Performance of a Decision Feedback Equaliser for a TDMA Digital Mobile Radio Transmission

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Résumé

L'objet de cet article est l'étude de l'égaliseur adaptatif à retour de decision (Decision Feedback Equaliser), pour une transmission radio mobile AMRT. L'algorithme adaptatif est l'algorithme de Kalman. Nous étudions d'abord les longueurs optimales de la séquence d'apprentissage et des symboles de données d'une trame, pour différentes valeurs du débit et de la vitesse du véhicule. Nous simulons ensuite les performances de l'égaliseur.

Abstract

This paper studies the use of an adaptive Decision Feedback Equaliser for a TDMA digital mobile radio transmission. The adaptive algorithm is the Kalman algorithm. We first study the optimum lengths of the training sequence and of the data symbols sequence of a slot, given different bit rates and vehicle speeds. The BER is then simulated.

1. Introduction

Mobile radio is characterised by the transmission of the signal through a time-variant multipath propagation channel. The delay spread of the channel impulse response can vary between a fraction of the symbol duration to one or more symbols duration, depending on the environment of the mobile. This may cause severely intersymbol interference (ISI), which significantly degrades the performance of the transmission system. Further, mobile radio channels also suffer from the fast fading variation of thepaths due to the motion of the receiver. Adaptive equalisation techniques seem the most appropriate solution to overcome these impairments.

Decision Feedback Equalisation (DFE) gives better performance than linear eqnalisation on time-variant multipath channels [3]. To improve the performance, the tap weight coefficients of the DFE can be adjusted adaptively. In case of rapidly time-variant multipath channels, the adaptive algorithm must have fast initial acquisition and good tracking ability to follow the changes of the channel. The Kalman adaptive algorithm [1] meets this requirements, despite its complexity.

This paper investigates the performance of the DFE and of the Kalman adaptive algorithm for a time-division multiple access (TDMA) digital mobile radio transmission. We assume a 4-QAM modulation. First, the optimum lengths of the DFE and of the slot (training and data sequence) are examined. These values depend on the bit rate. We study three different bit rates. Then, for each bit rate, we give the performance of the DFE for different vehicle speeds.

The paper is organised as follows. Section 2 describes the system model. Section 3 presents the simulation results. The conclusion is summarised in Section 4.

2. System Model

Figure 1 shows the equivalent baseband system model under study. At the transmitter, the input data bits are mapped into a 4-QAM symbol denoted x_i. The overall filtering function is a raised-cosine function with a roll-off equal to 0.35. The symbols are then arranged in slots, and a TDMA transmission which multiplexes 4 users is assumed. A slot consists of a known training sequence of length N_t symbols, and of a data sequence of length N_d symbols (see Figure 2). The training sequence is used by the equaliser to converge. A short training sequence can limit the tracking ability of the DFE. On the other hand, a short data block means efficiency loss. Hence, the optimum values of N_t and N_d realise a compromise between the performance and the data efficiency. They are chosen by simulation in §3.1 and §3.2.

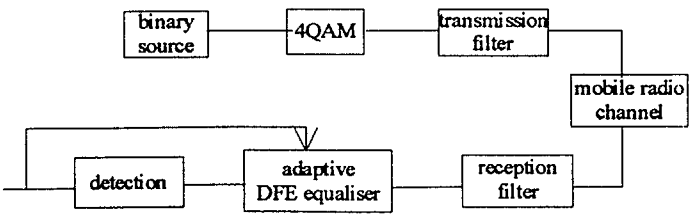


Figure 1. Baseband Transmission Model

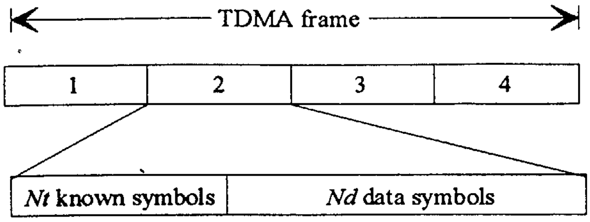


Figure 2. TDMA Frame Structure

In the channel, the received signal is given by

$$y(t)=\sum_{n=1}^{N}\alpha_n(t)\sum_{k}x_k h(t-\tau_n-kT)+w(t) \qquad (1)$$

where N is the number of paths, T is the symbol duration, $\alpha_n(t)$ and τ_n are the fading and the delay value of the n^{th} fading component respectively, $h(t)$ is the Nyquist filter impulse response, and $w(t)$ is a white Gaussian noise.

