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Research Article

Weighted Window and Class-Based Weighted Window Methods for Per-Station TCP Fairness in IEEE 802.11 WLANs

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TCP unfairness problem in access networks using the 802.11 has been studied by many researchers. Their solutions required that the existing MAC protocol be modified. However, since they did not consider the case when each wireless node has a different number of flows, they cannot provide fairness among wireless nodes having different numbers of flow in both directions. In order to resolve this problem, Weighted Window and Class-Based Weighted Window methods are proposed. In the Weighted Window method, each wireless node can control the rate of TCP flows based on TCP window size. By applying this method, per-station fairness can be achieved, regardless of the number and direction of flows in each wireless node. Furthermore, to improve and to provide fair bandwidth allocation in the Weighted Window method when the users have different requirements, the Class-Based Weighted Window method is proposed. Therefore, for wireless nodes with different requirements, fair allocation bandwidth between wireless nodes in the same class of bandwidth is achieved.

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 centres, 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 paper focuses on TCP fairness in WLAN.

Along with the IEEE 802.11 MAC protocol which is designed to provide an equal chance for each wireless node to access the channel, the IEEE 802.11e standard provides adjustable parameters within the MAC. 802.11e allows tuning of MAC parameters in order to achieve better performance.

Since the current Internet utilises TCP as the transport-layer protocol and IEEE 802.11 infrastructure mode as today's networks, the interaction between MAC and TCP can cause unfairness among the wireless nodes. The reason behind this will be discussed in the next section.

This paper focuses on providing a fair resource allocation mechanism in wireless networks. The first part of this paper deals with the fairness issue of the wireless nodes having different numbers and different directions of flow, while the second part focuses on fairness assurance in different classes of bandwidth.

This paper is organised as follows. Section 2 starts by presenting the overview of the problem related to TCP fairness over 802.11 networks. In Section 3, we review some related studies on per flow and per station problems, respectively. Section 4, models the unfairness problem. In Section 5, we explain the Weighted Window method and its

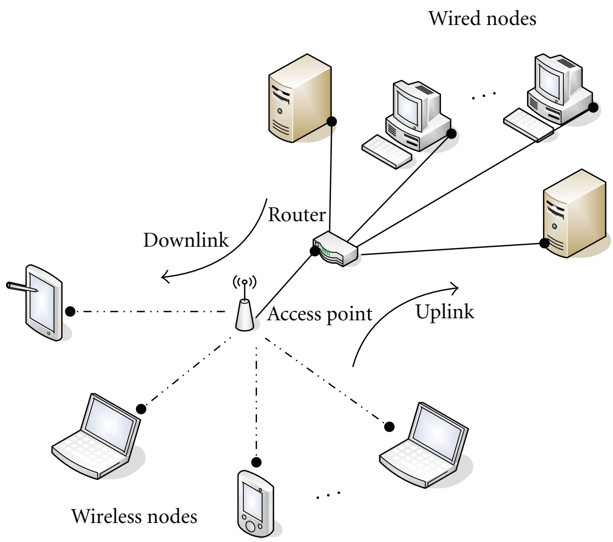

Figure 1: Network topology.

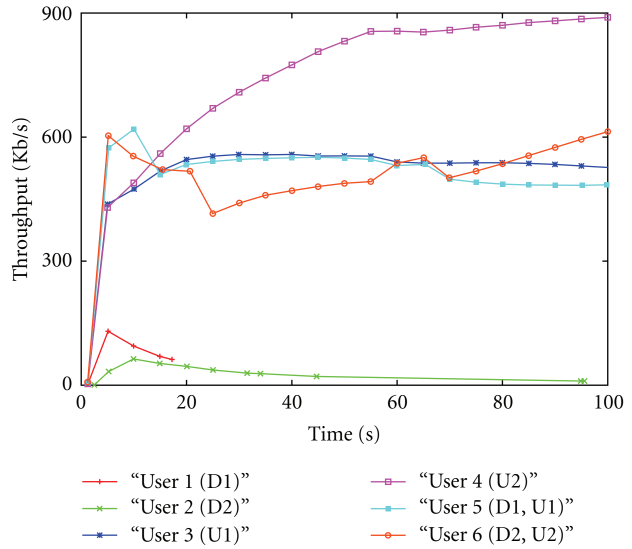

Figure 2: DCF, Throughput of wireless nodes having different number of TCP flows.

