Journal of Zhejiang University SCIENCE
ISSN 1009-3095
http://www.zju.edu.cn/jzus
E-mail: jzus@zju.edu.cn

On service differentiation in mobile Ad Hoc networks

ZHANG Shun-liang (张顺亮), YE Cheng-qing (叶澄清)†
(*College of Computer Science & Engineering, Zhejiang University, Hangzhou 310027, China*)
†E-mail: ycq@mail.hz.zj.cn

Received Jun. 25, 2003; revision accepted Sept. 27, 2003

Abstract: A network model is proposed to support service differentiation for mobile Ad Hoc networks by combining a fully distributed admission control approach and the DIFS based differentiation mechanism of IEEE802.11. It can provide different kinds of QoS (Quality of Service) for various applications. Admission controllers determine a committed bandwidth based on the reserved bandwidth of flows and the source utilization of networks. Packets are marked when entering into networks by markers according to the committed rate. By the mark in the packet header, intermediate nodes handle the received packets in different manners to provide applications with the QoS corresponding to the pre-negotiated profile. Extensive simulation experiments showed that the proposed mechanism can provide QoS guarantee to assured service traffic and increase the channel utilization of networks.

Key words: Mobile Ad Hoc networks, IEEE802.11, DIFS, Service differentiation, QoS (Quality of Service)
doi:10.1631/jzus.2004.1087 **Document code:** A **CLC number:** TP393

INTRODUCTION

In the past several years, researchers have made considerable efforts to provide QoS (Quality of Service) to Internet, with proposals such as Integrated Service (Braden *et al.*, 1994) and Differentiated Service (Blake *et al.*, 1998). Both of these architectures are based on sophisticated admission control and resource reservation mechanism to provide guarantee for absolute performance measures. At the same time, wireless networks are being increasingly deployed to extend wired networks to mobile users. QoS mechanisms are of particular relevance in the case of wireless networks, where the bandwidth is limited and the efficient use of it is of special importance. What is more, rapidly increasing multimedia applications impose requirements on communication parameters. Guaranteeing them in wireless environment is greatly challenging, especially for mobile Ad Hoc networks. They represent complex distributed systems, where mobile nodes are interconnected without the need for any fixed infrastructure. The dynamical network topology causes the rerouting among mobile nodes, which makes it difficult to provide real-time applications with appropriate QoS. Besides, the characteristic of wireless Ad Hoc networks makes it difficult to dynamically assign a central controller to maintain connection state. Due to these reasons, support QoS in wireless networks has been one of the focuses of research in recent years.

RELATED WORK

Researchers had made considerable effort to provide satisfactory levels of QoS in wireless communication. Currently, the IEEE802.11 for WLAN is the most widely used standard, so most of the existing schemes for providing QoS are aimed at IEEE802.11 wireless LANs, such as Blackburst (Sobrinho and Krishnakumar, 1999), enhanced

DCF (Benveniste *et al.*, 2001). Research (Lindgren *et al.*, 2001) revealed that Blackburst gives the best performance to high priority traffic with regard to throughput and access delay. However, it imposes on high priority traffic the requirement of constant access intervals. Though EDCF provides good service differentiation, it cannot provide so good service as Blackburst because of EDCF's high rate of collisions. Aad and Castelluccia (2001) proposed and analyzed three differentiation mechanisms for IEEE802.11 wireless networks: backoff based differentiation; DIFS based differentiation; maximum frame length based differentiation. Banchs and Perez (2002) also proposed a scheme to provide throughput guarantees for wireless LAN by Backoff based differentiation mechanism. Because of its stability problem (Aad and Castelluccia, 2002), this scheme unavoidably suffers from the same drawbacks. The aforementioned schemes for wireless networks lack the necessary admission control mechanisms. Recently, Ahn *et al.*(2002) proposed a network model for service differentiation in wireless Ad Hoc networks. It provides necessary admission controllers, which determine whether to admit the new real-time traffic based on the admitted real-time traffic load in networks. Without adopting the differentiation mechanism in IEEE 802.11, the admitted best effort traffic will compete for the resources with real-time traffic at the same priority and, in the worst case, may have to be dropped or saddled with degraded best effort delivery. Due to these problems, we proposed a scheme with both admission control mechanism and the differentiation mechanism of IEEE802.11 to provide assured service for real-time traffic. The basic IEEE802.11 medium access mechanism is DCF and is based on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol. The operation of 802.11 MAC is shown in Fig.1.

