Performance Evaluation of Self-Similar Models for Traffic on IEEE 802.11 Networks – Study of Case for the QRD Network

Evaluación del Desempeño de los Modelos de tráfico Auto-similares en redes IEEE 802.11 - Caso de Estudio Red QRD

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Abstract— This paper evaluates the performance of fractal or self-similar traffic models in IEEE 802.11 networks. This study is focused on the "Quindio Región Digital" (QRD) network. Performance evaluation of the traffic models is performed in three stages. In the first stage, we obtain the statistical characteristics of the current traffic on the QRD network. In the second stage, the most suitable traffic models are selected for the current characteristics of the QRD network such as out-of-saturation operation and management of heterogeneous traffic. In the third stage, we define a performance metric that is used to evaluate the traffic patterns through simulation.

Keywords— QRD, WLAN, MAC, time slot, contention window, self-similarity, traffic, correlation, goodness of fit test, snnifer.

I. INTRODUCTION

In the recent years, wireless networks have become popular for the design of access networks due to their potential benefits with respect to wired networks. Since the standard IEEE 802.11 has been widely accepted for the design of these networks, a detailed study of this standard provides useful tools to design and plan proper networks, and to meet user requirements with respect to information management and services.

This paper presents the performance evaluation of one popular method to model WLAN 802.11networks. This model takes into account an exponential backoff protocol under non-saturated stations and heterogeneous-traffic-flow conditions to compute the throughput of the distributed coordination function (DCF) for basic access. Therefore, this model is suitable for the analysis of traffic frames in a real network. In this paper, the performance of this model is compared using actual data from the "Quindío Región Digital" (QRD) network.

The model under analysis assumes that the probabilities of packet collision of a packet is constant and independent on the state and station regardless the number of retransmissions. This assumption, validated through simulations, shows high-accurate results even when the number of stations in the wireless LAN is greater than 10.

This paper is organized as follows. Section 2 defines the two medium access mechanisms used in DCF, basic mechanism and RTS/CTS (Request to send/Clear to send) mechanism, as well as a combination of both. Section 3 shows the results and statistics obtained for a real traffic in the QRD

network. Sections 4 and 5 include the performance evaluation of the model under study, which take into account real conditions such as non-saturated stations and heterogeneous traffic. Section 6 presents the simulation results that verify the performance of this model on the QRD network. Finally, Section 7 summarizes the results and discusses the performance of the model on real network data.

II. DISTRIBUTED COORDINATION FUNCTION 802.11

This section presents an overview of the distributed coordination function (DCF) described by the IEEE 802.11 protocol. A detailed description is included in [6], [7], [8], [10] and [15].

A station with a new packet to be transmitted senses the channel activity. If the channel is found inactive during a period of time equal to the distributed interframe space (DIFS), the station transmits. Otherwise, if the channel is found busy (immediately or during the DIFS), the station continuously senses the channel until it is found inactive during a DIFS. From this viewpoint, the station generates a random backoff interval before transmitting (i.e., performs an anti-collision protocol) to minimize the probability of collision within the packets transmitted by other stations. In addition, to avoid channel break, a station must wait for a random backoff time between two consecutive transmissions of a new packet even if the channel is found inactive during a DIFS. To improve efficiency, DCF uses a discrete backoff scale. The time following an inactive DIFS is sliced and a station can transmit only at beginning of each slot time. The size of the slot time "σ" is set equal to the time required by each station to detect the transmission of a packet from any other station.

TABLE I

Slot Time (ranura de tiempo), valores máximos y mínimos de la ventana de contienda para las tres especificaciones PHY del estándar 802.11: Frecuency Hopping Spread Spectrum (FHSS) Direct Sequence Spread Spectrum (DSSS), and Infrared (IR).

PHY	Slot Time (σ)	CWmin	CWmax
FHSS	50 μs	16	1024
DSSS	20 μs	32	1024
IR	8 μs	64	1024

