Using the Active Queue Management Schemes to achieve intra-class fairness for the 802.11 WLAN EDCA queues

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Abstract: In this paper the unfairness problems in wireless 802.11 LAN are researched and studied via simulation. The contributions are twofold. First of all, the intra-class fairness of the EDCA queues for downlink streams, in the presence of bidirectional traffic is investigated. Secondly, Active Queue Management schemes are evaluated as an possible improvement for the intra-class fairness. The simulation results show that some algorithms provide more equal share of wireless channel as well as the lower drop rate.

Key–Words: Active Queue Management, Wireless LAN, 802.11, Fairness

1 Introduction

Multimedia applications such as Voice over IP (VoIP), video streaming, Video on Demand (VoD) require different mean transmission parameters (throughput, delay, delay variation and drop rate) in comparison to data transmission performed by email, file transfer and web browsing applications. It brings out the necessity to provide different priorities to different applications, users or data flows or to guarantee a certain level of performance to a data flow; in short, to provide Quality of Service (QoS).

The wireless technology based on the IEEE 802.11 standard [13] remains the fundamental solution for wireless LANs. It is widely adopted in homes, offices and public areas causing ousting of wires, although it provides much slower and faultier transmission. High bit error rate along with slower transmission rates hamper the overall QoS and fairness provisioning. QoS must be provided at every stage of the transmission and when considering 802.11 WLANs, the weak point lies at the link layer, in the contention-based medium access algorithm.

The IEEE 802.11e amendment introduced new enhancements to enable QoS support in wireless LAN applications through modifications to the Media Access Control (MAC) layer. The amendment has been incorporated into the IEEE 802.11 standard published in 2007. It defines new Hybrid Coordination Function (HCF), where there are two access methods within: HCF Controlled Channel Access (HCCA) and Enhanced Distributed Channel Access (EDCA). The two aforementioned methods represent two different kinds of QoS support: parametrized and prioritized.

HCCA provides contention-free access to the medium by polling the stations and granting so called transmission opportunity of fixed size. Polling is performed in a way that allows fulfilling negotiated QoS requirements. The scheduling process is fairly sophisticated. All agreed traffic characteristics must be maintained as well as the time intervals for contention-based access. The standard does not define any particular scheduling algorithm. Some examples can be found in [9]. Despite the fact that the method seems a solution for the problem of providing QoS, it has not been implemented in any device so far. This is probably due to the complexity of the scheduling algorithm. HCCA is beyond the scope of the paper.

EDCA provides a prioritized QoS service by using an independent transmission queue for each traffic category called Access Category (AC). Traffic belonging to a higher priority class has a higher probability of accessing the medium, thus allows achieving a higher throughput when competing with lower priority traffic. It is achieved by differentiating inter-frame space (AIFS), minimum and maximum contention window size ($CW_{\text{min}}$ and $CW_{\text{max}}$) and transmission duration time (TXOP). With EDCA, each station can have up to 4 queues, mapped to different traffic classes. Service differentiation can be achieved by assigning different set of values for every queue contending for access. Traffic with different AC contends independently for the medium access within a station (see fig. 1).

Medium conditions can drastically change over
time which can lead to throughput degradation. As the network becomes overloaded, contention window size increases which leads to long backoff counters and high queue occupation [3].

There are several issues concerning the EDCA queues under congestion scenario. First of all the Access Point (AP) relays the traffic for all wireless nodes. With the contention-based MAC algorithm, all nodes (including AP) have the same priority in accessing the medium. This can lead to the significant unfairness between uplink and downlink flows [6, 8, 15, 16, 18, 20, 22, 23]. This problem is aggravated in the case of TCP flows because of the greedy nature of TCP protocol. Besides the uplink/downlink fairness, another fairness problem is the intra-class fairness i.e. among flows in the same directions, belonging to the same traffic category. The maximum bandwidth of the wireless channel is much smaller than bandwidth of the wired networks. Moreover the MAC overhead and half-duplex of wireless channel decrease the achievable throughput. The disparity makes the AP possible bottleneck in the downlink direction, therefore the buffer size of AP along with queueing strategy plays an important role for the TCP fairness [8, 20]. This especially concerns lower priority queues.

