Designing a Fair Scheduling Mechanism for IEEE 802.11 Wireless LANs

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***Abstract*— A fair scheduling mechanism called distributed elastic round robin (DERR) is proposed in this letter for IEEE 802.11 wireless LANs operated in a distributed manner. To quantify the fairness, we not only derive its fairness bound, but also observe the fairness through ratios of throughput and weight using a simulation approach. By numerical comparisons among DERR, distributed deficit round robin (DDRR), and IEEE 802.11e, we demonstrate that DERR outperforms the other two mechanisms in performance and fairness.**

***Index Terms*— Scheduling, wireless LAN, fairness, IEEE 802.11.**

I. INTRODUCTION

Wireless LANs can be easily deployed to connect mobile users to the Internet using either IEEE 802.11 or high performance LAN (HiperLAN). Since IEEE 802.11 is frequently adopted by industry, it becomes a dominant standard, including IEEE 802.11 (2 Mb/s), IEEE 802.11a (54 Mb/s), and IEEE 802.11b (11 Mb/s), etc. But the above variants are not originally designed to support quality of service (QoS) through the distributed coordination function (DCF), one of the media access control (MAC) mechanisms in IEEE 802.11 networks. To support QoS, different schemes, e.g., IEEE 802.11e, have been proposed to satisfy QoS requirements for different users. However, most of the proposed schemes well take care of high priority users by sacrificing users of low priority. Thus, they fail to conduct the fairness issue.

To achieve fairness, some fair scheduling schemes have been proposed for wireless LANs in the literature, e.g., distributed fair scheduling (DFS) [5], distributed weighted fair queueing (DWFQ) [1], and DDRR [4], etc. DFS tries to adjust backoff intervals to implement fairness, while DWFQ adjusts contention windows to fulfill fairness. However, both DFS and DWFQ have poor performance in throughput and delay due to latent collisions although better fairness can be achieved. To get better performance in throughput and delay, DDRR based on deficit round robin (DRR) [3] was designed to have different inter frame space (IFS) intervals using a mapping scheme to avoid possible collisions. Stimulated by both elastic round robin (ERR) [2] designed for wired networks and DDRR, DERR is proposed in this letter. Similar to ERR, the value of *allowance* to achieve fairness is determined according to requirements of users. To greatly avoid collisions, a mapping approach upon values of allowance is utilized to transform different values of allowance to different intervals of IFS. Hence, DDRR is the closest work to ours and will serve as a reference scheme along with 802.11e in later numerical experiments. Our numerical results show that DERR not only improves performance in throughput and delay, but also exhibits better fairness as compared to DDRR and 802.11e. Furthermore, fairness bounds for both DERR and DDRR not conducted by [4] are derived.

The rest of the letter is organized as follows. Section II describes the mechanism of DERR. As for the analysis of fairness bounds for DERR and DDRR, it is given in Section III. Section IV compares DERR with DDRR and 802.11e through numerical examples. Finally, Section V concludes the letter.

II. DESCRIPTION OF DERR

DERR is designed for IEEE 802.11 wireless LANs operated in the ad hoc mode using DCF. Without loss of generality, hosts with different QoS requirements are classified into different classes. In this letter, throughput is used for the classification purpose. For a DERR scheduler, *allowance* $A_i^j(t)$ (in bits) is used to indicate the minimum amount of data allowed to be transmitted by host j within class i at time t during its transmission phase. Since allowance is adjustable and smaller than the amount of data sent, the DERR scheduler continues sending data frames until the amount of total frames sent exceeds the allowance. The excess amount of data frames denoted by $E_i^j(t')$ (in bits) for host j within class i at time t' is calculated as follows:

$$E_i^j(t') = F_i^j(t') - A_i^j(t'), \tag{1}$$

where $F_i^j(t')$ (in bits) represents the total amount of transmitted frames at time t' by the host. Specifying $T_{E,i}$ (in seconds) for class i according to QoS consideration or requirement, we then notice that the value of $E_i^j(t')/T_{E,i}$ is proportional to the desired throughput specified by host j within class i since it is larger for a host with higher throughput requirement and vice versa. Applying $E_i^j(t')/T_{E,i}$, the next allowance at time t ($t > t'$) can be calculated using the following relation:

$$A_i^j(t) = \frac{E_i^j(t')}{T_{E,i}}(t - t') - E_i^j(t'). \tag{2}$$

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In (2), the excess amount $E_i^j(t')$ during its previous transmission is deducted for the sake of fairness. Note that all above operations are performed in a distributed manner rather than a centralized manner like those in [2].

Once the value of allowance is obtained, it can be used to get a corresponding value of $\text{IFS}_i^j(t)$ for host j within class i at time t as follows:

$$\text{IFS}_i^j(t) = \text{DIFS} - \alpha_E A_i^j(t)\text{rand}(1, \beta_E), \tag{3}$$

where α_E is a constant used to make $\text{IFS}_i^j(t)$ fall within PIFS and DIFS specified by the IEEE 802.11 standard and $\text{rand}(1, \beta_E)$ is a random number between 1 and β_E (> 1) which results in different values of IFS to avoid possible collisions. Working similarly to the DCF mechanism in IEEE 802.11 wireless LANs except the mapped IFS, the right for transmission can be determined and the contention resolution is not necessary if perfect discrimination among IFS's can be achieved. Of course, the backoff procedure is activated due to collisions caused by imperfect discrimination.

III. ANALYSIS OF FAIRNESS BOUNDS FOR DERR AND DDRR

The fairness measure (FM) is defined as follows (an analogous definition can be referred to [3]):

$$\text{FM}(t) = \max_{\forall i,j,p,q} \left| \frac{S_i^j(t)}{w_i} - \frac{S_p^q(t)}{w_p} \right|, \tag{4}$$

where $S_i^j(t)$ ($S_p^q(t)$) and w_i (w_p) are the mean throughput measured within time period $[0, t]$ for host j (q) within class i (p) and weight for class i (p), respectively. To have a quantitative view, we now analyze fairness bounds of FM for both DERR and DDRR in the following.

Theorem 1: Equating weight for class i, i.e., w_i to $K_E/T_{E,i}$, $\lim_{t\to\infty} \text{FM}(t) \le U/K_E$ for DERR, where K_E is a pre-specified constant and $U = \sup_{i,j,t} E_i^j(t)$.

Proof: Assuming that there are l ($l \ge 1$) times of frame transmission at time instants $t_1, \ldots, t_l$ within time period $[0, t]$, the total amount of frames transmitted within time period $[0, t]$ for host j within class i, i.e., $f_i^j(t)$ (in bits) is equal to $\sum_{\nu=1}^{l} F_i^j(t_\nu) = \sum_{\nu=1}^{l} A_i^j(t_\nu) + E_i^j(t_\nu)$ using (1). It is equal to $\{0 + E_i^j(t_1)\} + \{\{\sum_{\nu=2}^{l} [E_i^j(t_{\nu-1})/T_{E,i}](t_\nu - t_{\nu-1}) - E_i^j(t_{\nu-1})\} + E_i^j(t_\nu)\}$ using (2) with $A_i^j(t_1) = 0$ due to $E_i^j(0) = 0$. After a few algebraic manipulations, we have $f_i^j(t) = \sum_{\nu=2}^{l} [E_i^j(t_{\nu-1})/T_{E,i}](t_\nu - t_{\nu-1}) + E_i^j(t_l)$. The above relation leads to the following inequality $0 \le \lim_{t\to\infty} S_i^j(t)/w_i \le U/K_E$, $\forall i, j$ since $S_i^j(t) = f_i^j(t)/t$. Thus, $\lim_{t\to\infty} \text{FM}(t) \le U/K_E$ from (4) and the above inequalities. This completes the proof. ■

As for DDRR, the upper bound for FM is given in the following theorem.

