Evaluating the Performance of Various Architectures for Wireless Ad Hoc Networks

Mohan H.S [1], A Raji Reddy [2]
[1] Department of Information Science, Sri Jagadguru Balagangadhara Institute of Technology, Bangalore -560060
email id: mohan_kit@yahoo.com
[2] Professor, Dept of ECE, East point college of Engineering, Bangalore – 560016.

email id: pki_bgp@itiltd.co.in

ABSTRACT

A "mobile ad hoc network" is an autonomous system of mobile hosts connected by wireless links. The nodes are free to move randomly and organize themselves arbitrarily; thus, the network's wireless topology may change rapidly and unpredictably. Such a network may operate in a standalone fashion, or may be connected to the larger Internet.

The performance of such networks was evaluated based on simulations. In this paper, we evaluate the practicality of realizing an ad-hoc wireless network and investigate on performance issues. We have tried to simulate three different architectures for wireless networks and compare their performance based on a number of factors. This study centers around investigating the best architecture for ad hoc networks. We have used ns-2 for all our simulations. In all our simulations, we have tried to quantify the effects of factors like cluster size, routing protocols, mobility patterns and type of traffic, that affect the performance of ad hoc networks. Specifically, this paper evaluates the impact of these factors on the following performance metrics: throughput, average routing overhead, packet delivery ratio and end-to-end delay across the three different architectures.

Keywords-Ad hoc networks, wireless networks, multi hop, Hierarchical

I. INTRODUCTION

Ad hoc networks consist of wireless nodes that communicate with each other in the absence of a fixed infrastructure. These networks are envisioned to have dynamic, sometimes rapidly changing, random, multi hop topologies, which are likely composed of relatively bandwidth-constrained wireless links. In such a network, each mobile node operates not only as a host but also as a router, forwarding packets for other mobile nodes in the network that may not be within direct wireless transmission range of each other.

Each node participates in an ad hoc routing protocol that allows it to discover “multi-hop” paths through the network to any other node. The idea of ad hoc networking is sometimes also referred to as “infrastructure less networking”, since the mobile nodes in the network dynamically establish routing among themselves to form their own network on the fly.

Due to the limited transmission range of wireless networks interfaces, multiple network hops may be needed for one node to exchange data with another across the network. An important challenge in the design of ad hoc networks is the development of dynamic routing protocols that can efficiently find routes between two communicating nodes. These networks have received significant attention in recent years.

Some examples of the possible uses of such ad hoc networks include interactive education, business meetings, soldiers in battlefield, and emergency disaster relief. Also, the developing technologies of “wearable computing” and communications provide applications for this technology. When this technology is properly combined with satellite-based information delivery, ad hoc networks can provide an extremely flexible method for establishing communication for fire/ safety/ rescue operations or other scenarios requiring rapidly deployable communication.

A number of different architectures have been proposed for ad hoc wireless networks. At one end of the spectrum we have the single hop cellular architecture and at the other end we have the pure ad hoc architecture. The hierarchical routing architecture lies somewhere in between these two extremes. The primary objective of this study is to study these architectures and evaluate each one of them. We want to quantify these architectures and study their impact on the overall performance of the wireless network.

Quantifying the effects of these architectures will help guide the design choices and tradeoffs. Such studies will also high light the various factors that impact the performance of various architectures. This

n environment used. Section IV has simulation results and design analysis. Future work is presented in section V that is followed by the references which forms section VI.

II. ARCHITECTURES

In this section we discuss three different architectures for wireless ad hoc networks.

They are spread out on the wireless spectrum and this is our effort to combine the best of all the three worlds. Similar to a comparative study, which would

will help build robust and efficient protocols. For example, suppose node mobility is shown to have a greater impact on performance, and then we can design algorithms to adapt to node mobility. With this information we can build efficient networks tomorrow.

The remainder of this paper is organized as follows. In the following section, we briefly describe the three different architectures that we have analyzed. In section III, we talk about the simulatio

help, us select the appropriate architecture for our application.

