WLAN Token Passing MAC Proposal with Optimized FDD technique

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Abstract: – By considering a WLAN with a polling MAC scheme and a centralized topology based on a hub with control and relay functions, this paper investigates the problem of managing the resources relative to the uplink and the downlink. The proposed and analytically studied resources allocation is a FDD scheme, with a suitable organization of the signal and information packets on the band partition. In order to make realistic the investigation, a not ideal channel, characterized by a certain bit error probability, two ARQ strategies, to mitigate the error effects, and a traffic model, to consider packet routes from stations inside and outside the WLAN, are taken into account. A general performance optimization procedure, based on an opportune bandwidth partition selection, is presented and some results are shown, by considering a simple scenario.

Key-Words:–Computer Networks/Protocols, Queuing Theory and Communications/Traffic Problems

1 Introduction

The wireless access for a computer network has received in the last years a growing consideration [1] [2], due to the possibility of effectively using it in situations where the wired solutions are difficult to be installed. Furthermore, the radio access permits a high host location freedom and, with suitable signaling procedures, the terminal mobility. The broadcast nature of the wireless channel requires a capacity division scheme. Some different choices are possible, such as those based on random or deterministic protocols. In this paper we propose of using a token passing protocol, which is more reliable with respect the random ones for high throughput values and more versatile for a data traffic with respect the deterministic ones. The wireless LAN topology is usually peer-to-peer or centralized. In the former case the communications between the wireless stations are directly, in the latter a hub with relay function is present. In this work we have adopted the last solution, which presents a high link reliability, due to that the hub can be located in a strategic position, i.e. on the ceiling. Furthermore the hub is used as connection point to a wired network and performs control actions. This approach can be extended to a distributed system with intelligent and dynamic hub assignment, as addressed in [3], which can be degenerated to a peer-to-peer network. The polling action could be adapted to traffic and channel conditions by forcing the hub to schedule different access times to the stations. This problem has been studied in [4] and [5] both from a theoretical and implementation point of view but they do not specify ARQ and uplink versus downlink allocation strategy, which are the topics of this paper accompanied by of traffic and channel considerations.

As far as the uplink and downlink resource allocation is concerned, a frequency division duplex (FDD) technique is adopted. The bandwidth is split into two parts, one for the hub transmissions, $(1-\delta)C$, and one for the mobile host communications, δC, where C is the total available bandwidth. The hub sequentially gives the control to the stations; each station sends to the hub all queued packets and return the control. During the station transmission on the δC band, the hub can use its $(1-\delta)C$ band fraction to deliver its queued packets. The mobile host band is also used to pass the control, i.e. the token delivery from the hub to the generic mobile host and viceversa are performed on the δC band. This choice permits to hub and stations to not limit each other.

The token passing analysis follows the approach presented in [6]: first the average time necessary to pass the control through all stations is identified, called cycle time T_C, then two queue effects are taken into account. The former queue time, T_{q1}, is from a packet arrival to the control reception and the latter, T_{q2}, is from the control gain to the packet transmission. T_{q1} is computed by assuming uniform packet arrivals on the time in which the station is not holding the control. T_{q2} is evaluated by neglecting the time to pass the control and by modeling the system as it is composed by an unique aggregate queue, by using the $M/G/1$ [7] theory.

The packet length is assumed constant equal to F, due to that some extensive measures performed in our departmental LANs are showing packet lengths strongly concentrated around some fixed values. The number of stations in the LAN is assumed fixed during the network work, equal to N.

The developed model allows to specify the station position with impact both on performance and on propagation delay. As far as the propagation channel is concerned, it is possible to assume, in an indoor environment [4], its stationarity at least for a time in the order of 50-100 ms, within the range of system parameters of interest. With this assumption, we have verified that the cycle time is less than the stationarity time, so the bit error probability, P_b^v, results to be constant into a T_C in the link between the generic v-th station and the hub. Even if the channel is modeled as stationary, by adopting some interleaving strategies, the bit errors can be assumed to be independent each other [8]. The propagation delay, τ_p^v, is evaluated as $\tau_p^v = d^v/c$, where d^v is the distance between the v-th station and the hub and c is the light speed. Both P_b^v and τ_p^v are deterministic once stations positions are fixed, and they are correlated as a function of the distance.