Active Queue Management (AQM) schemes were designed to enable congestion control through notification by early packet dropping. More advanced AQM algorithms aim at protection of responsive flows against unresponsive traffic. RFC 2309 [4] recommended using AQM in Internet routers to improve the performance in terms of smaller overall queueing delays, reduced drop rate and prevention of synchronization caused by the drop tail strategy.

It is investigated how queue management is solved at routers and the theory is applied into the EDCA queues. Routers avoid a serious throughput reduction in the case of a mild congestion, by employing queue management mechanisms, namely Drop Tail and various AQM (Active Queue Management) schemes. Queuing directly influences packet transmission delays, experienced drop rate and dropping scheme. The usage of Drop Tail or any AQM scheme raises many new issues one of which is the buffer sizing.

The focus of the present paper is on the intra-class fairness in the EDCA queues. It is shown that in a typical configuration, some flows may grab most of the bandwidth while other may not be able to transmit for a long time. Through simulation, main flaws of identical, medium size, Drop Tail queues, used for each class by default, are depicted. Using of AQM schemes is proposed as a solution, especially for the low priority traffic. The approach requires changes only on the AP, no changes on wireless nodes are necessary.

The rest of the paper is organized as follows. In section 2 the related work, concerning fairness issues, is reviewed. In section 3 evaluated Active Queue Management schemes are described. Simulation results are presented in section 4. Section 5 concludes the paper.

2 Fairness issues in 802.11 WLAN

In the past several years, extensive studies have been carried out of the fairness issues in infrastructure, IEEE 802.11 wireless LANs. In [22] Q. Wu et al. indicate two main reasons for unfairness problem: the 802.11 MAC protocol and the cross-layer interactions.

The unfairness caused by MAC protocol, results from the contention-based DCF or the EDCA procedure. Every node competes for accessing the wireless channel. All nodes should have equal opportunity in accessing the medium and gain an equal share of wireless channel. However every node may experience different channel condition, may use different transmission rate. Therefore fair resource allocation has no simple definition. The problem is more thoroughly investigated in [5, 17] along with description of some enhancements for DCF procedure.

Interactions between TCP and MAC protocol result in uplink/downlink unfairness as well as unfairness between short-lived and long-lived flows. Since all wireless stations (including AP) share the same channel, each of them obtains a fraction $\frac{1}{N+1}$ of the transmission opportunities on average. However AP relays all downlink connections, therefore the share of AP is partitioned among all downlink streams. This makes AP a bottleneck for downlink connections. This problem is widely discussed in [6, 8, 15, 16, 18, 20, 22, 23]. In [8, 20] authors studied also the influence of the AP buffer size on uplink/downlink fairness and bandwidth allocation. For TCP flows loss of a data packet results in transmission rate reduction and loss of an acknowledgement packet may be irrelevant, because of the cumulative nature of
TCP acknowledgements. This aggravates the downlink/uplink unfairness. The unfairness between long-lived and short-lived flows is a well-known problem, extensively researched in wired network e.g [10]. In wireless LANs, the problem can be even more severe due to the high bit error rate causing more transmission problems.

Buffer size studies pointed out one more issue: the smaller buffer size the higher unfairness between uplink/downlink streams but also between flows belonging to the same station [8] or traffic category. The effect is most obvious for downlink streams. The reason for this is explained in [1]: because of the TCP congestion control mechanism, the presence of the AP bottleneck implicitly regulates the number of the contending stations on the WLAN. The second reason is the lower drop rate.

It is believed that the large buffer sizes lead to high delays and delay variations, especially for the low priority traffic. The larger delay the more probable that packet will be considered lost and retransmitted. This maintains high throughput but significantly lower goodput, due to the unnecessarily retransmitted packets. The throughput is calculated as the overall transmission and goodput as the effective transmission (without unnecessary retransmissions).

