Expedited Forwarding for WiFi

Fanilo Harivelo*, Gwendal Le Grand†, Pascal Anelli*, Jürgen Wolf‡ and Bernd Wolfinger‡
*IREMIA, Université de La Réunion
BP 7151, 15 Avenue R. Cassin, 97715 Saint Denis Messag 9, France
Email: {Fanilo.Harivelo | Pascal.Anelli}@univ-reunion.fr
†GET/Télécom Paris, LTCI-UMR 5141 CNRS, Département INFRES
37-39 rue Dareau, 75014 Paris, France
Email: gwendal.legrand@enst.fr
‡TKRN, Computer Science Department, University of Hamburg
Vogt-Kölln-Str. 30, 22527 Hamburg, Germany
Email: {jwolf | Wolfinger}@informatik.uni-hamburg.de

***Abstract*— It is essential to reserve resources in order to provide an acceptable quality of service in networks with real-time communication requirements. However, such reserved resources, e.g. bandwidth, may be unused as a consequence of the variations in the actual resource demands. Since bandwidth is scarce in wireless LANs (WLANs), QoS provisioning may be very expensive. Therefore, we propose a new resource management approach leading to a more efficient usage of the network in which communicating stations or end-users dynamically hand over some of the free resources temporarily to the other communication neighbors. This paper concentrates on two fundamental problems of such a demand-based sharing of resources: the current estimation of resource utilization, and the algorithm to share and redistribute resources with real-time requirements. This approach for resource and traffic management allows one to achieve significantly better utilization of network resources.**

***Index Terms*— QoS, Resource Management, Traffic Management, Real-Time Communications, Performance Evaluation, Differentiated Service, Wireless**

I. INTRODUCTION

Wireless LANs (WLAN) are becoming very popular with the widespread use of the IEEE 802.11 [1] networks whose the commonly known type is WiFi (Wireless Fidelity). Access methods used in broadcast multiple access networks like WiFi, the Distributed Coordinated Function (DCF) for WiFi, aims to share the bandwidth in a fair manner.

The push towards distributed multimedia communications over local-area networks has led to the requirement to transmit continuous media streams, such as audio and video streams, with sufficiently good quality. The fair share of ressources is become insufficient. The additional request is to provide a service level adapted for the new traffic sources. Basically, QoS (Quality of Service) may be provided to applications if the capacity of the communication resources is greater than required by the offered load. In packet networks, resource sharing is done dynamically between the traffic of the users. This may lead to situations in which resources have become insufficient for some flows, thus degrading the quality of the communication service.

One possible solution to this kind of problem is resource reservation. Reservation may be done individually per flow or for a set of flows. In the first case, the reservation is done at a set-up phase before data is transferred. In the second case, reservation is done statically by allocating resources to traffic classes and by controlling the offered load in the classes for which a certain degree of service quality has to be provided. This corresponds to building a logical network per traffic class. In the Internet context, the first approach is that of IntServ [2], and the second one, that of DiffServ [3].

Load variations in the network make it very difficult for flows with delay constraints to be supported. Actually, in case of overload, real-time traffic may be impacted so much that applications generating such flows may not work anymore.

QoS over WLANs has also been studied in other works. QoS can be provided at the MAC layer by weighing the exponential backoff timer [4] in order to implement a behavior similar to that of a guaranteed throughput scheduler such as Fair Queuing. The size of the contention window and the inter frame space may vary according to the traffic class [5]. The function used for the calculation of the backoff timer may also depend on the traffic class [6]. For real-time flows, the sender might be elected [2], [7] e.g. through a jamming sequence contest. Actually, it has been shown that DCF may provide weak delay guarantees to expedited forwarding flows as long as the IEEE 802.11 network is not in a saturated state [8]. IEEE 802.11e [9] offers enhancements to IEEE 802.11 MAC by supporting eight priority traffic classes that map directly upper protocol ones. It defines, among other things, Enhanced DCF (EDCF) mode in replacement of DCF mode. The common idea of these proposals is to give a higher priority for link access to privileged flows. Control may also be provided at the IP layer using a central control point that allocates dynamically the capacity to the various flows [10]. The control of best effort traffic to leave bandwidth available for real time traffic is also the basis of SWAN (Stateless Wireless Ad Hoc Network) [11]. To summarize, QoS can be provided either at MAC level or IP level. The first scheme defines the policy to choose the node that will access the physical medium whereas the second deals with the choice of the current packet to transmit in a node ([12]).

