Proceedings of the 5th WSEAS International Conference on Applied Computer Science, Hangzhou, China, April 16-18, 2006 (pp1095-1100)

A Stable QoS-Aware MAC and Routing Protocol for Differentiated Service in Mobile Ad Hoc Networks

Chenn-Jung Huang, Yi-Ta Chuang, Pei-Chi Yang
Institute of Learning Technology
National Hualien University of Education
Hualien, Taiwan 970

Wei Kuang Lai, Sheng-Yu Hsiao
Department of Computer Science and Engineering
National Sun Yat-Sen University
Kaohsiung, Taiwan 804

Abstract: - A mobile ad hoc network (MANET) is a collection of self-organized mobile nodes that are capable of communicating with each other without the aid of any established infrastructure or centralized administration. Routing algorithm has been a challenge task in the wireless ad hoc network for a long time due to the dynamic nature of network topology. A recent trend in ad hoc network routing is the reactive on-demand philosophy where routes are established only when required. The on-demand routing protocol for ad hoc network is appealing because of its low routing overhead and its effectiveness when the frequency of route re-establishment and the demand of route queries are not high. However, considering the increasing demand of Quality-of-Service (QoS) requirements in many applications, the current on-demand routing protocols used for ad-hoc network should be adapted appropriately to effectively meet the stringent QoS requirements of specific multimedia traffic. This work thus proposes a routing protocol wherein an adaptive backup route maintenance algorithm and a prediction-based congestion-avoiding alternative route construction mechanism are embedded to insure the high packet delivery for multimedia traffic in the volatile environments of a MANET. Meanwhile, a priority scheduler is used to make scheduling decisions so that the packet loss rate can be further reduced. The results of a series of simulations exhibit the practicability and feasibility of our approaches.

Key-Words: - AODV, Differentiated service, QoS, Particle swarm optimization, Grey theory, Fuzzy logic.

1 Introduction

Routing algorithm has been a challenge issue in a wireless ad hoc network for a long time due to the quick change of network topology. The routing protocols in ad hoc networks can be roughly divided into two categories, table driven and on-demand routing protocol. The on-demand routing protocol for ad hoc network is appealing owing to its low routing overhead and its effectiveness when the occurrences of route re-establishments and route queries are not frequent. Ad hoc On-demand Distance Vector (AODV) [1] and Dynamic Source Routing (DSR) [2] are two representative on-demand routing protocols. The key motivation behind the design of on-demand protocols is the reduction of the routing overhead since high routing overhead usually has a significant performance impact in low-bandwidth wireless links. The AODV combines the use of destination sequence numbers in the DSDV with the on-demand route discovery technique in the DSR to formulate a loop-free, on-demand, single path, distance vector protocol.

With the increasing demand for the provision of multimedia applications, such as Video on Demand (VoD), videoconference, and many WWW-based applications, a great deal of attention is being paid to provide seamless multimedia access in ad hoc networks. Since the multimedia applications are very sensitive to the available bandwidth, jitters or delays in the networks, some sorts of service quality guarantees are desperately needed. The notion of Quality-of-Service (QoS) is a guarantee by the network to satisfy a set of predetermined service performance constraints for the user in terms of the end-to-end delay statistics, available bandwidth, probability of packet loss, and so on. The challenges increase even more for those ad hoc networks that support both best effort services and those with QoS guarantees. This work tries to tackle the critical challenge issue by incorporating a QoS extension to the AODV with adaptive backup route maintenance and prediction-based alternative route construction mechanisms. Meanwhile, a priority scheduler is embedded into the medium access control (MAC) protocol to support real-time traffic. Notably, The Differentiated Services (DiffServ) model is employed to treat real-time traffic and best effort traffic differently. The characteristic of DiffServ is that it does not have any end-to-end signaling mechanism and works on a service level agreement between the provider and the user. All packets from a user are given different service level and are treated accordingly.

The remainder of the paper is organized as follows. The conventional AODV routing algorithm is reviewed in Section 2. The modified AODV QoS routing embedded with a congestion-avoiding alternate route construction and adaptive backup route maintenance scheme are presented in Sections 3. A priority packet scheduler is proposed in Section 4. In Section 5, our scheme is compared to other above-mentioned approaches using GloMoSim wireless network simulator. Conclusions are given in Section 6.

