ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Routing Protocol to Improve QoS in Hybrid Ad Hoc Networks

G.Hima Bindu
M.Tech Student,
Department of CSE,
Sri Mittapalli Institute of Technology For Women,
Jntuk Guntur, India.

P.Swaroop
Assistant Professor,
Department of CSE,
Sri Mittapalli Institute of Technology For Women,
Guntur, India.

P.G.K.Sirisha
Professor & HOD,
Department of CSE,
Sri Mittapalli Institute of Technology For Women,
Guntur, India.

Abstract:

A lot of research is required to support real-time transmission with Quality of Service requirements in wireless communication. In the next generation wireless networks, mobile ad hoc networks should be integrated with infrastructure networks. The resource reservation-based QoS routing of MANETs is not applicable to hybrid networks because of inherit invalid reservation and race condition problems. To guarantee QoS in hybrid networks, we propose a QoS-based routing protocol by taking advantage of fewer transmission features of the hybrid networks. Simulation results indicate that the proposed routing protocol can improve QoS performance in terms of throughout packet delay and overhead.

Key Words:

Real-time transmission, Resource reservation based QoS routing, Hybrid networks, race condition problem, and overhead.

1 INTRODUCTION:

The rapid development of wireless networks has stimulated numerous wireless applications that have been used in wide areas such as commerce, emergency services, military, education, and entertainment. The number of WiFi capable mobile devices including laptops and handheld devices (e.g., smart-phone and tablet PC) has been increasing rapidly. For example, the number of wireless Internet users has tripled world-wide in the last three years, and the number of smartphone users in US has increased from 92.8 million in 2011 to 121.4 million in 2012, and will reach around 207 million by 2017 [1].

Nowadays, people wish to watch videos, play games, watch TV, and make long distance conferencing via wireless mobile devices "on the go." Therefore, video streaming applications such as Qik [2], Flixwagon [3], and Face Time [4] on the infrastructure wireless networks have received increasing attention recently. These applications use an infrastructure to directly connect mobile users for video watching or interaction in real time. The widespread use of wireless and mobile devices and the increasing demand for mobile multimedia streaming services are leading to a promising near future where wireless multimedia services (e.g., mobile gaming, online TV, and online conferences) are widely deployed. The emergence and the envisioned future of real time and multimedia applications have stimulated the need of high Quality of Service (QoS) support in wireless and mobile networking environments [5].

The QoS support reduces end to-end transmission delay and enhances throughput to guarantee the seamless communication between mobile devices and wireless infrastructures. At the same time, hybrid wireless networks (i.e., multi-hop cellular networks) have been proven to be a better network structure for the next generation wireless networks [6], [7], [8], [9], and can help to tackle the stringent end-to end QoS requirements of different applications. Hybrid networks synergistically combine infrastructure networks and MANETs to leverage each other. Specifically, infrastructure networks improve the scalability of MANETs, while MANETs automatically establish self-organizing networks, extending the coverage of the infrastructure networks.

In a vehicle opportunistic access network (an instance of hybrid networks), people in vehicles need to upload or download videos from remote Internet servers through access points (APs) (i.e., base stations) spreading out in a city. Since it is unlikely that the base stations cover the entire city to maintain sufficiently strong signal everywhere to support an application requiring high link rates, the vehicles themselves can form a MANET to extend the coverage of the base stations, providing continuous network connections. How to guarantee the QoS in hybrid wireless networks with high mobility and fluctuating bandwidth still remain an open question. In the infrastructure wireless networks, QoS provision (e.g., Intserv [10], RSVP [11]) has been proposed for QoS routing, which often requires node negotiation, admission control, resource reservation, and priority scheduling of packets [12].

However, it is more difficult to guarantee QoS in MANETs due to their unique features including user mobility, channel variance errors, and limited bandwidth. Thus, attempts to directly adapt the QoS solutions for infrastructure networks to MANETs generally do not have great success [13]. Numerous reservation-based QoS routing protocols have been proposed for MANETs [14], [15], [16], [17], [18], [19], [20], [21], [22] that create routes formed by nodes and links that reserve their resources to fulfill QoS requirements. Although these protocols can increase the QoS of the MANETs to a certain extent, they suffer from invalid reservation and race condition problems [12]. Invalid reservation problem means that the reserved resources become useless if the data transmission path between a source node and a destination node breaks.