The typical buffer size in WLAN, without QoS support, is between 50 to 100 packets. The buffer size of 150 packets provides uplink/downlink fairness, however leads to significant packet delays and delay variation. When considering the queue size for the EDCA procedure, we must remember that there are four queues in total. If each queue would be 50 packets long, the average delays for the low priority traffic would be unacceptably long. Therefore in this paper, the overall buffer size for EDCA doesn’t exceed 80 packets. Moreover, the usage of the AQM algorithm for all traffic classes is in author’s opinion unjustified, since VoIP and video transmission can use UDP instead of TCP protocol and UDP does not react to early packet drops.

The contributions of the paper are twofold. First of all, the intra-class fairness of the EDCA queues for downlink streams, in the presence of bidirectional traffic is investigated. Secondly, Active Queue Management schemes are evaluated as an possible improvement for the intra-class fairness.

The idea of using AQM, RED in particular, for the EDCA queues is not new. Yang et al. [24] presented a Priority Random Early Detection (PRED) algorithm, which integrated the Random Early Detection (RED) with the EDCA queues. PRED provides a queuing algorithm for the priority of the packets within each node. Authors claim that PRED obtains higher throughput, especially under heavy traffic load conditions, allowing the packet with higher priority to acquire more throughput than Drop Tail. In the presented scenario the queues size were set to 70 packets, which is rather large. The fairness issues were not studied.

The queue management strategies for a single MAC queue, designed for the uplink/downlink fairness improvement can be found in [8, 12, 16, 23].

3 Active Queue Management algorithms

Active Queue Management denotes the class of algorithms designed to provide improved queueing mechanism for network routers. The queue management is a very important element of the network infrastructure. It directly influences packet transmission delays. Implementing a queue management algorithm to obtain a very low level of the queue occupancy allows achieving high quality of the offered services. However, it can also lead to the link underutilization. In this paper four different Active Queue Management (AQM) algorithms are evaluated along with the Drop Tail strategy. A short description of each mechanism is presented below.

The idea of RED (Random Early Detection) is to notify the TCP sender about incoming congestion by dropping packets before the buffer overflow occurs. RED calculates the current network load by counting the exponential moving average of the queue size - avg. If avg is smaller than minth threshold all the packets are enqueued, if avg > maxth all the packets are dropped. When avg is between two thresholds, packets are dropped with linearly increasing probability. More accurate description of RED can be found in [7].

AVQ (Adaptive Virtual Queue) uses the idea of the virtual queue. A router with AVQ algorithm maintains a virtual queue whose capacity is less than or equal to the capacity of the link, c. To configure AVQ, the two parameters are required, namely γ and α which are the desired utilization and damping factor, respectively [14].

REM (Random Exponential Marking) tries to regulate the queue length to a desired value q_{ef}. It updates periodically the probability of dropping packets with step γ. The probability is calculated using parameter Φ [2].

The PI (Proportional Integral) controller uses the knowledge of the queue size to clamp the steady value of queue length to the specified reference value [11]. It uses the well known idea from control theory.

Although Active Queue Management allows achieving the desired average queue length, the simple
FIFO queue of fixed buffer size remains the most popular strategy applied at routers. The incoming packets are buffered until the queue is full. When there is no space left, packets are dropped. The algorithm is further 2 as Drop Tail (DT) strategy.

4 Simulation results

The ns-2 simulator was used to study the EDCA queues performance [19]. Since the EDCA model is not included in standard ns-2 release, the solution is based on Sven Wiethlter and Christian Hoene’s model, developed at Technical University of Berlin [21]. The model provides a dedicated, priority-driven queue management algorithm, implemented in set of classes. The main class used for the queue management operations (PriQ), stands for a configurable interface for 4 priority-specific Drop Tail queues. The model has been extended, providing a simple mechanism allowing utilization of any built-in AQM scheme for the selected EDCA queue.

The paper focuses on simulation model where WLAN is used as a last-hop network. The detailed simulation topology and scenario are described below, along with the simulation results.

4.1 Simulation scenarios and topology

The network topology is shown in fig. 2. The wired node is connected to the router with 10 Mbps links. The link propagation delay is set to 1 ms. The link from router R to Access Point AP has the propagation delay of 10 ms and the bitrate 10 Mbps. The wireless bandwidth is set to 11 Mbps which provides around 4–5 Mbps of effective bandwidth. There are 4 wireless nodes uniformly distributed around AP. The AP is the bottleneck for each downlink connection. The default MAC parameters for EDCA were used in the simulations.

