Performance Study of End-to-End Traffic-Aware Routing

Raad S. Al-Qassas, Lewis M. Mackenzie, Mohamed Ould-Khaoua
Department of Computing Science
University of Glasgow
Glasgow, G12 8RZ, UK
Email: {raad, lewis, mohamed}@dcs.gla.ac.uk

Abstract

There has been a lot research effort on developing reactive routing algorithms for mobile ad hoc networks (MANETs) over the past few years. Most of these algorithms consider finding the shortest path from source to destination in building a route. However, this can lead to some network nodes being more overloaded than the others. In MANETs resources, such as node power and channel bandwidth are often at a premium and, therefore, it is important to optimise their use as much as possible. Consequently, a traffic-aware technique to distribute the load is very desirable in order to make good utilisation of nodes' resources. A number of traffic aware techniques have recently been proposed and can be classified into two categories: end-to-end and on-the-spot. The performance merits of the existing end-to-end traffic aware techniques have been analysed and compared against traditional routing algorithms. There has also been a performance comparison among the existing on-the-spot techniques. However, there has so far been no similar study that evaluates and compares the relative performance merits of end-to-end techniques. In this paper we describe an extensive performance evaluation of two end-to-end techniques, based on degree of nodal activity and traffic density, using measures based on throughput, end-to-end delay and routing overhead.

1. Introduction

A Mobile Ad hoc Network (MANET) is a collection of wireless mobile nodes that form a temporary network without the need for any infrastructure or centralized administration. In such an environment, it may be necessary for one mobile node to enlist the aid of others in forwarding a packet to its destination due to the limited propagation range of each mobile node's wireless transmissions [1]. The communication in MANETs is peer-to-peer as the mobile nodes communicate directly with one another. In MANET resources like power and bandwidth are at a premium and it is important to minimise the use of these resources.

The routing protocol in MANETs is responsible for establishing and maintaining paths between nodes in the network. The topology of a MANET may change frequently as nodes may move or power themselves off to save energy. In addition, new nodes can join the network [2]. Consequently, connectivity information is often required to be collected periodically in order to get a consistent view of the network, but this increases the bandwidth consumption resulting from collecting this information. MANETs have limited bandwidth, and therefore need an efficient routing protocol that can establish and maintain routes for both stable and dynamic topologies with minimum bandwidth consumption.

A major challenge in MANETs is the design of a routing protocol that can accommodate their dynamic nature and frequent topology changes; the topology can change unpredictably, so the routing protocol should be able to adapt automatically. However, when designing a protocol, it is not only the frequent changes in the network that are of concern, but also the natural limitations that these networks suffer from, such as limited bandwidth and power. To deal with such issues a number of routing protocols have been proposed [3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13].

There has been a lot of work on developing reactive routing algorithms for ad hoc networks [3, 10, 12]. Most of these algorithms consider finding the shortest path from source to destination in building a route. However, this can lead to some nodes being overloaded more than others in the network. Therefore,

Proceedings of the 39th Annual Simulation Symposium (ANSS'06)
0-7695-2559-8/06 $20.00 © 2006 IEEE

a traffic-aware technique to distribute the load is highly desirable in order to make good utilisation of nodes' scarce resources. In addition it can be useful to prevent the creation of congested areas in the network, which can lead at the end into an improvement on the network performance. Furthermore, such a technique is a good way to achieve fairness in using node's limited resources.

A number of studies [14, 15, 16, 17, 18] have recently proposed traffic-aware techniques for distributing the load in reactive routing. These techniques can be classified into two main categories: *end-to-end* and *on-the-spot*; based on the way they establish and maintain routes between any source and destination. The first category is based on using end-to-end information collected along the path from source to destination. In this category, intermediate nodes participate in building the route by adding some information about their status. However the decision for selecting the path is taken at one of the ends, either the source or the destination. In the second category, information is not required to be passed to one of the ends to make a path selection decision; it is most likely that an intermediate node will do this job. Therefore the decision of selecting a path is made on-the-spot and taken by intermediate nodes. This study will focus on the end-to-end techniques. A comparison between on-the-spot techniques was presented in [17], but, there has been no similar study that evaluates and compares the performance properties of end-to-end techniques. Our goal is to carry out a thorough performance study of end-to-end techniques in situations where it is possible to select one from a set of feasible routes from source to destination in order to distribute the load over the whole set. Such a study will reveal the advantages and disadvantages of the proposed techniques and their applicability under various working conditions.