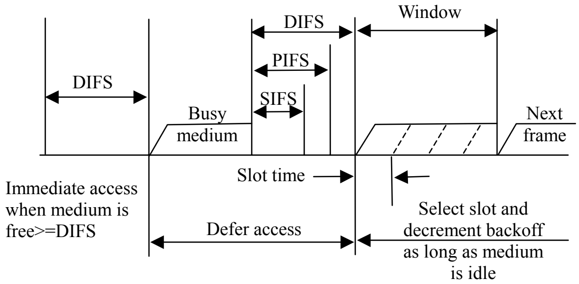

Fig.1 IFS relationships of IEEE802.11

DISTRIBUTED MECHANISM FOR SERVICE DIFFERENTIATION

Architecture

In order to support service differentiation and guarantee the QoS of assured service traffic, appropriate admission control mechanisms are indispensable. The model proposed by Ahn *et al.*(2002) was used by us to design a new model for the requirement of QoS. The new model is shown in Fig.2.

A classifier, a meter and a marker operate between the IP layer and the MAC layer with the differentiation mechanism. The classifier is able to differentiate TCP packets and UDP packets, forcing packets of flows that require assured service to pass through the meter and the marker. The meter measures the temporal properties of the stream of packets against certain traffic profile, which is negotiated with admission controller before packets enter into the network. Admission controller determines a committed rate according to the reserved bandwidth of a session and the remnant resource of the networks. If there is enough resource left, the committed rate is just the reserved bandwidth; oth-

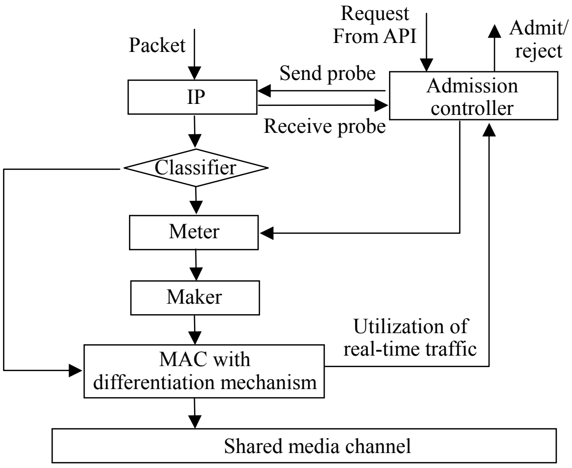

Fig.2 Model for service differentiation

erwise, it is the remnant bandwidth. If the real-time session cannot accept this, the admission controller will prevent it from entering into the networks. When a session is admitted, there is no admission control decision made at intermediate nodes. Rather, the admission controller determines whether a new real-time session should be admitted or not is conducted solely at the source node based on the result of end-to-end request/response probe. The marker sets the bit of mark in the packet header as IN (in profile) or OUT (out profile) according to the result of measurement by the meter and sets the rate label of flows in the packet header. The mechanism provides packets marked as IN with assured service and provides packets marked as OUT with best effort service.

