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Adaptative Rate Issues in the WLAN Environment

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1. Introduction

In this chapter, we investigate the problem of mobility in the WLAN environment. While radio conditions are changing, the Congestion Resolution Protocol (CRP) plays a key role in controling the quality of service delivered by the distributed network. We investigate different types of CRP to show the impact of one user to all the other ones. We place our work in an urban context where the users (bus passengers, walkers, vehicle network applications) are using an accessible WLAN (for instance WiFi) network via an access point and interact with one another through the network.

Accessing the network via an access point has become in the last years a more and more popular technique to do some networking at low cost. The reason for it is that the WLAN technologies such as WiFi do not require complex user registration, handovers, downlink/uplink protocol synchronization, or even planification for existing base stations (such as GSM BTS or UMTS Node-B). Of course such transmissions achieve much lower performance profile, but they are often delivered for free or almost for free, for instance simply to attract new clients in cafés or restaurants.

As a result, we come up wih new habits of communications which are not exactly the use for which engineers have designed WiFi for L (and other WLAN networks).

2. Overview of 802.11 modulation techniques

2.1 Techniques employed

In the course of its developpment, the 802.11x family has developped a surprising number of modulation techniques that deeply impact the final performance of the system. We summarize these techniques for a 20 MHz band in the 2.4 GHz frequency area in Tab. 1 (we skip here all the historical modulations that have since been abandonned). All these cards implement backward compatibility, which means that the most recent and sophisticated one also handles previous rates in order to be able to communicate with simpler/older cards. As a result, a new 802.11n card with 4 streams will be able to produce modulations in 44 different modes! We give in the following some explanations on the different modulation techniques employed for WiFi.

BPSK Binary Phase Shift Keying is a modulation technique that uses the phase of two complementary phases to code the bis 0 or 1. We plot its constellation diagram in Fig. 1.

QPSK Quadrature Phase Shift Keying uses four phases instead of two to code the signal, so that each symbol carries 2 bits instead of 1 for the BPSK.

Protocol (# streams)	Data rate per stream (Mbits/s)	Modulation & Coding
-	1,2	DSSS/BPSK QPSK/Barker seq.
b	5.5,11	DSSS/QPSK/CCK
g	6,9,12,18,24,36,48,54	OFDM/BPSK QPSK QAM/Conv. coding
n (1 st.)	7.2,14.4,21.7,28.9,43.3,57.8,65,72.2	OFDM/MIMO/Conv. coding
n (2 st.)	14.4,28.9,43.3,57.8,86.7,115.6,130,144.4	OFDM/MIMO/Conv. coding
n (3 st.)	21.7,43.3,65,86.7,130,173.3,195,216.7	OFDM/MIMO/Conv. coding
n (4 st.)	28.9,57.8,86.7,115.6,173.3,231.1,260,288.9	OFDM/MIMO/Conv. coding

Table 1. Different rate parameters for 802.11x at 2.4GHz within a 20 MHz band.

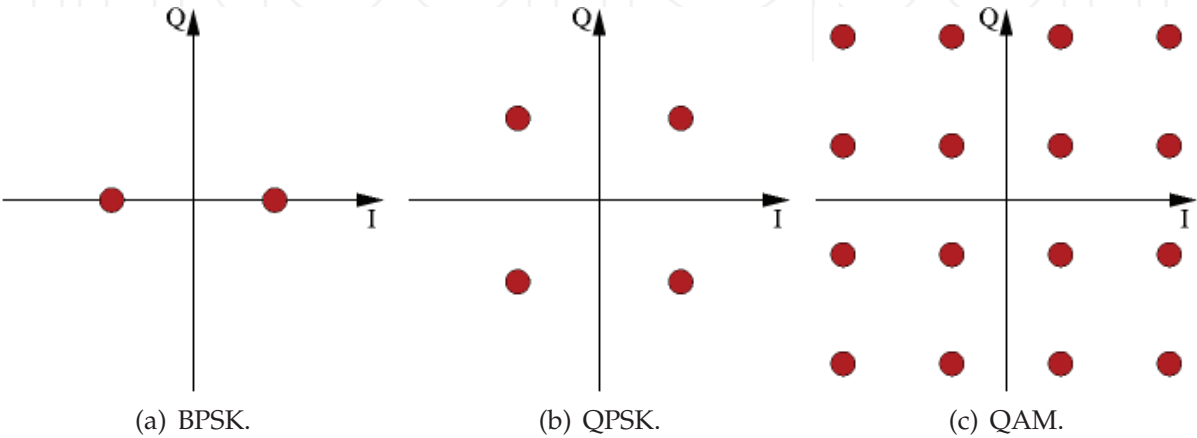(a) BPSK.   (b) QPSK.   (c) QAM.

Fig. 1. Constellation diagram for main 802.11 modulation techniques.

QAM Quadrature Amplitude Modulation combines amplitude modulation with phase modulation to carry more information. 16-QAM carries 4 bits, while 64-QAM carries 6 bits.

DSSS The Direct Spread Sequence Spectrum is a modulation technique that uses the whole band (here, 20 MHz) to encode the information via some coding techniques, more precisely Barker codes or CCK in the 802.11 context.

Barker sequences For the 1 Mbit/s coding, the pseudo-random sequence (10110111000) is used to code the "1" symbol, and its complement (01001000111) to code the "0" symbol, in a PSK modulating scheme. The 2 Mbit/s version is obtained by using QPSK modulation instead of PSK.

CCK The CCK (Complementary Code Keying) technique consists in using 16 or 256 different sequences coded in eight chips (QPSK symbols). The 16 or 256 different sequences allow to identify 4 or 8 bits of information.

OFDM The OFDM (Orthogonal Frequency-Division Multiplexing) is a technique that consists in dividing the channel into close sub-carriers to transmit data through these parallel sub-channels. Using orthogonality of signals, this technique allows to reduce significantly the spacing between sub-carriers and therefore improves spectral efficiency.

MIMO The Multiple-Input and Multiple-Output technique consists in using several input antennas and several output antennas in the devices, in order to use spatial diversity and therefore increase the throughput capacity.