2 Ad-Hoc on-Demand Distance Vector (AODV)

The AODV routing algorithm is a routing protocol designed for ad hoc mobile networks. The AODV is capable of both unicast and multicast routing. It maintains these routes as long as they are needed by the source node. Operations of unicast routing in the AODV can be simply divided into three parts: route request, route reply and route maintenance.

When a node wishes to send a packet to some destination node, it checks its route table to determine whether it currently has a route to that node. If so, it forwards the packet to the appropriate next hop toward the destination. However, if the node does not have a valid route to the destination, it must initiate a route discovery process.

The source node broadcasts a flooding ROUTE REQUEST (RREQ) packet. The broadcast ID and the IP address of the source node form a unique identifier for the RREQ. The intermediate nodes can avoid processing the same RREQ by using this unique identifier. After broadcasting the RREQ, the source node sets a timer to wait for a reply. When the route request process completes, a reverse route is set up.

A node receiving the RREQ may send a ROUTE REPLY (RREP) if it is either the destination or if it has a route to the destination with corresponding sequence number greater than or equal to that contained in the RREQ. When the route reply process is done, a forward route is set up. In this way, the source node knows how to forward data packets to the destination later.

As long as the route remains active, it will continue to be maintained. A route is considered active as long as there are data packets periodically traveling from the source to the destination along that path. When a link break occurs in an active route, the node at the upstream of the link break propagates a ROUTE ERROR (RERR) message to the source node to inform it of the now unreachable destination. After receiving the RERR, if the source node still desires the route, it can reinitiate route discovery.

A local repair mechanism had been added to the AODV to improve the packet delivery ratios. When a link break occurs in an active route, the node at the upstream of that break may choose to repair the link locally if the destination was no farther than several hops away. To repair the link break, the node broadcasts a RREQ for that destination. If the first repair attempt is unsuccessful, the node will send a RERR to the source node, the source may then re-initiate a new route discovery process.

3 Real-Time Traffic Routing Scheme Based on AODV

In the differentiated service model, traffic is divided into small number of classes and is allocated network resources on a per-class basis. The class is marked directly on the packet to determine the QoS behavior of a packet at a specified node in the network. The conventional AODV protocol is thus required to be modified correspondingly in our work to achieve QoS requirements for the multimedia traffic. Meanwhile, a congestion-avoiding alternate route construction and adaptive backup route maintenance scheme is proposed to build up a reliable routing path for the real-time traffic in order to satisfy its stringent QoS specification.

3.1 Modified AODV-BR

While conveying multimedia traffic, QoS requirements such as maximum delay and minimum bandwidth are specified when the RREQ propagates across the network. The intermediate nodes will forward the RREQ to all neighbor nodes only when QoS requirements are satisfied at each intermediate node.

Figure 1 shows an example of a RREQ message when the requirement of maximum delay is considered. Source node S fist specifies the maximum delay for a multimedia traffic to be ten. When the neighbor nodes A, E and C receive the RREQ, they will compare the specified maxi-mum delay time with the node traversal time set at the neighbor nodes. If node traversal time is smaller than the specified maximum delay time, the RREQ will be for-warded to next neighbor nodes, such as nodes B and F as shown in Fig. 1. Notably, the maximum delay time specified in the RREQ what nodes B and F receive is eight since the node traversal time for the intermediate nodes A and E is assumed to be two. When destination node D receives the RREQ message, it will send back the RREP to source node

S. The node traversal time for the intermediate nodes is accumulated during the propagation of the RREP.

Figure 2 illustrates an example that considers minimal available bandwidth as QoS requirement. The source node S sends a RREQ to neighbor nodes A, C and E with minimal available bandwidth requirement set to ten. When the neighbor nodes A, E and C receive the RREQ, they compare the specified minimal available bandwidth requirement with their residual bandwidth. If the residual bandwidth is not enough, the RREQ will be discarded. Destination node D replies to the source node by sending the RREP via reverse route. When the intermediate nodes on reverse route receive the RREP, they will com-pare their residual bandwidth with the required minimal available bandwidth specified in the RREP. If the residual bandwidth of the intermediate nodes is smaller, it will be set as the new minimal available bandwidth specification in the RREP.

