# A Multi-QoS Aggregation Mechanism for Improved Fairness in WLAN

Gatnau, Marta; Catania, Davide; Cattoni, Andrea Fabio; Ashta, Jagjit Singh; Mogensen, Preben

*Published in:*
Vehicular Technology Conference (VTC Fall), 2013 IEEE 78th

*DOI (link to publication from Publisher):*
10.1109/VTCFall.2013.6692041

*Publication date:*
2013

*Document Version*
Accepted author manuscript, peer reviewed version

# A multi-QoS Aggregation Mechanism for Improved Fairness in WLAN

Marta Gatnau Sarret,
Davide Catania,
Andrea F. Cattoni
*Department of Electronic Systems, Aalborg University Denmark*
*{mgs,dac,afc}@es.aau.dk*

Jagjit Singh Ashta
*Universitat Politecnica de Catalunya, Spain*

Preben Mogensen
*Nokia Siemens Networks and Department of Electronic Systems Aalborg University, Denmark*
*pm@es.aau.dk*

***Abstract*—The 802.11e and subsequently the 802.11n amendments brought Quality of Service (QoS) into the Wireless Local Area Network (WLAN) arena, in order to provide higher access priority to certain types of traffic such as video and voice. Unfortunately these improvements are not enough, since in very dense and highly loaded network conditions they can provide more harm than benefits, by making the lower priority traffic starve and increasing the average collision rate. This lack of performance in the Medium Access Control (MAC) layer is where we focused our work. We propose a solution that avoids the starvation of the lowest priority Access Categories (AC), taking into account the priority defined by the 802.11e amendment and at negligible or extremely low cost for the high priority ones. Simulation results presented in this paper prove the effectiveness of the method by showing delay improvements up to 92% in overcrowded and overloaded networks.**

## I. Introduction

Wireless Local Area Network systems had an undeniable market success in the previous years, especially under the very well known commercial name of WiFi. Since the introduction of the standard, more than 15 years ago, 802.11 [1] has undergone several modifications through various amendments, improving both the physical layer considerably and the MAC procedures accordingly.

The popularity of WiFi can be mainly attributed to its low setup cost, ease of use, and wide market footprint. While the most common application of WiFi is to provide wireless local area connectivity to home users, in more recent years, 802.11 systems are also seen as an offloading solution by mobile operators. The new hotspot deployment scenarios bring new challenges, in terms of QoS, into the picture. Whether WiFi is seen as a competitor to femtocells, or as part of a mobile networks operator's infrastructure for offloading purposes, QoS becomes an important feature to consider, as demonstrated by the increasing interest in the Hotspot 2.0 initiative [2].

Considerations about QoS were first taken into account in the 802.11e amendment [3]. The standard defines four types of AC, which are Voice (VO), Video (VI), Best Effort (BE) and Background (BK), and it aims at prioritizing these traffic types by making use of different Contention Window (CW) sizes and also different Arbitrary InterFrame Space (AIFS). 802.11e attemps to introduce QoS by setting up different random backoff period ranges for each traffic category. For example, on average, a VO packet will always wait less than a BE packet before being transmitted.

This mechanism has a significant cost for lower priority traffic flows, since they can practically starve in dense network deployments. But the drawbacks are not limited to that. During our study, an important problem was found. Since VO packets (highest priority traffic category defined) have a smaller average CW size, the collision rate on the medium increases. This problem is magnified in denser networks, leading the 802.11n system to perform better without the 802.11e features. The baseline results in this paper clearly show the phenomenon.

There are a number of previous works in literature, related to QoS and aggregation, trying to improve throughput, goodput and delay for high priority traffic, like [5] and [6]. But the majority do not take care of the traffic with lowest priority and none of them tries to create aggregated packets with different types of traffic within it. As an example, in [4] a small delay is introduced in all the different traffic queues in order to be able to receive larger aggregated packets, mainly aggregating more high priority packets. This fact maximizes the goodput of low priority traffic and increases the system effectiveness by reducing the channel access overhead. On the other hand, this enhancement increases the delay of the high priority ACs and also decreases slightly their goodput.

Another 802.11n feature that can be exploited in order to improve QoS, is the possibility of transmitting multiple ACs in the same burst, as defined in [7]. But as clearly explained in [8], the usage of such feature is restricted by the mandatory combination with power saving and polling–based (scheduled) channel access. Furthermore, each transmitted AC needs to be separated in the burst by an inter-frame space, typically short (SIFS) or reduced (RIFS).