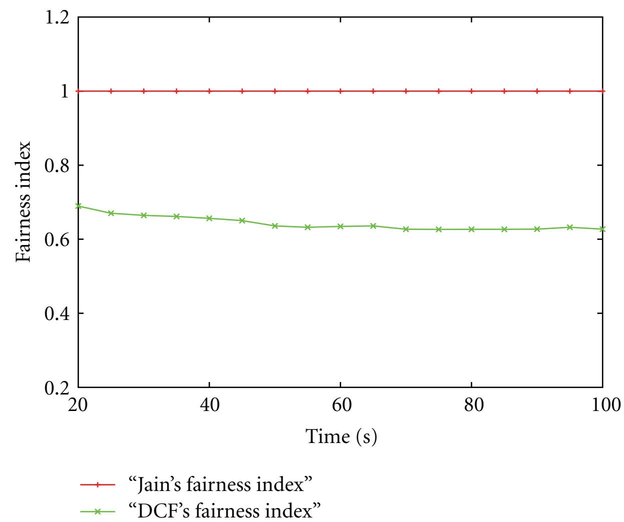

Figure 3: DCF fairness index.

concept. Section 6 is Class-Based Weighted Window method which is improved version of Weighted Window method. The paper concludes with final remarks.

2. Problem Overview

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

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

Apart from this, when a wireless node with uplink flow and another wireless node with downlink flow share a wireless channel, there are two types of packets buffered into 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 nodes. Traffic congestion at the AP occurs, resulting in packet losses due to queue overflow.

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

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

Figure 2 shows the throughput of six wireless nodes when each wireless node 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 node that has at least one uplink flow can use more bandwidth than other wireless nodes. In other words, a wireless node 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 nodes having uplink.

Figure 3 shows the unfairness problem using comparison of Jain's fairness index and DCF fairness index.

The Jain's fairness index is defined as

$$f(x_1, x_2, x_3, \dots, x_n) = \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n \sum_{i=1}^{n} x_i^2}, \quad 0 \leq f(\cdot) \leq 1, \qquad (1)$$

where x_i is the throughput of the ith wireless node and n is the number of wireless nodes.

"This index measures the "equality" of user allocation x" [1]. If all nodes get the same amount of resources (i.e., all x_i's are equal) then the fairness index will be one, implying that the allocation is 100% fair [1].

3. Related Work

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 nodes for different numbers and directions of flow.

Several studies investigating fairness have focused on the DCF for fairness at the MAC layer. Wang and Mujtaba [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 [4], 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 nodes start their back off procedures.

Per-flow queuing method was proposed by Wu et al. [5] 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 node 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 [6] study identified the unfairness problem. The paper analysed the cause of unfairness from two aspects: TCP-induced asymmetry and MAC-induced asymmetry. Apart from this, they analysed the interaction between congestion control of TCP and contention control of MAC. Based on this analysis, they concluded that wireless nodes 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 study [7] 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. [8] 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 node. The number of active wireless nodes can be clearly ascertained by listening to the medium using MAC [9, 10] and direction of flows in each wireless node is apparent using source and destination port numbers.

Based on pilosof's work, Lee et al. [11] improved both the TCP fairness and total throughput. Their solution is to modify the receiver window size on the basis of the maximum window size which is able to maximize the link utilization instead of the AP buffer size. They modify the receiver window size in all TCP acknowledgment packets passing through AP into not min (rwnd, $\lfloor B/n \rfloor$), but min (rwnd, $\lfloor W_{\max}/n \rfloor$). This scheme has to modify the TCP packet at AP.

Another study conducted by Detti et al. [12] proposed the Lossy Rate Control Solution which can be implemented with lower complexity compared to the solution of Pilosof et al. [8]. 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 node (WN) has only one Logical Link Control (LLC) queue and the AP has N (number of WNs) LLC queues to serve, the probability of gaining access to the channel is the same for AP, and all N wireless nodes. To overcome the problem, faced by Bottigliengo et al. [13], 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 nodes increases as the number of wireless nodes increases.

Since IEEE 802.11 [14] amended with IEEE 802.11e [15] (DCF and PCF are replaced by EDCA and HCCA) to provide better quality of service, some researchers addressed the impact of 802.11e MAC on TCP. Leith and Clifford [16, 17], use the 802.11e AIFS, TXOP and CW_{min} parameters to ensure fairness between competing TCP uploads and downloads. They modified the MAC and prioritised the TCP ACK by collecting TCP ACKs into a single class (i.e., queue them together in a separate queue at the AP) and confine prioritisation to this class. However, this solution is possible to adapt only to the network that supports IEEE 802.11e MAC.

