MEWLANA-Mobile IP Enriched Wireless Local Area Network Architecture

Mustafa Ergen, Anuj Puri

***Abstract*— The idea of extending Mobile IP capabilities to ad hoc networks introduces fast agent discovery, increases cell coverage of access points, and extends ad hoc network size by providing connection to the Internet. We aim to show that an adaptive protocol is required since different protocols are optimum for different environments. We propose two protocols called MEWLANA-TD and MEWLANA-RD based on DSDV and a novel ad hoc routing called Tree Based Bidirectional Routing (TBBR) respectively in addition to the proposed protocols based on on-demand routing. We classify the ad hoc environment into regions and present which protocol is appropriate for which region.**

***Index Terms*—MEWLANA, Mobile IP, Mobile ad hoc Network, GPS, Mobility Management, Extensions to Mobile IP.**

I. INTRODUCTION

Wireless communication has generated an explosive growth in the number of laptop computers and personal digital assistants (PDA) with the advancement in computer and wireless networks. Wireless networks can be classified into two types: networks with infrastructure (i.e., networks with base stations, gateway and routing support) and networks without infrastructure (i.e., ad hoc networks). Mobile IP has been proposed for networks with infrastructure by the IETF [1], [3]. Mobile IP tries to solve the problem of how a mobile may roam from its network and still maintain connectivity to the Internet. In contrast to the networks with infrastructure, ad hoc networks are formed purely by dynamically connected mobile nodes. All nodes in these networks behave as routers and take part in discovery and maintenance of routes to other nodes in the network. The ad hoc networks are used in military when a network needs to be set-up quickly, in rescue missions during times of a national crisis when the existing communication infrastructure is non-operational, or during meetings or a conference when a network needs to be set-up among the participants. There has been a significant amount of research done on Mobile IP [1], [2], [3] and on ad hoc wireless networks [4], [5]. Mobile IP allows a user to roam but requires that the user be directly connected to a base station. ad hoc networks are usually small in scale and a user may roam within them. In this paper we extend the capabilities of Mobile IP to ad hoc wireless networks. This allows ad hoc networks to be connected to base stations and allows a user to roam between ad hoc networks.

M. Ergen is a Ph.D. student at the Department of Electrical Engineering and Computer Science of University of California Berkeley, California, USA (email: ergen@eeecs.berkeley.edu).

A. Puri is a research professor at the Department of Electrical Engineering and Computer Science of University of California Berkeley, California, USA (email:anuj@eecs.berkeley.edu).

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The type of ad hoc routing used may depend on the ad hoc network size and the intensity of the traffic inside the ad hoc network. Previous research on this topic has focused on on-demand ad hoc routing protocols. In this paper we present Mobile Enriched Wireless Local Area Network Architecture (MEWLANA) that covers the remaining ad hoc routing types by proposing two different protocols: MEWLANA-TD and MEWLANA-RD. MEWLANA-TD is designed for table driven routing protocols and MEWLANA-RD uses a novel tree based ad hoc routing protocol.

MEWLANA-RD's solution can be extended to cellular phones in order to run them in ad hoc mode. This helps to reduce power consumption in phones and increase bandwidth efficiency of the base station.

The rest of the paper is organized as follows. Section 2 presents our motivation and discusses the previous work on this topic. Section 3 explains our protocol. Section 4 gives the performance analysis of the protocol under different environments. Section 5 discusses possible application and section 6 concludes the paper.

