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Training Based MIMO Channel Estimation

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Abstract— In this paper we give first some general background information on channel estimation. Then we introduce Least-squares (LS) channel estimation techniques. The idea is to use the channel decoded symbols as a new long training sequence in the channel estimator and thereby improve the quality of estimates. Simulation layout for this iteration is also shown. Finally, conclusions are drawn.
Keywords— Estimation, CIR, ISI, LS, LMMS.

I. INTRODUCTION

The radio channels in mobile radio systems are usually multipath fading channels, which are causing intersymbol interference (ISI) in the received signal. To remove ISI from the signal, many kind of equalizers can be used. Detection algorithms based on trellis search (like MLSE or MAP) offer a good receiver performance, but still often not too much computation. Therefore, these algorithms are currently quite popular.

However, these detectors require knowledge on the channel impulse response (CIR), which can be provided by a separate channel estimator. Usually the channel estimation is based on the known sequence of bits, which is unique for a certain transmitter and which is repeated in every transmission burst. Thus, the channel estimator is able to estimate CIR for each burst separately by exploiting the known transmitted bits and the corresponding received samples.

II. BACKGROUND FOR CHANNEL ESTIMATION

Fig.1 shows a generic simulation layout for a TDMA based mobile system, which exploits channel estimation and signal detection operations in equalization. The digital source is usually protected by channel coding and interleaved against fading phenomenon, after which the binary signal is modulated and transmitted over multipath fading channel. Additive noise is added and the sum signal is received.

Due to the multipath channel there is some intersymbol interference (ISI) in the received signal. Therefore a signal detector (like MLSE or MAP) needs to know channel impulse response (CIR) characteristics to ensure successful equalisation (removal of ISI). Note that equalization without separate channel estimation (e.g., with linear, decision-feedback, blind equalizers [2]) is also possible, but not discussed in this report. After detection the signal is deinterleaved and channel decoded to extract the original message.

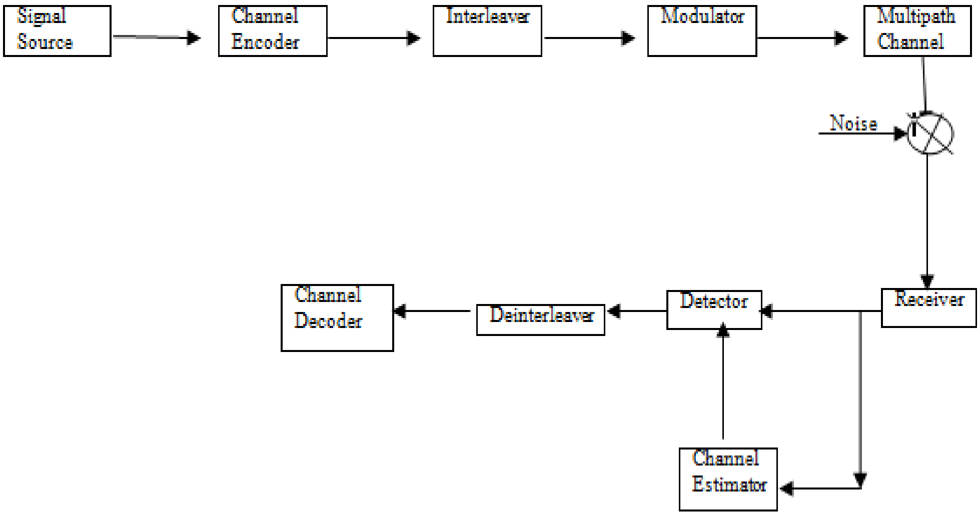

Figure 1. Block diagram for a system utilizing channel estimator and detection

In this report we are mainly interested in the channel estimation part. Usually CIR is estimated based on the known training sequence, which is transmitted in every transmission burst as Fig.2 presents for the current GSM system. The receiver can utilize the known training bits and the corresponding received samples for estimating CIR typically for each burst separately. There are a few different approaches of channel estimation, like Least-squares (LS) or Linear Minimum Mean Squared Error (LMMSE) methods [3,4].

