Class-Based Weighted Window for TCP Fairness in WLANs

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The explosive growth of the Internet has extended to the wireless domain. The number of Internet users and mobile devices with wireless Internet access is continuously increasing. However, the network resource is essentially limited, and fair service is a key issue in bandwidth allocation. In this research, the focus is on the issue of fairness among wireless stations having different number and direction of flows for different required bandwidth to ensure that fair channel is fairly shared between wireless stations in the same class of bandwidth. It is shown that the current WLANs allocate bandwidth unfairly. It is also identified that the cause of this problem of unfairness is the TCP cumulative ACK mechanism combined with the packet dropping mechanism of AP queue and the irregular space for each wireless station in AP queue. The proposed method allocate converged bandwidth by introducing a Class-Based Weighted Window method which adjusts the TCP window size based on the current conditions of the network and according to the network's requirements. This method works in wireless stations without requiring any modification in MAC. It can guarantee fair service in terms of throughput among wireless users whether they require the same or different bandwidth.
Keywords: *Wireless LAN, TCP, Fairness*

1 Introduction

The WLAN industry has emerged as one of the fastest-growing segments of the communication trade. Due to this growth, WLANs are widely deployed as they are lower in cost, faster and simpler to set up and use in comparison with the previous generation products, WLANs are widely deployed. In order to satisfy user's demand to access the Internet anywhere and anytime, WLAN in the infrastructure mode can provide network access in public areas, such as convention centers, campuses, airports and hotels. As the number of WLAN users has been rapidly increasing, fair service among users has become an important issue. Since most Internet services run over TCP connections, this research focuses on TCP fairness in WLAN.

In IEEE 802.11 [1], MAC protocol is designed to provide an equal chance for each wireless station to access the channel. Distributed Coordination Function (DCF) and Point Coordination Function (PCF) are two MAC techniques. The aim of DCF is to give equal access opportunity to all wireless devices and PCF gives more control to an Access Point (AP). Currently, most of the WLAN devices employ only DCF due to its simplicity and efficiency [10]. While the current Internet utilizes TCP as the transport-layer protocol and IEEE 802.11 infrastructure mode as today's networks, the interaction between DCF and TCP can cause unfairness among the wireless stations. The reason behind this will be discussed in the next section.

In general, there are two major studies in TCP fairness [2]. The first study seeks to provide fairness per-flow for uplink and downlink. The other study focuses on providing fair service among wireless stations for different numbers and directions of flow.

This paper is organized as follows: Section 2 starts by present the overview of the problem related to TCP fairness over 802.11 networks. In sections 3 and 4, we review some related works on per-flow and per-station problems respectively. In section 5 we explain the Class-Based Weighted Window method. Section 6 is the simulation results and effectiveness of the Class-Based Weighted Window method. The article concludes with final remarks.

2 Problem Overview

The system studied is a network consisting of wired and wireless stations. Each station can establish connections with corresponding stations in both directions (Uplink and Downlink) through an AP (see Fig. 1).

Whilst DCF is used to give equal access opportunity to all wireless devices, uplink wireless stations and AP always participate in the contention to access the channel. Thus the single uplink wireless station has a chance with the probability of one half, and each downlink wireless station has the opportunity to access the channel with the same probability divided between numbers of downlink wireless stations. Accordingly, unfairness will occur.

Apart from this, two types of packets are sent to the AP queue: TCP data frames for downlink flows and TCP Acknowledgement (ACK) packets for uplink TCP flows. The main cause of the unfairness is the packet dropping mechanism at the AP queue.

Furthermore, bandwidth of up to 11 Mbps for WLAN, which is much smaller than that of wired networks, is the cause of bottleneck among wired and wireless stations. Traffic congestion at the AP occurs, resulting in packet losses due to queue overflow.

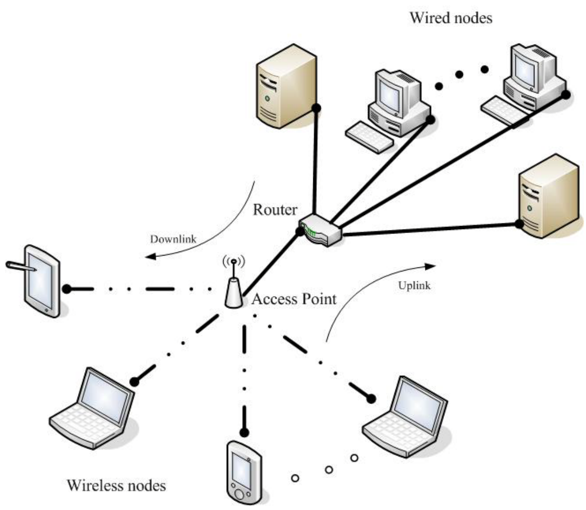

Fig. 1. Network Topology

Unlike the wired stations, wireless stations do not reduce window sizes due to the mechanism of cumulative acknowledgment. For this reason, if uplink and downlink TCP flows coexist, the wireless stations having uplink TCP flows tend to use most of the bandwidth.