In the rest of the paper, we will focus on one-hop wireless networks, i.e., networks where each node is at the transmission range of the others. We also suppose the nonexistence of hidden nodes. Our dynamic resource redistribution approach consists of the limitation of the normal load offered by each node in such a way to allow the sparing of resources for real-time traffic. In fact, this is equivalent to reserving bandwidth for an Expedited Forwarding (EF) service (as defined in the Diffserv architecture). However, it may lead to an underutilization of resources, for example when the real-time traffic load is smaller than what has been reserved for it. Moreover, this scheme is clearly not adapted to wireless links that have a scarce bandwidth as compared to wired links. In this way, we introduce a more efficient resource utilization by making real-time flows hand over some of the free resources temporarily to the Best Effort (BE) ones, but still respecting real-time constraints. The presented solution aims to avoid occurrence of congestion in the network.

II. Global overview of the architecture

We propose an architecture to support EF traffic over WLAN as well as to maximize bandwidth capacity utilization. It consists of a threshold allocation system to guarantee real-time requirements based on estimation of the current EF resource requirement and a method for sharing remaining bandwidth among best effort flows. In this paper, we mainly focus on networks with a limited number of nodes having the same broadcast domain, i.e, any node can directly communicate with other nodes in the network, to prevent from dealing with both hidden station and exposed station problems. Resources reserved by EF traffic are first allocated to nodes by the network administrator. Each node controls the traffic it sends in the network. The rate controller is based on a dynamic shaper. The shaping rate, depending both on local and overall traffics, is computed in order to reach Max-Min fairness for BE flows. For EF flows, it is deduced from the execution of a thresholds system whose purpose is to recover unused resources while assuring the QoS. Dropper component ensures that EF traffic respects its initially negociated profile, especially in terms of maximum generated rate, by discarding out-of-profile packets. To collect network state information, each node maintains a table containing resources usage which is keeped up to date with the help of signaling messages. Finally, the elected packets are scheduled according to a static priority scheduler ([13]) noted PQ in Fig. 1. The policy component in the node is pretty similar to the rate-controlled static priority service discipline. The difference bears on the rate controller. Each node calculates its allocation with the help of a distributed algorithm. The global architecture is represented in the figure (Fig. 1).

We will show in the next sections how to limit the overhead caused by signaling messages and how to keep the required level of QoS for EF flows while still assuring a good bandwidth utilization rate.

III. Access Control Algorithms

A. Weighted estimation

To make resource allocation for both EF and BE traffics, this approach depends on the actual load and is based on load estimators, which produce smoothed estimates over the time.

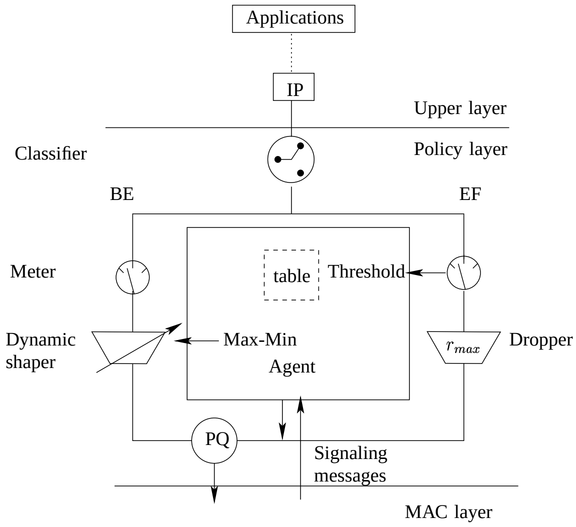

Fig. 1. Global Architecture

We will focus on a geometric estimator as presented in [14] and the way its utilization affects the performance of the flow. It is justified by the fact that geometric weighting is the dominating estimation method due to its ease of implementation. Arithmetic estimators would constitute an alternative possiblity (cf. again [14]).

