OPTIMISATION OF THE INTERFERENCE COST GENERATED BY THE RANDOM ACCESS CHANNEL OF THE UMTS FDD SYSTEM

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ABSTRACT

In this paper, we investigate the optimisation of the Random Access CHannel (RACH) of the UMTS FDD system in terms of generated interference. Conditional on open loop measurements, we search the best initial energy of the RACH in order to reduce the multiple access interference while keeping a reasonable mean access time.

1. INTRODUCTION

In the UMTS specifications [1], the Mobile Station (MS) should send a RACH preamble in order to access the network. At the Base Station (BS), the received signal is continuously correlated with this preamble sequence to detect MS access calls. This process is done within a delay window which depends on both the cell size and the channel delay spread. If any of these correlation modules is greater than a prefixed threshold, the BS sends an acknowledgement message. Unless this message is received, the MS makes a new tentative by sending the RACH preamble at a higher energy than the last transmission. A possible approach is to increase the preamble energy by a constant step in dB as proposed in the UMTS specifications.

Using open loop measurements, the MS estimates the average power profile of paths which are assumed to be the same in the uplink and the downlink. Based on these estimates, we seek for the best initial energy of the RACH preamble in order to reduce the Mean Total Spent Energy (MTSE) and ensure a reasonable Mean Access Time (MAT). Note that we have made abstraction of channel large effects : average path loss and shadowing. These effects should be taken into account in the final evaluation results.

The outline of the paper is as follows. Sections 2 and 3 derive respectively the expression of the False Alarm Probability and the Detection Probability of the RACH preamble. Section 4 derives the expression of the MTSE and the MAT. Then it determines the optimal initial energy of the RACH and the best step to increase it. Finally, section 5 draws some conclusions.

2. FALSE ALARM PROBABILITY

False Alarm situations occur if any of the correlations performed by the BS within the correlation window are greater than a detection threshold (T) in the absence of RACH preamble transmission. The value of the threshold T should be fixed in order to have a given False Alarm Probability P_{fa}. It's value depends on both the noise variance N_0 and the correlation window (W in multiple of the chip period). We suppose that the BS preamble search is made with a resolution equal to the chip period so that the noise components on the different correlations are independent from each other. Using this last assumption, we deduce the False Alarm Probability expression

$$P_{fa} = 1 - p(|z|^2 < T)^W = 1 - \left[1 - exp\left(-\frac{TN}{N_0}\right)\right]^W, \qquad (1)$$

where z is a gaussian random variable with variance N_0/N and N is the RACH preamble length.

Figure 1 depicts the evolution of P_{fa} with respect to the threshold T for N_0 = 4096, N = 4096 and W = 20. We see that a threshold T = 7.6 should be used to have P_{fa}=10^{-2}. Note that these results are in accordance with the simulations.

3. DETECTION PROBABILITY

A MS access call is detected if any of the correlations due to multipath components or background noise is greater than the threshold T. If we suppose that the channel delays match the correlation search positions, the Detection Probability (P_d) is given by

$$\begin{aligned} P_d(E_c) &= 1 - p\left(|z|^2 < T\right)^{W-L} \prod_{i=1}^{L} p\left(|z_i|^2 < T\right), \\ &= 1 - \left[1 - exp\left(-\frac{TN}{N_0}\right)\right]^{W-L} \end{aligned}$$

$$\prod_{i=1}^{L}\left[1-exp\left(-\frac{T}{(\sigma_i^2 E_c+N_0/N)}\right)\right], \quad (2)$$

where $z_i=\sqrt{E_c}h_i+n_i$, E_c is the transmitted chip energy of the RACH preamble, h_i is the i-th path amplitude with variance σ_i^2, n_i is a gaussian noise with variance N_0/N and L is the number of paths.