Admission control mechanism

The admission control is source-based. Each mobile node measures local resource availability by listening to packets sent within radio transmission range. When admitting a new session, the admission controller located at the source node sends a probing request packet toward the destination node to estimate the end-to-end bandwidth availability. After intercepting the probing request packet, each intermediate node between the source-destination pair updates the bottleneck bandwidth field of it if the local bandwidth availability at the node is less than the current value of the field. Then the value of the bottleneck field at the destination node represents the bottleneck bandwidth along the path. The destination node sends a probing response packet back to the source node to notify it the available bandwidth. According to this information, the admission controller determines whether a flow can get the expected Assured Service. Because of node mobility, the admission controller has to implement dynamic regulation of the AS traffic with source based regulation algorithms. Each node continuously and independently measures the utilization of the AS traffic to estimate the local available band-width. When a node detects congestion or overload conditions, it starts marking CE bit in the IP header of AS packets. If the destination node encounter packets with the CE bit marked, it informs source node by a regulate message. Then the source node initiates the re-establishment of flows that have previously been successfully admitted in the same way as admitting new flows.

Traffic policing and marking

At the source node, packets of flows requiring assured service are passed to meter and marker. Here, we adopt token bucket mechanism to measure the traffic. The token bucket gets filled at the committed rate, which is determined by admission controller after negotiation. For each successful transmission, the length of the transmitted packet in bytes is subtracted from the bucket. If there are no packets to be transmitted or the packet-sending rate is smaller than the committed rate, token bucket will overflow and the new generated tokens will be dropped. When a packet comes, the packet is marked as IN if there are tokens left. Otherwise, the packet is marked as OUT, which means setting a reserved bit in packet header. The default mark of a TCP packet is OUT. It can be set as IN to get the assured service if necessary. Besides, the marker sets the rate label in packet header after estimating the rate of packet stream of a flow. The rate is calculated by Eq.(1) (Stoica *et al.*, 1998). Let t_i^k and l_i^k be the arrival time and length of the *k*th packet of flow *i*. The estimated rate of flow *i*, r_i is updated every time a new packet is received:

$$r_i^{\text{new}} = [1 - \mathrm{e}^{\frac{-T_i^k}{k}}]\frac{l_i^k}{T_i^k} + \mathrm{e}^{\frac{-T_i^k}{k}} r_i^{\text{old}} \tag{1}$$

where $T_i^k = t_i^k - t_i^{k-1}$ and *k* is a constant.

Extension of IEEE802.11 MAC

Though differentiation mechanisms for IEEE 802.11 proposed by Aad can provide service differentiation, it left many questions to be resolved. One of the important questions is the parameter setting. How to set the parameters in various traffic load conditions to get the desired service differentiation and ideal medium utilization simultaneously? If the difference between the parameters is too small, the QoS of high priority flows cannot get guarantee. If the difference between the parameter is too large, the low priority packets have to wait unnecessarily long time although there are no high priority packets to be transmitted, which will decrease the channel utilization. Due to these problems, we proposed a scheme to resolve them. The main idea is that try to guarantee the original rate (the estimated rate when traffic is admitted into the networks) of assured service traffic and let the best effort traffic make the most of the remnant resource. Like DiffServ, the scheme provides a soft kind of QoS, i.e. statistical QoS guarantee is given to traffic aggregates, but an individual packet does not receive any kind of guarantee; statistical QoS guarantee is given to flow aggregates but an individual flow does not receive any kind of guarantee. This fits well the type of QoS that can be achieved with the distributed MAC. Based on the research of Aad, we adopt DIFS based differentiation mechanism and make some modification to DCF of IEEE 802.11. The DIFS is calculated according to the following method.

```
    Upon receiving a packet:
    $middle=(difs\_in+difs\_out)/2.0$
if (mark is IN and the node is intermediate node) {
    call procedure to calculate $act\_rate$
    call procedure to calculate $sum\_rate$
    $ratio=act\_rate/sum\_rate$
    if ($difs\_in*ratio>pifs$)
      $difs\_in*=ratio$
    else
      $difs\_in=(difs\_in+pifs)/2.0$
    if ($avg\_coll>c_1$) $difs\_in*=(1+a_1)$
    if ($difs\_in>middle$) $difs\_in=middle$
}
    if (mark is OUT) {
        if ($avg\_coll=0$) {
           $difs\_out*=(1-b_1)$
           if ($difs\_out<middle$)
           $difs\_out=middle$
        }    else if ($avg\_coll>c_2$)
        $difs\_out*=(1+a_1)$
}
```