As shown in Table I, the size of the slot time "σ" depends on the physical layer, and it represents the propagation delay involved in switching from a reception state to transmission state (i.e., RX-TX time) as well as the time to signal to the MAC layer
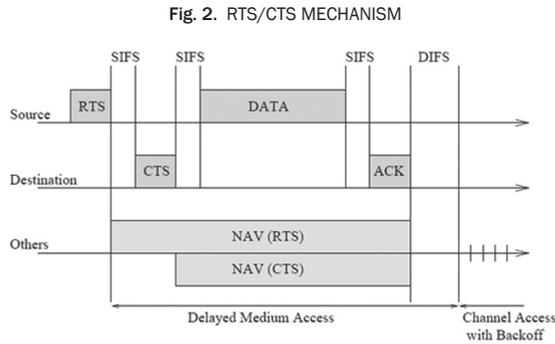
about the channel state (i.e., to detect a busy time). DCF adopts an exponential backoff behavior, in which the backoff time for each packet transmission is chosen to be uniform in the range (0,W-1), where W is called contention window, and this window depends on the number of failed transmission for a given packet. In the first transmission attempt, W is set to be equal to the minimum contention window (CWmin). After each failed transmission, W is doubled until reach its maximum value CWmax = 2^mCWmin. The values for CWmin and CWmax are reported in the final version of the standard [15]. The backoff time counter is stopped when a transmission is detected over the channel, and it is resumed when the channel is found inactive again for more than one DIFS. The station transmits when the backoff counter reaches zero. Fig. 1 depicts this operation.

Since CSMA/CA (Carrier Sense Multiple Access/ Collision Avoidance) is not based on the station capabilities to detect a collision by listening to their own transmissions, an affirmative acknowledge (ACK) is transmitted by target station to signal a successful packet reception. ACK is transmitted immediately following the packet reception, and this time interval is called short interframe space (SIFS). As long as the SIFS (in addition to the propagation delay) is shorter than a DIFS, none station is capable of detecting channel inactivity during a DIFS until the end of an ACK. If the transmitting station does not receive any acknowledge for a certain ACK waiting time, or a different transmission packet is detected over the channel, the transmission of packets is restarted according to the predefined backoff rules. The previous two-way transmission approach is called basic access mechanism. DCF defines an additional and optional four-way transmission approach. This mechanism is called RTS/CTS, which is shown in Fig. 2.

Fig.1. BASIC ACCESS MECHANISM
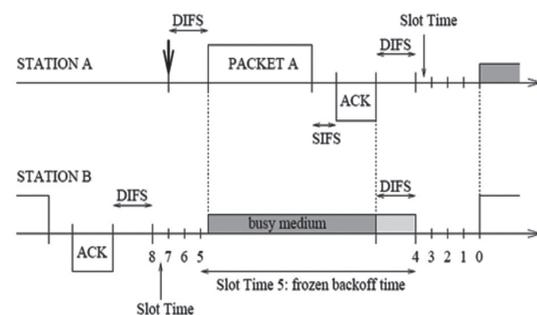
Source: P802.11, IEEE Standard for Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, November 1997.

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Fig. 2. RTS/CTS MECHANISM

Source: P802.11, IEEE Standard for Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, November 1997.

The station that requires a packet transmission must wait until the channel is found inactive during a DIFS, following the backoff rules explained above. Then, instead of transmitting the data packet, a preliminary short frame, called "request to send" (RTS), is transmitted. When the target station detects a RTS frame, it responses, after a SIFS, by sending a "clear to send" (CTS) frame. A station is allowed to transmit only if a CTS frame is received properly.

RTS and CTS frames carry out information about the length of the packet to be transmitted. This information can be read by any other listening transmitters, which update the network allocation vector (NAV) that stores information about the period of time when the channel is busy.

RTS/CTS mechanism is efficient in terms of system performance since it reduces the length of the frames involved in a contention process. In fact, even assuming perfect channel detection by each station, collision may occur when two or more packets are transmitted on the same slot time. If the two transmission stations employ a RTS/CTS mechanism, a collision is produced only in the RTS frame. However, this issue can be detected quickly by all transmission stations due to the lack of a CTS frame [5].

III. ACQUISITION OF A REAL TRAFFIC

This section shows the data obtained from a real traffic in the QRD network, and the statistics performed on this data.

### A. Capture of traffic in the QRD network and statistics estimation

A protocol analyzer was used to capture information about packets [12]. This information is grouped according to the arrival time and length of each packet. In this way, histograms and goodness of fit tests are used to estimate the statistics that characterize the traffic and features of the QRD network.

### B. Identification of the distribution function

The methodology of goodness of fit test proposed by Kolmogorov-Smirnov [11] is used to determine the distribution functions for the arrival-packet time and packet length. As a result of this test, the distribution function for the arrival-packet time is found to be exponential, this is shown in Fig. 3. With respect to the packet length (or equivalently, the average service time), the distribution function is uniform, this is shown in Fig. 4.