The remainder of this paper is organised as follows. Section 2 reviews two existing end-to-end techniques, namely *degree of nodal activity* and *traffic density*. Section 3 conducts a comparative study of the performance of the two techniques. Finally, section 4 concludes this study.

2. End-to-end traffic aware techniques

In this section we describe the two end-to-end techniques, *degree of nodal activity* proposed in Load-Balanced Ad hoc Routing (LBAR) [16] and *traffic density* defined in the routing algorithm Load Aware Routing in Ad hoc (LARA) [15].

2.1. Degree of nodal activity

The degree of nodal activity was defined in LBAR as a technique or metric for selecting the route with least traffic load. LBAR is a reactive routing protocol that focuses on how to find the path which would reflect the least traffic load based on a cost function. The cost function is calculated using two components: nodal activity and traffic interference. Nodal activity of a node is defined as the number of active paths passing through that node. An active path is an established path from a source to a destination. Traffic interference is defined as the sum of nodal activity for the node's immediate neighbours. The cost of a route is defined as the sum of a nodes' own nodal activity plus the activity of its neighbouring nodes. The path with minimum cost is that with minimum traffic and this is selected to be the route between source and destination.

Route discovery. The LBAR route discovery process is initiated whenever a source node needs to establish a path with another node. The source node broadcasts a setup message to its neighbours. The setup message carries the cost seen from the source to the current node. A node that receives a setup message will forward it to its neighbours after updating the cost based on its nodal activity value and traffic interference value. In order to prevent looping when setup messages are routed, the setup message contains a list of all node IDs used in establishing the path from source node to the current intermediate node. The destination node collects arriving setup messages within a route-select waiting period, which is a predefined timer for selecting the best-cost path. After the waiting period expires the destination sends an ACK message to the source node along the selected path. When the source node receives an ACK message, it recognises that a path has been established to the destination and then starts transmission.

Route maintenance. Route maintenance is triggered whenever a node on the active path moves out of the communication range, the case in which an alternate path must be found. If the source node moves away from the active path, the source has to reinitiate the route discovery procedure to establish a new route to the destination. When either the destination node or some intermediate node moves outside the active path, path maintenance will be initiated to correct the broken path. Once the next hop becomes unreachable, the node upstream of the broken hop propagates an error message to the destination node. The destination then picks up an alternative path and then sends an ACK message to the initiator of the error message. If the destination has no alternative path, it propagates an error message to the source, which will initiate a new route discovery if needed.

2.2. Traffic Density

The traffic density was proposed in LARA as a metric for selecting the route with the minimum traffic load. LARA uses traffic density to represent the degree of contention at the medium access control layer. This metric is used to select the route with the minimum traffic load when the route is setup. The LARA protocol requires that each node maintain a record of the latest traffic queue estimations at each of its neighbours in a table called the neighbourhood table. Traffic queue is defined as the average value of the interface queue length measured over a period of time. Traffic density of a node is defined as the sum of the traffic queue of that node plus the traffic queues of all its neighbours.

Route discovery. In LARA, the route discovery process is initiated whenever a node needs to establish a path with another node. In the route request process, the source broadcasts a route request packet that contains a sequence number, a source id and a destination id. A node that receives the request, broadcasts the request further, after appending its own traffic density to the packet. This process continues until the request packet reaches the destination. After receiving the first request, the destination waits for a fixed time-interval for more route request packets to arrive. When the timer expires, the destination node selects the best route from among the candidate routes and sends a route reply to the source. When the source node receives the route reply, it can start data transmission. If it does not receive any route reply within a route discovery period, it can restart the route discovery procedure afresh.