![Network topology](image)

Figure 2: Network topology

Two basic scenarios are used, both with bidirectional traffic. All connections are active during the entire simulation. Each simulation is run for 150 seconds.

**Scenario I** - Traffic is composed of bidirectional, FTP connections. Every wireless node transmits and receives data. One uplink connection belonging to the lowest priority traffic exists on every node. Additionally four downlink connections, two belonging to the second and two belonging to the third category class, exist on every node. TCP SACK is used at transport layer, packet size is set to 1500 bytes.

**Scenario II** - To the traffic introduced in Scenario I, eight Variable Bit Rate (VBR) connections exist, two on every node, one belonging to the highest and one to the first traffic category. VBR streams are generated using Pareto sources. ON/OFF times are set to 500ms, pareto shape parameter is 1.05. Packet size is set to 210 bytes and mean transmission rate is 64 kbps.

4.2 Simulation results

Four AQM algorithms are investigated - RED, PI, REM and AVQ and compared with simple FIFO (DT) queue. The parameters set for queuing algorithms are gathered in table 1. Algorithms are configured to maintain average queue 0 equal to 10 packets. Each EDCA queue has the same buffer size and configuration parameters.

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Buffer size</th>
<th>Parameters changed</th>
</tr>
</thead>
<tbody>
<tr>
<td>DT</td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td>RED</td>
<td>20</td>
<td>$minth = 5 \ maxth = 15$</td>
</tr>
<tr>
<td>PI</td>
<td>20</td>
<td>$q_{ref} = 10$</td>
</tr>
<tr>
<td>REM</td>
<td>20</td>
<td>$q_{ref} = 10$, $\gamma = 0.001$, $\Phi = 1.001$</td>
</tr>
<tr>
<td>AVQ</td>
<td>20</td>
<td>$\gamma = 0.5$</td>
</tr>
</tbody>
</table>

Table 1: Configuration parameters for AQM algorithms used in simulations.

4.2.1 Results for DT-EDCA queues

In scenario II, there are connections belonging to all traffic categories. The highest priority traffic (belonging to the 0 and 1 category) doesn’t utilize the whole queue and doesn’t experience any drop rate, therefore we can say that intra-class fairness is provided for those connections. Presented results concern only category 2 and 3.

Results for Drop Tail queues are summarized in table 2. Table comprises the average throughput and
In the first scenario, even thou there were only 8 downlink connections in each category, throughput fairness index is below 0.9. More flows would result in much lower value. The drop rate is high which also affects the intra-class fairness.

In the second scenario throughput JI is high for the category 2, however at the cost of much lower fairness in the lowest traffic category. In this scenario some flows were not able to transmit any packet. The unfairness is also visible in dropping scheme. Some flows experienced 100% drop rate which influences the drop rate JI.

### 4.2.2 Results for AQM-EDCA queues

Tables 3, 4, 5, 6 comprise results for AQM algorithms. First of all it can be noticed that the average throughput is comparable for all queueing strategies, however the drop rate can be significantly lower when using AQM. Especially for PI and REM the drop rate is almost two times lower than when using DT or RED.

Lower drop rate results in higher throughput JI. PI, AVQ and REM significantly improve the intra-class fairness for the first scenario. In the second scenario, among the lowest priority traffic there are always connections that are unable to transmit, therefore the throughput JI is low. For this scenario only RED provides fairness both in throughput and drop rate. In scenario II along with throughput JI degradation goes drop rate JI. This is due to experiencing 100% drop rate by some flows.

### 5 Conclusion

In this paper the intra-class fairness for the EDCA queues in wireless local networks is investigated as well as the different queueing strategies for those queues. Four Active Queue Management schemes along with Drop Tail strategy are evaluated.
The AQM approach maintains similar average throughput but improves the experienced drop rate. It also improves the intra-class fairness when there are connections belonging only to one or two categories. In case of all-service traffic the best results provides RED. The other AQM mechanisms, along with DT, penalize the lowest priority traffic. It leads to the situation when some flows are unable to send any data.

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References:


