Limited Flooding Protocol for Mobile Ad hoc Networks *

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Abstract

Mobile ad hoc networks are collections of mobile nodes without any fixed infrastructure or central co-ordinating mechanism for packet routing. Consequently, routing is a challenge. In this paper we propose a multipath routing protocol called Limited Flooding. The protocol is fully reactive and does not entail the computation of routing tables. It uses the basic features of flooding but restricts packet propagation by selecting a limited number of links. Discrete-event simulation is used to model ad hoc networks, and the performance of several variations of the protocol is evaluated. The simulation results show that Limited Flooding has better performance than pure flooding and is suitable for networks with unpredictable topological changes and highly mobile nodes.

Keywords: *Ad hoc networks, mobile networks, limited flooding, routing*
Computing Review Categories: *C.2.1, C.2.2*

1 Introduction

A mobile ad hoc network consists of fully mobile wireless nodes that can communicate directly while within the transmission range of each other or via intermediate nodes otherwise [13]. In this network, each mobile node functions not only as a host but also as a router to forward packets to other nodes. Thus, reducing the load at intermediate nodes and overall packet propagation are important considerations in designing routing protocols.

Due to node mobility and wireless transmission characteristics, conventional routing protocols cannot be used directly. Several protocols have been proposed for routing in mobile ad hoc networks [3–15, 18-22, 25]. These protocols are based on either reactive or proactive algorithms. In reactive protocols, routes are established when needed using a route discovery mechanism; in proactive protocols, routes are pre-computed. Some of these protocols use a clustering architecture to reduce routing, communication and computation overhead [4, 7, 9, 12, 15].

Flooding is a distributed procedure for data broadcast where packets are duplicated at each intermediate node and sent to other nodes: every incoming packet is sent out

*A preliminary version appeared in [8].

on every outgoing link except the one it arrived on. Flooding is a simple and effective routing technique that doesn't require the computation and maintenance of a routing table and avoids network delay by quickly delivering packets with minimal en-route computation. Most proposed routing protocols for mobile ad hoc networks use flooding for propagating control messages (such as route discovery) and update messages (for route maintenance). For example, see [5, 13, 10].

Several authors have proposed to use the basic ideas of flooding but to limit communication overhead. A Controlled Flooding protocol was proposed by Lesser and Rom [16]. In this, a message is broadcast based on the basic flooding mechanism but not throughout the network. Traffic is further limited by assigning a cost to each link and a wealth to each message. A message is sent on a link only if its wealth is at least the link weight. Upon receiving a message, an intermediate node deducts the cost of the link from the message wealth.

A similar routing protocol was proposed by Azar et al. [1] for high-speed networks. Here, the link was assumed to be of high capacity and the aim was to minimise the processing overhead at intermediate nodes. Various techniques of weight assignments were investigated to achieve optimal performance. A reliable broadcast protocol was proposed by Pagani [19] for networking environments where the rate of topology change is difficult to predict and provides routing algorithms that range between flooding and the traditional routing protocols.

We propose a multipath routing protocol known as Limited Flooding. The protocol is fully reactive and does not require the computation of routing tables. It uses the basic features of flooding, but restricts packet propagation by selecting a limited number of communication links. It is intended for networks with unpredictable topological changes and highly mobile nodes.

The limited flooding protocol is similar to the controlled flooding proposed by Azar et al. [1] and Lesser and Rom [16]. However, it uses adaptive mechanisms for restricting flooding in the network since the static weight assignment mechanisms proposed for fixed networks are unsuitable.

Discrete-event simulation was used for modelling ad hoc networks and performance evaluation. Several variations of Limited Flooding were examined in simulation experiments. The simulation results confirm that Limited Flooding has better performance than pure flooding and is suitable for dynamic mobile ad hoc networks.

The rest of this paper is organised as follows. Section 2 describes the Limited Flooding Protocol. Section 3 describes the simulation environment. Section 4 presents the results of the simulation experiments. Finally, Section 5 discusses conclusions and possible extensions.

2 The Limited Flooding Protocol

In our study, we consider a relatively highly mobile network environment and the use of more knowledge intensive algorithms can increase routing complexity and latency. Therefore, we have proposed less sophisticated algorithms for determining the number of transmission links and the actual links for packet forwarding at the intermediate nodes.

2.1 Overview

If the rate of topological change in a mobile ad hoc network is low, then the traditional routing algorithms can be used for packet routing: little overhead is incurred since routing information changes slowly. In a highly mobile environment, the traditional routing protocols fail. In proactive routing protocols the computed routes might be unusable due to frequent changes in network topology, so both route computation and route storage waste resources. On the other hand, reactive protocols may incur high communication overhead if the rate of topological change is high, since the algorithm will be executed too often. Moreover, the discovered routes might even be unusable, since the destination might have moved by the time the source sends the packet. Thus when nodes move quickly enough and frequently enough, the best strategy is to flood packets in the network [13].