The work presented in this paper attempts to go a step further, by trying to introduce fairness among the ACs. With fairness we mean to avoid the starvation of the lowest priority

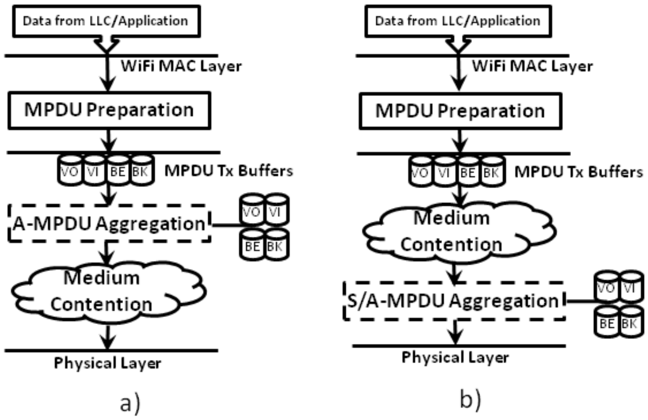


Fig. 1. a) Standard aggregation and b) Smart aggregation.

ACs, taking into account the priority defined by the 802.11e amendment and at negligible or extremely low cost for the high priority ones. In order to achieve such a goal, a new multi–QoS aggregation mechanism has been designed, by changing when and how the aggregation process is performed in the MAC protocol stack, and by introducing new multi–QoS frames that reduce the overhead due to the inter–frame spacing.

The rest of the paper is structured as follows: in Section II we make a quick review of the 802.11n aggregation mechanism. Section III delves deeper into the actual smart aggregation mechanism. Section IV shows and analyzes the simulation results and finally, Section V concludes the paper.

## II. 802.11n Aggregation

The aggregation feature introduced by the 802.11n amendment is a mechanism that allows the transmission of multiple packets at the same time, without waiting between the transmission of each of them.

The standard defines two types of aggregation, the Aggregated–MAC Service Data Unit (A–MSDU) and the Aggregated–MAC Protocol Data Unit (A–MPDU). We are going to focus on the description of the second one because is where we have focused our work.

The A–MPDU is composed by a set of MPDUs, separated by a delimiter. This configuration allows the possibility of retransmitting each MPDU separately. The acknowledgement of this frame is done by using the Block Ack (BA) mechanism.

The aggregation process and consequent creation of the A-MPDU is done before the medium contention. When the final packet is in the transmission buffers ready to be sent, the medium contention starts. Figure 1.a) shows this behaviour.

The Smart Aggregation Framework builds upon the existing QoS and aggregation schemes defined previously, as explained in the next Section.

## III. Smart Aggregation Framework

Smart Aggregation is a framework used to improve the type of fairness defined previously, using aggregation and multi-QoS features as bulding blocks. It is based on an optimized aggregation scheme, with the possibility of transmitting a MAC frame consisting of packets belonging to different AC. This, along with a packet preparation strategy that chooses which packets should be included in the final aggregated packet, allows us to transmit multi-QoS MAC frames.

The goal of the Smart Aggregation Mechanism is threefold:

- avoid starvation of the lowest ACs while keeping the same priority definition of the 802.11e amendment,
- reduce the number of collisions, due to a shorter contention time introduced by the VO traffic and
- improve the MAC efficiency reducing the overhead introduced by the MAC header when sending small packets (e.g. VO).

### A. Optimized Aggregation Scheme

Our optimized aggregation scheme changes when the final packet is prepared, swapping the last two blocks of the standard scheme (Figure 1.a)), as shown in Figure 1.b). It prepares the packets while the medium is being contended, until shortly before transmitting. This allows us to fill the aggregated frame with more packets, since additional packets might have arrived in the transmission buffers during the contention time.

In this way we are reducing the number of collisions because we are reducing the number of times the channel is accessed. The overhead is decreased and the MAC efficiency is improved because we are able to send more packets in the same frame and consequently we increase the ratio of data to control information.

So far we have dealt with two of the three problems we pointed out. At this point we have to focus on the network fairness to avoid starvation of low access categories. For this reason, the multi-QoS feature is considered.

### B. Adding the multi-QoS frames

As pointed out before in Section I, the multi-QoS feature can only be used in certain contexts. Particularly, the 802.11n amendment specifies that multi-QoS packets will only be transmitted within the Power Save Multi-Poll (PSMP) period and by the Access Point (AP), by sending A-MPDUs from different ACs in a burst transmission and acknowledging them using the multi-Traffic Identifier (TID) Block Ack mechanism. Thereby, it requires additional frames that increase the overhead and affects the MAC efficiency.