As a basis for load estimation, we assume that at instants t_i, $t_i = t_0 + i\Delta t$ for $i \geq 1$, $\exists s_i \backslash s_i = d_i/\Delta t$ where s_i represents generated data rate, d_i, the amount of data generated during $[t_{i-1}, t_i[$ and Δt, the measurement period.

The sequence of samples (s_i) is used to estimate the actual traffic rate $g(t_i)$ using an estimator. The estimator has to allow the algorithm controlling the bandwidth to react in an appropriate manner. Major changes in data rates must be detected quickly, while minor changes may be ignored to get a certain form of smoothness.

Our geometric estimator, denoted by G_α, is defined as follows:

$$g(t_i) = \alpha s_i + (1-\alpha) g(t_{i-1}), \quad i \geq 1 \tag{1}$$

where $\alpha \in]0,1]$ indicates how fast the estimator changes with a new sample and $g(t_0)$ has to be initialized.

For EF traffic, the actual level of load $\hat{\rho}(t_i)$ can be estimated by $\hat{\rho}(t_i) = min(g(t_i), r_{max})/r_{max}$ where r_{max}, the initial reserved data rate. Indeed, generated traffic rate must not exceed r_{max} as presented earlier, thus, $\hat{\rho}(t_i)$ will be less or equal to 1. A worst case scenario is the situation when the offered load ρ_i, with $\rho_i = min(s_i, r_{max})/r_{max}$, increases to its maximum after the EF flow redistributed all of its initial reserved value. It occurs, for instance, in the following scenario:

$$\rho_i = \begin{cases} 0 & i = 0 \\ 1 & i \geq 1 \end{cases} \tag{2}$$

According to [14], in worst case, the maximum backlog delay, defined as the time elapsing between the originating of data to be transmitted and being actually ready to send it is upper-bounded by:

$$\tau_{max} = \frac{1}{\alpha}\Delta t \tag{3}$$

The value of Δt depends on the flow delay constraints in the case of EF traffic. In particular, if a flow delay of τ^* is acceptable, we have to ensure that $\Delta t \leq \alpha \cdot \tau^*$.

B. Threshold allocation system

With the presented scheme, the reserved bandwidth may be unused as a consequence of the variations in the actual EF resource demands. That is, for instance, the case of a VBR flow. This subsection studies ways of how unused parts of bandwidth can be dynamically handed over to best effort flows of other nodes in case it's not needed by its original owner for some time. Bandwidth has to be given back sufficiently quickly if it's needed by its owner in order to meet real-time requirements. Each owner determines whether its communication load, i.e. the amount of data waiting for transmission, justifies the continued reservation of the bandwidth as allocated to him. If a sufficiently large amount of bandwidth is temporarily free, some will be passed to best effort traffic. The owner will continue to observe the arrivals at its transmission queue. If its local load is increasing again, it informs its neighbors who then have to give back resources. In addition, a system of load thresholds aims to assure real-time requirements and avoid oscillations caused by small variations, in determining when to free or claim back resources based on current load estimation. The idea behind the threshold allocation system is to allocate a little more resources to real-time traffic than it needs, to prevent from high delay in the case of a sudden increase of load, and to share the remainder to the best effort traffic. It leads to broadcast of signaling messages indicating the bandwidth consumed or allocated for local traffic.

Fig. 2 represents a state transition model with 4 states.