Fig. 3. EXPONENTIAL DISTRIBUTION FOR THE ARRIVAL-PACKET TIME ON JANUARY 26, 2011.
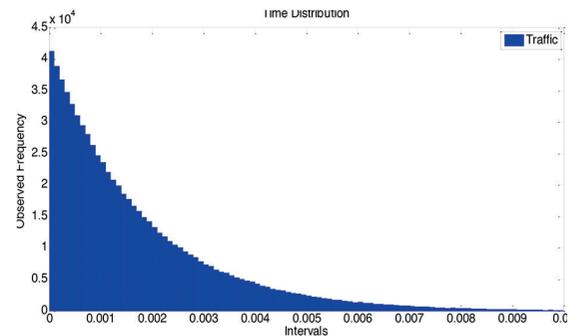
Source: Author of the project

Fig. 4. UNIFORM DISTRIBUTION FOR THE PACKET LENGTH
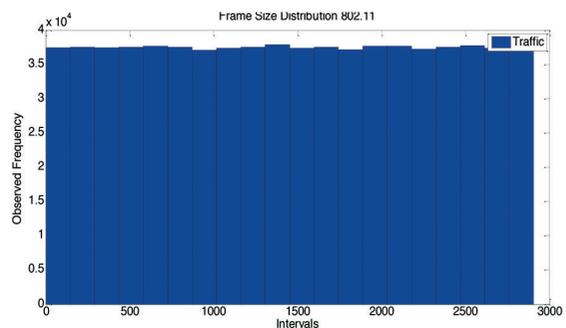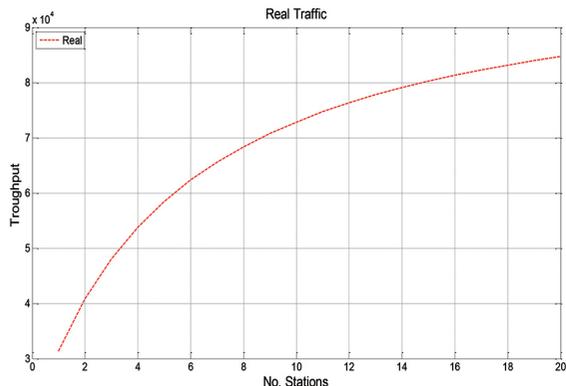

Source: Author of the project

IV. THROUGHPUT FOR THE REAL TRAFFIC AND SELF-SIMILAR MODEL

A. Throughput for the real traffic

From the QRD data, the time mean average of the packets is 0.0076 seconds, which suggests that the actual offered traffic is λ_k = 7.6ms.

Fig. 4 shows an uniform distribution for the length of the payload bits in the packets. The mean value is 1452.76 bytes, i.e., L_k = 1452.76 bytes. Hence, the throughput in Mbps against the number of network stations is shown in Fig. 7. From this figure, it is possible to determine the maximum throughput of a network with different number of terminals by dividing this value by the number of terminals. Thus, if packets with an average length of 1452.76 bytes are transmitted to any rate such as 1, 2, 11 or 54 Mbps, the maximum throughput is 90 kbps, this is shown in Fig. 5. Asumming 20 terminals for the QRD network, the effective transmitsion rate by terminal are 4.5 kbps. This result is very accurate due to this analysis takes into account the time involved in solving collisions.

Fig. 5. THROUGHPUT IN THE QRD NETWORK AS A FUNCTION OF THE NUMBER OF STATIONS

Source: Author of the project

B.   Throughput for the self-similar model

A study about the self-similarity on aggregated traffic using the Hurst parameter for a wireless network close to the QRD network is presented in [4]. The degree of self-similarity is obtained for the QRD network from the arithmetic summation of the degree of self-similarity for each frame independently. In other words, the Hurst parameter is obtained separately for the data frame, the control frame, and the management frame, and those values are finally added together to obtain the Hurst parameter for the aggregated traffic.

In [1], [2], [3], [9], [13] and [14], the self-similar traffic for WLAN networks is modeled through an M / G / ∞ queue.

• Definition 1 [2]

A random process {X(t),t∈R} is called H-$_{sssi}$ if it is self-similar with a parameter H, and it has stationary increments.