We propose a multi-QoS Aggregation mechanism that can be used within any context, using newly improved frames and keeping the priority defined by the 802.11e amendment. We have designed a new frame for the A-MPDU, named SA-MPDU. The frame format of the SA-MPDU is the same as the standard one, but we are transforming it into a multi-QoS frame, allowing for multiple access categories to be aggregated all together.

The aggregation procedure is described by pseudocode in Algorithm 1 and illustrated in Figure 2.

For example, looking at Figure 2.b, if VI gains the access to the medium, the first packet in the aggregated frame will be VI. Then, if there are VO packets in the buffer, because

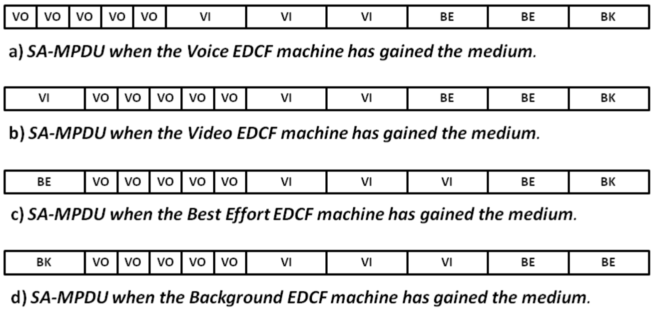


Fig. 2. SA-MPDU depending on the AC that has gained the medium.

**Algorithm 1** Smart Aggregation Procedure

$ac \leftarrow accessCategory$ {AC that has gained the medium}
$N \leftarrow 64$ {Max number of frames within an SA-MPDU}
$B \leftarrow 65535$ {Max number of bytes within an SA-MPDU}
$ap \leftarrow 0$ {Number of frames within an SA-MPDU}
$by \leftarrow 0$ {Number of bytes within an SA-MPDU}
$buf_i \leftarrow K_i$ {Packets in buffer i, where i={VO,VI,BE,BK}}
{Always aggregate packets for the same user}
**if** *ac* is different of VOICE **then**
  {Attach the first *ac* packet}
  $ap \leftarrow ap + 1$
  $by \leftarrow by$+*bytes of attached packet*
  $buf_i \leftarrow buf_i - 1$
**end if**
{Continue attaching following the 802.11e definition}
**while** $ap < N$ and $by < B$ and $buf_{VO} > 0$ **do**
  $ap \leftarrow ap + 1$
  $by \leftarrow by$+*bytes of attached packet*
  $buf_{VO} \leftarrow buf_{VO} - 1$
**end while**
**while** $ap < N$ and $by < B$ and $buf_{VI} > 0$ **do**
  $ap \leftarrow ap + 1$
  $by \leftarrow by$+*bytes of attached packet*
  $buf_{VI} \leftarrow buf_{VI} - 1$
**end while**
**while** $ap < N$ and $by < B$ and $buf_{BE} > 0$ **do**
  $ap \leftarrow ap + 1$
  $by \leftarrow by$+*bytes of attached packet*
  $buf_{BE} \leftarrow buf_{BE} - 1$
**end while**
**while** $ap < N$ and $by < B$ and $buf_{BK} > 0$ **do**
  $ap \leftarrow ap + 1$
  $by \leftarrow by$+*bytes of attached packet*
  $buf_{BK} \leftarrow buf_{BK} - 1$
**end while**

it is an AC with a higher priority than VI, the mechanism will attach all the possible VO packets within the aggregated frame. Finally, if it is possible and if there are any, it will attach VI, BE and BK packets, in decreasing priority order, always keeping in mind that all the packets are for the same user.

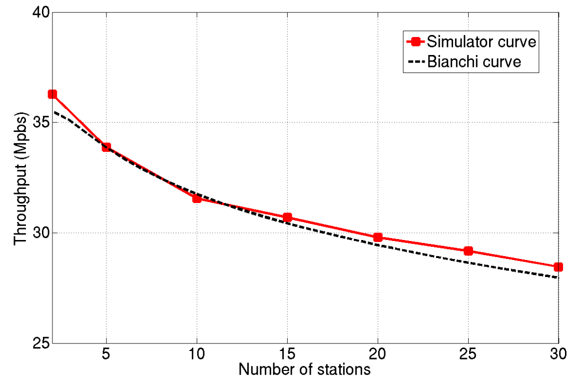


Fig. 3. Validation of our model against Bianchi's.