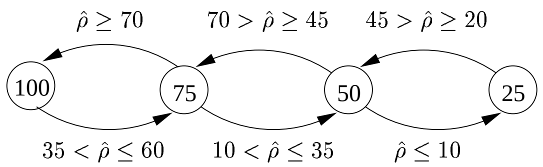

Fig. 2. State model with 4 states

State labels represent the percentage of the bandwidth reserved at setup time which should actually be allocated to the node. State transitions represent the crossings of thresholds constituted by the corresponding model. The fast transitions, representing thresholds which are not the closest to the current state, are not represented by the figure, but they exist in the model. By taking care of recalling bandwidth before the level of utilization is reached, real-time requirements can be achieved. The more states exist, the more efficient will be the gain in terms of local loss but the more signaling messages will be exchanged and the greater is the delay if fluctuations are rapid. Evidently, each station can use its own model. In the worst case, the sacrified capacity, which is the unused part of the allocated bandwidth, can not exceed the maximum difference between $\hat{\rho}$ and its associated state. The proposed model ensures that, at least, 60% of the initially reserved bandwidth is utilized, either by the owner, by other stations, or by both of them, assuming that best effort traffic is sufficiently high.

C. Resource Redistribution

As introduced earlier, to assure EF service, the BE traffic has to limit its rate to avoid and to spare bandwidth for real-time flows. This is done by means of a dynamic shaper localized at the outgoing interface of a node, before MAC layer. Thus, the proposed architecture can be combined with a MAC-level solution for providing QoS, such as the presently elaborated IEEE 802.11e access method. Packets classification relies on the content of the DS field in the IP header, used to demultiplex packets per class of service. The algorithm presented later, aims to tune the rate of the dynamic shaper to achieve expected QoS. Therefore, real-time traffic is isolated by reserving allocated bandwidth resulting from the threshold system and by sharing the remainder among BE flows. Each node must be aware of real-time load in the network to actually reserve that quantity. The algorithm controlling resource allocation to BE flows should maximize the bandwidth utilization and, as a consequence, should get knowledge of current demands of each flow. This is implemented with the help of a table representing the usage of bandwidth in the overall network. To keep tables synchronized, signaling messages containing traffic informations, are exchanged between nodes. These messages use broadcast to take advantage of the property of a wireless network. Thus, as all nodes execute the same algorithm with the same inputs, bandwidth will be kept stable.

An entry of the table contains, in particular, the following information for a node i:

- $addr_i$: represents the node address to which this entry is related.
- ref_i: is the bandwidth allocated to all EF flows deduced from the threshold system.
- gbe_i: corresponds to the estimated BE rate with the estimator introduced in the previous sections.
- $weight_i$: defines the relative importance of BE traffic in the execution of the algorithm in terms of source number. Its value is usually equal to 1. A value of 2 means that rate gbe_i is considered as being supplied by two sources.

A timer, representing the last broadcast from the corresponding host, is associated to each entry. The entry is removed from the table if the aging interval expires before the entry is refreshed. That deals with the dynamics of wireless networks. A small value of expiration time, makes the network more reactive to topology changes but will cause more signaling, while a big value gets the algorithm long to react. On receiving a signaling message, the related entry is updated, if it exists and the timer is rescheduled; otherwise, a new entry is created.

A message broadcast occurs on the following events:

- Variations in EF traffic, resulting in a state transition in the threshold allocation system.
- Major changes in local rate in terms of BE traffic in order to limit overhead due to signaling messages.
- The last broadcast was carried out early enough, so that the node must resend a message to refresh the state

information and thus to avert being removed from tables of the other nodes.

The distributed algorithm should attain a good performance in term of bandwidth utilization and must be responsive to changes in the flows requirements. Besides, its has also to deal with fair aspects of the sharing. Max-Min algorithm [15] is performed on the receipt of a signaling message or on the changes of local traffic state in order to determine local transmission rate.

