Improving Performance of Wireless Ad Hoc Networks Using a Few Point-to-Point Links

Rajendra V. Boppana   Zhi Zheng
Computer Science Department
The Univ. of Texas at San Antonio, San Antonio, TX 78249
boppana@cs.utsa.edu   zzhi@cs.utsa.edu

Abstract—**The current wireless technologies such as IEEE 802.11 (Wi-Fi) make ad hoc networking viable for small regions involving a few tens of mobile nodes, but such networks are unreliable. In this paper, we investigate the benefits of adding a few infrastructure nodes to an otherwise ad hoc network. These infrastructure nodes are interconnected among themselves with point-to-point (p2p) links in addition to Wi-Fi capability. We simulated small ad hoc and mixed networks with 50 mobile nodes and 9 fixed nodes with 12 wired links among them in a 1.5×1.5 Km^2 field. The 9 fixed nodes form a 3×3 grid in the middle of the field. We tested mixed and ad hoc networks for UDP and TCP traffic patterns. Our results show that mixed networks outperform ad hoc networks by providing 50-100% higher throughput and 50% lower average delay. The primary reasons for significantly higher performance are increased route stability even with a small number of wired links and less contention for wireless channels.**

I. Introduction

A mobile ad hoc network (MANET) is a collection of wireless mobile nodes dynamically forming a temporary network without the use of any existing network infrastructure or centralized administration. A MANET consists of mostly homogeneous wireless links, based on a standard medium access control (MAC) standard such as IEEE 802.11 [4] and Bluetooth [5]. Owing to the limited radio propagation range of the wireless devices used, messages among non-neighbor nodes go through multiple intermediate nodes to reach destinations.

Because of the multi-hop communication even for short geographical distances (say, 1 km) and random movement of mobile nodes, applications of ad hoc wireless networks are mainly restricted to small wireless *islands*, which can be useful for military or limited intranet applications. Without the reliability comparable to that of a wired network, and access to the Internet, these ad hoc networks are not useful for general purpose networking.

We believe that ad hoc networks with mixed point-to-point (p2p) and wireless links are suitable as medium range networks spanning, for example, a metropolitan area. Such mixed networks will have types of nodes: fixed or relatively stationary infrastructure nodes with wireless capability and

This research has been partially supported by NSF grant EIA-0117255 and AIA grant F30602-02-1-0001.

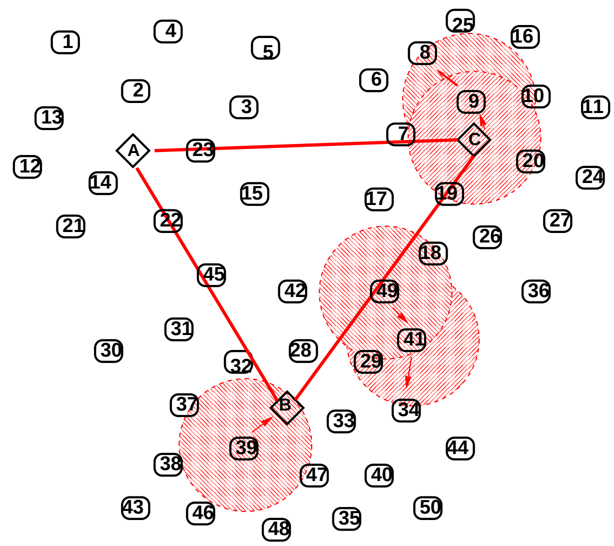

Fig. 1. Mixed point-to-point, p2p, and wireless network. Rectangular boxes with rounded corners and numbers inside indicate mobile nodes. Diamond shape boxes with letters inside indicate fixed infrastructure nodes. Dotted circles indicate the radio propagation ranges of nodes at center. Solid lines among A, B and C indicate p2p links. Two communications are shown. One is from node 39 to node 8 via p2p link BC. The other is from node 49 to node 34, which uses only wireless links. Without the p2p link BC, packets from 38 will need to go through nodes 49 or 41 and will interfere with the other communication.

p2p links among them, and mobile wireless nodes, which denote users. These networks can take advantage of the higher reliability and bandwidth of p2p links as well as the flexibility and low-cost of wireless links using ad hoc networking concepts. Because these networks make use of ad hoc networking, there is no need for fixed nodes to cover all the desired area with wireless links. When a fixed node is not available, a mobile node can send its data through other mobile nodes to the destination or to the nearest fixed node. An example mixed network with 3 fixed nodes and 3 p2p links among them added to a 50-node ad hoc network is shown in Figure 1.