3	58	26	58	3

Figure 2. GSM burst structure; channel estimator utilizes the known training bits.

III. LEAST-SQUARES (LS) CHANNEL ESTIMATION

3.1. Channel estimator for single signal

Consider first a communication system, which is only corrupted by noise as depicted in Fig.3 below. Digital signal **a** is transmitted over a fading multipath channel **h**L, after which the signal has memory of L symbols. Thermal noise is generated at the receiver and it is modeled by additive white Gaussian noise **n**, which is sampled at the symbol rate. The demodulation problem here is to detect the transmitted bits **a** from the received signal **y**. Besides the received signal the detector needs also the channel estimates which are provided by a specific channel estimator device.

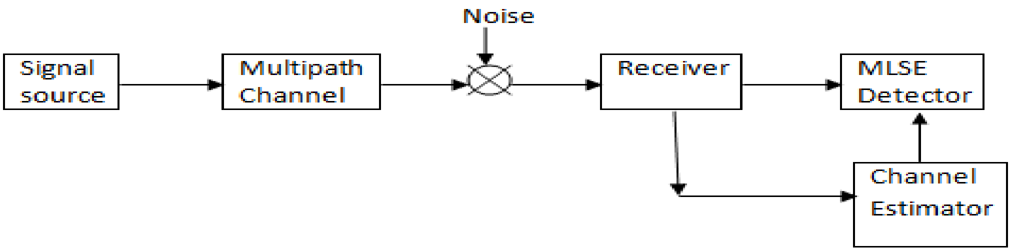

Figure 3. Block diagram of a noise-corrupted system.

The received signal **y** can be expressed as follows

$$y = Mh + n \qquad (1)$$

where the complex channel impulse response **h** of the wanted signal is expressed as

$$h = [h_0 \quad h_1 \quad \dots \quad h_L]^T \tag{2}$$

and **n** denotes the noise samples. Within each transmission burst the transmitter sends a unique training sequence, which is divided into a reference length of P and guard period of L bits, and denoted by having bipolar elements . Finally to achieve Eq. (1) the circulant training sequence matrix **M** is formed as

$$M = \begin{bmatrix} m_L & \dots & m_1 & m_0 \\ m_{L+1} & \dots & m_2 & m_1 \\ : & \dots & : & : \\ m_{L+P-1} & \dots & m_P & m_{P-1} \end{bmatrix} \tag{3}$$

$$\text{m} = [m_0 \; m_1 \dots m_{P+L-1}]^T \tag{4}$$

$$\hat{h} = \arg\min \left\| y - \tilde{M}\tilde{h} \right\|^2 \tag{5}$$

The LS channel estimates are found by minimizing the following squared error quantity Assuming white Gaussian noise the solution is given by [3] where denote the Hermitian and inverse matrices, respectively.

3.2. Joint channel estimator for 2 signals

Let us consider now a communication system in the presence of co-channel interference that is shown in Fig.4. Two synchronized co-channel signals have independent complex channel impulse responses **h** = , ,K, , n=1,2 and where L is the length of the channel memory. The sum of the co-channel signals and noise **n** is sampled in the receiver. The joint demodulation problem is to detect the transmitted bit streams **a**1 and **a**2 of the two users from the received signal **y**. To assist that joint detection operation the joint channel estimator provides channel estimates.[5,6]