We consider the typical urban (TU) propagation model, defined for the GSM system [4]. This model is characterised by six main echo paths (N=6), with uncorrelated Rayleigh amplitudes, Doppler spectrum and different average power:

Tap number	Relative Time (µs)	Average relative power (dB)
1	0.0	-3.0
2	0.2	0.0
3	0.5	-2.0
4	1.6	-6.0
5	2.3	-8.0
6	5.0	-10.0

Table 1. Taps settings for the Typical Urban (TU) area case

We study three bit rates: 250 kbit/s, 500 kbit/s and 1 Mbit/s. This leads to a symbol duration of T=8 µs, T=4 µs and T=2 µs respectively. Then, depending on the bit rate, the maximum delay spread of the channel (5 µs) is less than the symbol duration; greater than a symbol duration, or greater than 2 symbols duration.

For each bit rate, we simulate a vehicle speed of 3 km/h, 50 km/h and 150 km/h. The frequency carrier is 900 MHz.

The Decision Feedback Equaliser consists of a feedforward filter with K_1+1 taps and a feedback filter with K_2 taps. The output of the DFE is given by

$$\hat{x}_k=\sum_{j=-K_1}^{0}c_j^{(k)}y_{k-j}+\sum_{j=1}^{K_2}c_j^{(k)}\tilde{x}_{k-j} \qquad (2)$$

where $\tilde{x}_k$ is the detected version of x_k, and $\{c_j, j=-K_1{:}K_2\}$ are the coefficients of the DFE. These coefficients are adjusted adaptively by the Kalman algorithm. Given the above values of the maximum channel dispersion and of the symbol duration, we implement a DFE of length (K_1+1=3, K_2=3).

3. Simulation Results

3.1. Training Convergence

First, we study the training convergence of the DFE in order to determine the optimum value of N_t. It is then here assumed that the symbols fed back to the DFE are known ($\tilde{x}_k = x_k$ in (2)). Figures 3.a, 3.b and 3.c give the mean square error (MSE) at the output of the DFE versus the location of the symbol in the slot, for the three bit rates respectively. The signal-to-noise ratio is set to $E_b/N_0=10$ dB. The weighting factor of the Kalman algorithm was optimised by simulation (not presented in this paper) and set to w=0.95. In all cases, the minimum MSE is achieved when $N_t \geq 40$. However, to maintain a good data efficiency, we choose $N_t=20$, which leads almost in all cases to a MSE of 10^{-1}.