2.2 Range of communication

In a paper on adaptativiy and mobility, of course, the range of communication is a crucial parameter. Unfortunately, this very range is very variable depending on radio conditions. We try in this subsection to give a more accurate opinion on that question without falling into two main defaults of the literature on that topic, that would be (1) rely exclusively on simulations or (2) explain the theoretical context without answering the question of range.

Data rate (Mbits/s)	Modulation	Coding rate (R)
6	BPSK	1/2
9	BPSK	3/4
12	QPSK	1/2
18	QPSK	3/4
24	16-QAM	1/2
36	16-QAM	3/4
48	64-QAM	2/3
54	64-QAM	3/4

Table 2. Rate parameters in 802.11a and 802.11g.

We aim to obtain a realistic model for WLAN communications the following way. We take in this section as an example the model of IEEE 802.11g which is a precise, popular industrial context, in which the problem is really accurate. As mentioned in (*Part 11: wireless LAN medium access control (MAC) and physical layer (PHY) specifications*, 1999, chapter 17), the different rates in which such networks operate are the ones of Tab. 2. We can see a continuum of rates that varies from 6 Mbits/s to 54 Mbits/s. However, the radio conditions impact a lot the effective performance of terminals. We do not want to enter too deeply into some specific situations in this paper, but instead we try to extract general enough properties that can be extrapolated to numerous contexts. We need to say that, surprisingly, the theory says that BPSK has exactly the same performance as QPSK, so we will only plot curves for QPSK. We use first the *berfading* function of mathlab, and evaluate the coding gain as $1/R$. This simple implementation gives the plots of Fig. 2, for respectively, (a) a Rayleigh channel of diversity order 2, and (b) a Rice channel of diversity order 3 and K-factor 5.

Although these curves are quite different, they have some characteristics that are kept not only in these two cases, but with a large set of different diversity values ranging from 2 to 10 and, for the Rice channel, K-factors ranging from 1 to 100 or more. We plot in Fig. 3 the same curves, that we normalized by taking the logarithm, substracting the mean of the logarithms in the six cases, and scaling by the standard deviation.

This simple approach matches very well the data that some authors are giving on the range of operations for different configurations, as we plot in Fig. 4, with indoor ranges of Romano (2004), and ranges of *WLAN - 802.11 a,b,g and n* (2008). In (Segkos, 2004, page 93, Fig. 58), again, similar ranges are shown. The conclusion are always the same:

1. within each group of modulation (QPSK, 4-QAM, 64-QAM) the curves are closer one to another, than when one jumps from one group of modulation to another.

2. the closest curves are that of 48 and 54 Mbits/s,

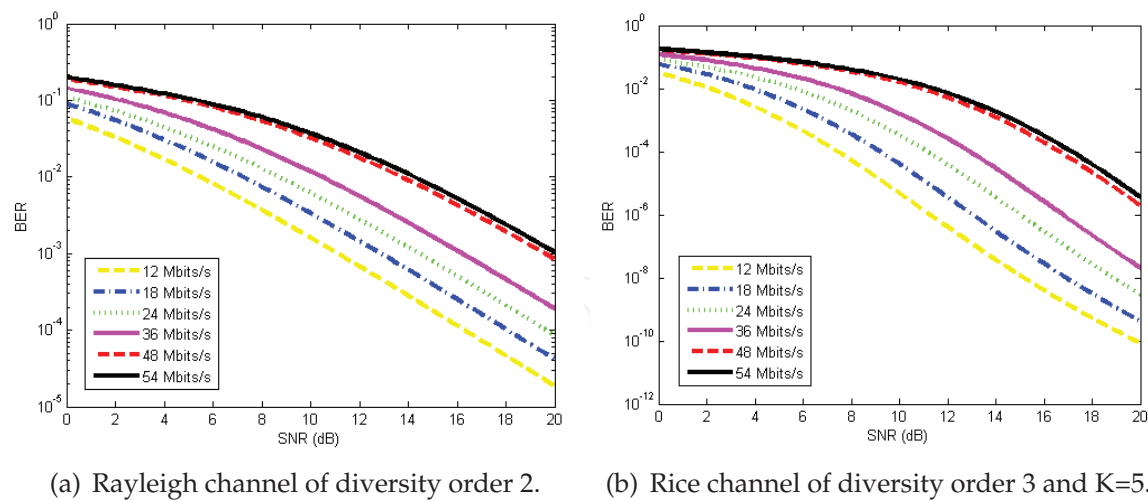3. the farthest curves are that of 36 and 48 Mbits/s.

(a) Rayleigh channel of diversity order 2.   (b) Rice channel of diversity order 3 and K=5.

Fig. 2. Various analytical SNR to BER behaviors.

(a) Rayleigh channel of diversity order 2.   (b) Rice channel of diversity order 3 and K=5.
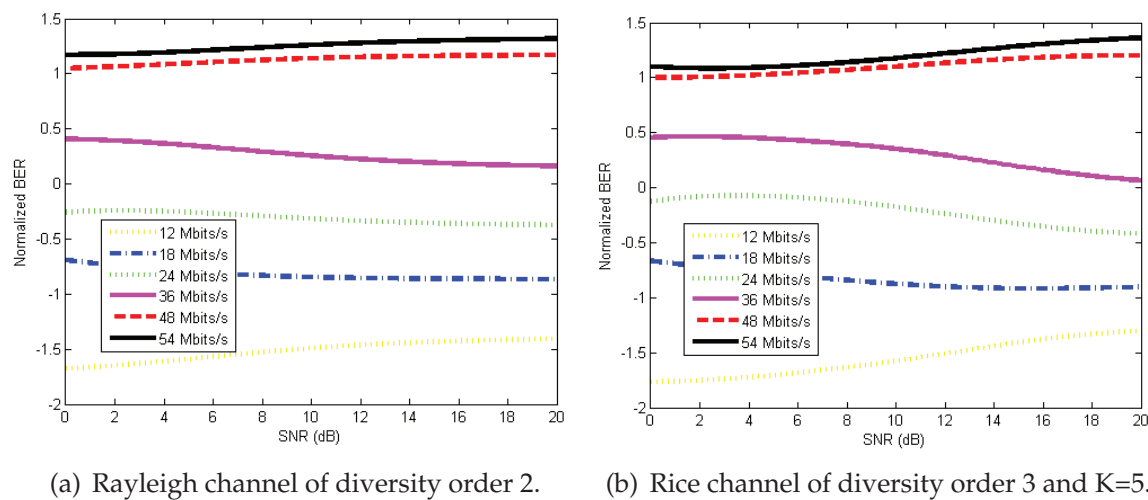
Fig. 3. SNR to normalized BER.