Up until now, many researchers have focused on TCP per flow. Since the previous researches focused on fairness among flows, they could not guarantee per station fairness when each wireless node has different numbers of flow; in this part, we consider only TCP fairness per station. With best of our knowledge only two per station techniques, which are shown below, have been studied before. The previous researchers did not consider the case when each wireless node has a different number of flows and they could not provide fairness among wireless nodes having a different number of flows [10].

Kim et al. [9] 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 node 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 nodes in that period. When the average transmitting time of wireless nodes during a sample period exceeds the target time, the wireless nodes 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 wireless node for transmission. By using this probability for dropping TCP packets for wireless nodes, the bandwidth of the wireless node can be adjusted. DATC scheme showed that the target rate for each wireless node can be achieved to ensure that each wireless node has fair bandwidth regardless of the number and direction of TCP flows. DATC can be implemented in wireless nodes.

Similarly, ATC scheme is another method that was proposed by Kim [10]. It also monitored the access time of each wireless node during the sample period and controlled the rate of transmission for each wireless node 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 wireless nodes, respectively. It works well but requires some computational work in AP and wireless nodes while the Weighted Window method is easy to implement. (More will be said about how much is "easy to implement" in Section 5.)

4. Analytical Study (Courtesy of Pilosof et al. [8])

In order to understand the issues behind the unfair behavior of TCP over wireless LAN, and to try to develop tools that enable a more equitable usage of the bandwidth resources, we conducted an analytical study of the problem.

One can model the base station buffer as a bounded size queuing system ($M/M/1/K$) of size B (assuming that a packet is cleared from the buffer only after it has been successfully transmitted). The probability that such a queue in its stable state has exactly K packets in the buffer is given by [18, page 104]. Pilosof et al. [8] use the ratio between the arrival rate and the service rate (ρ) for single flow scenario

$$\rho = \frac{R_u + R_d}{R_u} = 1 + \overline{R}, \tag{2}$$

where R_d and R_u are the rates of the downlink and uplink TCP flows, respectively, and $\overline{R} = R_d/R_u$.

For multiple flows, we can say that the buffer space is divided among all n flows, and therefore each one gets $1/n$ of the bandwidth and the ratio increases by a factor of n. Consider (2), for this case ρ is give by

$$\rho = \frac{R_u + nR_d}{R_u} = 1 + n\overline{R}. \tag{3}$$

The Pilosof et al.'s solution is "If there are n flows in the system and the base station has a buffer of size B, we set the receiver window of all the TCP flows to be the minimum of the advertised receiver window and $\lfloor B/n \rfloor$".

Unlike Pilosof et al. that studied TCP farness per flow, in this paper we focus on per station TCP fairness by modifying the Pilosof et al's solution when a number of wireless nodes are involved. More will be said about involving the number of wireless node later in following section.

Since the LossLess (Pilosof's scheme) is focused on per flow fairness, each wireless node has one flow while in real networks it might be more than one flow per wireless node. In order to make a fair comparison, each wireless node was set to have different number and direction of flows. Figure 4 shows the unfairness problem among wireless nodes and performance of LossLess scheme when it is modified to per station model.

By looking at Figure 4, the unfairness problem is apparent and it shows that each wireless node that has more flows, either uplink or downlink, will use more channel capacity. The wireless nodes having the same number of flows are in

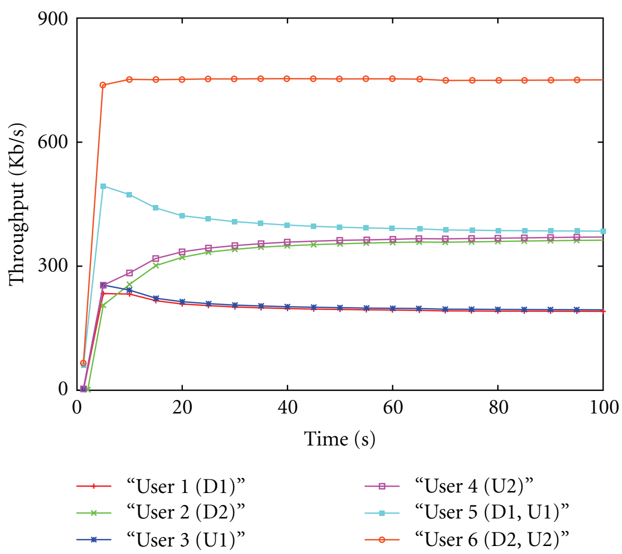

Figure 4: Throughput of LossLess scheme among wireless nodes having different number of flows.

