Fisheye State Routing: A Routing Scheme for Ad Hoc Wireless Networks

Guangyu Pei
Computer Science Department
University of California, Los Angeles
405 Hilgard Avenue
Los Angeles, CA 90095
email: pei@cs.ucla.edu

Mario Gerla
Computer Science Department
University of California, Los Angeles
405 Hilgard Avenue
Los Angeles, CA 90095
email: gerla@cs.ucla.edu

Tsu-Wei Chen
Bell Laboratories
Lucent Technologies
600 Mountain Avenue
Murray Hill, NJ 07974
email: tsuwei@research.bell-labs.com

Abstract – This paper presents a novel routing protocol for wireless ad hoc networks – Fisheye State Routing (FSR). FSR introduces the notion of multi-level fisheye scope to reduce routing update overhead in large networks. Nodes exchange link state entries with their neighbors with a frequency which depends on distance to destination. From link state entries, nodes construct the topology map of the entire network and compute optimal routes. Simulation experiments show that FSR is a simple, efficient and scalable routing solution in a mobile, ad hoc environment.

I. INTRODUCTION AND RELATED WORK

Ad hoc wireless networks are self-organizing, self-configuring and instantly deployable in response to application needs without a fixed infrastructure existence. Therefore, ad hoc networks are very attractive for tactical communication in military and law enforcement. They are also expected to play an important role in civilian forums such as convention centers, conferences, and electronic classrooms. Mobility, potentially very large number of mobile nodes, and limited resources (e.g., bandwidth and power) make routing in ad hoc networks extremely challenging. The routing protocols for ad hoc wireless networks have to adapt quickly to the frequent and unpredictable changes of topology and must be parsimonious of communications and processing resources.

Existing wireless routing schemes can be classified into two categories according to their design philosophy: (a) proactive (i.e., distance vector or link state based); and (b) on demand. Proactive schemes compute routes in the background, independent of traffic demands. Historically, the first type of routing scheme used in early packet radio networks such as the PRNET was the distance vector type [9]. The distance vector approach is simple but suffers from slow convergence and tendency of creating routing loops. Convergence and looping problems were later resolved by the Link State (LS) approach, which is widely used in wired nets (e.g., Internet [16] or ATM [1]). In Link State, global network topology information is maintained in all routers by the periodic flooding of link state updates by each node. Any link change triggers an immediate update. As a result, the time required for a router to converge to the new topology is much less than in the distance vector approach. Due to global topology knowledge, preventing routing loop is also easier. Unfortunately, as Link State relies on flooding to disseminate the update information, excessive control overhead may be generated, especially when high mobility triggers frequent updates.

The most recent addition to the family are the on demand routing schemes (e.g., AODV [18], DSR [8] etc). In these "reactive" protocols a node discovers a route in an "on demand" fashion, namely, it computes a route only when needed. Small Query/Reply packets are used to discover (possible more than) one route to a given destination. However, since a route has to be entirely discovered prior to the actual data packet transmission, the initial search latency may degrade the performance of interactive applications (e.g., distributed database queries). Moreover, it is impossible to know in advance the quality of the path (e.g., bandwidth, delay etc) prior to call setup. Such a priori knowledge (which can be easily obtained from proactive schemes) is very desirable in multimedia applications, since it enables more effective call acceptance control.

In general, on demand routing performs extremely well (low traffic and storage O/H) in large networks with light traffic (directed to a few destinations) and with low mobility. As mobility increases, the precomputed route may break down, requiring multiple route discoveries on the way to destination. Route caching becomes ineffective in high mobility. Since flooding is used for query dissemination and route maintenance, on demand routing tends to become inefficient when traffic load is high. As discussed in [6], routing load will grow as the traffic load increases for on-demand routing protocols. In the case of 100 nodes and 40 sources with uniform traffic pattern, the results in [6] show that both DSR and AODV will generate more routing overhead than actual throughput. Similar findings are also reported in [12].

A recent proposal which combines on demand routing and conventional routing is Zone Routing Protocol (ZRP) [10]. For routing operations inside a local zone, an arbitrary proactive routing scheme (e.g., distance vector) can be applied. For interzone routing, on demand routing is used. The advantage of zone routing is its scalability, as "global" routing table overhead is limited by zone size. Yet, the benefits of global routing are preserved within each zone. However, for the interzone routing, the on-demand solution poses the usual problems of connection latency and high routing load for dense traffic patterns.

