Direction-based TCP Fairness Enhancement in High speed IEEE 802.11n

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Abstract—Faster and larger transaction concerns in data communication are now an important field of study in academic and commercial research. As the number of users and the size of information to transmit increase, newer technologies should provide facilities to fulfill these needs. IEEE 802.11n is one of them. This high speed wireless standard is designed to guarantee faster delivery and better communication range. One of the most challenging issues in wireless local networks is the unfairness usage of bandwidth when using transport control protocol (TCP) with wireless media access control (MAC) protocols. In this paper we simulate two scenarios on normal and high speed WLANs with Network Simulator 2 (NS-2). The effect of throughput and access point (AP) buffer size on TCP fairness problem are discussed based on simulation outputs. The results show that in 802.11n channel utilization with equal throughput is more robust and both uplink and downlink flows of data can benefit from the channel bandwidth. We also proved that the lower buffer sizes provide better fairness in 802.11n environment. A specific range of buffer size is introduced in which the best fairness index is achieved in such a high speed standard. The main contribution of the paper is to introduce a technique to keep the fairness ideal in heavy loaded 802.11n networks. This modified traffic management technique is described, simulated and its result is compared with theoretically calculated fairness index.

Index Terms—TCP Fairness; High Speed WLAN; IEEE 802.11n; TCP Receive Window Size; NS-2

I. INTRODUCTION

Mobility and ease of access are becoming important demands on data communication. Even in ordinary environments people like to send and receive data in a wireless manner. Wireless communications are going to be the most popular ways of exchanging information for society. One of the issues researchers are focusing more recently is the growth of data capacity that is going to be exchanged. In such case we need a reliable high speed bandwidth to accommodate large amount of data and provide fast delivery. Many instances of wireless local area networks (WLANs) are introduced to cover these demands, including IEEE 802.11 b/g/n.

There are plenty of researchers that proposed different ways of interacting and improving WLAN performance and related issues. But those researchers that worked on fair usage of bandwidth in wireless communications have mentioned an important weakness in this area, i.e. the TCP’s unfairness behavior in sharing the communication channel for upload and download process. Since TCP is one of the most important protocols for exchanging data, it has become an attractive research topic for researchers and it may remain important for next few years.

To describe the TCP upload/download unfairness problem technically, we should consider the Distributed Coordination Function (DCF) technique which is used in IEEE 802.11 Media Access Control (MAC) protocol [1]. By applying this technique, all stations in wireless environment can have an equal chance of using the transmission channel. When this feature is applied in MAC protocol infrastructure mode with an AP, the competition for channel utilization between separate sending wireless stations and AP that is going to receive data from all stations, leads to unfair bandwidth usage. Since it is related to TCP upstream and downstream flows, we call it direction-based unfairness. In this situation lots of data packets which are going down stream to the AP may get dropped, because of DCF equal opportunity feature that helps upstream packets fill up the AP buffer [2]. For a mathematical description of direction-based fairness issue, we should say that in DCF WLAN environment each station has $1/(K+1)$ share of total transmission channel. As we know the AP supports downstream and upstream flows of data packets, so downstream share can be $1/(K+1)$ and upstream has $K/(K+1)$ which means that upstream flows have $K$ times more transmit opportunities. This will result the unfair channel usage we were talking above. In other words, downstream flow of AP becomes a key factor of fairness researches on direction-based unfairness. It has been shown [3] that the management of the queue size in AP will have a dramatic effect on the scale of unfairness problem.

However, in this paper we will discuss on how this unfair situation behaves in high speed environment with more capacity of bandwidth. We will simulate this scenario and show the effect of increasing the transmission rate on fairness issue. The main work of this paper is going to focus on fairness variations in IEEE 802.11n. A practical management technique is introduced to control upstream and downstream traffic in order to keep the fairness ideal. Results show that both uplink and downlink data flows can have almost equal access to the communication channel. The effect of buffer size changes on fairness is evaluated by several simulations, leads to
find the suitable buffer size for our experiment. The ideal buffer size then is used along with the proposed traffic management technique to reach better and more stable fairness in 802.11n. The whole work is implemented in 802.11b and 802.11n environment for comparison. The simulation is done by Network Simulator 2.