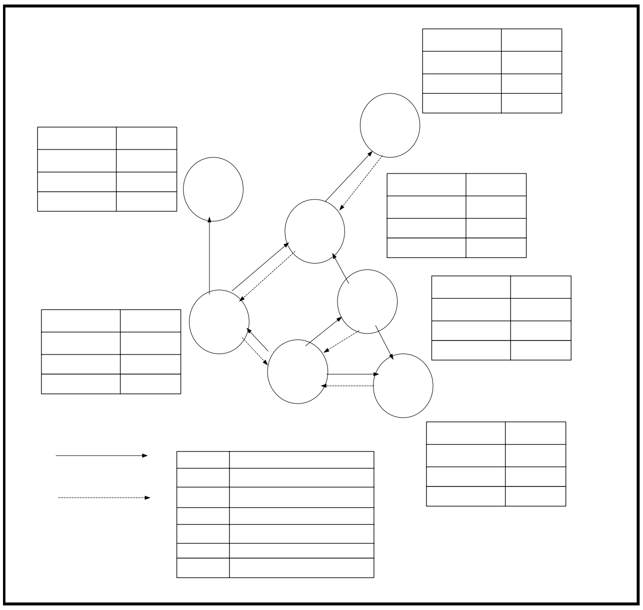

Fig. 1. A RREQ with Maximum Delay QoS requirement.

A node may receive numerous RREPs for the same route if the node is within the radio propagation range of more than one intermediate node of the primary route. In this situation, the node chooses the best route among them and inserts it to the alternate route table. When the RREP packet reaches the source of the route, the primary route between the source and the destination is established and is ready for use. The nodes that have an entry to the destination in their alternate route table are also part of the mesh.

Data packets are delivered through the primary route unless there is a route disconnection. When a node detects a link break, it performs a one hop data broadcast to its immediate neighbors. The node will log in the data header that the link is disconnected and the packet re-quires an alternate route for successful transmission. Upon receiving this packet, neighbor nodes that have an entry for the destination in their alternate route table, unicast the packet to their next hop node. Data packets therefore can be delivered through one or more alternate routes when a route break occurs.

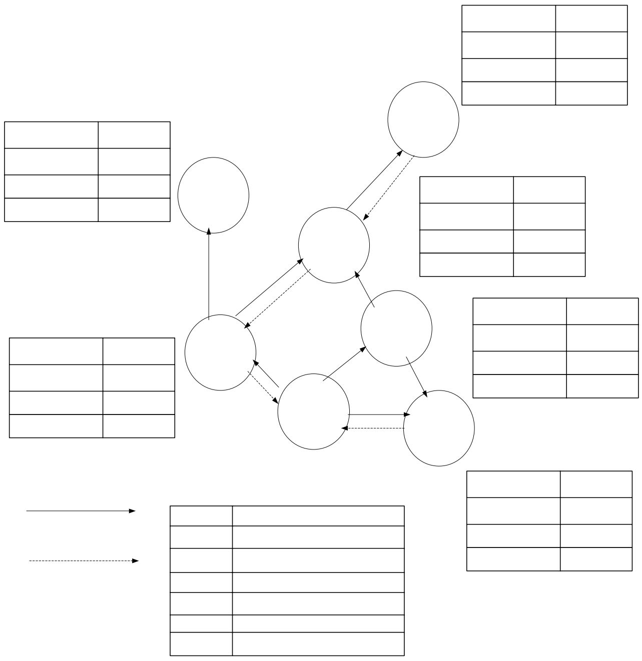

Fig. 2. A RREQ with Minimal Available Bandwidth QoS requirement.

When a node on the primary route receives the data packet from alternate routes, it operates normally and forwards the packet to its next hop if the packet is not a duplicate. The node that detected the link break also sends a ROUTE ERROR (RERR) packet to the source to initiate a route rediscovery. The reason for reconstructing a new route instead of continuously using the alternate paths is to build a fresh and optimal route that reflects the current network situation and topology.

This work allows the intermediate nodes to overhear both the RREP and the data packets transmitted by their neighbor nodes that are parts of the primary route. Thus the alternate routes can be created or updated at the intermediate nodes any time without increasing the overhead of sending the extra control packets on the net-works.

When an intermediate node in the primary route detects a link failure in the AODV-BR proposed in [4], it will perform a one-hop data broadcast to its immediate neighbors, and then sends a RERR packet to the source node to reinitiate a route discovery. Therefore, the AODV-BR does not actually repair the broken route; it simply uses the alternate routes to let those data packets “go around” the bro-ken part of the route. The "one-hop data broadcast" will result in poor performance under heavy traffic load because some unnecessary and duplicated data packets will be delivered through the alternate routes.