II. MOTIVATION AND PREVIOUS WORK

There has not been extensive research on the problem of extending Mobile IP (MIP) capabilities to an ad hoc network. One of the work is "MIPMANET: Mobile IP for Mobile ad hoc Network" [6] and another one is "Adding ad hoc Network Capabilities to Cellular IP" [7]. They both rely on on-demand routing as an ad hoc routing protocol. Their differences are that the former includes the foreign agent (FA) into the ad hoc network and uses Ad Hoc On Demand Distance Vector (AODV) as the routing protocol and the latter excludes FA from the ad hoc network and uses Dynamic Source Routing (DSR) as the routing protocol. Those designs suffer from high overhead of foreign agent advertisement messages (beacons). On the other hand, "Ad hoc Networking with Mobile IP" uses table driven (proactive) routing protocols with a modified RIP [8]. All these protocols are corner stones on this topic but they are not complete in the sense that using one type of ad hoc routing protocol does not cover the new issues which arise when MIP and ad hoc networking are merged and performance comparisons of sole ad hoc routing protocols become invalid because MIP is involved. Thus, the protocol designs based on the state of the art most efficient ad hoc routing protocol does not have to give efficient result in all cases because user expectations and situations vary. Therefore, efficient protocols can be designed with different type of ad hoc routing protocols for different environments. For example, let's distinguish the traffic as inside traffic where source and destination are in the same ad hoc routing domain and outside traffic where source and destination are in different domains. Inside traffic intensity is higher in a classroom where people know each other and connect with peers than in a subway where people rarely needs to connect to each other. Size of the network is larger in a conference room than in a small scale classroom or in a rescue mission. In addition to on-demand and table driven routing protocols, we introduce a novel ad hoc routing type called root driven routing. Using this protocol in networks where the intensity of the inside traffic is negligible makes this protocol efficient by eliminating the routing overhead. The main idea of our algorithm is formation of a tree whose root is FA and branches are mobile nodes (MN), and periodical initiation of this tree formation procedure by root.

In order to take into account these different cases, we designed two protocols called MEWLANA-TD which uses table driven routing type and MEWLANA-RD which uses root driven routing type. MEWLANA-TD uses Destination Sequenced Distance Vector (DSDV) routing protocol in which there is a trigger of the update either periodically or when there is a change in the routing table. DSDV enables each node have an entry in their routing table for all other nodes. MEWLANA-RD uses Tree Based Bidirectional Routing (TBBR) as the routing protocol. TBBR is a special routing protocol designed only by using MIP entities and introduces low overhead at the expense of performance degradation for inside traffic.

After describing the protocol MEWLANA, we will classify all protocols with the environments where they show optimum performance.

III. MEWLANA

Internet is considered as a three domain structure in order to have a clear understanding of the protocols. These are the Internet domain, the FA domain and the ad hoc domain. Internet Domain represents the Internet cloud and consequently includes home agents (HA) and correspondent hosts (CH). FA domain is considered as FA and MNs that are one hop away from FA. ad hoc routing domain is occupied with MNs. In our designs FA does not belong to the ad hoc domain and consequently does not use ad hoc routing. We take this approach in order to provide a clean cut distinction between ad hoc routing protocol and Mobile IP protocol and to make it compatible with IPv6 and co-located care of address.

MEWLANA architectures consist of FA agent discovery, MN registration, tunnelling and routing mechanisms for supporting this seamless routing problem. We consider broadcast type agent advertisement messages. We use agent advertisement and beacon interchangeably and they are always broadcast unless otherwise noted. Although agent solicitation is also a proposal for eliminating the overhead of agent advertisement, it is applicable only when there is a low demand for outside traffic and when some of the nodes may not want MIP service, In order to not to bother those MNs, FA does not advertise itself by broadcasting agent advertisement messages but MN who search for a FA send agent solicitation messages and then FA periodically unicasts the agent advertisement messages to those who are connected. But if there is a high demand for outside traffic, the overhead from agent advertisement may be balanced by the increase in agent solicitation.

A. MEWLANA-TD

MEWLANA-TD uses DSDV which is one of the well known table driven routing algorithm. It can also be extended to other table driven routing protocols as well. Network structure is shown in Fig. 1a.

1) Agent Discovery: In Mobile IP, agent advertisement message which is a variation of ICMP message is used in order to make MNs aware of the FA presence. In MEWLANA-TD, the situation is different. Agent advertisement message is not only sent to MNs inside FA domain like in basic Mobile IP but also duplicated by the MNs in order to spread the FA presence through the depth of the ad hoc domain. Agent advertisement messages include care of address (CoA), source address, and hop count. CoA will be the new gateway point to MNs and remains the same throughout the spreading process. Source address is the address of the node that is sending. Hop count is incremented each time the advertisement message is duplicated. These messages help the MNs to discover the access point to the Internet. In Figure 1, after getting the agent advertisement message, MN1 set the source address of the packet as the default gateway and learns its new CoA. After updating its CoA, MN1s send the agent advertisement message again by changing the source address and incrementing the hop count. Other MNs will acquire the CoA and their default gateway address for their routing tables from these duplicated agent advertisement messages in the same way.