Two easy ARQ strategies have been considered in order to have a correct packet reception: stop-and-wait and go-back-n [9]. The latter is used only for the hub packet transmissions, while all other communications are based on the former. In both cases the ACKs are one for each packet and token sent. By assuming the ACK length $A \ll F$, it is possible to neglect the ACK frame loss without any significant impairment on the performance. As far as the token is concerned, we assume a fixed length $K \ll F$, with $K > A$, to support signaling informations for bandwidth allocation and stations monitoring. The token loss possibility is taken into account throughout the paper. Beside the ARQ strategies, the FEC ones could be included to improve the system performance in terms of P_b^v.

Performance are investigated by computing the average access time T_{acc}, defined as the average time from a packet arrival in the system to the delivery to the final target without errors. The bandwidth partition, δ, has been optimized by minimizing the average access time, and its value is shown as a function of the basic system parameters.

The paper is organized as follows: in Section 2 the general traffic model for the wireless network is reported. Section 3 presents the ARQ strategies adopted and Section 4 shows the FDD protocol and the performance analysis. In Section 5 some details about scenarios and some numerical results are reported. Finally, in section 6 some conclusions have been drawn.

2 Traffic model

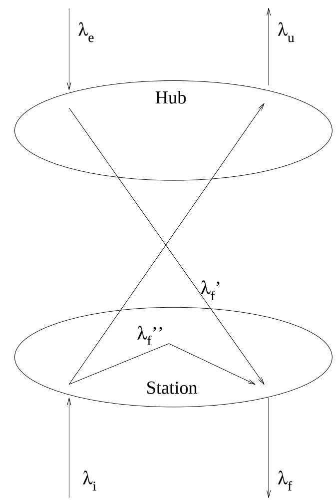

Figure 1: Traffic model related to a single station

Let us consider Fig. 1, where an uniform traffic situation is assumed and the labels i, f, e, and u identify the station input and output, hub input and output ports, respectively. Let λ_i and λ_f be the rates of packet generation and destination for a single station, respectively. Let the hub be modeled as a set of N entities, such that the total external arrival and departure rates to and from the hub can be split for each entity in the quantities: λ_e and λ_u. This split permits a one-to-one correspondence between hub and stations in force of the uniform traffic assumption. Let λ_f'' be the fraction of the rate λ_i, generated by a wireless station, which is addressed to another wireless station. In stationarity, it must be $\lambda_e + \lambda_i = \lambda_u + \lambda_f = \lambda$, where λ is the average arrival rate. The rates λ_i and λ_f'' can be expressed as functions of two characteristic parameter, α and ρ, as follows: $\lambda_i = \alpha\lambda$ and $\lambda_f'' = \rho\lambda_i$. The interLAN parameter α is the probability that the incoming packets are generated from a wireless station and the intraLAN parameter ρ that a packet remains in the LAN, i.e. that it is originated from and destined to a wireless station. From Fig. 1 it follows that $\lambda_f = \lambda_f' + \lambda_f''$ where $\lambda_f' = \lambda_e$.

By observing that it is not possible to have flow from port e to port u and by collecting the rates definitions, we have:

$$\begin{aligned}
\lambda_i &= \alpha\lambda = \alpha\frac{SC}{NF} \\
\lambda_e &= (1-\alpha)\lambda = (1-\alpha)\frac{SC}{NF} \\
\lambda_f &= (1-\alpha+\rho\alpha)\lambda = (1-\alpha+\rho\alpha)\frac{SC}{NF} \\
\lambda_u &= \alpha(1-\rho)\lambda = \alpha(1-\rho)\frac{SC}{NF}
\end{aligned}$$

where the generic arrival rate λ has been expressed as a function of the throughput S which represents the maximum bit per second which is possible to correctly send with respect to a certain fixed transmission rate C, for direct connections between entities ($S = N\lambda F/C$).