In the modified AODV-BR, the node that detects a link break will execute a handshake process with its immediate neighbors to repair the broken route. The hand-shake process is accomplished by two one-hop control signals: BACKUP ROUTE REQUEST (BRRQ) and BACKUP ROUTE REPLY (BRRP). If some intermediate nodes do not receive any reply signal after sending BRRQ signal, it will transmit a RRER signal back to the source node instead.

3.1.1 Particle swarm optimization approach

PSO is a computational intelligence approach to optimization that is based in the behavior of swarming or flocking animals, such as birds or fish. In PSO, every individual moves from a given point to a new one which is a weighted combination of the individual's best position ever found, and of the group's best position. PSO algorithm itself is simple and involves adjusting a few parameters. With little modification, it can be applied to a wide range of applications. Because of this, PSO has received growing interest from researchers in various fields.

As mentioned above, PSO is used to select the algorithm that repairs the broken link in this work. This work assumes that each node (particle) executes its individual PSO algorithm, and a swarm consists of all the nodes on the primary route. Moreover, it is observed that AODV-BR [4] outperforms AODV-LR (Local repair) when the moving speed of the intermediate node is fast, or the intermediate node is not close to the destination. This work then assumes the following equation is valid based on the simulation results of AODV-LR and AODV-BR,

$$BR(t) = x_1 \cdot (v(t))^{x_2} \cdot (h(t))^{x_3}, \quad (1)$$

where the inputs $v(t)$ and $h(t)$ denote the node speed and the remaining hop counts, respectively, and the output $BR(t)$ is compared with a predetermined threshold to decide which approach is chosen to construct the alternate path in case the link break occurs. The parameters x_1, x_2 and x_3 are expected to be determined by PSO technique. Notably, the fitness function used in PSO is the packet delivery ratio for multimedia packets at the intermediate node, since the achievement of the high packet delivery ratio is the main goal of this work. Meanwhile, packet delivery ratio achieved by the best particle on each active route is passed by HELLO message during each fixed time interval.

3.2 Congestion-avoiding alternate route construction

This work uses the length of queue and packet waiting time to predict and avoid possible node congestion. Grey model is used to predict the value of queue length and packet waiting time since these two metrics are both time series. Grey theory was initiated by J.L. Deng in 1982. It is very suitable for system with a real-time requirement since the processing only need a few data to get predictive value with high accuracy. The two predicted parameters are then fed into a fuzzy logic inference system to determine if congestion occurs.

In case congestion occurs in a node along the path, this node will send a control message to its neighbors notify that there is congestion. Once the message is received by its neighbor, if there is a packet sent through the node, it will re-initiate RREQ to construct a new route to the destination.

Figures 3 and 4 show the construction of alternate path to prevent the congestion. Consider a path S-A-B-C-D constructed as illustrated in Fig. 3. When there is a possible congestion detected at node B, it sends a congestion message to all its neighbors. As node A receives the message, it re-initiates RREQ to find an alternate path to destination D. After node A broadcasts RREQ, it sends an ACK message to node B to notify a route change. Thus, data packets can then be delivered via a new path S-A-E-C-D as shown in Fig. 4.

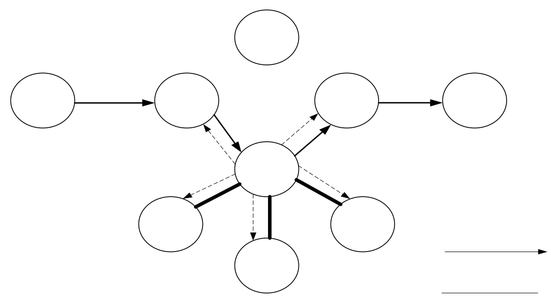

Fig. 3. Congestion message

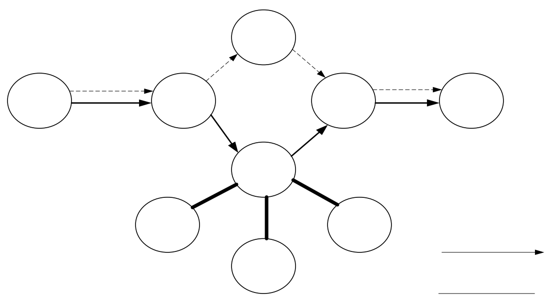

Fig. 4. Alternate path construction

4. Packet scheduler

In conventional AODV, the packets are processed in first-in-first-out (FIFO) manner and there is more chance that either more packets may be dropped or may not meet the QoS requirement. Motivated by the superior performance in many applications, this work attempts to employ particle swarm optimization (PSO) [4] to realize the prediction mechanism in the design of the priority scheduler. Priority index for each packet can be computed by,