II. LITERATURE REVIEW

Recently, several researchers worked on TCP fairness issues, with a particular attention to wireless environment [3-7, 11]. Also some authors focused on modelling and access point modification [8, 11, 16-20]. Results in [4] showed that TCP unfairness, which leads to unfair service, can be solved by preventing buffer overflow in the AP. The authors of [5] proposed a scheme in 802.11e, in which TCP Acknowledgement (ACK) packets are transmitted with minimal delay to enhance fairness issue. In this case the downstream TCP packets are transmitted by transmission opportunity bursting. In most works the results show improvement on either direction-based or size-based fairness, while in [6] a new queue-management policy, called Threshold-Based Least Attained Service-Selective Acknowledgment Filtering (TLAS-SAF), overcomes both fairness problems. However it is simulated in 802.11b and is not tested or proved for newer WLAN standards with increased bandwidth and throughput in transmission process.

Although several works have been done on mentioned fairness issue, but very few of them evaluate their results in IEEE 802.11n wireless environment. We believe that many fairness problems will be solved on high speed 802.11n WLAN since we have relatively more throughput in transmission process. But still the starvation of upstream flow of data packets should be controlled and evaluated on this environment. In [7], researchers tested the performance of the MAC protocol using three factors of aggregation, block acknowledgment and reverse direction which are supposed to enhance IEEE 802.11n MAC mechanism. By simulating the required platform in NS-2 they reached a considerable higher quality of VoIP service in proposed enhanced method.

There are some works that narrow their focus on access point modification and some that introduce fairness modelling and enhancement. In [8] authors provide a technique to control the TCP receiver window to prevent the buffer overflow at the access point. This technique needs additional computation and processing in the wireless nodes or access point itself. The authors in [9] and [10] modelled the 802.11 MAC mechanisms and assumed that there is no packet loss at the AP. This may happen in some specific situations like having very small amount of TCP receive window sizes. However access points in reality will lose packets even if there are few flows of data. On the other hand authors in [11] proposed solutions that do not need any changes in access points and improved the fair utilization of wireless channels by implementing the model in a test-bed environment.

A. High Speed IEEE 802.11(n)

IEEE 802.11n is a successor to the 802.11 wireless technologies in which two characteristics are improved. One is throughput with 20 to 600 Mbps, and the other is range. Actually these improvements are achieved by using the MIMO technique for multiple send and receive operations at the same time, see Fig. 1. MIMO stands for Multiple-Input Multiple-Output which will provide multiple channels for transmission. Efforts have been made to reduce the impact of signal fading in order to increase the transmission range.

These improvements in 802.11n are introduced by having enhancement in both physical and medium access control layers. MIMO and doubled channel rate (40MHz) is added to physical (PHY) layer. Frame aggregation, block ACK enhancement and reverse direction protocol are the features added to MAC layer.

In fact, providing these simultaneous channels in MIMO is possible by using a technique called Spatial Division Multiplexing (SDM). SDM multiplex several data streams that are transmitting in one channel at the same time. The number of data streams that can be created simultaneously is restricted by the number of transmitter and receiver antennas. 802.11n allows having 4 antennas at both side with 4 data streams, but the most common configuration which is used in 11n is $2 \times 2$: 2 that mean 2 antennas at transmitter and receiver sides with the overall 2 data streams. Although this feature leads to much better throughput, it may put the cost issue into consideration. This mechanism surely needs more equipment at both sides of transmission.

This high speed standard benefits from aggregation queue management too. This mechanism is the most highlighted feature of 802.11n that improves MAC efficiency. It combines several packets into one larger frame and decrease the total transmission overhead since the inter-frame time and also header overhead is reduced.

In both [7] and [12], authors proved the effect of these enhanced techniques by simulation and mathematically. The authors of [7] improved the VoIP transmission according to the MAC layer improvements. But what is not clear yet is the effect of higher throughput on the fairness issue. We will examine and answer this question here.

III. TRAFFIC MANAGEMENT TECHNIQUE IN 802.11N

In this section the idea of measuring fairness and improving it is described. It contains two parts. First is the buffer size variation technique to understand the effects of buffer size changes on fairness and to find an
optimum buffer size for our 802.11n scenario and its configuration. The second part introduces our proposed traffic management technique that helps to improve fair usage of bandwidth in heavy traffic situations. To compare this technique with a baseline a theoretically calculated fairness is represented at the section 3.3 based on ideal parameters.