Route maintenance. Route maintenance is triggered whenever a node on the active path moves out of the communication range, in which the case an alternate path must be found. If a link failure occurs during a data transmission session, the source is informed of the failure via a route error packet. On receiving a route error packet, the source initiates a new route request and queues all subsequent packets for that destination until a new route is found.

3. Comparison of End-to-End Traffic-Aware Techniques

The performance merits of the existing end-to-end traffic aware techniques like traffic density [15] and nodal activity [16] have been analysed and compared against traditional routing algorithms [3, 12]. There has also been a performance comparison among the existing on-the-spot techniques in the study of [17]. However, there has not so far been a similar study that evaluates and compares the relative performance merits of end-to-end techniques. Therefore, one of our research goals is to undertake a thorough study of end-to-end techniques in situations where it is possible to select one from a set of feasible routes from source to destination in order to distribute the load where possible. This study will demonstrate advantages and disadvantages and applicability under various working environments. In our study the performance of the traffic density and nodal activity is assessed through simulations implemented using the well-known network simulator ns-2 [19].

3.1. Simulation Model

The simulation model consists of the following main components: simulation area, simulation time, number of nodes, mobility model, maximum node speed, number of traffic flows, and traffic rate. The model is represented by two scenario files, which are the topology scenario and traffic scenario. The topology scenario corresponds to how nodes are distributed over the simulation area and their movement during simulation time. The traffic scenario file contains the type of data, number of flows, traffic rate, and flow start time and end time. In all scenarios nodes are assumed to be equipped with the wireless standard IEEE 802.11 with a transmission range of 250m and a bandwidth of 2 Mbps.

In order to maximise the opportunity of forming multiple paths between data flow sources and their destinations we have chosen to assume that they are stationary while the rest of the nodes in the network are mobile. The reason for this is that sources could come within the range of each other or be very close to doing so due to mobility. Therefore keeping them stationary can boost our study of the traffic aware techniques. This, of course, will not create fixed paths between source and destination pairs as intermediate nodes that form the paths are mobile. Figure 1 illustrates how sources and destination are placed in the topology.

We have implemented the traffic aware techniques, traffic density and nodal activity, under the AODV-like routing algorithm AOMDV [20]. AOMDV is a multi-path algorithm that supports loop-free multiple paths. The ns-2 source code for this algorithm is available and it is easier to modify this source code to simulate the traffic density and degree of nodal activity metrics rather than writing it from scratch.

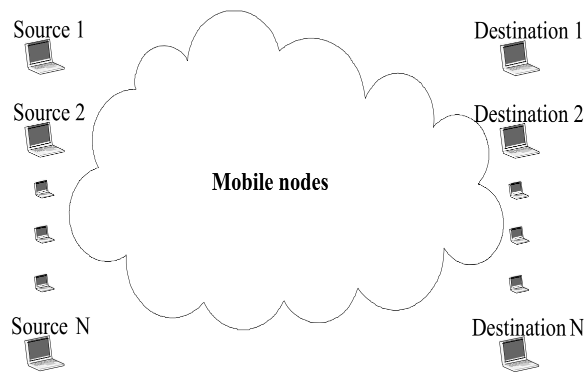

Figure 1. Illustration of how sources and destinations are placed in the topology.

3.2. Simulation Results

The evaluation is based on the simulation of 100 wireless nodes forming a MANET over a flat space of size 1200m × 1000m for a period of 900 seconds. Flows with Constant Bit Rate (CBR) data have been used. The traffic rate varied between 2, 4 and 8 packets per second representing low, medium and high traffic loads, respectively. The numbers of CBR flows used are 3 and 5 flows with packet size of 512 bytes. Nodes move according to the widely used random waypoint model [3]. In the random waypoint model each node remains stationary for a pause time period. When the pause time expires, the node selects a random destination in the simulation space and moves towards it. When the node reaches its destination, it pauses again for the same pause time. This behaviour is repeated throughout the simulation time. In all the simulated scenarios the pause time has been set to 0 seconds to allow all time mobility. The node maximum speeds varied between 1, 2, 5, 7, 10, 15 and 20m/s. For each speed we have made runs for 30 randomly generated topologies. Simulation parameters are illustrated in Table 1.

