts a *DHCP_discover*. Three nodes, *j*, *k*, and *m*, belonging to two sub-MANETs, receive the request and help forwarding the request to their DHCP servers. To avoid the *broadcast storm* problem [12], the forwarding is done by unicast. This can be achieved by configuring each internal mobile host as a DHCP relay.
The *DHCP_Discover* is forwarded by the DHCP relay to the DHCP server via RITA routing. The DHCP server then replies a *DHCP_Offer* by including an available IP address. Note that the host may receive multiple offers from several servers. So the host will broadcast a *DHCP_Request* to notify all DHCP servers the IP address that it selects. Again, the notification will be supported by unicast. The selected server then replies a *DHCP_Ack* if the IP is still available. Afterward, the *Duplicate Address Detection* (*DAD*) procedure will be executed to ensure that no other host is using the same IP address. There is also a parameter, called *lease*, after which the mobile host has to renew its temporary IP address with the same DHCP server. After obtaining an IP address, the host will turn itself into a DHCP relay of the DHCP server that it selects.

III.2 Mobility Management in Private Networks

Mobile IP [8] can maintain seamless connection for mobile hosts while roaming. In Mobile IP, a mobile host can use a co-located care-of address (CCoA) or a foreign-agent care-of address (FACoA) if there is a foreign agent in the foreign network. If the latter approach is adopted, routing in the low-tier network would cause problem because all hosts will use the same FACoA. Besides, agent advertisement in a MANET may also cause the broadcast storm. Consequently, we adopt the former approach in this work, and use DHCP to provide CCoAs. When a mobile host retrieves a CCoA, it registers to its home agent. The home agent will tunnel all packets destined to the mobile host here after to its CCoA. Unfortunately, the typical Mobile IP does not allow mobile hosts to roam into private networks because home agents cannot tunnel packets to a private CCoA. The other reason is that the original IP-in-IP tunnels hide port information, making NAT servers unable to do the translation. To maintain correct tunnels to mobile hosts in private networks, we adopt a mechanism called *NAT traversal* [9].

III.3 Load-Balancing Routing In RITA

A load-balancing routing protocol is designed to help mobile hosts choose their gateways. We adopt the RITA routing in [14] in our implementation. RITA tries to dynamically establish boundaries between gateways' service ranges by taking the load indices of gateways and the traffic loads of hosts into account. This scheme is fully distributed and can be run by each host independently. Each gateway g will periodically broadcast advertisement messages containing its current load index (*Lg*), which is the ratio of the traffic load of its high-tier interface to the maximum bandwidth of its high-tier interface. Each host *x* should keep a record of the load index of its current serving gateway. When a host *x* hears an advertisement from any gateway g, the following rules are executed:

1. If *x* currently has no serving gateway, it chooses *g* as its serving gateway by recording *g*'s current load index and setting the host leading to *g* with the shortest distance as its default gateway. Then *x* rebroadcasts the advertisement.
2. If *g* is already *x*'s serving gateway, *x* should update *g*'s index as necessary and rebroadcast the advertisement.
3. If *g* is different from *x*'s current serving gateway, say *g*', then *x* will update *g* as its serving gateway with a predefined gateway-switching probability *Pg* only if *x* has accepted *g*' as its serving gateway for over a time period.

IV. IMPLEMENTATION DETAILS

We have implemented a prototype in an environment with five IBM laptops, and each with an 802.11b NIC working in ad hoc mode to form the lowtier network. Two of them are equipped two PHS handsets to form the high-tier network. The operating system is the Windows 2000 Advanced Server supporting the following services. First, we activate the "Internet Connection Sharing" service on gateways to share their Internet connections with other hosts. Second, the "DHCP Server" service is also opened in each gateway. Third, the "Routing and Remote Access" service is activated in each host to offer routing services and to drive the TCP/IP forwarding engine.

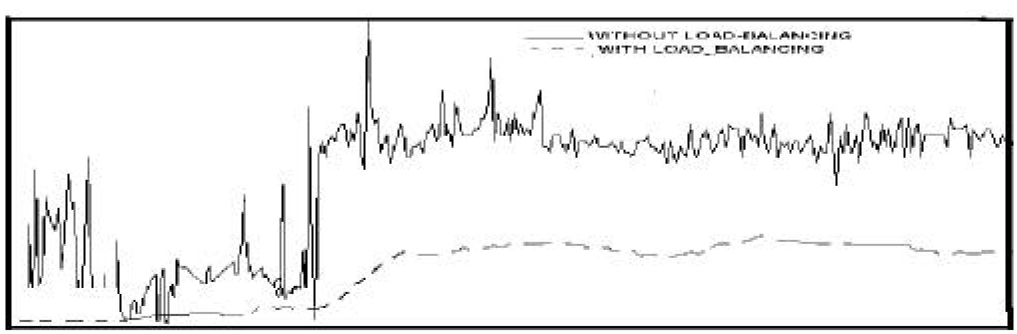

Fig.1: Trace of TCP/IP connectivity of Mobile Nodes in the MANET deployed in Lab.