Some differences, however, appear. For instance, it sounds like in the simulations and analytic tools (Fig 2 and (Segkos, 2004, page 93, Fig. 58)), the curves of rates 48 and 54 Mbits/s are much closer than they are in the tutorial curves of Fig. 4. We have observed this phenomenon with lots of different parameters for the Rayleigh and Rice channels.

As a result, we can conclude that the behavior of the channel for WLAN networks deeply depends on the type of radio conditions that are experienced. However, all the experiments we have done suggest that we can use a pathloss model where the gain follows a law in $K_r(d/\beta)^\eta$, where K_r depends on the rate r of the connection, d is the distance to the access point, and η the pathloss parameter, depending on radio conditions. Fig. 3 gives a sufficiently precise behavior of all the mechanisms to evaluate the channel.

3. Existing rate adaptation algorithms

There exist several algorithms that are intended to find the optimal rate of communication for WiFi terminals while exploring the channel. In order to adapt the rate of the packet, such

Compared estimation

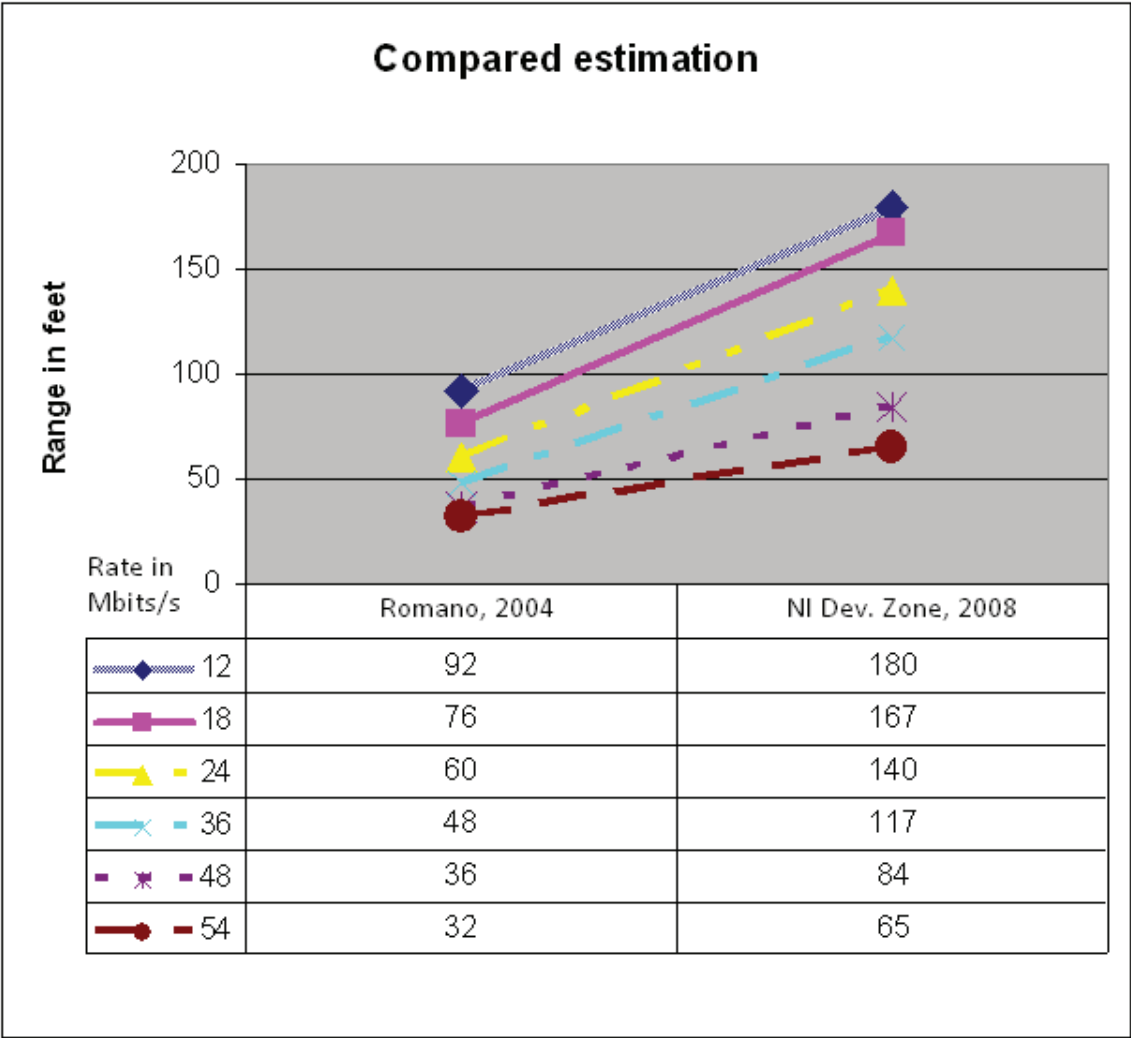| Rate in Mbits/s	Romano, 2004	NI Dev. Zone, 2008
12	92	180
18	76	167
24	60	140
36	48	117
48	36	84
54	32	65

Fig. 4. Comparative given ranges for 802.11g in the litterature.

an algorithm will certainly take into account the fact (or not) that the receiver emitted an acknowledgement at the end of the transmission, since this is mandatory in the legacy mode of IEEE 802.11x.

