A Cross-Layer Approach for Mitigating 802.11 MAC Anomaly Using SNR to Control Backoff Contention Windows

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***Abstract* — The standard 802.11 presents a Medium Access Control (MAC) anomaly when stations with different data rates operate at the same Access Point. This paper presents a strategy for using SNR to control the contention window and consequently mitigate the anomaly. Simulations using Network Simulators (NS) are presented to demonstrate the anomaly and to evaluate the mitigation anomaly strategy. The strategy configures the wireless stations with low SNR to work with large contention windows and wireless stations with high SNR with small contention windows. Using this strategy, the station with high SNR obtains higher throughput than the station with low SNR. The anomaly mitigation proposal creates a new option for network managers to control the PWLAN behavior using a combined SNR and QoS strategy. When the anomaly is not mitigated the QoS strategy does not work properly.**

***Index Terms* — 802.11, MAC, WLAN anomaly, Performance.**

***Resumo* — O padrão 802.11 apresenta uma anomalia na MAC (Controle de Acesso ao Meio) quando estações com diferentes taxas compartilham o mesmo ponto de acesso. Esse artigo apresenta um estratégia utilizando a SNR (relação sinal ruído) para controlar a CW (janela de contenção) e consequentemente reduzir o efeito da anomalia. Simulações usando o NS (Network Simulator) foram feitas para demonstrar a anomalia e a estratégia proposta. A estratégia baseia-se em fazer com que as estações com baixa SNR operem com uma CW grande enquanto as estações com boa SNR operam com uma CW pequena. Usando essa estratégia, a estação com boa SNR obtem uma vazão melhor que a estação com baixa SNR. Essa proposta cria uma nova opção para gerents de rede administrarem uma PWLAN combinando uma estratégia que pode ser associada a QoS. Se a anomalia não for reduzida, estratégias de QoS não funcionaram adequadamente.**

***Index Terms* — 802.11, Anomalia, Desempenho de Redes, MAC, Redes sem fio.**

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I. INTRODUCTION

With the proliferation of mobile computers and the popularity of Internet access, there is a growing need for networking. Although necessary, this cannot be carried out without regard for consequences. Connections must be provided with quality and speed. This is not always possible and one of the reasons could be due to the medium access control (MAC) anomaly.

It is already recognized that the 802.11 MAC [1] generates an anomaly whenever wireless hosts (WH) with different data rates share the same Access Point (AP). In traditional Wireless Local Area Networks (WLAN), this problem also exists, but in a less critical way due to users' low mobility. But in Public WLANs (PWLANs) with high mobility, the MAC anomaly provokes a great deal of deterioration in network performance.

Reference 2 evaluates the MAC anomaly for the 802.11 MAC standard. The 802.11 MAC is the same for all air interfaces, namely 11a, 11g and 11n. For the sake of brevity, this paper shall consider only the 802.11b even though the approach explored here may be extended to all the other interfaces.

Reference 3 proposes a solution to the MAC anomaly using the Quality of Service (QoS) strategy. However, such a strategy is not appropriate, because the QoS concerns the application layer rather than the physical and MAC layer, from which the anomaly arises.

In Reference 4, results of experiments show the anomaly in the Fat architecture and not in the proprietary Thin architecture. A proprietary architecture, such as a Thin architecture, keeps a stable connection to wireless hosts in good SNR conditions and only the host with low SNR has degraded performance. The good performance of Thin architecture can be justified by an anomaly mitigation proposal.

The anomaly mitigation strategy proposed in this paper uses the signal-to-noise (SNR) to control the contention window (CW) variation so as to prioritize the wireless stations with higher SNRs. The current 802.11b degraded the bit rate from 11Mbps to 5.5Mbps, 2Mbps or 1Mbps when the SNR is reduced. The Network Simulator (NS) [6] is used to assess the performance of this strategy.