Theorem 2: Letting weight for class i, i.e., w_i be $K_D/T_{D,i}$, $\text{FM}(t) \le Q/K_D$ for DDRR, where K_D is a pre-specified constant, $T_{D,i}$ is a time period, and Q is the *service quantum* defined in [4].

Proof: According to the mechanism of DDRR [4], the (instantaneous) amount of transmitted frames is less than the value of the so called *deficit count* which linearly increases with a fixed rate of $Q/T_{D,i}$ and decreases by the amount of transmitted frames after a transmission is completed. Thus, we know that the total amount of frames sent within time period $[0, t]$ for host j within class i, i.e., $f_i^j(t)$ satisfies the following inequality: $0 \le f_i^j(t) \le Qt/T_{D,i}, \forall i, j$, which yields $0 \le S_i^j(t)/w_i \le Q/K_D, \forall i, j$. Using the above inequality and (4) leads to $\text{FM}(t) \le Q/K_D$ which completes the proof. ■

IV. NUMERICAL RESULTS AND DISCUSSIONS

Using simulations written by *C programming language* and run on an IBM compatible PC, we evaluate the performance of DERR, DDRR, and 802.11e in terms of collision rate (number of collisions per second), throughput, delay, and fairness, observed respectively by difference of *fairness indices* and ratio of throughput and weight. The simulation environment employed here is a scenario operated in the ad hoc mode under a transmission rate of 2 Mb/s. Unless specifically claimed, we assume for DERR and DDRR that eight hosts exist in the system with parameters set as follows: 110 kb/s frame generation rate (100 kb/s data and 10 kb/s header) and 1000 bytes frame length (which are also employed by [4]). Also, $\beta_E = \beta_D = 1.9$, $K_E = K_D = 10^{-6}$ (i.e., $T_{E,i}$ or $T_{D,i}$ is $1/w_i$ micro-seconds), $Q = 80$ bits and perfect discrimination for IFS's are assumed. As for 802.11e, the default parameter setting is given in Table I.

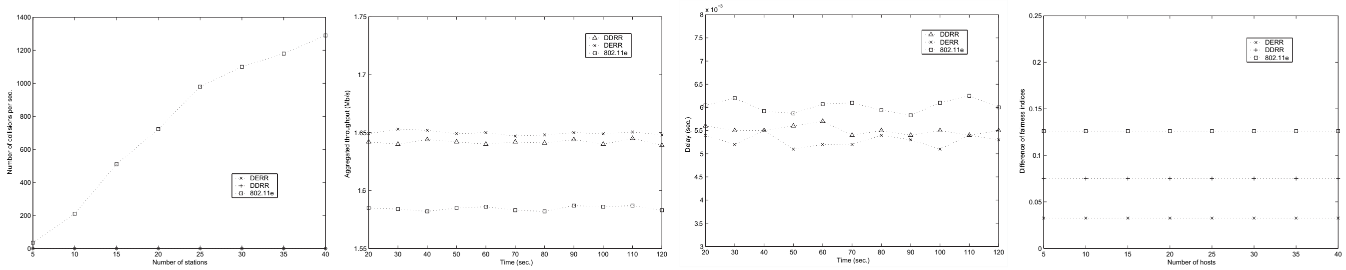
Compared to 802.11e, the random mapping of IFS used by DERR (or DDRR) can greatly avoid collisions as shown in Fig. 1(a) in which collision rates vs. different numbers of stations are observed. Fig. 1(b) (1(c)) shows that the aggregated throughput (delay) of DERR is 4.2% (12%) and 0.6% (3.3%) more (less) than 802.11e and DDRR, respectively. Obviously, DERR outperforms 802.11e and DDRR. Defining the *fairness index* as $(\sum_f \frac{S_f}{w_f})^2 / \sum_f \sum_f (\frac{S_f}{w_f})^2$ (fairness is reflected by the closeness to 1 (the perfect/ideal case)), where S_f and w_f represent throughput and weight of flow f, respectively, we use the reciprocal of difference of fairness indices with respect to the ideal case, i.e., $1/(1 - \text{fairness index})$ to represent the *degree of fairness* in the following. For various number of hosts, differences of fairness indices for DERR, DDRR, and 802.11 are shown in Fig. 1(d), which says that *degrees of fairness* for DERR, DDRR, and 802.11e are 32, 13, and 8, respectively. This implies that about 146% and 300% improvements are gained by DERR as compared to DDRR and 802.11e. Another way to observe fairness is ratio of throughput and weight (better fairness has a smaller standard deviation of ratios). Considering four classes (each contains two hosts) with weights 0.02, 0.03, 0.05, and 0.9, Figs. 2(a)–(c) exhibit ratios of different classes for DERR, DDRR, and 802.11e, respectively. We first note that results in Fig. 2 obey results given by Theorems 1 and 2. By calculation, the standard deviations for ratios of different classes are 0.053 for 802.11e, 0.018 for DDRR, and 0.0063 for DERR. Using the reciprocal of the standard deviation to stand for the degree of fairness, we show that about 185% and 740% improvements are gained by DERR as compared to DDRR and 802.11e. The above discussions demonstrate that DERR exhibits excellent fairness.