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With the availability of GPS [13] technology, any of the previous routing protocols can be assisted by GPS location information. For example, LAR [15] is an on demand protocol similar to DSR but it restricts control packet flooding by using location information. DREAM [3] is a location based proactive scheme. Each node in the network periodically exchanges control packets to inform all the other nodes of its location. Each control packet is assigned a *life time* based on the geographical distance from the sender. DREAM sends *short lived* packet more frequently than *long lived* packets due to the so called *distance effect*, i.e., the farther two nodes separate, the slower they seem to be moving with respect to each other. The data packet is broadcast to the nodes in the direction of the destination using only location information stored at the sender.

In this paper, we introduce a novel "proactive" routing scheme called Fisheye State Routing protocol. It is a link state based routing protocol which is adapted to the wireless ad hoc environment. The rest of the paper is organized as follows. In section II, we describe the Fisheye State Routing (FSR). Section III presents the performance results and we conclude our paper in section IV.

II. FISHEYE STATE ROUTING (FSR)

A. Network Model and Data Structures

Each node has a unique identifier. Nodes move around and change speed and direction independently. An undirected link (i, j) connecting two nodes i and j is formed when the distance between i and j become less than or equal to the transmission range R. For each node i, one list and three tables are maintained. They are: a neighbor list A_i, a topology table TT_i, a next hop table $NEXT_i$ and a distance table D_i. A_i is defined as a set of nodes that are adjacent to node i. Each destination j has an entry in table TT_i which contains two parts: $TT_i.LS(j)$ and $TT_i.SEQ(j)$. $TT_i.LS(j)$ denotes the link state information reported by node j. $TT_i.SEQ(j)$ denotes the time stamp indicating the time node j has generated this link state information. Similar, for every destination j, $NEXT_i(j)$ denotes the next hop to forward packets destined to j on the shortest path, while $D_i(j)$ denotes the distances of the shortest path from i to j. Additionally, one or more link weight functions may be defined and used to compute the shortest path based on a specific metric, possibly with constraints. For instance, a bandwidth function can be used to support QoS routing. In this paper, we limit ourselves to min hop paths, thus the link weight is 1.

B. The Fisheye State Routing (FSR) Protocol

FSR is an implicit hierarchical routing protocol. It uses the "fisheye" technique proposed by Kleinrock and Stevens [14], where the technique was used to reduce the size of information required to represent graphical data. The eye of a fish captures with high detail the pixels near the focal point. The detail decreases as the distance from the focal point increases. In routing, the fisheye approach translates to maintaining accurate distance and path quality information about the immediate neighborhood of a node, with progressively less detail as the distance increases.

FSR is functionally similar to LS Routing in that it maintains a topology map at each node. The key difference is the way in which routing information is disseminated. In LS, link state packets are generated and flooded into the network whenever a node detects a topology change. In FSR, link state packets are not flooded. Instead, nodes maintain a link state table based on the up-to-date information received from neighboring nodes, and periodically exchange it with their local neighbors only (no flooding). Through this exchange process, the table entries with larger sequence numbers replace the ones with smaller sequence numbers. The FSR periodic table exchange resembles the vector exchange in Distributed Bellman-Ford (DBF) (or more precisely, DSDV [17]) where the distances are updated according to the time stamp or sequence number assigned by the node originating the update. However, in FSR link states rather than distance vectors are propagated. Moreover, like in LS, a full topology map is kept at each node and shortest paths are computed using this map.

In a wireless environment, a radio link between mobile nodes may experience frequent disconnects and reconnects. The LS protocol releases a link state update for each such change, which floods the network and causes excessive overhead. FSR avoids this problem by using periodic, instead of event driven, exchange of the topology map, greatly reducing the control message overhead.

When network size grows large, the update message could consume considerable amount of bandwidth, which depends on the update period. In order to reduce the size of update messages without seriously affecting routing accuracy, FSR uses the fisheye technique. Fig. 1 illustrates the application of fisheye in a mobile, wireless network. The circles with different shades of grey define the fisheye scopes with respect to the center node (node 11). The scope is defined as the set of nodes that can be reached within a given number of hops. In our case, three scopes are shown for 1, 2 and > 2 hops respectively. Nodes are color coded as black, grey and white accordingly. The number of levels and the radius of each scope will depend on the size of the network.

