CONGESTION-AWARE ROUTING PROTOCOLS FOR AD HOC NETWORKS

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ABSTRACT

In this paper, we propose effective routing protocols that avoid congestion. The mechanism we propose for congestion-avoidance is based on the selection of the least congested routes as they are discovered, instead of the shortest ones. Using simulations, the proposed route discovery algorithms have achieved better packet delivery ratio (up to 11% improvement) as compared with the AODV routing protocol. The suggested protocols have been implemented and simulated using the GloMoSim 2.03 network simulator.

Keywords: Mobile ad hoc networks, on-demand routing, reactive routing, shortest-path routing, congestion-avoidance routing, congestion-adaptive routing, delivery ratio, control overhead, end-to-end delay, AODV.

1. Introduction

A mobile ad hoc network is a collection of mobile nodes that cooperate when and where needed to form a temporary network (infrastructureless network). It is characterized by battery constraints, lack of infrastructure, node mobility and limited wireless transmission range [1, 2, 3]. Since an ad hoc network does not require pre-existing infrastructure for communication purposes, it is suitable and ideal for cases where using a fixed network is time-consuming and costly, or impossible because of the existence of obstacles and limitations [4, 5]. This is the case in battlefield areas and in search and rescue operations, for example.

In this paper, we propose that the source and destination make route selection decisions. A destination immediately informs the source of a route request of the first route it knows of, and later it informs the source only of better routes as they are discovered. The source can begin packet transmission as soon as it receives the first route, and it can later switch to better routes as it receives them.

In this paper, routes are selected based on the number of routes that go through their nodes. It is expected that nodes located on fewer routes have lighter traffic and lower congestion. The proposed schemes use two route selection methods. In the first method, the route with the smallest average congestion level computed for the intermediate nodes between the source and destination is selected. In the second method, the route with the smallest maximum node congestion value is selected. The suggested schemes have been implemented and simulated using the GloMoSim 2.03 network simulator [6]. Using simulation results, we have compared our schemes with the well-known AODV routing protocol. We have selected AODV for the comparison because its delivery ratio is relatively high compared to other routing protocols, and it has a lot of features that make it a promising routing protocol [7]. The simulation results show that route selection based on the number of routes that go through nodes can result in substantial improvement in the delivery ratio as compared with AODV's route selection.

2. Previous Congestion Research

Congestion is one of the most important problems in ad hoc networks. It occurs when the number of packets being transmitted through a network region begins to approach the packet-handling capacity of the region. There are two mechanisms to deal with this problem: congestion avoidance and congestion control [8]. The objective of these two mechanisms is to maintain the number of packets within the various network parts below the level at which too many packets are dropped. The loss of packets normally means that they will be retransmitted, which consumes additional power and bandwidth.

2.1 Congestion-Aware Distance Vector Routing Protocol (CADV)

This protocol uses the delay of sending a packet as an indication of a node congestion level. In [9], every node maintains a routing table containing a set of useful information, such as destination, next hop to destination, expected delay at next hop, and distance to destination. Each routing entry is associated with an expected delay value, which indicates the congestion level at the next hop to the entry's destination. Every node calculates the expected delay of packets, which is the time that a packet is expected to wait in the node, and it broadcasts this information to neighbors. A routing decision is made based on the distance to the destination as well as the expected delay at the next hop. CADV tries to avoid the use of congested routes and gives priority to a route that has a low expected delay. For example, if a node needs a route to a destination, and it receives two routes to the destination, one from node A and another from node B. If the expected delay at node A is significantly less than that at node B, A will be chosen as next hop, even if the route via A is longer than the one via B.

