

Combined Pilot Aided and Decision Directed Channel Estimation For The RAKE Receiver

Anna Zhuang*
Nokia Mobile Mhones
P.O.Box 83, FIN-33721
Tampere, Finland
Anna.Zhuang@nokia.com

Markku Renfors
Telecommunications Laboratory
Tampere University of Technology
P.O.Box 553, FIN-33101
Tampere, Finland
mr@cs.tut.fi

Abstract

This paper presents pilot aided decision directed approach to estimate Rayleigh fading channel in Direct Sequence Code Division Multiple Access (DS-CDMA) Rake receivers. The algorithm is tested with different models of the mobile environment. Simulation results are evaluated against ideal estimates and the estimates obtained by conventional interpolation.

1. Introduction

In the 3rd Generation systems, channel estimation is a very crucial task due to the use of various data rates and different propagation environments. We consider here the RAKE receiver which has the capability of separating the multipath components and then combining synchronously into one large signal instead of rejecting them as unwanted interferers. The delays and complex channel coefficients must be estimated for each multipath component, or each finger of the RAKE receiver. In this paper, we concentrate on the complex channel coefficient estimation and the delays are assumed to be known. The focus is on the downlink of the WCDMA system. Although continuous pilot signal is available for the purpose of channel estimation, it cannot be utilized in all the situations and hence it is relevant to study channel estimation in the case where there is no aid of continuous pilots [1].

The complex channel coefficient estimation problem is two-fold:

1. The data modulation must be removed: either known symbols or the data decisions made by the receiver can

*The work was carried out when Anna Zhuang was working in Telecommunications Laboratory of Tampere University of Technology

be used to remove the effect of data. Pilot symbols can be used as known symbols.

2. Rough channel estimates must be filtered: after the data modulation has been removed, the so-called rough channel estimates are filtered to suppress the noise.

Complex amplitude estimation (amplitude and phase estimation) for each individual channel tap is required for coherent detection. The accuracy of the estimate is essential from the link performance point of view. Variable mobile speed grades require a lot from the speed of the algorithm, and in the extreme case, call for an adaptive solution.[4]

When the known symbols (pilots) are time-multiplexed with data at uniform time intervals and therefore the pilot signal is transmitted in conjunction with the data channel, the possible methods of performing the estimation are:

1. Using only pilot symbols for tap gain estimation, and interpolating the tap gain values for the data symbols.
2. Using, in addition to the pilots, the data symbols for tap gain estimation in the decision-directed (DD) mode.
3. Using, in addition to the pilots, the data symbols for tap gain estimation in the non-data-aided (NDA) mode.

Pilot based interpolation techniques make use of the known symbols and neglect data bearing symbols. At the receiver, channel gain estimates are obtained with the help of the received pilot symbols and locally generated pilot (reference) symbols. The gain estimates corresponding to each data symbol can be obtained by interpolating between two successive pairs of the gain estimates which were derived from the known symbols. Since the interpolation technique uses only the pilot symbol energy for the estimation, it faces difficulties with high mobile speeds because in order to get a good enough estimate, a long time constant must be used and thus, the system cannot track the channel.

The decision feedback approach uses all the received symbols. Preliminary hard decision of the data symbols is made and the obtained raw tap gain estimates are later filtered with the low-pass filter. If the symbol energy is very small, the decision feedback performance starts to degrade because of the increased symbol errors. The decision errors may cause hang-ups. Pilot symbols within the data help to prevent that.

In summary, conventional decision-directed amplitude and phase tracking techniques are prone to false lock, hence, they do not provide sufficient performance. Estimation technique, which ignore data-bearing symbols, and make estimation based only on the known pilot symbols does not provide sufficient estimation when the fading is fast. A possible solution is to combine these two to produce a robust technique for estimating the fading channel [2].

The paper is organized as follows. The pilot aided decision directed algorithm is presented in Section 2. Section 3 describes simulation environment and presents the results. Concluding remarks are made in the Section 4.

2. Pilot aided decision directed channel gain estimation

It was initially shown in [2] for shadowed mobile satellite fading channels, that the technique which makes use only of the known symbols neglecting data bearing symbols can be significantly improved without dramatic increase of complexity. Interpolation based channel tracking has a great advantage of providing true estimates, since it relies only on the known pilot symbols. To get estimates even closer to the true values, pilot aided interpolation can be extended to pilot aided decision directed technique (PADD). It will consist of an initial estimator, which will perform basic pilot assisted linear interpolation and provide tentative channel estimates, and a final estimator incorporating fading phase information extracted from the data symbols. Thus this technique results in two stage channel gain estimation. The procedure is the following:

1. From the reference pilot symbols and received pilot symbols obtain preliminary channel estimates, average the estimates so that one value per slot is available.
2. If desired, for the slow fading channel further filtering of the estimates can be performed.
3. Use linear interpolation to obtain channel estimates associated with the data symbols.
4. Estimate data symbol (divide received symbol by previously obtained channel gain).
5. Make a decision about the received data symbols.