The reduction of routing update overhead is obtained by using different exchange periods for different entries in routing table. More precisely, entries corresponding to nodes within the smaller scope are propagated to the neighbors with the highest frequency. Referring to Fig. 2, entries in bold are exchanged most frequently. The rest of the entries are sent out at a lower frequency. As a result, a considerable fraction of link state entries are suppressed in a typical update, thus reducing the message size. This strategy produces timely updates from near stations, but creates large latencies from

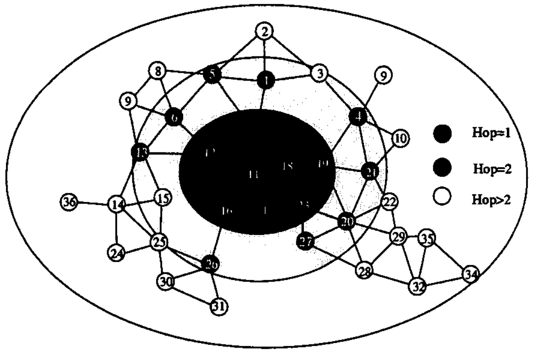
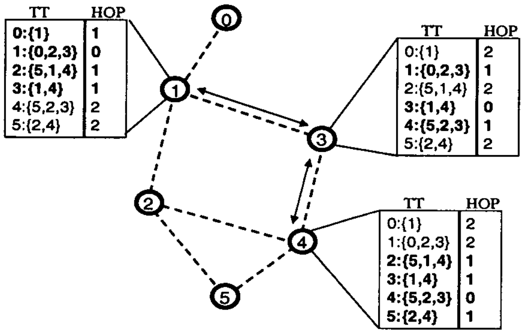


Fig. 1. Scope of fisheye

stations afar. However the imprecise knowledge of the best path to a distant destination is compensated by the fact that the route becomes progressively more accurate as the packet gets closer to destination. As the network size grows large, a "graded" frequency update plan must be used across multiple scopes to keep the overhead low.



TT	HOP
0:{1}	**1**
1:{0,2,3}	**0**
2:{5,1,4}	**1**
3:{1,4}	**1**
4:{5,2,3}	2
5:{2,4}	2

TT	HOP
0:{1}	2
1:{0,2,3}	**1**
2:{5,1,4}	2
3:{1,4}	**0**
4:{5,2,3}	**1**
5:{2,4}	2

TT	HOP
0:{1}	2
1:{0,2,3}	2
2:{5,1,4}	**1**
3:{1,4}	**1**
4:{5,2,3}	**0**
5:{2,4}	**1**

Fig. 2. Message reduction using fisheye

The FSR concept originates from Global State Routing (GSR) [5]. GSR can be viewed as a special case of FSR, in which there is only one fisheye scope level. As a result, the entire topology table is exchanged among neighbors. Clearly, this consumes a considerable amount of bandwidth when network size becomes large. Through updating link state information with different frequencies depending on the scope distance, FSR scales well to large network size and keeps overhead low without compromising route computation accuracy when the destination is near. By retaining a routing entry for each destination, FSR avoids the extra work of "finding" the destination (as in on-demand routing) and thus maintains low single packet transmission latency. As mobility increases, routes to remote destinations become less accurate. However, when a packet approaches its destination, it finds increasingly accurate routing instructions as it enters sectors with a higher refresh rate.

III. PERFORMANCE EVALUATION

A. Simulation Environment

We implemented our routing scheme within the GloMoSim library [19]. The GloMoSim library is a scalable simulation environment for wireless network systems using the parallel discrete-event simulation language called PARSEC [2]. The distributed coordination function (DCF) of IEEE 802.11 [11] is used as the MAC layer in our experiments. It uses Request-To-Send (RTS) and Clear-To-Send (CTS) control packets to provide virtual carrier sensing for *unicast* data packets to overcome the well-known hidden terminal problem. Each data transmission is followed by an ACK. *Broadcast* data packets are sent using CSMA/CA only. The radio model uses characteristics similar to a commercial radio interface (e.g., Lucent's WaveLAN). Radio propagation range for each node is 150 meters and channel capacity is 2 Mbits/sec. In most of experiments unless specified, the network consists of 100 nodes. The simulation area is 1000 × 1000 meter square. Each simulation executed for 30 minutes of simulation time.

