Evaluating the Performance of a Demand-Driven Multicast Routing Scheme in Ad-Hoc Wireless Networks

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Abstract

Instead of sending data via multiple unicasts, multicasting reduces the communication costs by minimizing the link bandwidth consumption and delivery delay. This is especially important in the context of mobile, wireless environments where bandwidth is scarce and hosts have limited power. Multicast communication in the context of ad hoc wireless network is a very useful and efficient means of supporting group-oriented applications, where the need for one-to-many data dissemination is quite frequent in critical situations such as disaster recovery or battlefield scenarios. The objective of this paper is to propose and evaluate a demand-driven multicasting routing mechanism for ad hoc wireless network. The mechanism is an extension of our previously proposed stability-based unicast routing scheme that relies on determining link stability and path stability in order to find out a stable route from a source to a destination. The proposed multicast routing mechanism depends only on local state information (at source) for constructing a multicast tree. It is demand-driven in the sense that whenever a source needs to communicate with a set of destinations, it discovers the routes and creates a multicast tree dynamically. It has been shown that the proposed multicast routing scheme reduces both the control traffic and the data traffic and decreases the delivery delay considerably when compared to multiple unicasts.

1. Introduction

An ad hoc wireless network can be envisioned as a collection of mobile routers, each equipped with a wireless transceiver, which are free to move about arbitrarily. The mobility of the routers and the variability of other connecting factors results in a network with a potentially rapid and unpredictable changing topology. These networks may or may not be connected with the infrastructure such as internet, but still be available for use by a group of wireless mobile hosts that operates without any base-station or any centralized control. The basic assumption in an ad-hoc network is that two nodes willing to communicate may be outside the wireless transmission range of each other but still be able to communicate in multiple hops, if other intermediate nodes in the network are willing to forward packets from them [1, 2]. Applications of ad hoc networks include military tactical communication, emergency relief operations, commercial and educational use in remote areas, etc. where the networking is mission-oriented and / or community-based.

Multicast communication in this context is a very useful and efficient means of supporting group-oriented applications, where the need for one-to-many data dissemination is quite frequent in critical situations such as disaster recovery or battlefield scenarios [3]. Instead of sending data via multiple unicasts, multicasting reduces the communication costs by minimizing the link bandwidth consumption and delivery delay. This is especially important in the context of mobile, wireless environments where bandwidth is scarce and hosts have limited power.

However, the dynamics of ad-hoc wireless networks as a consequence of host mobility and disconnection of mobile hosts pose a number of problems in designing even unicast routing schemes for effective communication between any source and destination [2]. The conventional routing protocols that require to know the topology of the entire network is not suitable in such a highly dynamic environment, since the topology update information needs to be propagated frequently throughout the network . On the other hand, a demand-based route discovery procedure generates large volume of control traffic. In a highly mobile environment with a large number of nodes, even if a route is discovered, a route rediscovery needs to be initiated when an intermediate node, participating in a communication between two nodes, moves out of range suddenly or switches itself off in between message transfer [1,2,4,5].

Thus, designing effective multicast routing solution in this environment is far more complex. The objective of this paper is to propose and evaluate a demand-driven multicasting routing mechanism for ad hoc wireless network. The mechanism is based on a stability-based unicast routing scheme[6] that relies on determining link stability and path stability in order to find out a stable route from a source to a destination. The proposed multicast routing mechanism depends only on local state information (at source) for constructing a multicast tree and is demand- driven in the sense that whenever a source needs to communicate with a set of destinations, it discovers the routes and creates a multicast tree dynamically. It has been shown that the proposed multicast routing reduces both the control traffic and the data traffic and decreases the delivery delay significantly. It is to be noted that the proposed on-demand multicast routing is a generalized form of our stability-based unicast routing. When number of destination is one, the proposed multicast scheme will be reduced to unicast routing with no additional overhead.

2. Related Work

Researchers in the area of multicast routing in ad-hoc wireless network have proposed several ad hoc multicast routing schemes; the spectrum spans from pure Internet multicast routing based schemes to a pure flooding scheme. However, since fixed network multicasting is based on state in routers (either hard or soft), it is fundamentally unsuitable for ad hoc network where topology is changing frequently due to unconstrained mobility [3].