In order to compute the average access time, it is necessary to evaluate the packet routing probabilities, P_{if}, P_{iu} and P_{ef}, relative to if, iu and ef routes, respectively. Let us observe that the if traffic is always relative to different stations, even if the uniform traffic assumption permits to model it on the same station. Then, the packet routing probabilities are: $P_{if} = \lambda_f''/\lambda = \rho\alpha$, $P_{iu} = \lambda_u/\lambda = \alpha(1-\rho)$ and $P_{ef} = \lambda_f'/\lambda = 1 - \alpha$

Let us remember that, in force of the hub relay function assumption, communications between wireless stations always experiment up and down cumulative paths. Let us call the hub with B (to remember that it is the base station) and the generic v-th station M_v (to remember that it is the mobile station). Then, by defining T_B^v and T_M^v the v-th correct packet delivery average time in the downlink and in the uplink, respectively, the network average access time becomes:

$$T_{acc} = \frac{1}{N(N-1)} \sum_{v=1}^{N} \sum_{w=1, w \neq v}^{N} [T_M^v P_{if} + T_M^v P_{iu} + \\ + T_B^v P_{ef} + T_B^w P_{if}] \tag{1}$$

3 ARQ Techniques

As above introduced, in order to have correct packet transmissions we have considered two simple ARQ techniques: stop-and-wait and go-back-n [9].

3.1 Stop-and-wait

The ARQ stop-and-wait approach, with strictly timeout, can be briefly analyzed as follows: let $t_G(Z)$ be the total transmission time of a frame of length Z, $t_i(Z) = it_G(Z)$ the time spent for i retransmissions and $P_i(Z) = (1-P_b)^Z[1-(1-P_b)^Z]^i$ the probability to have i retransmissions with independent bit errors. Then the two merit factors of interest, the first and second order moments of the service time $x(\cdot)$, used into the following derivation, are:

$$E[x(P_b, Z)] = t_G(Z) + \sum_{i=1}^{\infty} t_i(Z)P_i(Z) = \frac{t_G(Z)}{(1-P_b)^Z}$$
$$E[x^2(P_b, Z)] = t_G^2(Z) + \sum_{i=1}^{\infty} t_i^2(Z)P_i(Z) + \\ +2t_G(Z)\sum_{i=1}^{\infty} t_i(Z)P_i(Z) = \frac{2-(1-P_b)^Z}{(1-P_b)^{2Z}} t_G^2(Z) \tag{2}$$

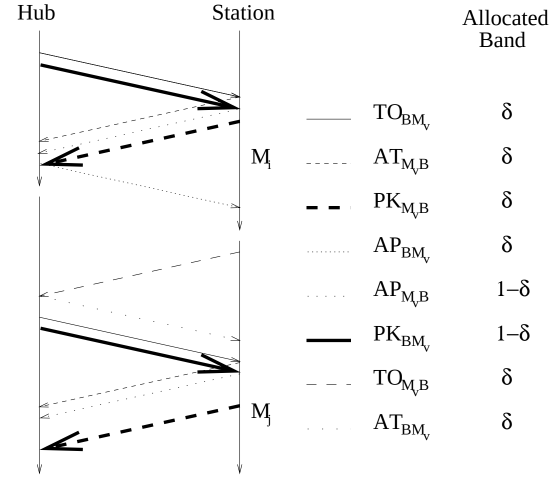

Figure 2: FDD protocol

3.2 Go-back-n

Let us introduce the go-back-n ARQ procedure with the conservative assumption that for each packet an ACK is sent, even if this is not strictly necessary. The timeout can be also considered strictly and the performance can be briefly analyzed as follows: let t_F be the packet transmission time, $t_G(Z)$, $t_i(Z)$, $P_i(Z)$ and Z defined as in the stop-and-wait case. Thus, the two merit factor parameters, the first and second moment of the service time, used into the following derivation, are:

$$E[\tilde{x}(P_b, Z)] = t_F + \sum_{i=1}^{\infty} t_i(Z)P_i(Z) = \\ = \frac{1-(1-P_b)^Z}{(1-P_b)^Z} t_G(Z) + t_F E[\tilde{x}^2(P_b, Z)] = \\ = t_F^2 + \sum_{i=1}^{\infty} t_i^2(Z)P_i(Z) + 2t_F \sum_{i=1}^{\infty} t_i(Z)P_i(Z) = \\ = t_F^2 + \frac{[1-(1-P_b)^Z][2-(1-P_b)^Z]}{(1-P_b)^{2Z}} t_G^2(Z) + \\ + 2\frac{1-(1-P_b)^Z}{(1-P_b)^Z} t_F t_G(Z) \tag{3}$$