The key problem is the irregular space for each wireless station in the AP queue, that is, the number of wireless stations and flows per wireless station are disproportionate to the AP queue size.

3 Per-Flow TCP Fairness

Several studies investigating fairness have focused on the DCF for fairness at the MAC layer. Wang et al. [3] showed that the unfairness between uplink and downlink flows in infrastructure networks is due to contentions at the MAC layer. They believe that the AP should have smaller a contention window than the STAs. To let AP have more chances to access the channel, the contention window of AP is modified and the AP waits for Point coordination function InterFrame Space (PIFS) instead of DCF InterFrame Space (DIFS) in the first defer period.

In [7], Downlink Compensation Access (DCA) scheme is proposed. This solution aims at providing a controllable resource-allocation method between uplink and downlink traffic flows and adapting the parameters according to the dynamic traffic load changes. In DCA, an AP accesses the channel in advance before other wireless stations start their back off procedures.

Per-flow queuing method was proposed by Wu et al. [8] for solving unfairness between upstream and downstream TCP flows. In this method, the fair share of the wireless LAN among all the upstream and downstream flows can be controlled by a weighted polling strategy. Each flow has a queue in AP and the queue is selected by a weighted polling strategy. According to the queue size and buffer overflow, different polling weights apply to data queues for downlink TCP flows and ACK queues for uplink TCP flows by AP. When a wireless station has several flows, it raises the problem of flow differences in MAC layer. In addition, for different RTTs of flows, it is difficult to determine the polling weight of each queue.

Park et al.'s [9] study identified the unfairness problem. The paper analyzed the cause of unfairness from two aspects: TCP-induced asymmetry and MAC-induced asymmetry. Apart from this, they analyzed the interaction between congestion control of TCP and contention control of MAC. Based on this analysis, they concluded that wireless stations have the opportunity to participate in the MAC layer contention by considering the TCP congestion control. They mentioned that for resolving the MAC induced unfairness, attention could be focused on TCP congestion control mechanism.

A recent study [10] involved a dual queue based scheme. It focused on the consequence of a packet drop in AP queue. As mentioned in Section 2, the AP queue has two types of TCP packets data packets for downlink TCP flows and ACK packets for uplink TCP flows. These two types of packets are quite different due to the consequences of a packet drop. The new scheme separated the two different types of packets by using two queues, which are applied at AP: one queue for the TCP data packets, and another one for the ACK packets. For controlling the service rate of each queue, the AP uses the selected mechanism by applying different probabilities. Furthermore, the circumstances of setting the queue selection probabilities for the downlink data queue and the uplink ACK queue are explained. The purpose of this setting is to make the throughput ratio equal to one.

Pilosof et al. [5] undertook preliminary study on TCP fairness in 802.11 networks in the presence of both mobile senders and receivers. They considered the fairness problem through analysis, simulation, and experimentation of the interaction between the 802.11 MAC protocol and TCP. Four regions of TCP fairness were identified according to the buffer availability at the base station. From this study and the results of simulations, it can be observed that the AP buffer size indeed plays a critical role in determining the ratio between the flows. As a solution (LossLess scheme), the receiver window of all the TCP flows is set to be the minimum of the advertised receiver window and $\lfloor B/n \rfloor$, where n is the number of flows in the system and B is the base station buffer size. The proposed solution can be implemented at the base station above the MAC layer. Two problematic points in the implementation of this solution are: (i) determine the exact number of active flows, and (ii) deciding whether the TCP connection is upstream or downstream. Nevertheless, for the Weighted Window method, determining the number and direction of flows is the duty of the wireless station. The number of active wireless stations can be clearly ascertained by listening to the medium using MAC [11, 12] and direction of flows in each wireless station is apparent using source and destination port numbers.

Another study conducted by Detti et al. [6] proposed the Lossy Rate Control Solution which can be implemented with lower complexity compared to the solution of Pilosof et al. [5]. This approach aims to reach fairness by controlling the flow rates without concerning itself about the packet loss. In order to limit the rate of total uplink flows, Detti et al. suggested a method in which the AP drops the received packets of uplink TCP flows when the rate of uplink flows exceeds one half of its bandwidth. Therefore, half of the bandwidth is for uplink flows and the rest of the bandwidth can be used for downlink flows. This solution can be implemented in the AP. However, it does not support the case of different numbers of flow for uplink and downlink.

