Achieving Weighted Fairness in IEEE 802.11-based WLANs: Models and Analysis

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Abstract: In this paper, we consider the problem of providing weighted fairness among multiple priority classes in a IEEE 802.11-based wireless local area network (WLAN). An enhanced DCF method is proposed to properly control the transmission probability of a node that can reflect the weighted fair share among the data traffic flows in the multi-class environment. For this method, we present an analytical model to obtain its throughput performance and the transmission probability capable for the fairness. We numerically evaluate the method with different simulation scenarios. The results well validate the proposed method that can actually fulfill the design aim of weighted fairness, and can provide the differentiation service in the WLAN.

Key–Words: Weighted Fairness, Quality of Service, IEEE 802.11 DCF, Multiple Classes, Performance Analysis.

1 Introduction

The main objective of the next-generation broadband wireless networks is to provide suitable levels of Quality of Service (QoS) over IP-based wireless access networks. As one of the most successful MAC protocols for these networks, IEEE 802.11 DCF [1], however, pays no attention to the QoS provision, such as throughput guarantees, among traffic connections of different priorities. In fact, the above missed in DCF, has been identified as one of the most important issues when designing the wireless card of next-generation. Thus, in this paper we study the challenging problem to achieve the weighted fairness for data communications in WLANs. To this end, the ideal weighted fairness should be defined at first. Assume that there are N different priority classes. Each class i is characterized by a positive weight, ψ_i, with the assumption of $1 = \psi_1 > \psi_2, ..., > \psi_n > 0$. Assume further that each node carries only one traffic flow. The set of nodes carrying class i traffic is denoted by f_i. Let $w_i(t_b, t_e)$ be the amount of class i traffic during the time interval $[t_b, t_e]$. In order to achieve fair share to all traffic flow, it requires

$$\frac{w_i(t_b, t_e)}{\psi_i} = \frac{w_j(t_b, t_e)}{\psi_j}, \ \forall i, j \in \{1, ..., N\} \quad (1)$$

As shown above, the ideal weighted fairness cannot be actually achieved since data transmitted on a real network is packetized. However, when considered with IEEE 802.11 WLANs, each data packet in the higher layer is fragmented into smaller MAC frames for transmission, which provides a reasonable assumption that each data flow has the same MAC frame size. Let $P_{s,i}$ be the probability that a MAC frame is transmitted from a node in class i and successful. With this, it is considered that all the traffic flows within a WLAN would fairly share the wireless medium and the weighted fairness in the WLAN is achieved, in a probabilistic sense, if the following condition holds

$$\frac{P_{s,i}}{\psi_i} = \frac{P_{s,j}}{\psi_j}, \ \forall i, j \in \{1, ..., N\} \quad (2)$$

The remaining parts of this paper are organized as follows. In Sections 2 and 3, we briefly summarize the legacy IEEE 802.11 DCF and the P-IEEE 802.11 DCF adopted, respectively. Following that, a Markov chain analysis for the P-IEEE 802.11 DCF in the multi-class environment is given in Section 4. According to this model, the transmission probability to achieve the weighted fairness is derived in Section 5. The analytical results are examined with the experiments in Section 6. The related works are summarized in Section 7 as reference. Finally, conclusions are drawn in Section 8.

2 IEEE 802.11 DCF

The basic scheme for IEEE 802.11 Distributed Coordination Function (DCF) is Carrier Sense Multiple

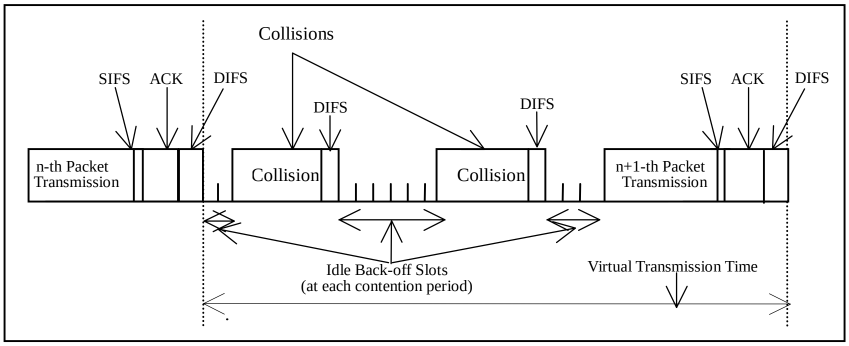


Figure 1: The basic operations of IEEE 802.11 DCF.

Access with Collision Avoidance (CSMA/CA). A collision can be caused by two or more stations trying to transmit a frame at the same time. After each frame transmission, the sender waits for an acknowledgement (ACK) from the receiver. If no ACK is received, a collision must have occurred and the frame is retransmitted.

It is more precisely shown in Fig. 1 that before initiating a transmission, a node senses the channel to determine whether or not another station is transmitting. If the medium is sensed idel for an specified timer interval, called the distributed interframe space (DIFS), the node is allowed to transmit. On the other hand, if the medium is sensed busy, its transmission is deferred until the ongoing transmission terminates. In this case, the MAC adopts a slotted binary exponential backoff algorithm (BEB) to arbitrate the access. That is, it will uniformly choose a random backoff interval in $[0, CW-1]$ to initialize the backoff timer, where CW denotes the contention window size, and is set to CW_{min} for the first transmission attempt. The backoff timer will decrease if the channel is sensed idle, stop when the channel is in progress, and reactivate when the channel is sensed idle again for more than DIFS. Each time slot immediately following an idle DIFS is given its length equal to the time interval needed for any node to detect the transmission of a frame from any other node. When the backoff timer expires, the node will try to transmit its frame at the beginning of the next slot time. Finally, if the data frame is successfully received, the receiver will send its ACK after a specified interval, namely the short interframe space (SIFS), which is less than DIFS. The ACK is necessary because the inability of WLANs to listen while transmitting. If the ACK is not correctly received, the corresponding data frame will be retransmitted with the assumption of loss. In this case, the BEB adopted will double the contention window up to a pre-determined value CW_{max}.

3 P-IEEE 802.11 DCF

To deal with the weighted fairness problem and fulfill the design objective mentioned previously, we choose to extend the capability of P-IEEE 802.11 DCF protocol in [2] that does comply with the legacy 802.11 DCF and require no changes in the existing frame formats and access procedures.