A very popular approach to that question is that of ARF (*Auto-Rate Fallback*) Kamermann & Monteban (1997). The sender begins to send packets at the minimal rate. After N successes, the sender increases the rate to the next available rate in terms of speed. In case a failure occurs when the new rate is first tried, the rate is fixed to the previous one, and will not be improved again until N successes occur. If, at a given rate, two successive failures occur, then the rate is also decreased, and will also wait N successes before a new try to a faster rate is done.

An improved version, AARF (*Adaptive Auto-Rate Fallback*) Lacage et al. (2004), plays with the value N of successes before a try to faster rate is done. If a first test at a new rate fails, then the system will wait 2N successes to try again. This results in an improvement of the performance of the system.

The TARA scheme (*Throughput-Aware Rate Adaptation*) Ancillotti et al. (2009) combines the information of the Congestion Window (CW) of the MAC of 802.11 with specific parameters to improve the rate mechanism.

Another variant of ARF, ERA (*Effective Rate Adaptation*) Wu & Biaz (2007), tests, in case of collision, a retry at the lowest rate. This retry is used to infer whether the failure is due to a collision or to a radio (SNR) problem. The rate is changed only if the problem is supposed not to be a collision problem, that is, when the retransmission at lower rate is successful.

Indeed, it is not true that all defaults of acknowledgement are due to radio conditions (and accordingly rate of transmission). In fact, in saturation mode, up to 30% of packets are lost because of collisions. This has led to additional research work mainly in four directions:

- Obtain a measurement on the radio conditions. Two main methods are then possible. First, one can assume link symmetry, so that the transmitter will evaluate the signal-to-noise ratio of a packet from the receiver, Pavon & Choi (2003). Second, one can suggest to modify the RTS/CTS mecchanism so that the CTS would send back the received SNR to the receiver (Holland et al. (2001); Saghedi et al. (2002)). These ideas have several drawbacks as mentioned in Ancillotti et al. (2008). The former can only give an assumed SNR, while the latter supposes that both receiver and emitter implement this RTS/CTS modification. But the main inconvenient is that both mechanisms assume the knowledge of a SNR-to-Rate table, which is not easy to obtain and/or update.

- Distinguish physically loss reason. Some algorithms lie on the fact that the physical layer may distinguish packets that are lost due to channel collisions, from packets that are lost because of collisions. This could be for instance implemented by a feature that allows the receiver to say that he could decode the header of the packet (transmitted at minimal rate) but not the payload in itself, see Pang et al. (2005). Of course this solution requires a very specific hardware and nevertheless one cannot be sure that the collision detection feature is fully reliable.

- Test the channel in case of collision by an RTS/CTS. Several mechanisms – J.Kim et al. (2006); Wong et al. (2006) – decide, in case of collision, to send an RTS/CTS to test the channel. Of course, in case the channel comes close to saturation, this has a terrible impact on performance. This has also the terrible side-effect of employing the hidden station procedure (RTS/CTS) for a different purpose, which has several side-effects. Note that this defaults are partially corrected using probabilities in Chen et al. (2007).

- Use Beacon information. In the case where one terminal is connected to an Access Point, some SNR information can be used to have a first idea of the channel quality, see Biaz & Wu (2008).

4. Analytical model

In this section, we make the use of Markov analysis to infer important properties of the rate adaptation algorithm. We model in the following the ARF mechanism, knowing that this model is very popular, and can possibly be extended to alternative approaches. This can be viewed as an extension of the model of Bianchi (2000). It gives an interesting model where, as expected, the rate is connected to the size of the congestion window of the backoff process. Indeed, in IEEE 802.11x, when a station needs to send a packet, it goes through a phase called contention resolution protocol (CRP) that aims at deciding which stations - among the contending ones - will send a packet. In order to do that, it uses two main variables: the contention window (CW) and the backoff parameter (b). The contention window is set at the begining to a minimal value (CWMin) and doubles each time a failure is experienced,

to a maximum CWMax. When the maximum is reached, the CW parameter will stay at this value for a fixed number of retries as long as the transmission fails, and then aborts sending and falls to CWMin. In case of success, in all these cases, the next CW is set to CWMin. This typical behavior of CW has been discussed in many ways in the literature (Galtier (2004); Heuse et al. (2005); Ibrahim & Alouf (2006); Ni et al. (2003)), therefore in the following, we will simply use a series of constants $CW_0, \ldots, CW_m$, with $CW_0 =$CWMin and CW_1 being the value of CW after the first augmentation (2CWMin in the legacy case), and $CW_{m-retries+1} = \cdots = CW_m =$CWMax. It gives, in the legacy case, the following formula:

$$CW_i = \min(2^i \text{CWMin}, \text{CWMax}).$$

Meanwhile, when a transmission is to be done, the value of b is taken randomly between 0 and CW-1. If b equals zero, the station emits its packet as soon as the channel is available (that is, when the previous transmission is completed). Otherwise, b is decremented and the station waits for a small period (called a minislot) and listen to the channel to see if some other station did not start to transmit. If it is the case, it postpones its own emission to the end of the current transmission, and therefore freezes CW and b. Then, if b is equal to zero, it starts emitting. Otherwise b is decremented and so on.