6. Obtain one more channel gain estimate by dividing received symbols by the data decisions.
7. Set a threshold in the discriminator to make a decision which of the two channel gain estimates to use.
8. Filter the obtained channel gain estimates.

In case when the algorithm is applied in the RAKE receiver with QPSK modulation and decision about received data symbols is made after maximal-ratio combining (as it is shown in Figure 1), complex division in steps 4 and 6 can be replaced with conjugate multiplication.

The algorithm is attractive for its robustness (interpolation techniques don't have problems with locking to the false decision) and simplicity (no feedback is involved). However, it suffers from the common problem of all interpolation algorithm - the increase of the delay.

3 Simulation environment and results

Simulation tools used to study the algorithm's behaviour and to obtain the results are Cossap and Matlab. Channel type is Rayleigh fading channel with Additive White Gaussian Noise. In the Rayleigh fading multipath channels models, the Doppler effect caused by the receiver mobility is obtained by filtering noise with an appropriate IIR filter. Since the filter is fixed, different Doppler frequencies are obtained by interpolation. The Doppler frequency is changing according to the mobile velocity [3]. Three channel models were used in the simulations, [5]: indoor channel (3 multipath components, mobile velocity is 3 km/h), vehicular type A (6 multipath components, mobile velocity is 120 km/h), and vehicular type B (10 multipath components, mobile velocity is 250 km/h, 500 km/h).

The simulations were done for a chip rate of 4.096

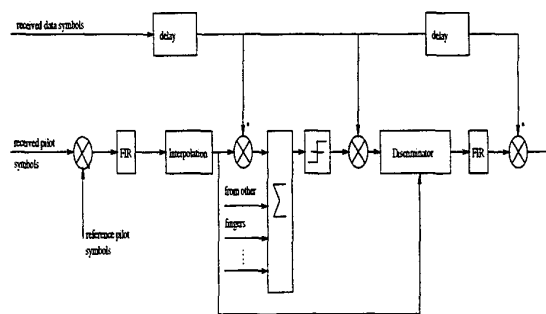


Figure 1. Pilot aided decision directed channel tracker

Mchips/s and the raw bit rate of 256 kbps. All the symbols in the time slot are spread with the same channelization code, which is a Walsh code and scrambled with a 10 ms segment of a Gold code of the length $2^{18} - 1$. 8 bits out of a slot were assumed to be pilots. The carrier frequency is 2.14 GHz. The chip shaping filter is a square root raised cosine filter with the roll-off factor of 0.22. A RAKE receiver with 4 fingers was used in the simulations. Channel coding, antenna diversity and power control were not included in the simulation model.

It is assumed that the multipath components with a power less than 10 dB below the power of the strongest multipath cannot be resolved. Hence, if the number of detected true multipaths is less than the number of the fingers in the Rake receiver, with properly applied thresholding, some fingers will be put on hold rather than processing the noise.

Filtered estimates of amplitude and phase for one RAKE finger are shown in Figures 2 and 3. All the results presented in Figures 2...4 are for the case of vehicular environment with the mobile velocity 120 km/h and the channel bit rate of 256 kbps. The delays were assumed to be known and constant throughout the simulation. Bit error rate for PADD algorithm in Figure 4 is evaluated against linear interpolation and ideal channel estimation. Ideal channel estimation implies that not only the delays are known but also the amplitudes and phases of the multipath components fed to each RAKE finger are known.

The filter applied to raw channel estimates was moving average filter. It proves to be a simple and robust one. However it should be noted that the filter length should vary depending on the channel conditions. Results presented in this paper are obtained with the filter length of 70, however other filters were also applied.

The total range of velocities (3, 120, 250, 500 km/h) and the bit rates (64-2048 kbps) were used in the simulations. The curves in the Figures 2 and 3 are a good representatives of the algorithm's performance. They show that with the midvalue of the velocity (120 km/h) and the midvalue of the bit rate (256 kbps), PADD algorithm performs really well and it is especially noticable in the poor channel condition. In the good channel conditions, interpolation based techniques lack of flexibility, but still performance degradation with respect to more sophisticated decision feedback algorithms is very small.

As for the other mobile environments, the algorithm performs extremely well in the indoor and gives pretty good results with the mobile velocity as high as 250 km/h. Obviously, PADD can not tackle the challenging task of channel estimation in case of 500 km/h. It probably does not need to be good at everything because more sophisticated multi-stage techniques are needed in this type of mobile environment.

4 Conclusions

This paper described one method to track fading channel which combines the best properties of decision feedback and decision directed techniques to produce pilot aided decision directed channel estimator.

