PERFORMANCE EVALUATION OF TDMA RECEIVERS USING MAXIMUM LIKELIHOOD ESTIMATION TECHNIQUES

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Abstract – **The performances of three TDMA receiver structures, using Maximum Likelihood Sequence Estimation (MLSE), Block Sequence Estimation (BSE) and Per-Survivor Processing (PSP) techniques were evaluated. The criteria adopted for analysis was according the minimum performance specifications of the IS-55 standard for transmissions over flat fading and frequency selective channels. The results stated that the three structures analyzed reach the minimums specified partially and the PSP structure had a better performance, despite the higher computational load required in this method.**

I INTRODUCTION

THE aims of this work are to evaluate the performances of TDMA receivers, using three different estimation techniques: Maximum Likelihood Sequence Estimation (MLSE) [1]; Block Sequence Estimation (BSE) [2]; and Per-Survivor Processing (PSP) [3]. All these techniques are based on the Viterbi algorithm [4] for data demodulation combined with adaptive algorithms for channel identification.

The simulations were carried out on complex baseband structures and regarding the specifications of IS-54 [5] and IS-55 [6] standards.

In the section II, some consideration related to the Mobile Communication System IS-54 (TDMA) and the channel transmission environment are presented. In the section III the estimation techniques are introduced and the receiver structures, as well. In section IV the simulated performances are commented and the final conclusions are presented on section V.

II MOBILE COMMUNICATION SYSTEM IS-54

In this system, the traffic digital channels are modulated with using $\pi/4$ DQPSK (*Differentially Quadrature Phase Shift Keying*).

For the simulations only the Radio Base Station (RBS) to the Mobile Station (MS) link is considered. The transmitted time slot is composed by a sequence of 28 bits, here designated as Training Sequence, followed by 296 bits of information.

For transmissions on flat fading channel and frequency selective channel, the minimum performance specified in the IS-55 standard are presented the Tables I and II, where the Bit Error Rate (BER) is related to MS speed (v), 2nd ray delay (T symbol period) and the Signal-Noise Rate (SNR).

To simulate the flat fading channel, two independent Gaussian sequences, with average null and unitary variance, are added in quadrature, resulting a complex sequence which its module has Rayleigh distribution and phase has uniform distribution. [7]. To obtain the Doppler Spectrum, each of the initial sequence was filtered by a conformer filter and normalized to present the unitary average power [8].

TABLE I

Minimum Performance Specifications Under Flat Fading Channel Transmissions

v (km/h)	SNR (dB)	BER
8	16	3%
100	16	3%

TABLE II

Minimum Performance Specifications Under Frequency Selective Channel Transmissions

v (km/h)	2nd ray delay	SNR(dB)	BER
8	$0.25T$; $0.5T$; $1T$	16	3%
50	$0.25T$; $0.5T$; $1T$	19	3%
100	$0.25T$; $0.5T$; $1T$	19	3%

Under flat fading channel transmission, the complex baseband equivalent of the received signal $z(t)$, is obtained by multiplying the samples of the sequence generated above and the samples of the transmitted signal, adding the Additive White Gaussian Noise (AWGN) samples.

For frequency selective channel transmission, the two-

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ray technique is used. It is simulated by taking two complex sequences generated according the method described above, each one multiplied by the complex baseband signal transmitted and applying a delay (2nd ray delay) in one of them. After that, the resulting sequences and the AWGN are added, resulting a complex sequence that is equivalent to the complex baseband signal received.

III Receivers

A. MLSE Adaptive Receiver

The MLSE adaptive receiver presented corresponds to the classical structure proposed by Forney, with some modifications. The first one is the use of a fixed receiver filter, matched only with the transmitter filter. The goal is to keep the noise uncorrelated, when the received signal is sampled at symbol rate [9].