V. CONCLUSIONS

A fair scheduling mechanism, i.e., DERR is proposed in this letter. DERR is suitable for IEEE 802.11 wireless LANs

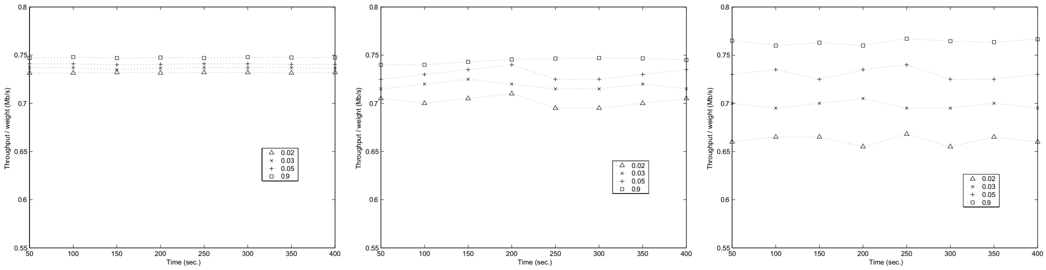
TABLE I
DEFAULT PARAMETERS FOR 802.11E

Weight	Priority	AIFS	$\mathrm{CW}_{\min}$	$\mathrm{CW}_{\max}$	Inter-Arrival Time	Frame Size	Buffer Size
0.9	7	PIFS	2^2-1	2^3-1	0.02 (Constant)	92 Bytes	20 kbits
0.05	2	DIFS	2^3-1	2^4-1	0.012 (Exp.)	1500 Bytes	2 Mbits
0.03	1	DIFS	2^4-1	2^5-1	0.012 (Exp.)	1500 Bytes	2 Mbits
0.02	0	DIFS	2^5-1	2^6-1	0.012 (Exp.)	1500 Bytes	2 Mbits



(a) Collision rate. (b) Aggregated throughput. (c) Delay. (d) Difference of fairness indices.

Fig. 1. Performance and fairness comparisons among DERR, DDRR, and 802.11e.



(a) DERR. (b) DDRR. (c) 802.11e.

Fig. 2. Ratios of throughput and weight for DERR, DDRR, and 802.11e under eight hosts with four different weights.

operated in the ad hoc mode and capable of avoiding collisions through a random mapping between allowance and IFS. We show that DERR outperforms DDRR and 802.11e since not only better performance in terms of delay and throughput is achieved, but also excellent fairness is exhibited by DERR.

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