This protocol is aim to solve the two major factors affecting its performance: transmission failures and idle slots due to back-off at each contention period. In fact, for solving that, many other approaches have been done with certain mechanisms that require some kinds of modifications to the DCF, and the solving approaches exhibit a reasonable trend toward the solution. However, it should be noted that although these approaches can increase the performance of WLANs to some extent, they are seldom considered with the compatibility issue to coexist with the legacy DCF. In fact, the conventional IEEE 802.11 wireless card is broadly accepted and well deployed in WLANs. It seems impossible to modify all these cards so that a certain modified 802.11-like MAC can be properly carried out for better performance. Thus, a soft-state modification on the MAC is more possible that provides a separate layer and involves no direct change on the conventional standard. To this end, we consider that

- instead of changing the existing standards such as the back-off procedures, MAC formats, and message sharing mechanisms in the DCF, the transmission probability in each back-off stage of contention window is directly manipulated, and
- for such manipulation, a separate layer between the standard access scheme and the physical layer is adopted.

As shown in Fig. 2, the P-IEEE protocol adopted uses a separate layer between the standard access scheme

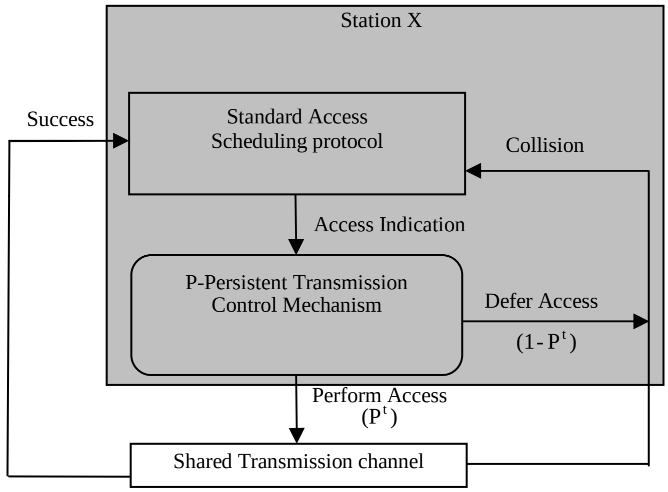


Figure 2: The architecture of P-IEEE 802.11 DCF.

and the physical layer to calculate the transmission opportunity for a node. When carried out, each node filters its transmission attempt based on the decision made in this layer. If the decision is positive, the frame under transmission is delivered by the normal DCF. Otherwise, the frame is deferred with a new back-off interval, just as that it encounters a collision in the legacy MAC.

Therefore, with this protocol a node can manipulatively control its transmission flow. However, it is still unknown that if a node in a certain priority class can decide the controlled p-persistent transmission probability for its transmission flow to cooperatively achieve the weighted fairness with other flows from different classes in the WLAN. For solving this problem, the controlled probability, called *P_T*, should be represented with a form that is analytically tractable in the multi-class environment. In this work, it is done with a simple non-uniform increasing function that can reasonably reflect the channel contention level sensed by a node in class i and back-off stage j. More precisely, with ϕ_i as the transmission factor for class i, the probability is represented by

$$P_{i,j}^{t} = 1 - \phi_i^{j+1} \tag{3}$$

Given the above, the corresponding architecture of P-IEEE for the multi-class environment is given in Fig. 3 for reference.

4 Throughput of P-IEEE 802.11 Protocol in Multi-Class Environment

4.1 Markov Model

For the throughput calculation in the multi-class environment, we first let the conditional collision probability of class i be P_i (as P in [3]). Given that, the successful transmission probability of a node in class i can then be represented by $1 - P_{c(i)} = (1 - P_i) \cdot P_{i,j}^t$. With this probability, a node will reset its back-off timer to a value within $W_{i,0}$ (the minimum window size of class i). On the other hand, the failure transmission probability of a node in class i can be given by $P_{c(i)} = 1-(1-P_i) \cdot P_{i,j}^t$. In this case, a node will defer its transmission to the next back-off stage, choosing a new back-off timer with a value within the window size of the stage. Besides, other non-null probabilities include the probability of 1 with which a back-off timer should decrease by 1 when the channel is sensed idle, and the probability of 1 with which a node should reset its contention window to $W_{i,0}$ when the maximum back-off stage m_i is encountered.

More precisely, for a node in class $i \in [1, N]$, let $b(i, t)$ be the stochastic process representing the back-off timer $k \in [0, W_{i,j} - 1]$, and $s(i, t)$ be the process representing the back-off stage $j \in [0, m_i]$. Thus, at time t, the state of a node in class i can be modeled with a discrete-time Markov chain $\{b(i, t), s(i, t)\}$, and fully determined by $\{i, j, k\}$, as shown in Fig. 4. With the Markov chain, the non-null probabilities

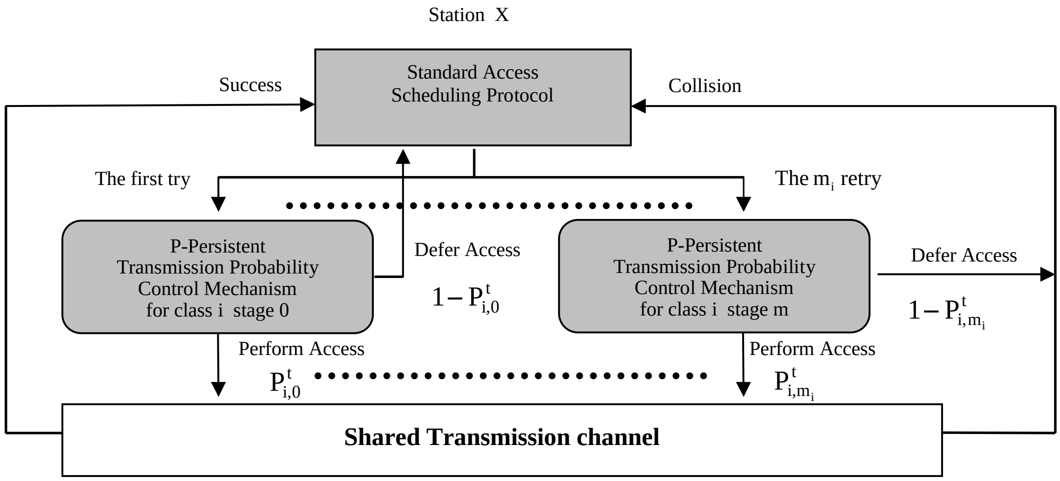


Figure 3: The controlled p-persistent transmission probability for a node of class i in each back-off stage.