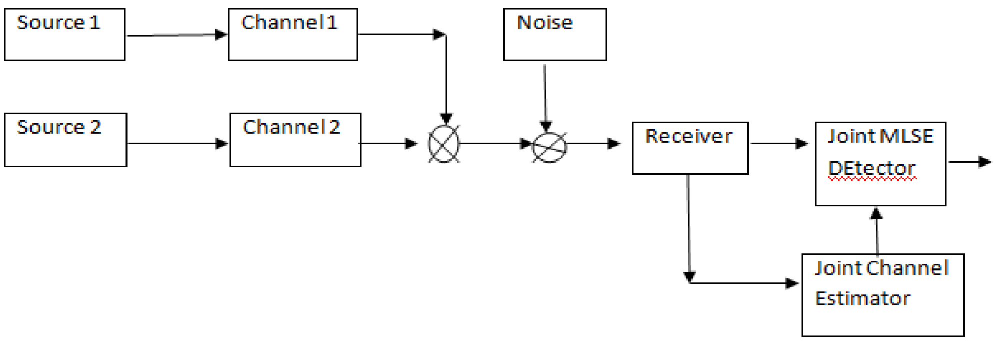

Figure 4. Block diagram of co-channel signal system.

The complex channel impulse responses of the two synchronous co-channel signals are expressed with a vector **h** as follows

$$\tilde{h} = \begin{bmatrix} h_{L,1} \\ h_{L,2} \end{bmatrix} \tag{8}$$

Containing the channel taps of the individual signals denoted by

$$h_{L,n} = \begin{bmatrix} h_{0,n} \\ h_{1,n} \\ : \\ h_{L,n} \end{bmatrix} \qquad \text{Where n=1,2} \tag{9}$$

Hence, **h** has totally (L +1) elements. Both the transmitters send their unique training sequences with a reference length of P and guard period of L bits. The sequences are denoted by

$$m_n = \begin{bmatrix} m_{0,n} \\ m_{1,n} \\ \vdots \\ m_{P+L-1,n} \end{bmatrix} \quad \text{Where n=1,2} \tag{10}$$

The circulant training sequence matrices are denoted by

$$M_n = \begin{bmatrix} m_{L,n} & \dots & m_{1,n} & m_{0,n} \\ m_{L+1,n} & \dots & m_{2,n} & m_{1,n} \\ \vdots & \dots & \vdots & \vdots \\ m_{L+P-1,n} & \dots & m_{P,n} & m_{P-1,n} \end{bmatrix} \tag{11}$$

Where n=1,2 and they are gathered into one large matrix

$$\tilde{M} = [M_1 M_2] \tag{12}$$

With these notations the received signal **y** is again given by

$$y = \tilde{M}\tilde{h} + n \tag{13}$$

The LS channel estimates can be found simultaneously for the both users by minimizing the squared error quantity, which produces in the presence of AWGN the following solution

$$\hat{h} = \arg\min \left\| y - \tilde{M}\tilde{h} \right\|^2 \tag{14}$$

$$= (\tilde{M}^H \tilde{M})^{-1} \tilde{M}^H y$$

Hence, it is very important to design those two training sequences in the joint channel estimation so that their cross-correlation is as low as possible to reduce noise enhancement.

3.3. Simulation of joint channel estimation

Simulation layout for joint channel estimation is shown in Fig.5. In joint channel estimation it is required to send a proper training sequence also for the interfering signal; hence the burst formatting is very important for the interferer also. Shortly, joint channel estimation requires more accurate modeling for the interferer, because the receiver exploits some known information on the interference as well.[7,8]