While each wireless station (WS) has only one Logical Link Control (LLC) queue and the AP has N (number of WSs) LLC queues to serve, the probability of gaining access to the channel is the same for AP, and all N wireless stations. To overcome the problem, faced by Bottigliengo et al. [4], equalising channel access between uplink and downlink flows is achieved using the design of a channel-aware scheduling scheme along with an adaptive Contention Window (CW) setting at the AP. The minimum contention window of wireless stations increases as the number of wireless stations increases.

4 Per-Station TCP Fairness

Up until now, many researchers have focused on TCP per-flow. In the next section, we will observe the per-station fairness through some related studies.

Since the previous researches focused on fairness among flows, they could not guarantee per-station fairness when each wireless station has different numbers of flow; in this part, we consider only TCP fairness per-station. Only two per-station techniques, which are shown below, have been studied before. The previous researchers did not consider the case when each wireless station has a different number of flows and they could not provide fairness among wireless stations having a different number of flows (D. Kim, 2006) [12].

Kim et al. [11] proposed a Distributed Access Time Control (DATC) scheme for per-station fairness in infrastructure WLANs. This study is based on channel access time. Each wireless station controls the rates of its TCP flows. In DATC scheme, a target access time is calculated by dividing a sample period over a number of active wireless stations in that period. When the average transmitting time of mobile stations during a sample period exceeds the target time, the mobile stations should prevent access to the channel. For each period, target access time will be updated according to the new condition of network. In addition, the dropping probability is calculated for each period of time by using the information about capacity of channel, calculated target time, and the time of use of each mobile station for transmission. By using this probability for dropping TCP packets for mobile stations, the bandwidth of the mobile station can be adjusted. DATC scheme showed that the target rate for each wireless station can be achieved to ensure that each mobile station has fair bandwidth regardless of the number and direction of TCP flows. DATC can be implemented in mobile stations.

Similarly, ATC scheme is another method that was proposed by Kim [12]. It also monitored the access time of each mobile station during the sample period and controlled the rate of transmission for each mobile station by dropping probability. Unlike the DATC scheme, controlling the fairness per-station is implemented at AP. However, in both, ATC and DATC require computational work in AP and mobile stations respectively.

It works well but requires some computational work in AP and mobile stations while the Weighted Window method is easy to implement. (More will be said about how much is “easy to implement” in the next section.)

5 Class-Based Weighted Window Method

This section deals with the class-based bandwidth allocation. Users require different amounts of bandwidth that are called Class (e.g. 128k, 512k, 1M) based on their need. The user’s needed class of bandwidth must be known by the ISP when it wants to provide Internet connection for the user so that it can configure the appropriate modem for that user.

In order to recover the unseen scenarios for the Weighted Window method [15], first we look at Weighted Window method. Fig. 2 shows the throughput of six wireless stations when each wireless station has different number of flows. User 1 and user 2 have one and two downlink flows respectively, while user 3 and user 4 have one and two uplink flows respectively. User 5 has an uplink flow and a downlink flow, and user 6 has two uplink and downlink flows. Each wireless station that has at least one uplink flow can use more bandwidth than other wireless stations. In other words, a wireless station that has more TCP uplink flows tends to use more bandwidth.

In addition, for the users having downlink flows, the bandwidth that they use during the simulation time is much lower than other wireless stations having uplink.

In order to resolve this problem, Weighted Window method can provide per-station fairness. Fig. 3 shows the throughput of six wireless stations in which each of them has a different number of flows in both directions with the same conditions as in figure 2. The throughput for each wireless station is computed every five seconds.