Race condition problem means a double allocation of the same resource to two different QoS paths. However, little effort has been devoted to support QoS routing in hybrid networks. Most of the current works in hybrid networks [23], [24], [25], [26], [27] focus on increasing network capacity or routing reliability but cannot provide QoS-guaranteed services.

Direct adoption of the reservation-based QoS routing protocols of MANETs into hybrid networks inherits the invalid reservation and race condition problems. In order to enhance the QoS support capability of hybrid networks, in this paper, we propose a QoS-Oriented Distributed routing protocol (QOD). Usually, a hybrid network has widespread base stations. The data transmission in hybrid networks has two features. First, an AP can be a source or a destination to any mobile node. Second, the number of transmission hops between a mobile node and an AP is small. The first feature allows a stream to have any cast transmission along multiple transmission paths to its destination through base stations, and the second feature enables a source node to connect to an AP through an intermediate node. Taking full advantage of the two features, QOD transforms the packet routing problem into a dynamic resource scheduling problem.

Specifically, in QOD, if a source node is not within the transmission range of the AP, a source node selects nearby neighbors that can provide QoS services to forward its packets to base stations in a distributed manner. The source node schedules the packet streams to neighbors based on their queuing condition, channel condition, and mobility, aiming to reduce transmission time and increase network capacity. The neighbors then forward packets to base stations, which further forward packets to the destination. In this paper, we focus on the neighbor node selection for QoS guaranteed transmission.

2 THE QOD PROTOCOL:

A. Network and Service Model:

We consider a hybrid wireless network with an arbitrary number of base stations spreading over the network. N mobile nodes are moving around in the network. Each node ni<i< NÞ uses IEEE 802.11 interface with the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol [28]. Since a hybrid network where nodes are equipped with multi interfaces that transmit packets through multi channels generate much less interference than a hybrid network

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

where nodes are equipped with a single WiFi interface, we assume that each node is equipped with a single WiFi interface in order to deal with a more difficult problem. Therefore, the base stations considered in this paper are access points (APs). The WiFi interface enables nodes to with both APs and mobile nodes. For example, in a University campus, normally only buildings have APs. Therefore, people that do not have WiFi access but close to buildings can use two-hop relay transmissions to connect to the APs in the buildings. Feeneyetal. [29] considered the similar scenario in his work. We use Ri and R0i to denote the packet transmission range and transmission interference range of node ni, respectively. We use di,j to denote the distance between nodes ni and nj. A packet transmission from ni to nj is successful if both conditions below are satisfied [30]: 1) dij ≤ Ri, and 2) any node nk satisfying dk,j ≤Rk is not transmitting packets, where 0 < k < N and k ≠ j.

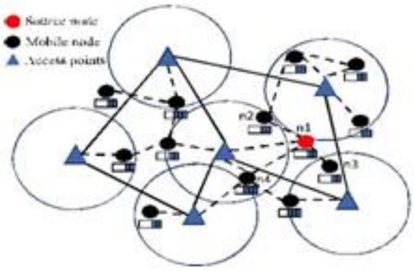

Fig. 1. The network model of the hybrid networks.

The QoS requirements mainly include end-to-end delay bound, which is essential for many applications with stringent real-time requirement. While throughput guarantee is also important, it is automatically guaranteed by bounding the transmission delay for a certain amount of packets [31]. The source node conducts admission control to check whether there are enough resources to satisfy the requirements of QoS of the packet stream. Fig. 1 shows the network model of a hybrid network. For example, when a source node n1 wants to upload files to an Internet server through APs, it can choose to send packets to the APs directly by itself or require its neighbor nodes n2, n3, or n4 to assist the packet transmission.

We assume that queuing occurs only at the output ports of the mobile nodes [32]. After a mobile node generates the packets, it first tries to transmit the packets to its nearby APs that can guarantee the QoS requirements. If it fails (e.g., out of the transmission range of APs or in a hot/dead spot), it relies on its neighbors that can guarantee the QoS requirements for relaying packets to APs. Relaying for a packet stream can be modeled as a process, in which packets from a source node traverse a number of queuing servers to some APs [31]. In this model, the problem of how to guarantee QoS routing can be transformed to the problem of how to schedule the neighbor resources between nodes to ensure QoS of packet routing.