Figure 2 shows theoretical and simulation results in terms of the evolution of the Detection Probability with respect to the Signal to Noise Ratio (SNR=NE_c/N_0) for N_0 =4096, N=4096, W = 20 and T = 7.6. The multipath channel is a Rayleigh fading one with four paths of equal average powers and delays separated by the chip period. We verify that for high (resp. low) SNR the detection probability goes to one (resp. 10^{-2}). Moreover, we notice the conformity of the simulation results with the theoretical study.

4. OPTIMISATION OF THE INITIAL ENERGY OF THE RACH

The initial energy of the RACH preamble and the incremental power step should be chosen by taking into account both the Mean Total Spent Energy (MTSE) and the Mean Access Time (MAT). In fact, if a very small initial energy is used, the MAT will be large and the MTSE will be greater than necessary. In the contrary, if a very large initial energy is used, the MAT will be small but the MTSE will be very large. We propose next to investigate the effect of these parameters in two extreme situations : an independent and a constant multipath fading channel between all MS access attempts.

4.1. Independent channel scenario

If we suppose that each path amplitude over two MS access attempts is independent from each others, we deduce

$$MTSE=\sum_{n=0}^{+\infty}\sum_{j\leq n}E_{c,init}\Delta^j P_d(E_{c,init}\Delta^n)$$

$$\prod_{j<n}\left[1-P_d(E_{c,init}\Delta^j)\right], \quad (3)$$

where $E_{c,init}$ is the initial energy of the RACH preamble and Δ is the step used to increase it.

After some developments, the MTSE can be also written as

$$MTSE=\sum_{n=0}^{+\infty}(E_{c,init}\Delta^n)\prod_{j<n}\left[1-P_d(E_{c,init}\Delta^j)\right]. \quad (4)$$

The MAT is given by

$$MAT=\sum_{n=0}^{+\infty}\prod_{j<n}\left[1-P_d(E_{c,\,init}\Delta^j)\right]. \quad (5)$$

4.2. Constant channel scenario

The last expressions are valid even in this case, the only difference is that we have to replace P_d by the detection probability conditioned on a given channel draw. Then we should average the MTSE and the MAT expressions over these draws to obtain the average performance of the access process.

The module of any correlation due to the multipath channel follows a Rice distribution [2] :

$$p_{|z_i|/h_i}(x)=\frac{x}{\sigma^2}exp\left(\frac{-\left(x^2+s_i^2\right)}{2\sigma^2}\right)I_0\left(\frac{xs_i}{\sigma^2}\right), \quad (6)$$

where I_0 is the 0-th order modified Bessel function of the first kind, $s_i^2=E_c\left|h_i\right|^2$ and $\sigma^2=N_0/2N$.

By using this last expression, we deduce

$$p(|z_i|^2<T\;/\;h_i)=1-Q_1\left(\frac{s_i}{\sigma},\frac{\sqrt{T}}{\sigma}\right), \quad (7)$$

where Q_1 is the generalised Marcum's Q function [2].

Following the same approach as in (2), the detection probability conditioned on the channel draw is given by

$$P_d(E_c/\;h_1,\cdots,h_L)=1-\left[1-exp\left(-\frac{TN}{N_0}\right)\right]^{W-L}$$

$$\prod_{i=1}^{L}\left[1-Q_1\left(\frac{s_i}{\sigma},\frac{\sqrt{T}}{\sigma}\right)\right], \quad (8)$$

4.3. Simulation results

Figures 3 and 4 depict respectively the theoretical evolution of the MTSE and the MAT with respect to the initial Signal to Noise Ratio (SNR) , $NE_{c,init}/N_0$, in the same conditions as figure 2. We suppose that the channel amplitude is independent over MS random accesses, so that the MAT and the MTSE are given by (2), (4) and (5). In figure 4, we see that the MAT decreases if the initial energy of the RACH preamble or the step Δ increases. On the one hand, if the initial energy of the RACH is very low, the MTSE will be larger than necessary since the MS makes a lot of attempts before being detected. On the other hand, if the initial energy of the RACH is very large, the MTSE will be very large and the preamble is immediately detected. Finally, we notice that an initial SNR = 10 dB and a step Δ = 0.5 dB are a good choice. In fact, the MS spends almost the lowest energy while having a very reasonable MAT equal to 2 attempts.

