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Study on MMSE Interpolation Schemes Using Multiple Symbols

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다중 심볼을 이용한 MMSE 보간 기법에 대한 연구

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Abstract This paper presents the idea of interpolating between multiple sounding bursts to estimate the individual channels of a MIMO scenario. The performance of the proposed technique depends on the f_dT product and the number of transmit and receive antennas. In particular, this technique can be effective if the f_dT product is not too high and the number of antennas is not too large. Furthermore, there is a considerable difference in the performance of the 16 channels in the 4x4 MIMO case because the sounding bursts spread farther apart with time, meaning that the Doppler in the channel causes a greater error for the channels.

요 약 본 연구에서는 MIMO 환경 하에서 모든 개별 채널을 추정하기 위해 다수의 사운딩 버스트 사이의 보간 기법을 이용한 아이디어를 제시한다. 제안된 기법의 성능은 f_dT 값과 송수신단의 안테나 개수에 크게 의존하고 있으며 특히 본 연구를 통하여 제안된 기법은 f_dT 값이 아주 크지 않거나 또는 안테나의 개수가 많지 않을 때 효과적임을 보인다. 또한 우리는 추정 채널의 개수와 안테나의 개수가 클 때는 사운딩 버스트들이 시간상에서 더 멀리 퍼져 있기 때문에 채널의 도플러 현상이 채널에 더 많은 오류를 유발할 수밖에 없으며 이로 인해 최상과 최악의 채널 추정 성능 차이가 더욱 커짐을 보인다.

Key Words : Interpolation, MIMO, MMSE

1. Introduction

We focus on the problem of channel estimation for multiple-input and multiple-output (MIMO) systems[1-4], using Orthogonal frequency-division multiplexing (OFDM)[5-7] sounding (or Pilot) signals, a critical component in many modern wireless communication systems. There can be two basic components to this problem: Estimation of the channel parameters based upon observing the received sounding signal after passage through the channel; and optimum design of the sounding signal itself[8,9].

Applications include channel estimation for demodulating signals in data transmission, as well as for purposes of characterizing the outdoor channel in various locales.

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Especially, we consider the Minimum Mean Square Estimation (MMSE)[10,11] of channel parameters based on a discrete time model of the time varying channel. We present the idea of interpolating between multiple sounding bursts in order to estimate all the individual channels of a MIMO scenario. From the simulation results, we show that this technique can be effective if the $f_d T$ product is not too high and the number of antennas in not too large.

2. Formulation of the MMSE Receiver for Channel Sounding

We formulate the MMSE receiver for channel sounding in the time domain. The results apply equally well whether we generate the signal directly in the time domain or use OFDM to generate it. We consider first a Single-input Single-output (SISO) time varying linear channel with impulse response $\boldsymbol{h(n, k)}$. Our model of the second order statistics of the channel is that

$$E\{h(n,i)\,h^*(m,j)\} = C\,J_0\left(2\pi f_d T_s (n-m)\right)e^{-i\alpha/L}\,\delta(i-j)$$

For notational convenience we let the input to the channel be $\boldsymbol{x^*(n)}$, where the asterisk means complex conjugate transpose. Then the output can be written

$$y(n) = \sum_{k=0}^{L-1} h(n,k)\,x^*(n-k) \quad + \; w(n)$$

or

$$y(n) = \boldsymbol{x}^*(n)\,\boldsymbol{h}(n) + w(n)$$

where $\boldsymbol{w(n)}$ is white noise with zero mean and variance σ^2.

3. MMSE Interpolation using multiple Symbols

Let $\boldsymbol{h_{ij}(n)}$ (abbreviated as $\boldsymbol{h_{ij}}$ in the diagram below) denote the impulse response vector, at time $\boldsymbol{n}$, from the $\boldsymbol{j^{th}}$ transmit antenna to the $\boldsymbol{i^{th}}$ receive antenna, and consider the following pattern of transmission and reception in which the various channels are measured in succession.

3.1 2x2 MIMO case

For illustration purposes we consider a 2 x 2 case in the diagram as shown in [Fig. 1].