2.2 Congestion-Aware Routing Protocols for Ad Hoc Networks

In [10], an on-demand routing protocol that uses the route congestion level as selection metric is proposed. The route congestion level depends on the congestion level of intermediate nodes, where the congestion level of a node is the number of active routes that the node is a part of. When a source wants to send data packets to a destination, and there is no known route to the destination, the source broadcasts a route request (RREQ) packet towards the destination. When the destination receives a route request packet, it sends back a route reply (RREP) packet towards the source using the inverse of the path taken by the request packet to reach the destination. When an intermediate node receives a RREP packet, it attaches its congestion level to the RREP packet and sends back the packet towards the source. This procedure continues until the RREP packet reaches the source node. The source waits some period of time so as to possibly receive multiple RREP packets, and select the best route based on the congestion level. There are two approaches to selecting a route to the destination. In the first approach, a source selects the route with the least average congestion level computed for all intermediate nodes on the route. In the second approach, the source selects the route with the least maximum congestion value considering all route intermediate nodes. Also in [10], another algorithm where intermediate nodes attach the used fraction of their buffers to the RREP packet was proposed. When the source receives a RREP packet, it waits for some time period, expecting to receive additional RREPs. Then, it selects the route with the minimum average buffer ratio.

3. Proposed Congestion-aware Route Establishment Algorithm

In Figure 1, the network consists of a group of mobile nodes, where some routes have been established. The routes are 2-5-9-10 form node 2 to node 10, 6-5-4 from node 6 to node 4, and 1-5-9-10 from node 1 to node 10. Based on this information, we can see that node 5 is located on three routes, while node 9 is located on two routes. The probability of packet dropping at these two nodes can be expected to be higher than at other nodes in the network. The reason is that these nodes likely receive more packets than the other nodes, and since node buffer space is limited, overflow and packet dropping are more likely to occur. Now, suppose that node 0 wishes to send data packets to node 10. Using the traditional routing protocols (shortest-path), the source node may select the least hop-count route 0-2-5-9-10. But, this route may not be the best with respect to congestion, because node 5 is located on three routes and node 9 is located on two routes. We can see in Figure 1 that the route 0-6-7-8-12-10 may be the best route with respect to congestion because its nodes are overall located on fewer routes.

3. 1 The Proposed Schemes

3.1.1 Min_Total_CA Scheme

In this scheme, a source-destination route with the minimum total congestion value is selected. Each route has a forward congestion value and a backward congestion value. The forward value is determined during the route discovery process. It represents the sum of the congestion values from the source to the current node, while the backward value is determined during the route reply process, and it represents the sum of the congestion values from the destination to the current node. In this scheme, the congestion level of a node is the number of active routes that the node is a part of.

When a source wants to send data to a destination, but it does not have route to the destination, it prepares a RREQ packet where the forward and backward congestion levels are initialized to zero, then the source broadcasts the RREQ towards the destination. Each intermediate node that receives a RREQ packet checks to see if it is a duplicate or not, where a pair (source address, broadcast id) uniquely identifies a RREQ. Intermediate nodes process non-duplicate RREQ packets, and duplicate RREQ packets if they contain a smaller forward congestion level. In processing a RREQ, an intermediate node checks its route table for a known route to the destination. If there is one, it is checked for freshness, where a route is considered fresh if it has a destination sequence number larger than the destination sequence number in the control packet. If the route is not fresh or there is no route to the destination, the intermediate node adds its congestion level to the forward congestion level in the RREQ header, and the RREQ is broadcast. This process is repeated until the RREQ reaches the destination or an intermediate node that has a fresh route to the destination. The intermediate node records information needed to build a backward path for use in sending the route reply back to the source.

The destination node accepts duplicate RREQ packets. When the destination receives a RREQ packet, it searches its route table for a known route to the source, and if there is no such route, it sends a RREP using the inverse of the route in the RREQ header. But, if there is a known route to the source, the destination compares the forward congestion level in the RREQ received with the forward congestion level of the route currently in use. If it is smaller, the destination replaces its current route information with the RREQ packet route information and sends a RREP to the source. In summary, the destination immediately responds to the route request it receives first, but later new route requests are compared with the current one, and if the new route is better (its forward congestion value is less than the forward congestion value of the current route), it will be sent to the source node for future use. By applying this route selection algorithm, we expect to achieve better delivery ratio because data packets pass through less congested nodes, where the probability of packet dropping is lower. However, end-to-end delays may increase because the least congested route may not be the shortest one. Also, the control overhead may increase because intermediate nodes do rebroadcast some duplicate RREQ packets.