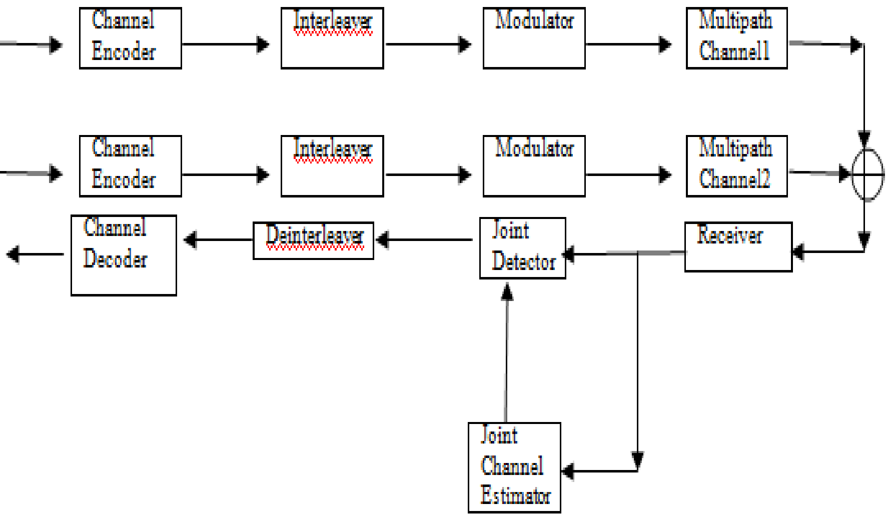

Figure 5. Simulation layout for 2 co-channels signals and joint channel estimation.

