User Fairness of IEEE802.11 WLAN Downlink

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***Abstract*—Widely deployed IEEE802.11 WLAN brings fairness problem among wireless stations (STA) in Wi-Fi hot spots. The reason of the unfairness is analyzed from two aspects in this paper, TCP-induced and MAC-induced asymmetry. We propose an adaptive CWmin approach to assure fairness between download and upload flow at AP. And also propose a user-fair download channel allocation algorithm. The novel aspect of these approaches is that it does not entail any modification of the IEEE 802.11 MAC protocol in STAs and easy to deploy. The simulation results indicate that the proposed approach can provide fairness to all STAs.**

Keywords- WLAN; IEEE802.11; Fairness;

I. INTRODUCTION

As the number of WiFi hot spots user increased, fairness between users became an important issue. Recent measurement studies show that 802.11 are unfair in allocating network bandwidth to STAs. It provides more opportunities to STAs which send out data packets, and less to STAs which accept packets from network [1][2][9]. As show in Figure.1, when two STAs share one AP(Access Point), there is competition between STAs and AP. STA A and B receive data from AP. AP competes with STAs, it obtains only 1/(2+1) of transmission opportunities. To STA A and B there are two aspects unfairness: a) AP cannot achieve twice more opportunities to visit wireless medium because it uses the same link layer protocol with STAs. This cause unfairness among uplink and downlink flows； b) Unfairness of downlink bandwidth share between STAs. The problem is getting serious during congestion. Fair and efficient medium access is becoming an important research problem to ISPs and users.

Most of works done to MAC fairness depend on coordination between STAs[1,5,15]. They are decentralized methods. The link layer protocol used by STAs needs partial or totally modified. And it's not easy to implement. This paper focuses on fairness problem of DCF (Distributed Coordination Function).

We proposed an easy solution that overcomes such problems. The proposed algorithm can be implemented at an AP without modification at STAs. We analysis the key role of CWmin played in this problem. We discovered that the value of CWmin is not direct proportion with its throughput. The proposed approch achieve fairness between STAs and AP through an adaptive CWmin in AP. And an algorithm of fair queue management to achieve fairness among STAs downlink flows. The AP maintains only one queue, not a separate queue for each STAs in the network. And it uses a variable called *service level* to indicate congestion at AP, *channel access rate* to indicate STA's share in downlink flow. The algorithm schedules according to the rate of *service level /channel access rate*. The paper discusses the approach and algorithm, does detailed simulation under various network configurations. The results clearly indicated that the proposed approach achieves its goals with respect to fairness, utilization.

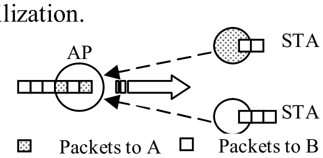

Figure 1. Competitions between AP and STAs

The remainder of this paper is organized as follows. The next section presents related works. Section III describes the model and proposed algorithm. Section IV analyzes its performance. Finally, the paper is concluded in Section V.

II. RELATED WORK

The IEEE 802.11 Working Group also initiated a Study Group (SG11e) with the charter to enhance the 802.11 MAC [4]. EDCF (Enhanced DCF), the proposed method provides differentiated channel access to frames with different priorities to support QoS. But EDCF does not deal with fairness between frames with different priorities.

The fairness of WLAN drown many researcher's attention [1][2][3]. In a distributed environment with AP, AP will compete for medium on behalf of all STAs receiving packets. Some approaches [5] propose to scale the contention window, or vary the backoff period [6] in order to improve priority level of the download traffic. In [7], they proposed a scheme with a release delay, which is the waiting time to attempt the transmission of the next scheduled packet in the transmission queue. In paper [8][9], authors developed a

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fully distributed algorithm that jointly solves the channel assignment, scheduling in multi-channel multi-radio ad hoc networks. All above methods are distributed and need coordinate from STAs.

The TCP congestion control mechanism can cause fairness problem in WLAN [10]. In [11], they investigate the TCP upstream/downstream unfairness issue over WLANs with per-flow queuing employed at AP. It maintains separate queue for each STAs in the network and increases complexity. A mechanism similar Diffserv is introduced in [12] to ensure fairness between competing TCP uploads and downloads. They try to enhance medium access opportunity of downlink TCP flows and to ensure fairness.