considered in above can be represented by

$$\begin{cases} P\{i,j,k|i,j,k+1\} & = & 1, \\ & & k\in(0,W_{i,j}-2), \quad j\in(0,m_i) \\ P\{i,0,k|i,j,0\} & = & \frac{(1-P_i)\cdot P^t_{i,j}}{W_{i,0}}, \\ & & k\in(0,W_{i,0}-1), \quad j\in(0,m_i) \\ P\{i,j,k|i,j-1,0\} & = & \frac{1-(1-P_i)\cdot P^t_{i,j-1}}{W_{i,j}}, \\ & & k\in(0,W_{i,j}-1), \quad j\in(1,m_i) \\ P\{i,0,k|i,m_i,0\} & = & \frac{1}{W_{i,0}}, \\ & & k\in(0,W_{i,m_i}-1) \end{cases} \tag{4}$$

Denoting the stationary distribution of the Markov chain with $b_{i,j,k}$, we have the following relationship between back-off stages:

$$b_{i,j-1,0}\cdot\left(1-(1-P_i)\cdot P^t_{i,j-1}\right)=b_{i,j,0}$$

$$\longrightarrow \quad b_{i,j,0} = \prod_{k=1}^{j}\left(1-(1-P_i)\cdot P^t_{i,k-1}\right)\cdot b_{i,0,0}, \quad j\in(1,m_i) \tag{5}$$

In addition, the relationships between the neighboring back-off states can be represented by

$$b_{i,0,k}=b_{i,0,k+1}+\frac{1}{W_{i,0}}\cdot \left[(1-P_i)\cdot\sum_{k=0}^{m_i-1}P^t_{i,k}\cdot b_{i,0,0}+b_{i,m_i,0}\right], \quad k\in(0,W_{i,0}-1) \tag{6}$$

and

$$b_{i,j,k} = b_{i,j,k+1}+\left(1-(1-P_i)\cdot P^t_{i,j-1}\right)\cdot b_{i,j-1,0}, \quad j\in(1,m_i), \quad k\in(0,W_{i,j}-1) \tag{7}$$

From (5), and (6), we can deduce for all $k \in (0, W_{i,j}-1)$

$$\begin{aligned} b_{i,0,k} &= b_{i,0,k+1}+\frac{1}{W_{i,0}}\cdot \left[(1-P_i)\cdot\sum_{j=0}^{m_i-1}P^t_{i,j}\cdot\prod_{k=0}^{j-1}(1-(1-P_i)P^t_{i,k})\cdot b_{i,0,0}+b_{i,m_i,0}\right] \\ &= \frac{W_{i,0}-k}{W_{i,0}}\cdot \left[(1-P_i)\cdot\sum_{j=0}^{m_i-1}P^t_{i,j}\cdot\prod_{k=0}^{j-1}(1-(1-P_i)P^t_{i,k})\cdot b_{i,0,0}+b_{i,m_i,0}\right] \end{aligned} \tag{8}$$

and for all $k\in(0,W_i-1)$ and $j\in(1,m_i)$

$$b_{i,j,k}=\frac{W_{i,j}-k}{W_{i,j}}\left(1-(1-P_i)\cdot P^t_{i,j-1}\right)\cdot b_{i,j-1,0} \tag{9}$$

Owing to the chain regularities, for each $k \in (0, W_{i,j}-1)$, we have

$$b_{i,j,k} = \frac{W_{i,j}-k}{W_{i,j}} \cdot \begin{cases} (1-P_i)\cdot\sum_{j=0}^{m_i-1}P^t_{i,j}\cdot \\ \prod_{k=0}^{j-1}(1-(1-P_i)P^t_{i,j})\cdot b_{i,0,0}+b_{i,m_i,0}, & j=0 \\ \left(1-(1-P_i)\cdot P^t_{i,j-1}\right)\cdot b_{i,j-1,0}, & 0<j\le m_i \end{cases} \tag{10}$$

A solution for $b_{i,0,0}$ in terms of average conditional collision probability, P_i, and the P_T in back-off stage, $P^t_{i,j}$, is found by imposing the normalization condition on the Markov process as