II. WLAN 802.11

The IEEE 802.11 and 802.11b standards [1][7] define the physical layer and Medium Access Control – MAC sub layer, which use CSMA/CA (Carrier Sense Multiple Access) in the DCF (Distributed Coordination Function). This protocol is based on the principle in which a host wishing to transmit senses the channel before transmitting [1][6].

The DCF based on the CSMA/CA uses a binary slotted exponential random backoff. Whenever a backoff occurs, the backoff time is randomly drawn from a uniform distribution over the interval [0, CW], CW being doubled for a retry and reset for a new packet, with its maximum reaching *CW*max = 1023.

In our proposal, the exponential backoff is changed to fixed values, which are chosen in accordance with the SNR.

The 802.11 standard allows two configurations: infrastructure mode and Ad hoc mode. Infrastructure mode uses the AP as a centralized point and Ad hoc uses pear-to-pear connection among wireless hosts. The infrastructure mode is analogous to the base station in a cellular communication network [6], providing a coverage area to connect wireless hosts with wired network and Internet.

Another important characteristic of the 802.11 used in our analyzis is the DRS (dynamic rate shifting). Adaptive (or Automatic) Rate Selection (ARS) and Dynamic Rate Shifting (DRS) are how bandwidth is adjusted dynamically by wireless stations.

This adjustment occurs as distance increases between the wireless station and the access point (or possibly if interference increases). As the distance grows, the signal strength will decrease to a point where the current data rate cannot be maintained. As the signal strength drops, the client will drop its data rate to the next lower specified data rate. The bit rate hierarchy, used for example in 802.11b are 4: 11Mbps, 5.5Mbps, 2Mbps, and 1Mbps. We could considerate the 802.11g too.

This paper considers only infrastructure mode and DCF (Distributed Coordination Function) with a downlink UDP traffic (from the wired station to the wireless station).

III. MAC ANOMALY: A BRIEF OVERVIEW

The MAC anomaly arises from the network access fairness policy, in which any terminal experiences the same access probability independent of its localization or transmission rate.

This anomaly is illustrated by using two pairs of stations, namely EH1-WH1 and EH2-WH2, as depicted in Figure 1, where EH is a wired host and WH a wireless host.

The anomaly analysis illustrated here considers (i) the infrastructure mode, which uses an Access Point (AP) as a centralized point, (ii) the downlink traffic and (iii) the Constant Bit Rate (CBR). Collisions are not considered here. With these conditions, the two pairs of stations are continuously sending data.

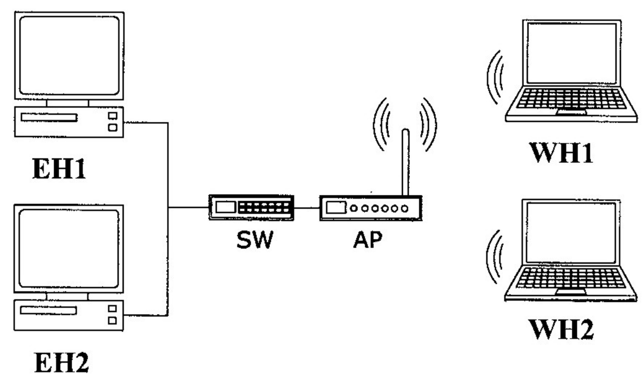

Fig 1 – MAC anomaly evaluation

The efficiency is different for each data rate and can be calculated using long or short preamble [8]. Table 1 shows the physical layer data rate efficiency considering short preamble.