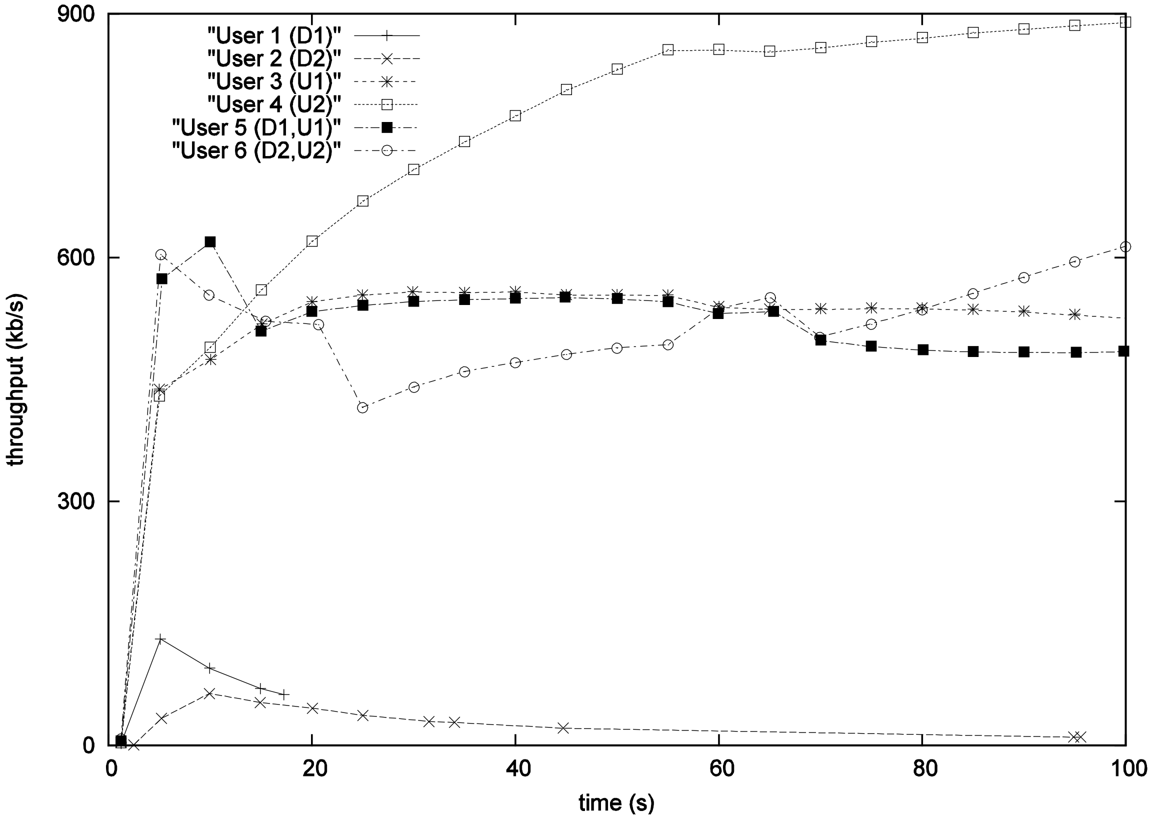

Fig. 2. DCF, Throughput of wireless stations having different number of TCP flows

As can be seen in figure 3, the Weighted Window method can keep the bandwidth of each user at nearly the same level.

During the 100 seconds simulation time, the throughputs of all wireless stations start to converge after 20 seconds. The first 20 seconds are for initializing time of simulator. The throughput of each wireless station is close to 400 Kb/s, which is similar to DATC [11].

The Class-Based Weighted Window is proposed in order to improve the weighted window method proposed in [15] to satisfy users requiring different amounts of bandwidth, and to guarantee the fair resource allocation among users in different bandwidth classes.

In addition to discussing the properties of the proposed method, it is shown that the method achieves fair service for any single wireless station among the wireless stations in the same class of bandwidth inside the network. Simulation results under various network conditions are also presented to validate the effectiveness of the proposed method. The results of simulations showed that the users share the bandwidth nearly proportional to their classes. The throughput of each user and the Jain's fairness index [14] are also shown in this paper.

In the Class-Based Weighted Window method, the TCP window size controls the rate of each wireless station, again in order to allocate the access bandwidth of each wireless station fairly. The TCP window size, which is calculated by each wireless station itself, is determined as

$$(\text{TCP Window Size})_{ij} = \left\lfloor \frac{(B/m)}{n_i} \times c_j \right\rfloor \quad (2)$$

where i denotes the i^{th} wireless station and j denotes the j^{th} class in the network. Classes of bandwidth are specified by the weights of each wireless station.