Raffaele B. [14] investigated the complex interaction of the TCP flow control mechanisms and MAC collision avoidance techniques in 802.11b-based hot spot networks. Based on the interaction between TCP congestion control and MAC contention control, Eun-Chan P. [15] proposed a cross-layer feedback approach to assure per-station fairness and to ensure high channel utilization.

The algorithm proposed in this paper need to be implemented at AP and without modification at STAs, not lie on coordination of STAs. We introduce the notion of *service level* to quantify the traffic load and the notion of *access rate* of each station to denote channel usage. The AP shapes traffic based on both parameters. Then fairness is ensured among all stations.

III. MODEL AND THE PROPOSED ALGORITHM

A. Model

Consider a wireless network of m STAs that can be represented via a graph G. And it is know that two STAs connected with an edge cannot transmit simultaneously due to share nature. Such network with AP can be represented by an adjacent matrix.

$$A = A_{ij} = \begin{array}{c} 1\,2\,3...m \\ \begin{bmatrix} 111\,...1 \\ 000...0 \\ 000...0 \\ . \\ . \\ 000...0 \end{bmatrix} \end{array} \quad (1)$$

Here 1 denote AP，and 2、3⋯m are other STAs in area.

Consider a dynamic traffic model in which each transmitter share channel in slot time. Each station receives packets from up layer to transmit. Packets arrive at STA according to independent Poisson processed. The rate of its arrivals denoted λ_i. Hence packets may be queued during processing, we assume C_i is longest queue allowed in station i, and n_i is actual length of the queue. Let s_i indicate activity of the STA so that its value are (0,1). Assume there are always packets to transmit. Let w_i represent STA's CWmin. The w_i value is used to randomly choose the number of slot time in the range of [0, w_i], which is used for backoff duration.

For a fixed $w=(w_1, w_2, \cdots, w_m)$, $s=(s_1, s_2, \cdots, s_m)$ is an Markov process in the space $S_G=\{s\in\{0,1\}^m$. Let π^w denote the distribution of s when each station operates with a fixed rate. The object of this paper is to find moderate w so that the value of s is fairly distributed among all STAs. The joint process $(s, n)=(s_1n_1, s_2n_2, \ldots, s_mn_m)$ is also Markovian.

To ensure fairness in Wi-Fi hot spot networks, there must be equilibrium channel occupancy distribution for AP and other STAs.

$$\pi_o^w(s, n) = \frac{1}{Z(G,w)} \times \prod_{i=1}^{m} w_i^{s_i} \times \prod_{i=1}^{m} \frac{\rho_i^{n_i}}{\sum_{k=0}^{C_i} \rho_i^k}, \quad s \in S_{G_i} \quad (2)$$

Where

$$Z(G, w) = \sum_{s\in S_G} \prod_{i=1}^{m} w_i^{s_i}$$

$$\rho_i = \lambda_i / \mu_i^w$$

The values of (2) are equal subject to s_1=1and s_1=0. And μ_i^r is the rate of each station.

In such networks, c_i is fixed for each station. The w_i is fixed for STAs. s is a function of n and w. To select an appropriate w_1 of AP, we must know the value of m.

B. Fairness between uplink and down link flows

We continue to consider a hot spot with STA number of m-1. Assume there are always packets to transmit after the completion of each successful transmission. We referred p as *collision probability*, meaning the probability of a collision seen by a packet being transmitted on the channel.

The independence of p is also assumed, and is supposed to be a constant value. To make difference of AP and STAs, use r_A to denote the probability of AP send packet in a time slot, and. r_S to denote the probability of STA. We have

$$r = \frac{2(1-2p)}{(1-2p)(CW\min+1) + pCW\min(1-(2p)^n)} \quad (3)$$

In which n represents count of retransmission times. For the constant backoff window problem

$$r = 2/(CW\min+1) \quad (4)$$

Let P_{AP} be the probability that there is one transmission in the considered slot time. Let P_{STA} be the probability that of all STAs. We have

$$\begin{aligned} P_{AP} &= r_A(1-r_S)^{m-1} \\ P_{STA} &= (1-r_A)(m-1)r_S(1-r_S)^{m-2} \end{aligned} \quad (5)$$