With the advent of new technologies, it is feasible to design the proposed mixed networks. The IEEE 802.11 has

Presented at WNCG Symposium, October 2004.

already been a popular MAC protocol for ad hoc wireless networks. The 802.11 is a short haul (for distances less than 376m) wireless link protocol. The fixed infrastructure nodes and p2p links among them are not difficult to set up. The p2p links can be wired links or long haul wireless links. For example, the new IEEE 802.16 [6] and soon to be standardized IEEE 802.20 [7] are examples of long haul (for distances less than 50 Km) wireless link protocols. The infrastructure nodes can be already existing fixed nodes connected via p2p links (for example, access points connected to the Internet)or semi-permanent nodes that remain stationary for a few hours and have p2p links implemented via a different wireless technology. More importantly, elaborate design and implementation to ensure complete geographical coverage by fixed nodes is not necessary, since gaps in the coverage can be managed using ad hoc networking provided there is enough node density. Recently, a few researchers have started investigating the benefits of mixed networks [9], [2], [10].

In this paper, we are interested in exploring the performance benefits of p2p links in ad hoc networks. To evaluate the performance benefits of mixed networks over ad hoc wireless networks, we simulated ad hoc and mixed networks with 50 mobiles and 9 infrastructure nodes. We evaluated their performance for UDP and TCP traffic. Our results indicate that mixed networks provide significantly better throughput and packet delays. With a few p2p links added to an otherwise ad hoc network, the throughput can be doubled even when p2p and wireless links have similar bandwidth.

The rest of the paper is organized as follows. Section II presents simulation analysis of mixed networks and ADVS. Section III concludes the paper.

II. Performance Analysis

We used the Glomosim simulator, version 2.03 for performance analysis of ad hoc and mixed networks. We used the well-known AODV [11] and ADV [3] routing protocols for ad hoc networks. For mixed networks, we modified ADV to take advantage of wired links whenever feasible. The modified routing algorithm is called ADVS.

Node Mobility Model. The Glomosim simulator has a built-in random node mobility model called random waypoint (RWP). The RWP model is used extensively in ad hoc network simulations [8]. We modified the mobility model slightly to let nodes wrap around and reenter the field from opposite side when they reach an edge of the field. This avoid the clustering in the middle effect observed for RWP [12]. Node speeds are chosen to vary uniformly between 1 m/s and 29 m/s. We use the pause time 0 seconds, which corresponds to continuous motion.

Types of Networks. We simulated ad hoc and mixed networks with 50 mobile nodes in a 1.5×1.5 Km^2 field). We simulated three types of networks: (a) 50 mobile nodes and all nodes only have wireless capability, (b) 50 mobile nodes and additional 9 fixed nodes, with only wireless capability, and (c) 50 mobiles, 9 fixed nodes with wireless capability and 12 wired links among them. The 9 fixed nodes form a 3×3 grid in the middle of the field. The distance between adjacent fixed infrastructure nodes is 500m. So they can not communicate with one another directly with wireless links.

We modified Glomosim simulator so that a specified list of stationary nodes can be placed at predetermined locations, while the remaining nodes are placed randomly in the filed with the specified mobility model.

Types of Links. We used two types of links for simulations: single rate 802.11 wireless links with 2Mb/s bandwidth (BW) and 376 m radio range, and p2p full-duplex wired links with 2Mb/s BW and 2.5 μsec. We limited the BW of wired links to 2 Mb/s to show that even with such low BW, mixed networks can outperform ad hoc wireless networks significantly. For mixed networks, the wireless link to wired link cost ratio is set to 10 so that ADVS prefers wired links in finding low-cost routes.

Traffic Models. We used TCP and UDP traffic patterns. We used both HTTP to simulate TCP traffic and constant bit rate (CBR) to simulate UDP traffic. We vary the network load for TCP traffic by varying the number of HTTP connections. We vary the network load for the case of CBR traffic by varying the packet rates of 25 CBR connections. Packet size is fixed at 512 bytes.

For each data point, 10 600-second simulations with different initial placement of nodes is run and results are averaged to minimize the impact of a particularly bad or good scenario.

Routing Protocols. We implemented ADVS in Glomosim simulator [1]. ADVS is an enhanced version of the ad hoc network routing protocol ADV and has additional logic to take advantage of wired links among fixed nodes which ADV doesn't have. We used ADVS for all types of networks. For ad hoc wireless networks, ADVS is the same as ADV. In addition, we also simulated an compared AODV routing protocol for ad hoc wireless networks (distributed with Glomosim code) to illustrate that the results obtained with ADV are representative of the performance achievable in wireless ad hoc networks.

Metrics and Parameters. We use throughput, average packet latency, and routing overhead over wireless links to evaluate the routing protocols and networks.