4 FDD Protocol Description and Analysis

In our FDD system the token passing is using the band δC so that the hub actions are not interrupted by the control passing activity. All ACK are sent on the same bandwidth used for the packet or token transmission, i.e. the hub B waits for a packet ACK on the $(1-\delta)C$ band used to send the packets, and waits for a token ACK on the δC band used to deliver the token; the generic station M_v waits for the packet and token ACK on the δC band, used both for packet and for token transmissions. The bandwidth split can be adaptively changed as a function of network throughput, but is fixed from packet to packet.

A description of the proposed FDD protocol is reported in Fig. 2. Let us start with the case where the control is on the hub: B transmits the token, TO_{BM_v}, to the generic station M_v, on the δC band, and waits for the ACK, AT_{M_vB}, sent by M_v into the same band. Now, M_v has the control and sends, over the δC band, any queued packets, PK_{M_vB}, followed by the token TO_{M_vB}. If the hub correctly receive all packets and token, sends for each packet an ACK, AP_{BM_v}, and for the token the ACK AT_{BM_v}, on the δC band. In all above described transmissions a stop-and-wait ARQ strategy is adopted. In the same time the hub B sends, on the $(1-\delta)C$ band, all queued packets PK_{BM_v} and waits for the ACK, AP_{M_vB}, on the same band. In this case the ARQ technique considered is a go-back-n. The go-back-n ARQ permits to the B to work independently from M_v, otherwise the system could be degenerated to a time division duplex.

As far as the cycle time evaluation is concerned, due to that the time to poll all wireless stations is different from that necessary to the hub to deliver all queued packet, the main idea is to separately evaluate the time spent for serving the stations T_{CM} and that of the hub T_{CB}, as functions of the effective cycle time T_C; then, in a stationary situation we force the cycle time to be $T_C = \max\{T_{CM}, T_{CB}\} \forall \delta$.

The T_{CM} is built by considering the actions of the generic M_v station on the δC band. M_v must wait for the token reception, must send the packets arrived with rate λ_i, and must release the control. For each frame transmission the M_v must also wait for an ACK and must send an ACK to the hub to confirm the token reception. Let us remember that the ARQ technique used is a stop-and-wait. Then, by considering the Poisson distribution $\Pi_n(y) = \frac{y^n}{n!}e^{-y}$, where y is the product of the arrival rate and of the observation time, and by using the Eq. (2) for the average service time to correctly deliver a frame, T_{CM} results:

$$T_{CM} = \sum_{v=1}^{N}\left[\sum_{n=1}^{\infty}\Pi_n(\lambda_i T_C)\frac{n t_{GM}^v(F)}{(1-P_b)^F} + \frac{2 t_{GM}^v(K)}{(1-P_b)^K}\right] = \\ = \sum_{v=1}^{N}\left[\lambda_i T_C \frac{t_{GM}^v(F)}{(1-P_b)^F} + 2\frac{t_{GM}^v(K)}{(1-P_b)^K}\right]$$

where $t_{GM}^v(Z) = (Z+A)/(\delta C) + 2\tau_p^v$ with $Z = F$ and $Z = K$ are the times to deliver packet and token, respectively, including the relative ACKs.