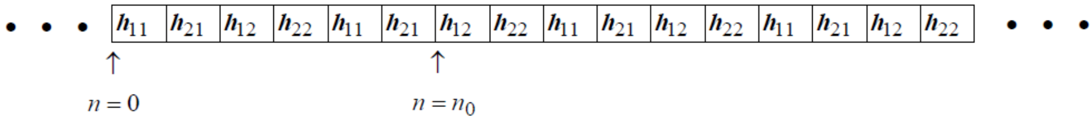
We would like to measure the complete MIMO channel at a single time instant, $\boldsymbol{n_0}$. To discuss this, let us define the time origin $\boldsymbol{n=0}$ as the first sample of the leftmost point in the diagram above. Assume that we wish to estimate $\boldsymbol{h_{ij}(n_0)}$ where $\boldsymbol{n_0}$ is chosen, for example, as shown in Fig. 1. Focusing first on the measurement of $\boldsymbol{h_{11}(n_0)}$, the diagram in Fig. 2 highlights only those bursts of time in which the channel $\boldsymbol{h_{11}}$ is being probed.

The proposed technique uses the MMSE estimate of $\boldsymbol{h_{11}(n_0)}$ based upon the measured received signal from some number, $\boldsymbol{M_s}$, of sounding symbols surrounding the time instant, $\boldsymbol{n_0}$. In Fig. 2, for example, suppose that $\boldsymbol{M_s=4}$. Then, $\boldsymbol{h_{11}(n_0)}$ is estimated based upon the received signal samples during the four sounding symbols highlighted in the diagram. To be specific, suppose that each of the sounding symbols has a guard interval of length $\boldsymbol{T_g}$ samples followed by $\boldsymbol{N}$ samples for measurement. Each symbol is then $\boldsymbol{T_{sym}=T_g+N}$ samples long and, according to the diagram, we are estimating $\boldsymbol{h_{11}}$ at the time $\boldsymbol{n_0=6T_{sym}}$. The MMSE estimate of is based upon the received signal samples in the four intervals, $\boldsymbol{T_g+1 \le n \le T_{sym}}$, $4\boldsymbol{T_{sym}+T_g+1 \le n \le 5T_{sym}}$, $\boldsymbol{8T_{sym}+T_g+1 \le n \le 9T_{sym}}$, and $12\boldsymbol{T_{sym}+T_g+1 \le n \le 13T_{sym}}$.

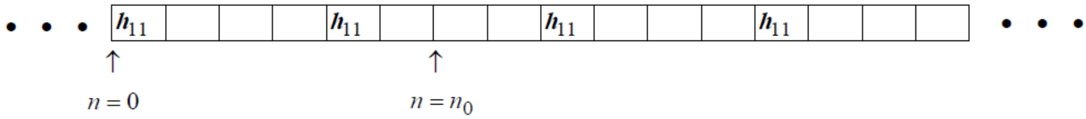
If we next focus on the measurement of $\boldsymbol{h_{21}(n_0)}$, the diagram in Fig. 3 highlights only those bursts of time in which the channel $\boldsymbol{h_{21}}$ is being probed.

In this case we estimate $\boldsymbol{h_{21}(n_0)}$ based upon the received signal samples during the four sounding symbols highlighted in this diagram. The estimation of the other two channels is done similarly, as illustrated in the diagrams in [Fig. 4].

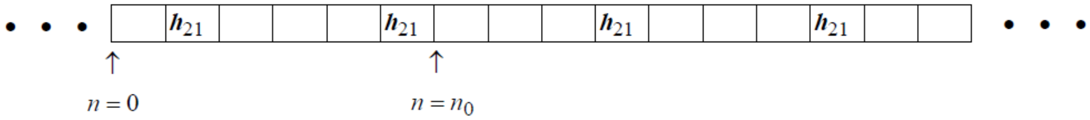
From the discussion above it can be seen that the only essential difference between the estimators for each of the four channels is the relative position of the point $\boldsymbol{n_0}$ with respect to the sounding symbols in each case. In a time varying channel this will cause the estimation performance to be different for the different channel impulse responses. The channels for which the time $\boldsymbol{n_0}$ is within, or close to, a sounding symbol for that channel should have better performance than those channels for which $\boldsymbol{n_0}$ is farther from the sounding symbols for them.