FGMP [7], the Forwarding Group Multicast Protocol, proposes a scheme that are hybrid between flooding and source based tree multicast. The proposed multicast protocol scheme keeps track not of links but of groups of nodes which participate in multicast packets forwarding. To each multicast group G is associated a forwarding group, FG. Any node in FG is in charge of forwarding (broadcast) multicast packets of G. The nodes to be included in FG are elected according to members' requests. Instead of data packets, small membership advertisement packets are used to reduce overhead caused by broadcasting. However, in order to advertise the membership, each receiver periodically and globally flood its member information.

AMRoute [8], the Ad hoc Multicast Routing Protocol, creates a per group multicast distribution tree using unicast tunnels connecting group members. The protocol has two main components : mesh creation and tree creation. Certain nodes are designated as logical core nodes that initiate mesh and tree creation; however, the core can migrate dynamically according to group membership and network connectivity. Logical cores are responsible for initiating and managing the signaling component of AMRoute, such as detection of group members and tree set up. Bi-directional tunnels are created between pairs of group members that are close together, thus forming a mesh. Using a subset of available mesh links, the protocol periodically creates a multicast distribution tree. AmRoute assumes the existance of an underlying unicast routing protocol and its performance is influenced by the characteristics of the unicast routing protocol being used. The AMRoute simulation runs on top of TORA [5] as underlying unicast protocol. The network dynamicity was emulated by keeping node location fixed and breaking / connecting links between neighboring nodes. Thus, the effect of actual node mobility on the performance is difficult to interpret. Moreover, the signaling generated by underlying unicast protocol (TORA in this case) is not considered in the measurements.

The Core- Assisted Mesh Protocol (CAMP) [9] generalizes the notion of core-based trees introduced for internet multicasting into multicast meshes that have much richer connectivity than trees. A shared multicast mesh is defined for each multicast group. The advantage of using such meshes is to maintain the connectivity even while the network routers move frequently. CAMP consists of the maintenance of multicast meshes and loop-free packet forwarding over such meshes. Multicast packets for a group are forwarded along the shortest path from sources to receivers defined within the group's mesh. CAMP rebuilds meshes at least as fast as CBT and PIM can rebuild trees. However, the effect of mobility on the performance has not been clearly evaluated. The topology under experimentation has 30 routers with high connectivity (average of six neighbors each) and at the most 15 routers out of 30 are assumed to be mobile.

AMRIS [10], the Adhoc Multicast Routing Protocol utilizing Increasing id-numberS, assigns an identifier to each node in a multicast session. A pre-multicast session delivery tree rooted at a special node (by necessity a sender) in the session joins all the group members. The tree structure is maintained by assigning identifiers in increasing order from the tree root outward to the other group members. All nodes are required to process the tree set up and maintenance messages that are transmitted by the root periodically. It has been assumed that most multicast applications are long-lived; therefore rapid route reconstruction is of greater importance compared to rapid route discovery. The performance of the proposed scheme has yet to be evaluated.

ODMRP [11], the On-Demand Multicast Routing Protocol, also uses a mesh-based approach for data delivery and uses a forwarding group concept. It requires sources rather than destinations to initiate the mesh building by periodic flooding of control packets. It applies on-demand procedures to dynamically build routes and maintain multicast group membership. A soft-state approach is taken to maintain multicast group member.

It has been shown that the performance of multicast tree maintenance mechanisms degrade rapidly with increased mobility. Thus, multicast approaches that rely on maintaining and exchanging multicast-related state information are not suitable in highly dynamic ad-hoc network with frequent and unpredictable changing topology [3]. In the domain of ad hoc networks, several researchers have pointed out that on-demand flooding schemes to discover a route (whether unicast or multicast) is more suited than a state-based routing mechanism. These on-demand schemes are based on local state information and do not use periodic messages of any kind (e.g., router advertisements and link-level status messages), thereby significantly reduce network bandwidth overhead, conserve battery power, reduce the probability of packet collision, and avoid the propagation of potentially large routing updates throughout the ad hoc network.

Thus, keeping in mind the dynamic nature of ad hoc network topology due to unconstrained mobility as well as the application domain of ad hoc network, we have developed a demand-driven multicast routing scheme with the following assumptions:

- The proposed multicast routing mechanism depends only on local state information at source for constructing a multicast tree and is demand- driven in the sense that whenever a source needs to communicate with a set of destinations belonging to a multicast group, it discovers the routes to the individual destination and creates a multicast tree dynamically at source for that given group.
- Stability-based multicast routing scheme proposed here will ensure that the life-span of the multicast tree so formed will be sufficient to complete the required volume of data transfer at that instant of time.
- Each node knows its multicast group membership id(s). One node may belong to multiple multicast groups and it maintains all the multicast group ids to which it belongs. Multicast group creation may be source-initiated where a source creates a multicast group-id and informs its members; or, it may be destination-initiated where a node, willing to become a member of a multicast group, collects its multicast group-id from any node belonging to the same multicast group. There is no global group-membership-management-protocol; the application domain of ad hoc network does not demand that.