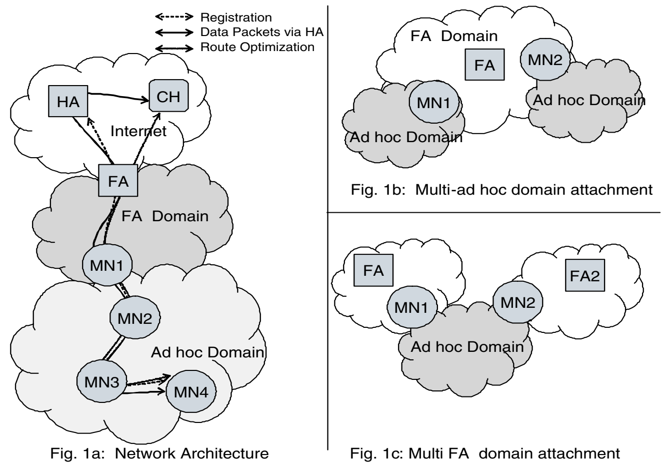

Fig. 1. Network

In this learning and setting process, protocol relies on DSDV and beaconing. There may be situations, where mobile node gets the beacon before the DSDV route update process is completed. In this synchronization problem, MN stops duplicating the beacon until its routing table contains the prospective IP address. Hop count usage has several advantages: Firstly, it restricts the Mobile IP users by terminating the duplicating process for a certain hop count, secondly, it gives MN an understanding of the distance to the access point and lastly, MN uses the hop count as a movement detection mechanism to determine which FA to connect for a good connection if ad hoc domain is attached to more than one FA domain as in Fig 1c. This procedure guarantees that each MN has a CoA and set it as

TABLE I

ROUTING TABLES

	Destination	Next Hop
MN1	MN2	MN2
	MN3	MN2
	MN4	MN2
	FA	FA
	*	FA
MN2	MN1	MN1
	MN3	MN3
	MN4	MN3
	FA	MN1
	*	MN1
MN3	MN4	MN4
	MN2	MN2
	MN1	MN2
	FA	MN2
	*	MN2
MN4	MN3	MN3
	MN2	MN3
	MN1	MN3
	FA	MN3
	*	MN3

its default router. Table I shows the situation after the procedure is completed for the network in Fig. 1a.

Dynamic Beaconing: Usage of table driven ad hoc protocol allows us to beacon as much as it is necessary. We limit the MN beaconing by checking the changes in its routing table. These changes are *node join* or *leave* and *route change*. If the change is *node join* then MIP initiates the beaconing mechanism in order to inform new MN about the access point. If it is a *route change* or *node leave* that means every node in the network is aware of the CoA and they only have to change their default gateway and refresh the registration. This dynamic beaconing overcomes the high overhead of beacon flooding present in the protocols designed with on-demand routing protocols.

2) Registration: MN sends registration request to its HA via the new FA and new CoA is used after the registration reply comes. Since the ad hoc medium is unreliable, registration process is performed after each beacon. FA keeps a table composed of MAC/IP address entries where the MAC/IP pair is acquired from the packet of a MN. For instance, in Fig. 1a, FA keeps the MAC address of MN1 and IP address of MN4 for MN4. This eliminates the possible failure in a network represented in Fig. 1b where each MN belongs to different ad hoc domains. With this procedure, FA identifies the gateways to the MNs.

3) Tunneling and Route Optimization: Tunnelling is same as basic MIP and done between FA and HA. HA encapsulates the packets and FA decapsulates them and send to the mobile. In the route optimization procedure, normally FA advertises its CoAs and MN chooses one of them. If the route optimization is initiated, Correspondent Node sends directly the packets to the CoA of MN. In this case, since MN is in the ad hoc domain, packets can not reach MN directly. Protocol handles this by adding CoA address also to the FA table for each MN and when the data has come to the network from a CH, it captures the packet and checks the corresponding IP address and MAC frame from its table according to the CoA in the packet.

B. MEWLANA-RD

MEWLANA-RD uses a novel root driven ad hoc protocol called Table Based Bidirectional Routing (TBBR). As we mentioned before, the routing table formation is done only with MIP entities and no additional ad hoc protocol is used. The protocol is optimized for the case when most of the traffic is for outside. Routing Table formation is done with agent advertisement and registration request messages and repeated after each registration renewal.