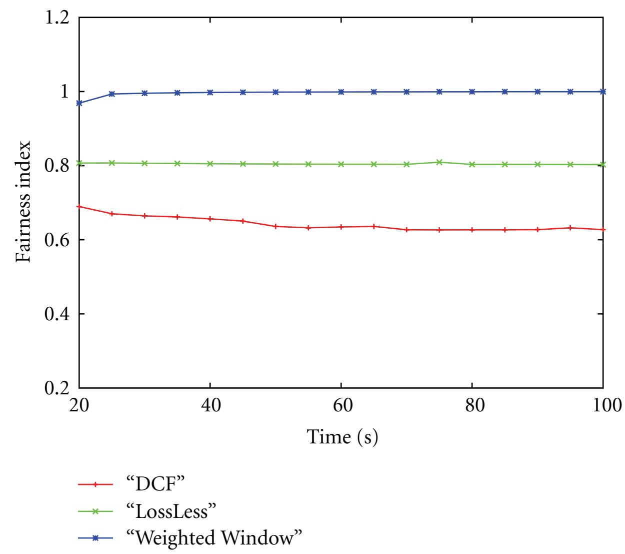

Figure 5: Fairness index computed every 5 seconds.

the same level of throughput. In other words, the throughput for each wireless node depends on the number of flows that it has. The reason is the TCP window size. The LossLess scheme sets an equal TCP window size for each flow. Thus, if the wireless nodes have different number of flows, per station unfairness will occur.

Therefore, LossLess scheme cannot guarantee fairness among wireless nodes having different number of flows while the Weighted Window method (Figure 7) can provide fair service among wireless nodes with the same condition as Figure 4.

Apart from this, Figure 5 shows that based on the packets delivered during the simulation time of 100 seconds, the fairness index (Jain's fairness index [1]) for Weighted Window method is almost one. The fairness index is computed every five seconds.

5. Weighted Window Method

This part focuses on the fairness among wireless nodes, each of which has TCP flows. When unfairness occurs, each wireless node can control the flow rates via the mechanism of reducing the rate of TCP flow by decreasing the window size for sender. By manipulating the window size, it is possible to ensure that the TCP sender window is limited to whatever value was decided upon.

Wireless nodes which are doing transmission at the moment of counting are called active wireless nodes. Each wireless node can count the number of active wireless nodes in a wireless domain using MAC layer [10] and change the window size of TCP layer to control the transfer rate [8] according to the number of active wireless nodes.

On the other hand, in order to control the rate of wired stations, the window size field in the acknowledgement control message is employed. The data field in TCP header is removed only when the packet transmission is an acknowledgement. The window field in the acknowledgement packet tells the sender how many packets can be sent to the destination the next time. Before sending the packets, the sender checks the window field in the acknowledgement packet to know how many packets can be sent. The maximum value that can be set for TCP window size in each transmission cannot be greater than the AP queue size.

Pilosof et al.'s [8] solution for per flow TCP fairness was to allocate an equal space from the AP queue for each flow, whereas the proposed method in this paper is to allocate an equal space from the AP queue for each wireless node [19]. Thus, if there are m number of wireless nodes with n number of flows in each wireless node, and the base station has a buffer size of B, in the system, wireless node (without having to receive any information from AP) will set the receiver window of TCP flows to be

$$(\text{TCP Window size})_i = \left\lfloor \frac{B/m}{n_i} \right\rfloor, \tag{4}$$

where i denotes the ith wireless node of the network.

Figure 6, shows the concept of (4).

It is apparent from Figure 6 that each wireless node has equal space from AP queue (4). It means that each wireless node divides the AP queue according to the number of active wireless nodes and then according to its own number of flows in order to adjust its sending rate based on AP queue division. In order to implement such a solution, one needs to keep a counter that approximates the number of current TCP flows in each dynamic wireless node. IP addresses and the port numbers [8] will identify the number of flows. Each wireless node can count the number of wireless nodes (m) correctly by listening to the channel. All wireless nodes can find which wireless node is doing the transmission, and count the number of current active wireless nodes [9]. All this process is done in each wireless node itself and has nothing to do with AP (distributed).