TABLE I
PARAMETERS WE HAVE USED TO RUN THE SIMULATIONS.

| Parameter | Value/State/Type |
|---|---|
| 802.11 version | 802.11n w/ and w/o 802.11e |
| Number of users | Variable |
| Buffer size | Unlimited |
| Traffic balancing | US = (1/6)*DS |
| QoS | Enabled in DS / Disabled in US |
| Scenario | Single 10x10 room and 1 AP |
| Frame type | A-MPDU or SA-MPDU |
| Physical data rate | 144 Mbps |

TABLE II
DOWNLINK OFFERED LOAD PER USER.

| Access Category | Packet size | Packet interval | Offered load |
|---|---|---|---|
| Voice | 160 bytes | 20 ms | 64 kbps |
| Video | 1280 bytes | 10 ms | 1024 kbps |
| Best Effort | 1500 bytes | 12.5 ms | 960 kbps |

It is important to remark that Smart Aggregation does not consider multi-user, meaning that all the packets within the Smart frame will be destined for the same user.

## IV. PERFORMANCE EVALUATION

We have designed and implemented a detailed WiFi model in a system level simulator and subsequently validated (see Figure 3) against the model presented in [9]. While the Physical (PHY) Layer is simplified and assumes a fixed Modulation and Coding Scheme (MCS), the MAC implementation is much more detailed and includes most of the basic features available in the standard, like the RTS/CTS mechanism and the periodic Beacon transmission.

The scenario we have simulated is summarized in Table I. To be more realistic, we considered asymmetric traffic load, which means that the offered upstream traffic is $1/6$ of the downstream traffic. QoS is disabled in the upstream, i.e., the only type of traffic transmitted from all the stations to the AP is BE. In the downstream, the AP transmits VO, VI and BE packets to all the stations, and its offered load is detailed in Table II and it has been extracted from [10], also for validation.

We are going to focus on the delay, defined as the period of time from the moment a frame arrives at the buffer until it is

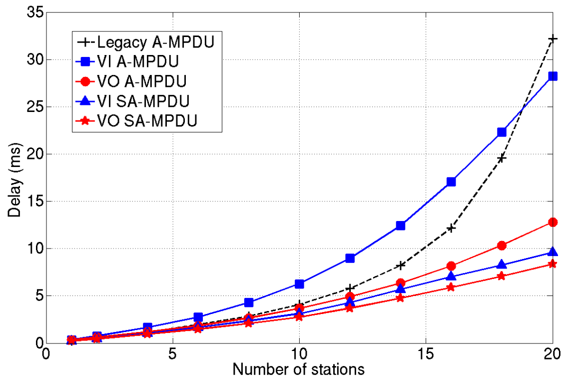


Fig. 4. Downstream average delay for Voice and Video packets

TABLE III
DOWNLINK DELAY (IN MS) COMPARISON FOR 20 USERS

| | Downstream | | |
|---|---|---|---|
| **Station** | **Voice** | **Video** | **Best Effort** |
| Legacy A-MPDU | 32.30 | 32.30 | 32.30 |
| QoS A-MPDU | 12.79 | 28.25 | 137.00 |
| SA-MPDU | 8.38 | 9.59 | 10.17 |
| Smart vs Legacy | -74.1% | -70.3% | -68.5% |
| Smart vs QoS | -34.5% | -66.1% | -92.3% |

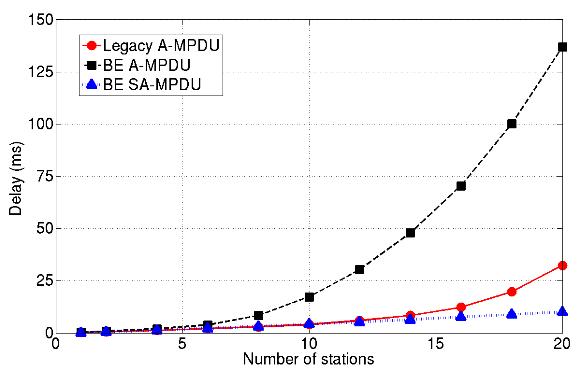


Fig. 5. Downstream average delay for Best Effort packets

received successfuly by the receiving station, and we also show how the goodput is affected due to the strangling effect caused by the presence of multiple upstream users. We are going to compare the results for three configurations: the standard aggregation without QoS, which means that the only used type of traffic is legacy (equivalent to BE when QoS is used), the standard aggregation using QoS and finally the Smart Aggregation. In addition, we will focus on the downstream flow because it is the most affected. The results are presented into two different representations, delay against the number of stations and Cumulative Distribution Function (CDF) of the delay.