$$P_k(t) = \frac{1}{[h_k(t)]^{x_1} \cdot [v_k(t)]^{x_2}} \cdot \max\{[d_k(t)]^{x_3}, 0\} \cdot [r_k(t)]^{x_4}, \quad (2)$$

where $v_k(t)$ denotes peed of the node that moves fastest among the nodes on the active route, $h_k(t)$ represents remaining hop counts, $d_k(t)$ stands for remaining end-to-end deadline target of the packet, and $r_k(t)$ is packet delivery ratio of the flow, respectively. The parameters x_1, x_2, x_3 and x_4 are expected to be determined by the PSO technique.

5. Simulation and Analysis

A series of simulations were conducted to evaluate the performance and behavioral specifics of the ad hoc QoS routing protocols by using GloMoSim network simulator. Our proposed approach (QoS-MAODV) is compared with pure QoS extension of AODV in our work (QoS-AODV) [3] and QoS extension of AODV with backup route mechanism (QoS-AODV-BR) [4].

5.1 Simulation scenario

The simulation environment is a 1500×300 square meter, and 50 nodes are randomly distributed within this network. The detailed simulation parameters are listed in Table 1. Notably, CBR/UDP traffic is generated between randomly selected pairs of nodes and the bandwidth for each channel is 2M bps. The CBR data packet size is 512 byte and packet rate is 4 packets per second. Each node randomly selects a target location, and moves toward that location by a random speed. Once it reaches that position, it will stay still for a random pause time. After that pause time, it selects another target location and repeats the process.

5.2 Simulation results

Packet delivery ratio of multimedia traffic achieved in our scheme (QoS-MAODV) is first compared with QoS-AODV and QoS-AODV-BR under different moving speed range for the network node as shown in Fig.5. Note that packet delivery ratio refers to the total amount of received data divided by the total amount of data transmitted during the simulation. As QoS-AODV simply drops data packets when routes are disconnected, its packet delivery ratio is worse than the other three schemes as illustrated in Fig. 5. Meanwhile, because QoS-MAODV attempts to transmit packets with congestion avoidance mechanism, it apparently outperforms the other two protocols, especially when network topology changes dramatically.

Table 1. Simulation parameters

Parameter Type	Parameter Value
Simulation Time	300 sec
Simulation Terrain	1500 m x 300 m
Number of nodes	50
Mobility model	random waypoint
Mobility	0~30 m/s
Temperature	290 K
Path loss model	Two-Ray
Radio frequency	2.4GHz
Channel bandwidth	2M bps
Mac protocol	802.11
Transmission Range	250m
CBR data sessions	10

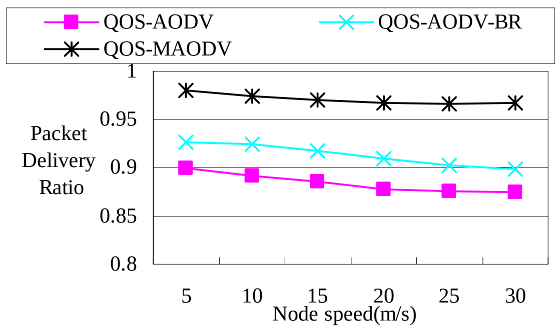

Fig. 5. Packet delivery ratio for the real-time traffic.

The comparison of end-to-end delay is illustrated in Fig. 6. Notably, the delay is measured for those data packets that reach their destination. The proposed QoS-MAODV still has better performance than the other two QoS extensions of AODV schemes since the proposed QoS-MAODV schemes can construct reliable route before congestion occurs, whereas other two QoS extension AODV schemes simply re-construct the primary route in the presence of link break and result in spending more time on re-constructing route. Therefore, the packets that are successfully delivered to the destination can go through the “smoother” route and achieve shorter end-to-end delay in the proposed QoS-MAODV scheme.