$$1=\sum_{j=0}^{m_i}\sum_{k=0}^{W_{i,j}-1}b_{i,j,k} \tag{11}$$

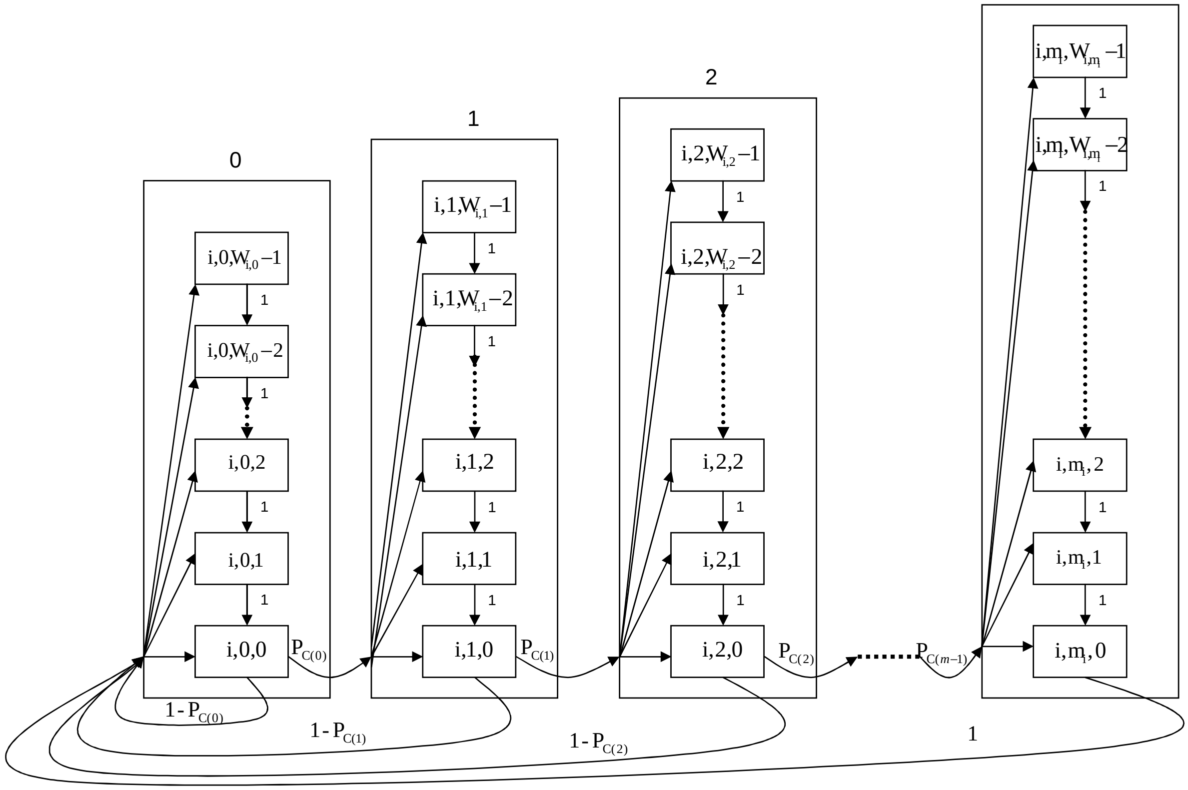


Figure 4: The Markov chain model for the MAC under the multi-class environment.

Finally, since a node transmits a frame when the back-off timer reaches zero and the P_T in the back-off stage, $P^t_{i,j}$, allows the transmission, the probability τ_i that a node transmits a frame in a randomly chosen time is obtained as

$$\tau_i = \sum_{j=0}^{m_i} P^t_{i,j} \cdot b_{i,j,0} \tag{12}$$

In the stationary state, the probability P_i that a s-tation in the back-off stage for class i senses the channel busy is given by

$$P_i = 1 - (1-\tau_i)^{n_i - 1} \cdot \prod_{h=1,h\neq i}^{N} (1-\tau_h)^{n_h} \tag{13}$$

Consequently, the set of Eqs. (12) and (13) $(i = 1,...,N)$ represent a nonlinear system of equations with $2N$ unknowns τ_i and P_i, which can be solved by numerical methods.

4.2 Throughput Analysis

We now consider the throughput calculation. For this, we let P_{tr} be the probability of at least one transmission in a slot time, which can be obtained by $P_{tr} = 1 - \prod_{h=1}^{N}(1-\tau_h)^{n_h}$. Similarly, let $P_{s,i}$ be the probability of a transmission that is successful for a node in class i, and P_S be the probability that a successful transmission occurs in a slot time, which can be obtained by $P_{s,i} = \tau_i \cdot (1-\tau_i)^{n_i-1} \cdot \prod_{h=1,h\neq i}^{N}(1-\tau_h)^{n_h}$, and $P_S = \sum_{i=1}^{N} n_i \cdot P_{s,i} = \sum_{i=1}^{N} \frac{n_i \cdot \tau_i}{1-\tau_i} \cdot (1-P_{tr})$, respectively. With these probabilities, we can express the throughput for a node in class i, S_i, and the overall system throughput, S, as the following ratios

$$S_i = \frac{P_{s,i} \cdot E[P]}{(1-P_{tr}) \cdot \sigma + P_S \cdot T_s + (P_{tr} - P_S) \cdot T_c} \tag{14}$$

$$S = \frac{P_S \cdot E[P]}{(1-P_{tr}) \cdot \sigma + P_S \cdot T_s + (P_{tr} - P_S) \cdot T_c} \tag{15}$$

where T_s denotes the average time the channel is sensed busy because of a successful transmission, and T_c denotes that for a collision. $E[P]$ is the average frame length and σ represents the duration of an empty slot time.

In addition, although RTS/CTS mode exits for mitigating hidden terminal problem, it incurs significant overhead and is often not used [4]. Thus, we consider the throughput calculation and the corresponding times only for basic mode

$$\begin{cases} T_s^{bas} &= DIFS + H + E[P] + \delta + SIFS + ACK + \delta \\ T_c^{bas} &= DIFS + H + E[P^*] + SIFS + ACK \end{cases} \quad (16)$$

where H denotes the physical header plus the MAC header, and δ denotes the propagation delay. $E[P^*]$ represents the average length of the longest frame payload involved in a collision. With the consideration of the same frame size, $E[P^*]$ is now equal to $E[P]$.

5 Weighted Fairness with P-IEEE 802.11 DCF

In this section, we introduce a method to obtain weighted fairness among data traffic in different priority classes. For doing so, we take $P_{s,i}$ (given previously) into the weighted fairness in (2), and after some simple manipulations, we have

$$\frac{\tau_i \cdot (1-\tau_i)^{n_i-1} \cdot (1-\tau_j)^{n_j}}{\psi_i} = \frac{\tau_j \cdot (1-\tau_j)^{n_j-1} \cdot (1-\tau_i)^{n_i}}{\psi_j}, \ \forall i,j \in \{1,...,N\} \quad (17)$$

Further, without loss of generality, we let $\tau_i = \tau_1$, which leads to

$$\tau_j = \frac{\psi_j \cdot \tau_1 \cdot (1-\tau_1)^{n_1-1}}{\psi_i \cdot (1-\tau_1)^{n_1} + \psi_j \cdot \tau_1 \cdot (1-\tau_1)^{n_1-1}} = \frac{\psi_j \cdot \tau_1}{\psi_1 - \psi_1 \cdot \tau_1 + \psi_j \cdot \tau_1} \quad (18)$$

In other words, any $\tau_j, j \neq 1$ can be represented in terms of ψ_j, ψ_1, and τ_1. Thus, if the transmission probability of class 1, τ_1, can be given, the transmission probabilities of the other classes, τ_js, can then be obtained with τ_1 and the weights ψ_js.

6 Performance Evaluation

In this section, we report on experiments made in order to verify the theoretical results derived previously. In the experiments, we implement P-IEEE with multiple classes on the Pythagor simulator [5] and let all nodes with IEEE 802.11a PHY be uniformly distributed in the WLAN. Each node has a flow with 2000-bytes of UDP packets toward a randomly chosen destination, resulting in the saturated throughput as required. With the assumption of no hidden terminal problem, P-IEEE and IEEE 802.11 MAC are both taken into account for the throughput weighted fairness, with different scenarios. However, we show only the results of 6 Mbps data rate in IEEE 802.11a PHY, due to space limitations. Other results with different data rates have the same trend, and can be represented by that of 6 Mbps. With that, we investigate the impact of the number of nodes in each priority class on the weighted fairness.