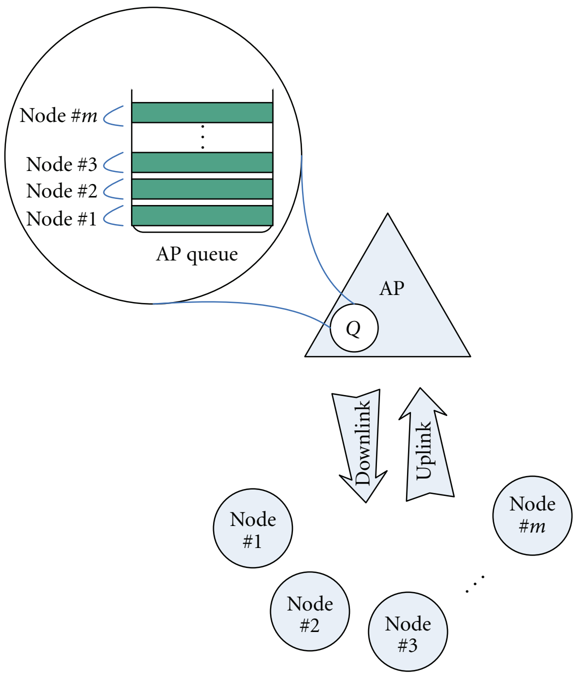

FIGURE 6: Conceptual view of Weighted Window method.

The prospect of coding for the proposed method in NS [20] is as follows:

...

$B \leftarrow$ AP queue size;

$m \leftarrow$ number of wireless nodes; // from MAC layer.

$n_i \leftarrow$ number of flows; //using TCP header.

Update ( ) {

  if $((B/m/n_i) < (\text{TCP window size})_i)$

  $(\text{TCP window size})_i \leftarrow ((B/m)/n_i)$;

}

...

The impact of this solution is clear when we apply it in the same scenario as Kim et al. [9], with the modified TCP window size.

As shown in Figure 1, a network is composed of one AP and a number of wireless nodes, each of which has different number of uplink and downlink flows with the wired stations. AP is connected to a router, which is the gateway to wired stations. 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 a 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 (Figure 2), we set the advertised window size to 42 for all TCP flows.

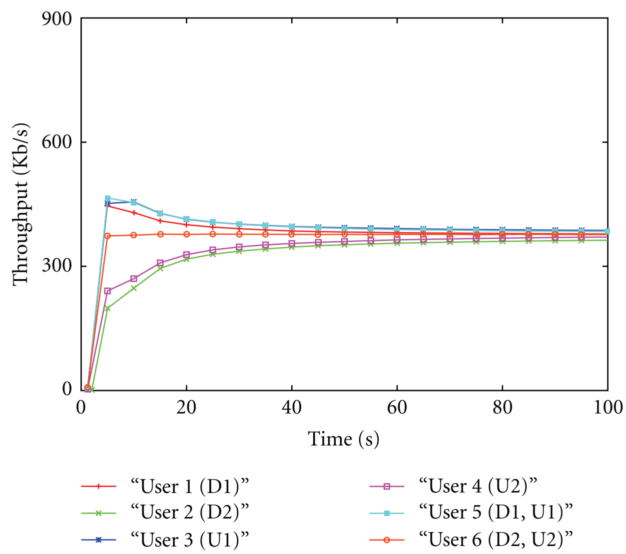

FIGURE 7: Throughput of wireless nodes using Weighted Window method.

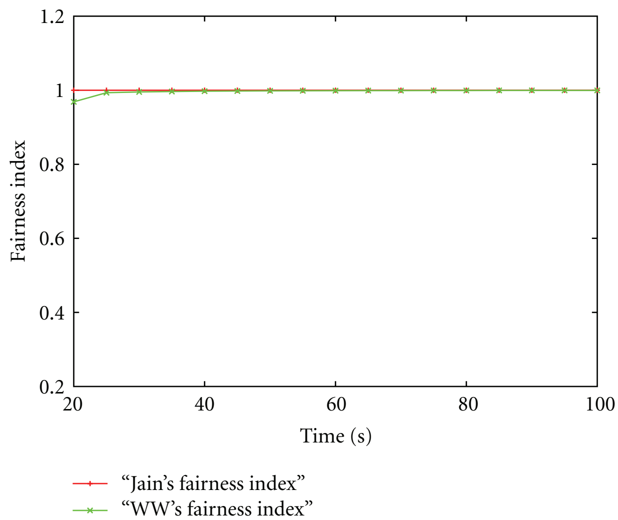

FIGURE 8: Fairness Index computed every 5 seconds.

In order to resolve this problem, Weighted Window method can provide per station fairness. Figure 7 shows the throughput of six wireless nodes 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 node is computed every five seconds.

As can be seen in Figure 7, 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 nodes start to converge after 20 seconds. The first 20 seconds are for initialising time of simulator. The throughput of each wireless node is close to 400 Kb/s, which is similar to DATC [9].