where *difs_in* and *difs_out* are DIFS for packets with mark such as IN or OUT respectively; *middle* is the mean of them; *avg_coll* is the number of collisions in average a packet experiences before it is successfully transmitted; *act_rate* is the estimated aggregate rate of flows; *sum_rate* is the sum of the original assured rate of flows when admitted by admission controller; c_1 and c_2 are threshold values. When receiving packets, nodes classify them according to the mark in the packet header and process them with different methods. To avoid the interference among different priority traffic, we make some modification to the queue mechanism of basic DCF. It is shown in Fig.3.

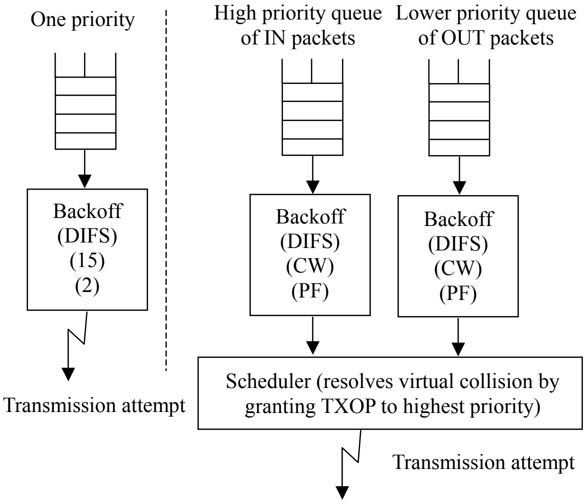

Fig.3 Queue of basic DCF and proposed DCF

To improve the channel utilization, we keep the equation $difs\_in<difs\_out$ without guaranteeing $difs\_out-difs\_in>=RR_{in}$ (maximum random range). When receiving packets with mark as IN, intermediate nodes estimate the rate of packet stream with Eq.(1). The estimated rate is not per flow rate but the aggregate rate of flows. By the rate label in packet header, intermediate nodes can infer the original assured rate of these flows. If *act_rate* less than *sum_rate*, they decrease *difs_in* to increase the transmission of packets with the mark as IN. Otherwise, *difs_in* is increased to decrease the transmission of packets with the mark as IN. *difs_in* is adjusted only by intermediate nodes while *difs_out* is adjusted by all related nodes. When receiving packets with the mark as OUT, nodes infer the traffic load of the network by *avg_coll*. If it is small enough, nodes "think" there is enough remnant resource and decrease *difs_out*. If it is too large, nodes "think" the network is in heavy load condition and increase *difs_out* to decrease the transmission rate of best effort traffic. When adjusting DIFS, certain constraints must be satisfied to keep the original IFS relationship of IEEE802.11. Besides, it is necessary for controlling overload, which affects medium utilization. The average collision number is calculated by Eq.(2):

$$coll_{\text{avg}}^{n} = (1-w)coll_{\text{cur}} + w \cdot coll_{\text{avg}}^{n-1} \qquad (2)$$

where $coll_{\text{avg}}^{n}, coll_{\text{avg}}^{n-1}, coll_{\text{cur}}$ are average collision number of current, average collision number of the last time and current collision number respectively; w is weight. According to the research (Banchs and Perez, 2002), we set w as 0.2. Besides, Banchs advises the threshold value is set as 4, so we set c_1 as 5 and c_2 as 3 to give assured service traffic enough priority. The parameters of a_1, b_1, which determine the step of adjustment of DIFS, are set as 0.1 and 0.01 respectively in experiment, optimum values need to be investigated further.