B. An Overview of the QOD Protocol:

Scheduling feasibility is the ability of a node to guarantee a packet to arrive at its destination within QoS requirements. As mentioned, when the QoS of the direct transmission between a source node and an AP cannot be guaranteed, the source node sends a request message to its neighbor nodes. After receiving a forward request from a source node, a neighbor node ni with space utility less than a threshold replies the source node. The reply message contains information about available resources for checking packet scheduling feasibility (Section 2.4), packet arrival interval Ta, transmission delay TI!D, and packet deadline Dp of the packets in each flow being forwarded by the neighbor for queuing delay estimation and distributed packet scheduling (Section 2.5) and the node’s mobility speed for determining packet size (Section 2.6). Based on this information, the source node chooses the replied neighbors that can guarantee the delay QoS of packet transmission to APs. The selected neighbor nodes periodically report their statuses to the source node, which ensures their scheduling feasibility and locally schedules the packet stream to them. The individual packets are forwarded to the neighbor nodes that are scheduling feasible in a round-robin fashion from a longer delayed node to a shorter delayed node, aiming to reduce the entire packet transmission delay.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Algorithm 1 shows the pseudocode for the QOD routing protocol executed by each node.

Algorithm1. Pseudo code for the QOD routing protocol executed by a source node.

```
if receive a packet forwarding request from a source node then
    if this.Space Utility < threshold then
        Reply to the source node.
    end if
end if
if receive forwarding request replies for neighbor nodes then
    Determine the packet size Sp(i) to each neighbor i
        based on equation $Sp(new)\gamma = \frac{\gamma}{vi} Sp(unit)$
    Estimate the queuing delay Tw for the packet for each
        neighbour based on equation
        $Tw(x) = \sum_{j=i}^{x-1} (T(j)I \rightarrow D.[T(x)w/T(j)a])(0 < j < x)$
    Determine the qualified neighbors that can satisfy the deadline requirements based on $T_w$
    Sort the qualified nodes in descending order of Tw
    Allocate workload rate Ai for each node based on
        equation for workload allocation.
    for each intermediate node ni in the sorted list do
        Send packets to ni with transmission interval Sp(i) /Ai
    end for
end if
```

The packets travel from different APs, which may lead to different packet transmission delay, resulting in a jitter at the receiver side. The jitter problem can be solved by using token buckets mechanism [33] at the destination APs to shape the traffic flows.

3 RELATED WORKS:

A. Infrastructure Networks:

Existing approaches for providing guaranteed services in the infrastructure networks are based on two models: integrated services (IntServ) [10] and differentiated service (DiffServ) [42]. IntServ is a stateful model that uses resource reservation for individual flow, and uses admission control [10] and a scheduler to maintain the QoS of traffic flows. In contrast, DiffServ is a stateless model which uses coarse grained class-based mechanism for traffic management. A number of queuing scheduling algorithms have been proposed for DiffServ to further minimize packet droppings and bandwidth consumption [43], [44], [45], [46], [47]. Stoica et al. [48] proposed a dynamic packet service (DPS) model to provide unicast IntServ-guaranteed service and Diffservlike scalability.

B. MANETs:

A majority of QoS routing protocols are based on resource reservation [12], in which a source node sends probe messages to a destination to discover and reserve paths satisfying a given QoS requirement. Perkins et al. [20] extended the AODV routing protocol [49] by adding information of the maximum delay and minimum available bandwidth of each neighbor in a node’s routing table. Jiang et al. [15] proposed to reserve the resources from the nodes with higher link stability to reduce the effects of node mobility. Liao et al. [50] proposed an extension of the DSR routing protocol [51] by reserving resources based on time slots. Venataramanan et al. [39] proposed a scheduling algorithm to ensure the smallest buffer usage of the nodes in the forwarding path to base stations. However, these works focus on maximizing network capacity based on scheduling but fail to guarantee QoS delay performance. Some works consider providing multipath routing to increase the robustness of QoS routing. Conti et al. [16] proposed to use nodes’ local knowledge to estimate the reliability of routing paths and select reliable routes. The works in [17] and [18] balance traffic load among multiple routes to increase routing reliability. Shen et al. [19] proposed to let a source node fetch the lost packets from its neighbors to recover the multicast traffic. Shen and Thomas [21] proposed a unified mechanism to maximize both the QoS and security of the routing. Li et al. [22] proposed a centralized algorithm to optimize the QoS performance by considering cross-layer design among the physical layer, MAC layer, and network layer.