By looking at Figure 8, which is based on the packets delivered during the simulation time of 100 seconds, the

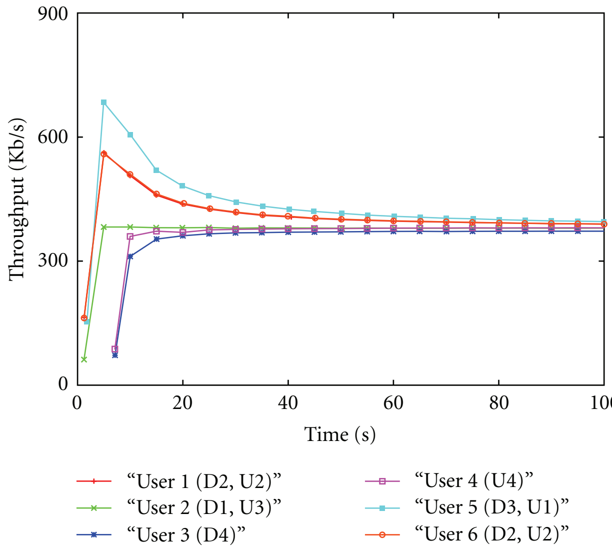

Figure 9: Throughput of same number of flows but different directions using Weighted Window method.

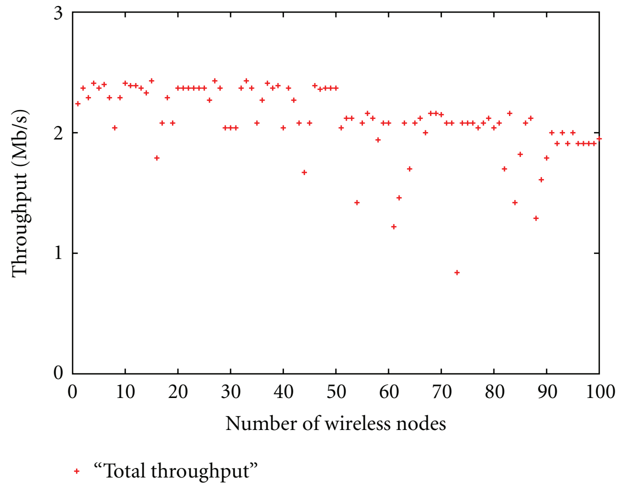

Figure 10: Effect of large number of wireless nodes.

fairness index (Jain's fairness index [1]) for Weighted Window method is almost one.

5.1. Fairness among Wireless Nodes Having the Same Number of Flows but Different Directions. Since the previous scenario concerns about different numbers of flow per wireless node, the simulation in this section considers wireless nodes having the same numbers of flow but different directions, to study the effect of different scenarios on the proposed method. In order to study the throughput of wireless nodes, the network was configured as follows User 1 and 6 have two downlink flows and two uplink flows each; User 2 has a downlink flow and three uplink flows; while User 3 and User 4 have four downlink flows and four uplink flows, respectively. User 5 has three downlink flows and an uplink flow.

As can be seen in Figure 9, the Weighted Window method can provide per station fairness even when each wireless node has different directions of flow. The throughput for each wireless node is close to 400 Kbps, similar to the results in Section 5. So the proposed method can guarantee fair service among wireless nodes regardless of the numbers and directions of flow per wireless nodes.

5.2. Effect of Large Number of Wireless Nodes. In the case of large number of wireless nodes in the network called burst time (which might happen in convention centers, workshops, or any other places where a large number of users need to access the bandwidth at same time), the Weighted Window method can provide fair throughput for each wireless node too.

In order to simulate this kind of situation, the maximum number of wireless nodes that an AP can support should be known. Because of the various number of wireless nodes that can be supported by different types of AP [21], it is assumed that there were 100 wireless nodes, each of which has a downlink and an uplink TCP flow during the simulation time of 100 seconds. The AP queue size has been set to 1000 packets. Figure 10 shows the throughput of all wireless nodes.

The fairness performance of Weighted Window method is maintained even with an increasing number of wireless nodes. The total throughput is shown for each wireless node, which is the amount of throughput for downlink plus the throughput for uplink in the corresponding node. The value for throughput in Y-axis is in Mbps and most of the wireless nodes have a throughput near to 2 Mbps.

6. 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., 128 k, 512 k, 1 M) 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 the case IEEE 802.11e, the class will replaced by the priority queue. The queue with higher priority will used for higher demanding wireless node in terms of bandwidth.