We define $P_{success}$ to denote success probability and P_{idle} to denote idle probability

$$\begin{aligned} P_{success} &= P_{AP} + P_{STA} \\ P_{idle} &= (1-r_A)(1-r_S)^{m-1} \end{aligned} \quad (6)$$

We express S as the ratio of normalized channel utilization without considering propagation delay.

$$S = \frac{E[P]}{T_S - T_C + [(1-P_{idle})T_C + P_{idle}\sigma]/P_{success}} \quad (7)$$

Where σ is length of idle time slot, T_S denote the component of success slot and T_C denote the component of collision slot. To maximize S, we must maximize

$$\frac{P_{success}}{(1-P_{idle})T_C/\sigma+P_{idle}} = \frac{(m-1)(1-r_A)r_S(1-r_S)^{m-2}+r_A(1-r_S)^{m-1}}{T_C^*[1-(1-r_A)(1-r_S)^{m-1}]+(1-r_A)(1-r_S)^{m-1}} \quad (8)$$

In which

$$T_C^* = T_C/\sigma .$$

It is obvious that the value of S is interrelated with probability of collision. Equation (8) can be simplified in hot spot environment to

$$P_{AP} = P_{STA}$$
$$r_A/(1-r_A) = (m-1)r_S/(1-r_S) \quad (9)$$

From (4) and (9), we have

$$CW_{AP}\min = (CW_{STA}\min - 1)/(m-1)+1 \quad (10)$$

We plot (10) in Figure 3B. Note that evaluation of CW_{AF}min in (10) is similar with the simulation results as curve A indicates.

C. *Fairness among STAs compete for downlink bandwidth*

Let us define $d_i=a_i/a_f$ as the ratio that STA i expect to acquire in downlink flow at AP. In which a_i represents real *access rate* acquire from AP and a_f denotes fair *access rate* at AP. The network utility maximization problem of AP we would like to solve is as follows:

$$NETWORK(A,\ C:a_i): Maximize \sum d_i^{in}, \sum a_i^{out} \quad \text{Subject to } A \le C \ \text{ Over } a_i \ge a_i^{out} \ge 0 \quad (11)$$

To optimize service at AP, it should serve STA with lower d_i and serve all STAs in the area considering fairness at the same time. $a_i \geqslant a_i^{out}$ denote that some packets will be dropped during congestion.

The algorithm records d of each STA at AP's interface. It uses only one queue to manage all downlink packets. It queues packets with lower d value, drops or mark packets with high d value. So that packets of all STAs receive fair service. The process is indicate by

$$Drop_i = \begin{cases} 0, & \text{non-congestion} \\ \max(0, 1-d_{avg}/d_i) & \text{congestion} \end{cases} \quad (12)$$

In which $Drop_i$ is the drop probability of STA's packets. And d_{avg} is fair service d of downlink queue at AP which shows service capability of AP in period of time. Equation (11) means transmission during regular time and drop during congestion.

To calculate d_{avg} we must know d value of each STA that need to keep status of each downlink flow at AP. We use exponential average of d to represent d_{avg} approximately, as show in (13).

$$d_{avg} = (1\text{-}W_p)\times d_{avg} + W_p \times d \quad (10) \quad (13)$$

D. *Algorithm*

First, the number of STAs is observed at AP. The algorithm adjusts CWmin to achieve fairness between uplink and downlink flows. Then, we calculate *service level* d_{avg} to schedule packets. At last, it does schedule according d_{avg} and *di* of each STA recorded by AP. Flows with higher d_i than d_{avg} is shaped to lead rate adjustment of source. Congestion is avoided throughout the whole process and fairness is ensured between flows.

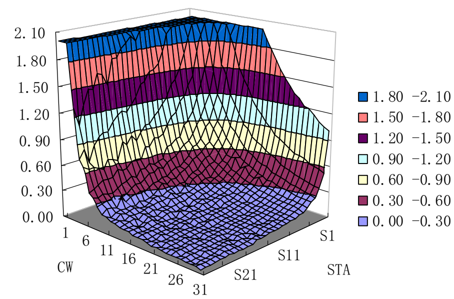

Figure 2. The acquired bandwidth ration of AP and STAs

We conducted extensive ns-2 simulations to plot CWmin curve under different environment. AP and STAs send CBR(Constant bit rate) data into the network at the same time. We change CWmin of AP (from 1 to 31) and number of STA (from 1 to 30) at same time. The simulation was done ten times. We static average rate acquired by AP and STAs. Then plot its value as show in Figure 2 and 3.