C. Wireless Sensor Networks (WSNs):

RAP [52] and SPEED [53] give a high delivering priority to the packets with longer distance/delay to the destination. However, both methods require each sensor to know its own location, thus they are not suitable for a highly dynamic environment. Felemban et al. [54] and Deb et al. [55] proposed to improve routing reliability by multipath routing. However, the redundant transmission of the packets may lead to high power consumption.

D. Hybrid Wireless Networks:

Very few methods have been proposed to provide QoS guaranteed routing for hybrid networks. Most of the routing protocols [23], [24], [25], [26], [27] only try to improve the network capacity and reliability to indirectly provide QoS service but bypass the constraints in QoS routing that require the protocols to provide guaranteed service. Jiang et al. [56] proposed a resource provision method in hybrid networks modeled by IEEE802.16e and mobile WiMax to provide service with high reliability. Ibrahim et al. [23] and Bletasa et al. [24] also tried to select “best” relay that has the maximum instantaneous value of a metric which can achieve higher bandwidth efficiency for data transmission. Ng and Yu [25] considered cooperative networks that use physical layer relaying strategies, which take advantage of the broadcast nature of wireless channels and allow the destination to cooperatively “combine” signals sent by both the source and the relay to restore the original signal. Cai et al. [26] proposed a semidistributed relaying algorithm to jointly optimize relay selection and power allocation of the system. Wei et al. [57] proposed to use the first-order finite state Markov channels to approximate the time variations of the average received signal-to-noise ratio (SNR) for the packet transmission and use the adaptive modulation and coding scheme to achieve high spectral efficiency. Lee et al. [58] presented a framework of link capacity analysis for optimal transmission over uplink transmission in multihop cellular networks. Wei et al. [27] proposed a two-hop packet forwarding mechanism, in which the source node adaptively chooses direct transmission and forward transmission to base stations. Unlike the above works, QOD aims to provide QoS guaranteed routing. QOD fully takes advantage of the widely deployed APs, and novelly treats the packet routing problem as a resource scheduling problem between nodesand APs.

4 PERFORMANCE EVALUATIONS:

This section demonstrates the distinguishing properties of QOD compared to E-AODV, S-Multihop, Two-hop through simulations on NS-2. E-AODV is a resource reservation-based routing protocol for QoS routing in MANETs. This protocol extends AODV by adding information of the maximum delay and minimum available bandwidth of each neighbor in a node’s routing table. To apply E-AODV in hybrid networks, we let a source node search for the QoS guaranteed path to an AP. The intermediate nodes along the path reserve the resources for the source node. In S-Multihop, a node always forwards a packet to a next hop node that has small buffer usage than itself until the packet reaches an AP. In Two-hop, the source node adaptively chooses direct transmission (i.e., directly transmit packets to the AP) and forward transmission (i.e., transmit packets through a forwarding node) to forward packets to APs. In the simulation, the setup consists of six APs with IEEE 802.11 MAC protocol are uniformly distributed in the area. We randomly selected two source nodes to send packets to APs in every 10 s. A node’s traffic is generated with constant bit rate (CBR) sources. The generation rate of the CBR traffic is 100 kb/s. Unless otherwise specified, the speeds of the nodes were randomly selected from [1-50]m/s. Since the number of successfully delivered packets within a certain delay is critical to the QoS of video streaming applications, we define a new metric, namely QoS guaranteed throughput (QoS throughput in short), that measures the throughput sent from a source node to a destination node satisfying a QoS delay requirement as 1 s. This metric can simultaneously reflect delay, throughput, and jitter features of packet transmission.

A. Performance with Different Mobility Speeds:

In this experiment, a node's mobility speed was randomly selected from [1 , x] m/s (x=1, 10, 20, 30, 40). Fig. 1 plots the QoS packet delivery ratios of all systems versus the node mobility speed.

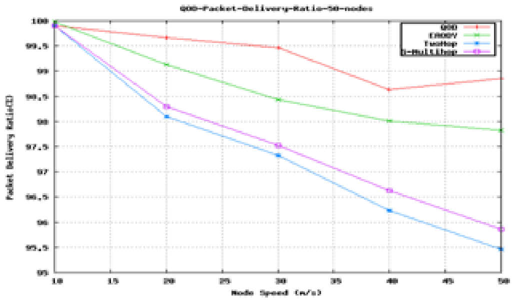

Fig.1 Packet Delivery Ratio Vs Node Speed (m/s)

It shows that the QoS packet delivery ratios of all systems decrease as node mobility increases. This is because higher mobility causes higher frequent link breakages, which leads to more packet drops. Re-establishing the broken links results in a long transmission delay for subsequent packets. We can also see that the QoS packet delivery ratios of QOD and E-AODV slightly decrease, but those of Two-hop and S-Multihop decrease sharply.