Figure 4 plots the average delay for VI and VO traffic versus the number of stations that are present in the network. We observe that the VI delay reduction is higher than the VO one. This is because VO is the AC with highest priority and

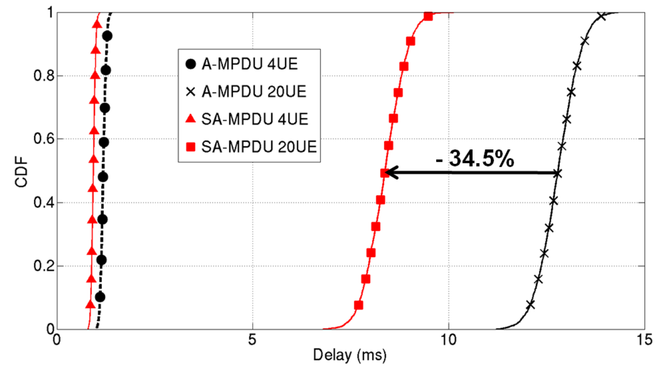


Fig. 6. Voice downstream delay

there is not much room for improvement. In either case, the SA mechanism improves both delays and it is still keeping the prioritization between the ACs.

Numerical results and a relative comparison for 20 users (the extreme case when the network is overcrowded) are shown in Table III. Regarding the legacy case, all delays for all types of traffic are the same because there is not any priority defined, therefore there is not a distinction between ACs. It is reasonable that, comparing the cases with and without QoS, the reduction of the delay for VO and VI will be higher than BE because of the priority defined by the 802.11e. Regarding the 802.11 QoS aggregation, the table shows that the delay for BE traffic is much higher than the ones for VO and VI (10.7 and 4.8 times more, respectively). But using the Smart Aggregation Framework these differences are lowered, and the priority defined by the 802.11e amendment is respected. In the SA case, the delay reduction is higher for low priority traffic because it is the most affected. Nevertheless, the delay of high priority ACs is also decreased.

As pointed out before, the main problem appears when the network is overcrowded. In this situation, the delay reduction is very significant, especially considering that the SA mechanism reduces the VO delay by 34.5%, as shown in Table III.

Figure 5 plots the average delay for BE traffic versus the number of stations that are present in the network. The first thing we notice is that when the network is overcrowded, the delay when using the standard aggregation is even higher than without using QoS. Using the SA mechanism, the delay for the lowest ACs gets improved, even when compared with the legacy case. The reason for this improvement is because every time the VO or the VI ACs gain the medium, accordingly to Algorithm 1, BE or BK packets might be attached to the Smart frame. This fact increases the number of opportunities to send low priority traffic.

In Figure 6 and 7 we compare Smart Aggregation with the QoS aggregation, analyzing the system in two situations: a lightly loaded condition (4 users in the network) and an overcrowded situation (20 users).

Figure 6 shows the CDFs for the VO access category. From this figure we can see that, even though VO is the access

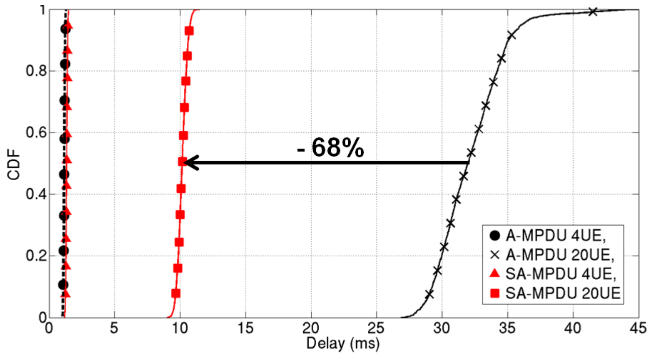


Fig. 7. Best Effort Downstream delay

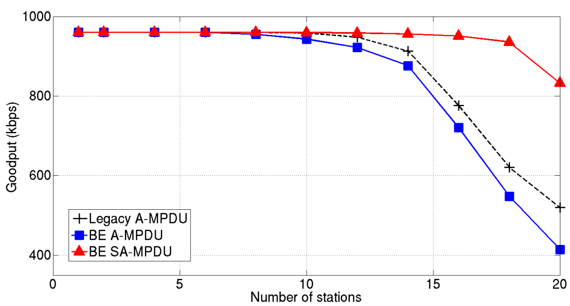


Fig. 8. Downstream average goodput for BE packets for 54 Mbps

category with the highest priority and the smallest delay, the Smart Aggregation framework is also beneficial for it.