The second modification is related with the channel estimation. Due to the time variant characteristic of the mobile channel and regarding that the Viterbi Algorithm performance is strictly linked to the channel estimation accuracy, it is necessary that these estimations are updated as fast as possible. However, as the usual, Viterbi Algorithm supplies symbol estimation only when a natural or forced merges occurs. The channel estimation cannot track the time variations of the channel if this delay is too long, affecting the receiver performance. To avoid this, a modification on the channel estimator was adopted. The channel estimator is fed with a "pre-estimation" of the symbols, obtained from the survivor with the lowest path metric at that instant. In this configuration, the channel estimation are updated at each horizontal movement inside the trellis, it means, after the processing of all states of the trellis in one determined instant. The algorithm used for the channel estimation was the LMS (*Least-Mean-Square*), presented on its recursive form as follows:

$$\hat{f}_{k+1,i} = \hat{f}_{k,i} + \beta\left(z_{k-d} - \sum_{i=0}^{M} \hat{f}_{k,i}\hat{\hat{a}}_{k-d-i} \right)\hat{\hat{a}}^{*}_{k-d-i} \qquad (1)$$

where:

$\hat{f}_{k,i}$ is the i^{th} sample the estimated channel coefficients sequence, at the instant *k;*

β is the LMS convergence parameter;

z_{k-d} is a sample of the observed sequence, at the instant *k-d*;

$\hat{\hat{a}}_{k-d-i}$ is the "pre-estimation" of the symbol, at the instant *k-d-i*;

d corresponds to the delay, specified in number of symbols, of the "pre-estimation".

The block diagram of the MLSE adaptive receiver simulated is presented in the Fig. 1.

The time slot processing is initiated with the key Ch_1 on position "a", during the initial 14 symbols (training sequence). After that, the time slot is processed with the key on the position "b", where the channel estimator is fed by "pre-estimation".

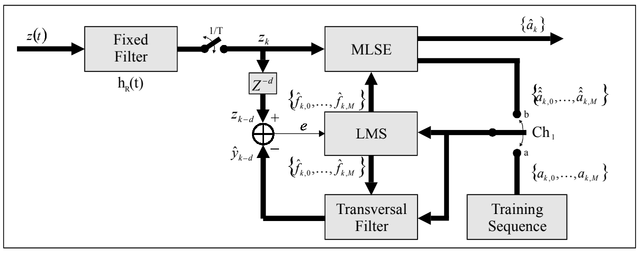

Fig. 1. Block Diagram of the MLSE Adaptive Receiver.

B. BSE Adaptive Receiver

This receiver uses the Block Sequence Estimation algorithm, where the time slot is processed in blocks. Each block is used for channel and symbol estimation, it means that, the metric calculation unit is fed in blocks of N_b symbols, originating a data demodulation also in blocks.

Similarly to the MLSE, the BSE adaptive receiver uses a fixed receiver filter, matched only with the transmitter filter, to keep the noise uncorrelated, when the received signal is sampled at symbol rate.

During the training sequence processing, the receiver uses the LMS algorithm to find the channels coefficients (Ch_1 on position "a"). After that, it starts the use the BSE algorithm to perform the channel and symbol joint estimation (Ch_1 on position "b").

The block diagram of the BSE adaptive receiver simulated is presented in the Fig. 2.

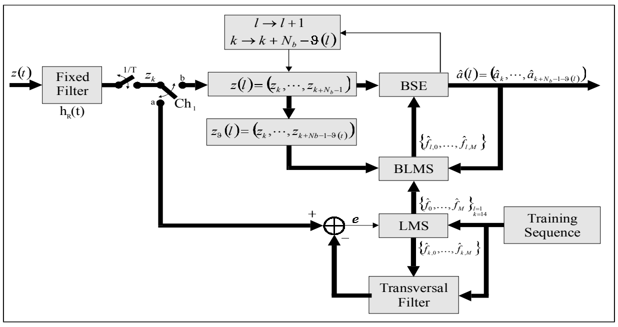

Fig. 2. Block Diagram of the BSE Adaptive Receiver.

C. PSP Adaptive Receiver

The main characteristic of this method consists on the use of a symbol sequence, associated with each survivor, for the channel coefficients estimation (per-survivor).

Similarly to the MLSE and BSE receivers, the PSP receiver also uses a fixed receiver filter.

During the training sequence processing, this receiver uses the LMS algorithm to find the channels coefficients (Ch_1 on position "a"). After that, it starts to operate according the PSP algorithm.

The Fig. 3 presents the block diagram for simulated complex baseband PSP receiver.

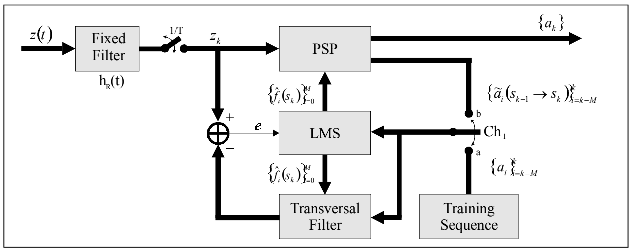

Fig.3. Block Diagram of the PSP Adaptive Receiver.