Two-hop and S-Multihop have much more hops in the routing paths from the source nodes to APs than QOD and E-AODV. A longer routing path produces higher probability of link breakdown during the packet transmission. As E-AODV and QOD only have two hops in the routing paths to APs, the short paths have lower probability to break down. Even if a link breaks down, the source node can quickly choose another forwarder. Therefore, node mobility does not greatly affect these two protocols.

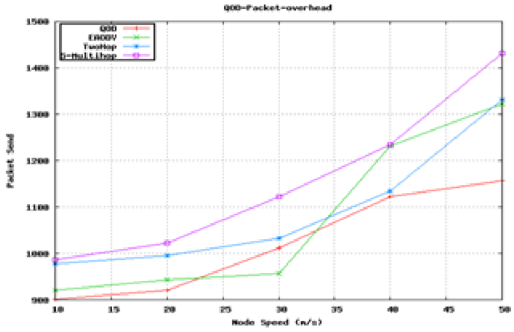

Fig.2 Packet overhead Vs Node speed (m/s)

We define the overhead rate as the size of all control packets generated by the system in 1 s. The control packets include all control packets and packet headers excluding the data packets. Fig. 2 plots the overhead rates of different systems with different node mobility speeds. We see that the overhead rates of all systems increase as node mobility increases, and the result follows S-Multihop>E-AODV>Two-hop>QOD when node mobility is larger than 35 m/s. The overhead of QOD mainly consists of two parts.

The first part is caused by periodical status information exchanges. A source node needs to exchange its status information with its neighbour nodes periodically during the packet transmission time for packet scheduling. With higher node mobility, a source node meets more nodes, leading to more exchanged information. The second part is caused by the packet heads. Although the packet size of each packet is reduced as node mobility increases, more packets are generated for a given data stream. The extra packet heads increase the overhead of QOD. Consequently, as node mobility increases, the overhead of QOD also increases.

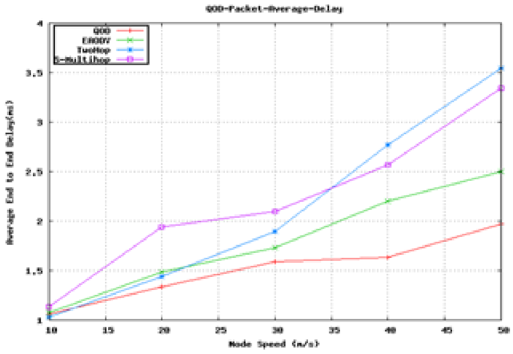

Fig. 3 Packet average delay Vs Node speed (m/s)

Fig. 3 shows packet average delay performance of four systems with respect to node mobility. The QOD protocol experience less delay compared to E-AODV, Two-hop and S-Multihop as alternate path searching delay is less in QOD.

B. Performance with Different Workloads:

Figs. 4 plot the QoS throughput of the systems with different number of source nodes when the average node mobility is 0 and 20 m/s, respectively. Each node’s mobility speed is randomly chosen from the range 0 m/s to the average mobility. More source nodes generate more workload in the system. We see from figure that as the number of source nodes increases from 0 to 3, the QoS performance of QOD increases almost linearly. In these cases, the capacity of the system is not saturated, and hence the QoS throughput increases almost linearly as the workload grow.

When the number of source nodes increases to 5, the QoS throughput increases at a slower rate. In QOD, when a source node finds that all of its neighbors cannot guarantee the QoS of its packets, it stops generating new packet flows into the system based on the admission control policy. Generating more packets into the networks may further decrease the QoS performance of other source nodes.