We describe our model in Fig. 5. In this figure the state s_j^i corresponds to the situation where the rate is j and the congestion window CW_{i-1}. The probability p_j represents the probability that a transmission at rate j fails. One can see in the figure also small states between s_0^i and s_0^{i+1}. Those states represent the fact that N successful transmissions at rate r_i are necessary to try to send at rate r_{i+1}. The colors of the vertices (or the levels of gray) correspond to the rate of transmission of the state in question. The state s_+^r represents the case where the current rate is r and at least the last transmission at that rate was successful.
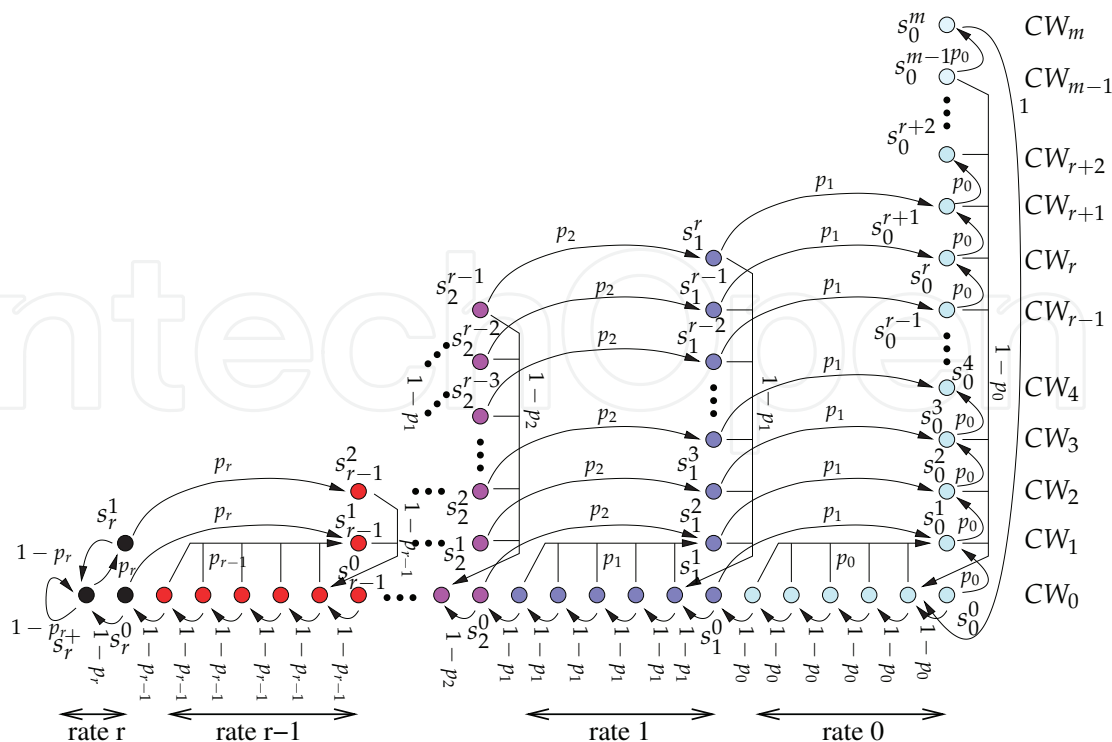

Fig. 5. Model including ARF in the backoff process.

Note that, if we extend the model similarly to Bianchi (2000) to represent the backoff variable, this is a discrete Markov process. Note also that a simpler model also appears in the literature (Singh & Starobinski (2007)) that expresses two models, one for the rates, and one for the ARF internal behavior, and mixes them based on semi-markov properties. Note that our model captures fine properties of backoff behavior, and complex mechanisms of rate improvement.

4.1 Analysis of the left-hand part

Let now design by π_i^j the probability that the transmitter is in state s_j^i. We also note π_+^r the probability that the transmitter is in state s_r^+. The analysis of the left part of Fig 5 gives:

$$\begin{cases} \pi_+^r = (1 - p_r)(\pi_+^r + \pi_0^r + \pi_1^r), \\ \pi_1^r = p_r \pi_+^r. \end{cases} \tag{1}$$

And therefore

$$\pi_1^r = \frac{1 - p_r}{p_r} \pi_0^r. \tag{2}$$

4.2 Analysis of the intermediate part

Let us now analyze an intermediate level of the model. We can see on Fig. 5 that, for $k \in \{2, \ldots, r\}$,

$$\begin{cases} \pi_{i+1}^{k-1} = p_k \pi_i^k, \text{ for } i \in \{1, \ldots, r+1-k\}, \\ \pi_0^k = (1 - p_{k-1})^N \sum_{i=0}^{i=r+2-k} \pi_i^{k-1}, \\ \pi_1^{k-1} = p_k \pi_0^k + p_{k-1}((1 - p_{k-1}) + (1 - p_{k-1})^2 + \cdots + (1 - p_{k-1})^{N-1}) \sum_{i=0}^{i=r+2-k} \pi_i^{k-1}. \end{cases} \tag{3}$$

Rearranging the two last lines of (3) gives

$$\pi_1^{k-1} = \left(p_k - 1 + \frac{1}{(1 - p_{k-1})^{N-1}} \right) \pi_0^k \qquad \text{for } k \in \{2, \ldots, r\}. \tag{4}$$

We show by induction that

$$\sum_{i=0}^{i=r+1-k} \pi_i^k = \frac{\pi_0^k}{p_k}. \tag{5}$$

Obviously, using (2), equation (5) is true for $k = r$. Now we suppose that (5) is true for the values $\{k, \ldots, r\}$. Using the first line of (3) and (4) we have

$$\sum_{i=0}^{i=r+2-k} \pi_i^{k-1} = p_k \sum_{i=0}^{i=r+1-k} \pi_i^k + \left(\frac{1}{(1 - p_{k-1})^{N-1}} - 1 \right) \pi_0^k + \pi_0^{k-1}.$$

Using the induction we have

$$\sum_{i=0}^{i=r+2-k} \pi_i^{k-1} = \frac{1}{(1 - p_{k-1})^{N-1}} \pi_0^k + \pi_0^{k-1}.$$

We now replace by the second line of (3) to get:

$$\sum_{i=0}^{i=r+2-k} \pi_i^{k-1} = (1 - p_{k-1}) \sum_{i=0}^{i=r+2-k} \pi_i^{k-1} + \pi_0^{k-1}.$$

Hence the result for $k \in \{1, \ldots, r\}$ in (5).