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

In the Weighted Window method, fairness among wireless nodes having different numbers and directions of flow is guaranteed. The Weighted Window method provides fair service among users using only the same bandwidth. But it does not consider wireless nodes requiring different bandwidth in different classes. Since providing fair service among wireless nodes should not affect the different types of applications with different requirements of bandwidth in the network, the class-based bandwidth allocation is proposed.

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

$$(\text{TCP Window Size})_{ij} = \left\lfloor \frac{(B/m)}{n_i} \times c_j \right\rfloor, \quad (5)$$

where i denotes the ith wireless node and j denotes the jth class in the network. Classes of bandwidth are specified by the weights of each wireless node.

Each wireless node per class has equal space in the AP queue as mentioned in (5) above. The prospect of coding for the proposed method in NS is as follows:

```
...
B ← AP queue size;
m ← number of wireless nodes; // from MAC layer.
n_i ← number of flows;          //using TCP header.
c_j ← weight of wireless nodes;
Update ( ) {
        if (((B/m)/n_i × c_j) < (TCP window size)_ij)
        (TCP window size)_ij ← ((B/m)/n_i × c_j);
}
...
```

In order to investigate the fairness among wireless nodes in different classes, it is assumed that there are three user classes each of which has a weight of 1, 2, and 3, respectively. The simulation time is 100 seconds and the throughput is measured in Kbps. Figure 11 shows the throughput of each user when there are four users in each class. The users share the bandwidth equally and the throughput of each class converges at 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.

By looking at Figure 11, one can observe 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, the amount of bandwidth used by each class is controlled by the TCP window size in each wireless node.

Furthermore, the amount of data each wireless node sends and receives depends on which class the wireless node is. So the time to initialise and reach the steady state for each class will be different. The more amount of data, the more time it takes to control the transmission rate. As shown in Figure 11, class 3 needs more time (in the simulation process) to show that a fair throughput is provided among wireless nodes via Class-Based Weighted Window method.

Figure 12 shows the throughput of wireless nodes having different classes. The condition of the network is the same as in Figure 11 except that the number of wireless nodes per class is as follows: Class 1 (C1), class 2 (C2), and class 3 (C3) have two, three, and four wireless nodes, respectively.

According to Figure 12, the throughput for the first two wireless nodes, both in class 1, is almost 200 Kbps; the next three wireless nodes 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 wireless node. The simulation results showed that the Class-Based Weighted Window method can guarantee fair service among the same and different number of wireless nodes per class. In addition, the proposed method is adapted to the reality of wireless networks.

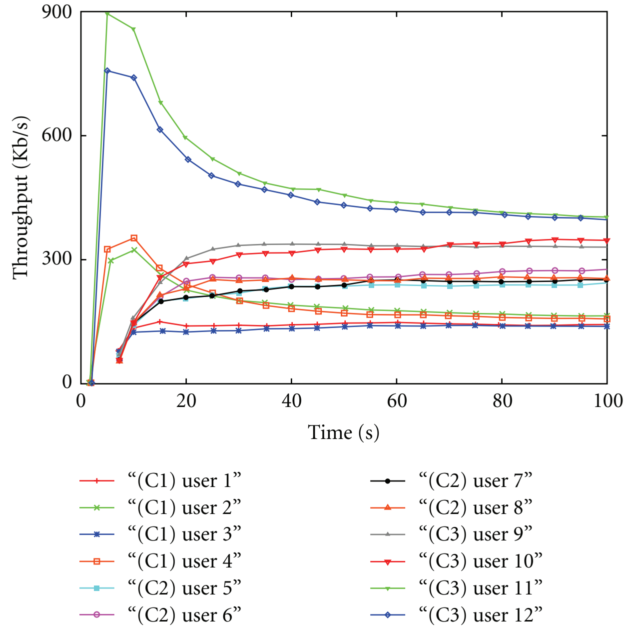

FIGURE 11: Throughput of the same number of wireless nodes per class.

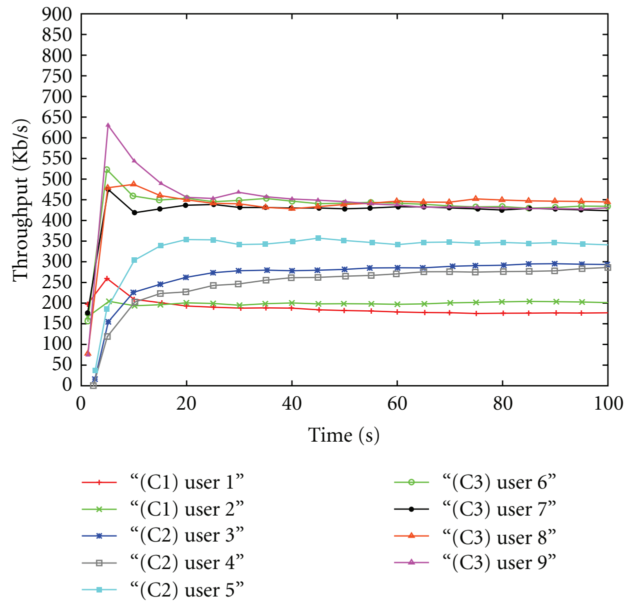

FIGURE 12: Throughput of different number of wireless nodes per class.