The performance of the two techniques is measured by: *throughput*, *end-to-end delay* and *routing overhead*. The throughput is the amount of data received at the final destination over the simulated time averaged over number of flows. This measure provides an indication of the efficiency of the technique as it shows the amount of data that the protocol is able to deliver to destinations. End-to-end delay is the average time interval between the generation of a packet in a source node and the successful delivery of the packet at the destination node. It counts all possible delays that can occur in the source and all intermediate nodes. Routing overhead is the number of routing (control) packets sent throughout the simulated time. The smaller this value the better the performance and the more efficient the usage of resources.

Table 1. The system parameters used in the simulation experiments

Parameter	Values
Number of nodes	100
MAC layer	IEEE 802.11
Transmission range	250m
Simulation area	1200m x 1000m
Simulation time	900s
Mobility model	Random waypoint model
Maximum speed	1, 2, 5, 7, 10, 15 and 20m/s.
Pause time	0s
Traffic type	CBR
Packet size	512 bytes
Packet rate	2, 4, 8 packets/s
Number of flows	3, 5
Number of runs per data point	30

Figures 2 to 7 show the average throughput for the two traffic aware techniques: traffic density and nodal activity. Figure 2 demonstrates the behaviour of the two techniques for 3 light traffic flows with a rate of 2 packets per second. From the figure we can observe that throughput decreases for both techniques as the mobility increases. This is because the increase in mobility causes frequent topology changes resulting in broken routes. Nonetheless, traffic density shows better throughput compared to nodal activity under various mobility speeds. Figure 3 shows the behaviour of the two techniques under medium traffic rate of 4 packets per second for 3 flows. The figure shows that traffic density performs better than nodal activity. Although the throughput decreases while nodes' speed increases the throughput difference between the techniques is almost the same. Figure 4 depicts the performance under a higher traffic rate of 8 packets per second for 3 flows. The figure shows that traffic density outperforms nodal activity with a maximum throughput difference of 1300 bps.

Figure 5 demonstrates the performance of the two techniques in the presence of 5 flows with traffic rate of 2 packets per second. The figure shows a drop in the throughput value compared to that one in Figure 2. The reason behind this is that we have two extra flows sharing the resources with the previous three. In addition the throughput is averaged over 5 flows instead of 3. The figure reveals that even if we increase the number of flows to 5, traffic density still outperforms nodal activity. Figure 6 shows the behaviour of the two techniques under medium traffic rate of 4 packets per second. The figure shows that traffic density continues to perform better than nodal activity. Figure 7 depicts the performance under the higher traffic rate of 8 packets per second. The figure shows clearly that traffic density outperforms nodal activity.

Figures 8 to 13 demonstrate the end-to-end delay for traffic density and nodal activity. Figure 8 shows the behaviour of the two techniques under light traffic for 3 flows with a rate of 2 packets per second. The figure shows clear advantage for the traffic density technique in all of the simulated mobility speeds, especially at maximum speed of 20m/s. The same behaviour is depicted under moderate traffic where 3 flows are used with a packet rate of 4 packets per second as it is shown in Figure 9, where the traffic density is the one with better performance. On the other hand, Figure 10 shows quite even performance for the two techniques under high traffic rate of 8 packets per second.

Figures 11 to 13 show the behaviour of the two techniques under light, moderate and high traffic with rates of 2, 4 and 8 packets per second, respectively, in the presence of 5 flows. Figure 11 shows that traffic density clearly outperforms nodal activity with a difference up to 200 ms. Similarly in Figure 12 traffic density is the one with better end-to-end delay, with a difference up to 100 ms. However the two techniques show similar performance under high traffic conditions as it is shown in Figure 13. Nevertheless we should bear in mind that even if the two techniques have shown similar delay, traffic density has the upper hand in terms of throughput under the same scenarios.

Figures 14 to 16 show the routing overhead of traffic density and nodal activity under light, moderate and high traffic with rates of 2, 4 and 8 packets per second, respectively, for 3 traffic flows. Figure 14 shows the two techniques with almost similar generated overhead. On the other hand, Figure 15 depicts traffic density with the higher overhead and nodal activity is the one with better performance, when the traffic rate increases, with a difference less than 8%. The difference increases under higher traffic conditions to reach up to 12% of maximum generated overhead in Figure16.

Figures 17 to 19 show the routing overhead of traffic density and nodal activity under light, moderate and high traffic with rates of 2, 4 and 8 packets per second, respectively, for 5 traffic flows. The overhead in general is higher than it is in figures 14 to 16, which is normal as the number of flows is increased to 5 from 3. Figure 17 shows the nodal activity with less overhead and hence better performance. Figure 18 depicts traffic density with the higher overhead and nodal activity is the one with better performance, with a difference about 9% of overhead. The difference increases under higher traffic conditions up to about 12% of overhead as depicted in Figure16.

4. Conclusions and future work

In this study, we have conducted a performance evaluation of two existing traffic aware techniques namely traffic density and degree of nodal activity to assess their behaviour under similar working environments. Simulation results have shown that the traffic density technique outperforms the nodal activity in both throughput and end-to-end-delay in most of the simulated scenarios. However, nodal activity has shown better performance in terms of routing overhead. As a next step of this study we intend to carry out further investigations of the comparative performance of the two techniques under different working environments by changing the traffic patterns, mobility pattern, network size, and topology area.

5. References

[1] D.B. Johnson, Routing in ad hoc networks of mobile hosts, Proc. Workshop on Mobile Computing Systems and Applications, *IEEE Computer Society*, Santa Cruz, CA, December 1994 pp. 158-163.

[2] W. Chen, N. Jain and S. Singh, ANMP: Ad hoc network management protocol, *IEEE Journal on Selected Areas in Communications*, Vol. 17, No. 8, August 1999, pp. 1506-1531.

[3] 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.

[4] Z. Haas and M. Pearlman, The performance of Query Control Schemes for the Zone Routing Protocol, *IEEE/ACM Transactions on Networking*, Vol. 9, Issue 4, August 2001, pp. 427-438.

[5] C.E. Perkins and P. Bhagwat, Highly dynamic Destination-Sequenced Distance Vector routing (DSDV) for mobile computers, *Proc. ACM SIGCOMM'94*, London, September 1994, pp. 234-244.

[6] R.S. Al-Qassas, A. Al-Ayyoub, and M. Ould-Khaoua, Bandwidth-efficient routing protocol for mobile ad hoc networks, *IEE Proc.-Software*, Vol. 150, No. 4, August 2003, pp. 230-234..

[7] S. Murthy and J.J. Garcia-Luna-Aceves, An efficient routing protocol for wireless networks, *ACM Mobile Networks and Application,* Special Issue on Routing in Mobile Communication Networks, Vol. 1, No. 2, October 1996, pp. 183-197.

[8] T. Clausen and P. Jacquet, Optimized Link State Routing protocol, *IETF MANET*, Internet Draft, Jul. 2003.

[9] R. Ogier, F. Templin and M. Lewis, Topology Dissemination Based on Reverse-Path Forwarding (TBRPF), *IETF MANET*, Internet Draft, Oct. 2003.

[10] Y. Ko, N.H. Vaidya, Location-Aided Routing (LAR) in mobile ad hoc networks, Wireless Networks, Vol. 6, No. 4, 2000, pp. 307-321.

[11] C.-K. Toh, Associativity Based Routing for ad hoc mobile networks, *Wireless Personal Communications Journal*, Special Issue on Mobile Networking and Computing Systems, Vol. 4, No. 2, March 1997, pp.103-139.

[12] C.E. Perkins and E.M. Royer, Ad-hoc On-demand Distance Vector routing, *Proc. 2nd IEEE Workshop on Mobile Computing Systems and Applications*, New Orleans, LA, Feb. 1999, pp. 90-100.

[13] V.D. Park and M.S. Corson, A highly adaptive distributed routing algorithm for mobile wireless networks, *Proc. of IEEE INFOCOM '97*, Kobe, Japan, April 1997, pp. 1405-1413.