1) Agent Advertisement: Tree construction from root to the branches is performed with beaconing. In order to eliminate loops, each MN keeps a Depth Level Number (DLN) which is acquired from the hop count of the beacon. MN processes only the beacons that have smaller hop count number than its DLN. Consider Fig. 2, FA sends periodic beacons and each MN who gets the beacon first compare its DLN with the hop count number. If hop count number is smaller, it sets its DLN to the hop count, sets its default gateway as the source address in the beacon and learns its CoA. After the beaconing mechanism is done, each mobile has a default gateway entry in their routing table as shown in Fig. 2 marked by (1). The routing from FA to ad hoc domain still requires the registration procedure since the routing is bidirectional.

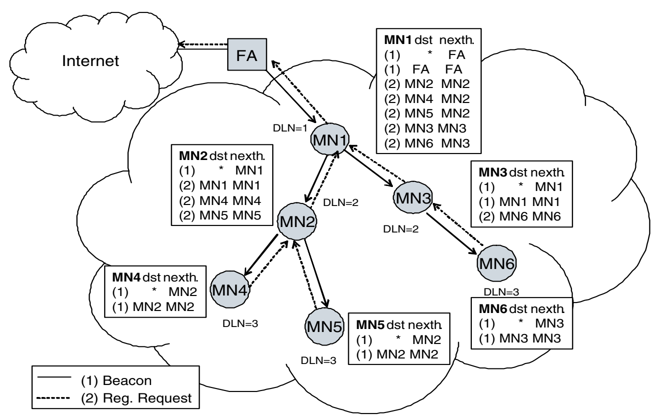

Fig. 2. Routing Table Formation in TBBR

2) Registration: In order to establish the routes marked by (2) in Fig. 2, we introduce multi-hop registration request mechanism. Considering Fig. 2, if MN4 wants to send registration request, it creates the same packet as in Fig. 3 and sends it to the MN2. When MN2 gets this packet, it creates a route in which the destination is home address and next hop is the source address. In this case, MN2 creates a route for the MN4. After this, MN2 sends the packet to MN1 by only changing the source and destination IP field as MN2 and MN1 respectively. MN1 now creates a route in which destination is MN4 and the next hop for this destination is MN2. As a result of this multi-hop registration request messaging, all MNs on the route learn the next hop to the original source and establish a route from FA to ad hoc domain. Registration procedure is completed after MN gets the registration reply message. This procedure is repeated in every beacon spreading in order to overcome the route changes. Inside traffic is handled by the MIP if the nodes are not in the same tree. As a result, even if the two MNs are in the same ad hoc domain but occupied in different part of the trees, the data are first sent to their HA and tunnelled to the FA then FA send the data to the tree where MN is in by looking at its table.

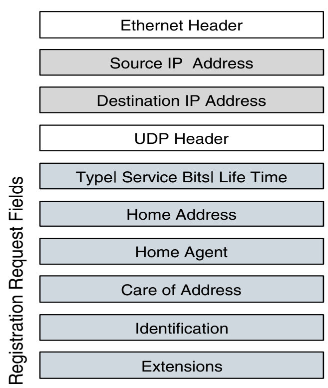

Fig. 3. Multi-Hop Registration Request Format

IV. Performance Analysis

In this section, we are going to compare the MIPMANET, MEWLANA-TD and MEWLANA-RD protocols. We choose MIPMANET because it is designed with an on-demand routing protocol. We classified the environment based on the ad hoc network size and intensity level of inside traffic where that of outside traffic is considered constant. Although a more appropriate classification also takes the movement pattern into account but we are not going to consider it because of easy penetration of the boundaries.

"Ad hoc Routing Overhead" ($AHRO$), "Mobile IP Overhead" ($MIPO$) and "Number of Hops to route packets for Inside Traffic" ($NHIT$) are taken to be basic criteria in our performance evaluation. Besides these, clean interface between MIP and ad hoc routing protocol and routing efficiency inside ad hoc routing are also considered to be important as a design issue. MIPMANET uses on-demand routing protocol in which overhead of routing is eliminated by only demanding on it when there is a need. Thus, it is efficient for networks that have high inside traffic and large network size as shown in Fig. 4. The reason why it is not suitable for small size networks (region II in Fig. 4.) is MEWLANA-TD reduces overhead of MIP with its dynamic beaconing algorithm and proactive property of DSDV provides competent performance like in wired routing. If the size of the network increases, the performance of the MEWLANA-TD degrades because of the overhead of