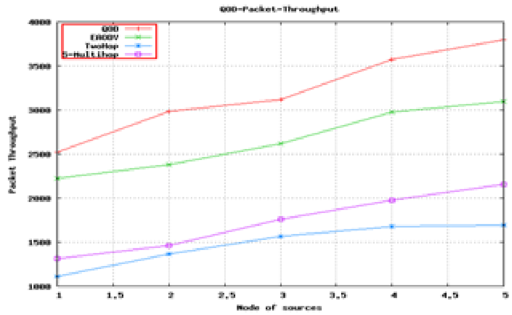

Fig 4. QOS throughput Vs Number of sources

C. Performance with Different Network Sizes:

Fig. 5 illustrate the QoS throughput of the systems with different number of nodes at the average mobility speed of 0 and 20 m/s, respectively. Both figures show that as the number of nodes in the system increases, the QoS throughput of QOD increases, that of Two-hop remains constant, but those of E-AODV and S-Multihop decrease.

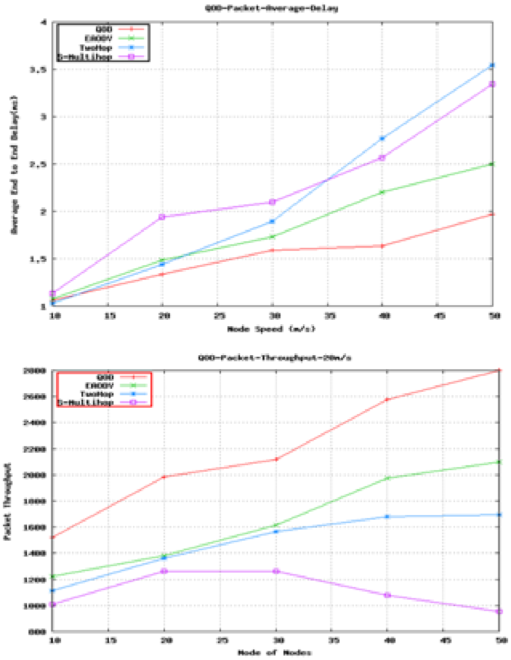

Fig. 5 QoS throughput Vs number of nodes

The throughput increase in QOD is caused by the increasing number of nodes in the system, which leads to an increasing number of neighbors of a node, enabling it to have more available resources for packet traffic scheduling.

5 CONCLUSION:

It has been proven that Hybrid wireless networks be a better network structure for next generation wireless networks. Providing QoS routing in hybrid networks is essential to support real time transmission. To provide QoS services in a highly dynamic scenario, by taking advantage of the unique features of hybrid networks a distributed routing protocol is developed. In this protocol, a source node can directly transmit packets to an AP, it QoS-guaranteed direct transmission is possible. Otherwise, the source node can schedule the packets through a qualified neighbors selected by neighbor selection algorithm which is a part of proposed protocol. In this protocol distributed packet scheduling is employed to reduce the packet transmission time. A packet resign algorithm is used to assign packets to nodes based on their mobility. The redundant traffic elimination and soft-deadline-based algorithms are used to improve throughput and scheduling feasibility respectively. Experimental results indicates that the proposed routing protocol is improves the QoS Hybrid network

6 REFERENCES:

[1] "A Majority of U.S. Mobile Users Are Now Smartphone Users," http://adage.com/article/digital/a-majority-u-s-mobile-userssmartphone- users/241717, 2013.

[2] Qik, http://qik.com, 2013.

[3] Flixwagon, http://www.flixwagon.com, 2013.

[4] Facebook, http://www.facebook.com, 2013.

[5] H. Wu and X. Jia, "QoS Multicast Routing by Using Multiple Paths/Trees in Wireless Ad Hoc Networks," Ad Hoc Networks, vol. 5, pp. 600-612, 2009.

[6] H. Luo, R. Ramjeey, P. Sinhaz, L. Liy, and S. Lu, "UCAN:A Unified Cell and Ad-Hoc Network Architecture," Proc. ACM MobiCom, 2003.

[7] P.K. Mckinley, H. Xu, A. Esfahanian, and L.M. Ni, "Unicast-Based Multicast Communication in Wormhole-Routed Direct Networks," IEEE Trans. Parallel Data and Distributed Systems, vol. 5, no. 12, pp. 1252-1265, Dec. 1992.

[8] H. Wu, C. Qiao, S. De, and O. Tonguz, "Integrated Cell and Ad Hoc Relaying Systems: iCAR," IEEE J. Selected Areas in Comm., vol. 19, no. 10, pp. 2105-2115, Oct. 2001.

[9] J. Zhou and Y.R. Yang, "PAR CelS: Pervasive Ad-Hoc Relaying for Cell Systems," Proc. IFIP Mediterranean Ad Hoc Networking Workshop (Med-Hoc-Net), 2002.