Linear interpolation is a simple and reliable algorithm. Its simplicity is that only estimates from two consecutive slots are needed to make the algorithm work. And it is reliable because it uses estimates based on the known pilot symbols, i.e., it always uses only true information. Interpolation works well with slowly fading channels and as fading goes faster, the performance start to degrade. When the noise level is high, linear interpolation gives somewhat more reliable estimates than decision directed techniques. The major drawback of interpolation techniques is that they introduce a long delay. Prefiltering prior to interpolation, although improves performance dramatically when the fading is slow, is not appropriate when the fading is fast.

Decision feedback algorithms are fast. However, since their performance degrade when there are erroneous decisions, the performance is not very good when the noise level is high. The use of two stage estimation, like PADD, in the decision directed approach can improve the performance.

Simulations prove that PADD achieves good results in estimating the fading channel even with the high velocities. The algorithm is attractive for its robustness (interpolation techniques don't have problems with locking to the false decision) and simplicity (no feedback is involved). However, it suffers from the common problem of all interpolation algorithm - the increase of the delay.

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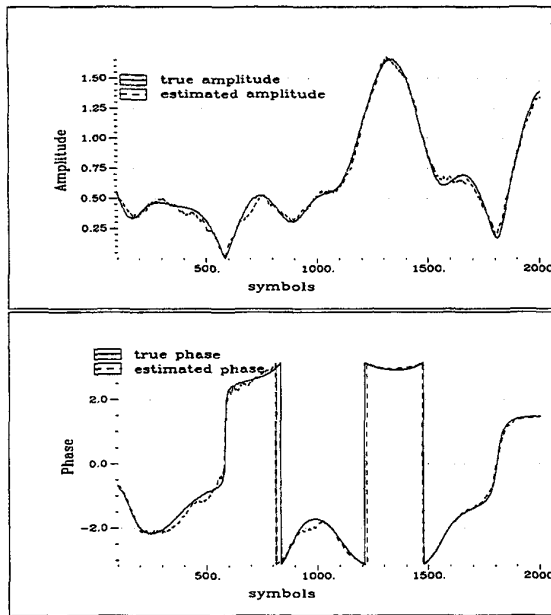


Figure 2. Filtered estimates of amplitude and phase for the case of vehicular A environment with velocity 120 km/h, channel bit rate of 256 kbps, and E_b/N_0 of 5 dB.

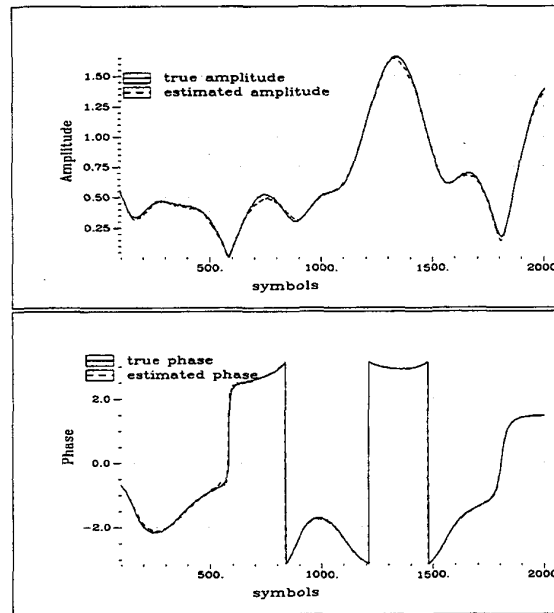


Figure 3. Filtered estimates of amplitude and phase for the case of vehicular A environment with velocity 120 km/h, channel bit rate of 256 kbps, and E_b/N_0 of 25 dB.

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Acknowledgement

This work was carried out in the project "Digital and Analog Techniques in Flexible Receivers" funded by the National Technology Agency of Finland (Tekes).

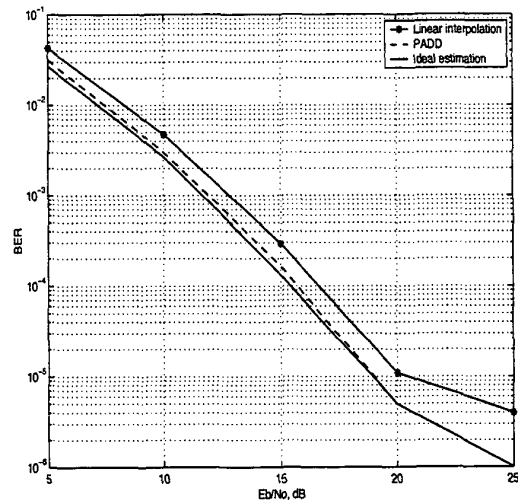


Figure 4. Bit error rate for the case of vehicular A environment with velocity 120 km/h and channel bit rate of 256 kbps.