Performance Evaluation of the IEEE 802.11 WLAN Supporting Quality of Service

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Abstract: This paper presents a performance evaluation of a new solution for the support of QoS by IEEE 802.11 WLAN. It aims at the improvement of the Medium Access Control (*MAC*) by taking into account information from both physical and network layers for packets differentiation scheduling. An analytical model based on stochastic Petri nets representing the dynamics of the new MAC is evaluated. Then, OPNET simulations are carried out based on the new MAC in order to evaluate its performance. Comparison between analytic and simulation results show the interest of our Cross-Layer approach which allows improving or at least keeping the same network performances while supporting Quality of Service.

Keywords: MAC, Quality of Service, Stochastic Petri nets, modeling, performance evaluation, simulation, wireless LAN.

1. INTRODUCTION

IEEE 802.11 specifies the Medium Access Control (*MAC*) and the physical layer (*PHY*) for wireless connectivity within a local area [IEEE 802.11, 1999]. The goal is to allow interoperability between WLANs systems of the various manufacturers and meet a need increasingly important for wireless communications.

Two types of wireless local area network architectures exists [Mühlethaler, 2002]: ad hoc architecture and architecture with access point AP (or infrastructure).

The *MAC* sublayer provides the control of the medium access, deliver data in a reliable way and protect data. It defines two access methods: the Distributed Coordination Function (*DCF*), which is mandatory, and the Poling Coordination Function (*PCF*), which is optional. However PCF function, supposed to support real time services, is not implemented in the majority of the commercial 802.11 products. Moreover, the co-operation between *PCF* and *DCF* modes leads to performance degradation [Visser et al., 1995]. Besides, *DCF* can be used in ad hoc network as in infrastructure network, whereas *PCF* is used only in infrastructure network. So, we choose a distributed control for the medium access ensured by *DCF*.

The fundamental access method is a *DCF*. It is known as carrier sense multiple accesses with collision avoidance (*CSMA/CA*). It is based on the listen-before-talk scheme.

The 802.11 standard defines a random Backoff time following a busy medium condition in order to reduce the probability of collisions. In addition, an immediate positive acknowledgment is used to confirm reception.

Two access types are proposed by DCF: basic access and *RTS/CTS* (Request To Send / Clear To Send). Compared to the former, the latter sends *RTS/CTS* frames of small sizes before sending the data frames, thus making it possible to minimize the collisions. Moreover, *RTS/CTS* mechanism is used to improve the access control and solve the problem of hidden stations. *RTS* frame is sent before each data frames transmission. In answer, the receiving station sends a *CTS* frame to confirm being ready to receive. Thus, all stations update their network allocation vector (*NAV*) according to *RTS/CTS*.

A station shall sense the medium to decide if another station is transmitting. If the medium is free during a Distributed Inter Frame Space (*DIFS*), the station waits for an additional random time (Backoff time) to avoid collision with other "waiting" frames then it sends the frame and awaits an acknowledgment (*ACK*). If the medium is determined to be busy, the sending is differed according to the Backoff procedure. During the contention window *CW* ($CW_{min} \leq CW \leq CW_{max}$), the Backoff time is decreased as long as the medium is sensed idle. If the latter is sensed busy, Backoff time is frozen. When it reaches zero, the frame is transmitted. The medium state (idle/busy) is indicated by the carrier sense function which is performed both through physical and virtual mechanisms.

Backoff time is given by the following formula:

$$BackoffTime = Random() * aSlotTime \qquad (1)$$

Where *aSlotTime* depends on the physical layer parameters and *Random( )* is a uniform value of distribution in [0, *CW*]. *CW* is an entire in [CW_{min} , CW_{max}] defined by the physical layer.

When there is a collision and no *ACK* is received, the Backoff time increases according to the following formula:

$$n \leftarrow n+1$$

$$CW(n) = (aCW_{\min} + 1) * 2^n - 1 \qquad (2)$$

In order to improve the *MAC* level according to the medium conditions indicated by the *PHY* layer, many studies were undertaken. [Qiao et al., 2002] used combination of the *SNR* ratio, the test frames count and average load as metrics for the connection adaptation algorithm. The latter is based on a pre-established table of a better transmission rate for future transmission attempts. [Chevillat et al., 2003] took into account the acknowledgment obtained by observation to evaluate the medium quality. Thus, if the number of successive succeeded transmissions exceeds *S*, then rate increases. Otherwise, if the number of failed successive transmissions exceeds *F*, then the rate decreases. [Barry et al., 2001] proposed a method based on modification of the maximum and minimum bounds of the contention window in order to be able to support two service classes, with high priority and "Best effort". The emulation of the *MAC* sub layer (Virtual MAC) and application of virtual sources (*VS*) make possible observation and medium state evaluation by following real packets in parallel and in passive way. In [Pavon et al., 2003], the approach is based on the level of the received signal (*RSS*) as a decision metric in order to adapt dynamically the transmission rate knowing that the emitted signal level is constant and that relation between *RSS* and *SNR* (Signal to Noise Ratio) is linear. [Lampe et al., 2002] proposed the prediction of Packet Error Rate (*PER*) as decision criterion for the connection adaptation. This is done thanks to the temporary medium transfer function, and the *SNR C/I* (Carrier/Interference) ratio.

In addition, many approaches were developed in order to improve the *MAC* level according to the medium conditions. In a certain way, the proposed approaches improve the performance of the 802.11 standard but only from a network charge point of view [Bedoui et al., 2005]. However, the increasing number of multimedia applications such as VoIP and video streaming, and the expansion of the Internet causes the taking into account of real time constraints. New multimedia flows are as demanding in quality of service as it is insufficient to be limited to only one layer to support the QoS. Thus, any proposed approach for QoS improvement must deal with the performance metrics relating to physical and network layers, such as packets loss and throughput.

2. AN APPROACH FOR THE SUPPORT OF QOS

Many researches concerning IEEE 802.11 WLAN proposed solutions to improve performance of the *MAC* sublayer without really taking into account the mutual interaction between *MAC* sublayer on a side and Network layer and of the *PHY* layer on the other side.

We proposed a solution for *MAC* QoS improvement based on the integration of information resulting from the Network layer and from the *PHY* layer of IEEE 802.11 which is the base of IEEE 802.11 a/b/g.

2.1 PHY and MAC interaction

Based on the information resulting from the *PHY* layer, we distinguish between Measured Value Parameters (*BER*, *SNR*, etc.) and those with Values defined by the standard according to the concerned physical layer (*aSlotTime*, *aCWmax*, *aCWmin*, *DIFS*, *SIFS*, *PIFS*, etc.).

Bit Error Rate (*BER*) indicates quality and state of medium but its value is calculated only at the receiving station. Then, the transmitting station is considered "blind" in meaning of *BER* and it will be informed of the medium quality only if it will becomes receiving station.
Signal to Noise Rate *SNR* is a *PHY* layer parameter which concerns the useful rate depending on data packets computing. This parameter is calculated not only on the level of the receiving station but also at the transmitting station. Thus, we choose *SNR* parameter:

$$SNR = \frac{Emitted\,/\,received\_signal\_power}{Noise\_power} \qquad (3)$$

According to medium quality, this parameter will indicate to the *MAC* what kind of traffic to send. Assume that $(SNR)_{BE}$ is the acceptable limit of *SNR* for the “Best Effort” traffic and $(SNR)_{QoS}$ is the acceptable limit of *SNR* for the “QoS” traffic.

The following condition must be observed:

- If $(SNR) < (SNR)_{\mathrm{BE}}$, then station differs transmission ;
- If $(SNR)_{\mathrm{BE}} \leq (SNR) < (SNR)_{\mathrm{QoS}}$, then station differs transmission if we have QoS traffic, otherwise it emits the Best Effort traffic ;
- If $(SNR) \geq (SNR)_{\mathrm{QoS}}$, then station transmits in both cases of Best effort or QoS traffic.

This proposal shows clearly the advantage of interaction between layers and the narrow dependence between decision to emit or differ the transmission on MAC, *SNR* ratio on PHY and traffic classes on Network layer.

It’s possible to consider only QoS traffic allowed if the *SNR* is unfavourable. Although this increase the likelyhood that QoS messages are delivered timely, it reduce overall traffic which represents a considerable disadvantage.

2.2 MAC and Network interaction

With an aim of supporting the multimedia applications, *IP* networks use *Diffserv* architecture ensuring service differentiation. To be treated in a particular way by various network nodes, packets are classified and marked. This classification is not known by traditional *MAC* sublayer since it supposes that there is no difference between traffic flows.
In order to improve the *MAC* level to be able to support the QoS, we propose to jointly exploit information obtained from *PHY* and Network layers to deliver packets following their priorities according to QoS requirements.

In a *WLAN*, frames must be differentiated according to priority classes indicated by high layers in order to ensure point-to-point QoS based on *DiffServ*. When a data frame *MSDU* (MAC Service Data Unit) arrives at *MAC* sublayer, it