III RESULTS

The simulation conditions that each receiver was submitted were identical, it means that, the noise sequences and channel sequences were the same. By this way, the results obtained reflect just the differences among the estimation methods evaluated.

Initially, the configuration parameters were optimized, regarding the best tradeoff among all conditions specified on the IS-55 standard. After that, performance curves of BER *versus* SNR and BER *versus* 2[nd] ray delay were obtained, highlighting the situations were the minimum requirements were reached.

The effects caused by channel estimator, resetting after each time slot processing, were investigated. The BER *versus* SNR curves were traced for resetting and non-resetting channel estimator operations. It was observed that resetting the channel coefficients before each block processing does not affect the receiver performance. By using a double β (LMS convergence parameter) during the training sequence processing, it was possible to reinitialize the channel estimator to reach the same values of the non-reinitialized one before the end of the training sequence, as stated on the Fig. 4. This behavior was found in all models analyzed.

During the BER analysis, as function of the bit position in the time slot, it was observed that under low speeds the BER has a uniform distribution inside the time slot, as showed on the Fig. 5 (e.g. MLSE receiver). However, it does not occur for higher speeds, as illustrated in Fig. 6 (e.g. MLSE receiver), were there is a degradation of the BER which is proportional to bit position.

This characteristic is well explained by the fact that on the beginning of data sequence processing, right after the training sequence processing, the channel coefficients estimation are very close to the real ones. As far as the processing goes from the beginning, the quality of the channel estimation is affected by the symbol estimation errors, closing the degradation loop. This characteristic was found in all the three receivers.

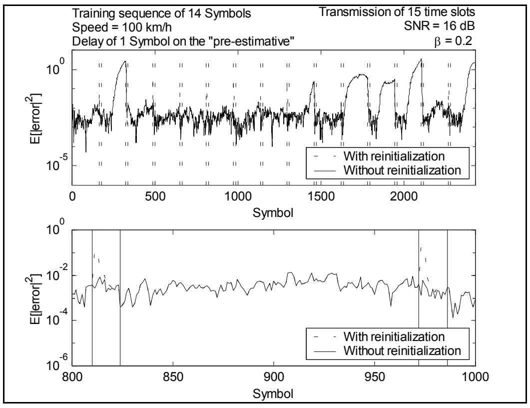

Fig. 4. Channel estimator error.

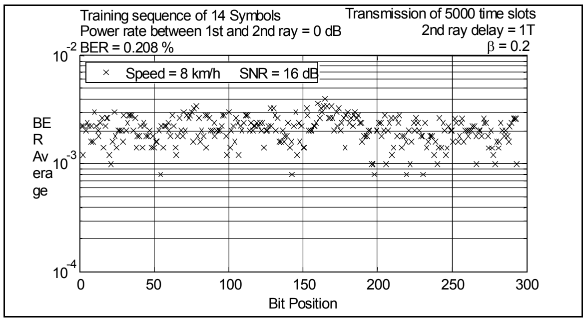

Fig. 5. BER *versus* bit position in the time slot for MLSE receiver.

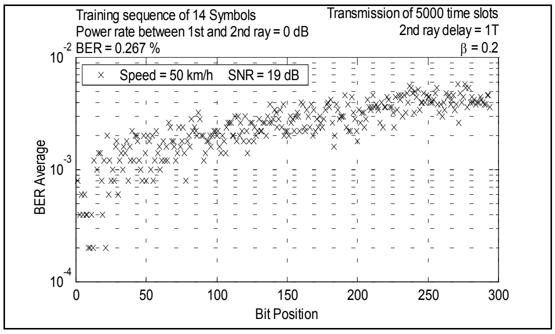

Fig.6. BER *versus* bit position in the time slot for MLSE receiver.

Before the individual analysis, it is convenient to highlight some considerations that are common to all the models evaluated:

- For all simulations only the link Radio Base Station (RBS) to the Mobile Station (MS) was considered and the training sequence estimation was not considered on BER calculations;
- The vector with the discrete channel coefficients used had unitary memory;

- When no other condition were highlighted, the channel estimator is being reinitialized before the processing of each time slot;
- The impulse response for flat fading channel and frequency selective channel used has unitary average power. On the frequency selective channels, both rays have the same average power.
- To increase the convergence speed of the channel estimator, during the training sequence processing, a double β was adopted.