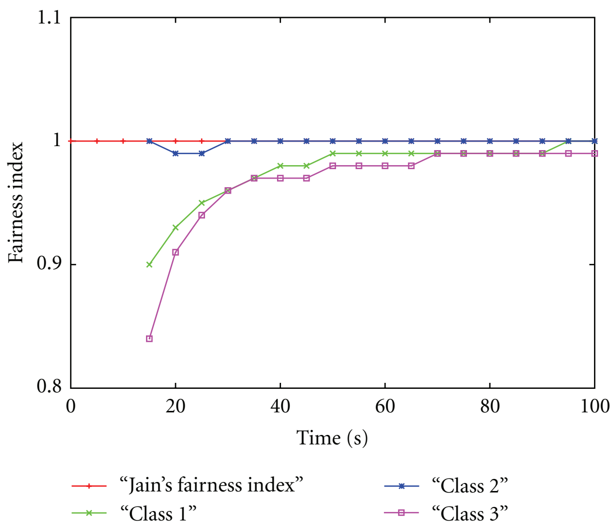

Figure 13: Fairness index for the same number of wireless nodes per class.

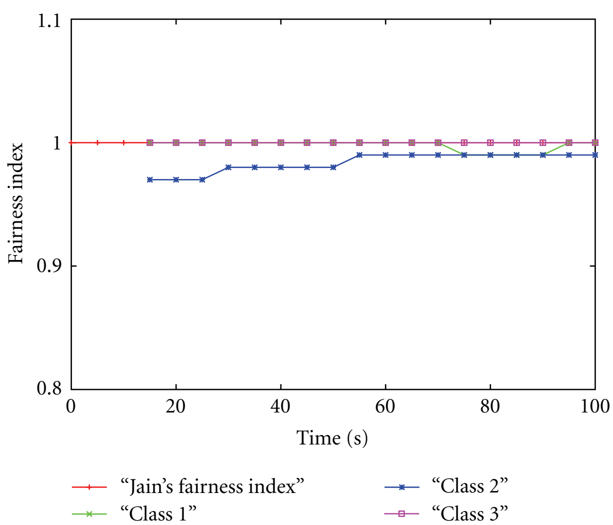

Figure 14: Fairness index for different number of wireless nodes per class.

Figure 13 shows the fairness index of the same number of wireless nodes per class, and the fairness index is computed every five seconds, while Figure 14 shows the fairness index of different number of wireless nodes per class with the same computation intervals. As can be observed from both Figures 13 and 14, the bandwidth allocation for different number of wireless nodes per class (Figure 14) is closer to the ideal fair service in comparison with the same number of wireless nodes per class (Figure 13) in terms of fairness. The ideal fair service is when fairness index equals one, as indicated by Jain's fairness index.

The interval value for Y-axis in Figures 13 and 14 is 0.1 in order to increase the accuracy, and the starting point of fairness index trend is the 15th second.

7. Conclusion

In the first part of this paper the focus was on the issue of fairness among wireless nodes having different numbers and directions of flow. It was shown in this part that the current WLANs allocate bandwidth unfairly. It was also identified that the cause of this unfairness problem is TCP cumulative ACK mechanism combined with the packet dropping mechanism of AP queue and the irregular space for each wireless node in AP queue. The proposed method allocates converged bandwidth by introducing Weighted Window method which adjusts the TCP window size based on the current conditions of the network. Therefore, this method works in wireless nodes without requiring any modification in MAC.

The second part dealt with the fair bandwidth allocation problem for different required bandwidth which aims to improve Weighted Window method to assure fair channel is fairly shared between wireless nodes in the same class of bandwidth. The proposed Class-Based Weighted Window method adjusts the TCP window size of each wireless node according to their weights. So the wireless nodes share the wireless channel fairly in terms of throughput

The proposed methods can guarantee fair service in terms of throughput among wireless users either they require the same or different bandwidth.

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