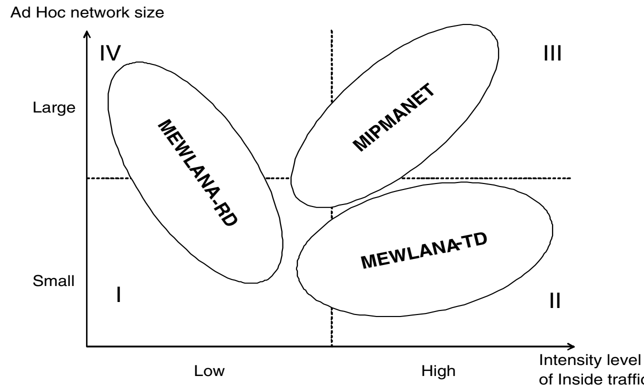

Fig. 4. Classification of ad hoc environment

the routing table exchanges. MEWLANA-RD eliminates overhead of ad hoc routing by using TBBR at the expense of performance degradation at inside traffic. Its performance in networks with low intensity of inside traffic is better than the other two protocols. Although it also uses broadcast beaconing, negligible routing overhead makes it suitable for region II in Fig. 4. MEWLANA-RD is also suitable for running cellular phones in ad hoc mode where every call should reach the base station of the cellular phone company even if the destination and host are in the same domain. As Fig. 4 indicates, all ad hoc routing types are appropriate for region one because their performances show slight differences in low inside traffic and small size networks. In order to prove this theoretical result, we setup a simulation environment in Network Simulator 2 [9]. The major mechanism studied with the simulation is the performance comparison of MEWLANA-RD, MEWLANA-SD and MIPMANET. Simulation results show various results because of their dependence to the simulation parameters. Our approach in our simulation is to lessen this dependence and make the results as much as immune to the different simulation setups. Our objective here is to obtain a value called Performance Factor (PF) for each protocol. We formulate a formula which gives PF with the parameters $MIPO$, $AHRO$ and $NHIT$ where A is for scaling and B, C, D are weight factors.

$$PF = \frac{1}{A}(B\frac{1}{MIPO} + C\frac{1}{AHRO} + D\frac{1}{NHIT})$$

In our simulation scenario, ad hoc network size is changed by changing the mobile nodes in the domain. Constant bit rate (CBR) sources are used to represent the inside traffic intensity. Each CBR source sends 10 packets per second containing 512 bytes of data. CBR agents are active from the beginning to the end of the simulation. For each simulation run, we change the ad hoc network size and the number of the CBR sources. Beacon period time is taken as 1s. We did not limit the agent advertisement life time because of our initial assumption that every node wants to connect to the Internet. We did the simulation for the scenarios of 4, 8, 32, 64, 128 ad hoc nodes and 1 to 10 CBR sources. In each run, we calculated the PF for each parameter pair by observing the $MIPO$, $AHRO$, and $NHIT$. In our calculation B, C and D are equal to 1 and A is used to scale the PF between 0 and 1. We take B, C, D equal in order to give equal weight to each overhead. We repeat the process for each three protocol and draw its 3d graph with MATLAB with its interpolation tool in order to clearly represent the performance comparison.