A. MLSE Adaptive Receiver

This receiver has the following configuration parameters:

- LMS convergence parameter used on the channel estimator (β);
- "Pre-estimation" delay of the symbols that feed the channel estimator.

The β optimization showed that this value is strictly related to the MS speed. However, β = 0.2 produced a good performance in all situations.

A null "pre-estimation" delay yielded the best performance for operations under flat fading channel. However, the same did not occur under frequency selective channel. For this reason, a "pre-estimation" delay of 1T symbol was adopted, once the performance was acceptable for both channels.

The Fig. 7 shows that the MLSE proposed satisfies the minimum conditions specified for the flat fading channel, once in both speeds the BER is bellow of 3% before the SNR limits specified. Observing the Fig. 8, regarding frequency selective channel, the MLSE receiver just satisfy the minimum conditions for a 2nd ray delays of 1T symbol.

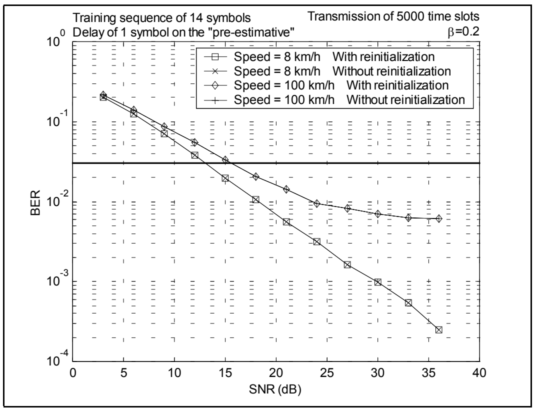

Fig. 7. BER *versus* SNR on flat fading channel.

Additionally, identical performances, with and without channel estimator resetting, are stated on the Figs 7 and 8.

In the Fig. 9, except for the speed of 100 km/h, the receiver reached the minimum performance specified, once the BER was lower than 3% for any 2nd ray delay. The variable performance is explained by the fact that the channel estimator is sampled at symbol rate, becoming a hard task for the estimator to track the channel coefficients when the 2nd ray delay is very different of entire multiples of T.

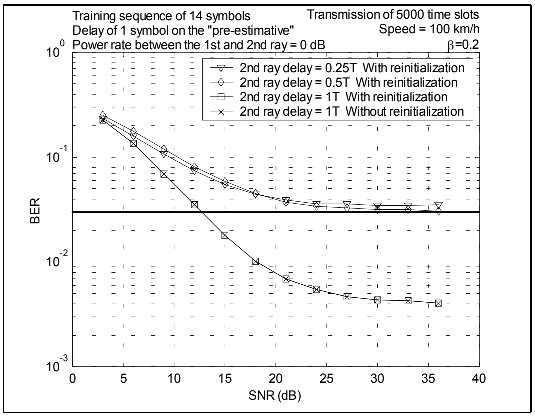

Fig. 8. BER *versus* SNR on frequency selective channel.

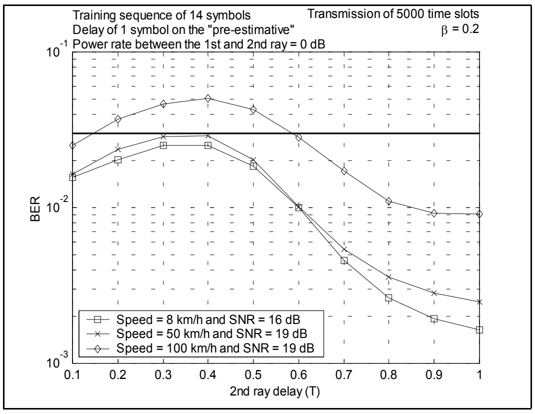

Fig. 9. BER *versus* 2nd ray delay.

B. BSE Adaptive Receiver

This receiver has the following configuration parameters:

- Block size (Tb);
- LMS convergence parameter (β);

Due to the strong dependency of this parameters, a joint optimization was used and the following tendencies were found:

- Similar to the MLSE receiver, the β value is strictly related to the MS speed;
- For low speeds, Tb has no influence on the performance, that is basically determined by β;
- For high speeds, the Tb influence begins to be significant on the performance.