6.1 The 2 classes case

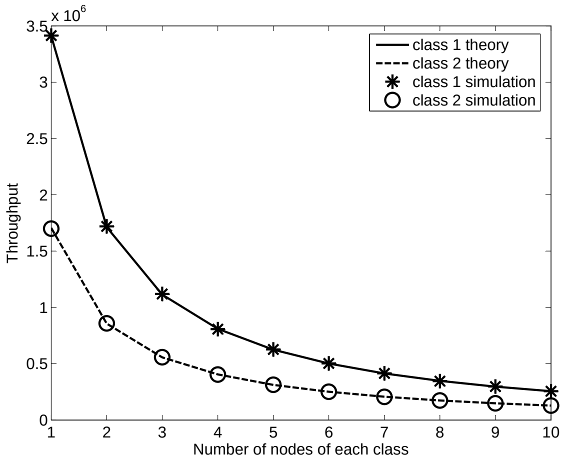
In the first set of experiments, two classes are involved and the weighted shares between the two classes are 1 and 0.5, respectively. Moreover, the number of stations of each class increases from 1 to 10, which represents different scenarios of the experimented wireless network. For each scenario, we let τ_1 be 0.05 and 0.2, respectively. Then, as indicated previously, given the transmission probability of class 1, τ_1, along with the weights ψ_js, we can eventually obtain the transmission probabilities of the other classes, τ_js to fulfill the requirement of weighted fairness.

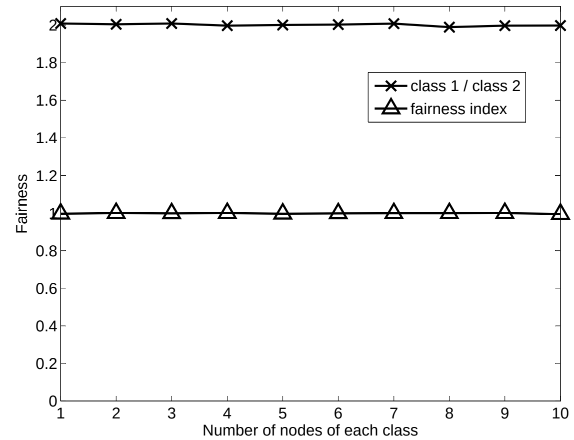
In addition to the above, we conduct these experiments with two different fairness metrics to quantitatively evaluate these MACs. The first metric is the direct ratio between the performance metrics from these classes. More precisely, we consider the throughput ratio as $\frac{S_i}{S_j}$. The second metric is the so-called $fairness\ index$ in [6]. In this metric, S_f denotes the throughput of traffic flow f, and ψ_f denotes the associated weight. The throughput fairness index, F_s, is then defined as

$$F_s = \frac{\mu(S_f/\psi_f)}{\mu(S_f/\psi_f) + \alpha(S_f/\psi_f)} \quad (19)$$

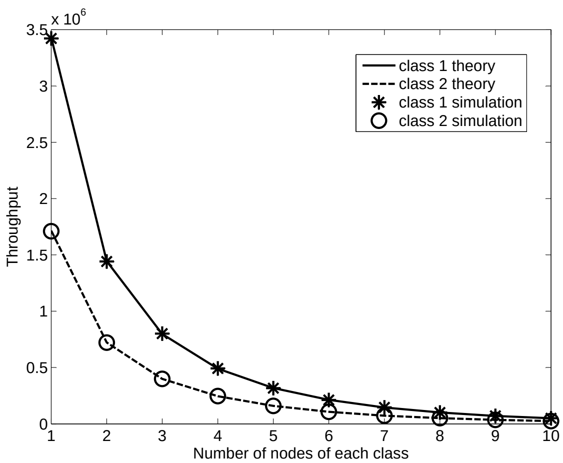
where μ and α denote, respectively, the mean and the standard deviation of S_f/ψ_f over all the active data traffic flows.

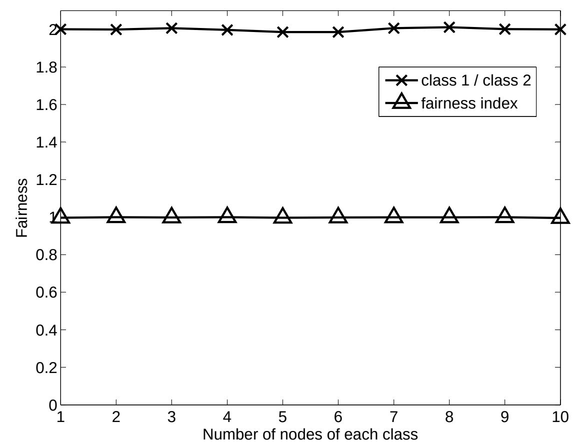
Figure 5(a) shows the throughput results, with lines denoting the theory's and symbols denoting the simulation's. From this figure, we have the following points of observation. First, the simulation results well match those of theory. This indicates that our analysis can correctly evaluate these methods. Second, the throughput of class 1 is almost 2 times that of class 2 in all scenarios. The fair share is expected and can be further confirmed in Fig. 5(b), in which the lines and symbols both denote the simulation results. It is readily observable from this subfigure that the direct ratio between class 1 and 2 is about 2 and the fairness index is about 1 despite the scenarios. Both indicate the same results on the fairness. However the former represents the desired fair share between these two classes while the latter shows the fairness in the sense that the weighted share is nearly identical for





(a) (b)





(c) (d)

Figure 5: Throughput results of 2 classes: (a) throughput of $\tau_1 = 0.05$, and (b) fairness of $\tau_1 = 0.05$,(c) throughput of $\tau_1 = 0.2$, and (b) fairness of $\tau_1 = 0.2$.

each traffic flow with few variations. All the above indicates that the design goal, achieving weighted fairness, can be actually obtained with our method based on the P-IEEE protocol. Third, as one can expect, a higher τ_1 can lead to a higher throughput. This is reflected in Fig. 5(c), showing that $\tau_1 = 0.2$ does provide better throughputs than $\tau_1 = 0.05$. However, regardless of the throughput differences, Fig. 5(d) shows the same weighted share as that shown in Fig. 5(b). That is to say, the weighted fairness can be actually achieved by the proposed method with the equation of (18), for a given τ_1.