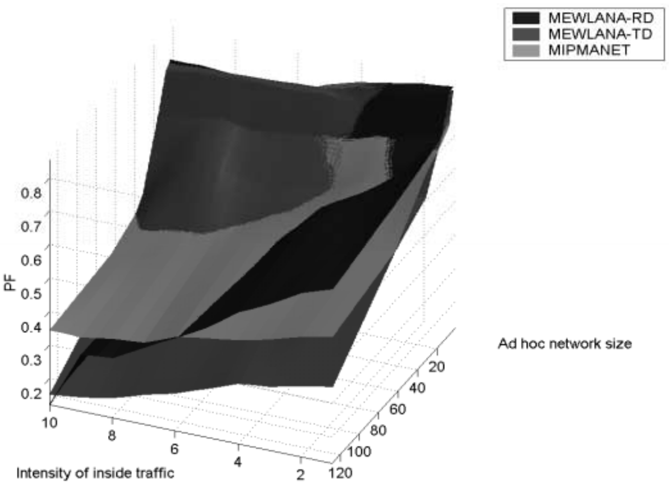

Fig. 5. Performance Factor

As Fig. 5 represents, since performance degrades with the increase in inside traffic and the size of network, all protocols showed almost monotonically decreasing PF values except small fluctuations. Those fluctuations arise because of the random movement patterns. MEWLANA-TD showed better performance when there is high traffic intensity and the network is small in size. If the network size is so small, then $NHIT$ is almost same for all routing types and increase in traffic does not shows big differences in PF values. This is the reason why all PF values almost same in the small size and low intensity region. The PF value of MEWLANA-RD decreases faster when the size and inside traffic of the networks is getting higher. This is because of using MIP for routing packets between trees since with the increase in network size, there may be multiple trees and even if host and destination are in the same tree, average traverse of packet is still higher because of bidirectional routing. On the other hand, MEWLANA-RD shows great performance when there is low intensity inside traffic. This is the case which is important for future wireless systems because people want to use their high-tech wireless devices everywhere with the high involvement of Internet with our daily life.

V. Application

As we show that different environments require different protocol designs, we can make the protocol selection adaptive and indication of which protocol is efficient can be sent to the mobiles by FA messages. Since FAs are stationary, protocol requirement for its place will be constant. As a result, MN is going to switch its protocol according to the places where it is roaming. For example, FA can advertise MEWLANA-RD in a subway, coffee shop or park, MEWLANA-TD in a small size classroom or in a rescue mission, and MIPMANET in a conference or an exhibition. This adaptive procedure provides optimum performance in every environment when MIP capabilities are extended to ad hoc networks.

VI. Conclusion

In this paper we presented an extension to Mobile IP about interconnecting Mobile IP with an ad hoc network. Extending Mobile IP capabilities to ad hoc networks has several advantages. These consist of connecting ad hoc nodes to the Internet, increasing cell coverage of Mobile IP. User expectations vary when Mobile IP and ad hoc networking is merged.

We showed that different expectations arise in different environments and require different protocols. In order to get optimum efficiency in these environments, we propose two protocols called MEWLANA-TD and MEWLANA-RD, based on table driven and route driven ad hoc routing protocols respectively in addition to the proposed protocols based on on-demand routing protocols. According to our classification, we showed that MEWLANA-TD is suitable for ad hoc networks whose size is small and inside traffic is high and that MEWLANA-RD gives efficient results for ad hoc networks whose size is large and inside traffic is low with its novel routing protocol Tree Based Bidirectional Routing (TBBR).

We compared the MEWLANA-TD, MEWLANA-RD and MIPMANET with our simulation study. The result of the simulation study showed that all three protocols give optimum performance in different environments. After proving our argument intuitively and with a simulation, we propose a possible usage in an application.

At the moment, we are working to investigate other aspects of the protocol in detail. We are looking into throughput analysis, adaptation to IPv6 and co-located Care of Address and implementation issues.

References

[1] The Internet Engineering Task Force (IETF), *www.ietf.org*

[2] M. Ergen, S. Coleri, B. Dundar, A. Puri, J. Walrand, and P. Varaiya, *Position Leverage Smooth Handover Algorithm for Mobile IP*, IEEE ICN 2002, Atlanta, August 2002.

[3] C. E. Perkins, *Mobile IP: Design Principles and Practices*, Addison-Wesley, 1998.

[4] E. Royer, C. Toh, *A Review of Current Routing Protocols for ad hoc Mobile Wireless Networks*, IEEE Personal Communications, Vol. 6, No.2, pp.46-55, April 1999.

[5] J. Broch, D. Maltx, D. Johnson, Y. Hu, J. Jetcheva, *A Performance Comparison of Multi-Hop Wireless ad hoc Network Routing Protocols*, The fourth annual ACM/IEEE international conference on Mobile computing and networking, October 25-30, 1998, Dallas, TX USA

[6] U. Jonsson, F. Alriksson, T. Larsson, P. Johansson, G. Q. Maquire Jr., *MIPMANET-Mobile IP for Mobile ad hoc Networks*, MOBIHOC 2000.

[7] R. Bhan, A. Croswell, K. Dedhia, W. Lin, M. Manteo, S. Merchant, A. Pajjuri, J. Thomas., *Adding ad hoc Network Capabilities to Cellular IP*, www.columbia.edu.

[8] H. Lei, C. E. Perkins, *Ad hoc networking with Mobile IP*, 2nd European Personal Mobile Communication Conference, Sept. 1997.

[9] Network Simulator 2, *www.isi.edu/nsnam.*