2. A Stability-Based Framework For Unicast Routing

Affinity a_{nm} between two nodes n and m in a network is a prediction about the span of life of the link l_{nm} in a particular context. For simplicity, we assume a_{nm} to be equal to a_{mn} and the transmission range R for all the nodes are equal. To find out the affinity a_{nm} , node m samples the strength of signals received from node n periodically. Since the signal strength is roughly proportional to $1/R^2$, we can predict the current distance d at time t between n and m. If V is the average velocity of the nodes, the worst-case affinity a_{nm} at time t is (R-d)/V, assuming that at time t, the node m has started moving outwards with an average velocity V. For example, If the transmission range is 300 meters, the average velocity is 10m/sec and current distance between n and m is 100 meters, the life-span of connectivity between n and m (worst-case) is 20 seconds, assuming that the node m is moving away from n in a direction obtained by joining n and m..

In an ad hoc network, relationship among nodes is based on providing some kind of service, and stability can be defined as minimal interruption in that service. Most of the routing schemes discussed so far in the literature in the context of ad hoc network do not consider the user mobility pattern in order to find a more stable path rather than a shortest path. The idea of selecting stable routes within a dynamic network has been proposed earlier. However, in those methods, stability is not explicitly evaluated.

Given any path p = (i, j, k, …, l, m), the **stability of path p** at a given instant of time will be determined by the lowest-affinity link (since that is the bottleneck for the path) and is defined as $\min[a_{ij}, a_{jk}, \ldots, a_{lm}]$. In other words, stability of path p between source s and destination d, a^p_{sd}, is given by $a^p_{sd} = \min_{\forall i,j} a^p_{ij}$

3. Demand-Driven Multicast Routing

The mechanism for multicast routing is based on the stability-based unicast routing scheme described in [6]. The mechanism comprises of four sequential steps. First, the source initiates a route discovery to get all the paths to individual destinations; next, it selects the stable routes from them and constructs a sub-graph connecting the source and the destinations; next, the source extracts multicast tree(s) from this sub-graph; finally, the source communicates the data to destinations using the multicast tree(s).

3.1 Path Finding Mechanism

The **path finding mechanism** described here is an extension of the scheme presented in [6].It has been pointed out that source-initiated routing is a better scheme for ad-hoc network where the topology changes rapidly and unpredictably [1,2]. In this scheme, a source initiates a route discovery request when it needs to send data to a destination. The basic scheme is discussed in [6].

A source initiates a route discovery request when it needs to send data to a set of destinations belonging to a multicast group. The source broadcast a route request packet to all neighboring nodes. Each route request packet contains source id, destination ids (or multicast group id), a request id, a route record to accumulate the sequence of hops through which the request is propagated during the route discovery, and a count n which is decremented at each hop as it propagates. When n=0, the search process terminates. The count n thus limits the number of intermediate nodes (hop-count) in a path in order to reduce unconstrained propagation of control packets. Through simulation, the optimum value of n has been estimated to be 5.

When any node receives a route request packet, it decrements n by 1 and performs the following steps:

- If the node is one the destination nodes (i.e. belongs to the multicast group), a route reply packet is returned to the source along the selected route, as given in the route record which now contains the complete path information between source and that destination node. At the same time, the node id is appended to the route record in the route request packet and the request is re-broadcast in search of other destinations.
- Otherwise, if n=0, the route request packet is discarded.
- Otherwise, if this node id is already listed in the route record in the request, the route request packet is discarded (to avoid looping).
- Otherwise, the node id is appended to the route record in the route request packet and the request is re-broadcast.

When any node receives a route reply packet, it performs the following steps :

- If the node is the source node, it records the path from source to one of the destinations .
- If it is an intermediate node, it appends the value of affinity and propagates to the next node listed in the route record to reach the source node.

3.2 Constructing Stable Sub-graph Connecting Source and Destinations

Let us assume that a source wants to send NUM number of packets to a set of destinations. The source initiates a route discovery request as described earlier and waits for the route reply packets from each destination belonging to the multicast group until timeout. For each path p, it computes its stability η^p . To evaluate whether the path is stable enough to complete the data transfer between s and d, the following condition needs to be checked:

$\eta^p_{sd} > NUM * t_p$,

where t_p is the average end-to-end delay per packet and depends on the bandwidth and number of hops. If this condition holds good, the path is selected. Thus, all the *stable* paths between source and destinations are selected. As a next step, a graph is constructed containing all those stable path. This is a *stable* sub-graph of the given network that contains the source, the set of destinations belonging to a multicast group and a set of intermediate nodes connecting them.

3.3 Constructing Multicast Tree at the Source

Once a stable sub-graph has been constructed at source, the source deploys a multi-directional search technique [12] to find out the connectivity among source node and destination nodes with a minimum set of intermediate nodes. Let M be the multicast group containing source node and destination nodes. Conceptually, the search technique is a multi-directional, step-by-step breadth-first search starting from all the nodes in M. It eventually finds out the connectivity among all the nodes in M through a minimal set of intermediate nodes. A distributed version of this algorithm is given in [12]; however, since the source contains the entire sub-graph, it employs a centralized version of this algorithm in order to find out the stable multicast tree at source. Once the connectivity is known, the sub-graph is traced back in order to find out the desired multicast tree at source.

4. Performance Evaluation

4.1 Simulation Set up

By and large, the available simulators to suit the present context were either wireless link simulators to model wireless link characteristics or network simulators to study networking algorithms and protocols in a static setting. Only in recent years, some efforts have been made to combine these two classes of simulators to model and study wireless mobile network characteristics [13,14]. However, they are inadequate to model and study ad hoc wireless network. ns, for example, initially provided no direct support for mobility or shared wireless radio channel. A recent release provides some support for modeling wireless LANs; even then, it cannot be used for studying multi-hop ad hoc networks directly [15].

In order to model and study the performance of the proposed framework in the context of ad hoc wireless networks, we have developed a simulator with the capability to model and study the following characteristics:

- Node mobility
- Link stability (*affinity*)
- Affinity- based path search
- Dynamic network topology depending on mobility and transmission range
- Physical and data link layers in wireless environment

The performance of the proposed scheme is evaluated on a simulated environment under a variety of conditions. In the simulation, the environment is assumed to be a closed area of 1000 x 1000 unit in which mobile nodes are distributed randomly. We ran simulations for networks with 20 mobile hosts with range of transmission varying from 250 to 350 unit in each case. The bandwidth for transmitting data is 400 kbps.

In order to study the delay, throughput and other time-related parameters, every simulated action is associated with a simulated clock. The clock period (time-tick) is assumed to be one millisecond (simulated). For example, if the bandwidth is assumed to be 400 kbps and the volume of data to be transmitted from one node to its neighbor is 4 kb, it will be assumed that 10 time-ticks (10 millisecond) would be required to complete the task. The size of both control and data packets are same and one packet per time-tick will be transmitted from a source to its neighbors.

The pattern and speed of movement of individual node ranges from 10 units and 30 units per second. Each node starts from a home location, selects a random location as its destination and moves with a uniform, predetermined velocity (10 units or 30 units per second) towards the destination. Once it reaches the destination, it waits there for a pre-specified amount of time, selects randomly another location and moves towards that. However, in the present study, we have assumed zero waiting time to analyze worst-case scenario. Also, we have assumed that nodes are moving with a uniform velocity of 20 units / sec.

4.2 Simulation Results

Control Message Overhead. On-demand route discovery generates large number of control packets due to unrestricted propagation of route request packets throughout the network. It has been observed that [6] with increasing transmission range, since the network is more strongly connected (i.e. each node has more number of neighbors), the control traffic increases rapidly due to this unrestricted propagation of control packets over the network.

When a source wants to communicate simultaneously with multiple destinations using multiple unicast rather than multicast, the source generates multiple route request packets, one for each destination. In multicast routing, the source generates a single route request packet for all the destinations. As a result, the number of control packets generated in the network to complete the route discovery would be much larger in the former case. Figure 1 shows the average number of control packets generated for multiple unicast and multicast for different number of destination nodes in multicast group for different transmission range (R). The node mobility is assumed to be fixed at 20 units per second. As expected, multicast mechanism generates less number of control packets as compared to multiple unicast; the effect is more pronounced with increasing number of nodes.

Multicast Efficiency. In ad-hoc network, data from source would reach the destination in multiple hops through intermediate node. In multiple unicast, the same data packets may need to travel through same set of intermediate nodes in order to reach different destinations. Using multicast, we intend to avoid this duplication of data traffic which, in turn, reduces the data traffic in the network. Multicast efficiency, M_E, is a measure of reduction in data traffic in the network and is defined as :

$$M_E = \frac{\sum_{\text{for all destinations}} \text{Number of nodes in unicast route}}{\text{Number of nodes in Multicast Route}}$$

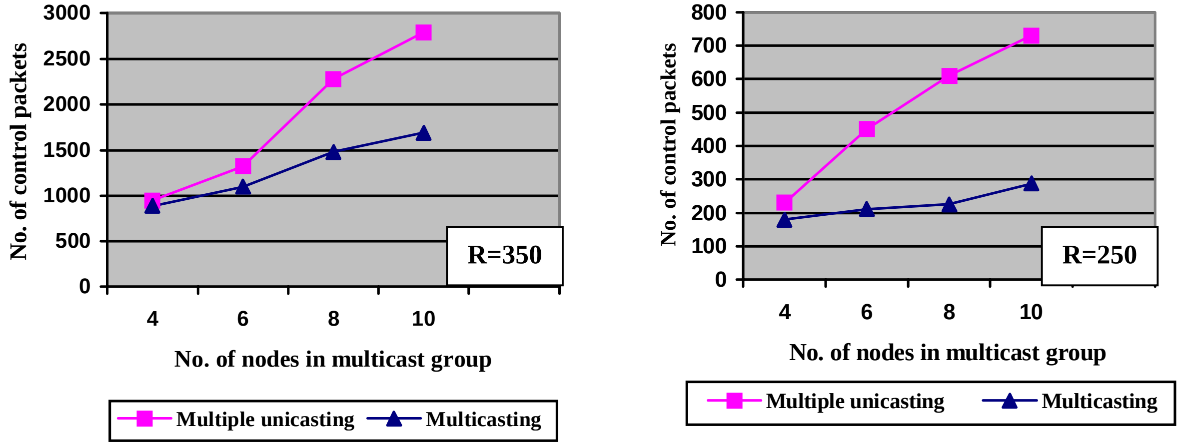

Figure 1. Number of control packets generated for different number of nodes in multicast group at different transmission range (R).

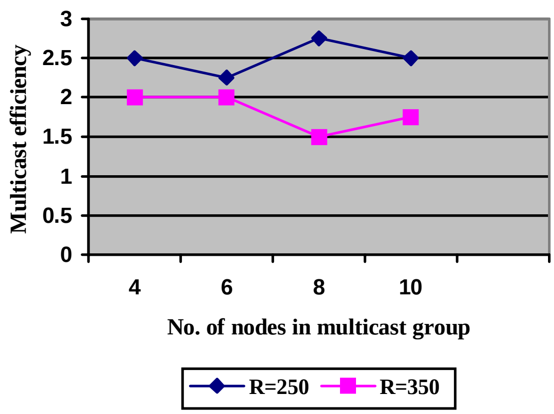

Figure 2. Multicast efficiency for different number of nodes in multicast group at different transmission range

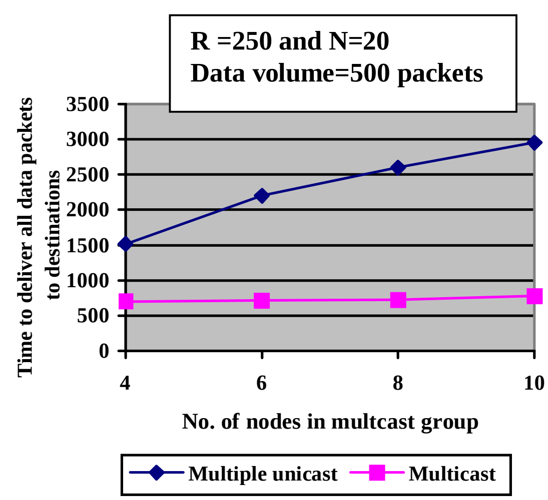

Figure 3. Time to deliver all data packets to destinations with multicast and multiple unicast

M_E = 1 indicates that there is no difference between multicast and multiple unicast. This would happen when all the unicast routes are disjoint i.e. there is no common node among the unicast routes. Figure 2 shows the average Multicast Efficiency for different number of nodes in multicast group (source + destinations). The node mobility is assumed to be uniform at 20 units per second. In all cases, multicast efficiency is more than one. The improvement is more significant at low transmission range. The reason is, at higher transmission range, some source-destination pairs are directly connected (single-hop connectivity). However, low transmission range is a preferred configuration, since at higher transmission range, the control traffic increases the congestion due to unrestricted propagation of control packets over the network.

Delay in Data Communication. Figure 3 shows the average time taken by a set of data packets (500 packets) to reach all destination nodes using a) multiple unicast and b) multicast routing schemes. Since multicast reduces both control and data traffic, the delay would be substantially less compared to multiple unicast.

5. Conclusion

A demand-driven multicasting routing mechanism for ad hoc wireless network has been proposed and evaluated in this paper. The mechanism is a generalized form of a stability-based routing scheme that supports both unicast and multicast routing and relies on determining link stability and path stability in order to find out a stable route from a source to destination(s). The proposed multicast routing mechanism depends only on local state information (at source) for constructing a multicast tree and is demand- driven in the sense that whenever a source needs to communicate with a set of destinations, it discovers the routes and creates a multicast tree dynamically. It has been shown that the proposed multicast routing scheme reduces both the control traffic and the data traffic and decreases the delivery delay significantly.

References

[1] D. B. Johnson and D. Maltz, Dynamic source routing in ad hoc wireless networks, T. Imielinski and H. Korth, eds., *Mobile computing*, Kluwer Academic Publ. 1996.

[2] S. Corson, J. Macker and S. Batsell, Architectural considerations for mobile mesh networking, Internet Draft RFC Version 2, May 1996.

[3] K. Obraczka and G. Tsudik, Multicast Routing Issues in Ad Hoc Networks, Proc. of the IEEE ICUPC ‘98, October 1998.

[4] Z.J.Haas, A new routing protocol for the reconfigurable wireless networks, ICUPC’97, San Diego, CA, Oct. 1997.

[5] V. D. Park and M. S. Corson, A highly adaptive distributed routing algorithm for mobile wireless networks, Proc. IEEE INFOCOM ’97, Kobe, Japan, April 1997.

[6] K. Paul, S. Bandyopadhyay, D. Saha and A. Mukherjee, Communication-Aware Mobile Hosts in Ad-hoc Wireless Network, Proc. of the IEEE International Conference on Personal Wireless Communication, Jaipur, India, Feb. 1999.

[7] Ching-Chuan Chiang, Mario Gerla, and Lixia Zhang, Forwarding Group Multicast Protocol(FGMP) for Multihop, Mobile Wireless Networks, ACM-Baltzer Journal of Cluster Computing: Special Issue on Mobile Computing, Vol. 1, No. 2, 1998

[8] M.Liu, R.R.Talpade, A.McAuley and E.Bommaiah, AMRoute: Adhoc Multicast Routing Protocol, CSHCN TR 99-1, University of Maryland, USA.

[9] J.J.Garcia-Luna-Aceves and E.Lmadruga, A Multicast Routing Protocol for Adhoc Networks, Proc. of the IEEE INFOCOM’99,New York, March 1999.

[10] C.W.Wu, Y.C.Tay and C-K.Toh, Adhoc Multicast Routing Protocol utilizing Increasing id-numberS, Internet-draft, draft-ietf-manet-amris-spec-00.txt, November,1998.

[11] Sung-Ju Lee, W.Su and M.Gerla, On-Demand Multicast Routing Protocol (ODMRP) for Adhoc Networks, Internet-draft, draft-ietf-manet-odmrp-01.txt, June 1999.

[12] S. Bandyopadhyay. An Architecture for Distributed Knowledge Processing”, Journal of New Generation Computing Systems, Vol 4, no.1, 1991.

[13] K. Fall, and K. Varadhan. ns Notes and Documentation. The VINT Project, UC Berkeley. http://www-mash.cs.berkeley.edu/ns/,1997.

[14] J. Short, R. Bagrodia and L. Kleinrock. “Mobile Wireless Network System Simulation.” *Wireless Network Journal 1*, no. 4, 1995.

[15] Josh Broch,; D.A. Maltz; D.B. Johnson; Y. Hu and J. Jetcheva. “A Performance Comparison of Multi-Hop Wireless Ad Hoc Network Routing Protocols.” In *Proceedings of the Fourth Annual ACM/IEEE International Conference on Mobile Computing and Networking* (Mobicom’98), Dallas, Texas, Oct. 25-30, 1998.