6.2 The 3 classes case

In the second set of experiments, we demonstrate service differentiation for 3 priority classes with the weighted fair share of $\phi_1 = 1$, $\phi_2 = 0.5$ and $\phi_3 = 0.1$. Similarly, in order to study the impact of the number of nodes in each priority class on the service differentiation, we make also 10 different simulation scenarios with the number of stations of each class increasing from 1 to 10. Figure 6 shows the throughput results and the corresponding fairness values for $\tau_1 = 0.05$. With this figure, we find that 1) the weighted fairness among data traffic in the 3 different priority classes is exactly 1:0.5:0.1 with only a few fluctuations, as expected. The latter is more clearly demonstrated in Fig. 6(b) that the direct ratio between class 1 and class 2 has the value around 2 and that between class 1 and class 3 has the value around 10. In addition, the fairness index in Fig. 6(b) also confirms the ratios with the value near 1 in all experiments.

Similarly, figures 6(c) and (d) shows the results of

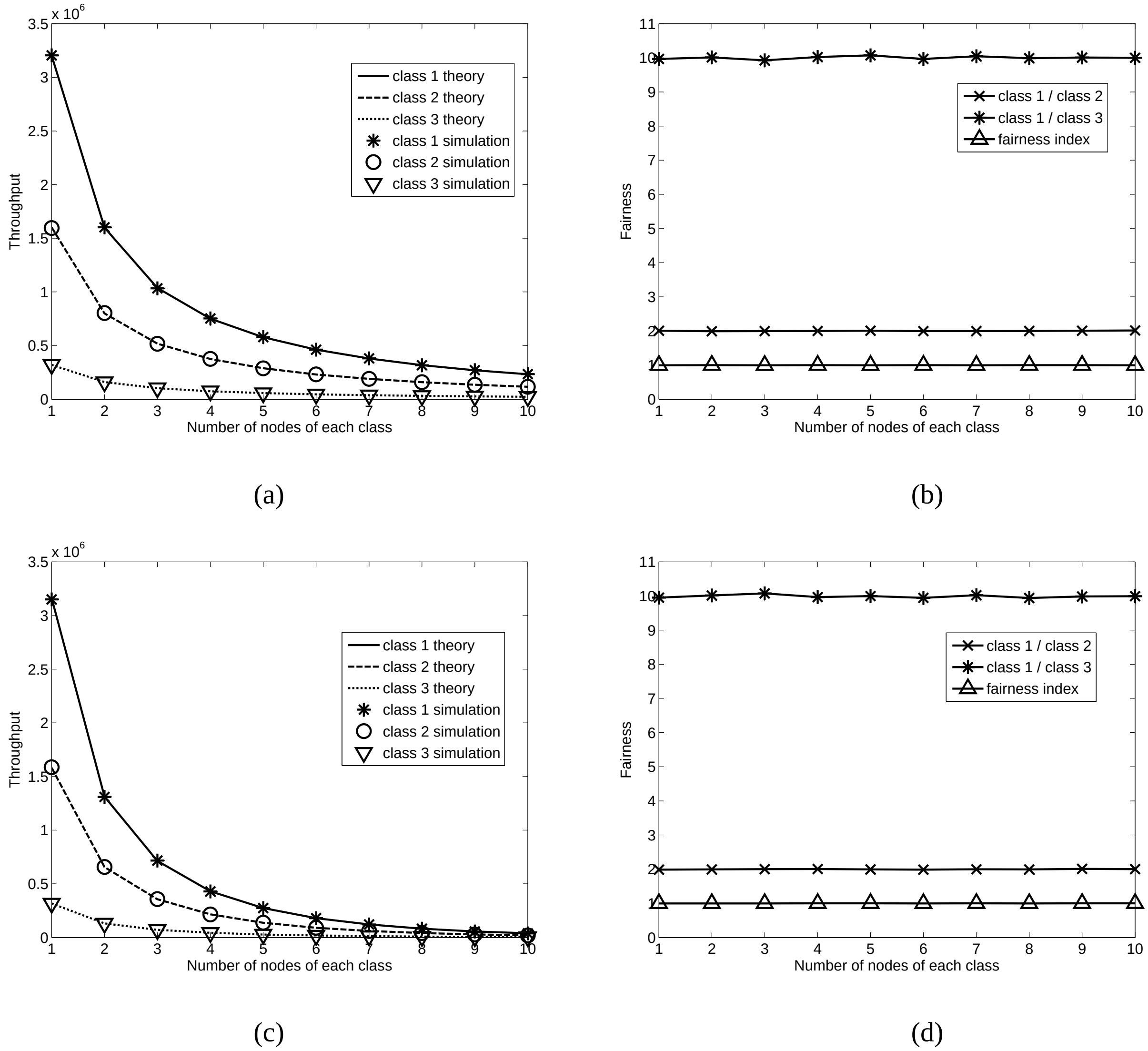


Figure 6: Throughput results of 3 classes: (a) throughput of $\tau_1 = 0.05$, and (b) fairness of $\tau_1 = 0.05$,(c) throughput of $\tau_1 = 0.2$, and (b) fairness of $\tau_1 = 0.2$.

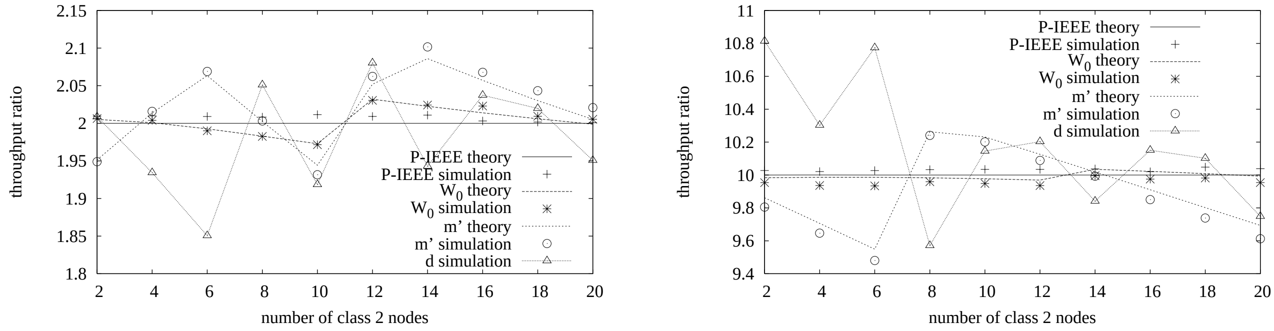
$\tau_1 = 0.2$. With the same trend of Figs. 6(a) and (b), it exhibits again that the proposed method can lead to the same weighted fairness among data traffic flows from different priority classes, despite the scenarios.

6.3 Comparison with 802.11e Parameters

In this set of experiments, we compare ϕ of P-IEEE with the parameters proposed in IEEE 802.11e, i.e., the initial window size, W_0, the maximum contention window size, m', and the difference between each class's AFIS, d. In terms of the capability of achieving weighted fairness in a WLAN, these parameters are evaluated theoretically and verified with simulations. Without loss of generality, they are all examined with 2 priority classes and the weighted share of 2 and 10, respectively.

In addition, we let the number of nodes of class 1 be 2 and that of class 2 vary from 2 to 20, which provides the ratio between the number of competing nodes in the two classes ranging from 1 to 0.1. Given that, the MAC parameters of class 1 are fixed to a given value so that those of class 2 can be adjusted to achieve the desired fair shares. To be specific, the parameters for class 1, ϕ_1, W_{0_1}, and m'_1, are all given with values of 0.5, 16, and 5. On the other hand, only one of these parameters for classes 2, i.e., ϕ_2, W_{0_2}, and m'_2, is varied for the desired fairness. However, since m'_2 can not be obtained with a reasonable value when W_{0_1} and W_{0_2} are both 16 for all different numbers of nodes, we use the adjusted W_{0_2} for the m' parameter adjustment.

Similarly, with W_0 and m' being fixed in both classes, we examine different AIFS difference values



(a) (b)

Figure 7: Throughput ratios obtained by manipulating different parameters. The desired ratios are (a)$\frac{S_1}{S_2} = 2$, and (b) $\frac{S_1}{S_2} = 10$.

of d (i.e., $AIFS[2] - AIFS[1]$) to find the best that can achieve the desired fairness. However, except the simulation, there provides no theoretical results because the analysis of AIFS differentiation is out of scope of this work. Apart from that, we can obtain each parameter for adjustment not only from simulations but also from theoretical solutions of Eqs. (12), (13), and (18).

The results are shown in Fig. 7. As can be seen, the approach of adjusting m' widely fluctuates around the desired ratios (2 and 10). That is, a slight change of the parameter may have a great impact upon the parameter adjustment for the weighted fairness. For example, fixing $m'_1 = 5$ may provide 1.613 or 2.394 of m'_2 depending on the network congestion level (the total number of competing nodes). However, as it should be, the MAC protocol refines both values to the closet integer, 2, and the parameter values become equal even though the significant difference between them exists, which induces the fluctuation. Similarly, adjusting the AIFS difference value of d also results in a curve with observable fluctuation.

On the other hand, it can be readily seen that setting ϕ provides more accurate results than adjusting the parameters of IEEE 802.11e for supporting the weighted fairness. As shown in the figure, without the requirement of adjusting ϕ to its closet integer, P-IEEE can theoretically achieve the perfect weighted fairness. This is confirmed by our simulations, which shows that the values of P-IEEE are very close to the desired ratios, and well matches the results in theory.

7 Related Works

Since IEEE 802.11 becomes the de facto standard for WLANs, there are quite a lot of related works proposed either for obtaining its theoretical limits or for improving its performances. According to their properties, we may classify these previous works into three categories as follows. The first aims to modify either the parameters of this MAC (e.g., initial contention window, interframe time, backoff parameter, etc.) or the existing standards (e.g., back-off procedures, MAC formats, etc.) so that the behavior of contention can be well shaped and better performance can be resulted [7–13]. The second uses the theoretical results derived from a p-persistent CSMA variant that can approximately represent the IEEE 802.11 MAC to adjust its parameters for increase of performance [14–16]. The third concerns a dynamic procedure that can self-adapt the contention level by using certain measurement metrics derived from the calculations given in their works [17, 18]. In addition to the above, many analytical works for the MAC have also been proposed in literature to estimate possible throughput and other performance metrics when the DCF MAC is adopted in WLANs or in ad hoc wireless networks [3, 19–22].

Specifically, many related works have been done to develop scheduling algorithms for wireless networks to achieve weighted fairness. However, most of them are centralized or polling-based protocols. Recently, with the distributed EDCF in IEEE 802.11e, some works have also been done for service differentiation by using different priority schemes based on, for example, setting different IFS, CW, or backoff parameters specified in the MAC. More precisely, we can also classify these differentiation schemes into three categories: backoff-based schemes [23–26], IFS-based schemes [25, 27] and hybrid schemes [28, 29]. For the first, bakoff-based schemes can be further divided into the following sub-categories: 1) differentiating the initial window size [24, 26], 2) differentiating the window-increasing factor [26], 3) differentiating the maximum backoff stage [26], 4) differentiation the maximum window size [24], 5) differentiating the bacoff time distribution [23, 25], and 6) combining two or more of the above differentiating schemes [24, 26]. On the other hand, Hybrid schemes, such as [28, 29], are usually sought to adopt both backoff-based and IFS-based ones. However, all the above IEEE 802.11e-based approaches consider only how to manipulate the existing IEEE 802.11e parameters to achieve the differentiation service, which involves no innovation for the standard. On the contrary , with an innovative mechanism, recently in [30] we propose a method to achieve uplink and downlink resource allocation in the IEEE 802.11 DCF-based WLANs without the aid of the existing IEEE 802.11e paramters. Given the merits of this approach, however, it considers only 2 classes, and provides no general solution for the number of classes larger than 2, and thus can not solve the weighted fairness problem under consideration.

8 Conclusion

In this paper, we use a p-persistent transmission control protocol to enhance the legacy IEEE 802.11 DCF with the capability of achieving weighted fairness among data traffic in different priority classes in WLANs. Experiment results show the correctness and effectiveness of the proposed method that can actually achieve the weighted fair share.

When compared with other possible IEEE 802.11 variants, this method may be considered as a more convenient alternate that can properly provide differential services in the WLANs, with the p-persistent transmission probability, P_T, as a parameter that can comply with the legacy DCF. Given the characteristics of simplicity and complete distribution, the issue about how to extend this method to achieve not only the weighted fairness but also maximize the system throughput and minimize the frame delay at the same time is still a challenging problem even not impossible, which will be our future work.

References:

[1] IEEE 802.11 II: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, Standard, IEEE. August 1999.