TABLE 1
Data Rate Efficiency

Physical Data Rate (Mbps)	Transmission Efficiency
11	59.3%
5.5	69.6%
2	74.3%
1	76.9%

In these conditions, the throughput R_{Tn} of each wireless station can be determined using the total number of bits transmitted B_{Tn} by WH n and the total observation time T_T such that:

$$R_{Tn} = \frac{B_{Tn}}{T_T} \quad (1)$$

The total transmitted bits can be calculated by:

$$B_{Tn} = \rho_n R_n T_n \quad (2)$$

where ρ_n is the transmission efficiency, R_n is physical data rate and T_n is the total time transmission of the station WH n. This time can be calculated for each station as:

$$T_n = T_T C_n \quad (3)$$

where C_n represents proportion of transmit time, considering a long period of observation and equal probability of transmission. Since 802.11b MAC gives equal channel access probability but not equal time to all terminals, bit-rate difference is not at all translated into throughput difference. With CBR traffic this factor can be obtained by analyzing the proportion of time a station uses the channel. Manipulating these equations yields:

$$R_{Tn} = \rho_n R_n C_n \quad (4)$$

In order to substantiate the existence of an anomaly, consider WH1 with a data rate of 11 Mbps and WH2 with 1 Mbps. The fair access to the channel (provided by CSMA/CA) causes a slow host transmitting at 1 Mbps to occupy the channel eleven times longer than hosts emitting at 11 Mbps. On average, the proportion of transmission time for each pair is

$$C_1 = 1/12 \qquad C_2 = 11/12 \quad (5)$$

Now, using this in (4) then:

$$R_{T1} = 543 kbps \qquad R_{T2} = 704.9 kbps$$

It is interesting to observe that WH1 with a physical layer data rate of 11Mbps has a throughput lower than WH2, which is operating with 1Mbps data rate.

A way to evaluate the performance is the average throughput:

$$R_m = \frac{R_{T1} + R_{T2}}{2} \quad (6)$$

For two stations using the values obtained the average throughput is 623.95 kbps.

This shows that a single host transmitting with a lower rate is really able to reduce the performance of all hosts and consequently the performance of the entire network. This anomaly holds whatever the proportion of slow hosts.

The generalized average throughput expression will be:

$$R_m = \frac{1}{N} \sum_{i=1}^{N} \rho_i R_i C_i \quad (7)$$

This expression will be used to analyze the anomaly mitigation approach.

IV. ANOMALY MITIGATION STRATEGY

The anomaly mitigation strategy proposed here suggests that the CW values be changed as a function of the SNR values. More specifically, the higher the SNR the smaller the CW. This way, the fairness strategy terminals with better propagation conditions are allowed to make the best of these conditions.

Again, the scenario in Figure 1 is used to find the network performance with the application of the proposed strategy. In this scenario, for illustration purposes, the station with the best SNR (WH1) is assigned CW=CWmin=31 while the station with the worst SNR (WH2) is assigned CW=CWmax=1023.

Defining:

$$\beta = \frac{CW \max}{CW \min} \quad (8)$$

it is possible to say that on average WH1 transmits β times more than WH2, and consequently β bits more as well.

So the overall transmission time becomes:

$$\mathrm{T_T} = \beta(T_1) + (T_2) \quad (9)$$

Adapting equation 2 and 3, this gives us:

$$B_{Tn} = \rho_n R_n T_n \beta \quad (10)$$

$$C_1 = \frac{\beta T_1}{\beta T_1 + T_2} \text{ and } C_2 = \frac{T_2}{\beta T_1 + T_2} \quad (11)$$

With this assumption and that of Section III, the throughput is given by

$$R_{T1} = \rho_1 R_1 \frac{T_1}{T_1 + \dfrac{T_2}{\beta}} \quad (12)$$

Similarly, let R_{T2} be the corresponding throughput for the "slow" host (WH2):

$$R_{T2} = \rho_2 R_2 \frac{T_2}{\beta T_1 + T_2} \quad (13)$$

Using these new equations and considering CW_{min}=31 and CW_{max}=1023, we can numerically show that the throughput obtained is:

$$R_{T1} = 3{,}38 Mbps \qquad R_{T2} = 137 kbps$$

which is rather different from what was obtained previously. The average throughput is then $R_m = 1758$ Mbps, i.e. an increase factor of 2.8 has been obtained.