[14] M.R. Pearlman, Z.J. Haas, P. Sholander, and S.S. Tabrizi, On the impact of alternate path routing for load balancing in mobile ad hoc networks, *Proc. ACM MobiHoc*, 2000, pp. 3-10.

[15] V. Saigal, A.K. Nayak, S.K. Pradhan and R. Mall, Load balanced routing in mobile ad hoc networks, *Computer Communications*, Vol. 27, Issue 3, Feb. 2004, pp. 295-305.

[16] H. Hassanein and A. Zhou, Load-aware destination-controlled routing for MANETs , *Computer Communications*, Vol. 26, Issue 14, Sep. 2003, pp. 1551-1559.

[17] S.B. Lee, Jiyoung Cho, and A.T. Campbell, A hotspot mitigation protocol for ad hoc networks, *Ad hoc Networks Journal*, Vol. 1, No. 1, March 2003.

[18] J. Gao and L. Zhang, Load balanced short path routing in wireless networks, *INFOCOM 2004*, Vol. 2, March 2004, pp. 1098-1107.

[19] The Network Simulator ns-2, http://www.isi.edu/nsnam/ns.

[20] M. K. Marina and S. R. Das, On-demand multipath distance vector routing in ad hoc networks, *Proc. International Conference for Network Protocols* (*ICNP*), Nov. 2001, pp. 14-23.

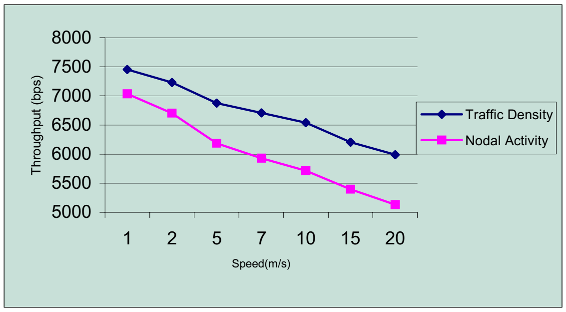

Figure 2. Throughput for 3 flows of traffic with a rate of 2 packets/s.

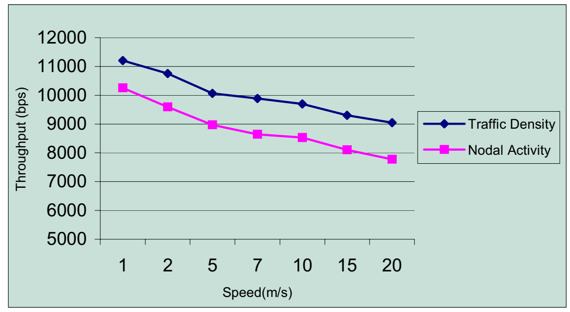

Figure 3. Throughput for 3 flows of traffic with a rate of 4 packets/s.

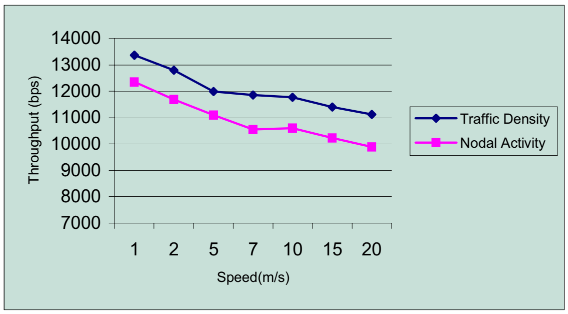

Figure 4. Throughput for 3 flows of traffic with a rate of 8 packets/s.

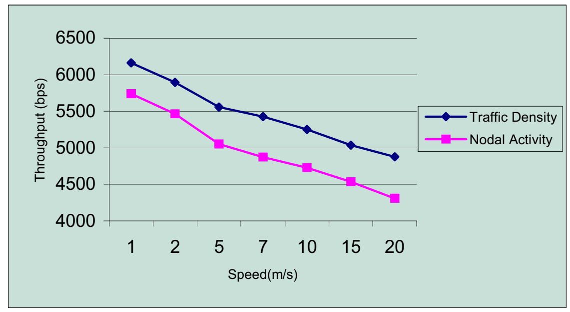

Figure 5. Throughput for 5 flows of traffic with a rate of 2 packets/s.