A. Buffer Size Variation Technique

Two scenarios are defined for comparison purpose. One is 802.11b and the other is 802.11n. In both scenarios we defined 10 nodes to fill up the bandwidth by streaming the TCP traffic. Then the buffer size of the access point is changed in the range of 10 to 200. As it was expected these changes result different fairness indexes. At the end two range of buffer sizes that we can see the best fairness are introduced in section 5. Then the optimum buffer size is used in 802.11n scenario for implementing the proposed traffic management technique. In the same topology and scenarios we examine the effect of throughput on fairness by increasing the number of nodes and consequently the number of data streams or traffic volume. The number of nodes is changed from 10 to 100. The results were interesting regarding the robustness of 802.11n in this variation. It is also discussed in section 5.2.

B. Proposed Traffic Management Technique

Unfair usage of bandwidth happens when the number of flows increases and produces higher volume of traffic. Fairness has a direct relation with throughput, see equation (4.1) in section 4. If we can control the throughput and restrict upstream flows from growing more than downstreams, we can enforce fairness in scenarios introduced in section 4.

To control the throughput we need to find an optimum TCP receive window size and set it in our network transmission. In this way we can keep the fairness in an ideal form. This job is described in section 3.4 and the result is 30 packets in our 802.11n scenario. Since this proposed model is going to be implemented in 802.11n environment, first we should analyze the up and downstreams behaviour in 802.11n to see when the unfairness problem occurs. By simulation it is understood that when the total throughput becomes greater than 56Mbps downstream packets start to drop more than before and the access point buffer fills up with more upstream flows than the other one.

A new algorithm is introduced to control this unfair behaviour by restricting upstream throughput from growing. Based on this algorithm when the throughput passed a threshold which is 56, the TCP receive window size will be set to 30 packets, as we got this ideal window size by simulation, to enforce the fairness. Although this method has computational overhead, but we will get better results, see section 5.

The following pseudo code shows the algorithm used to implement the proposed technique.

```plaintext
1. While the number of flows > 1
2. For each flow in data transmission
   1. Calculate the total throughput of all flows
   2. If the throughput is above the threshold
      1. Set TCP RW size to 30 packets
      3. Else
         1. Continue on default TCP windowing
      End
   End
End
```

C. Fairness Index and its Derivation

To implement our work and have theoretical baseline, it is decided to calculate the fairness based on simulation result by changing the TCP window size. In this case an optimum window size will be understood by simulation results. This is shown in section 5.5. When the desired TCP receive window size is found, it is used to calculate the fairness theoretically as the base comparison parameter. Then the same calculation is done based on simulation results to see the improvement. The results show a great improvement in keeping the fairness near ideal value in heavy traffics.

Now we describe how an extension for fairness formula is calculated. The most important factor we use to calculate the direction based fairness is throughput. Throughput is also related to the window size and delay. Mo and Walrand [13] considered a model of network represented by the following equation for flow rate ($x_i$):

$$x_i(\text{Delay}) = \omega$$

$\omega$ refers to window size. Then the authors [13] wrote the equation (1) as

$$x_i((Aq) + d_i) = \omega_i, i \in N$$

The Eq. (2) shows that total number of packets $a_i$ for each connection $i$ equals to $x_i d_i$ of packets plus total number of $x_i (Aq)_i$ packets of connection $i$ in buffers. The equation (2) is rewritten as follows:

$$x_i = \frac{a_i}{d_i}, \text{ for } i \in N$$

In equation (3) $\omega$ is the window size and $d$ represents the total delay of transfer and inside delay of buffer $(Aq)$. $x_i$ shows the throughput of the $i^{th}$ flow in the network. Jain’s fairness index [14] is as follow:

$$\text{Fairness} = \frac{(\sum_{i=1}^{n} x_i)^2}{n \sum_{i=1}^{n} x_i^2}$$

The parameter $n$ represents the number of flows and $x_i$ is the throughput of $i^{th}$ flow. The fairness can be any number between $1/N$ and 1. Whenever we have equal allocation of bandwidth for all flows, the fairness will be 1.

What we can conclude on equations (3) and Jain’s index (4) to achieve a derivation of fairness formula based on TCP receive window size and delay.

$$F = \frac{(\sum_{i=1}^{n} \frac{a_i}{d_i})^2}{n \sum_{i=1}^{n} (\frac{a_i}{d_i})^2}$$

The results of using the equation (5) and simulation are shown and discussed in section 5.
D. Implementing the Proposed Technique

This section describes how the whole work is implemented to reach an improved fairness index in IEEE 802.11n. As it is mentioned all the works are simulated in NS-2 simulator. Both 802.11 and 802.11n environment are provided in this tool with their specific configuration.