Each intermediate node that receives a RREP packet checks to see if the RREP is the first reply or not. If it is, the intermediate node adds its congestion level to the backward congestion value contained in the RREP header, updates its route table, and forwards the RREP to the next hop towards the source. If the received RREP is not the first reply, the intermediate node checks the freshness of the route in the RREP. If it is fresher than the current one (has a destination sequence number larger than that of the route currently in use), the intermediate node updates its route table and forwards the RREP to the next hop towards the source. But, if the route in the received RREP is as fresh as that of the current route, the intermediate node compares the backward congestion level in the RREP with the backward congestion level of the current route, and uses the best one (the least congested one) for sending data.

When a source node receives a RREP packet, it checks its route table to determine if it is the first reply to a route request or not. If it is, the source starts using the route received; otherwise it checks the route freshness. If the new route received is fresher than the one currently in use (has a destination sequence number larger than that of the route being used), the source updates its route table and starts using the new route for sending data. But, if the two routes have the same freshness, the source compares the backward congestion level in the RREP with that of the current route, and starts using the best one (the least congested one) for sending data.

Example 1. In Figure 1, the route 0-2-5-9-10 has a congestion level of 6 (i.e., 1 + 3 + 2 = 6), the route 0-6-7-8-12-10 has a congestion level of 5 (i.e., 2 + 1 + 1 + 1 = 5), and the route 0-6-5-9-10 has a congestion level of 7 (i.e., 2 + 3 + 2 = 7). Therefore, the route 0-6-7-8-12-10 is selected by this scheme as the best route.

3.1.2 Min_Max_CA Scheme

This Min Maximum Congestion Avoidance (Min_Max_CA) algorithm is similar to the Min_Total_CA algorithm, except that an intermediate node does not add its congestion level to the congestion level in the RREQ and RREP packets, but it compares the congestion levels. If the node's congestion level is larger, it replaces the congestion level of the RREQ/RREP control packet.

Example 2. Considering Figure 1 again, the route 0-2-5-9-10 has a MAX value of 3, the route 0-6-7-8-12-10 has a MAX value of 2, and the route 0-6-5-9-10 has a MAX value of 3. Therefore, the route 0-6-7-8-12-10 is selected as the best route.

4. Simulation

We implemented the proposed algorithms in the GloMoSim [6] simulator so as to evaluate their performance and compare them to the well-known routing scheme AODV. Our simulations model a network of 50 mobile nodes placed randomly within a 1000 meter × 1000 meter area. Each node has a radio propagation range of 250 meters, and the channel capacity is 2 Mb/s. A free space propagation model was assumed, and the MAC layer conforms to the IEEE 802.11 protocol. Data traffic is generated by constant bit rate (CBR) sources. The size of the data packets is 512 bytes. Node mobility follows the random waypoint model, and node velocity is distributed uniformly over the range zero to ten meters/second; this environment is commonly used [11, 12]. Each simulation run lasts for 300 seconds and was repeated 12 times. To comprehensively measure the performance of our routing schemes, we used various mobility levels by using pause times of 0, 100, 200 and 300 seconds. In addition, we used source traffic loads of 1, 2, 4 and 6 packets per second, repeated for 5, 10, and 15 sources.

4.1 Performance Metrics

There are several metrics that are commonly used for evaluating the performance of routing algorithms. In our study, we use the delivery ratio, end-to-end delay and overhead parameters, as was done in [12, 13].

Delivery Ratio: the delivery ratio is the ratio of the number of data packets received by the destinations to the number of data packets sent by sources [12]. For example, if by the end of simulation, the destinations have received 600 data packets out of 1000 data packets that were sent by the source, then the delivery ratio is **60%.**

Average End-to-End Delay: is the average of the times it took packets to travel from sources to destinations [12].

Control Overhead: is the ratio of the number of control packets (route discovery and maintenance packets) to the number of data packets [13].