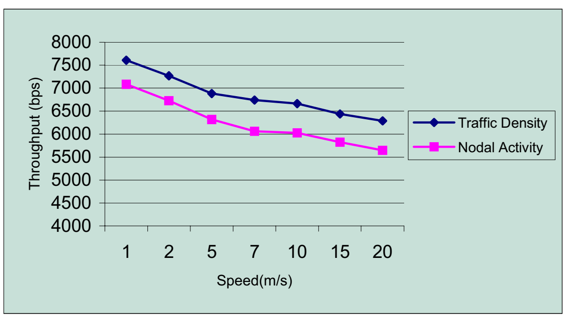

Figure 6. Throughput for 5 flows of traffic with a rate of 4 packets/s.

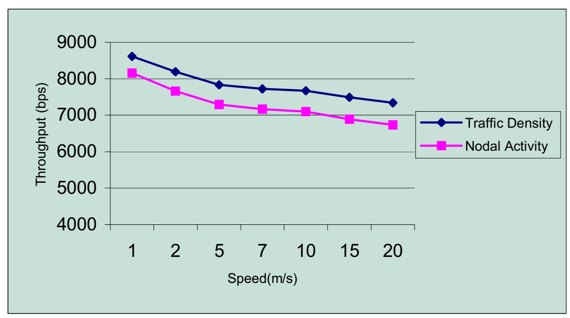

Figure 7. Throughput for 5 flows of traffic with a rate of 8 packets/s.

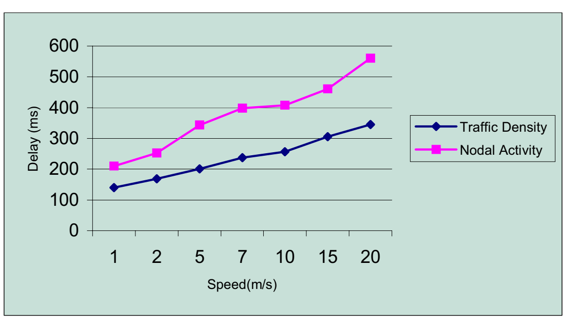

Figure 8. Delay for 3 flows of traffic with a rate of 2 packets/s.

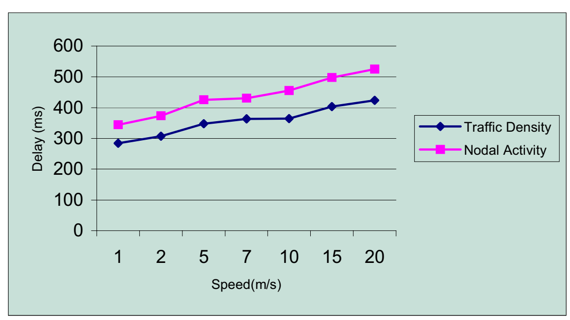

Figure 9. Delay for 3 flows of traffic with a rate of 4 packets/s.

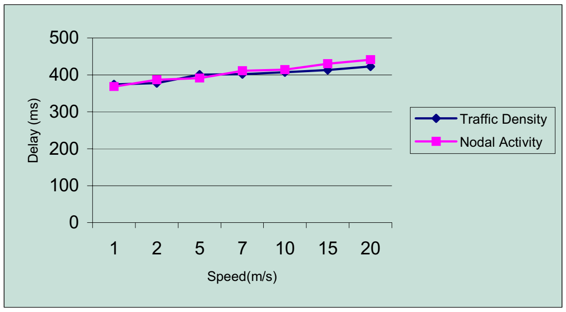

Figure 10. Delay for 3 flows of traffic with a rate of 8 packets/s.