Figures 5 and 6 compare the obtained performance for an independent and a constant channel amplitude over MS random accesses. We notice that the MTSE and MAT are larger for the constant channel scenario. In fact, if the module of the channel draw is low the MS will make a lot of access attempts before being detected. Moreover, we see that the optimal choice of the RACH initial energy is almost in the same region in the two scenarios. However, the gap between this optimum and the other choices can be greater in the constant channel scenario. Finally, we see that simulation results are in accordance with the theoretical study for the independent channel scenario. Simulation results for a mobile speed equal to 3 km/h give an intermediate performance between the constant and the independent scenarios.

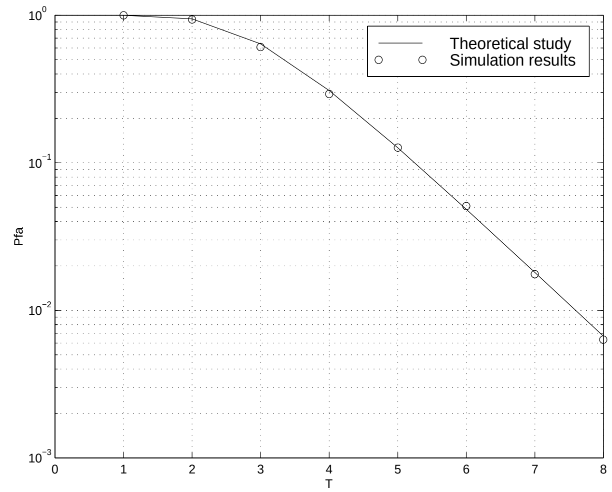

Fig. 1. Evolution of the P_{fa} with respect to the threshold.

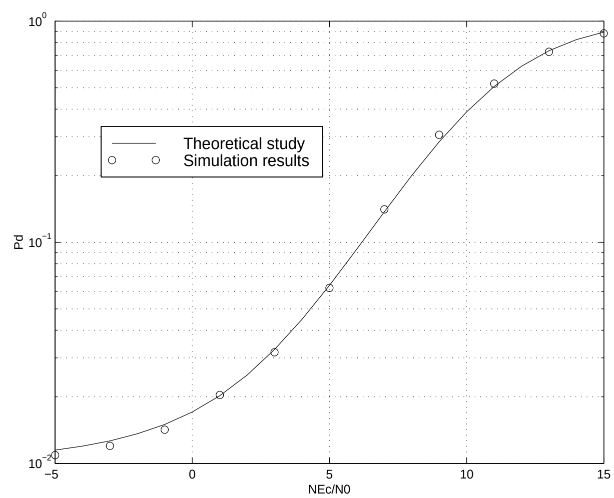

Fig. 2. Evolution of the P_d with respect to the SNR.

5. CONCLUSION

In this paper, we have investigated the choice of the best initial energy of the RACH preamble in order to reduce the multiple access interference. An initial signal to noise ratio equal to 10 dB and an incremental power step equal to 0.5 dB were shown to be the best choices. In fact, the total spent energy is almost the lowest one and the mean access time is acceptable.

6. REFERENCES

[1] 3GPP TSG RAN #5 (99)587, October 1999, TS 25.211 v3.0.0 (1999-10), “Physical channels and mapping of transport channels onto physical channels (FDD)”.

[2] J. G. Proakis, Digital communications, M.C. Graw-Hill, Third edition, 1995.