Calculating the original rate of assured service traffic

The original assured rate of a flow is the rate of the stream of packets that are marked as IN when entering into the network. To get the original rate of assured service traffic, we design a data structure about flow state and let each intermediate node store the structure of flows passing through it.

```
Struct flow_state {
  double time_stamp;
  double rate_label;
  int present;
  } fs_[flow_id];
```

where time_stamp is the latest time that a packet of the flow passing through the node; rate_label is the rate of packet (with mark as IN) stream of the flow; present means whether the flow is passing through the node. The sum of the original assured rate of flows is calculated by summing the rate_label of flows. Due to the dynamic characteristics of wireless Ad Hoc networks, rerouting among nodes causes flows passing different routes with time. So the flow state information stored in each node should be updated at certain time interval. In experiments, we set it as 1 s. If a packet (with the mark as IN) is the first packet of a flow, the node stores the flow state information. Otherwise, the stored information is updated. If none of the packets of a flow pass through the node at the certain interval time, the flow state information stored in the node will be deleted and its original rate is subtracted from the *sum_rate*.

EXPERMIMENT AND PERFORMANCE EVALUATION

In order to prove the feasibility of the proposed scheme and investigate its performance, we implemented it in ns-2 simulator and conducted extensive simulation experiments. The simulated network had a square shape of 500×500 m^2, where all wireless Ad Hoc mobile nodes shared a single radio channel of 11 Mbps. The number of the mobile nodes varied from 10 to 50. Mobility patterns were generated randomly with a maximum speed of 20 m/s. DSDV (Perkins and Bhagwat, 1994) was used for routing in the simulation. The simulation ran for 40 s. Real-time traffic was modeled as UDP flows and best effort traffic was modeled as TCP flows. The number of UDP flows was about 1/2 of the number of nodes and the number of TCP flows was about 1/4 of the number of nodes. Both TCP packet size and UDP packet size were 512 bytes. Packet interval was 40 ms.

In the first experiment, we investigated the relationship between the reserved bandwidth and the QoS of real-time flows acquired. There were 50 mobile nodes in this experiment. The default value for *difs_in* and *difs_out* were 0 and 16 respectively, which means the number of time slots increased from the basic value of DIFS of IEEE802.11. The result is shown as Table 1 showing that the QoS that these real-time flows acquired corresponded to the reserved bandwidth. When the reserved bandwidth was 0.05 Mbps and the data send rate of the source was about 0.1 Mbps, lots of packets could not get tokens. They were set as OUT and got best effort service as TCP packets. The QoS of these real-time flows could acquire degrades greatly and were only a little better than best effort flows. When the reserved bandwidth is 0.1 Mbps and the source sending the data was about the same rate, most of packets could get tokens and were marked as IN. The QoS of these real-time flows acquired improved considerably. The goodput increased, maximum packet delay decreased and standard delay deviation also decreased simultaneously. Due to the burst of the traffic, a few packets were set as OUT, so the maximum packet delay of the real-time flows was still a little large. In the case of reserved bandwidth of 0.2 Mbps, almost all of the packets of real-time flows were set as IN packets and got assured service. So the QoS of real-time flows acquired improved again. Compared with best effort flows, real-time flows get better QoS. To investigate the performance of the proposed scheme further, we provide TCP flows with AS service and provide UDP flows with BE service and repeat the last experiment. The experiment result is listed in Table 2, showing that TCP flows get the QoS corresponding to their reserved bandwidth. With the increase of the reserved bandwidth, TCP flows get better QoS, the goodput increased and the average packet delay decreased at the same time. Because UDP flows are provided with BE service, the QoS they acquired was greatly decreased compared with that of the last experiment. When TCP flows reserved a bandwidth of 0.2 Mbps, they