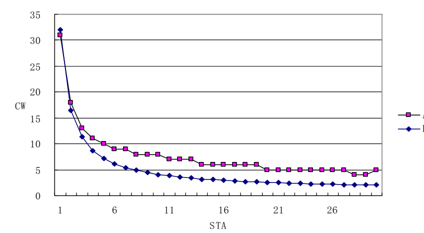

Figure 3. CWmin with equale ration under defferent STA number

CWmin parameter recommendation in IEEE802.11b is 31. So we set the tune range of CWmin from 1 to 31. On the other hand, as the number of STA increased, the performance of network decreased rapidly. We assume STA number is selected from 1 to 30. It is considered to be reasonable. As show in Figure 1, lower Cwmin means better capability to compete. But it is not direct proportion. We plot the curve display the relation between CWmin of AP and the number of STAs in Figure 2. The curve is used in following experiments.

We record different transmission time of STAs at AP out interface. The value of the time shows access rate to channel of each STA. The equation is (12), in which *tx_time* is transmission time, *current_time* is current time，*last_tx* is latest time transmission packets, *fairshare_* is fair share of each station calculated by average of all STAs.

$$d = \frac{tx\_time}{(current\_time + tx\_time - last\_tx) * fairshare\_} \quad (12)$$

The algorithm use active queue length to indicate early congestion, similar with RED.

$$Avg\_queue = (1 - W_q) \times Avg\_queue + W_q \times q\_ \quad (13)$$

When queue length *Avg-queue* is larger than *minth*, there is congestion. When larger than *maxth*, it's considered as serious congestion.

Average service level d_{avg} is exponential average of d_i. The weight W_p is set to 0.02 with experience. Once a STA expects to acquire excess share during serious congestion, d_{avg} is multiplicative decreased to converge. The queue length is kept between *minth* and *maxth*, and the algorithm works normally.

The pseudo code of UFAP algorithm:

```
Upon each arriving packet P:
if（new destination IP）
     update CWmin;
update average queue size avg_queue;
update flow d;
if（avg_queue => minth）{
     Drop_probability calculation;
     if drop packet
        return;
     if（avg_queue => maxth）
        multiple decrease d_avg with weight;
     else
          update the average utility d_avg;
     return;
}
```

IV. ANALYSIS AND PERFORMANCE EVELUATION

Evaluation is done with ns-2[16]. We develop our UFAP algorithm based on 802.11Ext module. We considered a Wi-Fi hot spot access network consisting of an AP and a number of wireless stations, as shown in Figure 1. The Basic Access method is set to DCF since the similar result with RTS/CTS is show in our experiments.

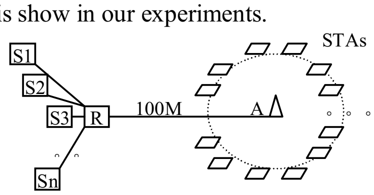

Figure 4. A network with STA nodes and AP.

A. Fairness bitween STAs with defferent download rate

First we focused on the fair channel sharing between downlink flows. Ten CBR sources include S1－S10 send packets to their destinations. So that it will come into being different load level at AP. The source rate ranging from 64kb to 640Kb at AP. Finally we plot the results after simulation of 100 seconds.

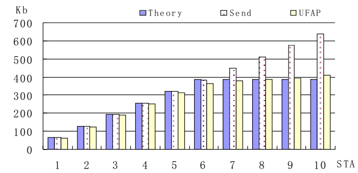

Figure 5. Bandwidth allocation among 10 STAs during congestion

Figure 5 shows the average throughput of STAs, respectively for source rate, theory rate and rate acquired under UFAP. As show in Figure 5, S1－S5 send rate ranging from 64Kb to 320Kb. Their rate are low than theory fair share, and their demands are fulfilled completely. But S1－S5 send rate ranging from 384Kb to 640Kb.The values are near or larger than their fair share. Packets in excess of 380Kb are dropped. The bandwidth is allocated fairly among all STAs during congestion.