If we combine equation (5) and the second line of (3) we have

$$\pi_0^k = \frac{(1 - p_{k-1})^N}{p_{k-1}} \pi_0^{k-1}. \tag{6}$$

Now, before evaluating the last stage of the Markov model, we get an analytical expression of any other state π_i^j with $j \geq 1$ in terms of π_0^1. The simplest expression comes from (6):

$$\pi_0^k = \frac{(1 - p_1)^N \ldots (1 - p_{k-1})^N}{p_1 \ldots p_{k-1}} \pi_0^1 \qquad \text{for } k \in \{2, \ldots, r\}. \tag{7}$$

Then, using (4), one can deduce

$$\pi_1^k = \left(p_{k+1} - 1 + \frac{1}{(1 - p_k)^{N-1}} \right) \frac{(1 - p_1)^N \ldots (1 - p_k)^N}{p_1 \ldots p_k} \pi_0^1 \qquad \text{for } k \in \{1, \ldots, r - 1\}. \tag{8}$$

Now, let us see a more general case, with $i \geq 2$ and $j \geq 1$.

$$\begin{aligned}
\pi_i^j &= \pi_1^{i+j-1} p_2 \ldots p_i \qquad \text{using the first line of (3)} \\
&= \left(p_{i+j} - 1 + \frac{1}{(1 - p_{i+j-1})^{N-1}} \right) p_2 \ldots p_i \frac{(1 - p_1)^N \ldots (1 - p_{i+j-1})^N}{p_1 \ldots p_{i+j-1}} \pi_0^1 \qquad \text{using (8), with } i + j \leq r
\end{aligned}$$

We then get the following formulas:

$$\pi_i^1 = \frac{(1 - p_1)^N \ldots (1 - p_{i-1})^N}{p_1} \left((1 - p_i) - (1 - p_{i+1})(1 - p_i)^N \right) \pi_0^1,$$
$$\text{for } i \in \{2, \ldots, r - 1\}, \tag{9}$$

and

$$\pi_i^j = \frac{1}{p_1} \frac{(1 - p_1)^N \ldots (1 - p_{i+j-2})^N}{p_{i+1} \ldots p_{i+j-1}} \left((1 - p_{i+j-1}) - (1 - p_{i+j})(1 - p_{i+j-1})^N \right) \pi_0^1,$$
$$\text{for } i \geq 2, \ j \geq 2, \ i + j \leq r. \tag{10}$$

Of course, the case $i + j = r + 1$ remains. It gives:

$$\begin{aligned}
\pi_i^{r+1-i} &= \pi_1^r p_2 \ldots p_i \qquad \text{using the first line of (3)} \\
&= \frac{1 - p_r}{p_r} p_2 \ldots p_i \pi_0^r \qquad \text{using (2)} \\
&= \frac{1 - p_r}{p_r} \frac{p_2 \ldots p_i}{p_1 \ldots p_{r-1}} \left((1 - p_1)^N \ldots (1 - p_{r-1})^N \right) \pi_0^1 \qquad \text{using (7).}
\end{aligned}$$

We distinguish the cases $i = r$, $i = r - 1$, and others, and we obtain

$$\pi_r^1 = \frac{1 - p_r}{p_1} \left[(1 - p_1)^N \ldots (1 - p_{r-1})^N \right] \pi_0^1, \tag{11}$$

$$\pi_{r-1}^2 = \frac{1 - p_r}{p_r} \left[(1 - p_1)^N \ldots (1 - p_{r-1})^N \right] \pi_0^1, \tag{12}$$

$$\pi_i^{r+1-i} = \frac{1 - p_r}{p_1 p_r} \frac{(1 - p_1)^N \ldots (1 - p_{r-1})^N}{p_{i+1} \ldots p_{r-1}} \pi_0^1 \qquad \text{for } i \in \{1, \ldots, r-2\}. \tag{13}$$

4.3 Analysis of the right-hand part
The analysis of the chain of Fig. 5 gives the following formulas:

$$
\begin{cases}
\pi_{i+1}^0 = p_o \pi_i^0 & \text{for } i \in \{k+1, \ldots, m-1\} \\
\pi_{i+1}^0 = p_o \pi_i^0 + p_1 \pi_i^1 & \text{for } i \in \{1, \ldots, k\} \\
\pi_0^1 = (1 - p_0)^N \sum_{i=0}^{i=m} \pi_i^0 + p_0(1 - p_0)^N \pi_m^0 \\
\pi_1^0 = (1 - p_0) \left(1 - (1 - p_0)^{N-1} \right) \sum_{i=0}^{i=m} \pi_i^0 + p_1 \pi_0^1 + p_0 \pi_0^0 + p_0 \left(1 - (1 - p_0)^{N-1} \right) \pi_m^0
\end{cases} \tag{14}
$$

Since there is no entering state for s_0^0, the corresponding probability is a stationary state will verify $\pi_0^0 = 0$. Then, if we denote

$$\pi_{\geq j}^0 = \sum_{i=j}^{i=m} \pi_i^0,$$

we can deduce from the last line of equation (14) the following:

$$\pi_1^0 = \frac{(1 - p_0) \left(1 - (1 - p_0)^{N-1} \right) \pi_{\geq 2}^0 + p_1 \pi_0^1 + p_0 \left(1 - (1 - p_0)^{N-1} \right) \pi_m^0}{1 - (1 - p_0) \left(1 - (1 - p_0)^{N-1} \right)} \tag{15}$$

We can now make use of the following family of polynomials:

$$
\begin{cases}
Q_1(X) = 1 - X + X^N, \\
Q_{p+1}(X) = Q_p(X) - (1 - X)^p (X - X^N), & \text{for } p \geq 1.
\end{cases} \tag{16}
$$

We can rewrite this formula as follows for $p \geq 1$

$$
\begin{cases}
Q_{p+1}(X) = Q_1(X) - ((1 - X) + \cdots + (1 - X)^p)(X - X^N), \\
\qquad = 1 - X + X^N - (1 - X) \frac{1 - (1 - X)^p}{X}(X - X^N), \\
\qquad = 1 - X + X^N - (1 - X)(1 - (1 - X)^p)(1 - X^{N-1}).
\end{cases}
$$

Finally it gives:

$$Q_{p+1}(X) = X^{N-1} + (1 - X)^{p+1}(1 - X^{N-1}), \qquad \text{for } p \geq 1. \tag{17}$$

We then aim at proving the following formula for $i \in \{2, \ldots, r\}$:

$$Q_i(1-p_0)\pi_i^0 = p_0^{i-1}\left((1-p_0)-(1-p_0)^N\right)\pi_{\geq i+1}^0 + p_0^i\left(1-(1-p_0)^{N-1}\right)\pi_m^0$$
$$+ \sum_{j=1}^{j=i-2} p_0^{i-j-2}(1-p_0)^N\ldots(1-p_j)^N(1-p_{j+1})\pi_0^1 \tag{18}$$
$$+ p_0^{i-1}p_1\pi_0^1 + p_0^{i-2}(1-p_1)Q_1(1-p_0)\pi_0^1$$
$$- Q_{i-1}(1-p_0)(1-p_1)^N\ldots(1-p_{i-1})^N(1-p_i)\pi_0^1$$

The case $i = 2$ comes from the second line of equation (14) and equations (15) and (8). The following cases are obtained by induction using again the second line of (14) in conjunction with (9).