The T_{CB} is built by considering the hub actions on the $(1-\delta)C$ band. B must send the information packets to the generic station, characterized by a rate λ_f and wait for the relative ACKs, with a go-back-n ARQ procedure. Then, with an approach similar to that of the T_{CM} case, by considering the Eq. (3) for the average service time to correctly deliver a frame, T_{CB} results:

$$T_{CB} = \sum_{v=1}^{N}\left[\sum_{n=1}^{\infty}\Pi_n(\lambda_f T_C) n \cdot \right. \\ \left. \cdot \left(\frac{1-(1-P_b^v)^F}{(1-P_b^v)^F} t_{GB}^v(F) + t_{FB}\right)\right] = \\ = \sum_{v=1}^{N}\left[\lambda_f T_C\left(\frac{1-(1-P_b^v)^F}{(1-P_b^v)^F} t_{GB}^v(F) + t_{FB}\right)\right]$$

where $t_{GB}^v(F) = (F+A)/((1-\delta)C) + 2\tau_p^v$ and $t_{FB} = F/(1-\delta)C$.

As far as the queue times is concerned, let us start with the evaluation of T_{q1M} and T_{q1B}, i.e. the times from a packet arrival to the control gain relative to generic station and hub, respectively. The T_{q1M} is computed by considering an uniform distribution of the packet arrival on the time in which the station M_v is not holding the control:

$$T_{q1M}^v = \frac{T_C - \lambda_i T_C \frac{t_{GM}^v(F)}{(1-P_b)^F}}{2} = \frac{T_C}{2}\left[1 - \lambda_i \frac{t_{GM}^v(F)}{(1-P_b)^F}\right]$$

The T_{q1B} is equal to zero, due to that the hub can always transmit its packets.

The queue times from the control gain to the packet transmissions, T_{q2M} and T_{q2B}, relative to station and hub, respectively, are computed by neglecting the token transfer time and by modeling the system as an unique queue system with a single server. Then, we can use the Pollaczek-Khinchine formula [7] valid for the M/G/1 systems. Regarding the T_{q2M} the average arrival rate is $\Upsilon = N\lambda_i$ and the utilization factor is $\Gamma = \Upsilon E[x(P_b^v, F)]$, then:

$$T_{q2M}^v = \frac{\Upsilon}{2(1-\Gamma)} E[x^2(P_b^v, F)] = \\ = \frac{N\lambda_i}{2(1 - N\lambda_i E[x(P_b^v, F)])} E[x^2(P_b^v, F)]$$

where the first and the second order moments of the service time can be obtained from eq. (2).

As far as the queue time T_{q2B}^v is concerned, the average arrival rate is $\Upsilon = N\lambda_f$ and the utilization factor is $\Gamma = \Upsilon E[\tilde{x}(P_b^v, F)]$, then:

$$T_{q2B}^v = \frac{\Upsilon}{2(1-\Gamma)} E[\tilde{x}^2(P_b^v, Z)] = \\ = \frac{N\lambda_f}{2(1 - N\lambda_f E[\tilde{x}(P_b^v, F)])} E[\tilde{x}^2(P_b^v, Z)]$$

where the first and the second order moments of the service time can be obtained from eq. (3).

Finally, the expressions of the times T_M^v and T_B^v necessary to compute the average access time as in Eq. (1) result to be:

$$T_M^v = T_{q1M}^v + T_{q2M}^v + E[x(P_b^v, F)]$$

$$T_B^v = T_{q2B}^v + E[\tilde{x}(P_b^v, F)] + \tau_p^v$$

In order to optimize the performance, the bandwidth partition δ is further chosen by minimizing the average access time T_{acc}. When the throughput S is specified, only one domain bandwith split point, which achieves this minimum, is identified.

5 Numerical Results

In this section some numerical results regarding the developed theory are presented and discussed. The wireless stations are located on a circular area of 100m radius and their position is randomly selected with uniform distribution on the radius. During the cycle time, the channel is stationary and we have modeled it with an attenuation law in the form $A(d) = A(d_0)d^\beta$ where $\beta \in [2, 4]$. The normalization constant, $A(d_0)$, has been defined to include both transmitter and receiver antenna parameters. At the channel input, it is possible to specify a constant signal-to-noise ratio, γ, which includes the following system behaviors: noise figure, transmitted power, bit rate and equivalent antenna temperature. With this approach the working frequency is included in the $A(d_0)$ parameter. In the following we have fixed $A(d_0) = 68dB$.