For first part of our work we needed to find an optimum buffer size so that it brings us the best fairness index. Our main goal is to find this ideal buffer size in 802.11n. But to have basic results for comparison, the standard 802.11 is implemented with 2Mbps data rate. By changing the amount of buffer size we found exact ranges that shows best fairness index in both environments. The results for this comparison are shown in section 5.

Then 802.11n is simulated with the optimum buffer size we got from previous experiment. The proposed traffic management technique in which the TCP receive window size is controlled, applied in the simulation. Based on the simulation results we got the fairness which is almost ideal when compare it to the fairness without the proposed technique. Our mathematically fairness results that are discussed in section 3.3, also proved the outcome of the simulation. All these results are shown and discussed in section 5. Fig. 2 shows the total process flow chart.

IV. SIMULATION AND EXPERIMENT SCENARIOS

In this section, all information about our simulation is described in detail, including the simulation tool and its settings, parameters, network topology and performance metrics.

Several simulations are done in a low and high speed environment to compare the fairness issue in normal 802.11 and 802.11n. The comparison is based on the result of simulating two WLAN technologies through Network Simulator-2 [15] (NS-2). This simulator has become a standard tool for network researches recently. The ability to update and modify this open source simulator makes it a popular research and presenting tool for academic researchers.

The topology used in our both scenarios is shown in fig. 3. As we discussed above the TCP fairness problem occurs at the AP. We consider any number of wireless nodes as well as a specific wireless station as an access point in the topology. This AP is connected to a server through cable and wireless nodes will communicate with the server via AP. To be close to reality all nodes are capable of moving across the simulation area. However, we are not going to focus on mobility since our observation is on the AP buffer.

A. Scenario I: Simulating the Topology in Standard 802.11 Environment

To accomplish this part we used the default settings of NS-2 wireless libraries with a fixed simulation time. The parameters for simulation are shown in table I. MAC parameters are based on 802.11 standards.

Ten to one hundred nodes are defined to transmit high amount of TCP traffic to and from the server. Traffic is configured to fill up the bandwidth. FTP application is used for each TCP agent. Also a 100Mbps wired link is defined between AP and server. The TCP NewReno protocol as well as mobility is applied in simulation to keep it closer to reality. This simulation repeated twenty
times with different buffer sizes. Outputs are presented in section 5.

### TABLE I. SIMULATION PARAMETERS FOR 802.11 SCENARIO

<table>
<thead>
<tr>
<th>Simulation Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation area</td>
<td>1000 x 1000m</td>
</tr>
<tr>
<td>MAC type</td>
<td>802.11</td>
</tr>
<tr>
<td>Traffic</td>
<td>TCP</td>
</tr>
<tr>
<td>Antenna</td>
<td>Omni</td>
</tr>
<tr>
<td>Propagation model</td>
<td>Two-ray ground</td>
</tr>
<tr>
<td>Agent type</td>
<td>TCP NewReno</td>
</tr>
<tr>
<td>Segment per ACK</td>
<td>1</td>
</tr>
<tr>
<td>Application</td>
<td>FTP</td>
</tr>
<tr>
<td>AP to Server link</td>
<td>100 Mbps</td>
</tr>
<tr>
<td>Wired delay</td>
<td>2 ms</td>
</tr>
<tr>
<td>Interface Queue type</td>
<td>DropTail</td>
</tr>
<tr>
<td>Number of nodes</td>
<td>10-100</td>
</tr>
<tr>
<td>Mobility</td>
<td>YES</td>
</tr>
<tr>
<td>Simulation Time</td>
<td>200s</td>
</tr>
<tr>
<td>AP buffer size</td>
<td>10-200</td>
</tr>
<tr>
<td>Threshold</td>
<td>3000</td>
</tr>
<tr>
<td>MAC basic rate</td>
<td>1Mbps</td>
</tr>
<tr>
<td>MAC data rate</td>
<td>2Mbps</td>
</tr>
</tbody>
</table>

#### B. Scenario 2: Simulating the Topology in High Speed 802.11n Environment

Same preferences are used in this scenario except the MAC protocol and queue model which are defined based on IEEE 802.11n standard. NS-2 C libraries are modified to fulfill this standard requirement. The module in [7] is applied in simulator to provide simulation environment. The parameters are shown in table II.