[10] R. Braden, D. Clark, and S. Shenker, Integrated Services in the Internet Architecture: An Overview, IETF RFC 1633, 1994.

[11] E. Crawley, R. Nair, B. Rajagopalan, and H. Sandick, Resource Reservation Protocol RSVP, IETF RFC 2205, 1998.

[12] I. Jawhar and J. Wu, "Quality of Service Routing in Mobile Ad Hoc Networks," Network Theory and Applications, Springer, 2004.

[13] T. Reddy, I. Karthigeyan, B. Manoj, and C. Murthy, "Quality of Service Provisioning in Ad Hoc Wireless Networks: A Survey of Issues and Solutions," Ad Hoc Networks, vol. 4, no. 1, pp. 83-124, 2006.

[14] X. Du, "QoS Routing Based on Multi-Class Nodes for Mobile Ad Hoc Networks," Ad Hoc Networks, vol. 2, pp. 241-254, 2004.

[15] S. Jiang, Y. Liu, Y. Jiang, and Q. Yin, "Provisioning of Adaptability to Variable Topologies for Routing Schemes in MANETs," IEEE J. Selected Areas in Comm., vol. 22, no. 7, pp. 1347-1356, Sept. 2004.

[16] M. Conti, E. Gregori, and G. Maselli, “Reliable and Efficient Forwarding in Ad Hoc Networks,” Ad Hoc Networks, vol. 4, pp. 398-415, 2006.

[17] G. Chakrabarti and S. Kulkarni, “Load Balancing and Resource Reservation in Mobile Ad Hoc Networks,” Ad Hoc Networks, vol. 4, pp. 186-203, 2006.

[18] A. Argyriou and V. Madisetti, “Using a New Protocol to Enhance Path Reliability and Realize Load Balancing in Mobile Ad Hoc Networks,” Ad Hoc Networks, vol. 4, pp. 60-74, 2006.

[19] C. Shen and S. Rajagopalan, “Protocol-Independent Multicast Packet Delivery Improvement Service for Mobile Ad Hoc Networks,” Ad Hoc Networks, vol. 5, pp. 210-227, 2007.

[20] C.E. Perkins, E.M. Royer, and S.R. Das, Quality of Service in Ad Hoc On-Demand Distance Vector Routing, IETF Internet draft, 2001.

[21] Z. Shen and J.P. Thomas, “Security and QoS Self Optimization in Mobile Ad Hoc Networks,” IEEE Trans. Mobile Computing, vol. 7, pp. 1138-1151, Sept. 2008.

[22] Y. Li and A. Ephremides, “A Joint Scheduling Power Control and Routing Algorithm for Ad Hoc Networks,” Ad Hoc Networks, 2008.

[23] S. Ibrahim, K. Sadek, W. Su, and R. Liu, “Cooperative Communications with Relay-Selection: When to Cooperate and Whom to Cooperate With?” IEEE Trans. Wireless Comm., vol. 7, no. 7, pp. 2814-2827, July 2008.

[24] A. Bletsas, A. Khisti, D.P. Reed, and A. Lippman, “A Simple Cooperative Diversity Method Based on Network Path Selection,” IEEE J. Selected Areas in Comm., vol. 24, no. 3, pp. 659-672, Mar. 2006.

[25] T. Ng and W. Yu, “Joint Optimization of Relay Strategies and Resource Allocations in Cellular Networks,” IEEE J. Selected Areas in Comm., vol. 25, no. 2, pp. 328-339, Feb. 2004.

[26] J. Cai, X. Shen, J.W. Mark, and A.S. Alfa, “Semi Distributed User Relaying Algorithm for Amplify-and-Forward Wireless Relay Networks,” IEEE Trans. Wireless Comm., vol. 7, no. 4, pp. 1348- 1357, Apr. 2008.

[27] Y. Wei and D. Gitlin, “Two-Hop-Relay Architecture for Next- Generation WWAN/WLAN Integration,” IEEE Wireless Comm., vol. 11, no. 2, pp. 24-30, Apr. 2004.

[28] Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, IEEE-SA Standards Board, 1999.

[29] L. Feeney, B. Cetin, D. Hollos, M. Kubisch, S. Mengesha, and H. Karl, “Multi-Rate Relaying for Performance Improvement in IEEE 802.11 WLANS,” Proc. Fifth Int’l Conf. Wired/Wireless Internet Comm., 2007.

[30] P. Gupta and P.R. Kumar, “The Capacity of Wireless Networks,” IEEE Trans. Information Theory, vol. 46, no. 2, pp. 388- 404, Mar. 2000.

[31] H. Zhang, “Service Disciplines for Guaranteed Performance Service in Packet-Switching Networks,” Proc. IEEE, vol. 83, no. 10, pp. 1374-1396, Oct. 1995.

[32] M. Karol, M. Hluchyj, and S. Mogan, “Input versus Output Queueing on a Space-Division Packet Switch,” IEEE Trans. Comm., vol. 35, no. 12, pp. 1347-1356, Dec. 1987.

[33] S. Sahu, P. Nain, C. Diot, V. Firoiu, and D. Towsley, “On Achievable Service Differentiation with Token Bucket Marking for TCP,” Proc. ACM

SIGMETRICS Int'l Conf. Measurement and Modeling of Computer Systems (SIGMETRICS), 2000.

[43] J. Kurose and K. Ross, Computer Networking: A Top Down Approach Featuring the Internet. Addison Wesley, 2004.

[44] L. Kleinrock, "Queueing System," Computer Applications, 1976.

[45] A. Parekh and R. Gallager, "A Generalized Processor Sharing Approach to Flow Control," Proc. IEEE INFOCOM, 1992.

[46] J.C.R. Bennett and H. Zhang, "WF2Q: Worst-Case Fair Weighted Fair Queueing," Proc. IEEE INFOCOM, 1996.

[47] S. Golestani, "A Self-Clocked Fair Queueing Scheme for Broadband Applications," Proc. IEEE INFOCOM, 1994.

[48] I. Stoica and H. Zhang, "Providing Guaranteed Services without Per Flow Management," Proc. ACM Special Interest Group Data Comm. (SIGCOMM), 1999.

[49] C. Perkins, E. Belding-Royer, and S. Das, Ad Hoc on Demand Distance Vector (AODV) Routing, IETF RFC 3561, 2003.

[50] W.H. Liao, Y.C. Tseng, and K.P. Shih, "A TDMA-Based Bandwidth Reservation Protocol for QoS Routing in a Wireless Mobile Ad Hoc Network," Proc. IEEE Int'l Conf. Comm., 2002.

[51] D.B. Johnson and D.A. Maltz, "Dynamic Source Routing in Ad Hoc Wireless Networks," Mobile Computing, vol. 353, pp. 153- 181, 1996.

[52] C. Lu, B. Blum, T. Abdelzaher, J. Stankovic, and T. He, "RAP: A Real-Time Communication Architecture for Large-Scale Wireless Sensor Networks," Proc. IEEE Real-Time and Embedded Technology Applications Systems, 2002.

[53] T. He, J. Stankovic, C. Lu, and T. Abdelzaher, "SPEED: A Stateless Protocol for Real-Time Communication in Sensor Networks," Proc. 23rd Int'l Conf. Distributed Computing Systems, 2003.

[54] E. Felemban, C. Lee, and E. Ekici, "MMSPEED: Multipath Multi- Speed Protocol for QoS Guarantee of Reliability and Timeliness in Wireless Sensor Networks," IEEE Trans. Mobile Computing, vol. 5, no. 6, pp. 738-754, June 2006.

[55] B. Deb, S. Bhatnagar, and B. Nath, "ReInForm: Reliable Information Forwarding Using Multiple Paths in Sensor Networks," Proc. IEEE 28th Ann. Int'l Conf. Local Computer Networks, 2003.

[56] P. Jiang, J. Bigham, and J. Wu, "Scalable QoS Provisioning and Service Node Selection in Relay Based Cellular Networks," Proc. Fourth Int'l Conf. Wireless Comm. Networking and Mobile Computing (WiCOM), 2008.

[57] Y. Wei, M. Song, F.R. Yu, Y. Zhang, and J. Song, "Distributed Optimal Relay Selection for QoS Provisioning in Wireless Multihop Cooperative Networks," Proc. IEEE 28th Conf. Global Telecomm. (GlobeCom), pp. 1946-1951, 2009.

[58] S. Lee and S. Lee, "Optimal Transmission Methodology for QoS Provision of Multi-Hop Cellular Network," J. Wireless Networks vol. 16, pp. 1313-1327, 2010.