The random waypoint model [4], [8] was used in the simulation runs. In this model, a node selects a destination randomly within the roaming area and moves towards that destination at a speed uniformally distributed between 0 m/sec and 20 m/sec. Once the node reaches the destination, it selects another destination randomly and moves towards it after a predefined pause time. Aforementioned behavior is repeated for the duration of the simulation. The traffic is UDP sessions between random node pairs. The number of source-destination pairs is varied in the experiments to change the offered load in the network. The interarrival time of the data packets on each source/destination connection is 2.5 seconds to model an interactive environment. The size of data payload is 512 bytes. The load in the network is increased by increasing the number of connections. We used 10, 50, 300 and 500 communication pairs in our simulation experiments.

B. Simulation Results

The first experiment (Fig. 3) reports how routing overhead is reduced when number of fisheye scopes is increased. For 100 nodes, we reduce more than 80% of routing overhead by using 3 scopes instead of just one scope (where all routing table entries are being updated very frequently). Also note that there is not much reduction of overhead if the number of scopes is beyond 3. This is because most of the nodes are within 3 scopes for an area of 1000 × 1000 with 150 radio range. Thus, adding more levels than 3 only affects very few nodes. On the other hand, having multiple scopes decreases the routing accuracy and might degrade the network performance. Fig. 4 shows that the routing inaccuracies do result in a lower throughput between one scope and two scopes. However, the throughput is relatively insensitive to the number of scopes when number of scopes is greater than 2. This is because in a mobility environment, a change on a link far away from the source does not necessarily cause a change in the routing table at the source. Moreover, as a packet approaches its destination, the route becomes more precise.

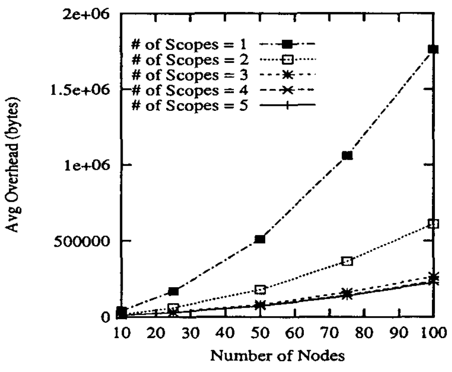


Fig. 3. Overhead, # of Scopes and # of nodes

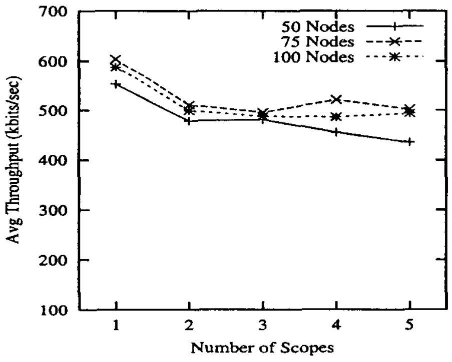


Fig. 4. Throughput, # of Scopes and # of nodes

Fig. 5 shows the normalized routing load as a function of offered load and mobility. Normalized routing load is the number of routing control packets transmitted per data packet delivered at the destination [6]. This metric shows the routing control penalty involved in delivering data. All previous simulation studies [6], [4], [7] focused on performance evaluation for small number of traffic pairs (up to 40 pairs). In our experiments, we study the performance of protocols under large number of traffic pairs in addition to small number of traffic pairs. For FSR, the number of control packets is a constant. It is independent of number of source/destination pairs. Thus, when the number of traffic pairs increases, the normalized routing load of FSR decreases. In AODV and DSR the number of control packets increases with number of pairs as well as with mobility. As number of pairs and load increase, the normalized

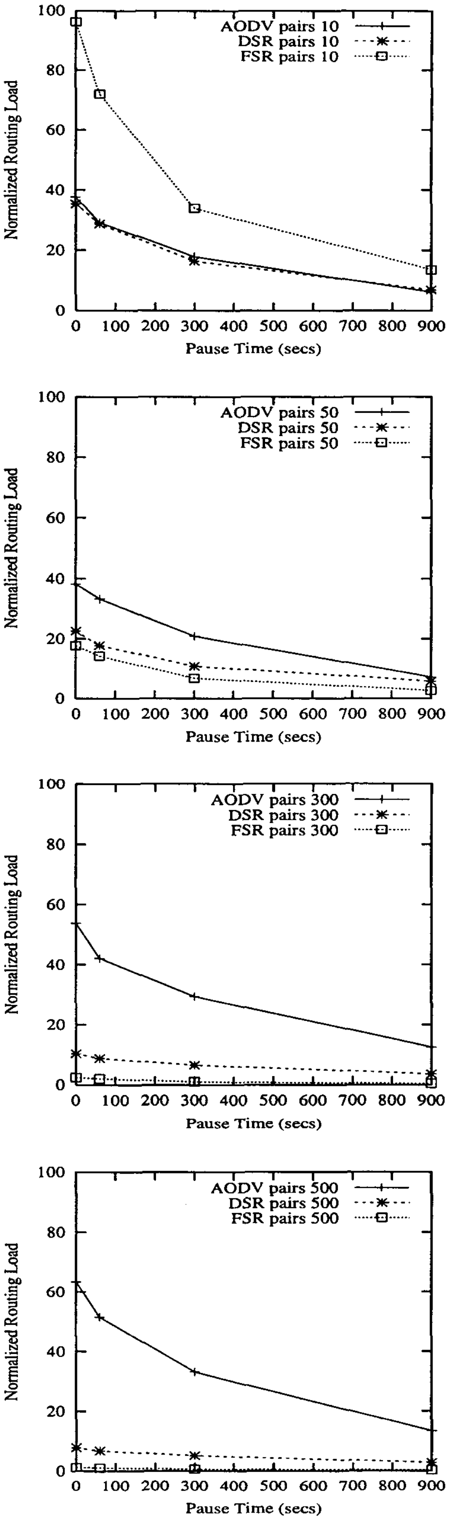


Fig. 5. Normalized Routing Load

load of on demand schemes is much higher than that of FSR.

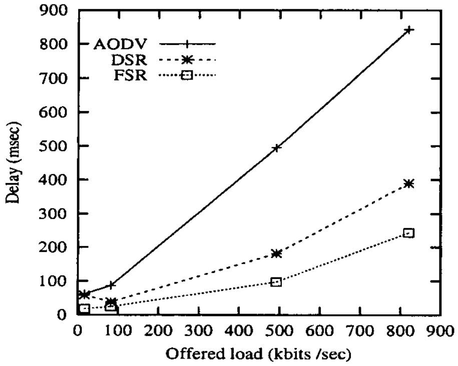


Fig. 6. Delay vs Offered Load

In Fig. 6, we report average delay as function of offered load. As the offered load increases, delay increases because of queue buildup. The delay of AODV increases faster than the other protocols because of the higher routing overhead and thus higher load. Fig. 7 shows the throughput of FSR outperforms on demand protocols when number of traffic pairs is large. All these simulation results clearly show that compared to on demand protocols, FSR exhibits a much better scalability of traffic loads.

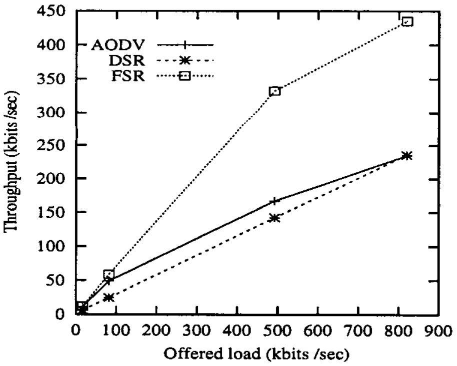


Fig. 7. Throughput vs Offered Load

IV. CONCLUSIONS

In this paper, we present a new routing scheme, Fisheye State Routing, which provides an efficient, scalable solution for wireless, mobile ad hoc networks. We have compared the performance of our routing protocol with on demand routing protocols such as AODV and DSR. When the number of communication pairs increases, on demand routing protocols will generate considerable routing overhead. Simulation shows that FSR is more desirable for large mobile networks where mobility is high and the bandwidth is low. By choosing proper number of scope levels and radius size, FSR proves to be a flexible solution to the challenge of maintaining accurate routes in ad hoc networks.

References

[1] The ATM Forum, "Private Network-Network Interface Specification v1.0," 1996.