IV. Evaluation and Results

In the following, we will use the four-states thresholds model which gives a maximum backlog delay of $1.75\Delta t$ with a geometric estimator $G_{0.3}$ according to [14]. If the time-critical traffic requires a maximum delay of $175\ ms$, then, that leads us to Δt set to $100\ ms$

The evaluation of this work is done using the NS-2 simulator. We use a network model with 6 nodes, 5 of which send traffic to the 6^{th}. The medium capacity is set to $1\ Mbit/s$. The first four senders generate best effort traffic CBR with a rate of $400\ kbit/s$, starting one after the other, that highly overload the network. The last sender generates EF traffic with a rate varying between 0 and $320\ kbit/s$. The EF flow (Fig. 3) is a real VBR traffic obtained from an MPEG encoded movie. All BE data packets are $512\ bytes$ long. One BE sender starts moving during the simulation at $t = 600\ s$ and gets out of the coverage area of the other nodes at $t = 628\ s$. The frame size of a signaling message is set to $64\ bytes$. We study 3 scenarios in wireless LANs: (1) EF and BE flows with no QoS support (WLAN), (2) EF and BE flows with traffic control but without using the threshold system (WLAN + QoS), and finally (3) EF and BE flows with traffic control and usage of the threshold system (WLAN + Thresholds). The curves of flows throughput are expressed in terms of normalized throughput defined as the ratio throughput to medium capacity. Each type of curves uses the same scale range to make comparisons easier.

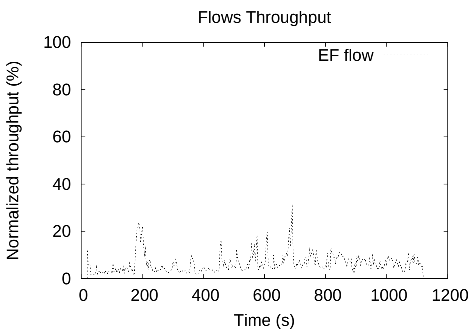

Fig. 3. Traces of "Star Trek" movie

In the first scenario (Fig. 4), bandwidth usage is high and no flow differentiation can be observed. One notes that achieved throughput decreases abruptly at some instants in time. The bandwidth and delay needed by the MPEG flow cannot be met. Actually, the flow experiences a maximum delay of $1.881\ s$ and a high delay variation of $85\ ms$.

In the second case (Fig. 5), real-time constraints are met for the MPEG flow. The MPEG flow experiences a maximum

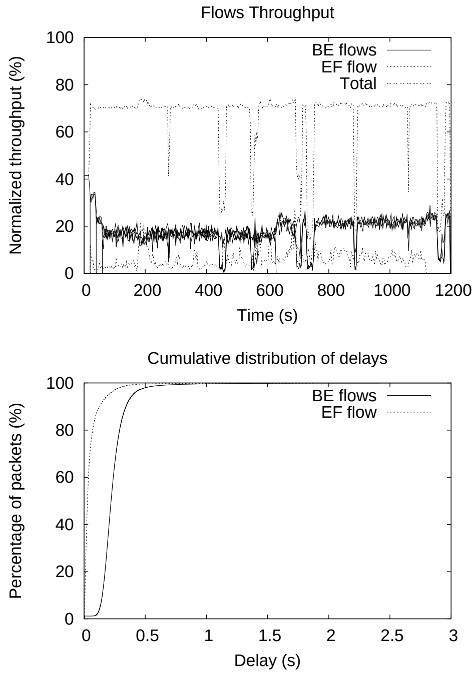

Fig. 4. Scenario 1: Throughput and cumulative distribution of delays in the network without QoS control

delay of $35\ ms$ and a small delay dispersion ($4\ ms$). However, there is no statistical gain and link capacity is underutilized with only $42.82\ \%$ of the available bandwidth being used. The signaling overhead is low ($0.61\ \%$ of the achieved bandwidth).