• Lemma 1 [2]

It is assumed that {X(t),t∈R} is a non-degnerative process H-$_{sssi}$ with an inifity variance. Then, 0 < H ≤ 1, X(0) = 0 and the covariance is defined by

$$R(t_1,t_2) = \frac{1}{2}\{[|t_1|^{2H} + |t_2|^{2H} - |t_1 - t_2|^{2H}]\sigma_x{}^2\} \quad (1)$$

If X(t) is a non-degenerated process H-$_{sssi}$ with finite dispersion, then 0 < H ≤ 1. During simulation of the traffic, the range 0.5 < H < 1 is particularly interesting since the process H-$_{sssi}$ X(t) with H < 0 cannot be measured, and it belongs to a pathological case. While the case H > 1 is forbidden since the stationary condition in this process is cumulative. In practice, the range 0 < H ≤ 0.5 can be excluded because this cumulative process is called short range dependence (SRD). For practical purposes only the range 0.5 < H < 1 is relevant. In this range, the correlation factor for the cumulative process Y(t):

$$Y_k = X(k) - X(k-1), \qquad k \in \mathbb{Z} \quad (2)$$

has the following form:

$$r(k) = \frac{1}{2}[(k+1)^{2H} - 2k^{2H} + (k-1)^{2H}] \quad (3)$$

C.   M / G / ∞ Queue

The M / G / ∞ process is defined as follows. The discrete-time M / G / ∞ queue is modeled with slot time "σ" as time interval. All Poisson-type arrivals within the slot time are used for service before the beginning of the next slot, where W(s=k), k=1,2,..., is the probability density function (pdf) of the service time S given in slot-time "σ" units. For this system, it is known that the pdf of the queue length is a Poisson distribution at the end of each slot time with mean λ = $λ_o$*M[s], where $λ_o$ is the average number of arrivals when the system is at the state 0 in the M / G / ∞ queue. However, the next queue lengths at the end of the slot time are correlated with autocorrelation function r(k) = P(S > k). Hence, if this queue-length process is used to generate the arrivals for the analyzed system, the next arrival process A is obtained from the marginal distribution of A, which is a discrete-time Poisson process with parameter λ for each slot

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time, and P(S > k) is the autocorrelation function. In practice, it is necessary to obtain the autocorrelation function r(k), which could be used to compute the distribution required for the service time. In particular,

$$P(S > k) = P(\tilde{s} = k)M[S] = [r(k) - r(k+1)]N(S) \quad (4)$$

Whatever $P(S>0) = 1$ and $r(0) = 1$, by definition, $M[S] = 1 / [1-r(1)]$. Then, for the long-range dependence (LRD),

$$r(k) = \alpha k^{-\beta}, \quad 0 < \beta < 1 \quad (5)$$

Where $\alpha = r(1) = 1 - M[S]$. As a result, the arrival process is and asymptotic self-similar process with Hurts exponent $H = 1 - \beta / 2$.

Since the M / G / ∞ queue describes only a discrete-time arrival process, the next step is the generation of isolated arrival times. This procedure is obtained by grouping arrivals of K≥1 slot times followed each other, and strong distribution over all intervals of length $t_o = \sigma k$ seconds.

Let N be the number of arrivals within k slot times. Since N is a Poisson process, the assignment of each arrival inside the interval corresponds to a uniform distribution (the distribution of interval times between arrivals is still non-exponential).

The offered traffic obtained from (3) and (5) in terms of the autocorrelation function r(k), where k is the average time of a packet on backoff state taking into account the collisions described above, is given by

$$r(k) = \alpha k^{-\beta} = \frac{1}{2}[(k+1)^{2H} - 2k^{2H} + (k-1)^{2H}] \quad (6)$$

Since

$$H = 1 - \frac{\beta}{2} \quad (7)$$

then

$$\alpha k^{-\beta} = \frac{1}{2}[(k+1)^{2-\beta} - 2k^{2-\beta} + (k-1)^{2-\beta}] \quad (8)$$

where k is $W_{average}$ or the average time of a packet on backoff state. Since this process is uniform, and the contention window is 256, this average time is 128. H is the Hurst parameter. To find the most suitable Hurst parameter that matches the real traffic model, the throughput is varied in the range 0.5<H<1. According to this value, it is possible to determine if the self-similar model is the best description for the real traffic in an IEEE 802.11 network. The variations of the H parameter are shown in Fig. 6.

$r(k)$ is the same ρk, i.e., the offered traffic, which is replaced in the throughput $S_k(n)$:

$$S_k(n) = \frac{\rho_k(n)}{X_k(n)}L_k \quad (9)$$

Up to this point, all parameters are replaced to solve the above equation except the Hurst parameter, which is varied to determine the degree of self-similarity in the model, and so to obtain the features of a real traffic.