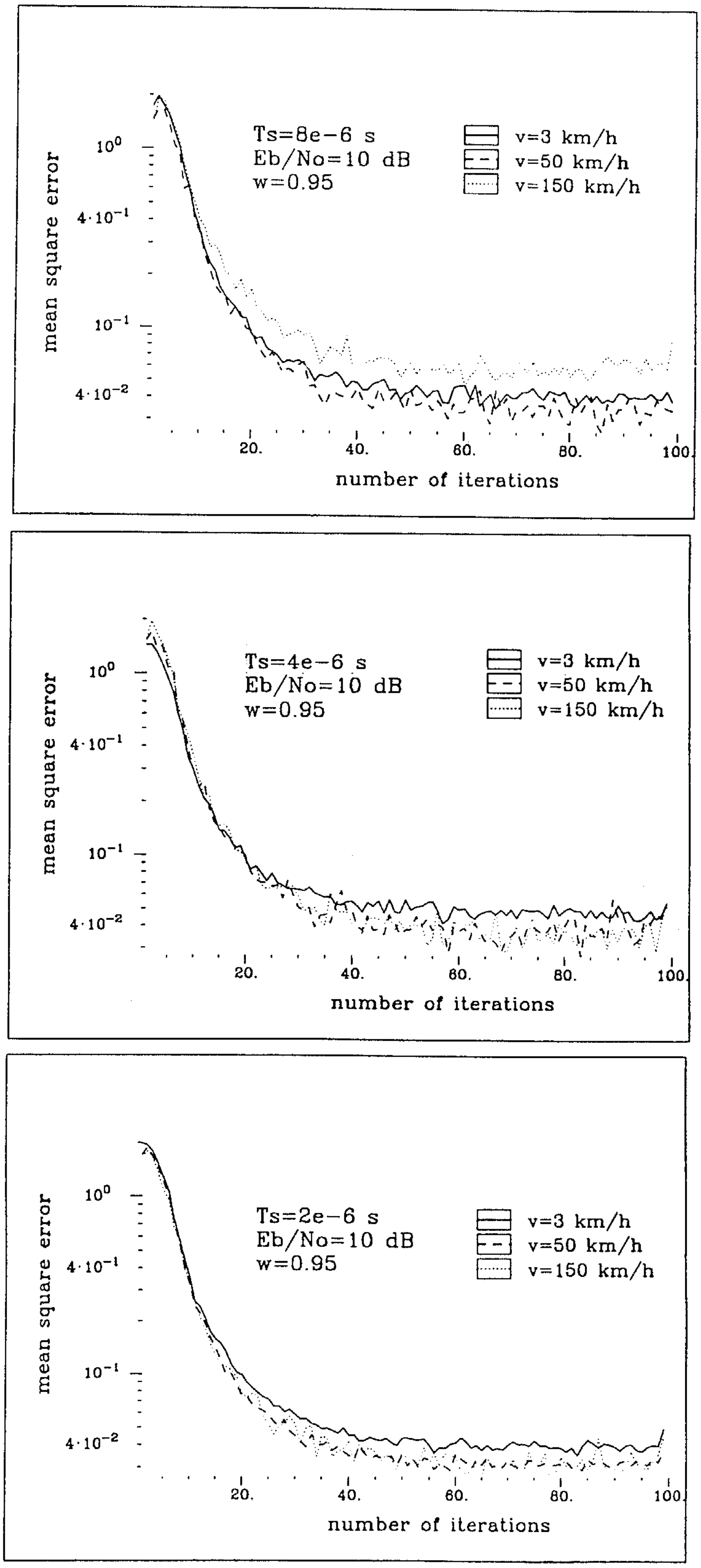
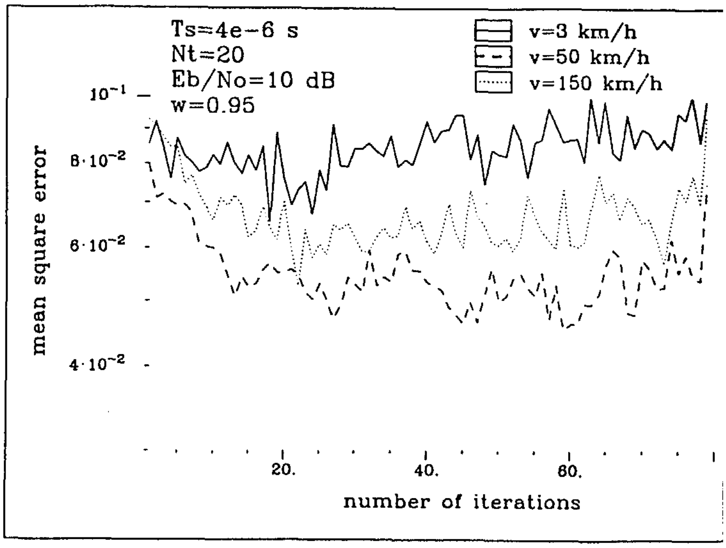
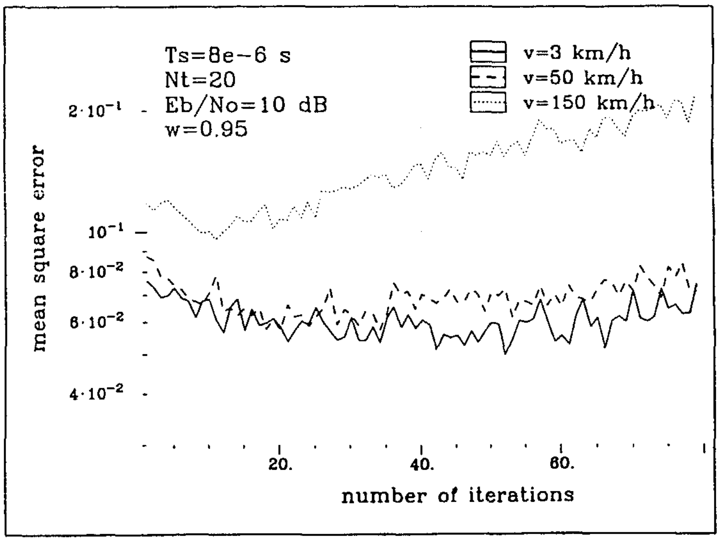