Table 1 Relationship of reserved bandwidth and the corresponding QoS of flows

Reserved bandwidth		0.05 Mbps	0.1 Mbps	0.2 Mbps
AS traffic (UDP flows)	Average goodput (KB/s)	10.76	11.75	12.24
	Maximum goodput (KB/s)	20.33	21.40	25.71
	Maximum packet delay (ms)	2563.51	482.52	94.02
	Average packet delay (ms)	310.43	61.54	33.25
	Standard deviation of delay	537.96	71.69	22.17
BE traffic (TCP flows)	Average goodput (KB/s)	24.89	18.94	18.77
	Maximum goodput (KB/s)	56.96	41.43	29.64
	Maximum packet delay (ms)	1913.02	1744.64	1140.76
	Average packet delay (ms)	474.98	499.65	440.31
	Standard deviation of delay	460.06	470.76	344.42

Table 2 Relationship of reserved bandwidth and the corresponding QoS of flows

Reserved bandwidth		0.05 Mbps	0.1 Mbps	0.2 Mbps
BE traffic (UDP flows)	Average goodput (KB/s)	8.35	8.76	8.45
	Maximum goodput (KB/s)	14.07	22.05	17.40
	Maximum packet delay (ms)	1173.32	1143.54	1955.37
	Average packet delay (ms)	89.57	113.39	991.34
	Standard deviation of delay	209.95	126.79	272.52
AS traffic (TCP flows)	Average goodput (KB/s)	27.45	28.97	31.36
	Maximum goodput (KB/s)	40.86	45.59	53.24
	Maximum packet delay (ms)	1840.52	1263.54	364.74
	Average packet delay (ms)	693.64	271.58	43.81
	Standard deviation of delay	633.37	338.31	62.01

could get much better QoS then UDP flows. The result proved that the scheme could protect responsive TCP flows from non-responsive UDP flows. In fact, due to the dynamic characteristic of Ad Hoc networks, it is very difficult to provide applications with absolute QoS in all conditions and guarantee the reserved bandwidth of an application absolutely. However, we can provide applications with the QoS corresponding to the bandwidth they reserved.

In the second experiment, we investigated the performance of the DCF with the mechanism of adaptively adjusted DIFS compared with the original DCF in various node number conditions. The number of the nodes varied from 10 to 50 and traffic load increased simultaneously. The default value for *difs_in* and *difs_out* were 0 and 8 respectively. The reserved bandwidth of real-time flows was 0.2 Mbps. The result of experiment is shown in the following figures. From them, some phenomenon can be found. With the increase of the node number and the traffic load, the goodput of each flow can acquire decreases while the average packet delay increases gradually. Besides, the Goodput of best effort flows decreases rapidly while the goodput of assured service flows only decreases a little. Compared with original DCF, the proposed DCF increases the goodput of the best effort flows considerably and makes the assured service flows get more bandwidth when traffic load is heavy. Thus it can improve the channel utilization and provide assured service flows with better QoS guarantee. Besides, compared with the proposed and original methods, SWAN makes the average packet delay decrease considerably. However, its goodput is smaller than other methods also.

CONCLUSION

Based on the existing research work, the paper combines the admission control mechanism and the differentiation mechanism of IEEE802.11 and proposed a distributed network model that supports service differentiation in mobile Ad Hoc networks. Extensive simulation experiments showed that the