4.2 Simulation Results

In Figures 2, 3 and 4, we plot the average performance computed for all scenarios considered in this paper. As can be seen in Figure 2, our Min_Total_CA and Min_Max_CA schemes outperformed AODV regarding the delivery ratio for almost all mobility levels (pause times of 0, 100, 200 and 300 seconds). They outperformed AODV for all packet transmission rates (1, 2, 4 and 6 packets/sec) and number of sources (5, 10 and 15 sources). For example, when the transmission rate is four packets per sec, the number of sources is fifteen, and mobility is high (pause time = 0), the two algorithms outperform AODV by 11.75 and 8.33 percent, respectively; while for low mobility (pause time = 300 seconds) they outperform AODV by 10.41 and 4.41percent, respectively. When the number of sources was decreased to 10 and 5, the two algorithms outperformed AODV by small values. For example, when the number of connections is ten, mobility is high and the transmission rate is one packet per second, Min_Total_CA and Min_Max_CA outperform AODV by 3.66 and 3.33 percent, respectively, while they outperform AODV by 1.66 and 2.00 percent, respectively when the number of connections is five. We can see that our proposed algorithms outperform AODV for almost all scenarios, especially when the traffic load on the system is heavy; the reason is that they succeed in choosing less congested routes, which decreases the number of dropped packets.

The average end-to-end delay of the proposed schemes against AODV was fluctuating slightly. This is because there are two alternatives: traveling through a shorter route that may be congested (AODV approach), or traveling through a longer route that is likely to be less congested (the proposed approach). However, analyzing the results obtained for the different scenarios, it can be seen that AODV and Min_Max_CA have almost similar overall performance, but the performance of Min_Total_CA is significantly worse.

The overhead of the proposed protocols as compared with the overhead of AODV is overall higher. This is because intermediate nodes in the proposed protocols broadcast duplicate packets that have smaller congestion values in order to allow destination nodes to receive multiple requests and choose the best route (least congested one). The destination node may send many replies for the same request. It can be seen in Figure 4 that Min_Max_CA outperforms Min_Total_CA and that the performance of Min_Max_CA is very close to that of AODV under high mobility.

5. Conclusions

In this paper, we have proposed routing schemes that take into account the congestion status of intermediate nodes and try to avoid using routes that go through congested areas, where a node’s congestion level is the number of active routes that pass through the node. A source and destination make routing decisions by selecting the least congested route, where the congestion of a route is determined as the total congestion value computed for intermediate nodes, or as the maximum congestion value at the intermediate nodes. Detailed simulations were used to evaluate the performance of the proposed congestion-based routing schemes and to compare them with AODV routing. The simulation results show that the proposed schemes can result in substantial improvement in the packet delivery ratio.