Figure 3.a, 3.b, 3.c. Training Convergence Rate of the adaptive Kalman DFE(3,3) in the TU channel

3.2. Tracking Performance

Then, we study the capability of the DFE to track the channel. The aim is to determine the optimum data sequence length N_d. Assuming a training sequence length $N_t = 20$, we calculate the mean square error at the output of the DFE when the symbols fed back to the DFE are the previous detected symbols, versus the location of the data symbol in the slot. The signal-to-noise ratio is set to $E_b / N_0 = 10$ dB. The results are represented in Figures 4.a, 4.b and 4.c, for the three bit rates respectively. Except for T=8 µs and v=150 km/h, the level of the MSE mean square error is maintained until $N_d = 60$.





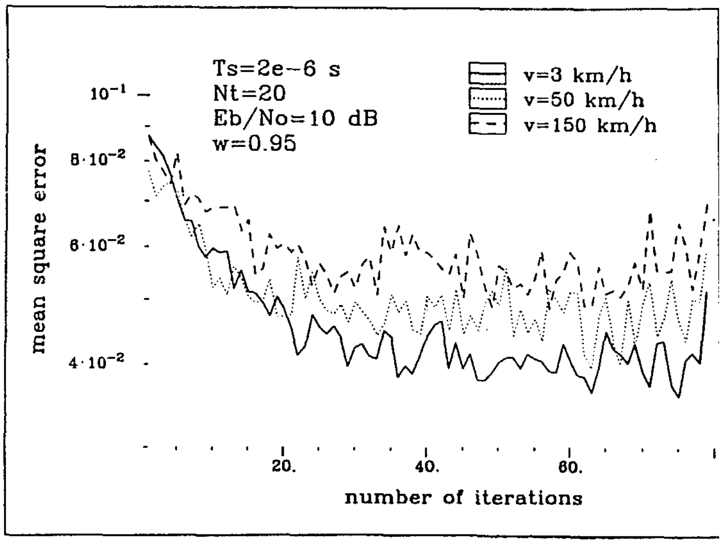


Figure 4.a, 4.b, 4.c. Tracking Convergence Rate of the adaptive Kalman DFE(3,3) in the TU channel (training sequence length $N_t = 20$)

3.3. BER

We now simulate the performance of the adaptive DFE in the TU channel, with slots of length $N_t = 20$ and $N_d = 60$. Figures 5.a, 5.b and 5.c give the BER versus the E_b / N_0, for the three bit rates respectively.

In all cases, the performance exhibit an irreducible BER when $E_b / N_0 \geq 20\ dB$, which may be caused by a bad tracking of the Kalman algorithm.

When the symbol duration is T=8 µs or T=2 µs, the worst performance is obtained with the higher vehicle speed i.e., 150 km/h. This is due to the difficulty for the Kalman algorithm to follow the rapidly channel variations. However, when T=4 µs, the worst BER is obtained at 3 km/h.

Now, if we compare the different bit rates, we observe that the performance improves when the bit rate is increased. In the case of the lower bit rate (T=8 µs), the maximum delay spread of the channel is less than the symbol duration, and the channel can be viewed as a flat Rayleigh channel. The use of a DFE brings no improvements. The improvement of performance with the increase of the bit rate can be explained by a diversity effect of the channel which is used by the receiver.

4. Conclusion

We give the performance of the adaptive Kalman Decision Feedback Equaliser, applied to a TDMA digital mobile radio transmission. A 4-QAM modulation is assumed. We studied the influence of the bit rate (250 bit/s, 500 bit/s and 1 Mbit/s) and of the vehicle speed (3 km/h, 50 km/h and 150 km/h).

In all cases, an irreducible BER is observed when $E_b / N_0 \geq 20\ dB$.

The different bit rates lead to different ISI. The performance improves when increasing the bit rate. This can be explained by a diversity effect, when the maximum delay spread of the channel is greater than the symbol duration.