[2] J.S. Liu. Design and Performance Evaluation of a Distributed Transmission Control Protocol for Wireless Local Area Network. *IEICE Transactions on Communications*, E89-B(6), Jun. 2006.

[3] Giuseppe Bianchi. Performance Analysis of the IEEE 802.11 Distributed Coordination Function. *IEEE Journal on Selected Areas in Communications*, 18(3):535–547, March 2003.

[4] K. Xu, M. Gerla, S. Bae. How effective is the IEEE 802.11 RTS/CTS handshake in ad hoc networks? *in Proceeding of GLOBECOM'02*, 1:72–76, Nov. 2002.

[5] Dimitris El. Vassis. http://www.icsd.aegean.gr/telecom/Pythagor/.

[6] Daji Qiao and Kang G. Shin. Achieving Efficient Channel Utilization and Weighted Fairness for Data Communications in IEEE 802.11 WLAN under the DCF. *in Proc. of IWQoS'2002,* pages 227–236, 2002.

[7] Younggoo Kwon, Yuguang Fang and Haniph Latchman. A Novel MAC Protocol with Fast Collision Resolution for Wireless LANs. *in Proceedings of INFOCOM 2003*, 2003.

[8] Chonggang Wang, Bin Li, Bo Li, and Kazem Sohraby. An Effective Collision Resolution Mechanism for Wireless LAN. *in Proceedings of International Conference on Computer Networks and Mobile Computing (ICCNMC'03)*, 2003.

[9] Haitao Wu, Shiduan Cheng, Yong Peng, Keping Long, Jian Ma. IEEE 802.11 Distributed Coordination Function (DCF): Analysis and Enhancement. *in Proceeding of ICC'02*, 1:605–609, April 2002.

[10] Ahiann-Song Sheu, Tobias Chen, Jenhui Chen, and Fun Ye. An Improved Data Flushing MAC Protocol for IEEE 802.11 Wireless Ad Hoc Networks. *in Proceedings of VTC 2002-Fall,* 4:24–28, Sept. 2002.

[11] X. Yang and N. Vaidya. DSCR: A More Stable MAC Protocol for Wireless Networks. *Technical Report, University of Illinois at Urbana-Champaign*, 2002.

[12] Jain-Shing Liu and Chunhung Richard Lin. A Relay-based MAC Protocol for Multiple Rate and Multiple Range Infrastructure Wireless LANs. *Wireless Personal Communications Journal*, 34:7–28, 2005.

[13] Shun-Ping Chung and Wei-Sin Chen. Analysis of Prioritized IEEE 802.11 Wireless LAN with Non-Saturated Traffic. *WSEAS Transactions on Communications*, 5:1725–1732, Sept. 2006.

[14] L. Bononi, M. Conti, and E. Gregori. Design and Performance Evaluation of an Asymptotically Optimal Backoff Algorithm for IEEE 802.11 Wireless LANs. *in Proceeding of Hawaii Int'l Conf. System Sciences (HiCSS-33)*, 2000.

[15] Douglas S. Chan, Toby Berger, and Raj Bridgelall. Energy efficiency of CSMA protocols for wireless packet switched networks. *in Proceeding of WCNC'04*, 1:447–452, March 2004.

[16] Bai Xiang and Mao Yu-Ming. A Simple Adaptive p-persistent MAC Scheme for Service Differentiation and Maximum Channel Utilization. *WSEAS Transactions on Communications*, 7:1–7, Jan. 2007.

[17] Yong Peng, Haitao Wu, Shiduan Cheng, Keping Long. A New Self-Adapt DCF Algorithm. *in Proceedings of GLOBECOM '02*, 1:17–21, Nov. 2002.

[18] Yong Peng and Shiduan Cheng. Design of a Fine Tuned Self-Adapt DCF-Based Protocol. *in Proceedings of Int'l Conf. on Communication Technology 2003 (ICCT'03)*, 2:1220–1225, April 2003.

[19] H.S. Chhaya and S. Gupta. Performance Modeling of Asynchronous Data Transfer Methods in the IEEE 802.11 MAC Protocol. *ACM/Balzer Wireless Networks*, 3:217–234, 1997.

[20] Omesh Tickoo and Biplab Sikdar. Queueing Analysis and Delay Mitigation in IEEE 802.11 Random Access MAC based Wireless Networks. *in Proceedings of INFOCOM'04*, 2:1404–1413, March 2004.

[21] P.Chatzimisios, V. Vitsas and A. C. Boucouvalas. Throughput and delay analysis of IEEE 802.11 Protocol. *in Proceedings of the 5th IEEE International Workshop on Networked Appliances*, pages 168–174, Oct. 2002.

[22] V.M. Vishnevsky and A.I. Lyakhov. IEEE 802.11 Wireless LAN: Saturation Throughput Analysis with Seizing Effect Consideration. *Cluster Computing J.*, 5(2), 2002.

[23] D.-J. Deng and R.-S. CHang. A Priority Scheme for IEEE 802.11 DCF Access Method. *IEICE Transactions on Communications*, E82-B(1):96–102, Jan. 1999.

[24] A. Veres, A. T. Campbell, M. Barry, and L.-H. Sun. Supporting Differentiation in Wireless Packet Networks Using Distributed Control. *IEEE Journal on Selected Areas in Communications*, 19(10):2081–2093, Oct. 2001.

[25] X. Pallot and L. E. Miller. Implementing Message Priority Policies over an 802.11 based Mobile Ad Hoc Networks. *in Proc. of IEEE MILCOM*, 2001.

[26] Y. Xiao. A Simple and Effective Priority Scheme for IEEE 802.11. *IEEE Communication Letters*, 7(2):70–72, Feb. 2003.

[27] I. Aad and C. Castelluccia. Differentiation Mechanisms for IEEE 802.11. *in Proc. of IEEE INFOCOM*, 2001.

[28] S. Mangold, S. Chai, P. May, O. Kein, G. Hiertz, and L. Stibor. IEEE 802.11e Wireless LAN for Quality of Service. *in Proc. of European Wireless*, 2002.

[29] Y. Xiao, H. Li, and S. Choi. Protection and Guarantee for Voice and Video Traffic in IEEE 802.11e Wireless LANs. *in Proc. of IEEE INFOCOM*, 2004.

[30] Jain-Shing Liu. Uplink and Downlink Resource Allocation in IEEE 802.11 DCF-Based WLANs. *WSEAS Transactions on Communications*, 5:603–610, April 2006.