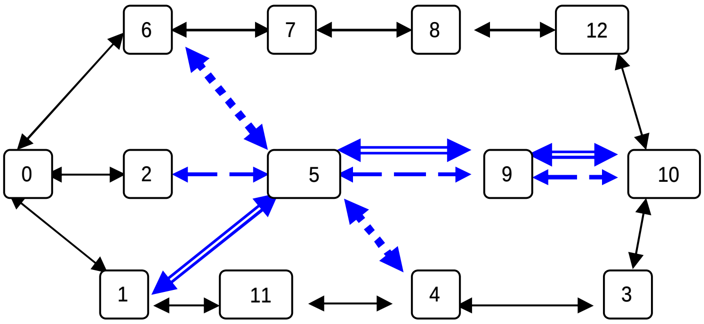

Figure 1. A group of mobile nodes with several active routes

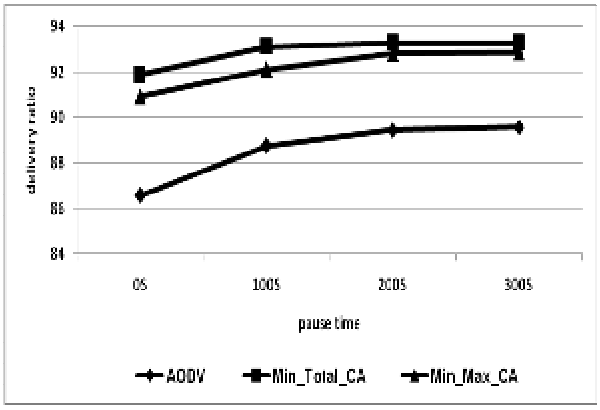

Figure 2. Average delivery ratio computed for all scenarios

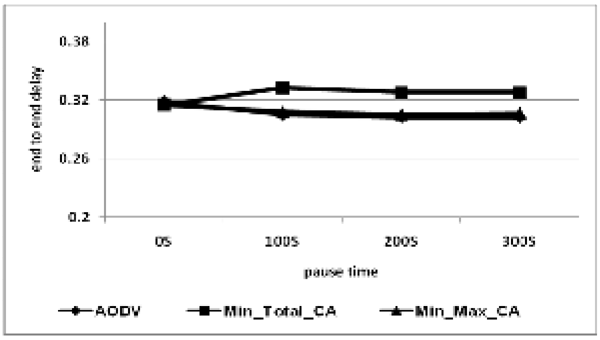

Figure 3. Average end-to-end delay computed for all scenarios

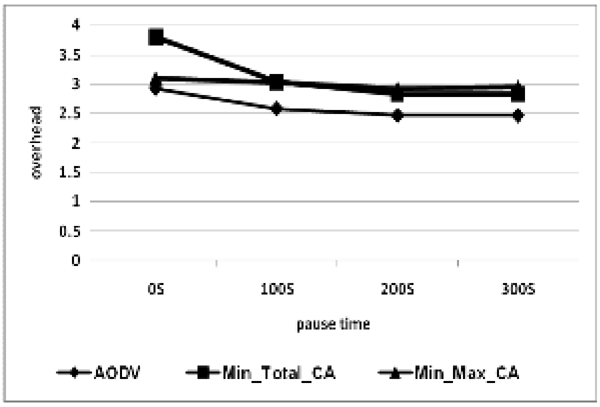

Figure 4. Average overhead computed for all scenarios

References:

[1] IETF Mobile Ad Hoc Networks (MANET) Working Group Charter. [Online] Available: http://www.ietf.org/html.charters/manet-charter.html [Accessed October 2008].

[2] Zhou L, Hass ZJ. Securing Ad Hoc Networks. IEEE Network. Nov.-Dec. 1999; 13(6): 24-30.

[3] Yi S, Naldrug P, Kravets R. A Security Aware Routing Protocol for Wireless Ad hoc Networks. In the proceedings of 3rd ACM international symposium of mobile ad hoc networking and computing 2002; 226-236.

[4] Sobeih A. Reliable Multicasting in Wireless Mobile Multihop Ad Hoc Networks. MS. Thesis; Egypt: Cairo University April 2002.

[5] Zimmerman TG. Personal Area Networks: Near-field Intrabody Communication. IBM Systems Journal 1996; 35(3&4): 609-617.

[6] Zeng X, Bagrodia R, Gerla M. GloMoSim: A Library for Parallel Simulation of Large-scale Wireless Networks. Proceedings of the 12th workshop on Parallel and distributed simulation, Banff, Alberta, Canada July 1998; 154-161.

[7] Gorantala K. Routing Protocols in Mobile Ad-hoc Networks. MS. Thesis; Sweden: Umea University June 2006.

[8] Jain R, Ramakrishnan K. Congestion Avoidance in Computer Networks with a Connectionless Network Layer. part I-Concepts, goals and alternatives. DEC Tech. Rep. TR-507, Digital Equipment Corporation, Littleton, Mass. April 1987.

[9] Lu Y, Wang W, Zhong Y, Bhargava B. Study of Distance Vector Routing Protocols for Mobile Ad Hoc Networks. Proceedings of the First IEEE International Conference on Pervasive Computing and Communications. IEEE Computer Society 2003; 187-194.

[10] Alkhaldy MH. Congestion Aware Routing Protocols for Ad Hoc Networks. MS. Thesis; Jordan; Prince Hussein bin Abdullah II Colleague for Information Technology, 2006.

[11] Lee SJ, Gerla M. Dynamic load-aware routing in ad hoc networks. Proceedings IEEE International Conference on Communications June 2001; 3: 206–210.

[12] Lakshmi M, Sankaranarayanan PE. Performance Analysis of Three Routing Protocols in Mobile Ad Hoc Networks. Asian Journal of Information Technology 2006; 5(1): 114-120.

[13] Ramesh B, Manjula D. An Adaptive Congestion Control Mechanism for Streaming Multimedia in Mobile Ad-hoc Networks. IJCSNS International Journal of Computer Science and Network Security June 2007; 7(6): 290-295.