We have assumed a BPSK modulation, with the possibility of using an adaptive equalization to neglect the potential selective fading inter symbol effects, so the bit error probability is $P_b = \frac{1}{2}\text{erfc}\sqrt{\gamma/A(d)}$.

Let us observe that the propagation delays τ_p^v and the bit-error-probabilities P_b^v are strictly correlated in virtue of the distance dependence and that, with a fixed scenario, these values are also fixed. It should be emphasized that, even if the selected scenario is simple, both for the positions generation and the modulation scheme used, the developed theory can be applied to more complicated and realistic environments.

All numerical results are computed by means of the following system parameters: $C = 10Mbs$, $K = 20$, $A = 10$ and the access times are usually normalized to the error free useful bit transmission time $T_{acc}C/F$.

In Fig. 3 the normalized average access time $T_{acc}C/F$ and the optimum band partition δ are shown for $N = 100$, $F = 1000$, $\alpha = 0.5$, and $\rho = 0.5$. One curve represent the case with $P_b = 0$ for all links, and the other the case with $\gamma = 155dB$ and

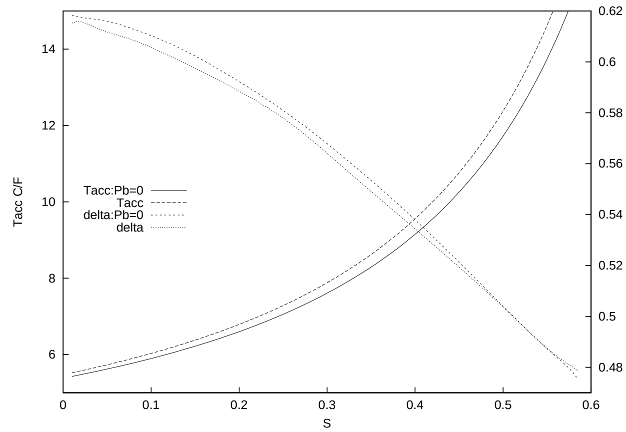

Figure 3: Normalized access time and bandwith partition as functions of the throughput S, with $N = 100$, $\alpha = 0.5$, $\rho = 0.5$ and for $\gamma = 155$dB, $\beta = 4$ or $P_b = 0$

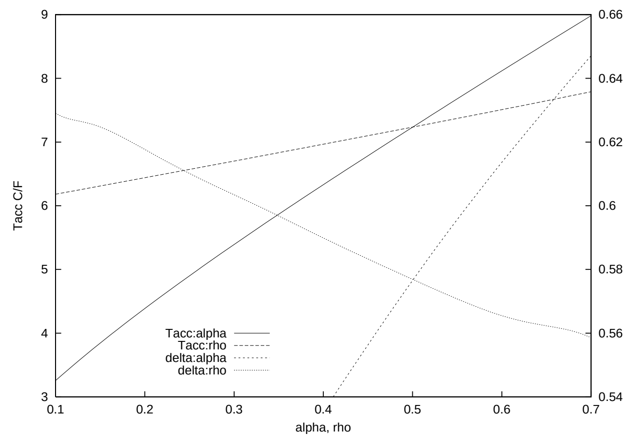

Figure 4: Normalized access time and bandwith partition as functions of the interLAN and intraLAN parameters, α and ρ, with $N = 100$, $S = 0.25$ and $\rho = 0.5$ or $\alpha = 0.5$, respectively

$\beta = 4$. In the following we assume these values of γ and β as reference. The classical performance decrease with throughput increase can be verified. The opposite trend for the partition bandwith δ is because, for the set α and ρ values, by increasing the throughput S the arrival rate λ_f increase more than the λ_i one and then the hub must have more band to deliver the packets arriving from outside and from inside the WLAN.