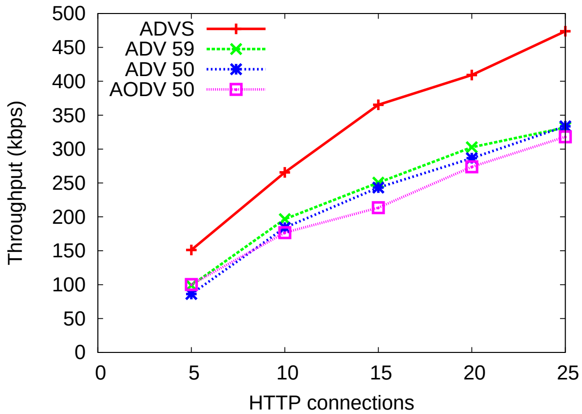

Fig. 2. Throughputs achieved for HTTP traffic on 50/59-node ad hoc networks. Each server has one client.

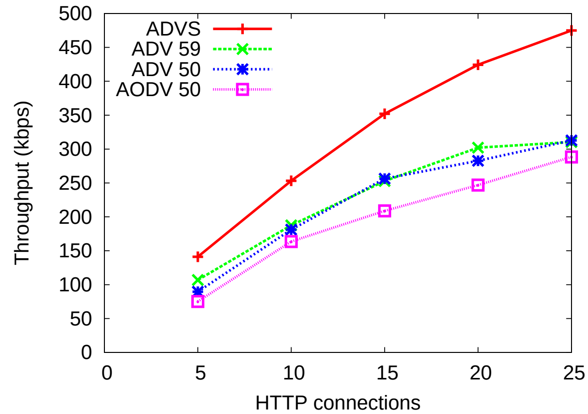

Fig. 3. Throughputs achieved for HTTP traffic on 50/59-node ad hoc networks. Each server has three clients.

A. TCP Traffic

ADVS is used to denote ADVS routing protocol in the 59-node mixed network and ADV 50 and ADV 59 are used to denote the ADV in 50-node and 59-node wireless networks, respectively. AODV 50 indicates the performance of AODV for the 50-node wireless network. To show that adding 9 extra nodes without p2p links is not beneficial, we also simulated ADV 59.

We have simulated TCP traffic using several HTTP connections. Figure 2 shows the throughput achieved for the case where HTTP server serves one client. Figure 3 shows the throughput achieved for the case when each server has three clients. Comparing these two figures, we find that the performance of AODV drops slightly with the increase in the number of clients per server. ADV 50 and ADV 59 perform similarly indicating that the fixed nodes by themselves do not improve performance. ADVS gives significantly higher throughput (50% more) compared to ADV 50 and ADV 59 because of the use of p2p links.

B. UDP traffic

The 25 CBR connections simulated use nodes 0-24 as senders and nodes 25-49 as destinations. To avoid using senders or destinations as fixed nodes, which could skew the results in favor of mixed networks, we have used 9 separate nodes as fixed infrastructure nodes. For this reason we simulated 59-node mixed network.

Figure 4 give the CBR traffic throughputs of ADVS, ADV 59, ADV 50 and AODV 50. The maximum throughput achieved with ad hoc wireless networks is 380 kb/s and with mixed networks 720 Kb/s, 97% higher. This is particularly striking when packet delivery rate given in Figure 5 is examined. Since ADV 59 and ADVS have the same number of mobile and fixed nodes, it is clear that the increase in performance is due to p2p links. To understand the reasons for this increase in performance, we examined the number of wireless hops taken by data packets. Figure 6 shows that the average number of wireless hops taken by a delivered packet in mixed networks is around 2.35 and that for wireless networks with ADV 50, ADV 59 or AODV is about 3.22. So the load placed on wireless links is reduced by $\frac{3.22-2.35}{2.35} = 37\%$. This accounts for some of the throughput increase we observed.

The rest of the improvement in throughput with p2p links is due to two factors: (a) less interference of transmission on wireless links because of fewer wireless links used by a data packet; (b) ADVS reduces the probability of broken routes and provides more stable routes by using wired links as much as possible. It is easy to see that interference on wireless links is reduced. We measured the average wait time, called NAV in 802.11 terminology, and found that mixed networks do have 50% shorter wait times to use wireless links. To examine the second factor, we calculated the rate of route breaks in each type of network, see Figure 7. The mixed network has much fewer broken routes than the wireless networks. It is particularly interesting to compare ADV and ADVS. The rate of broken routes increases rapidly for loads beyond 300 Kbps for ADV, while it is more gradual for ADVS. AODV has a higher rate of broken routes prior to saturation; this rate is bounded in saturation because it takes more time to repair routes compared to other algorithms.