### TABLE II. SIMULATION PARAMETERS FOR 802.11N (HIGH SPEED WLAN) SCENARIO

<table>
<thead>
<tr>
<th>Simulation Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation area</td>
<td>1000 x 1000m</td>
</tr>
<tr>
<td>MAC type</td>
<td>802.11n</td>
</tr>
<tr>
<td>Traffic</td>
<td>TCP</td>
</tr>
<tr>
<td>Antenna</td>
<td>Omni</td>
</tr>
<tr>
<td>Propagation model</td>
<td>Two-ray ground</td>
</tr>
<tr>
<td>Agent type</td>
<td>TCP NewReno</td>
</tr>
<tr>
<td>Segment per ACK</td>
<td>1</td>
</tr>
<tr>
<td>Application</td>
<td>FTP</td>
</tr>
<tr>
<td>AP to Server link</td>
<td>100 Mbps</td>
</tr>
<tr>
<td>Wired delay</td>
<td>2 ms</td>
</tr>
<tr>
<td>Interface Queue type</td>
<td>Aggregation</td>
</tr>
<tr>
<td>Number of nodes</td>
<td>10-100</td>
</tr>
<tr>
<td>Mobility</td>
<td>YES</td>
</tr>
<tr>
<td>Simulation Time</td>
<td>200s</td>
</tr>
<tr>
<td>AP buffer size</td>
<td>10-200</td>
</tr>
<tr>
<td>Threshold</td>
<td>500000</td>
</tr>
<tr>
<td>MAC basic rate</td>
<td>56-96Mbps</td>
</tr>
<tr>
<td>MAC data rate</td>
<td>56-96Mbps</td>
</tr>
</tbody>
</table>

To make our simulations more clear we should mention some assumptions which are common in all scenarios. All nodes in the topology will send and receive data packets to and from the server through access point. These nodes are able to move inside the simulation area and no one will fall out of range during simulation. Hidden nodes are also considered in simulation. There is no propagation error or any kind of interference over the wireless transmission media. The links are also assumed to work on a non failure basis.

Jain’s fairness index [14] is used as performance metric to evaluate our direction-based fairness problem. This equation is shown in equation (3.4).

The parameter \( n \) represents the number of flows and \( x_i \) is the throughput of \( i^{th} \) flow. The fairness can be any number between \( 1/n \) and 1. Whenever we have equal allocation of bandwidth for all flows, the fairness will be 1.

### V. RESULTS AND DISCUSSION

In this section, we discuss and present the simulation results which are produced by NS-2 for the mentioned scenarios. Outputs of the simulations are illustrated as graphs and will be analyzed during the discussion.

#### A. First Scenario (802.11)

The result of simulating 802.11 with default configuration in NS-2 shows that the TCP fairness is strongly dependant on buffer size and buffer management. Lower buffer sizes result in reduced fairness as the upstream flows fill up the access point buffer. But by increasing the buffer size, fair usage of bandwidth is observed. However, based on the algorithm we use in buffer management the buffer size cannot grow because there will be no use except increasing the time of processing in buffer management. As the Fig. 4 shows buffer sizes more than 190 packets return same results on fairness. The size between 190 and 200 could be ideal for this experiment. The result of this implementation is also proven by Khademi and Othman in [5]. They could achieve fairness between 0.93 and 1 by using their TLAS-SAF algorithm for both direction and sized base fairness.

![Figure 4. TCP fairness vs. Buffer size (802.11)](image)

According to the fairness index we see that the calculation is based on the throughput. Before we go to the fairness calculation it is better to have a look at the throughput results we got from the simulation. For this experiment we fixed the buffer size within the optimum range which is obtained from last experiment, see fig. 4. Then the number of nodes is selected as the changing parameter to see its impact on the uplink or downlink throughput. Fig. 5 shows that by increasing the number of nodes the uplink throughput will also increase which is a normal behaviour. But at the same time the downlink throughput has a dramatic degradation in the same scenario. The different throughputs show the unfair
utilization of the channel. We can expect that by increasing the number of nodes or in other word, the traffic load, the fairness index also shows degradation. Fairness index variation based on the number of nodes is shown in fig. 6.