Now, using the first line of equation (14) we have

$$\pi_{\geq r+1}^0 = \pi_{r+1}^0 + \pi_{r+2}^0 + \cdots + \pi_m^0$$
$$= \pi_{r+1}^0 + p_0\pi_{r+1}^0 + \cdots + p_0^{m-r-1}\pi_{r+1}^0$$
$$= \frac{1-p_0^{m-r}}{1-p_0}\pi_{r+1}^0.$$

We then start with the second line, again, of equation (14), that iis $\pi_{r+1}^0 = p_0\pi_r^0 + p_1\pi_r^1$, and combining with equations (18) for $i = r$ and (11) we get:

$$\pi_{r+1}^0 = \left(1 + \sum_{j=0}^{j=r-1} \frac{(1-p_0)^N\ldots(1-p_j)^N}{p_0^{j+1}}(1-p_{j+1})\right)\frac{p_0^r\pi_0^1}{(1-p_0)^{N-1}}. \tag{19}$$

Naturally, it gives, using now the first line of equation (14),

$$\pi_k^0 = \left(1 + \sum_{j=0}^{j=r-1} \frac{(1-p_0)^N\ldots(1-p_j)^N}{p_0^{j+1}}(1-p_{j+1})\right)\frac{p_0^{k-1}\pi_0^1}{(1-p_0)^{N-1}} \qquad \text{for } k \in \{r+1,\ldots,m\}. \tag{20}$$

Back-tracking further with the help of the second line of equation (14) along with equations (11) and (8), we can write:

$$\frac{\pi_k^0}{\pi_0^1} = \left(1 + \sum_{j=0}^{j=k-2} \frac{(1-p_0)^N\ldots(1-p_j)^N}{p_0^{j+1}}(1-p_{j+1})\right)\frac{p_0^{k-1}}{(1-p_0)^{N-1}} \tag{21}$$
$$- (1-p_1)^N\ldots(1-p_{k-1})^N(1-p_k) \qquad \text{for } k \in \{1,\ldots,r\}.$$

We summerize all the different values of the states with respect to π_0^1 in Tab. 3. We come to the conclusion that, even if this model is still analytical, the complexity is much more important than that of Bianchi (2000). All the formulas show the role of the barrier of value $(1-p_k)^N$ to come from rate k to rate $k+1$.

5. Conclusion

In this article, we have opened an approach to study the impact of mobility over WLANs. First, after reviewing different modulation aspects, we have shown some constants that appear in terms of the shape of the area where some rate of communication is likely to operate

Eq.	State	Ratio to π_0^1
(7)	π_0^k $k \in \{2,\ldots,r\}$	$\dfrac{(1-p_1)^N \ldots (1-p_{k-1})^N}{p_1 \ldots p_{k-1}}$
(8)	π_1^k $k \in \{1,\ldots,r-1\}$	$\left(p_{k+1} - 1 + \dfrac{1}{(1-p_k)^{N-1}}\right) \dfrac{(1-p_1)^N \ldots (1-p_k)^N}{p_1 \ldots p_k}$
(9)	π_i^1 $i \in \{2,\ldots,r-1\}$	$\dfrac{(1-p_1)^N \ldots (1-p_{i-1})^N}{p_1} \left((1-p_i) - (1-p_{i+1})(1-p_i)^N\right)$
(10)	π_i^j $i \geq 2,\ j \geq 2,\ i+j \leq r$	$\dfrac{1}{p_1} \dfrac{(1-p_1)^N \ldots (1-p_{i+j-2})^N}{p_{i+1} \ldots p_{i+j-1}} \left((1-p_{i+j-1}) - (1-p_{i+j})(1-p_{i+j-1})^N\right)$
(11)	π_r^1	$\dfrac{1-p_r}{p_1} \left[(1-p_1)^N \ldots (1-p_{r-1})^N\right]$
(12)	π_{r-1}^2	$\dfrac{1-p_r}{p_r} \left[(1-p_1)^N \ldots (1-p_{r-1})^N\right]$
(13)	π_i^{r+1-i} $i \in \{1,\ldots,r-2\}$	$\dfrac{1-p_r}{p_1 p_r} \dfrac{(1-p_1)^N \ldots (1-p_{r-1})^N}{p_{i+1} \ldots p_{r-1}}$
(19)	π_{r+1}^0	$\left(1 + \displaystyle\sum_{j=0}^{j=r-1} \dfrac{(1-p_0)^N \ldots (1-p_j)^N}{p_0^{j+1}} (1-p_{j+1})\right) \dfrac{p_0^r}{(1-p_0)^{N-1}}$
(20)	π_k^0 $k \in \{r+1,\ldots,m\}$	$\left(1 + \displaystyle\sum_{j=0}^{j=r-1} \dfrac{(1-p_0)^N \ldots (1-p_j)^N}{p_0^{j+1}} (1-p_{j+1})\right) \dfrac{p_0^{k-1}}{(1-p_0)^{N-1}}$
(21)	π_k^0 $k \in \{1,\ldots,r\}$	$\left(1 + \displaystyle\sum_{j=0}^{j=k-2} \dfrac{(1-p_0)^N \ldots (1-p_j)^N}{p_0^{j+1}} (1-p_{j+1})\right) \dfrac{p_0^{k-1}}{(1-p_0)^{N-1}}$ $-(1-p_1)^N \ldots (1-p_{k-1})^N (1-p_k)$

Table 3. Stationary probabilities for the model of Fig. 5.

well. These figures have been obtained in a very general context, taking into consideration practical and theoretical channel conditions, including Rice and Rayleigh channels.