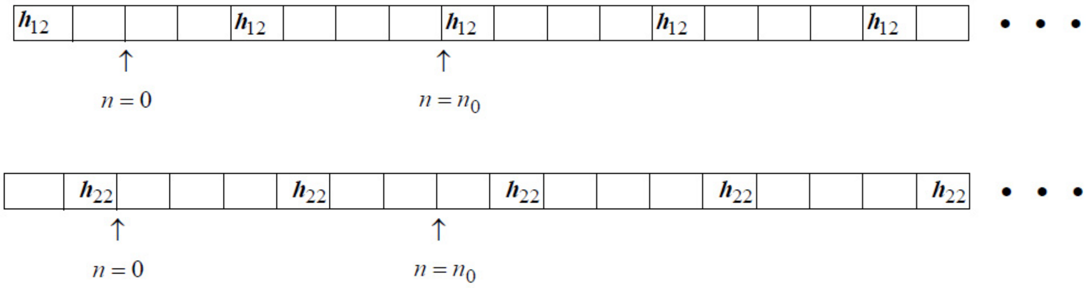
[Fig. 1] 2 x 2 MIMO case diagram (1)



[Fig. 2] 2 x 2 MIMO case diagram (2)



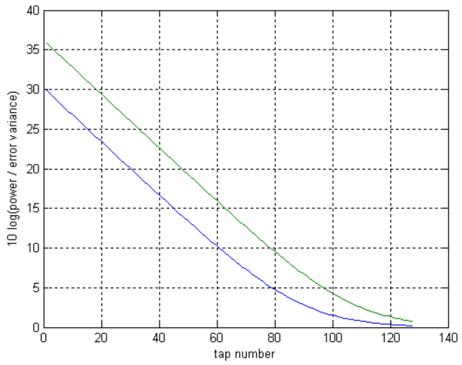
[Fig. 3] 2 x 2 MIMO case diagram (3)



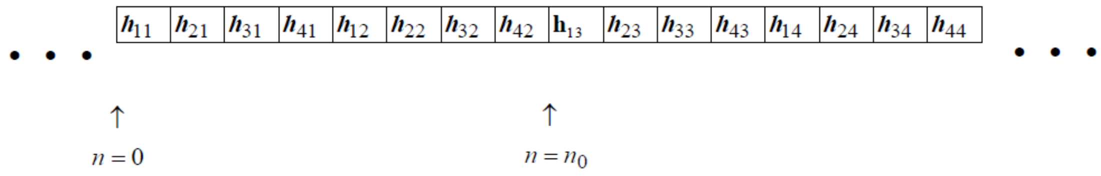
[Fig. 4] 2 x 2 MIMO case diagram (4)

To illustrate the performance of this technique, consider the following example, T_g=N=128, SNR=20dB, channel decay factor α=10, M_s=4, and the sounding signal has frequency domain subcarrier amplitudes with equal magnitude and randomly chosen bi-polar phase. The timing of the estimation point n_0 and the sounding symbols for each of the channels is as in the diagrams above. In Fig. 5, f_dT=0, so the channels are not changing with time.

The top curve in Fig. 5 is the estimation performance of all four of the channels $h_{ij}(n_0)$ with M_s=4. The bottom curve is shown for comparison. It is the performance when just one sounding symbol is used, M_s=1. We see that the estimation performance for all four channels is exactly the same when f_dT=0.We see that the estimation performance for all four channels is exactly the same when f_dT=0. This is because the channel is not changing so that all of the sounding symbols give equally reliable information about $h_{ij}(n_0)$, regardless of their timing relative to n_0. This figure also shows that the performance for M_s=4 is about 6 dB better than for M_s=1. This is because the channel is coherently combined over the four sounding symbols, while the noise is independent, so that we get a factor of 4(6dB) improvement.



[Fig. 5] Four symbol vs. One symbol with f_dT=0



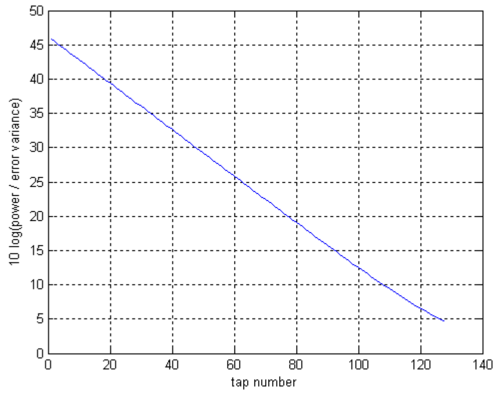
[Fig. 6] 4 x 4 MIMO case diagram

3.2 4x4 MIMO case

Next we consider a 4 x 4 MIMO case with channel probing sequence as shown in Fig. 6.