We also modify the Windows protocol structure to enable hosts to communicate with other hosts inside and outside the MANET. We intercept and encapsulate packets from the TCP/IP layer destined outside the MANET. The encapsulated packets will be sent back to the TCP/IP layer and wait to be transmitted. Note that packets destined inside the MANET will not be intercepted. Next, we introduce some tricks to manage routing tables. Recall that each mobile host has a home address and a CCoA. Since Windows picks the address with the same prefix as the default gateway as the source address for any IP packet without a route entry, we set each mobile host's default gateway as the home agent of the host. As a consequence of this, packets destined outside the MANET cannot be routed correctly because the default gateway is not correctly set to the serving gateway of each sub-MANET. The trace of Internet connectivity for the MANET architecture deployed in our lab is shown in Fig. 1.

V. CONCLUSION

In the literature, most works consider a MANET as a stand-alone network. In this paper, we design a multi-tier MANET, considering gateways as bridges to the Internet. This greatly improves the connectivity of MANET because cellular networks nowadays are almost globally available. However, Internet connectivity does cause several problems: address configuration, connection maintenance when roaming, and traffic bottleneck on gateways. In this paper, we show how to configure a MANET as a private network and modify DHCP to avoid possible broadcast storms.

Mobile IP and NAT traversal are adopted to provide seamless roaming capability in private networks. A load-balancing routing protocol was implemented to relieve the bottleneck problem. A prototype is implemented on Windows platform to verify our architecture and testing results do show the benefit of load-balancing routing.

REFERENCES

[1] C. E. Perkins, *Ad Hoc Networking*, Addison-Wesley, Boston, MA, USA, 2001.
[2] E. M. Royer, and C.K. Toh, "A review of current routing protocols for ad hoc mobile wireless networks", *IEEE Personal Communications*, Apr. 1999, pp. 46–55.
[3] C.E. Perkins, and P. Bhagwat, "Highly Dynamic Destination Sequenced Distance Vector (DSDV) Routing for Mobile Computers", *Communications Architectures, Protocols and Applications*, ACM Press, 1994, pp. 234-244.
[4] Y.-C. Tseng, C.-C. Shen, and W.-T. Chen. "Mobile IP and ad hoc networks: An integration and implementation experience", *IEEE Computer*, 36(5), May 2003, pp. 48–55.
[5] H.-W. Cha, J.-S. Park, and H.-J. Kim, "Support of Internet Connectivity for AODV", I-D draft-cha-manet-AODV-internet-00.txt, Feb. 2004.
[6] C. E. Perkins, R. Wakikawa, A. Nilsson, A. J. Tuominen, "Internet connectivity for mobile ad hoc networks", Wireless Communications and Mobile Computing (WCMC) 2002.
[7] P. Ratanchandani, R. Kravets, "A hybrid approach to internet connectivity for mobile ad hoc networks", Proceedings of IEEE Wireless Communications and Networking Conference (WCNC) 2003.
[8] C. Perkins, Ed., "IP Mobility Support for IPv4", RFC 3344, August 2002.
[9] H. Levkowetz, S. Vaarala, "Mobile IP Traversal of Network Address Translation (NAT) Devices", RFC 3519, April 2003.
[10] T. Kato, A. Idoue, H. Yokota, "Mobile IP using private IP addresses", Sixth IEEE Symposium on Computers and Communications, July 2001.
[11] A. Idoue, T. Kubo, H. Yokota, T. Hasegawa, and Ohashi, M., "Global roaming among mobile IP networks operated by different administrative domains support of incoming/outgoing calls for mobile nodes having private addresses", *IEEE Wireless Communications and Networking*, March 2003.
[12] S.-Y. Ni, Y.-C. Tseng, Y.-S. Chen, and J.-P. Sheu, "The Broadcast Storm Problem in a Mobile Ad hoc Network", ACM/IEEE International conference on Mobile Computing and Networking, 1999.
[13] C.-F. Huang, H.-W. Lee, and Y.-C. Tseng, "A Two-Tier Heterogeneous Mobile Ad Hoc Network Architecture and Its Load-Balance Routing Problem", IEEE VTC, 2003-Fall.
[14] Rahul Bhattacharya, P. Venkateswaran, S.K.Sanyal, R. Nandi, "RITA-An Efficient Routing In Total Ad Hoc Networks", M.V. Chauhan IEEE Reasearch Paper Contest, INDICON-2004.