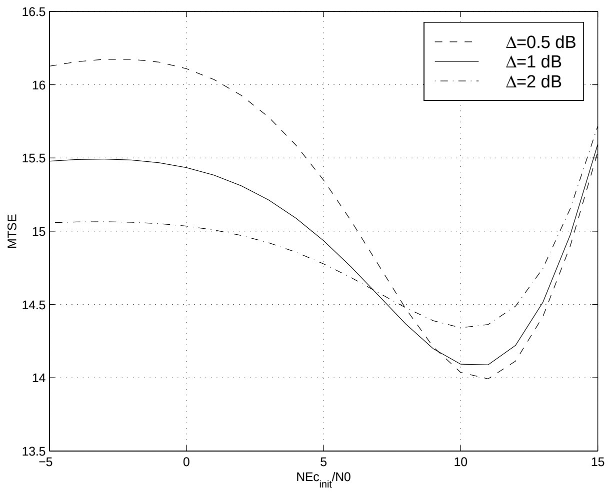

Fig. 3. Evolution of the MTSE with respect to the initial SNR.

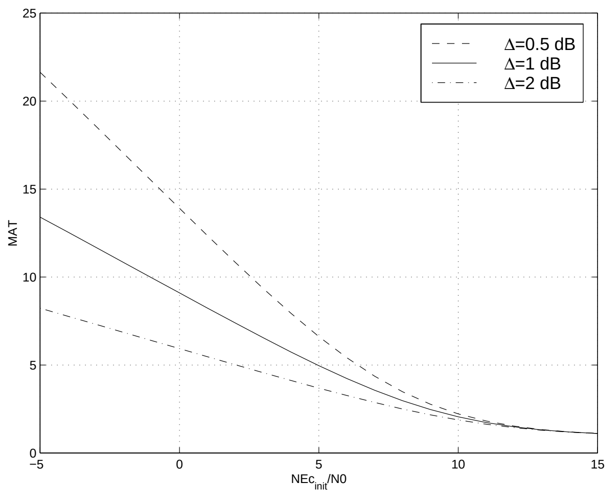

Fig. 4. Evolution of the MAT with respect to the initial SNR.

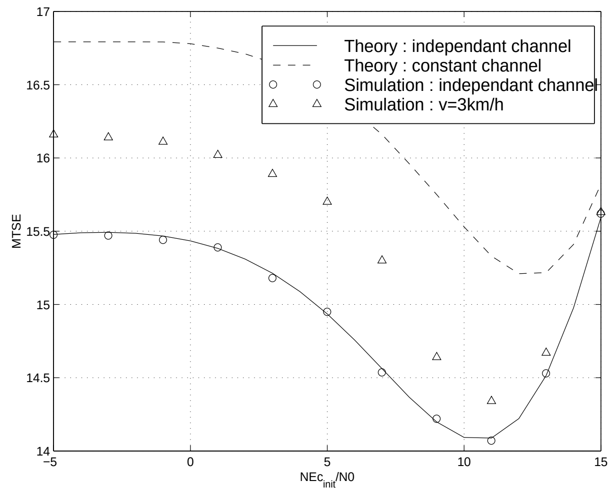

Fig. 5. Evolution of the MTSE with respect to the initial SNR.

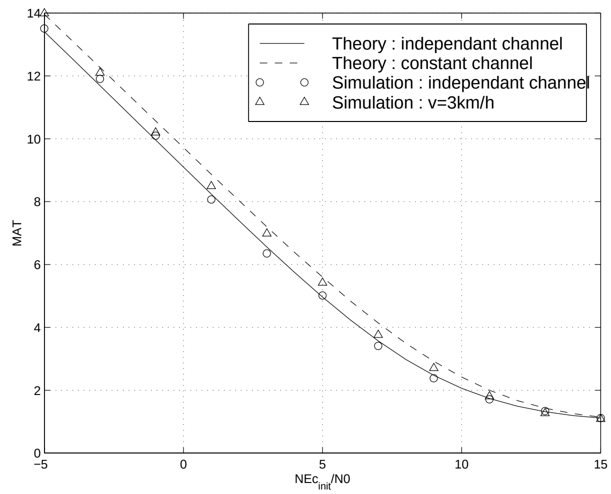

Fig. 6. Evolution of the MAT with respect to the initial SNR.