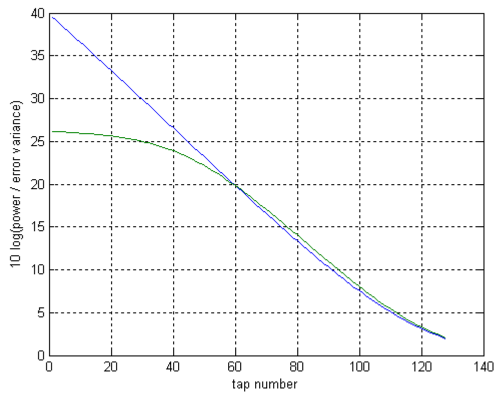
4. Performance Results

The parameters in the following figures are $\boldsymbol{T_g}$ = $\boldsymbol{N}$ = **128**, **SNR = 30 dB**, channel decay factor $\boldsymbol{\alpha}$=**10**, $\boldsymbol{M_s}$=**4**, and the sounding signal has frequency domain subcarrier amplitudes with equal magnitude and randomly chosen bi-polar phase. The timing of the estimation point $\boldsymbol{n_0}$ and the sounding symbols for each of the channels is as in the diagrams above. The next few figures show two curves in each figure. The two curves are the estimation performance curves for the best, and the worst, of the 16 channels to be estimated at $\boldsymbol{n} = \boldsymbol{n_0}$. The difference in the curves is the $\boldsymbol{f_dT}$ product, which is indicated in the figure caption.

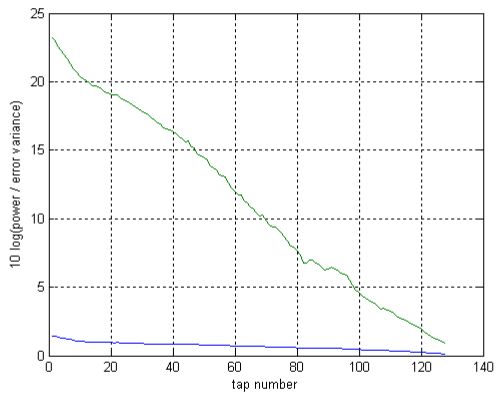


[Fig. 7] The best channel vs. The worst channel of 4 x 4 with f_dT= 0.

Fig. 7 shows that the estimation accuracy is the same for the best one and the worst one with $\boldsymbol{f_dT}$=**0**.



[Fig. 8] The best channel vs. The worst channel of 4 x 4 with f_dT= 0.01.

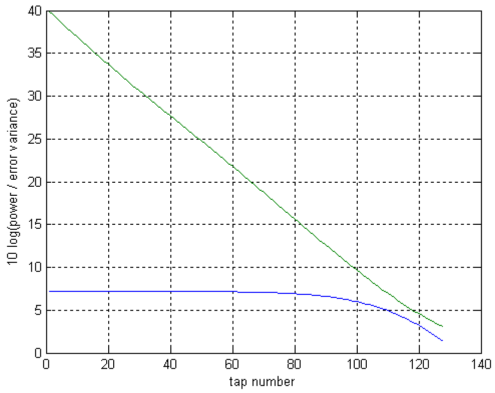


[Fig. 9] The best channel vs. The worst channel of 4 x 4 with f_dT= 0.05.

Figs. 8 and 9 show that there is considerable performance difference for the 16 channels in the 4x4 case. This is because the sounding bursts are spread farther apart in time so the Doppler in the channel causes greater error for the channels in which $\boldsymbol{n_0}$ is far from the nearest sounding burst. From these curves it is clear that the performance of this technique depends strongly on the

f_dT product and on the number of transmit and receive antennas. For a given f_dT product, if the number of antennas dictates that the interval between sounding bursts per channel is too high for good performance.

Fig. 10 shows the comparison of the MMSE estimator vs. the correlator estimator for the channel $h_{42}(n)$. The correlator simply uses the average of the correlations from the four probes of the $h_{42}(n)$ channel, since it does not exploit any information about the time variation in the channel. It simply operates as if the channel were time static.



[Fig. 10] MMSE vs. Correlator of $h_{42}(n)$ with f_dT= 0.005.

5. Conclusions

In this work, we suggested the idea of interpolating between multiple sounding bursts in order to estimate all the individual channels of a MIMO scenario. We showed that the performance of the proposed technique depends on f_dT product and on the number of transmit and receive antennas. Especially, it is shown that this technique can be effective if the f_dT product is not too high and the number of antennas in not too large. It is also shown that there is considerable performance difference for the 16 channels in the 4x4 MIMO case because the sounding bursts are spread farther apart in time so the Doppler in the channel causes greater error for the channels.

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