Figure 7 shows the CDFs for the BE access category. We can see that under lightly loaded conditions, SA gets almost the same performance as the non-QoS aggregation. This delay is slightly longer using SA than the 802.11 because at the same aggregated frame, if possible, our mechanism is also attaching other type of packets, and then the transmission time increases.

In addition, using the SA framework the network becomes more homogeneous because all users get a similar delay, and fair, because the mean delay is reduced. Therefore all users have a chance to transmit data.

To conclude and to prove that the system works with our framework, we test the system when a lower data rate (54 Mbps) is used, in the same extreme situation (20 users). Using the 802.11 QoS aggregation, just a few kbps of BE traffic are transmitted in order to be able to transmit VO and VI packets. This situation is solved using the Smart Aggregation framework because the delay is reduced and the carried BE traffic doubles, just reducing slightly VO and VI goodput (2.8% and 0.3% respectively). Comparing our framework with the non-QoS aggregation, the goodput of all ACs gets improved (VO by 75.5%, VI by 76.0% and BE by 60.1%). Figure 8 shows this improvement for the BE traffic, which is the most affected. In this case, the legacy traffic has the same offered load as BE traffic.

When a higher transmission rate is used (144 Mbps), the situation is much less critical, increasing the goodput between 1–5%. The problem is that we can not ensure a high transmission rate all the time, so if the Smart Aggregation framework is being used, the transmission of all type of data at any rate is guaranteed.

## V. Conclusion

The Smart Aggregation framework is designed as a multi-QoS strategy to avoid starvation of the access categories with low priority, taking into account the priority defined by the 802.11e amendment, at a negligigle or extremely low cost for the traffic with high priority.

Simulation results show that the proposed method brings gain for all the ACs, both in terms of delay and goodput. This gain is present in both extreme scenarios, when the network is overcrowded and when it is only slightly crowded.

As a future work we want to improve the A-MSDU and the Block Ack mechanism, to reduce the overhead and consequently improve the MAC efficiency. We also want to test how the Smart Aggregation Framework reacts when the network is heterogeneous, i.e., when the types of traffic that users transmit are different.

## References


[1] IEEE Std. 802.11-2007, *Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications*, 2007, pp. 1–1076.

[2] Wi-Fi Alliance, *Wi-Fi CERTIFIED Passpoint: A new program from the Wi-Fi Alliance to enable seamless Wi-Fi access in hotspots*, 2012

[3] IEEE Std. 802.11e-2005, *Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 8: Medium Access Control (MAC) Quality of Service Enhancements*, 2005, pp. 1–189.

[4] Skordoulis, D.; Qiang Ni; Geyong Min; Borg, K.; , *Adaptive Delayed Channel Access for IEEE 802.11n WLANs*, Circuits and Systems for Communications, 2008. ICCSC 2008. 4th IEEE International Conference on, pp.167-171, 26-28 May 2008

[5] Haifeng Zheng and Guotai Chen and Lun Yu, *Video transmission over IEEE 802.11n WLAN with adaptive aggregation scheme*, Broadband Multimedia Systems and Broadcasting (BMSB), 2010 IEEE International Symposium on, 2010, pp. 1–5.

[6] R. Riggio and D. Miorandi and F. De Pellegrini and F. Granelli and I. Chlamtac, *A traffic aggregation and differentiation scheme for enhanced QoS in IEEE 802.11-based Wireless Mesh Networks*, Computer Communications, volume 31, number 7, 2008, pp. 1290–1300.

[7] IEEE Std. 802.11n-2009, *Part 11: Wireless LAN Medium Access Control (MAC)and Physical Layer (PHY) Specifications Amendment 5: Enhancements for Higher Throughput*, 2009, pp. 1–565.

[8] Perez-Costa, X.; Camps-Mur, D.; , *IEEE 802.11E QoS and power saving features overview and analysis of combined performance*, Wireless Communications, IEEE , vol.17, no.4, pp.88-96, August 2010

[9] Tinnirello, I. and Bianchi, G. and Yang Xiao, *Refinements on IEEE 802.11 Distributed Coordination Function Modeling Approaches*, Vehicular Technology, IEEE Transactions on, 2010, pp. 1055–1067.

[10] Qiang Ni, *Performance analysis and enhancements for IEEE 802.11e wireless networks*, Network, IEEE, volume 7, number 4, 2005, pp. 21–27.