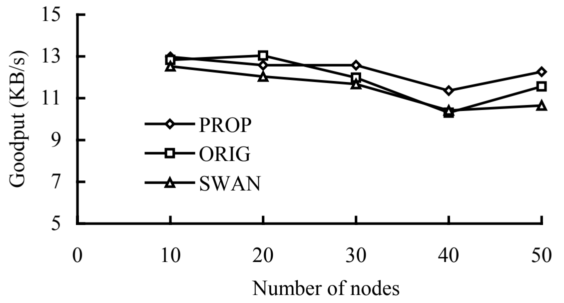

Fig.4 Goodput of UDP flows vs the number of nodes

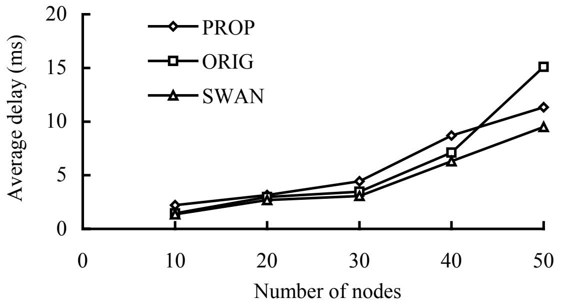

Fig.5 Average packet delay of UDP flows vs the number of nodes

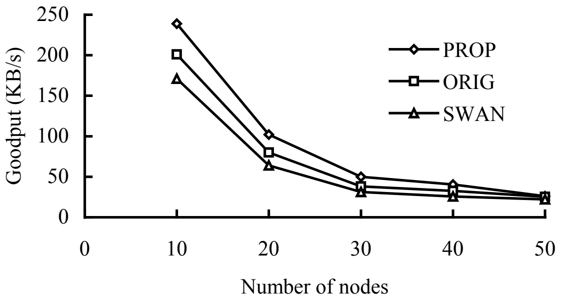

Fig.6 Goodput of TCP flows vs the number of nodes

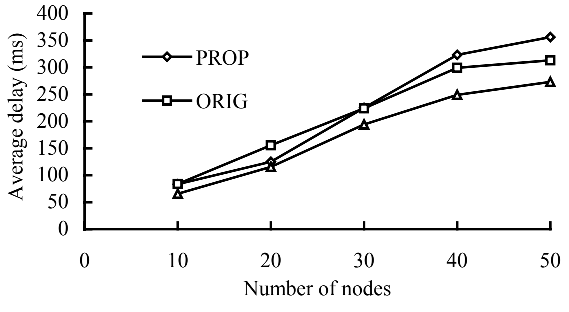

Fig.7 Average packet delay of TCP flows vs the number of nodes

proposed mechanism could provide various applications with the QoS corresponding to the their reserved resource and could guarantee the QoS of assured service traffic effectively. Compared with original DCF, the proposed mechanism of adaptively adjusting DIFS could increase the goodput of best effort traffic without degrading the QoS of assured service traffic.

References

Aad, I., Castelluccia, C., 2001. Differentiation Mechanisms for IEEE802.11. IEEE In Proc. INFOCOM'01, **1**:209-218.

Aad, I., Castelluccia, C., 2002. Remarks on Per-flow Differentiation in IEEE802.11. EW'02 (European Wireless), p.150-156.

Ahn, G.S., Campbell, A.T., Veres, A., Sun, L.H., 2002. SWAN: Service Differentiation in Stateless Wireless Ad Hoc Networks. IEEE In Proc. INFOCOM'02, **1**:457- 466.

Banchs, A., Perez, X., 2002. Providing throughput Guarantees in IEEE802.11 Wireless LAN. IEEE In Proc. WCNC'02, **1**:130-138.

Benveniste, M., Chesson, G., Hoeben, M., Castelluccia, C., 2001. EDCF Proposed Draft Text. IEEE Working document 802.11-01/131rl.

Blake, S., Black, D., Carlson, M., Shenker, S., 1998. An Architecture for Differentiated Service. RFC 2475.

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

Lindgren, A., Almquist, A., Schelen, O., 2001. Evaluation of Quality of Service Schemes for IEEE802.11. IEEE In Proc. LCN'01, p.348-351.

Perkins, C.E., Bhagwat, P., 1994. Highly dynamic destination-sequenced distance-vector routing for mobile computers. *ACM Computer Communication Review*, **10**:234-244.

Sobrinho, J.L., Krishnakumar, A.S., 1999. Quality of service in ad hoc carrier sense multiple access networks. *IEEE Journal on Selected Areas in Communications*, **17**(8):1353-1368.

Stoica, I., Shenker, S., Zhang H., 1998. Core–Stateless Fair Queuing: Achieving Approximate Fair Bandwidth Allocations in High-speed Networks. ACM In Proc. SIGCOMM'98, p.118-130.