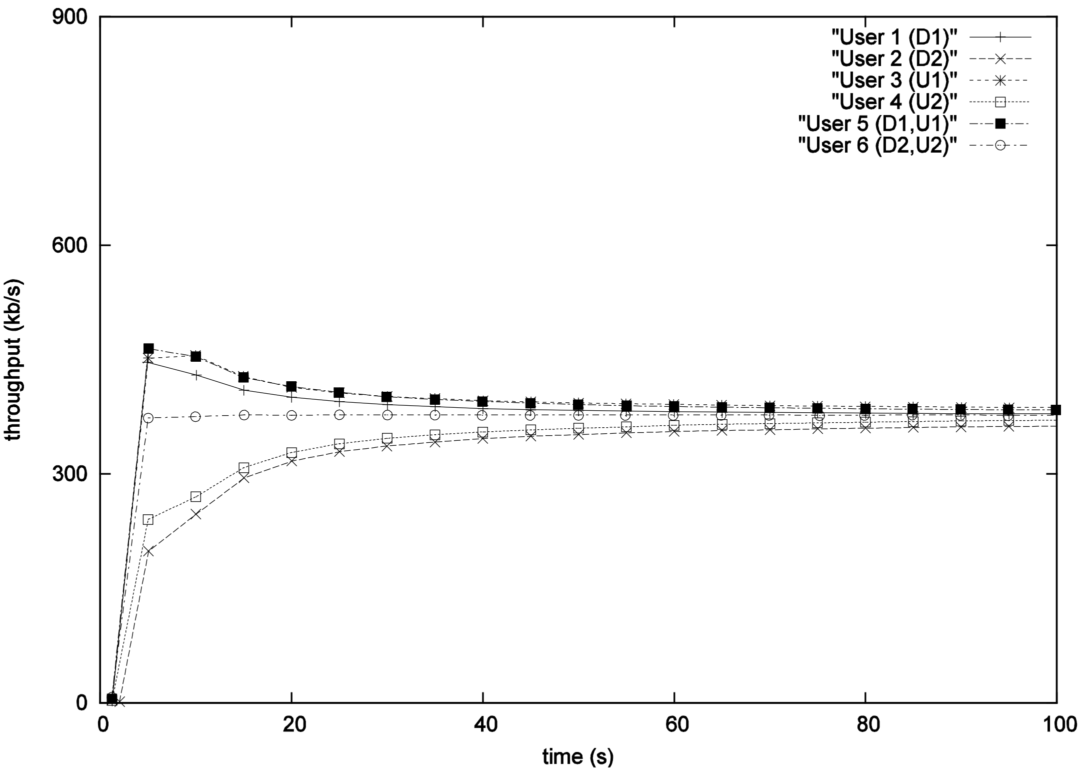

Fig. 3. Throughput of wireless stations using Weighted Window method

Each wireless station per class has equal space in the AP queue as mentioned in Equation (4) above. The prospect of coding for the proposed method in NS is as follows:

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B ← AP queue size;
m ← number of stations; *//from MAC layer*.
n_i *← number of flows;* *//using TCP header*.
c_j *← weight of stations;*
Update( ){

$$if\ ((\frac{B/m}{n_i}\times c_j) < (TCP\ window\ size)_{ij})$$

$$(TCP\ window\ size)_{ij} \leftarrow (\frac{B/m}{n_i}\times c_j);$$

}

…

The impact of this solution is made clear via simulation in various scenarios.

6 Simulation Study and Results Discussion

In this section, we investigate the performance of the Class-Based Weighted Window method via the ns-2 network simulator [13].

As shown in figure 1, a network is composed of one AP and the number of wireless nodes, each of which has different number of uplink and downlink flows with the wired nodes. AP is connected to a router which is a gateway to fixed nodes. The capacity of each wired link was set to 100 Mbps, which is much higher than 11 Mbps, the capacity of IEEE 802.11. Thus, the wireless channel link became the bottleneck link for the downlink flows. The propagation delay between the router and the AP was set to 20 ms, and those of the other wired links were set to be 50 ms.

The AP employed drop-tail queue management with the buffer size of 100 packets. We used TCP NewReno and set the TCP data frame length to 1000 bytes and for the first time to show the behavior of DCF, we set the advertised window size to 42 for all TCP flows.

In order to investigate the fairness among stations in different classes, it is assumed that there are three user classes; each of which has the weight of 1, 2, and 3, respectively. The simulation time is 100 seconds and the throughput is measured in Kbps. When there are four users in each class, figure 4 shows the throughput of each user. The users share the bandwidth equally and the throughput of each class converges to the same level of throughput. Class one (C1) has a level of throughput around 150 Kbps, class two (C2) has a level of throughput around 250 Kbps, and the third class (C3) has a throughput level close to 400 Kbps.