V. Simulation Results

The proposed strategy has been evaluated by means of NS-2 version 2.29 [5]. To compare the results we simulated scenarios using the strategy and not using the strategy, using Figure 1 as a scenario again.

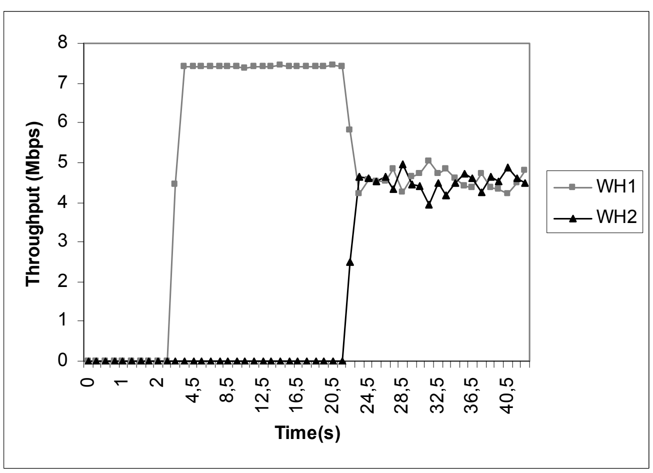

Fig 2 – WH1 and WH2 at 11Mbps

All the parameters of the simulation, such as CW_{min} *and* CW_{max}, have values defined in the 802.11b standard.

Initially, only WH1 is on and occupies the channel alone. After 20 seconds WH2 is introduced. Figure 2 shows the NS simulation throughput result for WH1 and WH2 at 11Mbps. In this case, both stations have a good SNR and share the radio channel in equal parts.

Figure 3 depicts the anomaly when the host operates with different SNRs: WH1 is operating with 11Mbps and WH2 with only 1Mbps. The throughput of the host transmitting at the higher rate is degraded to levels below the level of the lower rate.

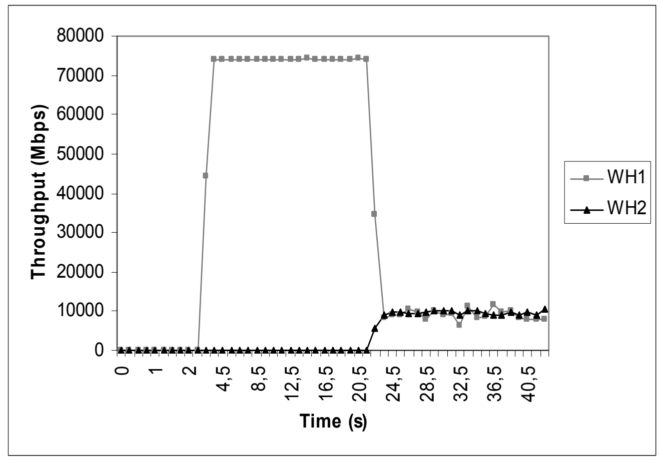

Fig 3 – The anomaly

Figure 4 shows the result with the anomaly mitigation strategy proposed here. Such a strategy penalizes the slow host and benefits the fast one.

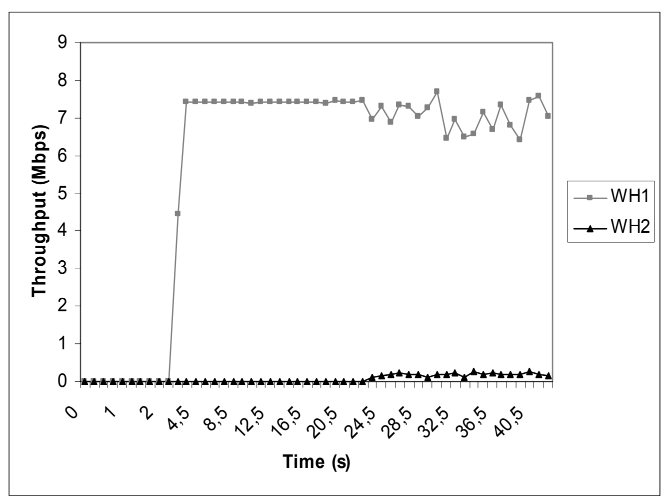

Fig 4 – With Strategy

It is clear that a greater β represents a strong rate of deterioration for the station working at 1 Mbps and better mitigation of the anomaly but it is possible to change the fixed CW to other values.