It is noteworthy that even though the wired link bandwidth is 2 Mb/s, adding 12 p2p links nearly doubles the throughput. If we use wired links with higher bandwidth, the throughput will be improved even further.

Figure 8 gives average packet delays for loads prior to saturation of ad hoc networks. At low to moderate loads (less than 150 kbps), all networks have comparable delays. As

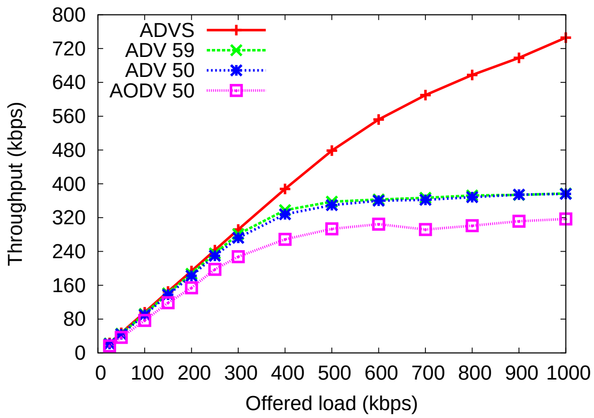

Fig. 4. Throughputs achieved for CBR traffic.

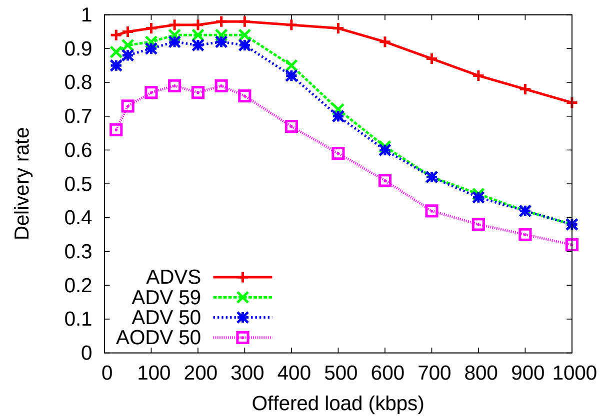

Fig. 5. Fraction of packets delivered for CBR traffic.

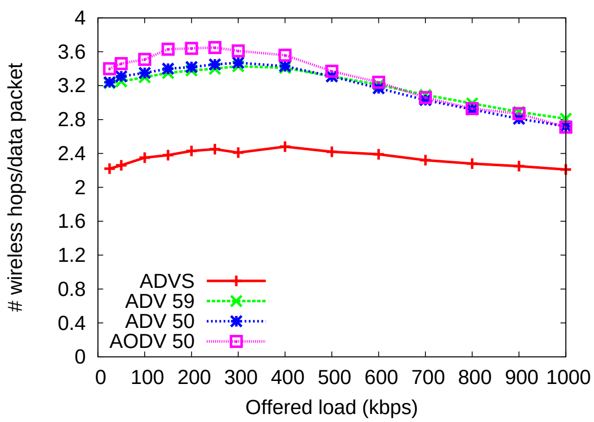

Fig. 6. Number of wireless hops used by a data packet.

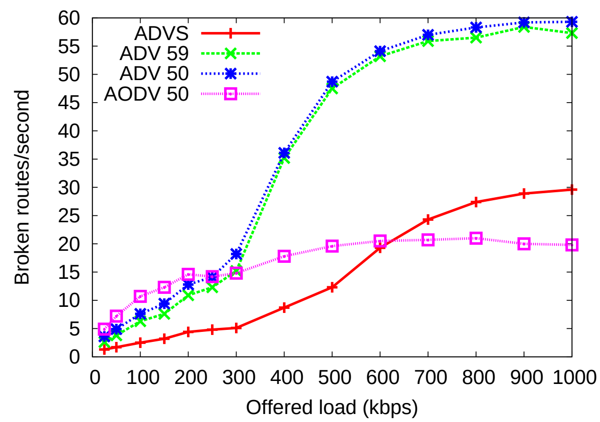

Fig. 7. Average rate of broken routes for the CBR traffic.

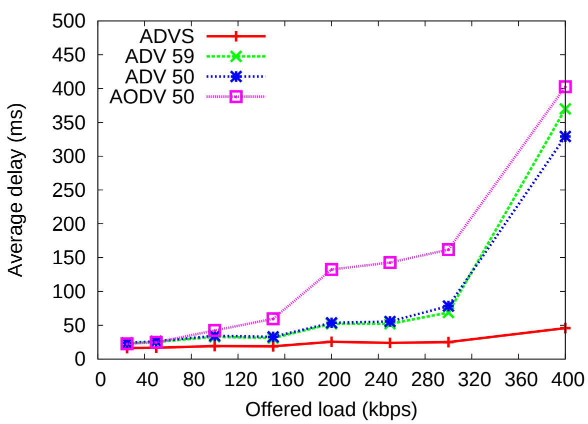

Fig. 8. Average packet delays in unsaturated networks.