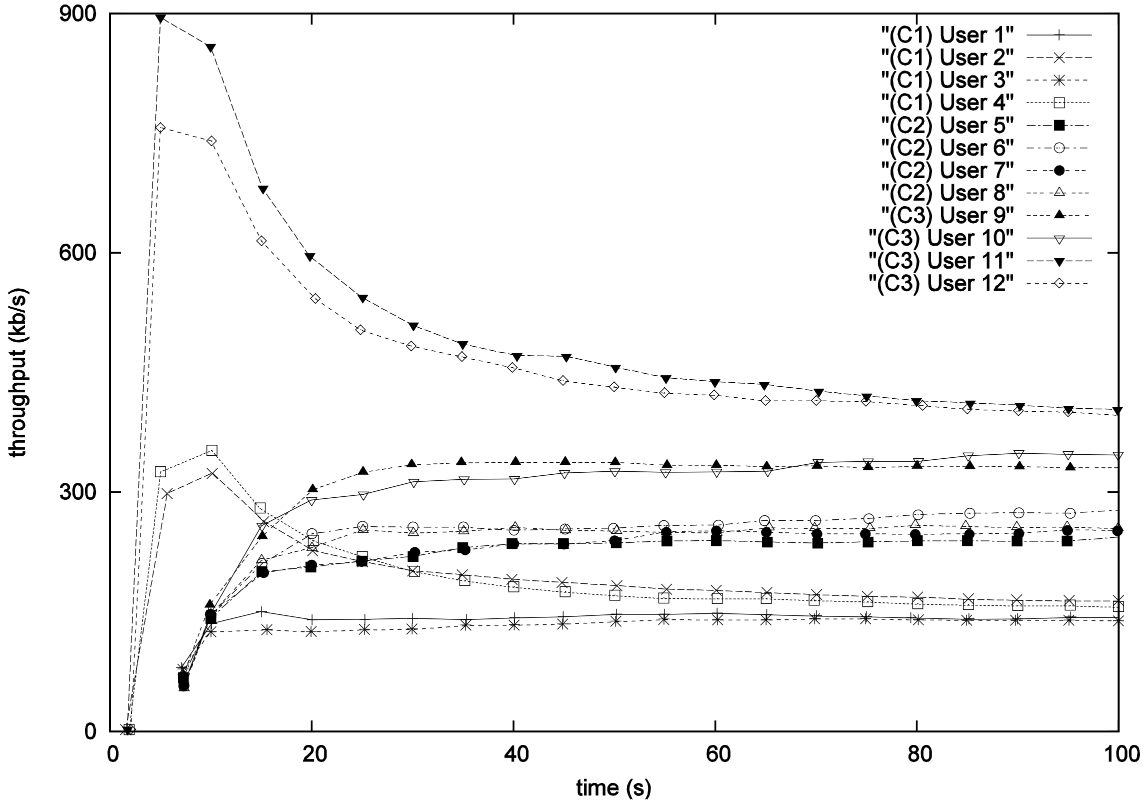

Fig. 4. Throughput of the same number of stations per class

By looking at figure 4, one can get that class 1 uses the lowest channel capacity, class 2 uses more than the first class, and the third class uses more bandwidth than the first two classes. Thus, by considering the definition of Class-Based Weighted Window method represented in section 5, the amount of bandwidth used by each class is controlled by the TCP window size in each station.

Furthermore, the amount of data each station sends and receives depends on in which class the station is. So the time for initialize and reach to the steady state for each class will be different. The more amounts of data, the more time it takes to control the transmission rate. As shown in figure 4, class 3 needs more time (in the simulation process) to show that a fair throughput is provided among stations via Class-Based Weighted Window method.

Figure 5 shows the throughput of stations having different classes. The condition of the network is the same as figure 4, only the number of station per class is as follows: Class 1 (C1), class 2 (C2), and class 3 (C3) has two, three, and four stations respectively.

According to figure 5, the throughput for the first two stations, both in class 1, is almost 200 Kbps; the next three stations in the second class are between 300 Kbps and 350 Kbps of throughput, and the third class is very close to 450 Kbps in terms of throughput for each station.

The simulation results have shown that the Class-Based Weighted Window method can guarantee fair service among the same and different numbers of station per class. Also the proposed method is adapted with the reality of wireless networks.