In this paper we consider a relatively highly mobile network environment with unpredictable changes in the network topology and network resources. To gain the advantages of both randomisation and multiple paths, we propose a multipath routing protocol which we call *Limited Flooding*. This lies between the two extremes of pure flooding and shortest path routing, but is much closer to flooding. The protocol should be applicable in areas including military communication networks, and vehicular speed applications such as mobile nodes on vehicles, ships, airplanes and the like.

Flooding is robust since forwarding of packets occurs along all possible routes at the same time. But improvements are needed to limit the flooding traffic. Limited Flooding uses the basic flooding algorithm but uses only a few links from each node for message propagation. It is fully reactive and does not require the computation of routing tables.

For relatively highly mobile environments and infrequently communicating nodes, Limited Flooding is expected to provide better performance than periodic or event-driven updates of link state information in link-state-based protocols. While the network overhead in limited flooding is per communication request, the overhead of link-state-based protocols is per link-state update. Also, for link-state-based protocols, link-state packets are flooded throughout the network every time the link-state is updated, whereas in limited flooding it is transmitted only along few selected paths. The protocol consumes less resources than pure flooding and may in some cases make more balanced use of the scarce wireless resources.

2.2 The limited flooding algorithm

On receiving a packet,

1. If destination is in list of neighbours then deliver the packet.
   Otherwise, perform the following steps;
2. Determine the number of links (see below);
3. Determine the actual links (see below);
4. Forward the packet along all chosen links.

We note some features. First, no route computation or maintenance occurs. Each node knows only its neighbours. Second, no central controlling mechanism is needed;

each node assigns a sequence number to each packet it generates to avoid duplicates. Third, intermediate nodes perform a simple operation: they forward packets to all other nodes selected by the protocol, but at most once.

For optimum bandwidth utilisation, it is necessary to determine the best number of links needed for packet forwarding at each intermediate node. The use of too many links may decrease latency at the expense of bandwidth utilisation since there will be high message propagation. On the other hand, using too few links may increase latency with less bandwidth utilisation due to slow message propagation. There is a trade-off between reduction of message propagation and ensuring message delivery.

For our investigations, we considered three methods for calculating the number of links, and two methods for then selecting the links. The three possibilities for calculating the number of links are:

- *Randomised:* the number of outgoing links is randomly determined. For the simulation, the number was chosen uniformly at random between one and the total degree.
- *Fixed-Proportion:* the same proportion of outgoing links is chosen at each intermediate node. Unless otherwise specified, the simulation used 50%.
- *Priority-based:* the number of links selected depends on whether the packet has a high or low priority. For high priority packets all links are used. In our simulation, 25% of packets were high priority; the remaining packets used a fixed $\frac{1}{3}$ of links at each node.

The two possibilities for selection of the actual links are:

- *Random links:* The actual links are chosen uniformly at random among the selected links.
- *Prescribed links:* For each node, a precedence ordering of links is maintained and if 5 links say are needed the first 5 links are used. (The precedence ordering is not altered, though links disappear while other links are added.) The idea is to make this option the opposite of random.

Randomisation should have several advantages. One is that random determination of links for packet propagation is expected to improve the balanced use of available bandwidth. Another is that randomisation reduces congestion and hence may minimise latency and packet loss.

2.3 Protocol applicability and assumptions

The main assumptions underlying the proposed protocols are: First, the underlying data link layer protocol ensures that each node is aware of the status of its links to neighbours. Thus, MAC provides immediate neighbour connectivity information. Second, intermediate nodes have sufficient buffer size for each incoming link and unbounded queues for each outgoing link. Third, nodes can initiate different messages simultaneously to any subset of nodes and messages can traverse a given link in different directions.

3 The Simulation Environment

In this section we model mobile ad hoc networks. The goal is to determine the effect of various simulation parameters on the relative performance of the limited flooding protocol and pure flooding in the presence of node mobility.

3.1 The network model

We have modelled a mobile ad hoc network as an undirected graph. Each vertex has a unique identifier and represents a mobile node capable of forwarding packets to its neighbours. The links are wireless communication paths between the mobile nodes. Each (identical) mobile node has a fixed communication area known as its transmission range. Two nodes within the transmission range of each other are neighbours in the graph.

3.2 The mobility model

There is not yet a standard mobility model for mobile ad hoc networks. Some authors of routing protocols have modelled mobile ad hoc networks using fixed networks with unreliable links [5, 18, 20]. They simulated the performance of their protocols assuming a higher link failure rate. In [24, 26], the random mobility model is used to model a mobile network. In this model, the current speed and direction of motion are independent of the previous values. A pure random mobility model may generate unrealistic motion behaviour.

We use the modified Random Waypoint mobility model proposed by Johnson [13], which is an extension of a random walk. The nodes move in the coverage area as follows:

- Each node begins the simulation by choosing randomly between moving and pausing.
- When moving, a node moves in a straight line. The speed is chosen randomly from a prescribed range and the direction is chosen randomly. The node moves for a specified time chosen randomly from a prescribed range.
- When pausing, the node remains stationary for an (exponentially) random period chosen from a prescribed range.