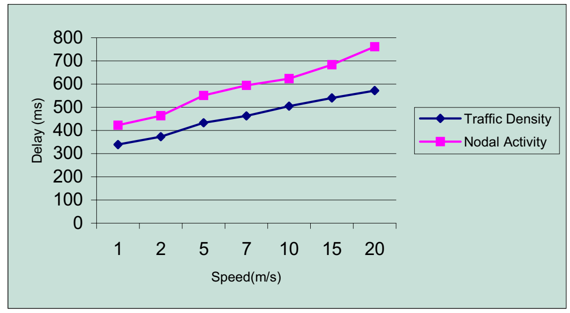

Figure 11. Delay for 5 flows of traffic with a rate of 2 packets/s.

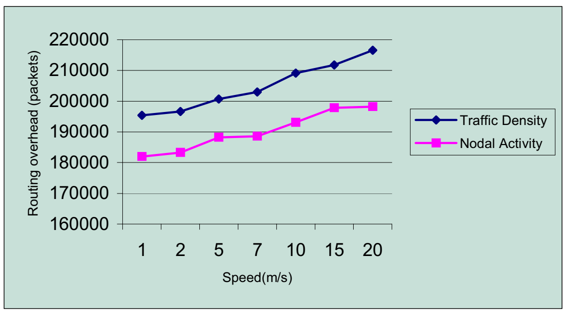

Figure 12. Routing overhead for 3 flows of traffic with a rate of 4 packets/s.

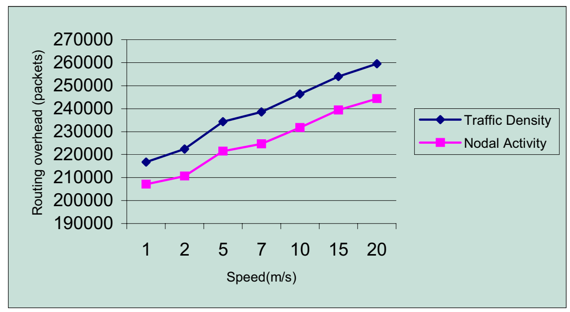

Figure 13. Routing overhead for 3 flows of traffic with a rate of 8 packets/s.

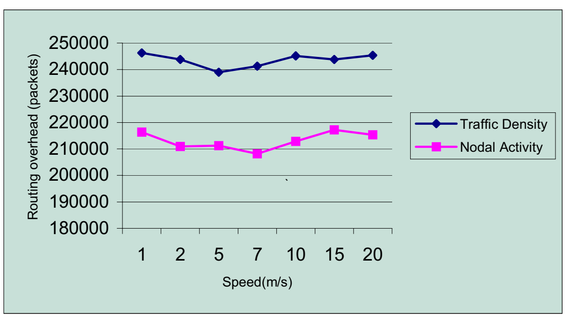

Figure 14. Routing overhead for 5 flows of traffic with a rate of 2 packets/s.

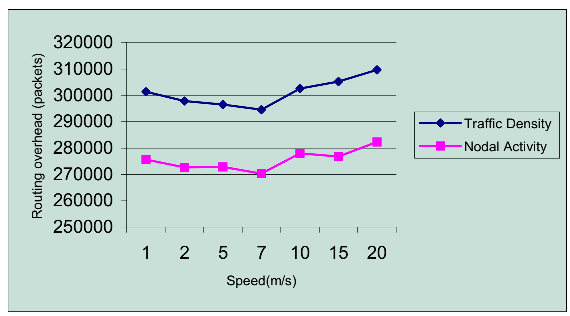

Figure 15. Routing overhead for 5 flows of traffic with a rate of 4 packets/s.

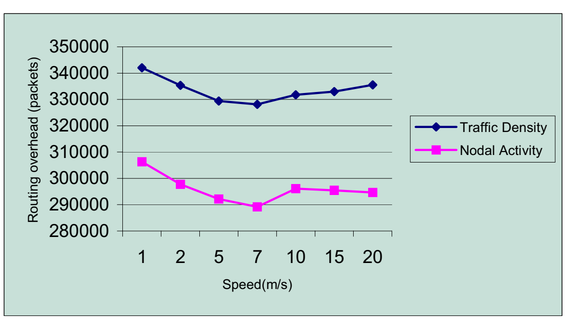

Figure 16. Routing overhead for 3 flows of traffic with a rate of 2 packets/s.