Fig. 4 reports the results as functions of the interLAN and intraLAN parameter, α and ρ, for $N = 100$, $S = 0.25$, $F = 1000$, and by assuming $\rho = 0.5$ or $\alpha = 0.5$, respectively. With the α and the ρ increase, the access time increases as consequence of the higher probability to experiment an uplink and a downlink in the packet delivery, due to that the traffic is generated in and addressed to a mobile station. The decrease of δ with ρ is because the portion of the WLAN traffic which remains in the network is growing, i.e. the portion of packets that must be transmitted by the hub to the generic

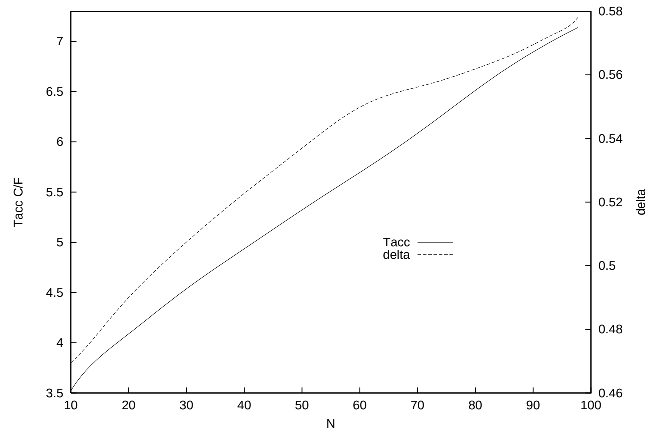

Figure 5: Normalized access time and bandwith partition as functions of the station number N, with $S = 0.25$, $\alpha = 0.5$ and $\rho = 0.5$

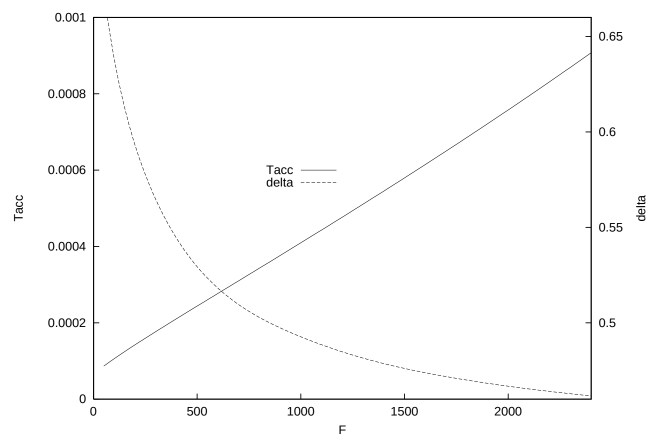

Figure 6: Access time and bandwith partition as functions of the packet length F, with $S = 0.25$, $N = 20$, $\alpha = 0.5$ and $\rho = 0.5$

station is higher. An opposite trend is verified by varying α, due to that increase the fraction of packets generated in a wireless station.

An investigation of the impact of the stations number, having fixed $S = 0.25$, $F = 1000$ and $\alpha = \rho = 0.5$ is reported in Fig. 5, where both access time and bandwidth partition are growing with the station number.

Finally, in Fig. 6 the investigation by varying F is given for $N = 20$, $S = 0.25$, $\alpha = 0.5$ and $\rho = 0.5$. In this case the absolute access time is computed by neglecting the normalization dependence on F. As expected the access time grows with the packet length increase, while δ decreases for considerations similar to those of Fig. 3.

6 Conclusions

Throughout the paper a FDD resources allocation method for wireless LANs with centralized topology has been presented and analytically studied for arbitrary traffic conditions, terminal distributions and not idle channel situations. Two ARQ strategies, to guarantee a correct packet reception, and a traffic model, to characterize the packet routes both from outside and inside the WLAN, have been introduced. Furthermore, a method for the evaluation of the optimum bandwidth partition, as a function of the system parameters, has been presented. Even if the results are given for a particular situation, the possibility of specifying the stations position in a real environment and of using effectively measured or predicted bit error probabilities makes this theory a flexible design tool. Further works can be addressed to compare the FDD resources allocation method proposed in this paper, with other ones, such as the TDD one, and to stress the systems with more complex users distributions, channel environments and traffic situations.

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