On top of that, we have described different existing systems for adapting the rate of communication in an unknown medium. We have shown many characteristics and also differences of the approaches.

Finally, we could open a new approach to the difficult, and yet unanswered question of designing a reliable analytical model to explain the behavior of such systems, taking the ARF scheme as a model one. In that case, we were able to highlight an high correlation between the Congestion Window (CW) of the system, and the rate at which packets are emitted. Not only that, but the analysis showed that all the stationary probabilities of the states of this Markov chain can be described with a closed formula. This opens new ways to research in that area and shows that the different mechanisms that have been implemented in the MAC systems of

WLAN cards have strong correlations with one another and therefore have to be redesigned with at least a global understanding of channel access problems (backoff and collisions) and rate adaptation questions.

6. References

Ancillotti, E., Bruno, R. & Conti, M. (2008). Experimentation and performance evaluation of rate adaptation algorithms in wireless mesh networks, *Proc. of 5th ACM PE-WASUN'08*, Vancouvert, BC, Canada, pp. 7–14.

Ancillotti, E., Bruno, R. & Conti, M. (2009). Design and performance evaluation of throughput-aware rate adaptation protocols for ieee 802.11 wireless networks, *Performance Evaluation* **66**: 811–825.

Bianchi, G. (2000). Performance analysis of the IEEE 802.11 distributed coordination function, *IEEE Journal on Selected Areas in Communications* **18**(8): 535–547.

Biaz, S. & Wu, S. (2008). Loss differentiated rate adaptation in wireless networks, *IEEE WCNC 2008*, Las Vegas, NV, USA, pp. 1639–1644.

Chen, X., Qiao, D., Yu, J. & Choi, S. (2007). Probabilistic-based rate adaptation for IEEE 802.11 WLANs, *Globecom'07*, Washington DC, USA, pp. 4904–4908.

Galtier, J. (2004). Optimizing the IEEE 802.11b performance using slow congestion window decrease, *Proccedings of the 16th ITC Specialist Seminar on performance evaluation of wireless and mobile systems*, Antwerpen, pp. 165–176.

Heuse, M., Rousseau, F., Guillier, R. & Duda, A. (2005). Idle sense: An optimal access method for high throughput and fairness in rate diverse wireless LANs, *SIGCOMM*, Philadelphia, USA.

Holland, G., Vaidya, N. & Bahl, P. (2001). A rate-adaptative MAC protocol for multi-hop wireless networks, *MobiCom'2001*, Rome, Italy, pp. 236–251.

Ibrahim, M. & Alouf, S. (2006). Design and analysis of an adaptative backoff algorithm, *Networking*, pp. 184–196.

J.Kim, Kim, S., Choi, S. & Qiao, D. (2006). CARA: collision-aware rate adaptation mechanism of IEEE 802.11 WLANs, *Infocom'2006*, Barcelon, Spain, pp. 1–11.

Kamermann, A. & Monteban, L. (1997). Wave LAN II: a high-performance wireless LAN for the unlicensed band, *Bell Labs Technical Journal* pp. 118–133.

Lacage, M., Manshaei, M. & Turletti, T. (2004). IEEE 802.11 rate adaptation: a practical approach, *MSWiM'04*, pp. 126–134.

Ni, Q., Aad, I., Barakat, C. & Turlletti, T. (2003). Modeling and analysis of slow CW decrease for IEEE 802.11 WLAN, *PIMRC*, Beijing, China.

Pang, Q., Leung, V. & Liew, S. (2005). A rate-adaptation algorithm for IEEE 802.11 WLANs based on MAC layer loss differentiation, *IEEE Broadnets 2005*, Boston, USA, pp. 709–717.

Part 11: wireless LAN medium access control (MAC) and physical layer (PHY) specifications (1999). IEEE Std 802.11a-1999.

Pavon, J. & Choi, S. (2003). Link adaptation strategy for IEEE wlan via received signal strength measurement, *Proc. ICC'03*, Vol. 2, Seattle, WA, USA, pp. 1108–1113.

Romano, P. (2004). The range vs. rate dilemna of (WLANs), EETimes Design.

Saghedi, B., Kanodia, V., Sabharwal, A. & Knightly, E. (2002). Opportunistic media access for multirate Ad Hoc networks, *MobiCom'2002*, Atlanta, Georgia, USA, pp. 24–35.

Segkos, M. (2004). *Advanced techniques to improve the performance of OFDM wireless LAN*, Master's thesis, Naval postgraduate school, Monterey, California.

Singh, A. & Starobinski, D. (2007). A semi markov-based analysis of rate adaptation algorithms in wireless LANs, *IEEE SECON*, pp. 371–380.

WLAN - 802.11 a,b,g and n (2008). NI Developper Zone.

Wong, S., Yang, H., lu, S. & Bharghavan, V. (2006). Robust rate adaptation for 802.11 wireless networks, *MobiCom'2006*, Los Angeles, California, USA, pp. 146–157.

Wu, S. & Biaz, S. (2007). ERA: efficient rate adaptation algorithm with fragmentation, *Technical Report CSSE07-04*, Auburn University.
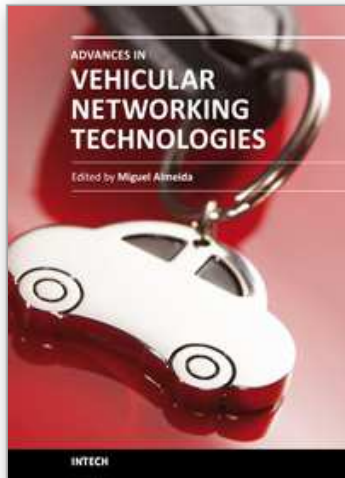
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