The vehicle speed affects the tracking ability of the adaptive Kalman algorithm. The worst performance is obtained with the higher vehicle speed when the channel varies rapidly.

5. References

[1] PROAKIS, *Digital Communications*, McGraw-Hill,1989.

[2] PROAKIS, "Adaptive Equalisation for TDMA Digital Mobile Radio", *IEEE Transactions on Vehicular Technology*, Vol.40, N°2, May 1991.

[3] LING and PROAKIS, "Adaptive Lattice Decision-Feedback Equalisers- Their Performance and Application to Time-Variant Multipath Channels", *IEEE Transactions on Communications*, Vol.33, N°4, April 1985.

[4] Recommendation 05.05, version 3.13, GSM.

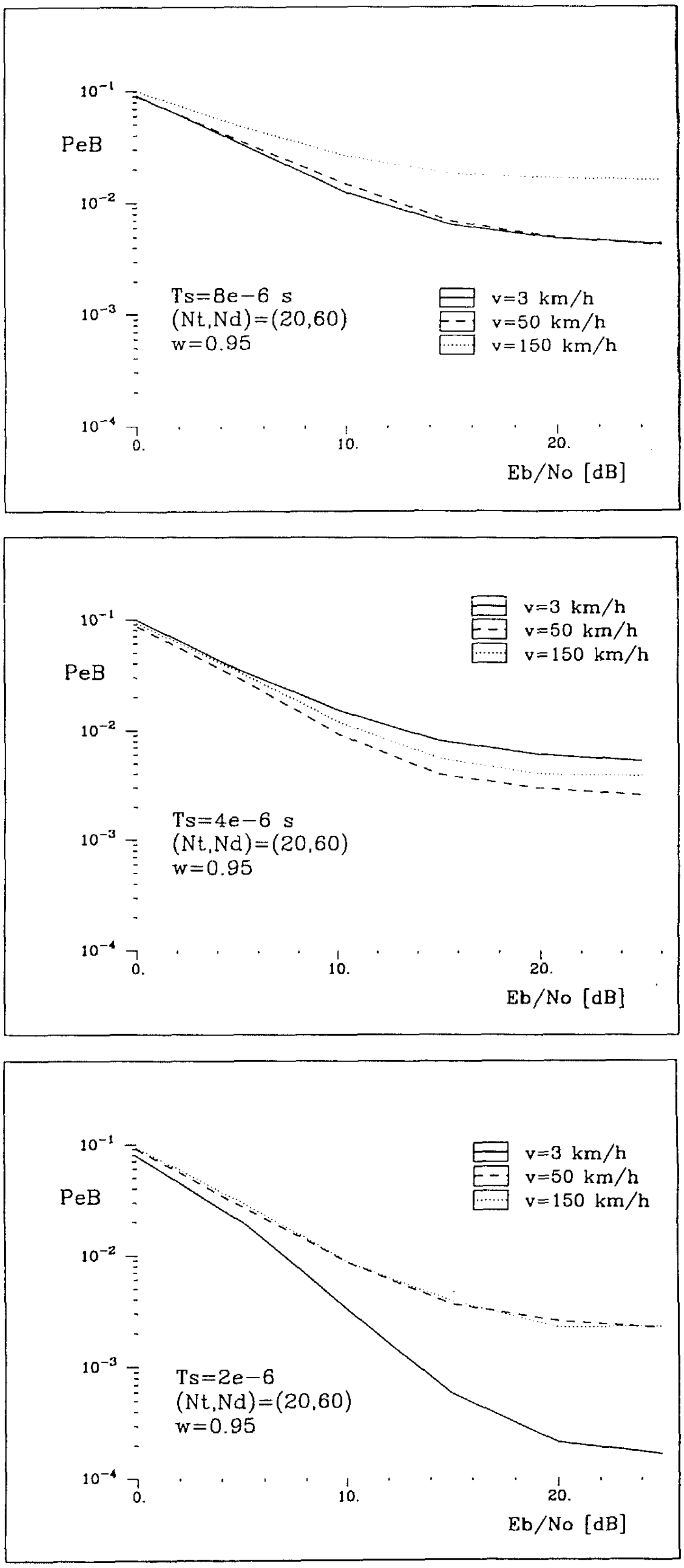


Figure 5. Bit Error Rate of the adaptive Kalman DFE(3,3) in the TU channel