Self-similar models takes Hurst parameter values within the range 0.5<H<1, where a value of H close to 1 corresponds to strong self-similarity. From Fig. 6, the Hurst parameter that better describes the real traffic is H = 0.61, which suggests that the model has a low degree of self-similarity. Therefore, self-similar models are not able to describe effectively the real traffic in wireless WLAN networks.

Fig. 6. EFFECT OF THE HURST PARAMETER ON THE THROUGHPUT
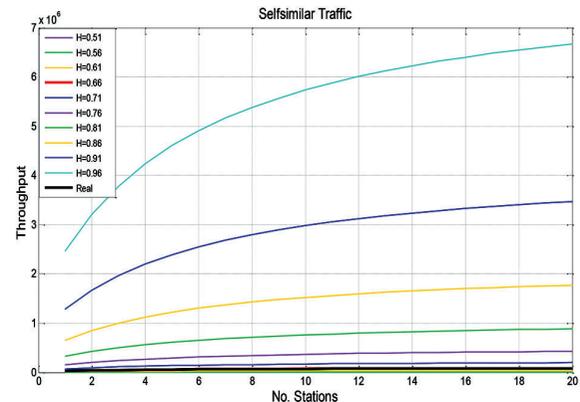
Source: Author of the project

V. RESULTS

The graphical results for the model under study for the QRD network (a WLAN IEEE 802.11g network) as well as the real traffic are shown in Fig. 7. This figure allows us to establish that the model describes the real traffic in the QRD network. In this figure, throughput for the real traffic is shown in red and the throughput for the self-similar model in blue.

From this figure, we can say that the model describes from good way the conditions of real traffic.

To support this claim, a numerical analysis based on correlation provides more accurate information than a graphical analysis. Correlation results for the self-similar model and the real traffic on the QRD network.

Correlation coefficient for the real traffic and the self-similar model:

$$0.941$$

Since the correlation coefficient is close to one, it is concluded that the model provide a strong correlation with the real data.

The previous results allow us to conclude that the model describes the features of IEEE 802.11 network traffic.

Fig. 7. THROUGHPUT FOR THE SELF-SIMILAR MODEL, AND REAL TRAFFIC.
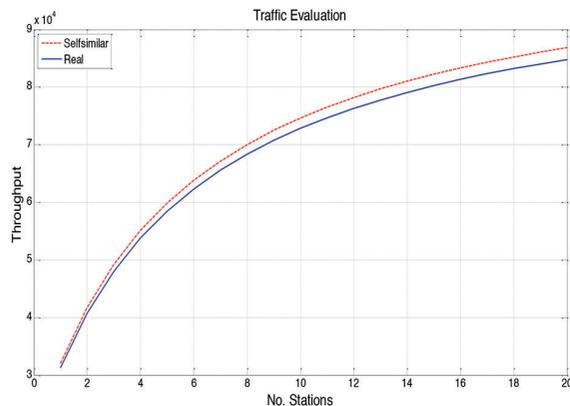
Source: Author of the project

VI. CONCLUSIONS

In this paper, the one popular traffic models for IEEE 802.11 wireless networks was evaluated. The model is based on self-similar theory, defining a simple but powerful model that captures all characteristics of the medium access control (MAC). It is important to highlight that this model depends exclusively on the distribution of packet arrivals obtained for the QRD network. The self-similarity of the traffic turns out relevant once the random process becomes similar at different scales, but this model (self-similar model) is no longer popular due to the mathematical complexity and the complex estimation of the self-similarity degree from the Hurst parameter. To estimate this self-similarity degree, it is necessary to determine the Hurst parameter separately for each frame, and then to obtain a unified Hurst parameter that

provides an estimation of the self-similarity degree for the actual traffic. Independently on the differences between both models, it is possible to conclude that the actual traffic in the WLAN QRD network is well described by a self-similar model. Under the assumptions about a memoryless Poisson process for the arrival time and the probability of packet collision independently on the previous state, it was possible to obtain a simulated throughput that matches the throughput obtained from a real traffic.

The most important reason why the model was selected for this study is the ability of this model to describe real conditions in non-saturated networks and heterogeneous traffic, i.e., streaming and elastic flows. Hence, it was feasible to perform a comparison under normal conditions, and these simulation results are close to real data.

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