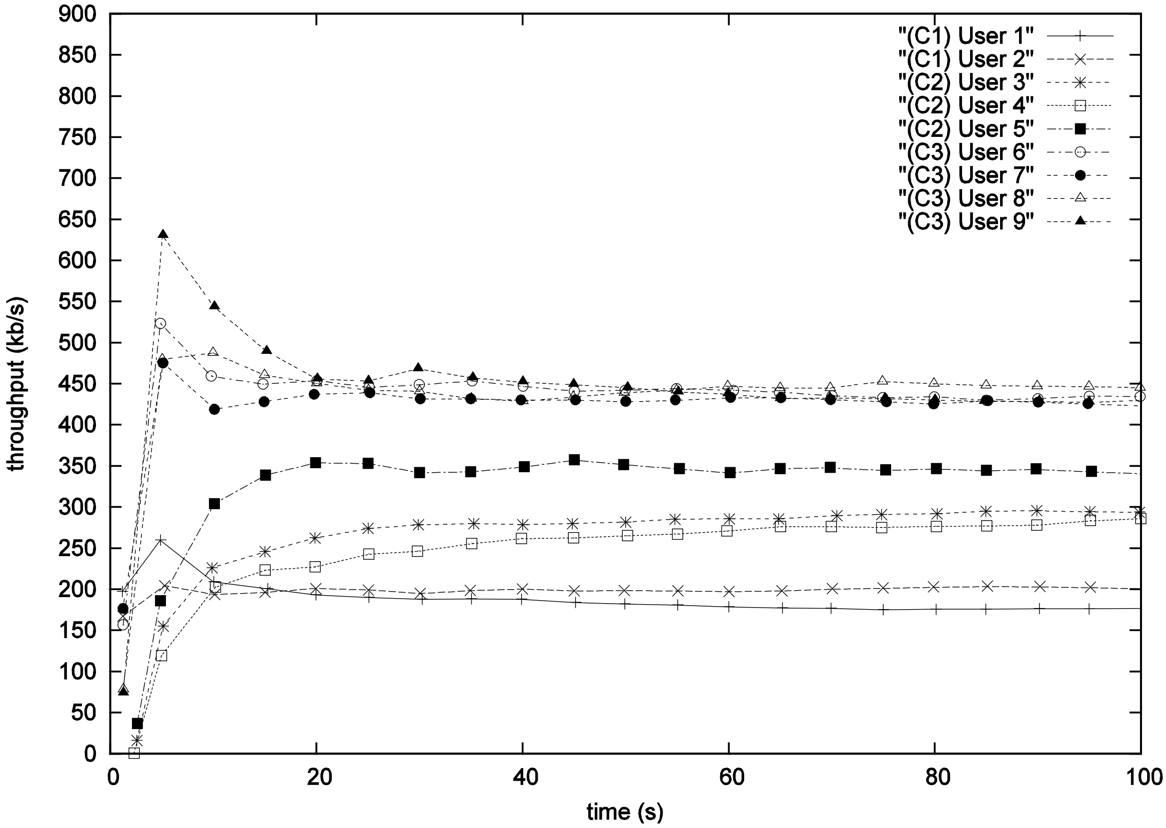

Fig. 5. Throughput of different number of station per class

Figure 6 shows the fairness index of the same number of stations per class and computed every 5 seconds, while figure 7 shows the fairness index of different numbers of station per class with the same computation intervals.

As can be found out from the two figures, the bandwidth allocation for different numbers of station per class (figure 7) is closer to the ideal fair service in comparison with the same number of stations per class (figure 6) in terms of fairness. The ideal fair service is fairness index equal to one, as indicated by Jain's fairness index.