To analyze this diagram we should see the uplink and downlink throughputs’ changing behaviour. As fig. 8 shows we have higher uplink throughput by increasing the number of nodes. Same calculation for downlink throughput shows a little decrease but it’s not too much. The reason is just because of huge amount of bandwidth and buffer management policies in IEEE 802.11n. This stable behaviour is also proved in [7]. There’s only a small amount of difference between uplink and downlink throughput in heavy traffic. Just when we rich to a high level of traffic, which is 80 nodes and more (56Mbps and more) in the simulation, the unfair usage of the bandwidth shows itself.

Based on this little difference between uplink and downlink throughput we can expect a very smooth degradation in fairness index. This is shown in Fig. 9.

B. Second Scenario (802.11n)

The second simulation on 802.11n is done with the same traffic and buffer parameters like the previous scenario. The results show that 802.11n by its fast transmission nature and its optimum queue management technique has a good and almost flat fairness regarding to buffer size changes. But what we understood from this simulation is that in this high speed WLAN standard we need a specific and small size of buffer to get the best result in fairness issue. As it is shown in fig. 7 the sizes between 65 and 75 have the highest fairness in the simulation.

Based on several simulations with different traffic loads and since we got the almost same results on fairness calculation, we can conclude that the buffer size in which we can have the best result in fairness for first scenario is 198 and for second scenario which is 802.11n, is 71 packets. However, these precise sizes are useful if we always have the same configuration and situation. It means that if we change the queue management algorithm or other parameters that affect the throughput volume, it will affect the fairness too. For example, in the next section some modifications have been done in TCP receive window size to achieve better fairness in 802.11n in heavy traffic environment. In that situation the optimum buffer size changed to 15 packets in which the fairness index becomes 0.997 that is ideal for our second
scenario. As it is mentioned before, it’s better to introduce an optimum range instead of an exact number.

These ranges are 190 to 200 for normal 802.11, and 65 to 75 for 802.11n. One of the reasons affects this buffer size, is the speed of packet processing in the buffer as well as aggregation queue management in 802.11n. In 802.11n there is a huge advance in speed and range and it provides better fairness in different aspect of transmission especially in TCP fairness problem which was the point of the research.

C. Traffic Management Technique

The idea of fairness enforcement is implemented on 802.11n standard. The result of changing TCP receive window size is shown in Fig. 10. By simulation it is proved that within the range of 27 and 30 we have the maximum fairness index of 0.997. For the greater window sizes the same fairness with a little decrease can also be observed but there will be more amount of packet loss that will affect the latency. This amount of packet loss is due to increased receiver window size. The lower window sizes have also an effect on the TCP congestion window behaviour and consequently decreases the effective throughput and finally the fairness decreases too.

To describe the difference between the formula result and controlled window size, we should consider the delay. In fact, the delay used in calculating the fairness formula is the propagation delay only. But the simulation results return a total delay of propagation as well as queuing delay which may vary based on congestion in the network. Although different enhancements have been done and algorithms have been introduced to improve the TCP fairness but this change could have less computational overhead since there is just one item that should be kept under control to get better result.

Figure 11. Fairness enhancement by applying the proposed technique for controlling TCP window size

VI. CONCLUSION AND FUTURE WORK

In this paper the power of bandwidth sharing in high speed wireless LANs is evaluated based on IEEE 802.11n. Because of high speed nature of these WLANs they can provide better fairness regarding to channel usage.

By simulation it is proved that the buffer size changes in this kind of networks affects the TCP fairness and it is shown that a particular range of buffer size will lead to have the best fairness index in heavy loaded traffics. Also it is proved that with a little modification in TCP receive window size in such a way that can restrict the size of this window in large traffics, will prevent the fairness index in 802.11n from falling and keeps it near 1, based on simulation results. A new technique is introduced to implement the idea of enforcing fairness in high speed 802.11n environment. The results of this technique is also compared and proved by mathematical calculation of fairness index based on predefined TCP receive window size.

Although many algorithms have been proposed to enhance the TCP fairness problem in wireless networks, but we believe that these improved algorithms brings more overhead and rarely used in real market. Instead changing buffer size or TCP window size produces lower overheads and lead to get better results in such scenarios.

Lots of works remain to be done in the future regarding to testing different queue management techniques and different WLAN standards. Simulations ignore many realistic parameters like noises or other interferences, so testing this idea in a real wireless network can be a great contribution in the future.

It is important to test 802.11n with different kinds of traffics. There are different priorities for various types of
traffic and may affect the fairness index. In this paper the direction-based fairness problem is considered, but lots of works can be done for sized-based fairness as well.

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