[2] R. Bagrodia, R. Meyer, M. Takai, Y. Chen, X. Zeng, J. Martin, and H.Y. Song, "PARSEC: A Parallel Simulation Environment for Complex Systems," *IEEE Computer*, vol. 31, no. 10, Oct. 1998, pp.77-85.

[3] S. Basagni, I. Chlamtac, V.R. Syrotiuk, and B.A. Woodward, "A Distance Routing Effect Algorithm for Mobility (DREAM)," In *Proceedings of ACM/IEEE MOBICOM'98*, Dallas, TX, Oct. 1998, pp. 76-84.

[4] J. Broch, D.A. Maltz, D.B. Johnson, Y.-C. Hu, and J. Jetcheva, "A Performance Comparison of Multi-Hop Wireless Ad Hoc Network Routing Protocols," In *Proceedings of ACM/IEEE MOBICOM'98*, Dallas, TX, Oct. 1998, pp. 85-97.

[5] T.-W. Chen and M. Gerla, "Global State Routing: A New Routing Scheme for Ad-hoc Wireless Networks," In *Proceedings of IEEE ICC'98*, Atlanta, GA, Jun. 1998, pp. 171-175.

[6] S.R. Das, C.E. Perkins and E. M. Royer, "Performance Comparison of Two On-demand Routing Protocols for Ad Hoc Networks", In *Proceedings of IEEE INFOCOM 2000*, Tel Aviv, Israel, Mar. 2000.

[7] P. Johansson, T. Larsson, N. Hedman, B. Mielczarek and M. Degermark, "Scenario-based Performance Analysis of Routing Protocols for Mobile Ad-hoc Networks," In *Proceedings of ACM/IEEE MOBICOM'99*, Aug. 1999, pp. 195-206.

[8] D.B. Johnson and D.A. Maltz, "Dynamic Source Routing in Ad Hoc Wireless Networks," In *Mobile Computing*, edited by T. Imielinski and H. Korth, Chapter 5, Kluwer Publishing Company, 1996, pp. 153-181.

[9] J. Jubin and J.D. Tornow, "The DARPA Packet Radio Network Protocols," Proceedings of the IEEE, vol. 75, no. 1, Jan. 1987, pp. 21-32.

[10] Z.J. Haas and M. R. Pearlman "Determining the Optimal Configuration for the Zone Routing Protocol," In *IEEE Journal on Selected Areas in Communications*, Aug. 1999, pp. 1395-1414.

[11] IEEE Computer Society LAN MAN Standards Committee, *Wireless LAN Medium Access Protocol (MAC) and Physical Layer (PHY) Specification*, IEEE Std 802.11-1997. The Institute of Electrical and Electronics Engineers, New York, NY, 1997.

[12] A. Iwata, C.-C. Chiang, G. Pei, M. Gerla, and T.-W. Chen, "Scalable Routing Strategies for Ad-hoc Wireless Networks," In *IEEE Journal on Selected Areas in Communications*, Aug. 1999, pp. 1369-1379.

[13] E.D. Kaplan (Editor), *Understanding the GPS: Principles and Applications*, Artech House, Boston, MA, Feb. 1996.

[14] L. Kleinrock and K. Stevens, "Fisheye: A Lenslike Computer Display Transformation," Technical report, UCLA, Computer Science Department, 1971.

[15] Y.-B. Ko and N.H. Vaidya, "Location-Aided Routing (LAR) in Mobile Ad Hoc Networks," In *Proceedings of ACM/IEEE MOBICOM'98*, Dallas, TX, Oct. 1998, pp. 66-75.

[16] J. Moy, "OSPF Version 2," In *IETF RFC 1583*, 1994.

[17] C.E. Perkins and P. Bhagwat, "Highly Dynamic Destination-Sequenced Distance-Vector Routing (DSDV) for Mobile Computers," In *Proceedings of ACM SIGCOMM'94*, London, UK, Sep. 1994, pp. 234-244.

[18] C.E. Perkins and E.M. Royer, "Ad-Hoc On-Demand Distance Vector Routing," In *Proceedings of IEEE WMCSA'99*, New Orleans, LA, Feb. 1999, pp. 90-100.

[19] M. Takai, L. Bajaj, R, Ahuja, R. Bagrodia and M. Gerla, "GloMoSim: A Scalable Network Simulation Environment," Technical report 990027, UCLA, Computer Science Department, 1999.