(a) Single-hop Cellular Networks are cellular networks. These are the most popular networks, i.e. legacy networks. These networks lie at the bottom of the performance stack with respect to wireless networks. They are very well suited for cellular networks though. However they do not seem to work for ad hoc networks. In these networks we need to have fixed base stations (or Access points in the 802.11 glossary) to encompass a service area (cell). Mobile nodes can connect to the base station in one hop.

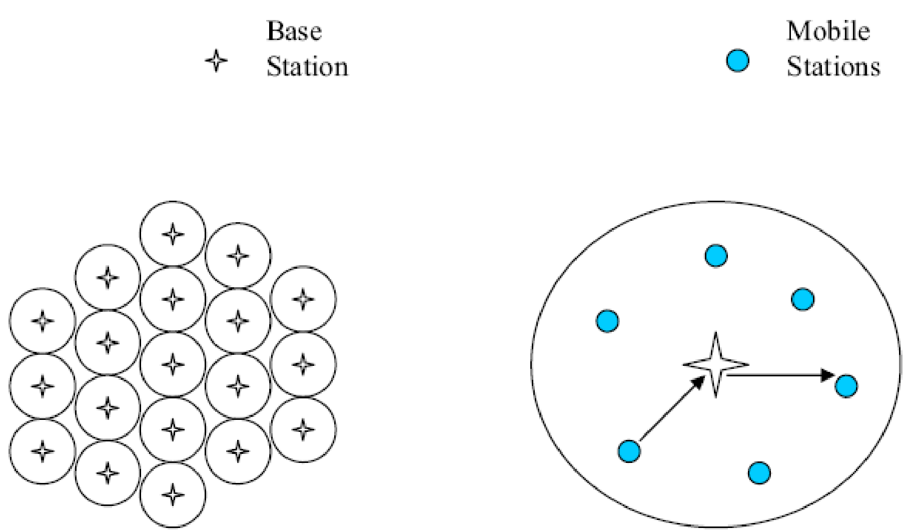

Figure 1. Single-hop Cellular Network

Mobile stations in the same cell are always mutually reachable in a single hop. Every packet originating from a mobile node must pass through the base station before reaching the destination. If the destination is in a different cell, the base forwards them to the base station of the cell where the destination resides. The base station of the destination's cell then forwards it to the destination in a single hop. Only the fixed base stations do the routing here and so only they need to maintain the routing tables. This saves the mobile nodes from the routing overhead. But this architecture has the "base station hop" overhead since all packets are routed through the base station.

(b) The Hierarchical routing architecture or the multi-hop architecture is similar to the single-hop architecture in some ways. It is also cluster zed architecture, i.e. the network is divided into multiple clusters and routing is basically within clusters and between clusters. A key feature of this architecture is that mobile nodes can directly communicate with each other if they are mutually reachable. This leads to multi-hop routing. If the source and the destination are in the same cell, other mobile nodes can be used to route packets to the destination. If not in the same cell, packets are routed through the base station. The basic idea is to organize nodes in groups, i.e. group nodes, which are geographically close to each other into explicit clusters. Each cluster has a cluster head (base station node) to communicate to other nodes on behalf of the cluster. Both routing table size and update packet size are reduced. Thus, control overhead is reduced. Inside the cluster, each mobile node maintains a routing table by which the route to any destination inside the cluster can be found. If the cluster size is big, the routing table size becomes an overhead for the mobile nodes.

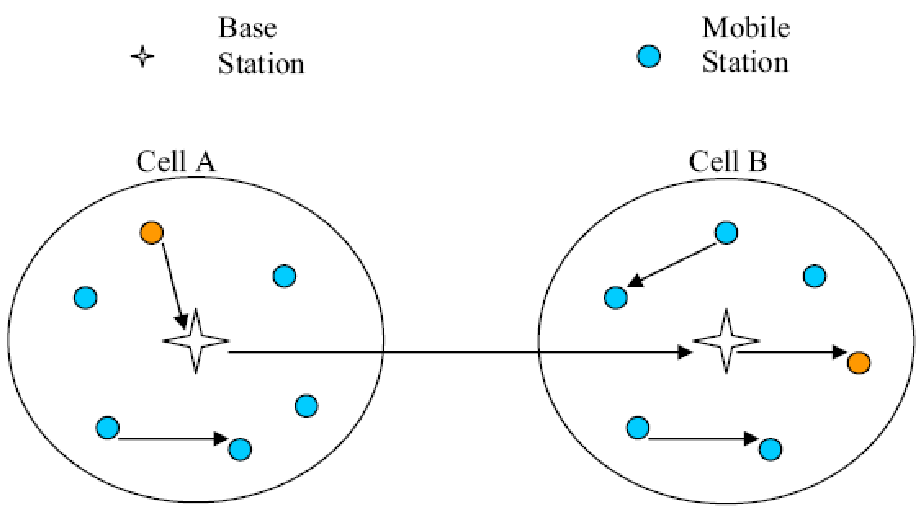

Figure 2. Multi-hop Network

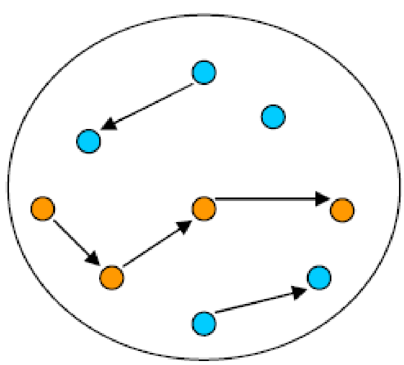

Figure 3. Pure ad hoc networks

(c) At the end of the spectrum, we have the "pure ad hoc networks". These are ad hoc networks in the true sense. There is no infrastructure at all. We just have mobile nodes with limited processing capabilities forming an ad hoc network. In this model, there are no base stations and because of a limited transmission range, multiple hops may be required for nodes to communicate across the ad hoc network. Routing functionality is incorporated into each node. Thus, these networks are characterized as having a dynamic, multi-hop and constantly changing topology. They are commonly referred to as packet radio networks. An advantage of these networks is their low cost because no infrastructure is required, and, therefore, can be deployed immediately.

III SIMULATION ENVIRONMENT

All the simulations were carried out on ns-2.
Ns-2 is a discrete event simulator developed by the University of California at Berkeley and the VINT project. It allows us to accurately simulate mobile wireless networks. The people at CMU have developed support for simulating multi-hop wireless networks complete with physical, data link and MAC layer modules.

- As one of our goals is to study the impact of routing in ad hoc networks, we have utilized four different routing protocols: Dynamic Source Routing (DSR), Destination Sequence Distance Vector (DSDV), Ad hoc On-Demand Distance Vector (AODV) and Temporally Ordered Routing Algorithm (TORA).
- Our models were simulated for 400 to 600 seconds.
- The IEEE 802.11 Distributed Coordination Function (DCF) is used as the Medium Access Control Protocol.
- We created various scenarios varying the cluster size each time. We had small clusters and big clusters with a maximum of 75 mobile nodes.
- Only 512 byte packets were used.
- We used the Friss-space attenuation (1/r2) radio propagation model for near distances and the Two ray Ground (1/r4) model for far distances.
- The node movement files were generated using CMU's scenario generator.
- The traffic pattern was generated using CMU's connection-generator. We used two types of traffic sources. We used TCP and CBR sources.

The mobility pattern was read from the mobility file that was generated. In this model, each node is placed randomly in the simulated area (1500X1500 m2). After remaining at the location for a specified pause time, the node then moves towards it's new destination as indicated in the mobility file. The scenario (mobility) file also specifies the speed with which the node moves. For fairness, identical mobility and traffic scenarios are used across the different simulations.

IV SIMULATION RESULTS AND DESIGN ANALYSIS

As mentioned in section II and III, we conducted simulations based on the three architectures. We varied the following factors:

- Number of nodes
- Cluster size
- Number of traffic sources
- Type of traffic
- Node speed
- Mobility patterns
- Routing protocols
- Pause Time

We looked at question like: Is cluster size a big factor? Should the cluster size be constant? Should the cluster size be the same? In order to evaluate the performance of ad hoc network architectures, we looked at the following parameters:

End-to-End Delay: The delay experienced by a packet from the time it was sent by a source till the time it was received at the destination.

Packet delivery ratio: The ratio between the number of packets originated by the "application layer" and the number of packets received by the final destination.

Average routing overhead: The average number of control packets produced per mobile node. Control packets include route requests, replies and error messages.

Throughput: Throughput measures the effectiveness of the network in delivering data packets. That is, how well does the network deliver packets from source to destination.

We need to realize that all the above metrics are related to each other even though some of them relate to protocol efficiency more than they do to architecture efficiency.

In the initial set of experiments, we focused on evaluating the architectures based on different routing protocols and different network sizes. The outputs can be seen below for pure ad hoc networks. For a 3-node network, there is nothing to choose from them. They all have similar performances as seen from the graph.
The End-to-End delays are also very similar.

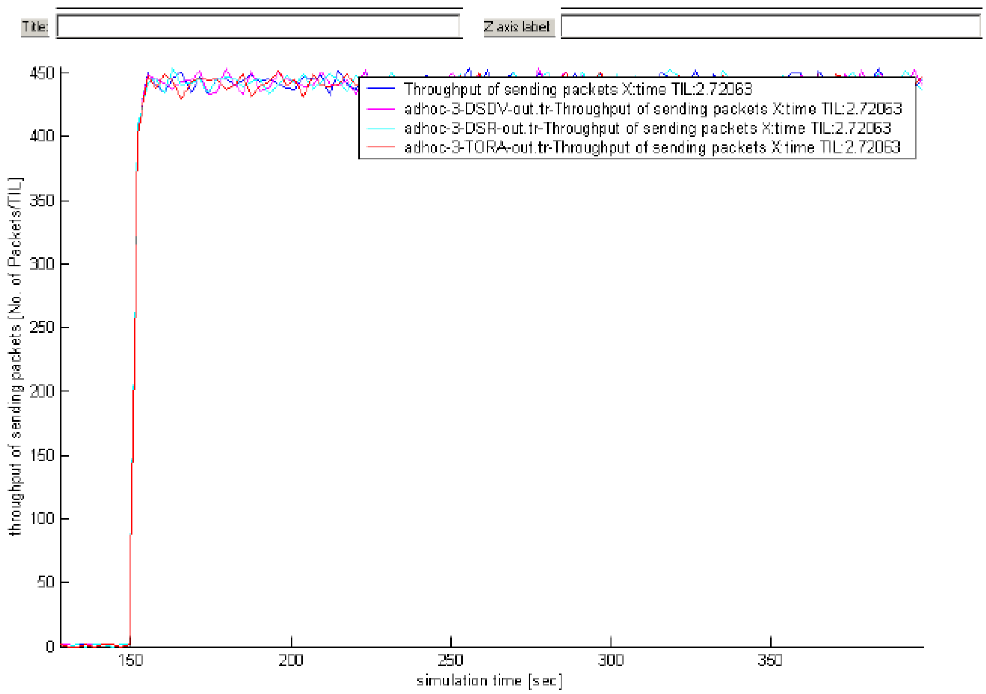

Figure 4. 3-node network

When the number of nodes is increased to 10, there is a slight variation in performance. DSR performs the best followed by AODV. As can be seen from the graph below. For this 10-node network we used 8 sources. DSR performs well with small number of sources. In this relatively small network, TORA gives the best performance when the End-to-End delay is considered.

For the next network, which has 20-nodes, we get almost similar performance from DSDV, TORA and AODV. Again, DSR performs the best as seen from the graph below. We used a maximum of 15 sources for this simulation. DSR gives the best performance even when we consider the End-to-End delay

After this, we tried the 30-node network. AODV performed much better than the others. DSR came a far second to AODV. We used 25 sources for this simulation. The End-to-End delay of AODV was much better than the others. DSR performs well with smaller networks and as the network size grows, the performance of AODV gets better.

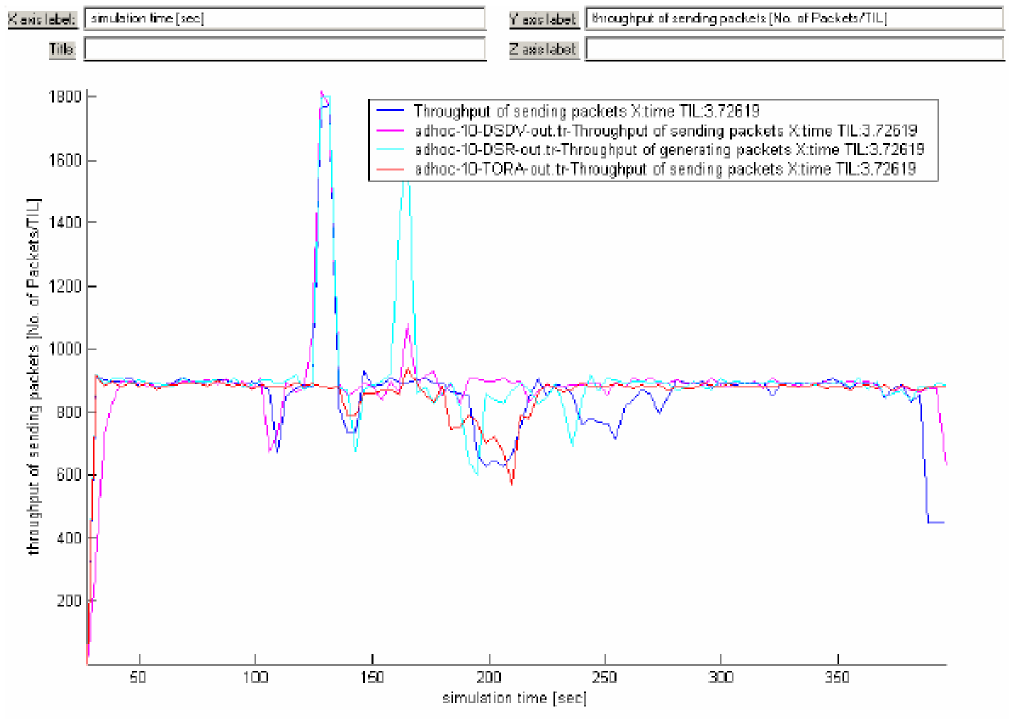

Figure 5. 10-node network

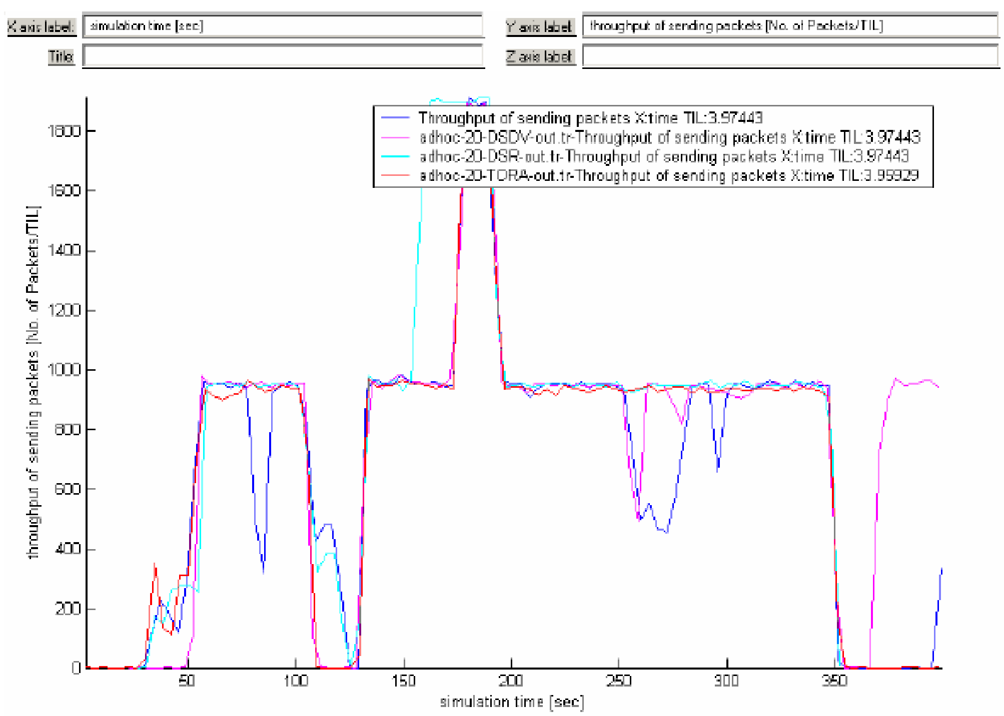

Figure 6. 20-node network

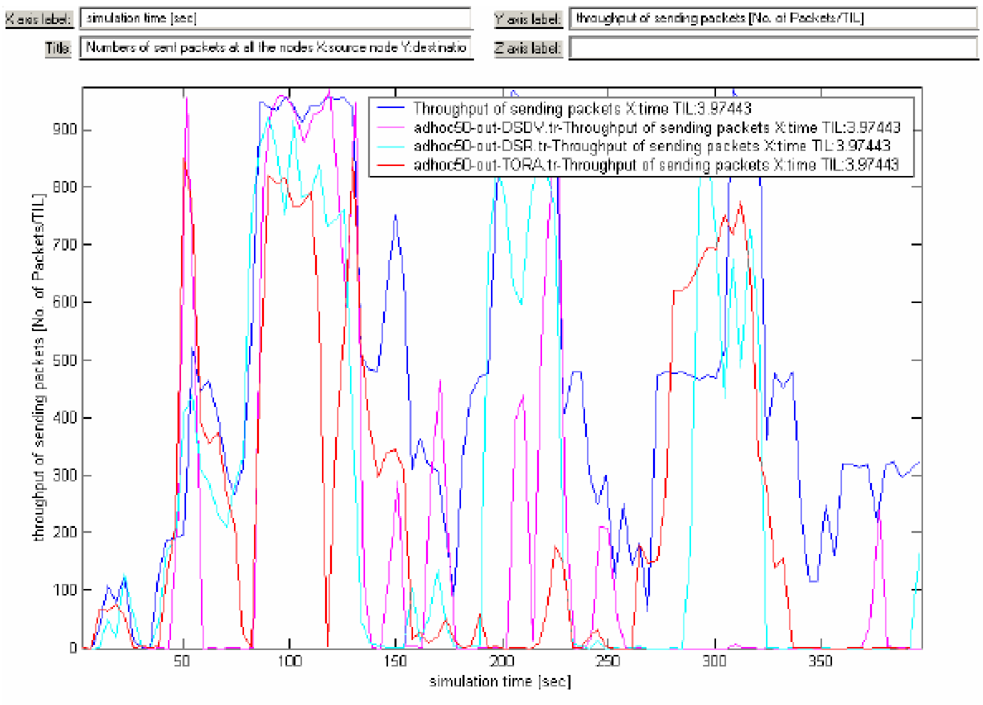

Figure 7. 50-node network

The throughput graph for a 50-node network is shown above. We can clearly see that AODV has better performance than the others. The End-to-End delay of AODV is also much better than the others. Again, AODV performs much better with larger networks.
We can make the following key observations:

- For small networks (less than 10 nodes) the single-hop cellular networks perform as well as the other two networks. When the network starts getting bigger, their performance starts to deteriorate. The single-hop cellular networks are best suited for cellular networks. We have to realize that the comparisons made here are done using multi-hop routing protocols, which are not built for the single-hop architecture. It would be fair for us to compare the single-hop network as a cellular network, i.e. when it is used as cellular network, with the multi-hop networks. This could be seen as future work.

- For a network with less than 30 nodes, the ad-hoc architecture showed better performance. This was verified with the 3-node, 10-node and the 20-node network.

- For networks with greater than 30 nodes, the multi-hop architecture gave better results than the ad hoc architecture. Although the packet delivery ratio was much better for ad hoc networks, the throughput was far greater in multi-hop networks. This was verified with the 30, 50 and 75 node networks.

The table below shows the levels of performance for each of the network architectures. We have used a 5-point scale to measure their performance. The scale takes into account the following performance factors: End-to-End delay, Packet delivery ratio and Throughput.