In the last scenario (Fig. 6), real-time constraints are still met (maximum delay of $58\ ms$, observed in a worst case when the traffic fluctuation is maximal). As compared to the previous case, overall bandwidth usage is improved ($61.50\ \%$ vs $42.82\ \%$) with the same proportion as delay variation increases ($6\ ms$ vs $4\ ms$). However, delay variation remains low as compared to that of the scenario without QoS. After the exiting of the moving node from the network at $t = 628\ s$, its bandwidth share is recovered by the remaining hosts within a small period of time. The signaling overhead remains low.

According to Table I, the mechanism generates less signaling overhead ($0.44\ \%$ vs $0.61\ \%$ of the achieved bandwidth) in terms of bandwidth usage but more signalling messages (6234 vs 6031) due to additional EF traffic check when a threshold system is used as compared to scenario without threshold systems. Nevertheless, the total number of packets increases slightly with the introduction of a threshold system because of the EF traffic control and the statistical gain. The number of MAC-level collisions ($1.78\ \%$ of transmitted packets) increases compared to scenario 2 ($0.44\ \%$) because bandwidth recovery generates more packets, but is significantly low compared to ($18.96\ \%$).

Therefore, our solution supports QoS for EF VBR flows and improves significantly bandwidth usage with only a low signaling cost. Results will undergo more improvements when the mechanism is combined with a MAC-level solution such as IEEE 802.11e.

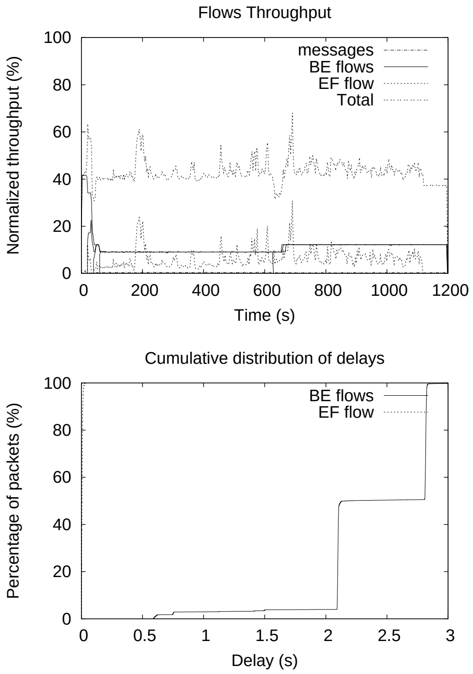

Fig. 5. Scenario 2: Throughput and cumulative distribution of delays in the network with QoS control but without bandwidth recuperation

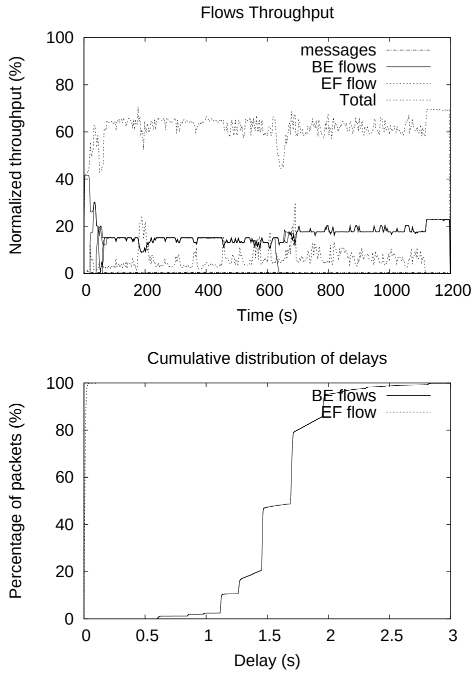

Fig. 6. Scenario 3: Throughput and cumulative distribution of delays in the network with QoS control and thresholds system

Scenario	WLAN	WLAN + QoS	WLAN + Thresholds
Bandwidth usage(%)	65.67	42.82	61.50
# Collisions	37423	597	3340
# Packets transmitted	197359	136487	188693
Bytes exchanged (MB)	98.88	63.45	91.28
# Signaling messages	0	6031	6234
# Dropped packets	287853	354608	302342
Max EF delay (s)	1.881	0.035	0.058
Mean EF delay (s)	0.053	0.006	0.009
EF standard (s) deviation delay	0.085	0.004	0.006