IV. SIMULATION RESULTS

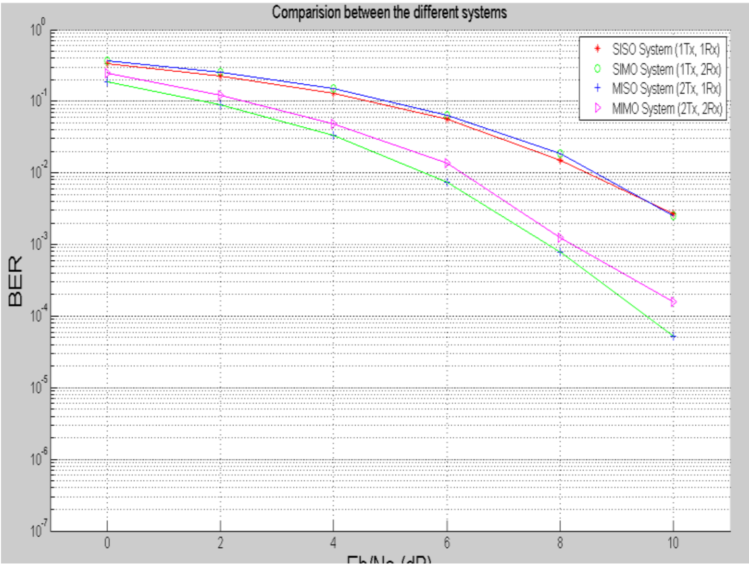

Fig 7 Comparison of MIMO Channel with other systems

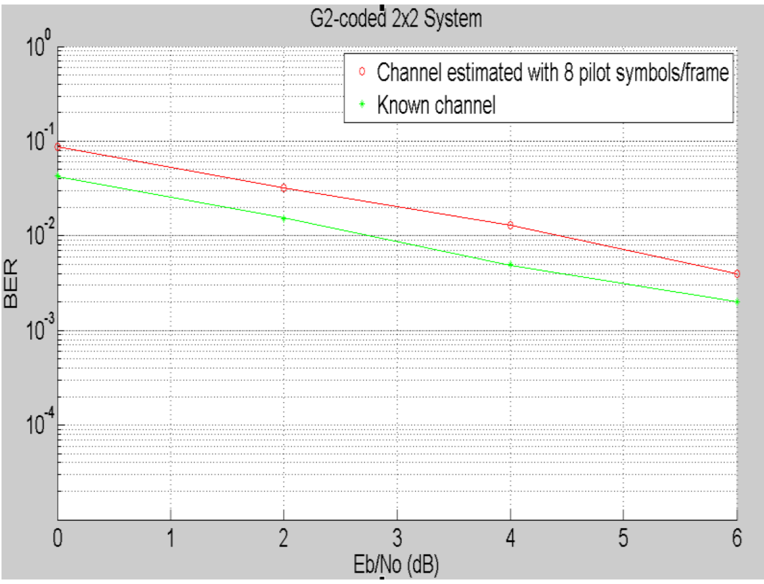

Fig 8 MIMO Channel estimation using 8 pilots

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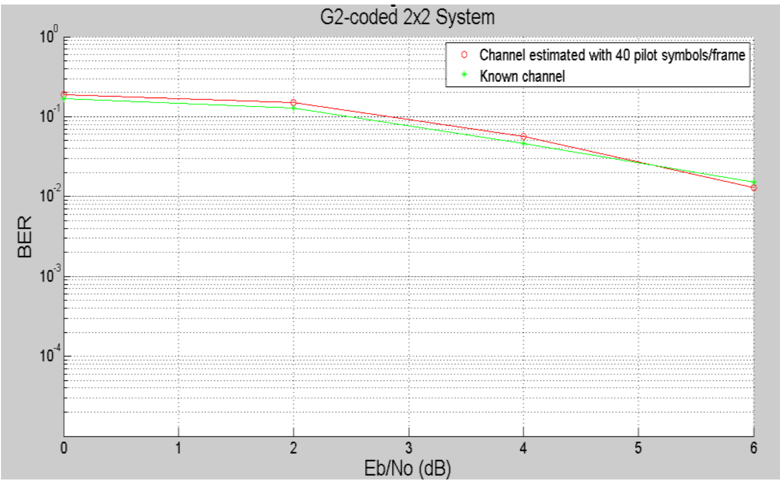

Fig 9 MIMO Channel estimation using 40Pilots

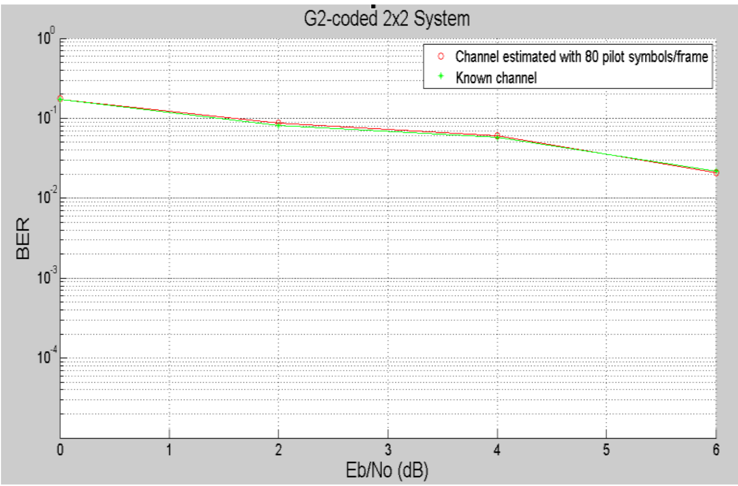

Fig 10 MIMO Channel estimation using 80 pilots

V. CONCLUSION

This report presents some approaches, how to model channel estimation in simulations. First we show a general simulation layout, which indicates that MLSE or MAP type of detection algorithms require a separate channel estimator to provide CIR estimate. It is also shown that the estimation is usually based on the known training bits and corresponding received samples.

LS channel estimation is thoroughly described. First we present the usual LS channel estimation for a single signal in the presence of noise. Then we enlarge the estimation for 2 co channel signals simultaneously, which is needed by a specific joint detection algorithm. This joint channel estimation requires a careful design of training sequences, since the cross-correlation properties should also be good for the sequences. When this joint channel estimation is simulated, one has to note that the interfering signal needs a proper modeling as well, because it is exploited in the receiver. Normally, interference can be just modulated random binary signal without any burst formatting. Iterative channel estimation method is then presented. The first iteration is conventional; e.g., LS channel estimation based on training sequence can be used. The received signal is then equalized and channel decoded. The decoded decisions are then interleaved back to the channel estimator, which begins the next iteration. The channel estimator can now use the whole burst (both data and training bits) as known and re-estimate CIR. We propose LMS adaptation rule here to avoid heavy computations. Iterative systems are often useful to simulate by using consecutive modules, which are describing different iterations.

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