There are a large number of scenarios to be evaluated. Figure 5 shows one of these scenarios, where the throughput is related to $1/\beta$ that and could be used for intermediary conditions. In reality the proposal creates a flexible policy for adjusting to achieve adequate performance.

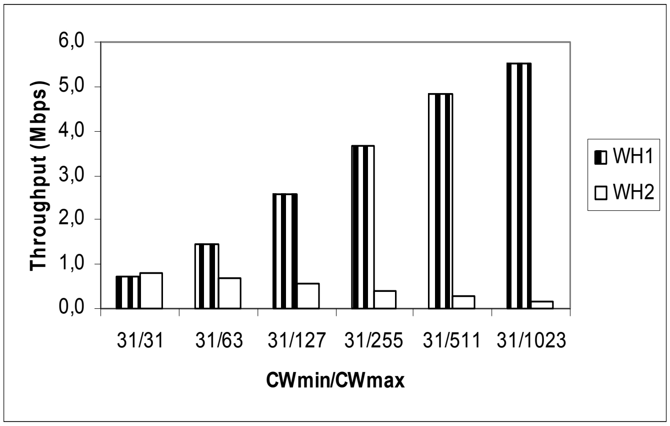

Fig 5 – CW Variation

The results shown in Table 2 demonstrate an increase of R_m (average throughput) by a factor of 3, similar to the result obtained in Section V.

TABLE 2
Anomaly mitigation strategy comparison

Station	With anomaly [kbps]	With the strategy [kbps]
1	637	4014
2	732	197
Average Throughput (Theoretical)	623.95	1758.5
Average Throughput (NS Simulation)	684.5	2105.5

Our simulation results show that the precision of the analytical expressions is fairly good. The expression for the theoretical throughput slightly underestimates the impact of collisions. However, this discrepancy results in only a very small difference between theoretical and simulation results.

VI. CONCLUSION

This paper proposes a strategy for mitigating 802.11 MAC anomaly by controlling the CW in accordance with the SNR. The analytical approach used was validated by means of simulation.

The result obtained demonstrated a fairness behavior, because the low SNR condition of one wireless host doesn't affect the others. This behavior is appropriate for a PWLAN that works with mobile users and in which this heterogeneous condition will be frequent.

In an experiment made by [4], they tested with Fat and Thin architecture four couples in similar condition as in this paper: three couples of hosts have good SNR condition operating near the AP with 11 Mbps. The other wireless host (WH4) was located in a place with low SNR.

With the Fat architecture is clearly verified the anomaly performance. But the Thin architecture analysis presents a very different result: when couple FH4-WH4 begins to transmit in low SNR, it doesn't affect the other couples. This represents that is possible to implement this kind of strategy proposed in this paper, once that in proprietary architecture this already exists.

It is required to implement our work in available source code, above the chipset or firmware, so it can eventually be ported to any IEEE 802.11 software driver running on an Access Point that provides sufficient information to the user about CW. Furthermore, CW_{min} is expected to be a configurable parameter in 802.11e.

The anomaly mitigation presented in this article opens a new option for network managers to control PWLAN behavior using a combined SNR and QoS strategy. When the anomaly is not mitigated, the QoS strategy does not work properly.

This option gives network managers the flexibility to make their enterprise policies more adequate. It also has great potential to improve the network performance.

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