3.3 The simulation language

We used PARallel Simulation Environment for Complex systems (PARSEC) for simulation of our routing protocol [2]. This is a C-based simulation language for discrete-event simulation models. PARSEC adopts the process interaction approach to discrete-event simulation. An object or a set of objects in the physical system is represented by a logical process and interaction among physical processes is modelled by time-stamped message exchanges among the corresponding logical processes.

Several simulation languages and tools are currently available, commercially or on public domain, for network simulations. However, we chose PARSEC since it separates the description of a simulation model from the underlying simulation protocol used to execute it, and has an easy and clean message-passing infrastructure. Also, PARSEC and its predecessor, Maisie have been widely used for network simulation including routing in mobile wireless networks. Thus at the time of decision-making, it was the only suitable free simulation language widely used in the domain.

3.4 The simulation environment

The simulation environment consists of the entities shown in figure 1.

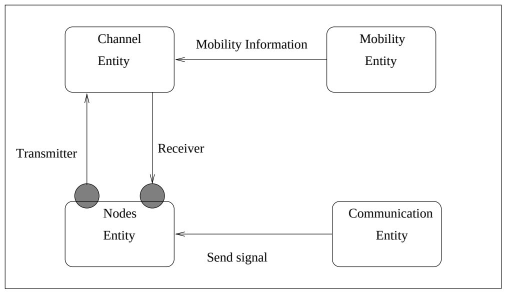

Figure 1: Simulation entities

- The mobile node is simulated by the *node* entity.
- Node mobility is simulated by the *mobility* entity. This tracks the location of the mobile nodes and implements the mobility model described above. At the beginning of the simulation, the N mobile nodes are randomly distributed on the universe (a 1 unit by 1 unit square).
- The *channel* entity models the wireless medium. Its function includes determining node reachability, recording the data packets to be sent and delivering packets to nodes in the hearing range. Channel capacity is 1 Mbit/s and the radio transmission range is a parameter. A free-space propagation model is assumed [23]; thus, two mobile nodes can directly communicate if the distance between them is less than the transmission range.
- The network traffic is generated by the *communication* entity. Large packets are used for data and small packets for control and other short messages. Packet type and destination are determined randomly.

Each simulation is executed for a specified length of time.

3.5 Performance metrics

Three parameters were identified for comparison of the limited flooding protocols with pure flooding.

1. *Mean Packet Relaying Load*: This is the average number of packets relayed per node in the network. This metric measures the mean traffic overhead that occurs at the intermediate nodes during packet forwarding.

2. *Mean Channel Utilisation*: This is the average percentage channel utilisation by packet transmission. The higher the utilisation, the greater the wireless channel utilisation overhead and the greater the congestion.

3. *Normalised Packet Delivery Ratio*: The average delivery ratio is computed as the ratio of the total number of packets successfully received to the total number of packets sent. The Normalised Packet Delivery Ratio for a given limited flooding protocol is computed as the ratio of mean delivery ratio of a limited flooding protocol to the ratio of pure flooding. This unit-free measure indicates how close the packet delivery capabilities of a limited flooding protocol and pure flooding are.

4 Results

The simulation was run for several transmission ranges and network size combinations. These are denoted by Tx and N respectively. This section presents a discussion of the results.

We have made several comparisons between Pure Flooding Protocol (PFP) and all variations of limited flooding protocols. Several thousand simulation runs were performed; we have included only a handful of the resultant data. Our conclusions are thus based on overall impression of the observed simulation results. Note that the simulations are only for comparison of the protocols and we make no claims about realistic operational scenarios.

Each performance metric was investigated separately as a function of transmission range and network size. The transmission range is varied between 10% and 50%. If transmission range is very high then virtually every node can hear every other nodes so the network is virtually complete (and thus uninteresting to us). The number of mobile nodes is varied between 5 and 20.

4.1 The effect of how the actual links are chosen

In figures 2–7, we show the results of runs of Limited Flooding where the two options, Fixed-Proportion Random Links (FLF-R) and Fixed-Proportion Prescribed Links (FLF-P), are compared. Similar results were obtained for the other options for choosing the number of paths, and are omitted.

Mean number of packets relayed. As figure 2 shows, when the transmission range increases, the number of packets relayed increases. As figure 5 shows, the packet relaying overhead rises slightly with network size. In all cases, the number of packets relayed is much lower for Limited Flooding than with pure flooding. While it is not always the case, the Random Link version tends to generate slightly less packets than the Prescribed Link version.

Mean channel utilisation. As figure 3 shows, as transmission range increases, channel utilisation slightly increases but both limited flooding protocols are lower than Pure Flooding. As figure 6 shows, channel utilisation is virtually unaffected by network size. In all cases, pure flooding has the highest channel utilisation. There is little to choose between the two versions of limited flooding.