After the optimization, it was found that a Tb of 8 symbols and β of 0.12 yielded an acceptable performance for all the situations required.

According to the Fig. 10, the BSE receiver performance did not reach the minimum required under flat fading channel and 100 km/h speed.

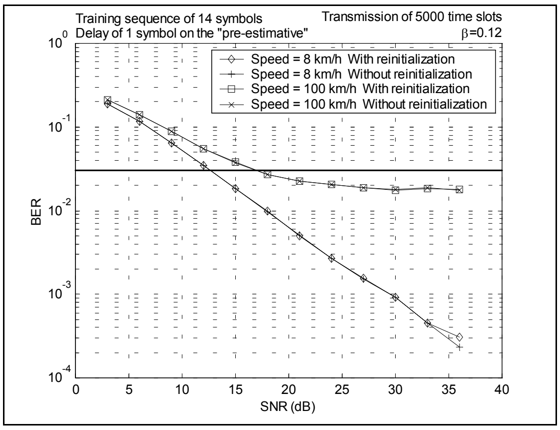

Fig. 10. BER *versus* SNR on flat fading channel.

Observing the Fig. 11, for frequency selective channel, the receiver presented better performance for 2nd ray delay close to 1*T*. However, it reached the minimum required only for 8 km/h speed, as showed on the Fig. 12.

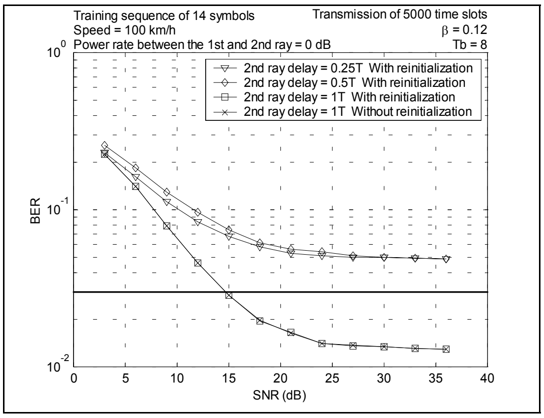

Fig. 11. BER *versus* SNR on flat fading channel

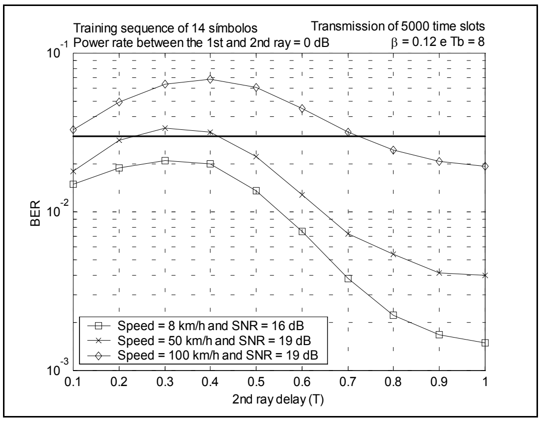

Fig. 12. BER *versus* 2nd ray delay.

C. PSP Adaptive Receive

For this receiver, the LMS convergence parameter used on the channel estimator (β) is the only configuration parameter. The optimization revealed a value of 0.2 for the simulation conditions adopted.

The receiver performance under flat fading channel is presented on the Fig. 13, where the minimum required was reached in both speeds.

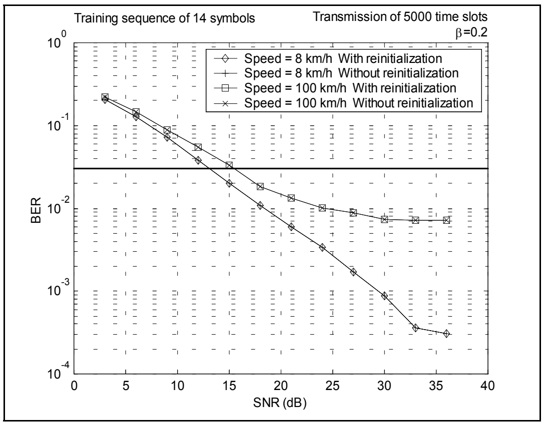

Fig. 13. BER *versus* SNR on flat fading channel.