TABLE I

STATISTICS OF THE NETWORK IN THE THREE SCENARIOS

V. CONCLUSIONS

In this article, we demonstrate a new approach to improve the efficiency of statistical resource reservation techniques. We propose weighting functions to estimate the load as well as a threshold system that enables redistribution of unused bandwidth. We show through simulation that the proposed mechanism has a low impact on delays and that the signaling overhead remains very limited. Our solution achieves an good usage of network resources even in highly loaded situations. Our future works will address the extension of our architecture trying to eliminate the need of exchanging dedicated control messages and taking into account hidden station problem. Thus, the table of resource usage and allocation will be deduced from network interface parameters.

REFERENCES

[1] LAN/MAN Standards Committee of the IEEE Computer Society, "Wireless LAN medium access control (MAC) and physical layer (PHY) specifications," *IEEE standard 802.11, 1999 Editions*, 1999.

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

[3] S. Blake, D. Black, M. Carlson, E. Davies, Z. Wang, and W. Weiss, "An Architecture for Differentiated Services," *RFC 2475, IETF*, December 1998.

[4] N. H. Vaidya, P. Bahl, and S. Gupta, "Distributed fair scheduling in a wireless LAN," *MOBICOM Mobile Computing and Networking, ACM*, pp. 167–178, August 2000.

[5] M. Benveniste, G. Chesson, M. Hoeben, A. Singla, H. Teunissen, and M. Wentink, "Enhanced DCF," *Working document draft text, IEEE*, 2001.

[6] I. Aad and C. Castelluccia, "Priorities in WLANs," *Computer Networks*, vol. 41, no. 4, pp. 505–526, March 2003.

[7] J. L. Sobrinho and A. Krishnakumar, "Quality of service in ad hoc carrier sense multiple access networks," *IEEE Journal on Selected Areas in Communications*, vol. 17, no. 8, pp. 1353–1368, 1999.

[8] M. Heusse, P. Starzetz, F. Rousseau, G. Berger-Sabbatel, and A. Duda, "Bandwidth allocation for DiffServ based quality of service over 802.11," *Globecom 2003, San Francisco*, December 2003.

[9] IEEE 802.11 WG, "Draft Supplement to Standard For Telecommunications and information exchange between systems-Local and metropolitan area networks-Specific Requirements- Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications, 1999. Medium Access Control Enhancements for Quality of Service (QoS), IEEE 802.11e/D2.0," *IEEE Draft*, November 2000.

[10] J. A. Garcia-Macias, F. Rousseau, G. Berger-Sabbatel, L. Toumi, and A. Duda, "Quality of Service and Mobility for the Wireless Internet," *Kluwer Wireless Networks*, vol. 9, no. 4, pp. 341–352, July 2003.

[11] G.-S. Ahn, A. T. Campbell, A. Veres, and L.-H. Sun, "SWAN: Service differentiation in stateless wireless ad hoc networks," *INFOCOM'02, New York, IEEE*, 2002.

[12] G. Le Grand, R. Meraihi, S. Tohmé, and M. Riguidel, "Intelligent Ad Hoc Networking to Support Real Time Services," *VTC, Vehicular Technology Conference*, October 2003.

[13] H. Zhang and D. Ferrari, "Rate-Controlled Static-Priority Queueing," *INFOCOM'93*, vol. 1, pp. 227–236, September 1993.

[14] B. Wolfinger, J. Wolf, and G. Le Grand, "Improving Node Behavior in a QoS Control Environment for Local Broadcast Networks," *Proceedings of SPECTS 2003, Montreal*, vol. 35, no. 4, pp. 361–371, July 2003.

[15] D. Bertsekas and R. Gallager, *Data Networks*, I. Prentice-Hall, Ed. Prentice-Hall, Inc., 1987.