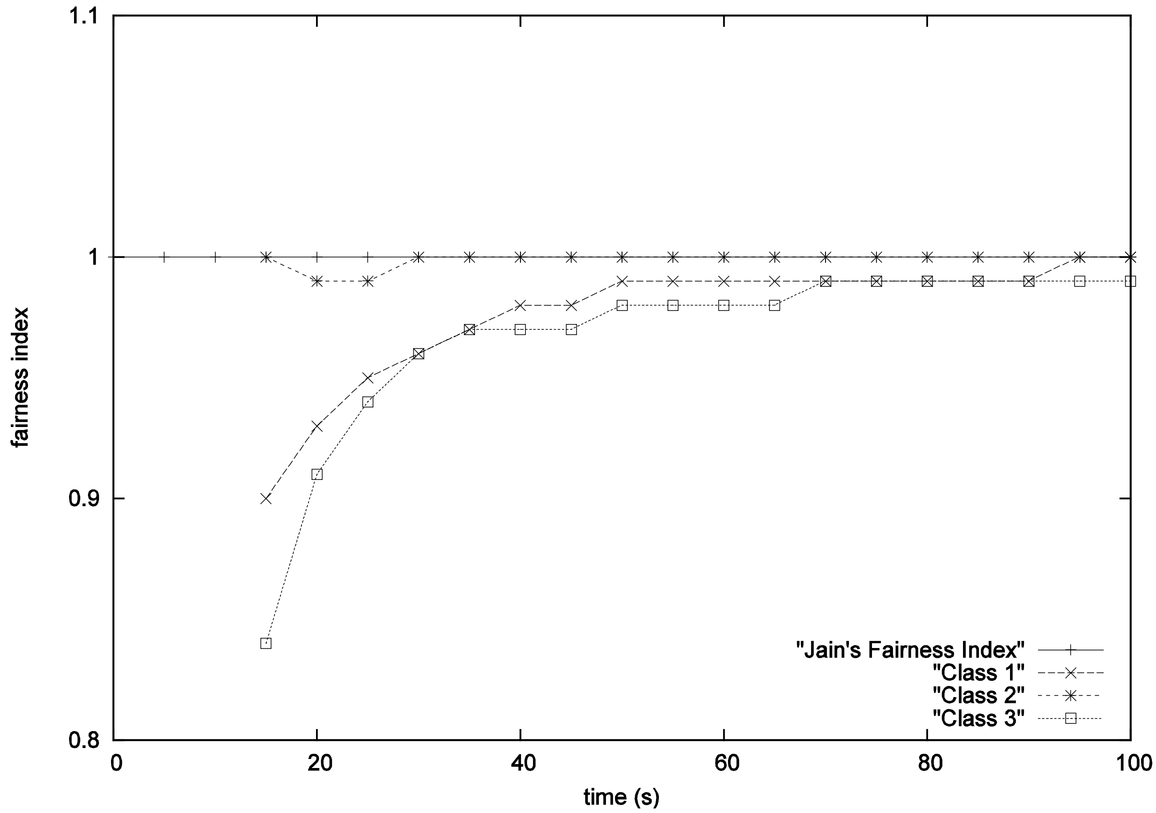

Fig. 6. Fairness index for the same number of station per class

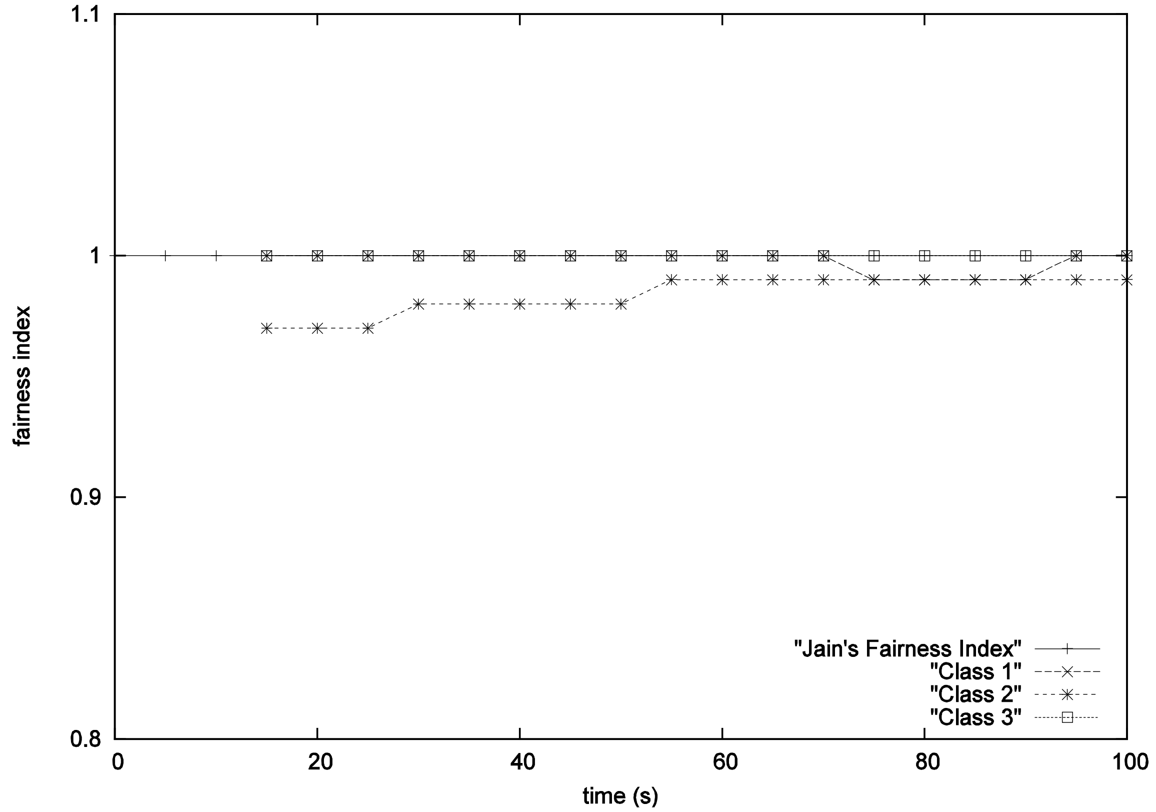

Fig. 7. Fairness index for different number of station per class

The interval value for Y-axis in figures 6 and 7 is 0.1 to increase the accuracy, and the starting point of fairness index trend is the 15^{th} second.

7 Conclusions

IEEE 802.11 access networks are known to induce unfairness among stations having a different numbers and directions of TCP flow. In order to solve this problem, we proposed the Class-Based Weighted Window method which controls the rate of TCP flows based on the window size of flows in each station. We showed that by using the Class-Based Weighted Window method, the throughput of each station converges to approximately the same value assuring that each station has fair bandwidth regardless of the direction and the number of TCP flows. Class-Based Weighted Window can be implemented in mobile stations and does not require any modification in the MAC layer. In that respect, we expect the Class-Based Weighted Window method can be extended to wireless mesh and WiMAX networks, which will be investigated further in future works.

Acknowledgements

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