Under frequency selective transmission and 100 km/h speed, the receiver reached partially the minimum required, as showed on the Fig. 14. However, according the Fig. 15, the PSP receiver reached the minimum performance required for 8 km/h and 50 km/h.

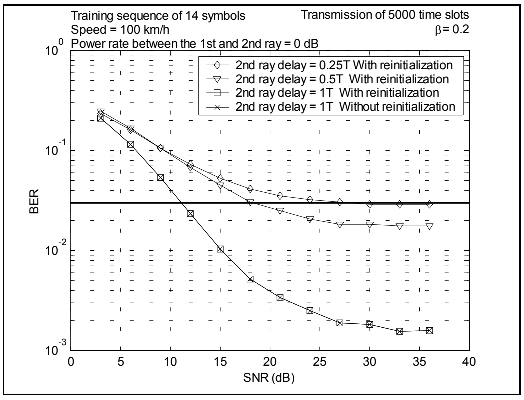

Fig. 14. BER *versus* SNR on flat fading channel.

Bearing in mind the results shown in Fig. 16 one concludes that: under flat fading transmission, it is possible to verify that the MLSE and PSP receivers presented similar performances. However, on the frequency selective environment, Fig. 17, the PSP receiver reached the best performance.

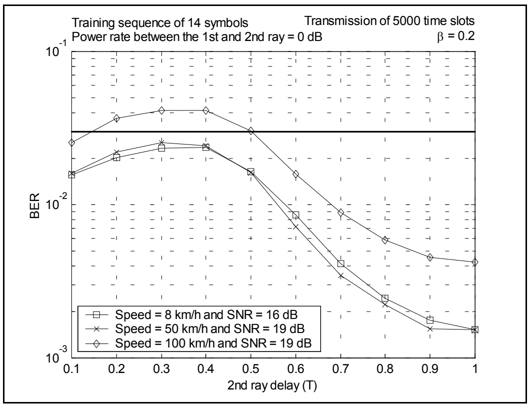

Fig. 15. BER *versus* SNR on flat fading channel.

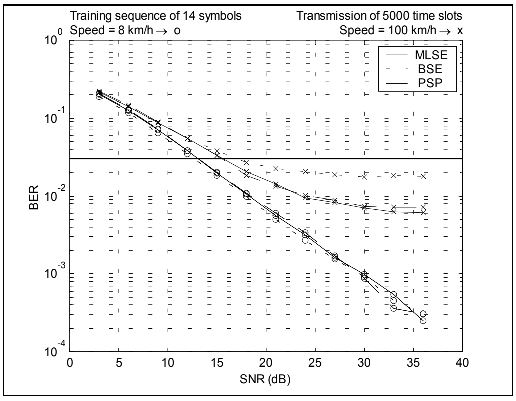

Fig. 16. BER *versus* SNR on flat fading channel.

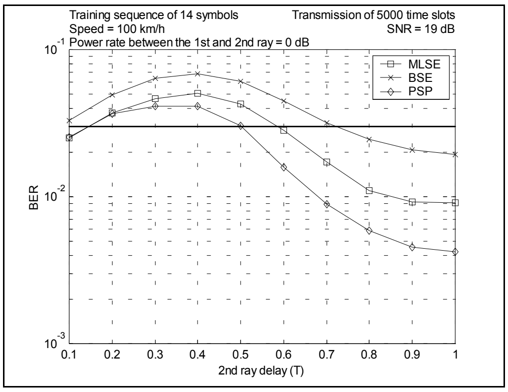

Fig. 17. BER *versus* 2nd ray delay.

V CONCLUSIONS

The performances of three receivers using techniques of maximum likelihood estimation were analyzed, checking its applicability to the TDMA mobile communication system.

The estimation techniques were based on the Viterbi algorithm for data demodulation combined with adaptive algorithms for channel identification.

All the receivers have a fixed filter, matched with the transmitter filter. This feature kept the noise samples uncorrelated, when the received sequence was sampled at the symbol rate.

It was observed that there was no loss of performance when the channel coefficients were reinitialized after each time slot processing, if a double β is used on the channel estimator during the training sequence processing.

The degradation effect of the performance, for high MS speeds, in relation to the bit position was showed as a common characteristic of all models.

The individual analysis revealed that the PSP receiver presents the highest performance in environments simulated. However, the computational capacity required is also higher.

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