Normalised packet delivery ratio. By definition, this ratio for flooding is 100% in the simulation experiments. It should be noted that results for this parameter are considerably variable (see figures 4 and 7). The increase in the transmission range results in increased packet delivery ratio while the change in network size does not yield consistent results.

Conclusion. All variations of the limited flooding protocol performed better than pure flooding. Also, randomly choosing the links tends to improve the packet delivery ratio and reduces the packet relaying overhead.

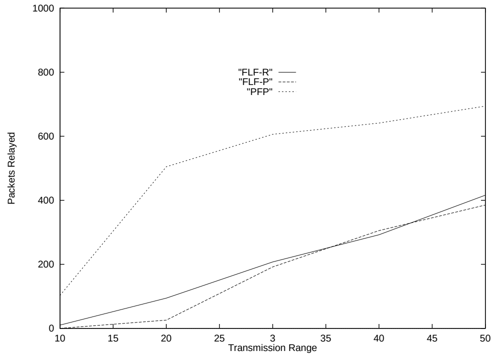

Figure 2: Packets relayed: N = 15

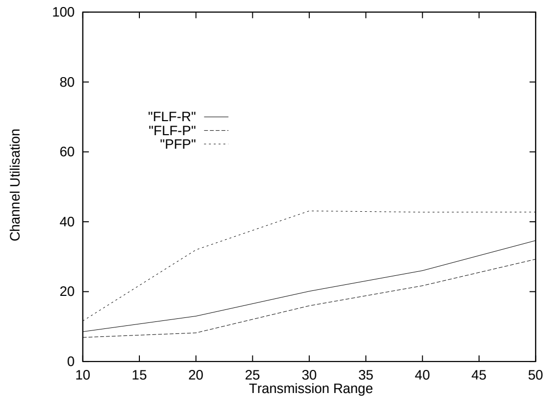

Figure 3: Channel utilisation: N = 15

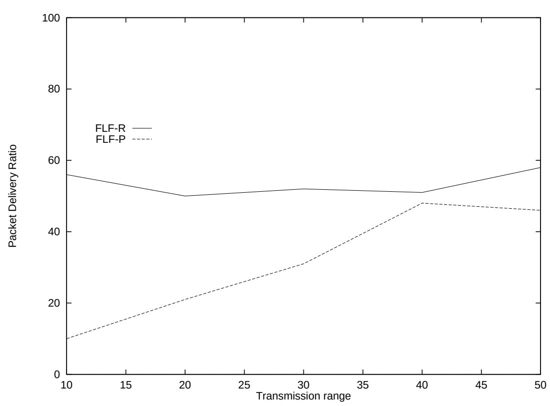

Figure 4: Normalised packet delivery ratio: N = 15

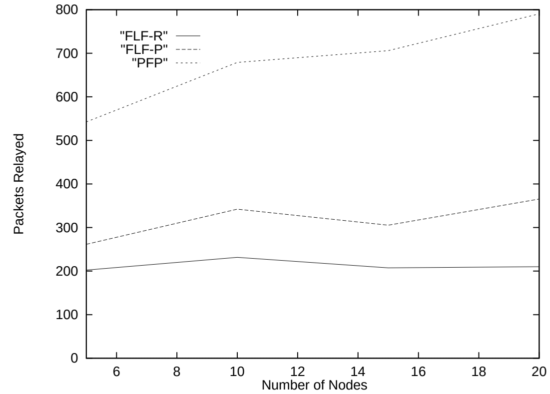

Figure 5: Packets relayed: Tx = 30% .

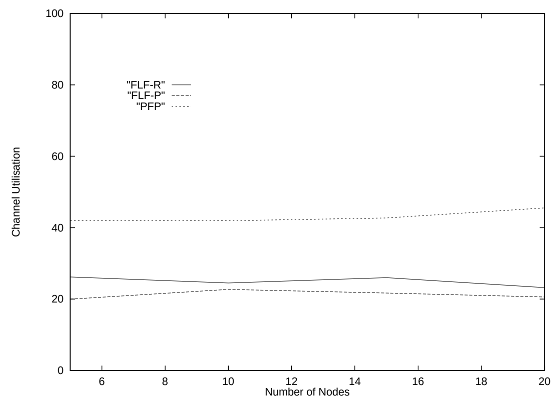

Figure 6: Channel utilisation: Tx = 30%.

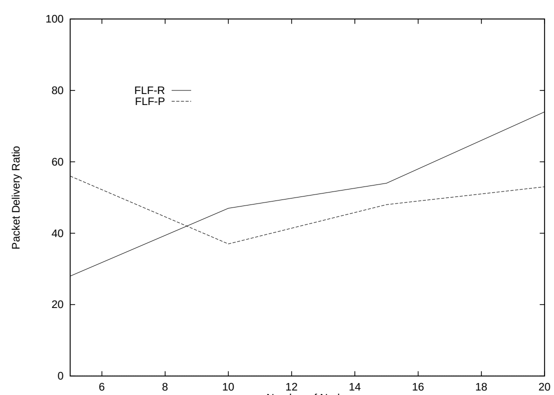

Figure 7: Normalised packet delivery ratio: Tx = 30%.

4.2 The effect of how the number of links is chosen

In figures 8–13, we show the results of runs where limited flooding chooses actual paths randomly, but compares the three options Fixed Proportion (FLF-R), Randomised (RLF-R) and Priority-based (PLF-R). The simulation results as a function of network size are presented in figures 8–10 and corresponding results as a function of transmission range in figures 11–13. In the simulations, transmission range of 40% units is used with varying number of nodes, whereas 10 mobile nodes are used with varying transmission range.

Mean number of packets relayed. As figures 8 and 11 show, the relaying load is always highest for pure flooding. Among the three versions of limited flooding protocol, randomly choosing the number of transmission links slightly reduces the packet relaying load both with increase in transmission range and network size.

Mean channel utilisation. As figures 9 and 12 show, all limited flooding protocols consume less wireless channel resources than pure flooding. Again, randomly choosing the number of transmission links slightly reduces the channel utilisation overhead both with increase in transmission range and network size.

Normalised packet delivery ratio. Figures 10 and 13 show the normalised packet delivery ratio for the three selected protocols. This and other results show that the packet delivery ratio is more variable with increase in network size. This probably occurs due to random mobility pattern that results in changing network topology as more nodes join the network. As figure 13 shows, the packet delivery ratio relatively increases with increase in the transmission range. This is due to increased node reachability and less dependence on the intermediate nodes.

Conclusion. The results indicate that random-based selection of the number of links slightly reduces the packet relaying overhead and channel utilisation.

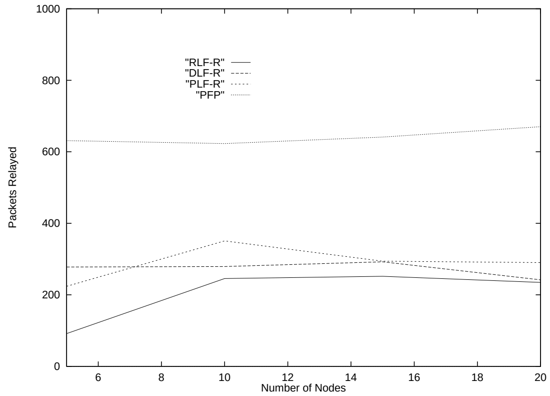

Figure 8: Packets relayed: Tx = 40%

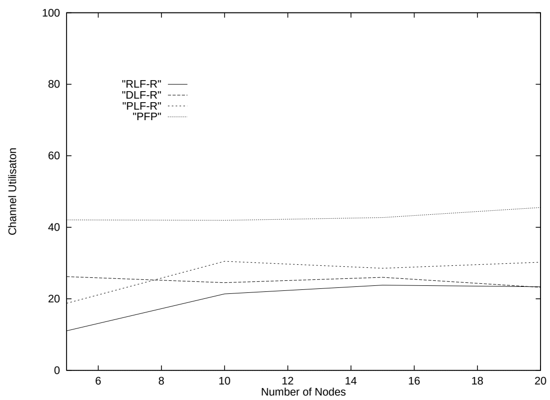

Figure 9: Channel utilisation: Tx = 40%

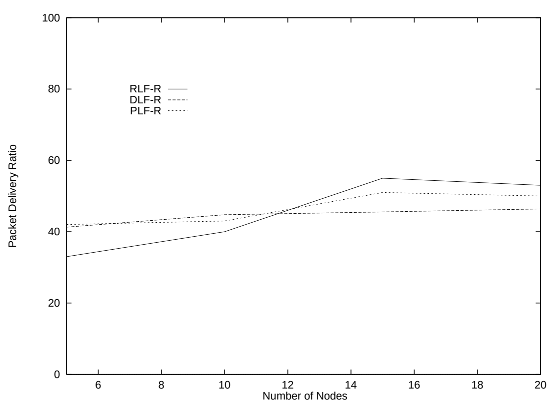

Figure 10: Normalised packet delivery ratio: Tx = 40%

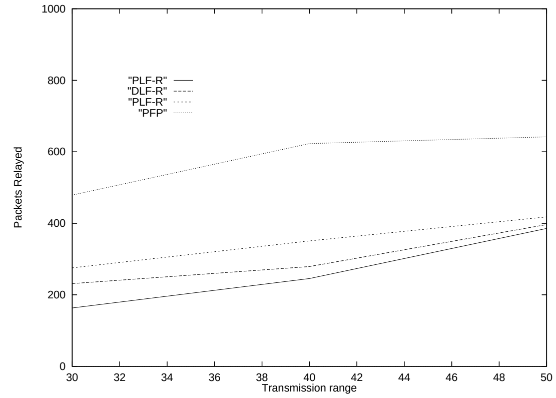

Figure 11: Packets relayed: N = 10

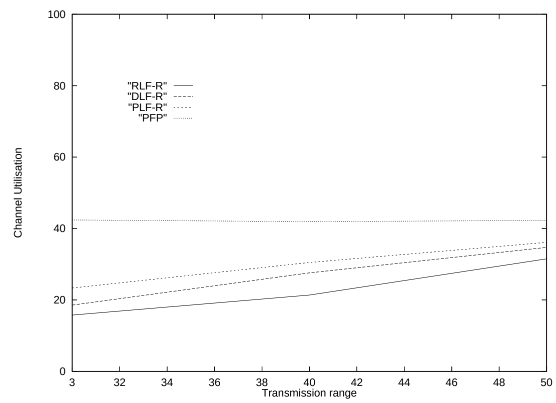

Figure 12: Channel utilisation: N = 10

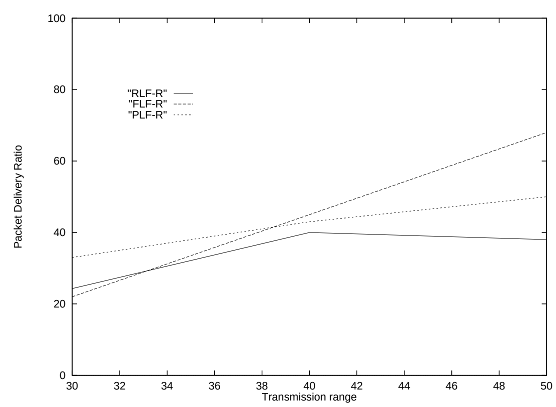

Figure 13: Normalised packet delivery ratio: N = 10

4.3 Comparison with flooding

In previous figures, we have seen that limited flooding does well compared to Flooding. In our final set of graphs we try to quantify this by considering the effect of the fixed proportion on protocol performance (with 100% meaning pure flooding). See figures 14-19. All using Fixed-Proportion Random Links.

Mean number of packets relayed. As figures 14 and 17 show, the packet relaying load increases and becomes closer to pure flooding for highest link proportion. At the link proportion of 60% the packet delivery ratio the lowest.

Mean channel utilisation. As figures 15 and 18 show, at all the fixed proportions of links, limited flooding protocols consume less wireless channel resources than pure flooding. Again, at the link proportion of 60% the channel utilisation is the lowest among the three variations of limited flooding.

Normalised packet delivery ratio. As figures 16 and 19 show, increased packet delivery ratio is observed both with increase transmission range and network size. It can be noted that, however that, there is a consistent increase with increase in transmission range (see figure 19). In general, when the network size increases, the packet delivery ratio is affected due to increased path length caused by changes in the network topology.

Conclusion. In general, the number of packets relayed and channel utilisation improves as the proportion of links used decreases.

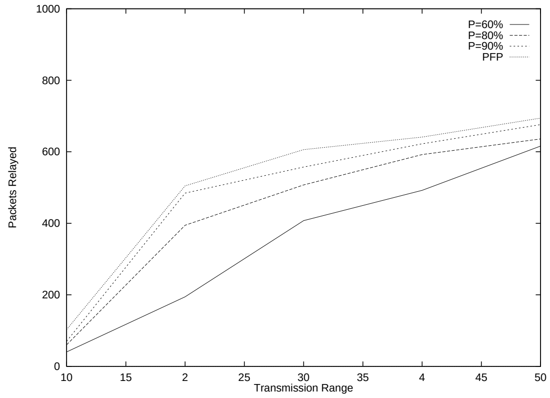

Figure 14: Packets relayed: N = 15

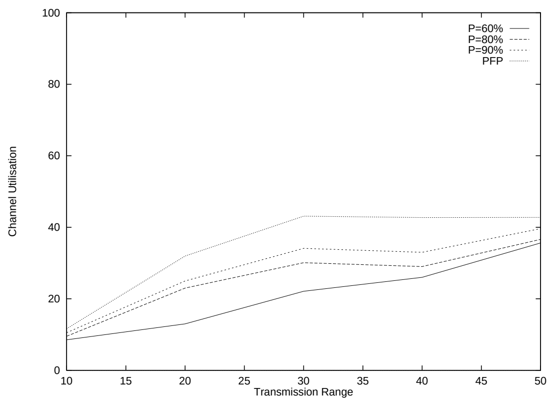

Figure 15: Channel utilisation: N = 15

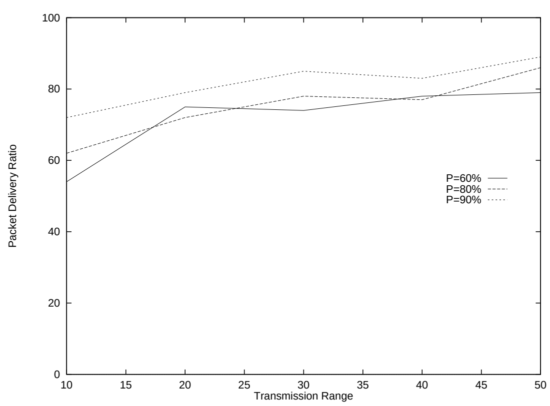

Figure 16: Normalised packet delivery ratio: N = 15

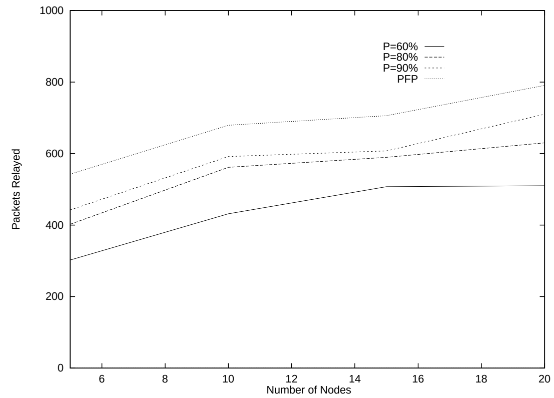

Figure 17: Packets relayed: Tx = 30% .

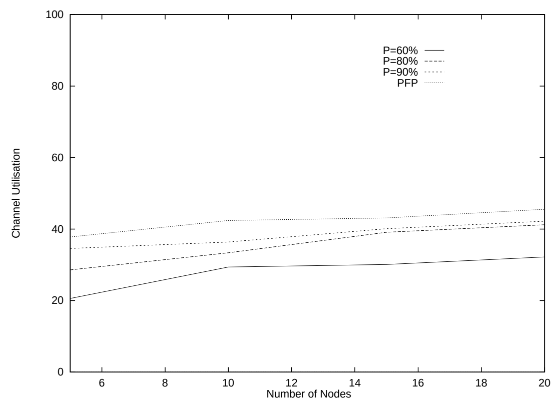

Figure 18: Channel utilisation: Tx = 30%.

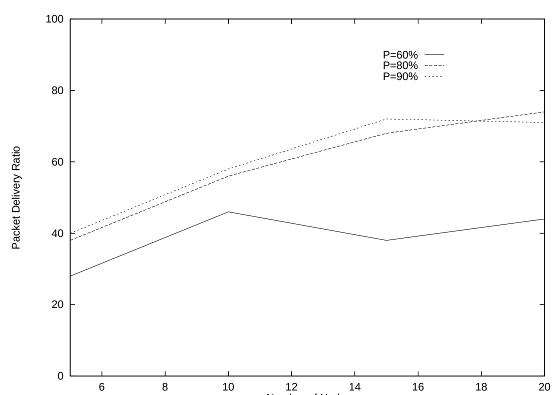

Figure 19: Normalised packet delivery ratio: Tx = 30%.

5 Conclusions and Future Work

5.1 Summary and Conclusions

Limited flooding uses the same principles as flooding but intermediate nodes pass on packets to only some of their neighbours. This protocol is suitable for networks with unpredictable topological changes and relatively high mobility since it does not require maintaining routing tables.

Several variations of the limited flooding protocol were explored. Performance was evaluated using discrete event simulation. The performance metrics used in the simulation were relaying load, channel utilisation and packet delivery ratio. Each metric was investigated as a function of network size and transmission range.

The simulation results show that limited flooding uses less resources than pure flooding for a reasonable packet delivery performance, and hence is suitable for routing in mobile ad hoc networks. Within limited flooding, the protocols based on randomised selection of paths slightly outperform those based on Prescribed Links. This probably occurs because randomised choice of communication paths results in a more balanced use of resources.

5.2 Future Work

Mobile ad hoc network applications environment include relatively static applications such as temporary network infrastructure setup in classrooms, conference halls, sale presentations etc., limited mobility applications where mobile nodes are held by pedestrians or highly mobile network applications where mobile nodes are mounted on fast moving systems. Our results indicate that, in relatively highly mobile network application scenarios, higher packet delivery ratio may not be achieved due to rapid topological changes that can cause frequent network partitions. Frequent partitioning of the network may cause route changes and this results in packet losses.

Further research can be carried out in many directions. Some of our future research directions are: First, the protocols can be evaluated using additional performance metrics and more varied models. For example, performance metrics such as mean end-to-end delay and mean throughput can be used to evaluate each protocol at varied transmission range and network size.

Second, the protocols can be optimised by designing additional mechanisms for further restricting packet propagation at different mobility rates. Also, the mobility model can be enhanced to support group mobility for modelling mobile nodes that move with common mission.

Third, the protocols can be updated by limiting the broadcast message to selected multicast group instead of the entire nodes in the network. We also expect that the use of limited flooding protocol for routing in a clustering architecture will be a good approach for reducing routing overhead in mobile ad hoc networks.

6 Acknowledgements

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References

[1] Y. Azar, J. Naor, R. Rom. *Routing Strategies in Fast Networks* IEEE Transactions on Computers, 45(2):165-173, 1996.