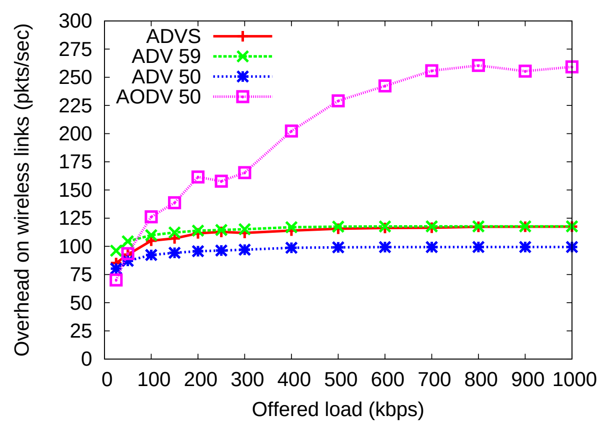

Fig. 9. Control packets transmitted on wireless links.

the load increases, the wireless networks saturate and packet delays grow rapidly. However, the mixed network saturates at higher loads and packet latencies do not grows as fast as in the other networks. It is clear that even in uncongested networks, mixed network provides lower latencies.

Figure 9 gives the CBR traffic overheads for the three networks. The overheads for ADVS, ADV 59 and ADV 50 are nearly constant as the offered load increases. But AODV has significantly higher overhead owing to its on demand approach of discovering and maintaining routes. Routing algorithms such as ADV which control the number of control packets tends to perform better in congested networks.

III. Conclusions

Pure ad hoc networks using wireless technologies such as Wi-Fi (IEEE 802.11) are useful for small intranet or military applications, but do not have the reliability expected by a user accustomed to broadband access to the Internet and wired networking infrastructure. So for general purpose mobile networking, it is necessary that wireless networks provide reliability and performance comparable to that of a wired network.

We have proposed mixed networks that are primarily ad hoc wireless networks with some fixed nodes and p2p links to provide better performance and reliability. We have shown using simulations that mixed networks can provide significantly higher throughput and lower packet delays.

In future, we intend to investigate the performance of multimedia applications on mixed networks. Another interesting topic to explore is optimal placement of fixed nodes and links and possibly using multiple wireless channels by fixed nodes.

References

[1] R Bagrodia et al. Glomosim: A scalable network simulation environment, v2.03. Parallel Computing Lab, UC Los Angeles, CA. http://pcl.cs.ucla.edu/projects/glomosim, December 2000.

[2] P. Bhagwat, B. Raman, and D. Sanghi. Turning 802.11 inside-out. In *HotNets-II*, 2003.

[3] R. V. Boppana and S. P. Konduru. An adaptive distance vector routing algorithm for mobile, ad hoc networks. In *IEEE Infocom*, April 2001.

[4] IEEE Standards Department. IEEE 802.11 standard for wireless LAN, medium access control (MAC) and physical layer (PHY) specifications, 1997.

[5] IEEE Standards Department. IEEE Bluetooth standard: Wireless mac and phy specifications for wireless personal area networks (wpans[tm]), 1997.

[6] IEEE Standards Department. IEEE 802.16 standard: Wirelessman standard for broadband wireless metropolitan area networks, 2004.

[7] IEEE Standards Department. IEEE 802.20 standard: Mobile broadband wireless access (mbwa), 2004.

[8] J. Broch et al. A performance comparison of multi-hop wireless ad hoc network routing protocols. In *ACM Mobicom'98*, Oct. 1998.

[9] R. Karrer, A. Sabharwal, and E. Knightly. Enabling large-scale wireless broadband: The case for taps. In *HotNets-II*, 2003.

[10] S. Mehra and C. Yu. Enhancing the performance of mobile ad hoc networks with the aid of internet gateways. In *ICWN 2004 International Conference*, 2004.

[11] C. E. Perkins, E. M. Moyer, and S. R. Das. Ad hoc on demand distance vector (AODV) routing. In *IETF, Internet Draft, IEEE RFC 3561, http://www.ietf.org/rfc/rfc3561.txt?number=3561*, July 2003.

[12] J. Yoon, M. Liu, and B. Noble. Random waypoint considered harmful. In *IEEE INFOCOM 2003*, 2003.