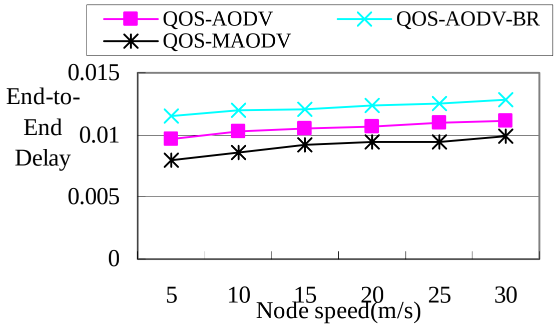

Fig. 6. Comparison of end-to-end delay of real-time traffic

This work further compared the performance of the proposed routing scheme without the PSO priority scheduler and (QoS-MAODV) with the PSO priority scheduler (QoS-MAODV-PSO). Meanwhile, the proposed QoS-MAODV scheme incorporated with a DLPS priority scheduler presented in the literature (QoS-MAODV-DLPS) [5] is also implemented here for comparison. As shown in Fig. 7, the proposed PSO priority scheduler achieves better performance than the DLPS priority scheduler. It is contributed by accurate derivation of parameters used in Eq. (2) via PSO technique and the consideration of the factor of network topology change in the computation of priority index for the transmitted packets.

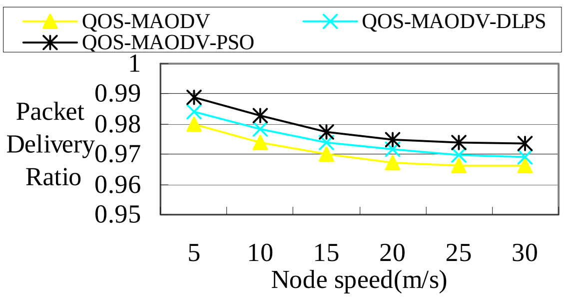

Fig. 7. Comparison of packet delivery ratio of real-time traffic for two priority schedulers

6. Conclusion

In this paper, a QoS extension of AODV routing protocols is presented to satisfy the demand of Quality-of-Service (QoS) requirements in many multimedia applications. The routing protocol attempts to construct a reliable route by accurately predicting and avoiding possible congestion occurrence by using grey theory and fuzzy logic system. Either of the traditional local repair and a modified AODV-BR is activated to search the alternate route based on the computation result of PSO technique. A priority scheduler is also incorporated into the routing scheme to improve the performance of ad hoc networks. The simulation results show that the proposed approach achieves better performance than plain QoS extension of AODV, QoS extension of AODV with backup route, and DLPS priority scheduler when packet delivery ratio of real-time traffic is used as the performance metric. Hence the proposed routing protocol is proved to be able to deliver multimedia data packets effectively in an ad hoc network which is notorious for the volatile change of network topology. Furthermore, the small computation overhead boosts the feasibility of the PSO technique in the real-time applications such as the priority scheduler in ad hoc networks as illustrated in this work. Subsequent research will investigate the feasibility of applying other intelligent tools such as neuro-fuzzy and genetic algorithms into the proposed scheme to further improve the performance of the alternate route construction process.

7. Acknowledgment

The authors would like to thank the National Science Council of the Republic of China, Taiwan for financially supporting this research under Contract No. NSC 94-2213-E-026-001.

References

[1] C. E. Perkins and E. Royer, “Ad Hoc On-Demand Distance Vector Routing,” *Proceedings of IEEE WMCSA*, Feb. 1999.

[2] D. B. Johnson and D. A. Maltz, “Dynamic Source Routing in Ad Hoc Wireless Networks,” In *Mobile Computing*, Kluwere Academic Publishers, 1996, pp.153-181.

[3] C. E. Perkins, Royer, and S. Das, “Ad Hoc On-Demand Distance Vector (AODV) Routing,” Internet Draft, draft-ietf-manet-aodv-13.txt, February 2003. (work in progress)

[4] S. J. Lee and M. Gerla, “AODV-BR: Backup Routing in Ad Hoc Networks,” *Proceedings of IEEE WCNC 2000, Chicago*, IL, Sep. 2000.

[5] I. Karthigeyan, B. S. Manoj, and C. Siva Ram Murthy, “A distributed laxity-based priority scheduling scheme for time-sensitive traffic in mobile ad hoc networks,” *Ad Hoc Networks*, vol. 3, no. 1, pp. 27-50, 2005.