[2] R. Bagrodia and R.A. Meyer. *PARSEC User Manual, Release 1.0,* UCLA Parallel Computing Laboratory, University of California, Los Angeles, February 1998.

[3] S. Basagni, I. Chlamtac, V.R. Syrotiuk and B.A. Woodward. *A Distance Routing Effect Algorithm for Mobility (DREAM),* Proceedings of the fourth Annual mobile computing and networking, October 1998.

[4] C-C. Chiang, H. Wu, W. Liu and M. Gerla. *Routing in Clustered, Multihop, Mobile Wireless Networks with Fading Channel,* The IEEE International Conference on Networks, pages 197–211, Singapore, April 1997.

[5] M.S. Corson and A. Ephremides. *A highly adaptive distributed routing algorithm for mobile wireless networks.* ACM/Baltzer Wireless Networks Journal, 1(1):61–81, 1995.

[6] B. Das and V. Bharghavan. *Routing in Ad hoc Networks using Minimum Connected Dominating Sets(MCDS),* Proceedings of 1997 IEEE International Conference on Communications (ICC'97), 1997.

[7] M.K. Denko and W. Goddard. *Routing Algorithms in Mobile Ad hoc Networks using Clustering* Proceedings of 1998 MSc/PhD annual Conference, University of Stellenbosch, South Africa, pp. 6-18, July 1998.

[8] M.K. Denko and W. Goddard. *Limited Flooding in Mobile Ad hoc Networks.* In proceedings of the 14th MSc/PhD Annual Conference in Computer Science, Golden Gate, South Africa, pp. 21-24, June 1999.

[9] M.K. Denko and W. Goddard: *Clustering in Mobile Ad hoc Networks.* In proceedings of the 5th International Conference in Communication systems (AFRICOM 2001), Cape Town, South Africa, May 2001.

[10] R. Dube. *Signal Stability based adaptive routing for Ad Hoc Mobile Networks.* IEEE Personal Communications, pp. 36–45, February 1997.

[11] Z.J. Haas and M. Pearlman. *Zone Routing Protocol (ZRP)* for ad hoc networks, Internet Draft, Internet Engineering Task Force, work in progress, December 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, Special Issue on Ad-Hoc Networks, pp. 1369–1379, August 1999.

[13] D.B. Johnson and D.A. Maltz. *Dynamic Source Routing in mobile ad hoc networks,* Mobile Computing, (Ed. T. Imielinski and H. Korth), Kluwer Academic Publishers, 1996.

[14] Y-B.Ko, N.H. Vaidya. *Location Aided Routing for mobile ad hoc networks* Proceedings of the fourth Annual mobile computing and networking, October 1998.

[15] P. Krishna, M. Chatterjee, N.H. Vaidya and D.K. Pradhan. *A Cluster-based Approach for Routing in Ad hoc Networks.* In proceedings of Second USENIX Symposium on mobile and Location Independent Computing, pp. 1–10, January 1996.

[16] O. Lesser, R. Rom. *Routing by controlled flooding in communication networks* in proceeding of IEEE INFOCOM'90,(San Francisco, CA), pp. 910–917, June 1990.

[17] J.P. Macker and M.S. Corson. *Mobile Ad hoc networking and IETF* Mobile computing and communication review, 2(1):9–14, January 1998.

[18] S. Murthy and J.J. Garcia–Luna–Aceves. *An Efficient Routing Protocol for Wireless Networks.* ACM Mobile Networks and Applications, Special Issue on Routing in Mobile Communication Networks, 1(1):183–197, October 1996.

[19] E. Pagani and G.P. Rossi. *Reliable broadcast in mobile multi-hop packet networks.* , Proceedings of the third annual ACM/IEEE International Conference on mobile computing and networking (MOBICOM'97), pp. 34–42, 1997.

[20] V.D. Park and M.S. Corson. *A highly adaptive distributed routing algorithm for mobile wireless networks,* Proceedings of 1997 IEEE Conference on Computer Communications (INFOCOM'97), April 1997.

[21] C.E. Perkins and P. Bhagwat. *Highly Dynamic Destination Sequenced Distance Vector Routing (DSDV) for mobile computers.* In proceedings of ACM SIGCOMM, pp. 234–244, 1994.

[22] C.E. Perkins. *Ad hoc on-demand distance vector routing,* Internet Draft, Internet Engineering Task Force, work in progress, December 1997.

[23] T.S. Rappaport. *Wireless Communications: Principles and Practices.* Prentice Hall, October 1995.

[24] M. Sanchez. *Mobility models.* http://www.disca.upv.es/misan/mobmodel.htm, 1998.

[25] C.-H. Toh. *A novel distributed routing protocol to support ad-hoc mobile computing,* Proceeding of 15th IEEE Annual International Phoenix Conference on Computer Communications, pp. 480–486, 1996.

[26] M.M. Zonoozi and P. Dassanayake. *User mobility modeling and characterisation of mobility patterns.* IEEE Journal of Selected Areas in Communications, 15(7):1239–1252, September 1997.