We can see that the performance of multi-hop networks is better than the performance of ad hoc networks when the network size is greater than 30 nodes.

Number of Nodes	Ad Hoc Network Performance	Multi-hop Network Performance
3	5	2
10	5	3
30	3	5
75	2	5

Scale:
5-Highest (Best)
1-Lowest (Worst)

In pure ad hoc networks, DSR performs much better when the network size is small, but when the network size grows, AODV outperforms DSR as the graphs tell us. One important observation is that, when we use DSDV, even though the throughput is less, the Packet delivery ratio is considerably high.

The table below shows the levels of performance for each of the network across the different routing protocols. We have used the 5-point scale again to measure their performance. The scale takes into account the following performance factors: End-to-End delay, Packet delivery ratio and Throughput. This table is an extension of the graphs shown above. It helps us to view the performance of various protocols relative to each other, which is very important.

Number of Nodes	DSDV	DSR	TORA	AODV
3 ≅ 5	3	4	3	5
10	3	4	4	5
20	3	5	3	3
30	3	4	3	5
50	3	4	3	5

Scale:
5-Highest (Best)
1-Lowest (Worst)

We also studied the impact of cluster size on the multi-hop network. We realized that the cluster size does not impact performance in a big way. If we consider throughput and packet delivery ratio, the impact on performance is not big. When we consider the average routing overhead, there is a big difference. The bigger the cluster size, the smaller the routing overhead. In general, it makes sense to keep the number of clusters small.

For example, in a 30 node multi-hop network,

(Overhead) for 3 clusters:
Routing messages = 29291
(Overhead) for 5 clusters:
Routing messages = 33660

We see how number goes up to for 5 clusters. The overhead shoots up with greater number of clusters.Slow simulation speed and large memory requirement of the ns-2 simulator forced us to restrict the network size to 75 nodes. Note that all prior reported simulation results with these ns-2 modules use only 50 nodes.

V. FUTURE WORK

We can simulate a proper cellular network as an instance of a single-hop network. This would be a fair comparison with the wireless architectures using the multi-hop routing protocols.

VI. REFERENCES

[1] Ying-Dar Lin and Yu-Ching Hsu. "Multihop Cellular: A New Architecture for Wireless Communications".

[2] R. Bruno, M. Conti, E. Gregori. "WLAN technologies for Mobile ad hoc Networks"

[3] Charles Perkins and Elizabeth Royer. "Ad hoc on-demand distance vector routing" In Proceedings of the 2nd IEEE Workshop on Mobile Computing Systems and Applications.

[4] Josh Broch, David Johnson, and David Maltz. "The dynamic source routing protocol for mobile ad hoc networks".

[5] J. Broach, D.A. Maltz, D.B. Johnson, Y-C. Hu, and J. Jetcheva. "A performance comparison of multi-hop wireless ad hoc network routing protocols".

[6] S. Cors and J. Mack. Mobile Ad hoc Networking (MANET). "Routing Protocol Performance Issues and Evaluation Considerations". RFC:2501

[7] C. K. Toh, Minar Delwar, and Donald Allen. "Evaluating the Communication Performance of an Ad hoc Wireless Network".

[8] Dmitri D. Perkins, Herman D. Huges, and Charles B. Owen. "Factors Affecting the Performance of Ad Hoc Networks".

[9] The VINT Project, UC Berkeley, LBL, USC/ISI, and Xerox PARC. Kevin Fall, Editor, Kannan Varadhan, Editor "The Network Simulator ns-2: Documentation."

[10] S.R. Das, R. Castaneda, J. Yan, and R. Sengupta. "Comparitive performance evaluation of routing protocols for mobile, ad hoc networks". In 7th Int. Conf. On Computer Communications and Networks, October 1998
[11] Per Johansson, Tony Larsson, Nicklas Hedman, and Bartosz Mielezarek. "Routing Protocols for mobile ad hoc networks – a comparitive performance analysis".
[12] John Jubin and Janet D. Tornow. "The DARPA packet radio network protocols". Proceedings of the IEEE, 75(1):21-32, January 1987.