As given in Figure 6, all STAs demands fulfilled during regular time. The UFAP algorithm shows good performance during both congestion and regular time.

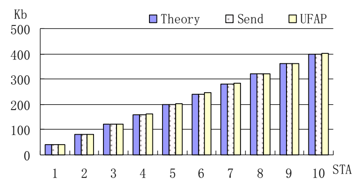

Figure 6. Bandwidth allocation among 10 STAs during regular time

B. Fairness between adaptive STAs

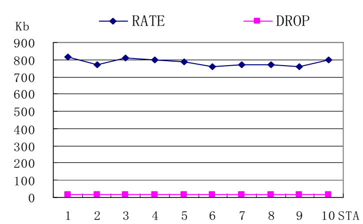

Figure 7. Downlink bandwidth allocation among adaptve flows at AP

Most of flows are adaptive TCP in networks. To evaluate performance in terms of adaptive TCP, this simulation focused on fairness between adaptive STAs. Ten STAs with FTP source using TCP/Reno send data into network. After ten repetitions, we static throughput acquired by each STAs. As show in Figure 7, RATE indicates throughput and DROP means packets dropped at AP downlink interface. Figure.7 reveals that all STAs received good service and the deviation between their bandwidth is lower than 2.17％.

C. bandwidth allocation between up/downlink flows

In last experiment, we change the number of STAs in the area. The simulation takes general AP without UFAP implemented as mark. To evaluate the influence of different CWmin at AP, we set STAs number to 4、10、20 and half of then send FTP packets to S series station, the other receive from their correspondence. Throughputs of each STAs are shown in Figure 8, 9 and 10.

As shown in Figure 8, there are four STAs. The CWmin value is set to 12 according to curve in Figure 3. STA3 and STA4 send TCP packets to AP. We can see unfairness on the curve of general AP without UFAP. But in the case of UFAP, the throughputs of all four STAs lie between 2000 and 2500. The bandwidth is allocated fairly among all STAs under UFAP. The deviation is lower than 0.97%.

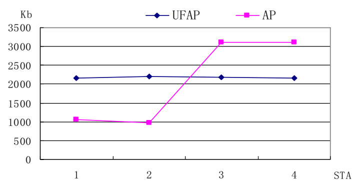

Figure 8. Downlink bandwidth allocation among 4 STAs at AP

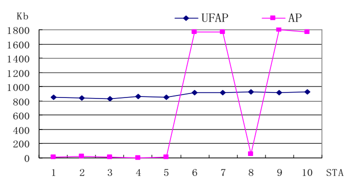

Figure 9. Downlink bandwidth allocation among 10 STAs at AP

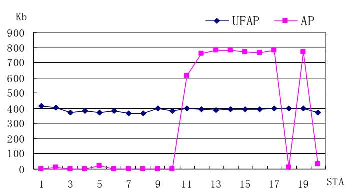

Figure 10. Downlink bandwidth allocation among 20 STAs at AP

Figure.9 reveals the results when STAs number set to 10. The CWmin value is set to 7 adaptively. The results are analogy between Figure.9 and 10. The deviation is lower than 4.18%. As STAs number increases, the deviation does not increase notably.

Figure.10 shows the bandwidth allocation of 20 STAs. The CWmin value is set to 5. The UFAP shows good performance under environment of large STAs number. The deviation is 2.88% in this experiment.

V. CONCLUSIONS

In this paper, we investigated the issue of fairness among STAs that send/receive traffic in IEEE802.11 hot spots. We proposed a UFAP algorithm. It achieves fairness between uplink and downlink through adaptive CWmin. To allocate downlink bandwidth to STAs it maintains only one queue, not a separate queue for each STAs in the network. With detailed evaluation, the feasibility and fairness of algorithm are showed in the article. The difference of UFAP and most other algorithms dealing with fairness issue in 802.11 networks is that this algorithm can be implemented at an AP without modification at STAs.

Future research would be development of an integrated solution for the problem of bandwidth allocation under scenario that has multi APs and more STAs (e.g. more than 30 STAs).

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